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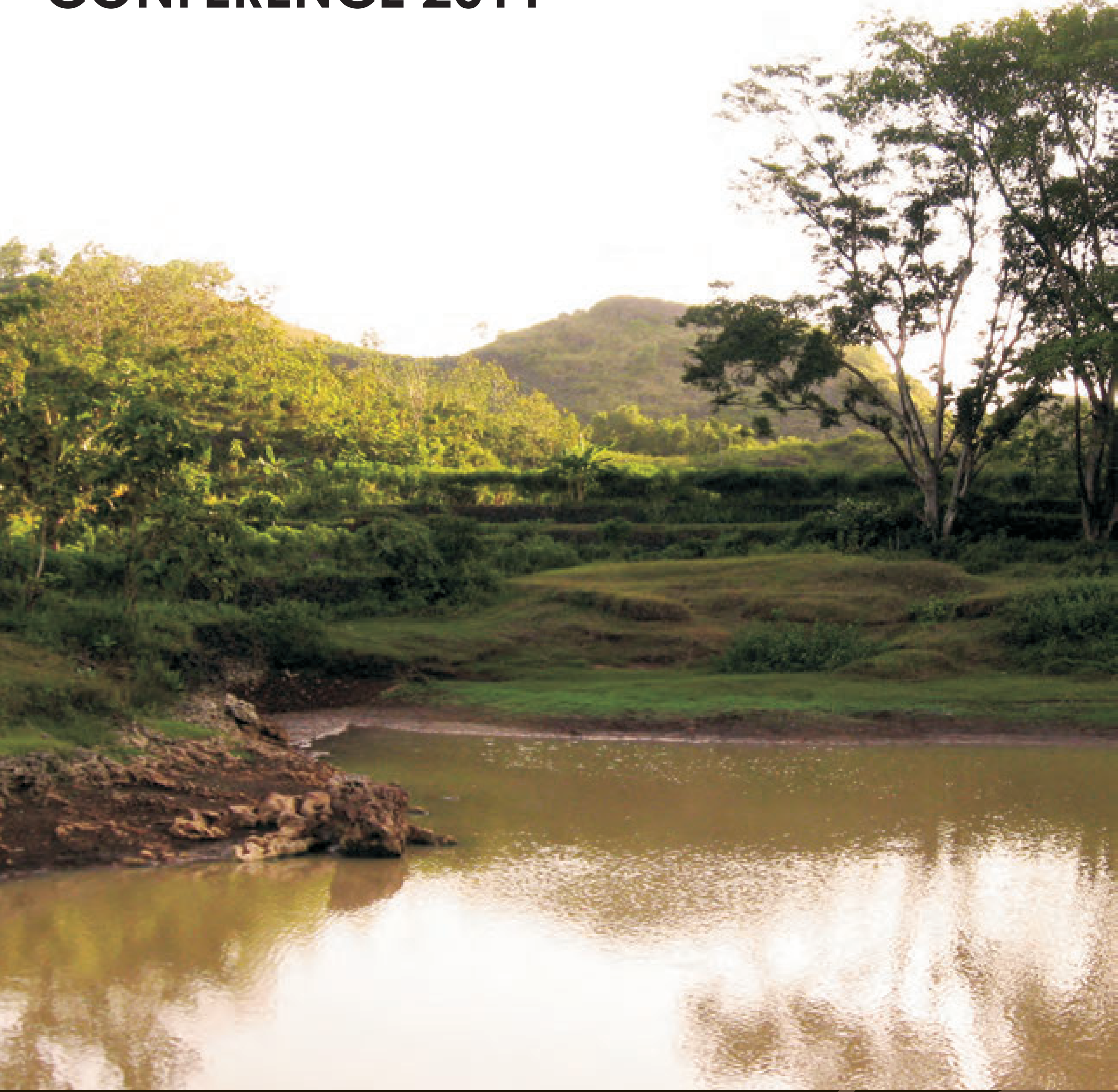

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Eko Haryono, Tjahyo Nugroho Adjie, Suratman

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ASIAN TRANS-DISCIPLINARY KARST CONFERENCE

Editors

EKO HARYONO, TJAHYO NUGROHO ADJI, SURATMAN

Karst Research Group
Faculty of Geography
Gadjah Mada University

Yogyakarta / 2011

Perpustakaan Nasional : Katalog dalam Terbitan

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Foreword

Karst area is well known for it's vulnerability to both geomorphic and anthropogenic process. Scientists and other practitioners have been developing a new strategies and method to ensure sustainable use of karst ecosystem. Karst area is also known for its beauty and exotics. This conference is intended to facilitate practitioners who have research works and experience in karst area of Asia. The conference is expected to be able to strengthen and promote collaboration among scientist, manager, adventurer who are interested in karst.

This book is published as part of the "Asian Trans-Disciplinary Karst Conference". Topics of the conference include:

- Geology and geomorphology
- Hydrology and Hydrogeology
- Water resource management in Karst
- Carbon cycle and climate change archive
- Biospeleology and biodiversity
- Cave and Karst Management
- Art, History, Medicine, Philosophy and the Social Science
- Archeology and Paleontology
- Method and technology for science, exploration and mapping

There are 57 published papers in this proceedings. These papers are written by 134 authors from 15 countries. This number represent a good response and confirm that the interest for studying karst is still high, especially researches those are conducted in Asia.

Dr. Eko Haryono

In Yogyakarta, December, 2010

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GEOLOGY AND GEOMORPHOLOGY

KARSTIFICATION AND BAUXITIC MINERALS EVOLUTION IN LATE CRETACEOUS SARVAK LIMESTONE IN THE DEHDASHT BAUXITE DEPOSITS, SOUTHWEST OF IRAN

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Abstract

The Mandan and deh-now Bauxite deposits is located in 40 km north-east of the Dehdasht city in Kohgiloye and Bovairahmad Province in the Zagros simply folded belt. The Bauxitic horizons are situated in eroded major NW-SE trending anticlines and occur in karst cavities near or at the boundary between the Sarvak and Illam Formation. Local uplift at the end of Cenomanian and mid-Turonian caused erosion and Karstification of the Sarvak Formation. Two major Middle Cretaceous unconformities can be increased economic importance of some major deposits such as Karst Bauxite deposits in the zagros fold belt. The investigations on the Sarvak Formation and bauxite minerals of the Mandan and Deh-now bauxite deposits characterized by the present of abundant Iron-oxides and Pyrites (Euhedral, framboiedal) revealed the Oxidation to recuction condition during the late Cretaceous in the zagros folded belt. Physico-chemical condition of bauxite minerals (Ph and Eh) has a signification effect on the mineral composition of bauxite and content of rock-forming elements. At least two bauxite mineralization episods can be distinigushed in the study area: (a) oxidize phase inclusive Beohmite, Diaspor, Hematite and kaolinite, (b) reduction phases are Pyrite, Chlorite.

Keywords: Karstification, Zagros, Iran, bauxite.

Introduction

As is well Know, bauxite is the major source of aluminum raw material. Bauxite deposits are commonly classified in three genetic types according to mineralogy, chemistry and host-rock lithology (Bardossy and Aleva, 1990).The karst bauxites can be formed by three geological mechanisms: 1) mechanical exhumation of the bauxite material to the limestone surface, 2) chemical transport of Al in solution from the weathering crust, and 3) bauxitization (lateritization) of the alumina silicates material accumulated on the limestone surface (Bogatyrev *et al.,* 2008). The mineralogical characteristic of the karst bauxite is very variety. Beohmite horizon., diaspore, gibbsite, hematite, goethite, kaolinite, anatas, rotile are major mineral in the bauxite The bauxite deposits in Iran can be divided spatially and temporally into three age-groups: permo -Triassic deposits in northwestern Iran, upper Triassic to lower Jurassic deposits in northern , and Cretaceous deposits in the Zagros simply folded mountain belt(Zarasvandi *et al.,* 2008). Initiatory study of bauxite deposits in the area have been reported by work Geology Survey of Iran in the 1963. The first systematic studies on mineralogy and genesis of the bauxite horizons in Southwestern of Iran have been carried out by the Zarasvandi *et al.,* 2010. The aim of this study is determination of mineralogy and textural characteristics of the bauxite deposits in the study area, in order to determine the sedimentary environment and status of bauxite mineralization.

Geology

The Mandan and Deh-now Bauxite deposits are located in 40 km north-east of the Dehdasht area in the Kohgiloye and Bovairahmad Province in Zagros simply folded belt**.** The Zagros mountains with about 150 to 250 km width and 2000km Long with NW-SE trend through the southern part of Iran (Liaghat *et al.,* 2003: Fig.1). The mountain belt has been divided into two NW-SE trending structural zones 1) imbricated belt, 2) simply folded belt (Sepehr *et al.,* 2004). Simply folded Belt lies to the southwest of the High Zagros fault. The sedimentary column in the Zagros estimated to be up 12 km and comprises the Cenozoic foreland sequence and the underlying Paleozoiec-Mesozoic deposits of the Arabian margin and platform (Ahmadhadi *et al.,* 2007). These deposites were formed in the oldest rocks of the area with late Cretaceous age. The Mandan deposite situated in the southern limb of the Mandan anticline and the Dehnow deposite situated in the northern limb of the Kuh-e-siah anticline. The Mandan anticline, measuring about 20 km long and 5 km wide. The kuh-e-siah anticline is a symmetrical fold and its axis trend is N40-45W (Fig. 2). Location of these bauxite deposits, is controlled by drainage and fault/fractures and therefore by geomorphologic and tectonic processes. Faults with N-S and E-W trending affected the Bangestan group (tropical Sarvak and Ilam Formation). The Bangestan group includes Sarvak, Surgah, Ilam, Pabdeh, Gurpi, and Asmari Formation, which form a progradational-retrogradational package of strata bounded by at least three major unconformities. The oldest stratigraphic unit in the area is the Sarvak formation with late Cretaceous age. The late Cretaceous sedimentary succession that includes the sarvak formation was dominated by widespread carbonate and resistant (cliff-forming) shallow-marine limestones (Alavi, 2004). Karstification of the sarvak Formation in these anticlines is very specific.The bauxite fill the karst cavies (sink holes) on top of the sarvak formation. The bauxite horizon in this deposit is consists of white, gray, black, pisolitic, red and yellow bauxites.

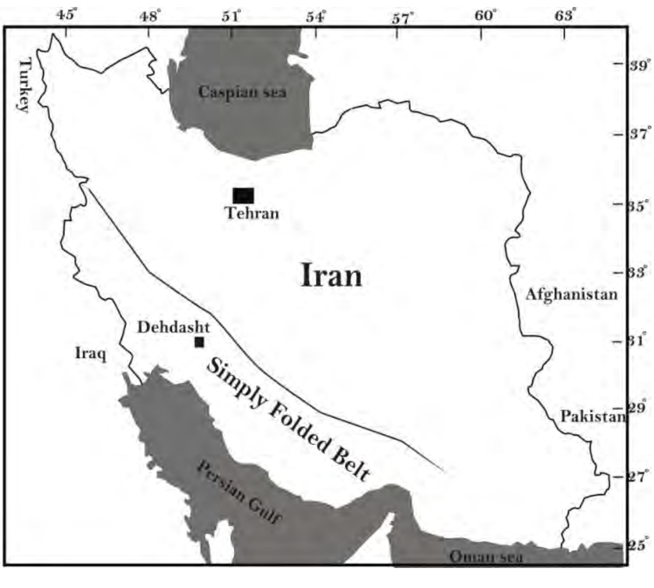

Figure 1. Geographic map of Iran showing the location of the Dehdasht area in the Zagros Fold Belt. (Modified from Liaghat *et al.,* 2003)

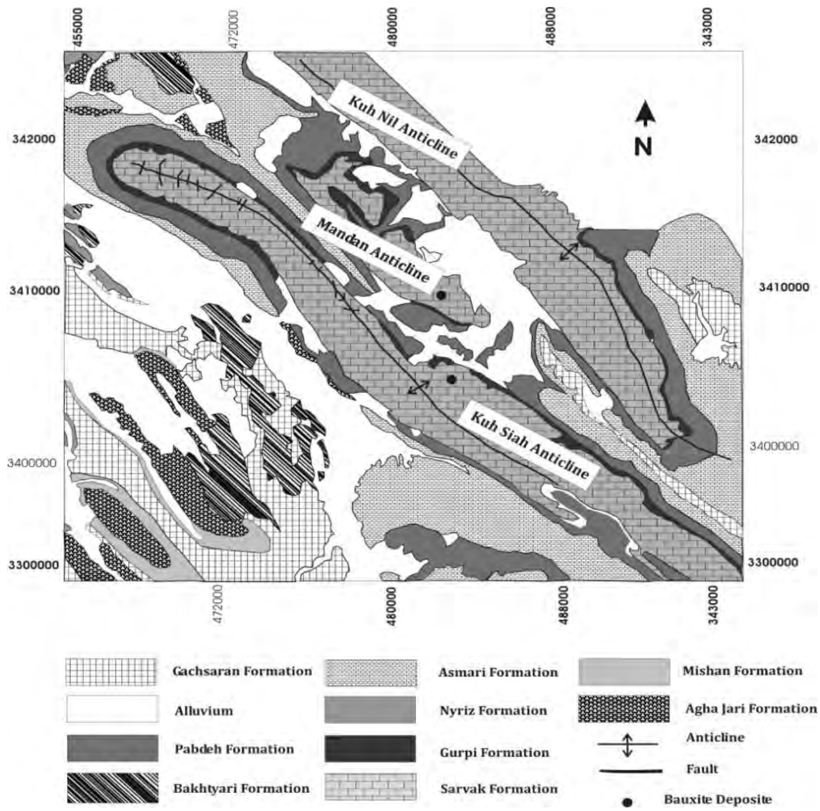

Figure 2. Generalized geologic map of the Dehdasht area.

Methodology

The field geology observation determines the Karst-development models are reflected in general systems of the karst stratigraphy in the Sarvak formation. The samples were collected from two different areas (Mandan and Deh-now). Also, Samples were selected from different layers of the bauxite horizon in the Dehdasht area. The Sarvak Formation and bauxitic layers were sampled along a vertical profile in the lower most part of a deposit filling a canyon-like karst caving. 10 samples were seleced for preparation of thin and Polish sections in the laboratory of Shahid Chamran University, Ahvaz, Iran. Mineralogical and textural studies in these samples were carried out using optical microscopy and X-ray diffraction (XRD).

Karstification

Karst is a special geological feature. Karst rocks are more easily soluble than the other rock types under specific conditions that depend also on the lithology (limestone, dolomite,gypsum, anhydrite, Rock salt, quartzite: Bosak, 2008). Karstification is a geological feature which can be increased economic importance of some major deposits such as Bauxite deposits. Karst bauxite lying on carbonate rocks can be identified with the karstic category, regardless of whether the bedrock surface is karstified or the degree of karstification (Mameli and Mongelli, 2007). Most (paleo) karst features include composite unconformities, representing long time –

spans without deposition (Bosak, 2008). Local uplift at the end of Cenomanian and mid-Turonian caused erosion and Karstification of the Sarvak Formation (Hajikazemi *et al.,* 2010). These two major Middle Cretaceous unconformities due to increased porosity and karstification in these strata. Karstification is importance diagenetic process to affect the upper Sarvak carbonates. The Karst features related exposure subarial in the upper Sarvak formation seen in the Mandan and Koh-e-Siah anticline surface section include:1) presence of cavernous prosity (Fig. 3A), 2) vuggs are partially or conformity filled by ferron calcite cement (Fig. 3B). Inter crystalline prosity filled by kaolinite indicate in these thin section (Fig. 3C). 4) Brecciation of carbonates (Fig. 3D). This study indicate that the Dehdasht bauxite horizon was formed by Karstification and weathering of the Sarvak Formation. In addition of this feature Climate, Hydrogeology, tectonic and geochemistry of host rock were played important role in Formation of bauxite horizon in the study area.

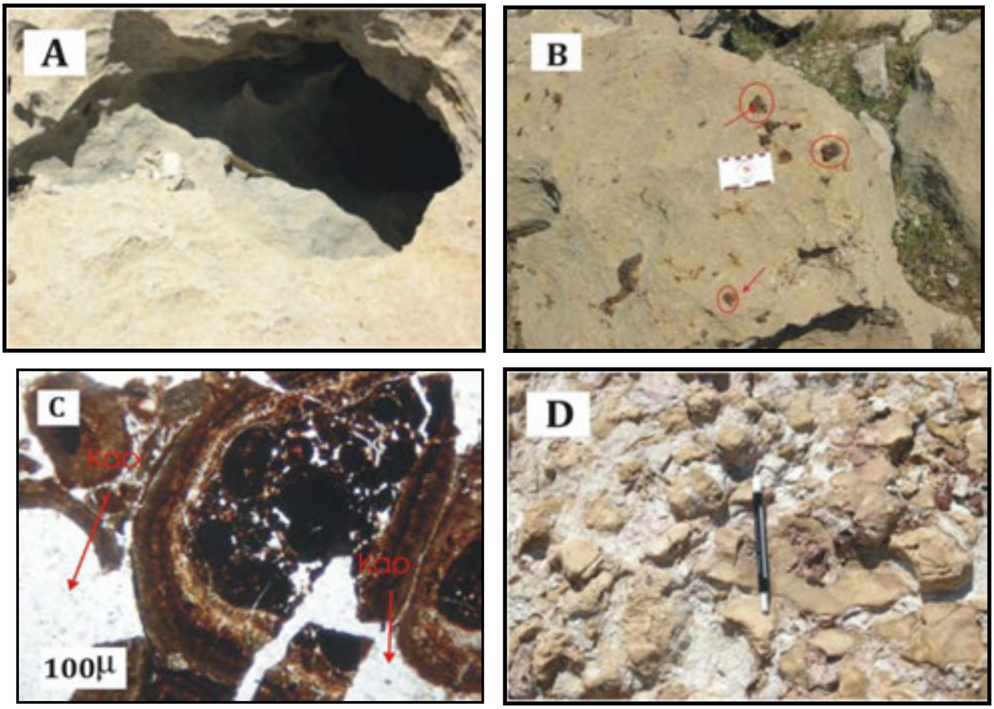

Figure 3. Field photogheraph and thin section photomicrographs of various karst features in theupper Sarvak Formation. A) cavernous prosity in the upper Sarvak Formation. B) vuggs are partially or comformity filled by ferron calcite cement. C) Inter crystalline porosity filled by kaolinite. D) brecciation of carbonates

Mineralization

The bauxite horizon in the study area from bottom to top consists of white, gray, black, pisolitic, red, yellow bauxites. Mineralogy is similar in all bauxitic layers and the main textures are pisolitic-ooide, ooide-spheroid, pisolitic, pelitomorphic and pseoudomorphic. Boehmite, Diaspore, Kaolinite hematite, chlorite and Calcite are the most important minerals in bauxitic layers of the Dehdasht area. Anatas and rutile are minor minerals in the horizon. X Ray diffraction (XRD) studies on the Dehdasht bauxites indicate that the porous matrix filled with composed of kaolinite, calcite (Fig. 4A). The mineralogical characteristics these bauxites deposits show that the battom of the sequences is argillaceous limestone of the Sarvak formation (Nasibpour.2000, liaghat *et al.,* 2003:Fig.4B).The Sarvak formation and gray bauxite minerals characterized by present of two types of Pyrite morphology (Euhedral, Framboiedal). This reveal the oxidation to reduction condition during the late Cretaceous in the zagros fold belt (Fig.3C and D). Microscopic observation show several pisolitic styles in the bauxite ore.It can classified into three types: 1) Pisolitic is sub-crushed, filled some of fracture by kaolinite (Fig. 3A), 2) Agregation of the pisolitic with light color which is show process deferrification in the bauxite deposits (Fig.3E) and 3) Pisolites with a core of beohmite surrounded by a cortex of a alternating hematite. This type is completely sphere with preserved cortexes (Fig.4F). Pisolites may result from different stage of weathering during climatic changes. It changes. It is inclusive two stages. In the first stage a large Al-hematite core formed resulting from a relative long period of dominantly wet tropical climate. In the second stage, in a short time drier conditions, possibly related to eustatic sea-level drops and favoring boehmite stability alternated with a time limited wetter climate favoring Al-hemaitite stability (Mongelli 2002).The presence of variable amounts of iron oxy-hydroxides is indicated by the intense red to light brown colors of the samples (Meyer *et al.,* 2002).

Discussion

The main bauxite ore bodies occur in the zone between the Sarvak and Ilam formation. Some of the ore deposits (small-size) such as karstic filling are present within Sarvak formation. Mineralogical compositions, environment, wall-rocks relationships and geological settings revealed that the Dehdasht bauxites deposits were formed in an intrakarstic environment during the late cretaceous age. Karstification of the host rocks may start during deposition phases and diagenesis-converting the soft sediment into consolidated material shortly after deposition (Bosak, 2008). Major diagenetic processes affecting the upper Sarvak carbonates include Karstification, calcite cementation and pyrite formation (Hajikazemi *et al.,* 2010). Physico-chemical conditions of bauxite deposition (pH and Eh) have a significant effect on the mineral composition of the bauxites and content of rock-forming elements (Mordberg, 1996). Under acidic and oxidizing condition, iron is Fe^{+2} and Fe^{+3} which are solution in water. On the basis of Laskou (2005) two types of bauxite samples can be distinguished: a) ferric bauxite samples (Fe^{+3}-rich) with pyrite (pisolitic and red bauxite) and b) ferrous bauxite samples (Fe^{+2}-rich) with pyrite (gray bauxite). Framboiedal pyrite is formed in reducing condition (Butler and Rickard, 2000).Filling fractures by Pyrite in matrix could indicate last stage of diagenesis. Deferrication in the bauxites is associated with organic matter and it can create acidic (PH=3-6) and reduction condition in the study area. At least two bauxite mineralization episodes can be distinguished in the study area: a) oxidize phase inclusive Bohmite, Diaspor, Hematite and Kaolinite and b) reduction phase with Pyrite and chlorite mineralization.

Conclusions

Boehmite, Diaspore, Kaolinite and Calcite are the most important minerals in bauxite layers of the Dehdasht deposites. Due to Boehmite mineralization in the study area erosion with intense weathering environment in the Touronian-Cenomanian suggest for the deposition of Bauxite in the Dehdasht deposite.

Existence of interclasts in the Pisolites indicates that these bauxites were transformed from the primary in situ environment to Karstic sedimentary basin as authogenic origin.

Two bauxite mineralization episodes can be distinguished in the study area: a) oxidizing phase inclusive Bohmite, Diaspor, Hematite and Kaolinite, b) reduction phase with Pyrite mineralization.

Karstification is a geological feature which can increase the economic importance of some major deposits such as Bauxite deposits.

The Sarvak formation and gray bauxite characterized by persent of two types of Pyrite (Euhedral and Framboiedal) and existence of iron oxides (hematite) in the pisolitic bauxite revealed change of status from Oxidation to reduction during the late Cretaceous of the zagros folded belt.

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MINING PROFILE AT SOUTH GOMBONG KARST AREA, KEBUMEN

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Abstract

South Gombong Karst region is an area that has scientific and economic value, especially important for support ecosystem and the living human. South Gombong Karst area has been classified into three zone conservations; zone I, II and III. This area is used for tourism, farming-irrigation, mining, forestry, and water supplay. South Gombong Karst area has a wide variety mineral resource potential; there are limestone, phosphate guano, andesite, bentonite, trass, kaolinite, mangaan, oil shale, and gold. There are 555,98 Ha of excellent quality limestones, 60% of these area is a part of karst zone I, 30 % karst zone II and last 10 % karst zone III. Guano phosphate-rich beds are associated with limestone caves, the igneous rock of andesite in the form of intrusive sill, dyke and a lava flow, member of Gabon Formation. Both guano phosphate and andesite have good quality. Ca-Mg bentonite and trass can be used for pozzolan cement. Kaolinite is useless for ceramics and fillers because was composed by higher content of Fe_2O_3. Manganees deposit found at both breccia of Gabon Formation and limestone of Kalipucang Formation. The total population of the South Gombong Karst area is estimated 182.167 people, with 59.9% as farmer, 11.22% trader, 4.6% miner, and 24.25% the other sector profession. Small mining of mineral resources at the South Gombong Karst area are mainly illegal mining activity by local community. Most of the limestone mining activities were done at karst zone II, large scale mining of andesite were done at Mangunweni, guano phosphate were mined at Sriwulung Cave and Banteng Cave, Mangaan were actively mined at Bleber, a part of karst zone II, gold mining activity were done at Jladri river with manual mining and tunneling by following the vein orientation. Mining activities have to be stopped at South Gombong Karst zone I, important be made mining area map, veterinarian, deligence based on rocks and geo-tourism in harmony with the purpose of conservation.

Keywords : South Gombong Karst region, mining potential, mining activity, regulation

Introduction

South Gombong Karst region is an area that has scientific and economic value. South Gombong Karst is a type of carbonate karst (limestone and dolomite are the most prevalent). Karst is a distinctive topography that develops as a result of the dissolving action of water soluble bedrock (British Columbia, Forest Ministry, 2003) which produces a landscape characterized by fluted and pitted rock surface, vertical shaft, sinkholes, springs, subsurface drainage systems, and caves. Between the hills develops karst valley, doline, uvala, and polye. Geologically, limestones in this area is a member of Kalipucang formation overlay at breccia a part of Gabon Formation. Caves and springs in this area are used by communities for their daily needs, especially for PDAM. Some caves have been managed and exploited as a tourist attraction, such as Jatijajar and Petruk caves.

South Gombong Karst area has a wide variety of potential natural resources, which included Ayah, Buayan and Rowokele district, but these locations should be protected. Recommended practices are need for manage and protect significant karst development both surface (e.g. sinkhole, stream, spring and cave entrance) and subsurface karst environment (e.g. underground stream and karst ecosystem)

Increasing market demand, especially raw minerals are generally in line with the increase in mining activity, both legal and illegal. In research areas there are several active mining sites and some of them have been abandoned.

Some mining activities are still active in KKGS, generally limestone, andesite, and breccia mines. Mining of manganese, phosphate, and calcite has been abandoned. The largest of limestone mining carried out in Redisari and Kalisari village, while andesite and breccias mining done at the Mangunweni and Rogodadi village.

This paper is aimed to study the mining profile at South Gombong Karst area. Mining activity in this area could be managed and benefied for the economic development. Efforts for and management of mining activities especially those that support the economic development must consider the preservation of the environment, so mining activities can be sustainable and not damaging development of karst, particularly surface and subsurface karst environment

Method

This study was done in some stages, mainly fieldwork consisting of geological mapping, observation of mining activity and distribution of materials deposits, also some laboratory analyses.

Regional Geology

Regional geology of research area is referred to geological map of Banyumas sheet (Asikin *et al.*, 1992). Physiographically, this area was known as the Southern Serayu Mountain (van Bemmelen, 1949) This area is located at south portion of the map and was known as South Gombong Karst. South Gombong Karst is divided into 4 kinds of morphology; there are planeplain morphology, hill sloping morphology, karst morphology, and steep hills morphology.

Planeplain morphology is located at the west and east of Karangbolong hill, a vast alluvial plain. In the east portion was known as Gombong - Puring planeplain and in the west portion was known as Rowokele - Ayah planeplain. These altitude ranges from 0 to 10 m above sea level with slope < 3%. Along the coast developed sand dunes morphology, as if looks like a patio that extends in the direction of the coastline.

The sloping hills morphology is located at the north portion of Banyumudal - Tugu – Kalisari village. In this area is composed of claystone, sandstone, calcareous sandstone a member of Halang formation. These altitude ranges from 10 to 25 m above sea level, with a slope of 3-25%.

Karst morphology in this area was caused by water that dissolved to form cones with gentle hills tophography, mainly composed by limestone. Karst morphology is characterized by the shape of the basement rocks, especially carbonate rocks, forming a cone or rounded hills, the topography is very rugged with steep slopes. The valley form dolina valley, uvala, and polye. This morphological unit occupies at the center to the north of the study area, curved half-circle with the height of the peak cone limestone 100-435 m above sea level. In the center part of karst formed a plateau which is covered by terarosa soil, is a rice paddy.

The steep hills morphology is located at the south portion, which is composed of breccias, conglomerates, sandstone, lava, and intrusive rock a part of Gabon Formation. Hilly slope varies between 15% to 25% and form the hilltops with altitude ranging between 100 and 400 m above sea level.

Stratigraphy

Sequence stratigraphy of this area referred to geological map of Banyumas sheet (Asikin *et al.*, 1992), which is composed of Gabon Formation (Tomg), Kalipucang Formation (Tmk), Halang Formation (Tmh) and Alluvial deposits (Qa), see figure 1.

1. Gabon Formation aged Late Oligocene – Early Miocene (Tomg), is composed of volcanic breccia, embedded in andesitic lava, tuff, lapilli and laharic materials. Some matrix has weathered to form trass, partly tuff also altered to form bentonite
2. Intrusive of andesit (Tma) (Early Miocene – Middle Miocene). This formation intrusives Gabon Formation.
3. Kalipucang Formation (Tmk), is not aligned on top of Gabon Formation,composed of coral limestone, encountered local clastic limestone and bituminous shale at the bottom. These formations form a karst morphology. Limestone has been largely calcifies forming caliche deposits (keprus stone).
4. Halang Formation aged Middle Miocene to Early Pliocene (Tmph) is a series of turbidity deposits consists of calcareous sandstone, pebbly sandstone, tuffaceous sandstone, marl, tuff marl, claystone.
5. Quaternary alluvium deposits (Qa) is the youngest sediment overlies all the existing formations. Found as deposits of loose sand beach.

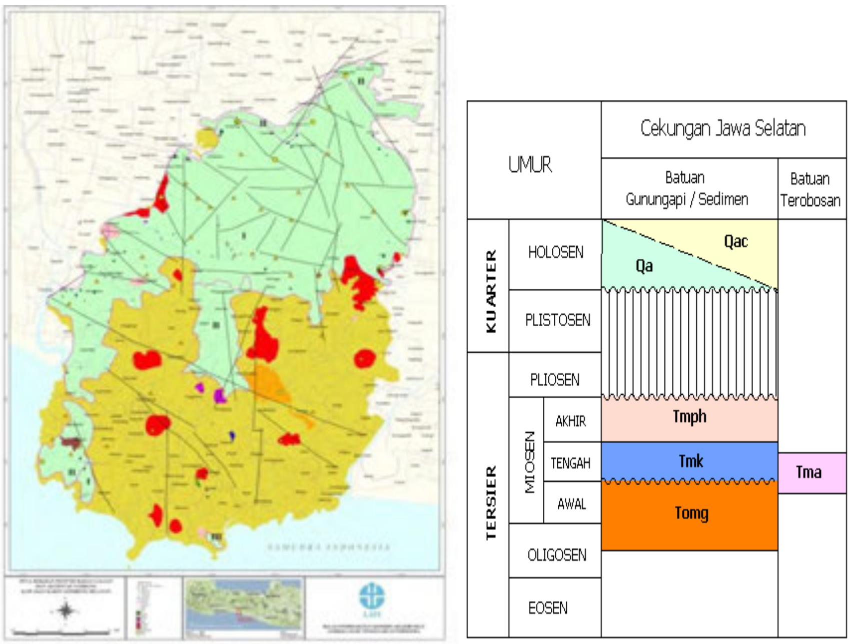

Figure 1. Potential mineral distribution at karst zoning maps and the sequence stratigraphy in the South Gombong Karst region

Results

Zonation of Karst Region. Karst region is a unique area, having important fuction with significant economic, scientific, biological, hydrological, geologically, enviromental and cultural values. Based on Decree of the Minister of Energy and Mineral Resources Number 1456 K/20/MEM/2000 Karst region could be classified into several zonations. Based on decree of the Minister ESDM No. 961.K/40/MEM/2003, limestone rocks at Karangbolong hill is a part of South Gombong Karst Region. South Gombong Karst Region could be divided into 3 regions, there are zone I, zone II, zone III. Karst zone I has a spread of approximately 74.6 %

of South Gombong Karst Region, providing an extensive area for potential karst development, zone II has a spread of approximately 15.9 %, and the last zone III has a spread of approximately 9.5 %. Karst zone I has great source springs, subsurface drainage systems and caves potential. Mining activity in this zone should not be done. Karst Zone II has a gorundwater recharge potential and the fossil cave which still allow for mining activities but on a limited scale. Karst Zone III is an isolated limestone areas, it is allowed to be mined.

Land Use Planning.

The planning and design of karst reserves should be based on a karst filed assessment. Recommended practices are provided for broad karst landscape and specific karst features. Land use in South Gombong Karst Region is consists of various types in accordance with the form morphology. Hilly areas are used for plantations, fields, gardens, paddies and settlements. Terrain areas are used to residential, paddies, and moor. Open land cover types include sandy land, agricultural land rare plants, and rain fed rice fields on dry season. Sandy beach covering all coastal beaches and estuaries are found in Cicingguling.

Plantation in South Gombong Karst Region is a highest type of land use in the research areas, has a spread of approximately 44.1%. This indicates that residential area in the research areas is smaller than plantations. This land is spread in the middle to southern areas on steep mountainous morphology. Settlements have a broad spread of approximately 15.2%, are found surrounding lowlands. In this area are found technical irrigated land and tourism locations such as Ayah Beaches and Jatijajar Caves.

Shrub has a spread of 15.8%, to plant shrubs and grasses. They are scattered on the morphology of karst around the middle to northern Mangunweni, Jatijajar, Kalisari, Redisari Village. Irrigated fields have a wide spread of 12.6%, in the vicinity of Bodo River and Cincingguling streams.

Moor, extensive spread of 10%, spread on the morphology of ramps in the northern hills and rugged mountain ranges around Srati and Karangduwur. Moor associated with mixed garden. This landuse due to the opening of the forest production. Crops are generally composed by cassava, peanuts and a rare plant timber.

Rainfed rice fields, vast reaches 1.9% which spread in upland karst area and being around the Pepino Hill forming dolina or uvala with a thin soil. Rainfed rice fields commonly founded at the Kalibangkang, Watukelir and Tlogosari village. Irrigation water is obtained from rainfall and seepages at the foot of limestone hills. Vacant land, the extent of about 0.1% around Redisari and Karangsari Village. This vacant land is generally overgrown with grass and weeds.

Pond, with a broad range of about 0.1% which was in the Ayah Village. Land use was associated with the river, so that its territory is relatively stagnant. Swamp, with a broad range of about 0.1% that were found locally in the vicinity of the Candirenggo and Ayah village. Marsh at this location is generally overgrown by plants.

Mining Profile.

Based on field observation in this area, there are nine material deposits which included limestone, phosphate, manganese, andesite, bentonite, kaoline, trass, gold, and oil shale. Mining profile at Table 1.

No	Kind of material deposit	Located	Potency	Total Miners	Mining Activity
1	Limestone	Zone I (74,6 %) Zone II (15,9 %) Zone III (9,5 %)	389.250.000 metric ton Good quality	177 entrepreneur 276 local people	Active mines at Zone I and II, illegal
2	Phospate	Zone I	Have not been well identified Moderate quality	9 entrepreneur 29 local people	Active mines at several caves, illegal
3	Manganese	Around karst zone	A thousand ton Poor-moderate quality	15 local people	7 exploration mine concession
4	Andesite	Around karst zone	106.130.975 m^3 Good quality	32 entrepreneur 120 local people	2 legal
5	Bentonite	Around karst zone	100.000 m^3 Moderate quality	-	-
6	Kaoline	Around karst zone	Have not been well identified Poor quality	-	Have seen be mined
7	Trass	Around karst zone	Have not been well identified Good quality	-	-
8	Gold	Around karst zone	Have not been well identified Good quality	6 local people	Active mines at Jladri
9	Oil shale	Around karst zone	7.264.176,20 ton hostrocks Moderate quality	-	1mine concession

Limestone is kinds of mineral deposit which is used for building materials and industrial raw material. Distribution of limestone in this area approximately 5083.5 hectare. Limestone in this areas is a part of Kalipucang formation, whereas is composed of reefal limestone in the upper part, and localy clastical limestone. Limestone mines in this area used to apply explosive materials. Mining activity could be seen at Jatijajar, Redisari, Kalisari, and Banyumudal village.

Table 2. Chemical analysis of Gunung Indrakila's limestone, Ayah district (Ansori C *et al.*, 2007)

Main Oksida	Dry analysis (%)	Wet analysis (%)	Method analysis
SiO_2	0,7123	0,7117	AAS
Al_2O_3	7,6664	7,6600	—
$CaCO_3$	91,6377	91,5609	—
Fe_2O_3	0,0869	0,0868	—
MgO	0,2746	0,2743	—
MnO	0,0608	0,0608	—
Na_2O	0,0074	0,0074	—
K_2O	0,0089	0,0089	—
PO_4			UV-Vis. Spect.

Based on the results of chemical analysis of limestone in the study area, showed that $CaCO_3$ content more than 90%, CaO 54.38 to 55.50%, MgO from 0.2746 to 0.49%. According to Indonesian Industrial Standard (SII), limestone material meets the requirements for use in the cement industry, because have high levels of $CaCO_3$> 85%, CaO> 50%, MgO <5%, so it can be concluded that the limestone at KKGS has very good quality as raw materials for cement industry. Actually this area has large reserves, but most included in the karst region first class that must be protected. Large-scale mining is not recommended in this area because of can damage cave ecosystems and sub surface river. Small-scale mining is still possible, especially in karst region class III or II, which is located on the north, especially around Kalisari, Banyumudal, Rogodono. That is because the north to the northwest is an area of ground water outflow. Mining activities in this area will not disturb the ecosystem and water system karst region. Based on the requirements in ASTM 258-52 (Rumidi S, 1998), the limestone of KKGS has good qualify for carbide and steel smelting. Limestone in this area also still need to be studied for other usage such as for bleach, soda ash, abrasive materials, disinfectant in agriculture, glaze materials, industrial glass, silica brick, the material floatasi precious metals refinery. Some limestone mines that took place is still done traditionally, in some places have used explosives. Most of the miners working without permission because the local government have no longer issue new and renewal SIPD accordance existing regulations.

Phosphate guano deposits are found as in the active or fossil cave, specially at Golek cave at the Mangunweni village, Kampret cave at the Banyumudal village; Sriwulung cave at the Buayan village; Banteng cave at the Sikayu village and several other caves. The Characteristics of phosphate have black color, dirty white to brown, generally massive, somewhat dense. Potential reserves of phosphate only locally, but if carried out small-scale mining is still possible. Content of P_2O_5 varies generally more than 30% (Ansori *et al.*, 2009) that qualify can be used as fertilizer industry.

Manganese, are found scattered in the form of nodules, lenses and layers. Manganese nodules and lenses are found in volcanic breccias and lava a member part of Gabon formations underlying karst topography in the Srati and Pasir village. Manganese layered under the limestone, unconfomity between the Gabon formation and Kalipucang formation in the karst zone II and zone I Bleber Mangunweni in Candirenggo, Rangkah, Wanadadi and Sikayu. Until now has been listed 7 KP exploration which were around the karst zone II or I.

Table 3. The results of manganese analysis (Ansori C, 2009)

No Sample	Location	Element	% Average
CA-4.a	Candirenggo	MnO_2	56,82
CA-8.a	Bleber	MnO_2	74,19
SR-10	Srati	MnO_2	49,89

Manganese minerals can be utilized in the metallurgical industry, batteries, and chemical. Generally, manganese is required for the industry with 85% MnO_2 content, so the quality of manganese in the study area less qualified.

Andesite, can be distinguished between the intrusive igneous rocks (breakthrough) and extrusive igneous rocks that produce lava. The presence of andesite lava may be insertions, could be as a dike and sill members of the Gabon formation. These rocks are found in at least 8 locations, with total reserves of approximately 106,130,975 m^3. Large-scale mining activities encountered in the Mangunweni, Candirenggo and Jintung village.

Table 4. The test results of physical and mechanical andesite (BAPPEDA Kebumen, 2004)

No	Sample Code	Specific gravity gr/cm^3	Compressive strength kg/cm^2	Cohesion (c) t/m^3	Friction angle (degree)
1	AN	2,33	779,56	170	28
2	AN-HJ	2,32	874,88	180	29
3	AN-HT	2,58	1.489,6	250	30

Utilization of mineral andesite in South Gombong Karst region commonly used as building materials, such as foundation, road material, split casting material mixture, as well as other civil engineering building. Based on the physical and mechanical test results, indicating that the andesite at South Gombong Karst region meet ASTM standards as the foundation-story building.

Bentonite, found at the Argopeni village, as a result of hydrothermal alteration processes of tuffaceous sandstone on Gabon formation. The potential reserves of 100,000 m^3.

Table 5. The result of the Argopeni‘s bentonite analysis (BAPPEDA Kebumen, 2004)

No	Parameter	Result(%)
1	CaO	1,46
2	MgO	1,71
3	$Na_2 O$	0,39

The above analysis shows that the content of CaO + MgO = 3.17%, while it Na_2O = 0.39% so that including calcium - magnesium bentonite. Type of this bentonite is only able to expand approximately 1.5 times (for Na-bentonite able to 8 times), so it needs to activated before activating media H_2SO_4 (5%) and HCl (5%), at a temperature of 1000 C within 2 – 4 hours (Rumidi S, 1998). So that the bentonite in the study area is less economical, due to the need for further processing and the amount of reserves that are less supportive.

Kaolin, are found in the Jintung, Ayah district, as a product of hydrothermal alteration of volcanic rocks of Gabon formation, in the form of a clay material. Its use as a main ingredient of paper industry both as fillings and coatings, as well as in the ceramics industry. Based on chemical analysis showed that the composition of CaO 10.2677%, Al_2O_3 composition

8.8282%. Therefore, the composition of the Fe_2O_3 and CaO are very high, and Al_2O_3 is very low, so the kaolin at this area not be utilized economically in the paper and ceramic industry (Ansori, 2009).

Trass, are found in the Jintung, Ayah district. It is estimated that a product of weathering of andesite and andesite breccia which rich in feldspar and silica. Total mineral reserves in the Jintung region, estimated that 60,000 m^3. Trass quality depends on the composition of the main chemical elements, such as SiO_2, Al_2O_3 and CaO. Based on the results of chemical analysis showed that the composition of the oxides SiO_2 = 45.96%, CaO = 15.00%, and MgO = 3.11%. Based on these datas could be concluded that this material meet the required strandar SII as cement-making materials Pozolan (Ansori C *et al*., 2009)

Gold, mining activities are found in the Jladri river, Buayan, Argopeni, and Ayah district. The existence of gold deposits in the study area are associated with quartz veins as a hydrothermal alteration products which associated with volcanic activity.

Bituminous shale, found in the Domas, Argosari village, Ayah district especially in Kali Kedungareng. Bituminous shale is characterized with black colour, dense, massive, rather soft shale resembles a flake. Stratigraphically, below the limestone member of Kalipucang Formation, which inserts a layer between the alternating sandstone, siltstone, and claystone. Based on the research Tobing (2003) bitumen in this area has an average oil content of 7 - 32.5 lt / ton, water content of 12-70 liters per ton of rock, sulfur content 3.68 - 11.2%, oil specific gravity 0.83 - 0.87%. Based on these data, could be conclude that bituminous shale in this area has contained light oil. Based on Tobing (2003) resources bituminous shale in this area 7,264,176.20 tons of solid bitumen. Crude oil which can be obtained from the extraction reached 829,941.24 barrels.

Population Profile.

The number of residents in South Gombong Karst region as many as 162,167 people, consisting of 81,724 women and 80,443 men. The biggest population in the Sikayu village, Buayan, but the smallest in the Kedungweru village, Ayah district. Most of the population earns a meager living as farmers (59.9%), traders (11.22%), miners (4.6%) and in other service sector (24.25%). While the extensive wetlands in the form of rainfed lowland and irrigated rice fields is only about 13.5%, so that more farmers who worked on the plantation sector and the vast field reached 54.1%.

Dicussions.

Karst zone I includes 74.6 % of area approximately 414.83 Ha extending from Banyumudal, Redisari, Kalisari, Sikayu, Jatijajar, Manguweni, Pakuran, Buayan, Rogodadi, Ayah, Tlogosari and Karangduwur village. In this area develops subsurface drainage systems, caves, dolines, cockpit and ponora, have highly productive aquatic systems, well developed underground drainage, laying up groundwater recharge. South Gombong Karst Region not has forest cover, it is important to preserve the underlying karst ecosystem.

Karst zone I has a wide variety mineral resources potential, there are limestone, phosphate guano and manganese, which has good quality and could be mined. Considering both groundwater conservation especially for groundwater recharge area and the important of karst development, mining activity is most probably could reduce the continuity of water infiltration function and water catchment area in a groundwater basin.

Limestone mines, especially mineral-transporting trucks also disturb the wildlife in this area. The first step after quarrying at around Jatijajar and Redisari village, limestone is heated to form quicklime directly on the flame until becomes red. Phosphate guano was mined on Banteng cave at the Pakuran. The excavation of the phospahate and limestone can affect karst ecosystems.

In view of this segment is a protected area should:

a. Not extend the operating license of lime quarrying and burning, in accordance with spatial and land use exists.
b. Transferring the business community diggers and lime burner to other activities that does not destroy nature, such as business tourism and agriculture sectors.
c. Changing production forest area into forest conservation, the result will be enjoyed by many people (tourism, water resources, environment, fisheries, and agriculture.

Karst zone II of about 88.23 ha (15.9%), including the Redisari, Kalisari, Banyumudal, Karangsari Kalibangkang, Watukelir, Argopeni village. There is no exposed caving system, springs, and lake. Morphology to form wavy hills, conical or curved at the top of the hill with a height of more than 100 m. Vegetation and forest cover is less, except in the south. Land used for forest crop production, especially teak and acacia. The Potential of karst region II such as limestone, andesite, manganese and phosphate. Excavations of limestone carried out by local miners scattered in the north, which borders directly with Halang Formation. This region has fuctioned as a buffer zone. which restrict the cultivation area (karst class III) and conservation areas (karst class I). Mining activity is still possible on parole by following the laws and regulations such as the environmental document or AMDAL. AMDAL study should be conducted in a multidisciplinary, with a fixed forward the aspects of sustainable development and participation of local communities (community development programs).

Karst zone III has no criteria as karst region class I and class II. This area is a remnant limestone karst, with an area of 52.92 ha (9.5%). This area is a farming area, so that the natural resources can be fully utilized. The implementation must adhere to the norms applicable regulations. The potential of limestone and manganese, covering most of the Jintung village. There are limestone excavation conducted for the needs of local residents.This region is a farming area so that the entire mining and other activities are very open to do, but must still consider the norms and rules that apply.

The outside of karst regions is mostly a part of Gabon and Halang formation, which composed by breccia. Encountered potential andesite, manganese, trast, bentonite and indications of gold. Morphology of this area shown as the high mountains with peaks G. Arjuna and G. Poleng, there is potential mass movement. Mining is still open but must comply with existing regulations and with regard to environmental conditions.

To improve the welfare of farmers which is the largest percentage of the population will be determined according to the type of plantation crops combined with farming so that the economic value becomes greater. The percentage of miners is not great but need both intensive and effective coaching. Commonly, mining activity in this area is a illegal miners so that environmental damage is feared to worsen in the future.

Conclusion

South Gombong Karst region included in the protected area. Karst zone I includes 74.6 % of area approximately 414.83 Ha. The mineral potential of zone I are limestone, manganese and phosphate. All mining activities must be stopped, which still exist should not extend the mining permit, mining business transferred to another business or other areas that enable, and change the production forests to forest conservation.

Karst zone II of about 88.23 ha (15.9%), including the Redisari, Kalisari, Banyumudal, Karangsari Kalibangkang, Watukelir, and Argopeni village. The mineral potential of zone II are limestone, andesite, manganese and phosphate. This area was fuctioned as a buffer zone. Mining activity in this area is still possible on parole by following the laws and regulations such as the environmental document.

Karst zone III covering an area of 52.92 hectares. The mineral potential of zone III are limestone, and manganese. Natural resources in this area can be fully utilized. The implementation must adhere to the norms applicable regulations. Outside of the region encountered andesite, manganese, trast, bentonite and the indications are allowed to conduct gold mining.

The incomes of farmers and miners need to increase in the karst region through the development of animal husbandry, plantation and development of tourism.

Acknowledgements

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ACTIVE CRUSTAL DEFORMATION AT THE COAST OF GUNUNG SEWU, JAWA

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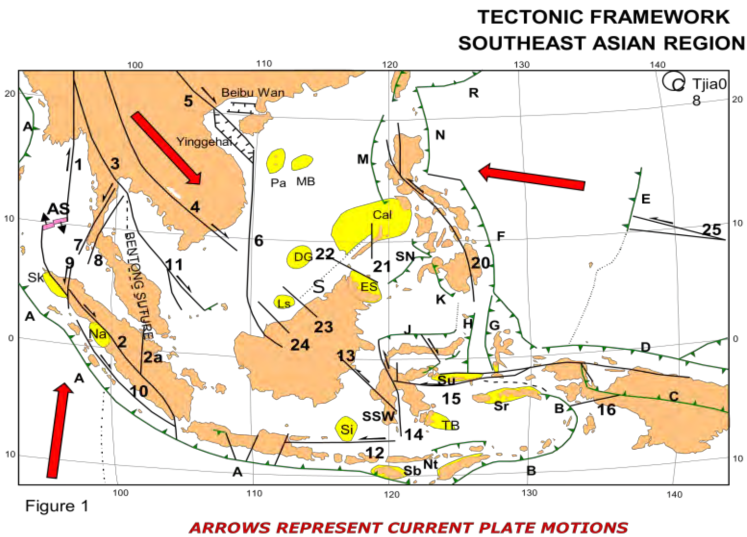
Abstract
Very recent uplift of 1 to 1.5 meter is indicated by anomalously high positions of well-developed mean sea-level notches on the limestone cliffs at many locations: such as at Baron, Sadeng, Krakal, Drini, Siung of the Gunung Sewu limestone coast. A study is planned to seek possible correlation with very strong subduction earthquakes that produced the disastrous tsunamis of Banyuwangi (1994) and Pangandaran (2006) or with earlier tremors in the past century. Older, so called neotectonic deformation of the crust is also well represented. (1) The accordant hill summits of the karst sinoid hills suggest some 200 m progressive uplift since the termination of deposition of the Wonosari beds, perhaps 5 million years ago. (2) A 40-meter high structural terrace that cuts across beds of the Oyo Formation at the Buyutan coast also supports *en bloc* uplift with only slight tilting seaward. (3) In the Baron-Sadeng area, three long lines of limestone ridges of divergent orientations suggest that in the Late Miocene during the deposition of the Wonosari beds, the Gunung Sewu terrane rotated counter-clockwise by 10 degrees. (4) Five observable terraces stacked on the east side of Pacitan Bay indicate tilt at 4 to 5 degrees seaward.



Geological setting of Gunung Sewu area in the active Sunda magmatic island arc

Introduction

Jawa Island is the magmatic part of the active Sunda double arc that includes Sumatera, Bali, the Lesser Sunda islands (Nusa Tenggara Barat-Nusa Tenggara Timur) and that farther towards east curves about the Banda Basin to end in the Banda Islands (figure 1). As such, geological activity in the form of explosive volcanism, variations in gravity anomalies, earthquakes related to subduction reaching down as deep as 700 km, large and extensive mass movements on land as well subsea have been the norm since late Cretaceous time, some one hundred million years ago. Crustal movements facilitated by faults, uplifts and subsidence of large areas are further evidence of crustal mobility. Average rates for uplifts and subsidence in the course of the Pleistocene range from 2 mm to over 10 cm annually (Tjia *et al*. 1972; Tjia, 1989). The Gunung Sewu terrane of karst limestone of Neogene age !0.4 to 5 million years old bears witness of uplift amounting to close to 300 meters. The stratified limestone and coral reefs were emplaced in a shallow sea 50 m to probably a hundred meters deep. The depositional surface was originally level. The entire limestone and associated clastic sediments, stratigraphically assigned as Wonosari and Oyo formations were raised virtually *en bloc*. Tropical weathering of predominantly chemical nature has carved the limestone plateau into numerous (*sewu* means thousand) hills, most with topographic relief between 50 m and over 100 m elevation. Small remnants of the original plateau determine accordant summits of the hills. This morphology of sinoid karst hills is known the world over as the Sewu type of tropical karst. Most of hills possess convex profiles resembling overturned coconut shells. Therefore, sinoids are the most appropriate term for the Sewu limestone hills. Tectonic stresses have generated numerous faults and regional joints in the limestone. These faults and joints facilitated dissolution into the limestone mass and produced linear topography, linear valley segments, and sinkholes aligned as lineaments. The lineaments have systematic patterns that can be classified into directions of tension, extension and shears. A more recent study of karst lineaments of Gunung Sewu was published by Haryono & Day (2007).

The objective of this communication is to draw attention to products of crustal deformation in the Gunung Sewu. To our knowledge the following observations have not been discussed by other workers of Gunung Sewu. We divide our discussion into deformation as ―neotectonic" manifestations and tectonic events of the geologically recent past. We use the term neotectonic for deformational events occurring since the Middle Miocene (15.5 Ma) up to the Pleistocene. ―Recent" denotes events occurring in the last ten thousand years of Earth's history.

Neotectonic Deformation

Accordant Hill Summits. The Wonosari Formation comprises Middle Miocene (around 15 to early Late Miocene (perhaps 8 Ma) stratified calcareous sediments and coral reef. The formation intercalates with the more siliciclastic but still calcareous Oyo Formation (Sartono, 1964; Samodra *et al*. 1992). The limestone and presence of reefs indicate depositional epineritic environments of around 50 m depth or shallower. Both formations were gradually raised some 200 meters above sea level. Remnants of the depositional surface now form caps of the sinoid hills and mark accordant summits (figure 2). Differential block uplift created karst hills with summit elevation ranging from 50 to slightly over a hundred meters local relief. The net uplift of the Sewu terrane amounting an estimated value of 200 meters precluded younger marine sedimentation over the Wonosari and Oyo sequences. Instead these formations are succeeded by terrestrial, polymict conglomerate of the Kalipucung Formation.of Pleistocene age.

Figure 2

Gunung Sewu at Punung - 1956

The typical Sewu-type of sinoid karst hills. Locality near Punung, photograph by P. Marks in 1956

Structural Plateau. At the Buyutan coast (South 08 ^{O} 13.084‘, East 110 ^{O} 55.291 _) is a 40-meter high structural plateau beveled across gently inclined layers of the Oyo Formation. The sedimentary layers dip 6 degrees seaward, a situation confirming that uplift was in near-vertical sense. At the foot of the high sea cliff is a terrace estimated at 6 m elevation indicating relative change of land-sea level. In the near shore are rocky islets forming sea stacks and a pillar. We interpret these rocky structures as remnants of a high promontory that underwent extreme destruction by pounding waves. The promontory would have caused wave refraction that concentrated abrasion onto the rocks. The plateau is rimmed by sinoids of the Wonosari limestone.

Gunung Sewu morphology to West of Teluk Baron.

1. Ria-type of shoreline controlled by sinoid hills.
2. Linear limestone ridges are raised barrier limestone edges, indicating 15-20 degrees counter-clockwise rotation of Sewu terrane of Pulau Jawa.
3. Hexagonal pattern (H) of hill assemblage is of unknown origin.

Gunung Sewu coast at palaeo-Sadeng outlet.
Three orientations of raised barrier limestone edges (3 oldest, 1 current) suggest episodic counter- clockwise rotation of the Sewu terraine of Pulau Jawa.

Figure 3. Rows of ancient depositional fronts of the elevated Wonosari Formation.has divergent orientations. Row 3 (oldest) makes a 10-degrees angle with the youngest row (1), while row 2 has an intermediate orientation. Google Earth images with annotations

Diverging Depositional Fronts. Satellite images of Gunung Sewu published by Google Earth show several long rows of limestone ridges among the isolated karst hills. Figure 3 shows examples from the vicinity of Sadeng and Baron. These rows are interpreted as depositional fronts of the Wonosari sediments, possibly marking ancient lines of breakers. The illustration shows that the row closest to the present coastline has an orientation that is about 10 degrees different compared to that of rows located farthest inshore. The second row has intermediate divergent orientation. We suggest that during pro-gradational deposition of the Wonosari beds the line of breakers change orientation which reflects a similar change in the shoreline orientation. These changes occurred counter-clockwise and amounted to about 10 to 15 degrees. Ngkoimani (2005) determined from paleomagnetic studies of Tertiary andesites of Central and East Jawa that since the period between 11 Ma and 6.7 Ma (Middle to Late Miocene), the respective Jawa terrain has rotated CCW by 8 to 10 degrees.

Terrace Sequences. The panoramic view of the eastern side of Pacitan Bay is on figure 4. The hilly terrain summits at around 170 m. Five terraces are observable from the opposite side of the Bay. The two lower terraces are level. Terraces 3 to 5 are inclined 4 to 5 degrees southward. The situation is interpreted that prior to the development of Terrace 2 the hilly terrain experienced tectonic uplift and tilting, while the lower two terraces were only vertically raised. Further study is needed to determine the contribution of varying sea levels to the terrace morphology. Nevertheless, Pacitan being located in the Sunda tectonic arc, tectonism can be regarded as the dominant contributor to elevation of the terraces.

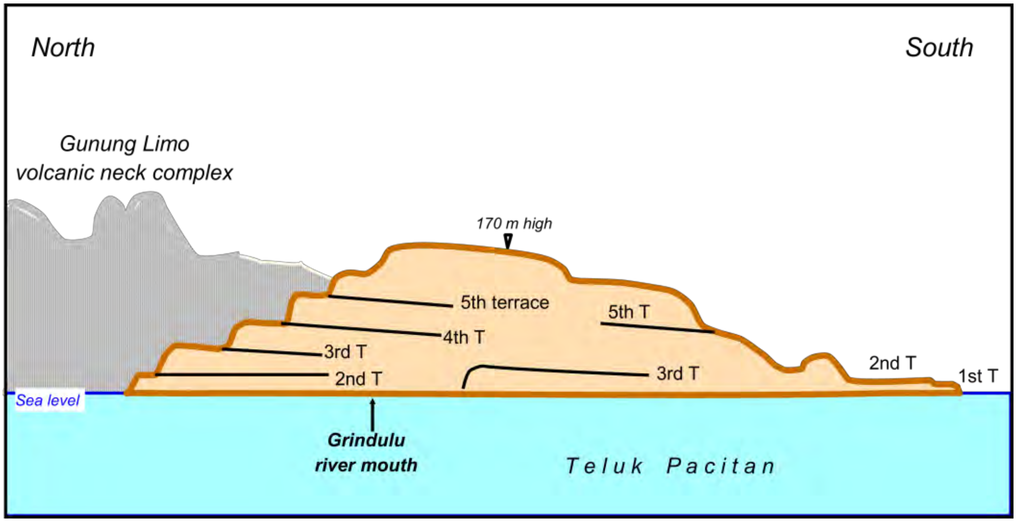


Figure 4 Field sketch of stacked terraces on the east side of Pacitan Bay

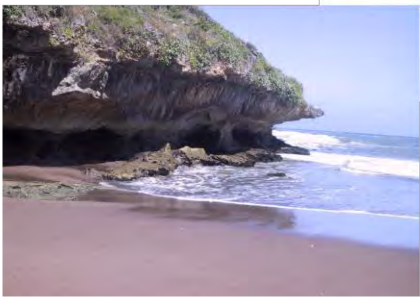
Active Deformation. Under this heading are described anomalous positions of geological features at the Gunung Sewu coast. No absolute dates are as yet available but in reference to similar features elsewhere and certain arguments set forth below, the anomalous positions are interpreted as products of recent Holocene events.

Beachrock. Calcareous beachrock develops within the intertidal zone, At Krakal coast are four or more stacked banks, each 10 t0 15 cm thick, of calcareous beachrock whose land ward edge reaches above the high-water mark. The beachrock is decaying. The anomalous high position and state of decay indicate a relative drop of sea level., or raise of the land. Further work is needed, especially in determining the age of the rock.

Mean sea-level Notches. On limestone coasts notches are carved into the cliffs. The deepest part of the notch corresponds with mean sea level, while the height of the notch opening is determined by wave action and tidal range. The higher the notch opening is, the more prominent is the wave action and the tidal range. The vigorous waves of the Indian Ocean that pound onto the Gunung Sewu coast easily accounts for the observed notch openings of 3 meters or more. However, the deep part of notches seen in many coastal cliffs at Watukarung, Klayar, Baron, and Sadeng for example, are a meter to 1.5 m higher than the current mean level of the sea (figures 5a and 5b). At these places, no lower level notches are seen. We interpret this to indicate the land was raised very recently by that amount. The event occurred very recently as no new notches have been formed that correspond with the present mean sea level. Two strong subduction earthquakes associated with several meters high tsunamis are known as the Banyuwangi-Rajegwesi (1994) and Pangandaran (2006) inundations. Further study is needed in this matter. The sudden uplift of 1 to 1.5 meter may be associated with earthquakes of magnitude 7 and higher. Correlation of meters high sudden elevation at the coasts in Japan and very strong tremors is well documented (National Research Center for Disaster Prevention, 1973).

Figure 5b

Pantai Baron, east cliff.
Notch is ~ 1.5 m above current MSL (photo).



Pantai Drini. Sea level is at current MSL,
Deep notch is ~ 1.5 m above this MSL.

Figure 5a

Elevated mean sea-level notches in the limestone cliffs of Drini (5a), Baron (5b) and Siung (5s) coasts

Figure 5c. Pantai Siung. Palaeo-sealevel notch raised ~ 1.5 metres.

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DIAGENETIC CHANGES ON SECONDARY POROSITY IN RESERVOIR POTENTIAL OF WONOSARI LIMESTONES, PANGGANG, GUNUNG KIDUL, YOGYAKARTA

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Abstract

This paper is attempted to study controlling factors on the formation of secondary porosity in Wonosari Formation of the Southern Mountains, within small area near Panggang Town, Panggang District, Gunung Kidul Regency. In that area, intensive karstification on the limestones producing karst topography and affected diagenetic characteristics. Some diagenetic components such as types and shape of cement and affected secondary porosity could be used to determine their reservoir potential. Panggang limestones are interpreted to be deposited on platform reef margin. Three measurement sections or tracks were established in the area, named A, B, and C respectively, and overall all tracks suggest coarsening upwards succesions. Track A consist of allochtonous facies which are composed mostly of floatstones and rudstones, sparingly with wackstones and mudstones. Their faunal assemblages are comprised of corals, molluscs, foraminiferans, sponges, calcareous alga and echinoderms. Track B also consist of floatstones and rudstones but amply with wackestones and mudstones. In opposite with other tracks, track C consists of mostly autochtonous facies which are mainly composed of boundstone facies. Their faunal assemblages are dominated by corals that mostly comprised by aragonite skeletals. Thus crystallization occurred significantly in this facies and implied to porosity declining. Consequently, quality of reservoir potential is decreasing.

Keywords: Panggang, Diagenetic, Wonosari Limestone, Porosity

Introduction

The Middle to Upper Miocene Wonosari Formation of Southern Mountains was first investigated by Kadar (1974; in Rahardjo, 1995), where is composed of reefal limestones, calcarenites and tuffaceous calcarenits. A research conducted by Gadjah Mada University reported that this formation consists of bedded to poorly bedded limestones, rich in coral fragments and algae plus some corals in growth position (Anonym, 1986).

Despite numerous studies on the formation (e.g. Toha *et al.*, 1994; Rahardjo, 1995; Fadilestari, 2009; Setiawan, 2009; Siregar, 2009), their diagenetic process and its implication to resevoir potential in Panggang Area are not well understood yet. Furthermore, it is equally important to document vertical sequnce of facies changes and faunal assemblage related to their diagenetic implication. Such vertical and lateral relationships provide evidences of diagenetic facies changes due to their textural and composition changes (Fig. 1).

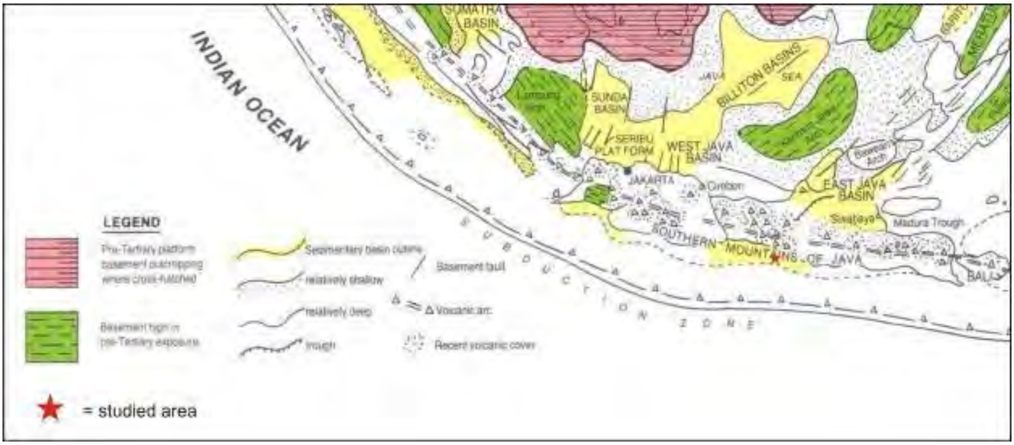

Figure 1. Generalized tectonic setting of Java (Satyana, 2005; after Koesoemadinata & Pulunggono, 1971). The location of studied area (in Southern Mountain zone) has been shown by the red star.

In need to study diagenetic process and their implication to reservoir potential in Wonosari Formation and the fact that there are few documented cases in local geologic literature, the purpose of this paper are as following:

1. study the lithofacies changes in Wonosari Formation in Panggang area;
2. calculate the percentage of secondary porosity generation due to diagenetic process; and
3. evaluate diaganetic processes had been occurred and their implication as reservoir potential.

General Setting and Stratigraphy

Exposures of Wonosari Formation formed conical hills belong to Thousand Mountain (Gunung Sewu), which were followed prominent intersecting joint systems which trend Northeast-Southwest, Northwest-Southeast and North-South (Anonym, 1986). This formation offers an excellent opportunity to study Tertiary Carbonates, consist of bedded to poorly bedded limestone, rich in coral fragments and algae plus some corals in growth position. Large foraminifera such as *Lepidocyclina sp.* and *Miogypsina sp.* can be found here, besides small foraminifera, molluscs and worm tracks (Anonym, 1986).

Wonosari Formation lies conformably on Sambipitu Formation and intertonguing to Upper Sambipitu Formation, Oyo Fomation and Kepek Fomation (Toha *et al*., 1994). This formation form in Upper Miocene to Lower Pliocene (Kadar, 1974 in Rahardjo, 1995). This limestones with a thickness of more than 200 meters, dip 5 to 12 degrees toward the south, werw deposited during the Upper Miocene in a shallow marine environtment, probably with small patch reefs (Anonym, 1986).

Facies

Three stratigraphic sections or measurement tracks were obtained to determine the vertical and lateral facies changes, named as track A, track B and track C, respectively (Figs. 2, 3). Both track A and track B indicate allochtonous facies which are consist of coarsening upward succesions, meanwhile track C suggests autochtonous facies.

Figure 2. Map of studied area which shows three stratigraphic measured tracks as labelled by track A, track B, and track C, respectively.

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Allochtonous Facies. Mudstone, wackestone, packestone, floatstone, grainstone and rudstone facies contribute for a thick (± 110 m) interval in both track “A” and track “B”. These facies were deposited in lagoonal back-reef environment, then underwent a vadose diagenetic zone where both crystallization and dissolution were occurred. Crystallization characterized by equant and pendant cements type and typically of intergranular, intragranular and fracturing porosity. However, these facies produced poor secondary porosity.

Interpretation of facies. Allochtonous facies are interpreted to be deposited in lagoonal back-reef environment. It is assumed that when the Southern Mountain uplifted in Upper Pliocene this area had became land and vadose environment prevailed. In this later vadose environment, they underwent both processes, crystallization and dissolution. Crystallization occur when the solution of saturated rain water started to precipitate. When pores in the vadose zone filled by water and air, gravitation forced the solution to drip and oversaturated, thus producing the pendant cement type. On the other way, when rainwater dissolved these facies, they formed vacant spaces, which is called as secondary porosity.

The secondary porosity. Generation of secondary porosity is controlled by the composition of original mineralogy. The porosity only derived from intergranular, intragranular and fracturing porosity while mouldic, fenestral, vuggy and cave porosity types were absent (Fig. 4). In addition, fracturing porosity only contribute small values; whereas it was expected that great numbers of fracturing porosity will increase the rocks permeability by increasing the potential quality of reservoir. There were 14 thin sections observed in both track A and B. The result shows that the percentage of average porosity is 7,6 % (Table 1.), which is mean this facies has poor quality parameter as reservoir potential.

Autochtonous Deposits. Boundstone and rudstone facies comprise a thick (± 79 m) interval in track C. This facies were deposited in front-reef environment. Similiar to allotochtonous facies, this facies also underwent diagenetic process in vadose zone, thus both crystallization and dissolution had been occurred. Crystallization characterized by mostly equant cement type while porosity is dominated by intergranular type. Unfortunately these facies generate poor secondary porosity value.

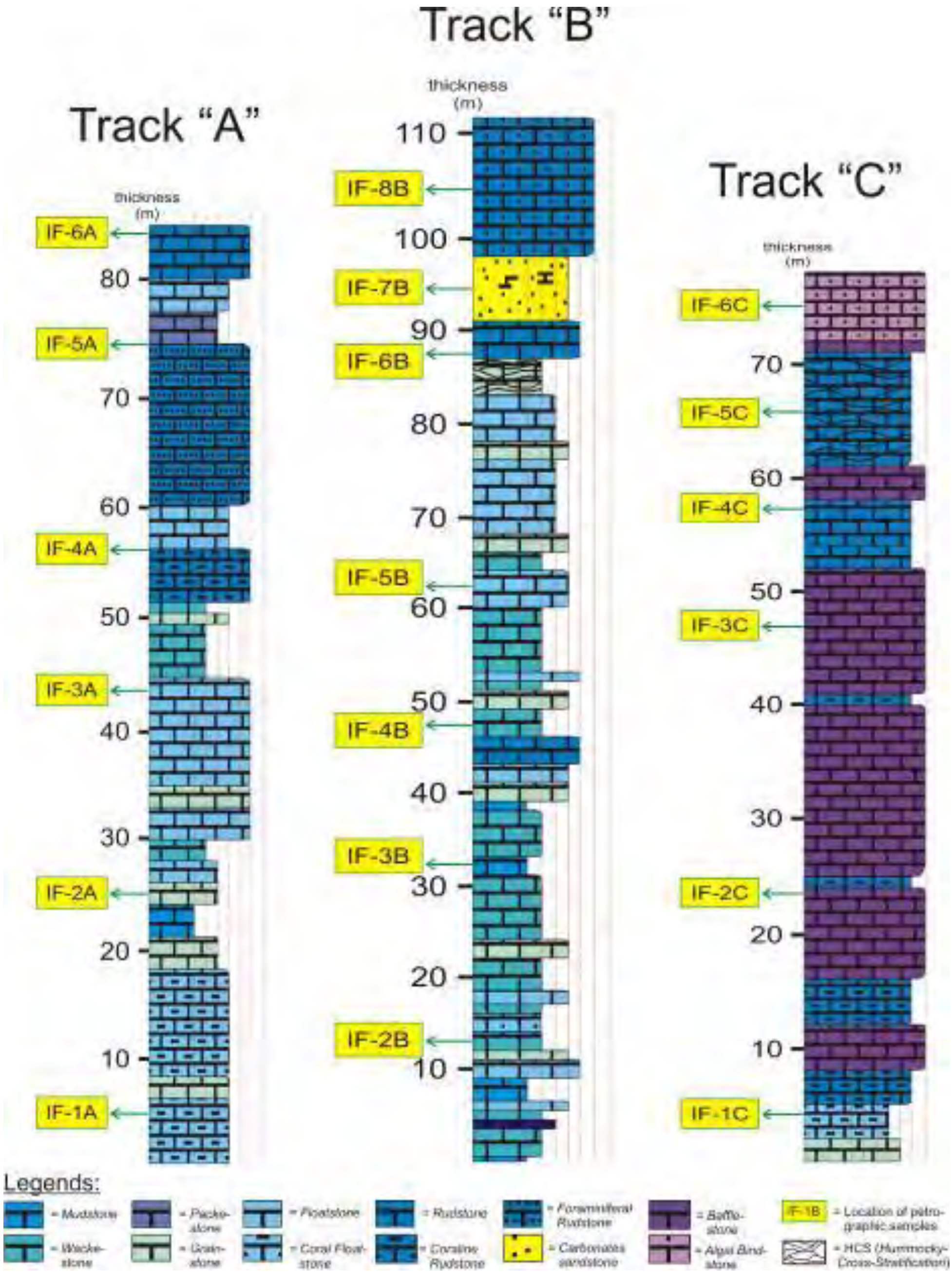

Figure 3. Measured sections of each tracks and location of petrographic samples.

Interpretation of facies. Autochtonous facies are interpreted to be deposited in front-reef environment. They consist of bafflestone, algal bindstone and rudstone. Their components comprised by mostly sclerectanian corals which were built by aragonite skeletal. Aragonites are more soluble and less stable than low-Mg calcite, thus their structures are easily replaced by more stable minerals like calcites and dolomite. Similar to the allochtonous facies, diagenetic processes after the Southern Mountain uplifted had taken place in vadose zone. Instead of producing pendant cement type, ongoing crystallization also generated equant type which is varied from fibrous to needle-like cement types.

The secondary porosity. When rainwater dissolved these facies, they formed vacant space as secondary porosity. As this facies consist of mainly scelerectanian corals which is comprised of aragonites skeletal, consequently many pores were generated. However, most of the pores were filled by saturated rainwater and thus crystallization more significantly occurred rather than porosity generation. The porosity only derive from intergranular, intragranular and fracturing porosity while mouldic, fenestral, vuggy and cave porosity types were absent (Fig. 4) Here, we should point out that fracturing and intragranular porosity contribute nothing to increase porosity in this facies. There were six thin sections observed in track C. The result shows that the percentage of average porosity is 1,9 % (Table 2), which is meant that this facies has very poor quality parameter as reservoir potential.

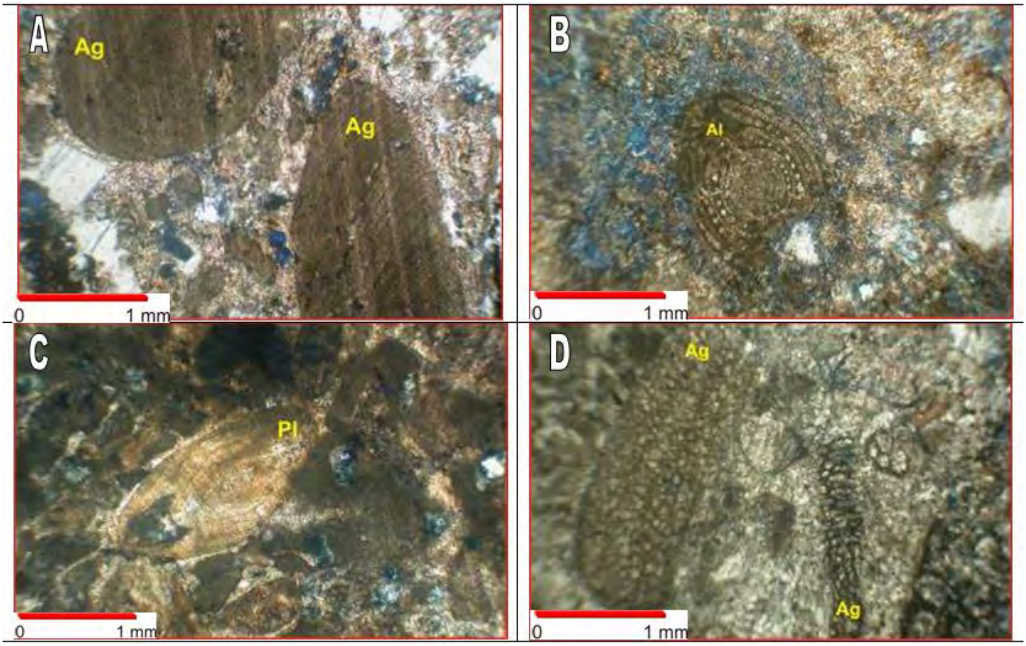

Figure 4. Some polarized petrographic samples (4x magnification): A. Foraminiferal floatsone (IF-5A), B. Sparitic wackestone (IF-1B), C. Algal foraminiferal rudstone (IF-6B), D. Algal coraline floatsone (IF-5A). (Ag = algae, Al = *Alveolina bontangensis* Rutten, Pl = *Palaeonummulites*)

Diagenetic Framework Related to Their Secondary Secondary Porosity Generation

Wonosari Formation in Panggang area comprised of allochtonous and autochtonous facies. Since early Upper Pliocene when Southern Mountain uplifted, vadose diagenetic environtments was starting to thrive.

Table 1. Percentage of porosity values in allochtonous facies.

Petrographic Samples Code	Porosity Type	Percentage (%)
IF-1A	intergranular	12
IF-2A	intergranular	8
IF-3A	intergranular	4
IF-4A	intergranular	4
IF-5A	intergranular	8
IF-6A	intergranular	13
IF-1B	intergranular	9
	intragranular	1
IF-2B	intergranular	4,4
	fracturing	2
IF-3B	intergranular	5,2
IF-4B	intragranular	5
IF-5B	intergranular	2,4
IF-6B	intergranular	6
	intragranular	4
IF-7B	intergranular	1
IF-8B	intergranular	5,4
	intragranular	5
Average		**7,6**

Table 2. Percentage of porosity values in autochtonous facies.

Petrographic Samples Code	Porosity Type	Percentage (%)
IF-1C	intergranular	3
IF-2C	intergranular	1,4
	fracturing	1
IF-3C	intergranular	0
IF-4C	intergranular	1
IF-5C	intergranular	3
IF-6C	intergranular	2,4
	intragranular	1
Average		**1,9**

Conclusions

- Wonosari Formation in Panggang area consist of allotochtonous and autochtonous facies which were underwent diagenetic processes in vadose environment.
- Allochtonous facies produced pendant cement types, as well as intergranular, intragranular and also fracturing porosity.

- Autochtonous facies produced pendant and equant cement type, as well as intergranular, intragranular and also fracturing porosity
- Both facies only generates very poor – poor percentage of secondary porosity. Allochtonous facies generated 7,6 % porosity and autochtonous facies produced only 1,9 % porosity. Crystallization play important role in decreasing facies porosity. Those value decrease the quality of reservoir potential.

Acknowledgement
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LITHOLOGICAL CHARACTERISTICS, SHAPE AND ROCK RELIEF OF THE LUNAN STONE FORESTS (SOUTH CHINA KARST)

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Abstract
Stone forests are unique karst surface landforms. The Lunan stone forests developed from underground karren, and where this type of surface is highly developed in China, it is defined as a ―shilin" landscape. Numerous examples of stone forests (shilin) that developed in almost identical conditions show that the diverse shape of the pillars is primarily a consequence of: 1) the properties of the rock, 2) the distribution and density of joints and fissures in the rock, and 3) its diverse stratification and composition. The Lunan stone forests formed in early Permian carbonates of the Qixia and Maokou formations. Characteristic of these are frequent alternations of very pure limestone, dolomitized limestone, and dolomite, the alternation of thin and thick layers, and in some places distinctive late diagenetic dolomitization and secondary porosity. The layers are mostly horizontal or inclined by five to ten degrees. Due to vigorous tectonic action, they are fractured by numerous vertical and subvertical joints and fissures. Because of the exceptional characteristics of this karst phenomenon in China, we propose that the term ―shilin" be used for this type of stone forest in the professional literature.

Keywords: Lunan stone forests, lithology, morphogenesis, rock relief

Introduction

Stone forests emerged from subcutaneous karst karren since the limestone was covered with thick layers of sediment and soil. They consist of stone pillars and teeth (Song, 1986). Stone teeth are smaller protuberances less than five meters tall. Pillars, however, are from five to fifty meters tall and of various shapes. They developed in diverse horizontal or gently sloping rock strata (5º-15º) cleft by vertical faults, joints, and fissures (Ford, Salomon, & Williams, 1996). The Lunan stone forests are considered a form of covered karst.

The central part of the Lunan stone forests spreads over eighty hectares; larger and smaller stone forests, however, cover as much as 350 km^2. Under the forests there are various karst cave networks.

We presented research on the Lunan stone forests in detail, described them, and assembled material on them in the book *South China Karst I* (Chen *et al*., 1998), *South China Karst II* (Knez *et al*., 2010) and elsewhere (e.g., Knez & Slabe 2001a, 2001b); this paper adds the results of the comparison of different types of stone forests.

Lithologic Properties of Stone Forests

The stone forest area (Fig. 1) consists of early Permian carbonates of the Qixia and Maokou formation. These are two of the most important basal formations from which numerous stone forests emerged in the southern Yunnan province of Lunan. Typical for Qixia formations are micrite limestone with intercalated dolomite and dolomitized limestone with intervening layers of slate. In the lower part of Maokou formations, limestone alternates with dolomite and dolomitized limestone. In the upper part we find a succession of limestone layers that in some places are thin and in others several meters thick as well as solid limestone that contains several-decimeter large nodules of chert in individual horizons.

Figure 1. One of Lunan stone forests.

The main lithologic properties of Maokou formations are roughly similar to those of Qixia formations, except that in Maokou carbonates we do not find a major influence of late diagenetic dolomitization and in some places a considerable secondary porosity. However, both show a strong diagenetic alteration of the basic rock, which is undoubtedly also a consequence of intensive volcanic (basalt lava) activity during the transition from the Paleozoic era to the Mesozoic era. The rock contains an extremely high percentage of carbonate.

In the area studied we find considerable variations in thickness, porosity, and degree and type of dolomitization, in the components of inclusions, and in the colour of individual layers that are reflected in the formation of the stone forests (Knez, 1998).

What is macroscopically most noticeable in the geological profiles is the different thickness of layers, which varies from ten centimeters to many meters, according to some data even more than thirty meters (Song, 1986). In the stone forests we encounter rock sequences composed of several meter thick homogeneous and compact layers where karstification is advancing considerably faster on the tops, along bedding planes and individual fissures, and below the surface (Shilin Central Forest, Naigu) as well as sequences of thin-layered (10 cm and more) limestone (Pu Chao Chun) where already intensive karstification is accelerating along numerous lithologic junctions. In the geological profiles we find an alternation of thickly-stratified and thinly-stratified carbonate as well (Naigu, Pu Chao Chun). Where the layers are thinner, the pillars can be much thinner due to more rapid corrosion (Naigu, Pu Chao Chun).

In some places we encounter thicker segments of very porous layers (Lao Hei Gin) where the intercrystal porosity exceeds 20% in most cases. Typical for these are dolosparite and dolomicrosparite of the grainstone type. Diameters of light brown and in some places extremely pure and almost completely transparent dolomite grains reach one millimeter while their average diameter is one third of a millimeter. In contrast to the homogeneous and compact rock, a segment of the porous layers does not karstify merely along the lithotectonic junctions but across the whole profile in accordance with the stage of porosity. The rate of karstification of such rock is substantially greater and additionally accelerated locally below the surface.

Late diagenetic dolomitization is also typical of some layers. Where increased porosity and dolomitization appear in the same layers (Lao Hei Gin), more intensive karstification is found as well. A special example is the dolomitization of only individual smaller fields in such a way that otherwise homogeneous, compact, and impermeable rock becomes freckled (Naigu). Dolomitized limestone is therefore less influenced by karstification than pure thickly-stratified limestone (Shilin Central Forest). To a lesser degree, we see that dolomite fields, usually with a diameter of a few centimeters, protrude from the rock.

Layers with inclusions more resistant to karstification protrude from the profiles as well. One example is the chert that is the result of allochemical early diagenetic processes (Shilin Central Forest, Naigu). Less soluble inclusions macroscopically influence slower karstification only locally while microscopically corrosion is substantially more intensive at the junctions between the inclusions and limestone.

Due to volcanic activity at the time of sedimentation and after it, the colour of the rock changes from light grey to yellow-brown.

Geologic Influence of the Shaping of Stone Forests

Influence of fissuring of rock on the shape of the forest and size of stone pillars. The networks of distribution of the pillars, that is, the ground plans of the stone forests, are congruent with the fracturing of the rock, in this case largely vertical, and take various shapes. The pillars can be linked in rows between distinct fault areas or close together, or the stone forest or parts of it can consist of individual wide or narrow pillars. Cracks between the pillars have thus been corroded to various widths ranging from a few dozen centimeters to ten meters and more. This diversity in the network of pillars can occur in the same forest, as for example in the Naigu forest (Fig. 2).

Figure 2. Naigu stone forest.

As a rule, pillars with smaller cross sections occur with a dense network of fissures (provided, of course, they are not diminished primarily by corrosion) and larger pillars occur with a sparser network. The latter, which can often be described as larger rock masses as well, have broader tops dissected into several points on thickly-stratified rock.

Influence of rock strata on the shape of stone pillars. The rock from which the stone forests developed consists of strata of different thickness and composition (Fig. 3). This is reflected in the shape of the stone pillars, particularly in their cross sections, the shape of their tops, and their rock relief.

The shape of pillars that develop on thick and uniformly composed rock strata shows hardly any influences but rather reflects a more or less uniform development from subcutaneous karren to stone forest. The central part of the Lunan stone forests is an example. Narrower pillars have pointed or blade-like tops and relatively flat or subcutaneously undercut walls. Wider stone pillars, however, often have broad tops dissected into many points with notches between them.

Longitudinal sections of pillars on thin rock strata (Pu Chao Chun) are often jagged since they are dissected by wall notches occurring along the bedding planes, or their shapes reflect the uneven resistance of the different rock strata to the factors of their formation. Cross sections of the pillars are of various sizes and shapes. Thinner strata disintegrate faster and therefore the pillar tops are relatively flat and have a typical rock relief (Pu Chao Chun). Where the strata are thinner, as a rule the pillars are narrow. Subcutaneous tubes occurring along bedding planes can develop into subcutaneous channels when they occur on the top of a stone pillar or be reshaped by rainwater.

Figure 3. Pu Chao Chun stone forest.

Figure 4. Lao Hei Gin stone forest.

Influence of rock composition on the shaping of stone pillars. Rock composition, particularly if it is diverse, may decisively influence the shape of the stone pillars, as much their longitudinal sections as the size of the cross sections.

Porous strata are often subcutaneously perforated (Fig. 4). and disintegrate more rapidly on the surface (Naigu, Lao Hei Gin). Above them occur forms typical of overhanging walls and below them of gently sloping wall sections. The pillars break fastest along them. The tops of pillars occurring on such rock are most often of ununiform shapes.

Rock strata with less soluble components usually protrude from the walls, and if they are at the top, the tops are broader than the lower parts of the pillar and the pillars therefore acquire characteristic mushroom shapes. These are particularly distinct if the pillars occur on rock whose lower strata are relatively more soluble, porous, or disintegrate rapidly (Naigu).

Rock Relief of Stone Forests

Subcutaneous rock forms. Subcutaneous rock forms are divided into rock forms that developed under sediment and soil due to water flowing along the contact between the sediment and the rock, rock forms that developed due to the percolation of water through soil that only partly covered the rock, and rock forms that developed at the top level of soil or sediment surrounding the rock (Slabe, 1999). The first group of subcutaneous forms includes subcutaneous scallops (Fig. 5) that developed on a relatively permeable contact between the rock and the sediment and subcutaneous channels of various sizes that developed due to water flowing concentrated along the contact between the wall and the sediment that covered the rock and filled the cracks along vertical fissures. The diameter of the largest channels can reach several meters. Many reach from the top to the bottom of the pillars and are therefore several dozen meters long.

The broader tops of pillars and teeth are dissected by medium-sized and smaller subcutaneous channels and cups that developed under soil which only partly covered the rock due to water percolating through the soil and flowing along the contact with the rock. The subcutaneous channels (Slabe, 1999: 259) have characteristic semicircular cross sections or cross sections like an inverted omega wider at the bottom and have diameters reaching one meter. At joints, particularly on the rim of the tops, they are narrower and deeper. Most frequently they are linked in a branching dissected network. The multiple levels of subcutaneous channels bear witness to the progressive exposure of the stone teeth. Subcutaneous cups (Slabe, 1999: 263) are semicircular cups of various sizes with diameters ranging from a few centimeters to a meter and more. They are found on the tops of broader stone pillars and at the bottom of funnel-shaped notches on the walls beneath them.

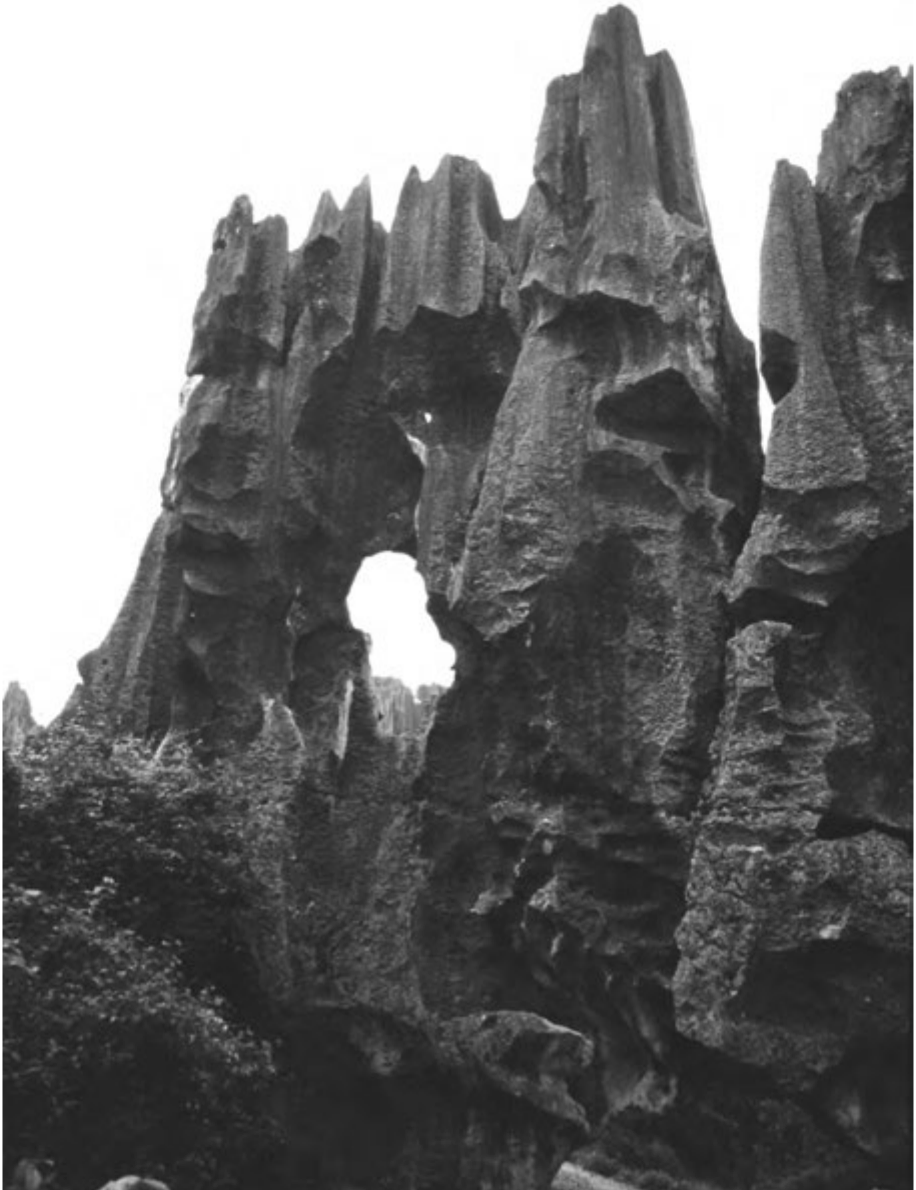

Figure 5. Subcutaneous scallops.

The most porous largely dolomite strata in the Naigu and Lao Hei Gin forests are relatively densely perforated with subcutaneous tubes with diameters ranging from several centimeters to a meter or two. On their circumferences we can find rock forms as well. Above-sediment channels are the result of water flowing over the sediment when the cavities were filled with sediment; floor channels developed when the cavities emptied as the level of sediment surrounding the pillars dropped.

Rock forms shaped by rainwater. Rock forms shaped by rainwater (Fig. 6) are naturally most distinct on the tops and upper parts of the walls of stone pillars; they include flutes, channels, rain pits, and solution pans. They often develop on old subcutaneous rock forms, reshaping them or in combination with the factors shaping subcutaneous rock forms creating composed rock forms.

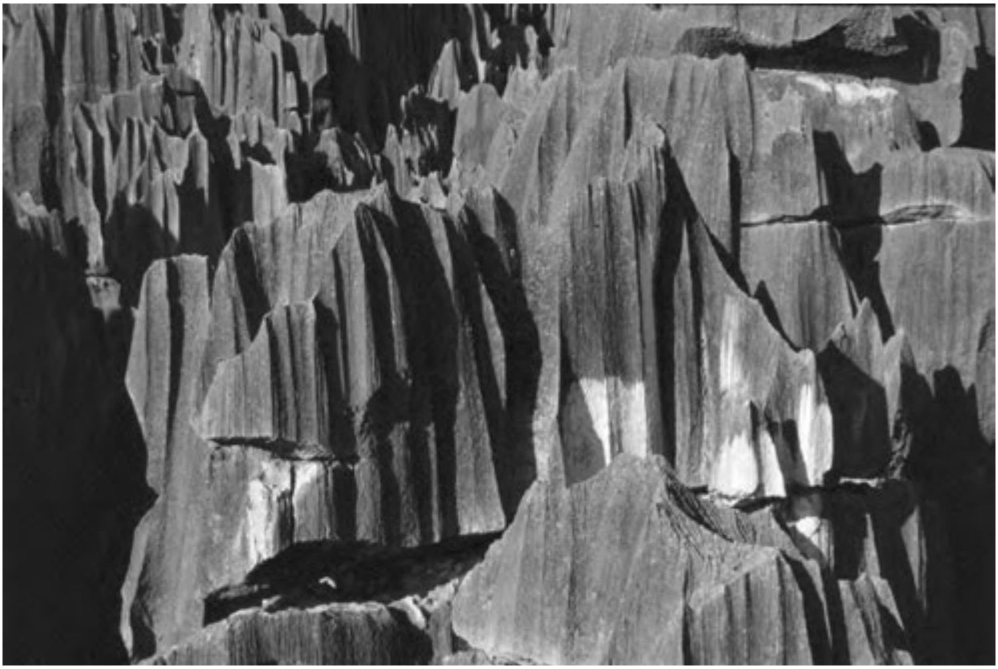

Figure 6. Forms shaped by rainwater.

Flutes are found usually on broader and dissected tops; on pointed tops they are rare, which is primarily the consequence of their steep walls. They occur on protuberances where they are arranged like rays around the highest point and on the walls of subcutaneous channels and exposed solution pans. Channels on steep walls dissect the stone pillar tops more distinctly. They have diameters of up to half a meter and measure up to five meters in length. They are relatively shallow, especially if compared to those linked to the subcutaneous shaping of the rock, and must be distinguished from the previously described channels linked to the development of subcutaneous rock forms. They are the trace of rainwater activity and frequently start on relatively sharp tops. In time, these channels also acquire a funnel-like outlet, even if less distinct at first.

Solution pans are found on broader stone pillar tops. Larger ones that developed from subcutaneous cups are often open, semicircular, and have drain channels and flutes at their circumference. Their diameters can exceed one meter. They are also found at the bottoms of the funnel-like notches that developed from subcutaneous cups.

Composed rock forms. Composed rock forms are also distinctive. These are larger channels on the lower parts of the pillar walls. They developed due to water flowing from the subcutaneous channels (Fig. 7) on the broader pillar tops or leading from funnel-shaped notches. At the bottom of these there are or once were subcutaneous cups. The rims of the tops therefore have larger or smaller funnel-shaped outlets (Naigu), most often reshaped by rainwater. Smaller but of similar origin are the vertical channels that lead from subcutaneous tubes. Rainwater has reshaped these, particularly deepening the former subcutaneous channels that crisscrossed the broader tops (Pu Chao Chun). The channels aretherefore the trace of subcutaneous dissolving of the rock and rainwater that may gradually completely dominate when the rock is exposed.

Figure 7. Subcutaneous channels.

Notches and half-bells occur where long-lasting levels of soil and sediment surrounded the pillars (central part of the stone forest, Lao Hei Gin; Slabe, 1999).

Conclusion

Numerous examples of stone forests (Fig. 8) that developed in almost identical conditions show that the diverse shape of the pillars is primarily a consequence of the properties of the rock, from the distribution and density of joints and fissures in the rock and its stratification to its composition. However, we must also consider the significance of the effect on their shaping by subcutaneous factors and transformation by rainwater, that is, the course of their development in various periods.

The Lunan stone forests formed in early Permian carbonates of the Qixia and Maokou formation. They are characterized by a diverse alternation of very pure limestone, dolomitized limestone, and dolomite, by alternating thin and thick layers, in some places by distinct late diagenetic dolomitization, and by secondary porosity. The strata are mostly horizontal or inclined by five to ten degrees. Due to vigorous tectonic action, they are fractured by numerous vertical and subvertical joints and fissures.

The diverse fracturing, stratification, and rock composition are reflected in the shapes of the stone forests and their stone pillars. In the same stone forest, which developed on diversely composed rock, pillars may be of various but typical shapes, the consequence of their development on different levels of a diverse rock column.

The shape of stone pillars occurring on thicker and uniformly composed rock strata reflects primarily the development from subcutaneous karren into a stone forest, and the traces of subcutaneous factors are gradually reshaped by rainwater. Cross sections of stone pillars occurring on thin rock strata are often jagged, and their tops (even of thinner pillars), which as a rule are pointed, are often flat, the consequence of the rapid disintegration of thin strata. Porous rock strata are most often subcutaneously perforated and disintegrate faster on the surface; the pillars are therefore narrower and the tops on such rock have no characteristic shapes. More resistant rock strata protrude from the cross section. The tops of the narrower pillars are sharp, sharpened as much by subcutaneous factors as by rainwater. The broader tops, however, are dissected by points and funnel-like cups.

The unique development of the stone forests is also reflected in their rock relief. Rainwater gradually reshapes the subcutaneous rock relief. The most distinct and particularly the largest rock forms are subcutaneous and composed rock forms. Subcutaneous rock forms include scallops, large channels, notches, half-bells, and subcutaneous channels and cups on broader tops. Composed rock forms include the channels that lead from the subcutaneous channels or subcutaneous cups and dissect pillar walls. Many pillars are subcutaneously undercut, while their tops have been reshaped by secondary subcutaneous rock forms and forms carved by rainwater. The rock relief of broader stone pillars is unique as well, particularly those with broader tops, either on thick rock strata where secondary subcutaneous forms occur or on tops that developed due to the disintegration of thin rock strata when subcutaneous tubes occurring along bedding planes developed into subcutaneous forms or large channels that were reshaped by rainwater. Both forms indirectly influence the shape of the pillar walls due to water flowing from them and carving channels. As a rule, smaller rock forms do not occur on dolomite rock, on very porous rock, or rock filled with larger inclusions.

Figure 8. Stone forest in the lake.

The development of stone forests and their rate of growth in a particular period are also influenced by the position and development of karst caves below them, that is, by the manner the water—and the sediment and soil with it—flows from the karst surface. Various periods can also be determined from the karst caves. In the Baiyun Cave below the Naigu stone forest we can identify periods characteristics of cave development in epiphreatic conditions when water flowed rapidly through the cave and deposited gravel, periods of the cave flooding and being filled with fine-grained sediment, and followed by a period of the rapid deepening of the central tunnel by a water current that swept away most of the sediment from the cave. This last event, which was a consequence of the rapid intermittent lowering of the water table below the stone forest, made possible its faster growth as well (Šebela *et al.*, 2001).

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KARST GEOMORPHOLOGIC CHARACTERISTICS AND TYPICAL LANDSCAPES AT DONG VAN KARST PLATEAU GEO-PARK IN HA GIANG PROVINCE OF VIETNAM

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Abstract

Dong Van Karst Plateau in Ha Giang Province of Vietnam draws great attention of tourists and scientists because it contains typical vestiges of the history of the earth crust‘s development, natural phenomena, unique landscapes in terms of aesthetics, rich bio-diversity and traditional culture of the local people. The local karst landscapes have unique advantages, first of all, due to their position in the ―Southeast Asian tropical karst region” which stretches from the south of the Yangtze River (in China) down to the equator. In this tropical area, there are many favourable conditions for the process of karstization to strongly develop, such as high rainfall, rich organic acids, abundant nitric acid due to thunder and lightning, and a lot of carbon dioxide, etc. However, the karstization process greatly depends on: a) Purity, absorbency, degeneration and thickness of karst; b) Characteristics, geological structure (uplifted block, sunken areas, lying position, synclinorium, density of broken faults, etc.); c) Characteristics of Neo-tectonic and topographic movements (watershed area, areas that are lower than the watershed areas, the roughness, etc.); and d) Climate (rainfall, intensity of rain, vaporization, temperature, etc.). This article is about the karst geomorphologic characteristics and typical landscapes of Dong Van Karst Plateau, such as karst monoclinal topography, karst flat surfaces, karst defiles, karst desert, karst forests, karst peaks, karst peak-cluster depression and karst cone-tower etc. With its karst geomorphologic characteristics and geomorphologic heritage significance, in 2009 Dong Van Karst Plateau (DVKPG) was recognized as Vietnam‘s first Geo-park and in 2010, DVKPG was recognized as a member of the Global Network of National Geoparks (GGN).

KARST DEVELOPMENT IN A RAPID TECTONIC UPLIFT HIGHLAND: AN EXAMPLE FROM OKSIBIL DISTRICT, CENTRAL PAPUA RANGE

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Abstract
Central Papua Range is a foremost physiographic feature in Papua with its highest peak in Indonesia – Carstenz Pyramid or Puncak Jaya – that reaches more than 4800 m height above sea level, trending relatively east-west and mainly composed of sedimentary rocks with ages ranged from Paleozoic to Quaternary. In this 100 km wide mountain belt, those rocks were strongly deformed and uplifted during Melanesia Orogenic that started from Early Miocene and culminated during Plio-Pleistocene. However, at certain places, when lateral deformation was less significant and the uplift became the sole tectonic processes, some sedimentary rocks maintain its nearly horizontal layers. This factor, when given to tropical limestones, such as ones found extensively at Oksibil District, part of Pegunungan Bintang Regency, that located in the axis of Central Papua Range, put a chance for a karst topographic to develop. Located in an elevation range from 1000 – 1500 m, those Eocene limestones maintain the karst topographic against the rapid uplift of the mountain belt. Some karst features, such as residual hills, disappearing stream, caves, natural bridges, and dolines were abundantly scattered across the landscape. However, field observation suggests that their distribution were limited by the presence of limestone debris as a direct product of rapid tectonic uplift. Thus, this fact provides an interesting illustration how a karst topographic developed and maintained in a rapid uplift highland.

Keywords: Karst Oksibil, Central Papua Range, Rapid Tectonic Uplift

Introduction

The Central Papua Range is a 1300 km long, 150 km-wide belt with rugged topography and numerous peaks over 3000 m in elevation. One of the peaks in Central Range is Puncak Jaya (4884 m), the highest peak in Southeast Asia and Australia. The geology of the Papua is very complex, involving oblique convergence between two plates; the Indo-Australian and Pacific plates (Dow *et al.*, 1988), and the Central Range, is commonly acknowledged as an active oceanic island arc - continent collision (Fig. 1). The Central Papua Range is a medial mountain range aligned relatively in ESE-WSW direction and composed of Australian shelfal sedimentary rocks which are ranged in age from Paleozoic to Quaternary, which are highly folded and intensively faulted during the active Melanesia Orogeny.

Based on the change from carbonate sedimentation to widespread clastic sedimentation derived from orogenic uplifts, the collision and orogeny apparently began in the late Miocene and culminated on Plio-Pleistocene (Dow dan Sukamto, 1984). Collisional delamination is proposed as the tectonic process that occurred within the subducting Australian lithosphere between 7 to 3 Ma. Besides involvement of crystalline basement, this process causes late-stage igneous activity and a vertical mountain uplift of 1 to 2 km.

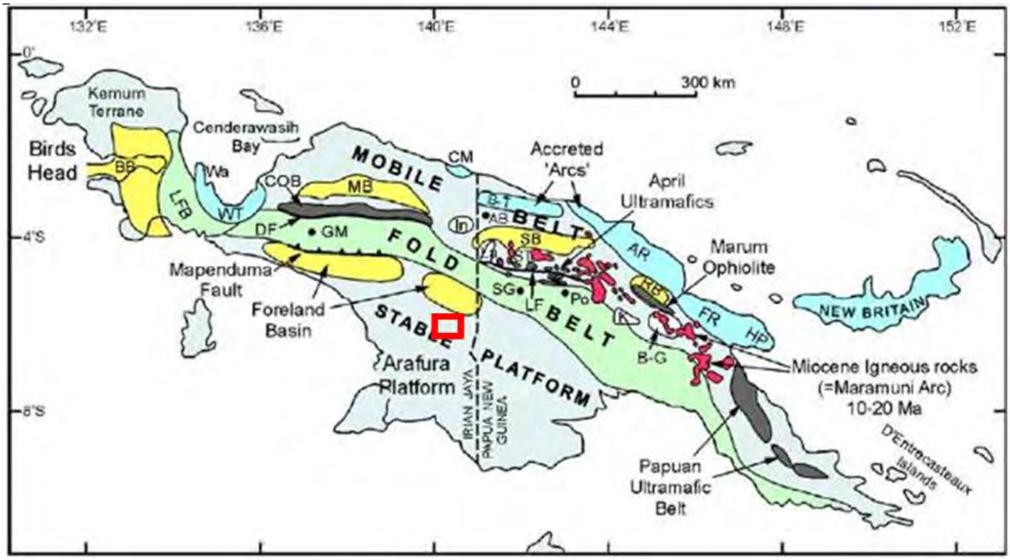

Fig 1. Structural elements of Papua. Red square indicates location of the study area, Oksibil.

One part of those uplifted Australian shelfal carbonates is found in Oksibil District, Pegunungan Bintang Regency (Fig. 1). In this remote area, karst topography is pronounced beneath a thick tropical rainforest, marking the surface with their numerous sinkholes and peculiar drainage pattern. A geological survey was conducted during April 2010 to observe the development of karst topography in an active tectonic uplift area. A number of sinkholes were visited and noted, as well as some of the surface rivers were followed to observed their interaction with the limestones. Some rock samples were petrographically analyzed to determine their ages and depositional environment.

Geology of Oksibil

Based on surface geological mapping, there are 3 lithologic units existed on Oksibil and are associated with limestones, which are bedded limestones unit, brecciated limestones unit, and their alluvium as the third unit (Fig. 2). Those three lithologic units were spread over NW-SE following the regional tectonic trends.

The bedded limestones are found in the southern and wetern part of the district (Fig. 2), having colors of dark grey, well bedded structures with average thickness of 10 – 40 cms and composed of reworked fossils in various sizes (Figs. 3, 4). Based on the macrofossil association, this unit was deposited in a reef-front environment at Early Oligocene to Middle Miocene (36 to 10 Mya) (Fig. 6). In general, this unit was tilted N-NE, which is in agreement with south-vengeance thrust fault that uplifted and tilted the Central Papua Range northward.

The brecciated limestones are found in the eastern part of the district (Fig. 2), composed of angular fragmented limestones in loose lime-sands (Figs. 5). The depositional environments and ages of its fragments were identical with the bedded limestones unit. Therefore based on its appearance and other geological characters, it was assumed that most probably this unit was colluvium (mass-wasting products) during uplifting of the bedded limestones unit. Intensive dissolution and calcite cementation caused this brecciated limestones lithified and became a lithologic unit, although as it was formed in a terrestrial environment it had never been really compacted by other sedimentary units. Thus, it can be concluded that those two units were unconformable. It was assumed that the age of the brecciated unit is supposed to refer the formation of Central Papua Range, i.e. Early Pliocene (~5 Mya).

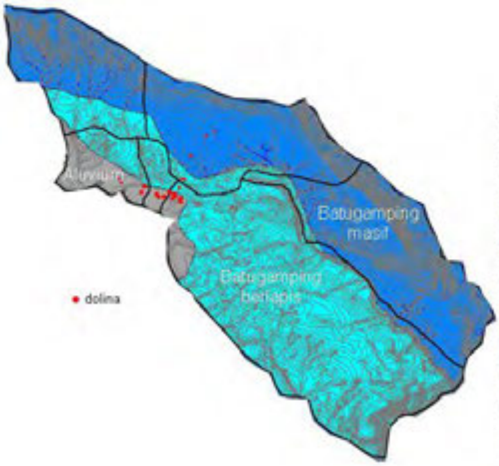

Fig 2 (left). Geological map of Oksibil with distribution of singkholes. Fig 3 (right). A bedded limestones on Oksibil River that tilted N 85^{o} E/10^{o}, camera facing southeast.

Fig 4 (left). Pelecypods fragments in the bedded limestones, found at the southeast slope of Bibunbun Hill. Fig 5 (right). The brecciated limestones at the south slope of Tibarsikin Hill, camera fasing west.

The youngest lithologic unit is alluvium which is observed in surrounding of Oksibil Town. This unit formed as an ancient floodplain of Oksibil River, as shown with lense structures with its material came from the two other units. The depositional age is recent and its forming processes is still active and can be observed recently. However, as an ancient flood deposits it occupied higher elevation than the active floodplain, indicating that this are is uplifted and produced river terraces.

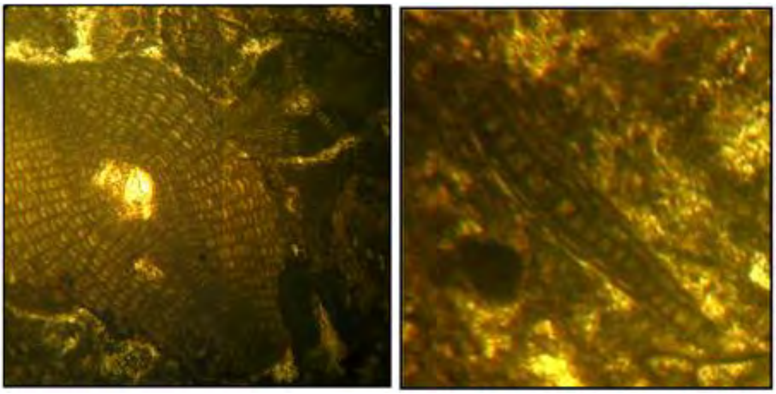

Fig 6. Lepidocyclina (left) and Miogypsina (right) found in the bedded limestones, indicating age of Td - Tf2 (Ealry Oligocene - Middle Miocene)

Geomorphology of Oksibil District

At Oksibil District, Pegunungan Bintang Regency, the orogeny produced a series of NW-SE aligned mountains and hills in elevation of 600 – 2400 m from sea level (Figs. 7, 8). Instead of their elevation, which maximum elevation of hills only reach up to 1500 m, those two geomorphic units also can be distinguished from their karstification processes. Karst features as a result of limestone surficial dissolution, such as doline and residual hills, are well developed in hills, thus can be used a unique character for this geomorphic unit to names as karstic hills unit (Fig. 8). Most of eroded material from the higher geomorphic unit were transported southwest and deposited along Oksibil River, forming an alluvial plain (Figs. 8, 9).

Rivers on Oksibil can be recognized in two distinct patterns (Fig. 7). On karstic hills their rivers formed a rectangular patter, whilst on mountainous area they formed dendritic pattern. Those running water had also effectively eroded surficial rocks. It is a common feature in an tectonically active uplifted area, where changes in erosional base level caused vertical erosion to be a dominant factor in lowering the valley. Thus, although the surrounding area are relatively flat and have a low relief like in karstic hills, its river valleys are deeply entrenched (Fig. 7), causing steep slopes along the rivers.

The ongoing Melanesia Orogeny tends to uplift the southern part of Oksibil District, meanwhile all the rivers are running southward to Digul Plain, thus they can be recognized as antecedent rivers, i.e. rivers that can maintain their running directions against the concurrent tectonic uplift. However, Oksibil River is one river that was failed to behave as antecedent, it was deflected northward and became underground river in the north of Village Oskop.

Karst Topography in Oksibil District

When a thick, gently tilted limestones covered an area a karst topographic is common to present. Dissolution as the karst forming processes are occurred in slow, vertical motion as surface water penetrates the rock pores with gravity as the main control. However, dissolution could be faster and locally concentrated when the limestones were fractured and thus providing an accummulation place for the surface water. Accordingly, typical karst topography were formed, such as sinkholes and residual hills. In its journey underground, dissolution also created cave systems and its speleothems, such as found in valley of Bukit Uraing and Bukit Oktumbaungke (Fig. 10).

Fig 7 (left). Topographic map of Oksibil. Red arrow indicates subterranean inflow of Oksibil River. Fig 8 (right). Geomorphological map of Oksibil. Red dots indicate location of sinkholes during the survey.

Fig 9. Morphology of Oksibil plain and its town, camera facing SW.

Sinkholes could be formed by two main processes, which are dissolution and collapse, respectively. Dissolutional sinkholes is formed due to concentrated surface water at certain places controlled by geological structures, and thus enhance the dissolution until a depression is created. This kind of sinkhole is recognized from its gentle valleys as occurred numerously in Oksibil (Fig. 11). On the second type, sinkholes are formed due to intesive undergorund dissolution that broaden the cave systems until the cave roofs collapsed. This type of sinkholes is reconized from its steep valleys and numerous limestones boulders on its floors (Fig. 12). When a surface stream enters the collapsed sinkhole it will prolong its underground journey as a subterranean stream as observed in Fig 13.

Fig 10. A cave was found in a valley between Uraing and Oktumbaungke hills. Speleothems are well developed (right).

Fig 11 (left). Dissolutional sinkhole at the southwest slope of Tumbakbayar Hill, camera facing west. Fig 12 (right). Collapsed sinkhole at the southwest slope of Polki Hill, camera facing north.

Fig 13. A subterranean inflow at the floor of sinkhole near Oksibil Town. Deposits of clay and gravels were observed (right).

Another requirement to develop a karst topography is a low-rate tectonic uplift acting upon the area. Therefore in an area where the rapid tectonic uplift occurred and producing high relief terrain, karst topographic will not be developed succesfully. This is the case in Oksibil, where karst topography only pronounced by sinkholes in a relatively flat area in the southern part of the district (Fig. 8). Rapid tectonic uplift also limited the karst development to reach its maturity as indicated by lack of enlargement of karst valley due to sinkholes growth to join each other.

Conclusions

- Karst topography is developed in Oksibil, but is limited by the effect of rapid tectonic uplift.
- The uplift worked twofold to limit the karst topographic development: (a) produced limestones debris as the brecciated limestones unit which its physical characteristics of loose matrices and extremely high porosity are not appropriate for karst processes; (b) promoted vertical dissolution to be more predominant karstic processes hence restricted the sinkholes lateral enlargement and keep the area immature with lack of wide and connected valley as well as residual hills.

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KARSTIFICATION DEVELOPMENT IN KARANGSAMBUNG MELANGE TERRAINS, CENTRAL JAVA PROVINCE, INDONESIA

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Abstract

Karst morphology of Neogene limestone develops at certain locations in Central Java Province, Java Island, Indonesia. One of those karst features is found in Karangsambung mélange terrains. Karstification development in this limestone has become an interesting issue. The objectives of the research are to identify Paleogene limestone distribution in Karangsambung mélange terrains and to define its morphogenesis. The methods in this research include preparing regional geological map Kebumen sheet as a field reference, the use of standard equipments for geological mapping, and 1:25.000 basemap. Mapping result is completed with description of rocks, petrographic analysis of limestone thin section, and morphogenesis identification responsible for karstification development. This research has indicated the presence of Paleogene limestone in Karangsambung melange terrain, Kebumen, Central Java, Eocene in age, specified by *Nummulites sp* fossil associated with Pre-Tertiary metamorphic rock, and ,in stratigraphic term, the rock appears as olistolith lenses. The rocks outcropped separately, morphogenically controlled by tectonic. Morphology resulted are hilly, isolated, developed karstification both major and minor. Major karst developed especially in in-layer as isolated hill of Gunung Jatibungkus.

Keywords: karstification, Paleogene limestone, Karangsambung Melange Terrain, in-layer, Nummulites sp.

FACIES AND DEPOSITIONAL ENVIRONMENT OF WONOSARI FORMATION, EASTERN PART OF THE SOUTHERN MOUNTAIN, PACITAN, AS A RESPONSE TO SEA LEVEL CHANGE

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Abstract
Wonosari Formation exposed in the western and eastern parts of the Southern Mountain of East Java. In the western part it is exposed in Wonosari (well-known as Gunung Sewu) and in the eastern part in Pacitan. One excellent exposure of this formation is found on the north cliff of G. Buwungan, Kebonagung, Pacitan, and is considered as an ideal outcrop to study the Wonosari Limestones in the eastern part. This outcrop offers a good chance in studying depositional environments and facies changes of the limestones. A detail stratigraphic section of physical and biological characteristics which was taken along the cliff and petrographic analysis suggest there are 6 facies types existed, they are (1) sandstone – siltstone facies, (2) packstone - carboneus claystone facies, (3) grainstone - rudstone facies, (4) grainstone - framestone facies with rudstone intercalation, (5) grainstone – floatstone facies and (6) layered algal bindstone facies. They indicate a depositional environment shifting from a lagoonal back-reef zone to reef-front and reef-flat have taken place. It suggests that a lateral depositional change from back-reef to reef-front within a vertical body of growth reef could be occurred in response to rising sea levels by prograding its growth geometry. This only could be happened when the rate of sea level rise was small and gave enough time for the reef to prograde into deeper water. In a short, it is called as a catch-up phase of reef growth.

Keywords: Wonosari Formation, Punung, Reef Growth, Catch-up Phase

Introduction

The Middle to Upper Miocene Wonosari Formation covered the Southern Mountain in its western and eastern parts. In the western part it is well exposed in Wonosari area, and because of its karstic topography, well-known as Gunung Sewu. To the eastern end, this formation that also known as Punung Formation could be observed in Kebonagung area, Pacitan. In the western part, the Wonosari Formation mainly composed of reefal limestones, calcarenites and tuffaceous calcarenits (Kadar, 1974; in Rahardjo, 1995), where at the southern section this formation consists of bedded to poorly bedded limestones, rich in coral fragments and algae plus some corals in growth position (Anonym, 1986). This western Wonosari Formation was deposited in a shallow marine environment probably with some small patch reefs (Toha *et al*., 1994). However, in the eastern part, this formation was recognized to be shelfal carbonates with average thickness of 200-300 m that composed of reefal limestones, bioclastics, and marl (Sartono, 1964).

Based on available literatures, number of papers with detail and in-depth study on the eastern Wonosari Formation is less that ones of the western Wonosari Formation. It was partly caused by some remoteness of excellent exposures of Wonosari Limestones on the eastern part. Considering those condition, authors are interested in studying one good outcrops of the eastern Wonosari Formation found at coordinate of S08^{o}10‘46” and E111^{o}09‘30,5” in the north cliff of G. Buwungan, Kebonagung, Pacitan (Fig. 1). This outcrop provides a complete vertical stratigraphic exposure and can be detailed into lithofasies analysis to determine depositional environments and dynamic sedimentation occurred during the rock formation.

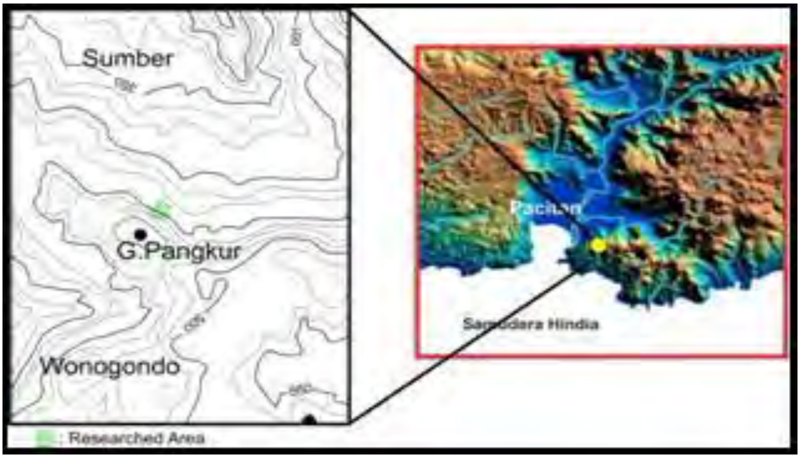

Fig 1. Map of the study area

To determine facies characteristics, detail stratigraphic measurements were obtained in a 1:100 scale. Facies sequence was used to determine the depositional environment and the controlling sedimentation dynamic. Furthermore, all those facies, environment and sedimentary dynamics could be used to deduce the condition of paleomorphology during limestone deposition.

The methods used in this study consist of two parts. The first is making stratigraphic columns that is measuraed from the outcrop and the second is laboratory observations of petrographic sample to determine the microfacies types. Field stratigraphic measurement includes of lithologic description, analysis of physical properties and observation of sedimentary structures. Petrographic observation in laboratory is conducted on a thin section samples to determine the composition of the constituent facies and lithologic type.

Results

Examination on the field stratigraphic measurements data and petrographic analysis indicate that there are six facies that formed in vertical sequence as follows:

1. Sandstone - siltstone facies (0-1.4 meters)
2. Packstone - carboneus claystone facies (1.4 – 2.8 meters)
3. Grainstone - rudstone facies (3.8 – 9 meters)
4. Grainstone - framestone facies with rudstone intercalation (9 – 31 meters)
5. Grainstone – floatstone facies (31 – 37.6 meters)
6. Layered algal bindstone facies (37.6 – 75 meters)

The first facies is sandstone - siltstone facies indicating the presence silisiclastic components originated from landward. This facies is present only as thick as 1.5 meters in a highly weathered condition of rocks, loose, and contain carbonaceous material in the rock composition. The second facies, packstone - carboneus claystone facies, has similar conditions to the lower facies, very weathered and difficult to determine distinct layer bedding in this 1.5 meters. Occasionally carbonaceous material was found to form lenses or continuous layers. Both facies are interpreted as deposited in a highly reductive environment as characterized by the intercalation of carbonaceous silts. Thus that those two facies are interpreted as products of back reef lagoon.

The third facies is grainstone - rudstone facies with inverse gradation. This facies is composed of grainstone that getting larger and coarser upwards and turned into rudstone. Rudstone is mainly composed of reworked gastropod shells and peleciypods ranging in size from 1 to 10 mm. The presence of calcite crystal and carbonate mud make the interpretation on depositional environment of this facies is the back-reef.

A thick grainstone - framestone facies with rudstone intercalation is present in the middle section. Grainstone - framestone existed with graded structure, whilst rudstone is inverted at the bottom. Framestone was grew from a collection of coral-shaped flat (platy coral) to form an encrusting layer, with a large size in between 10 cm to 30 cm. Coral growth was accompanied by the presence of lime-mud amongst them. Interpretation of depositional environment of this facies is assumed to be located in front of the reef body as the flat shape only grew below normal wave-base. The flat-shaped corals also suggested a small waves environment and its shallow depth in function to capture sunlight.

The next facies grainstone - floatstone facies. In this facies, grainstone initially existed and then coarsened upward onto floatsone, which came with skeletal grains in the form of platy coral with varied size of 15-20 cm. The occurrence of coral nodules in this facies suggests strong and larger waves that disturbed the laminae. Thus it is assumed that this facies was almost or already lied above normal wave-base, shallower toward the sea surface in the reef front.

The last facies and also the thickest one to be observed in the location is layered algal bindstone facies that showing agradational trend composed by interwoven braided algal in sizes of 10-15 cm, forming binding structures. This facies can be interpreted to be deposited above normal wave-base, with the presence of a strong sweep of waves, very close to sea level and located on the reef flat.

All those vertical facies succession suggest an indication of depositional environment shifting, from the reductive lagoonal area in the back reef zone to the reef front and reef flat. This indicates that a reefal depositional change can be changed within a body of coral growth in response to rising sea levels (Fig. 2). Reef growth in the study area responded to the rising of sea level by prograding its growth geometry. The rate of sea level rise was slow enough for the reef to prograde into deeper water. It is called as a catch-up phase of reef growth.

Figure 2 shows a schematic process of depositional change had been occurred in the study area that caused by sea level rise. In figure 2a early depositional environment was located in back-reef and sedimentation process influenced by terrigenous particle and local debris from reefs surrounded the lagoon. By the rising of sea level, reef growth trying to catch up and growth progradingly (Fig. 2b). The rising of sea level changes the geometry of basin and made a shifted depositional environment.

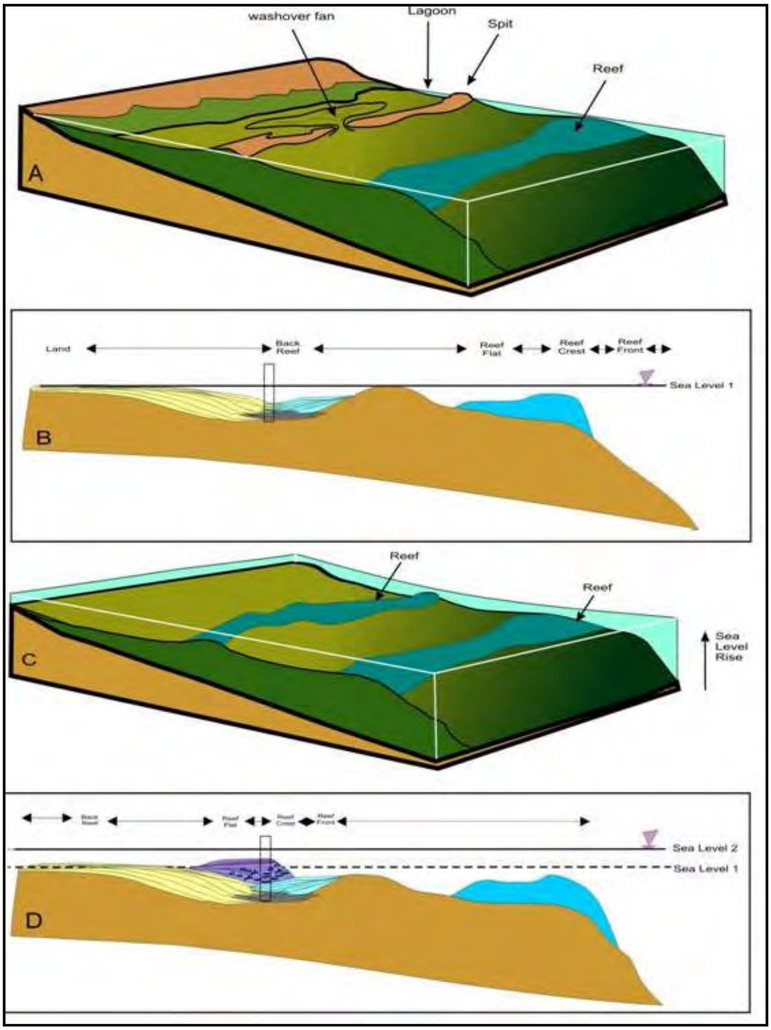

Fig 2. Schematic model of depositional changes in respect with sea level rise in the study area.

Conclusion

- The facies sequence from measured stratigraphy and petrographic analysis show that there are 6 facies developed in the study area; they are sandstone - siltstone facies, packstone - carboneus claystone facies, grainstone - rudstone facies, grainstone - framestone facies with rudstone intercalation, grainstone – floatstone facies and layered algal bindstone facies.
- Depositional environment of those facies had shifted from a restricted, reductive lagoonal environment in back reef became a reef front. The changes of depositional environment occurred as their response to the change of sea level, in a catch-up mode to produce a prograding built-up reef.

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HYDROLOGY AND HYDROGEOLOGY

HYDROLOGICAL ASSESSMENT OF A KARST AREA IN SOUTHERN JAVA WITH RESPECT TO CLIMATE PHENOMENA

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Abstract
The study area is the district Gunung Kidul in the south of Java. A sub territory of Gunung Kidul is the karst area Gunung Sewu ("land of thousand hills"). Due to the geology of this area, which is characterized by soluble limestone, there is barely any surface runoff so the water is collected in the underground karst systems. The climate of Gunung Kidul can be described as tropical winter monsoon climate with an average precipitation of approximately 2000mm. Additional to the spatial rainfall variation in Gunung Kidul there is also a temporal variation. Long-term rainfall is declining slightly, whereas there was a clear decrease in precipitation from 2002 to 2009. The trend of rainfall intensity gets higher from December to February but decreases in most of the other months, especially in the dry period. There is even a tendency of an extended dry spell period visible. Furthermore, the El Niño and La Niña events have influence on the rainfall variation, mainly in the months May until October, with years of either extremely low or high rainfall rates. The variation in precipitation has also consequences on the discharge of the underground river Bribin, which has its catchment area in Gunung Kidul. The present investigation shows that the decline in discharge since 2002 runs parallel to the decreasing precipitation numbers.

Keywords: Rainfall variability, El Niño Southern Oscillation, Indonesia

Introduction

One target of the United Nation Millennium Development Goals is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water […]". The water use has grown steadily and nowadays more than 1.2 billion people have to live under conditions of water shortage. Among others, the reasons for these symptoms of water scarcity are difficult access to reliable water supplies and an underdeveloped water infrastructure, according to the UN (United Nations, 2008). This difficult access to drinking water is especially a problem appearing in karst areas, where the water is stored in underground caves and fissures.

To define karst areas on their global expansion there are three common parameters: Soluble rocks that lead to forms of surface corrosion in addition to caves, channels and fissures in the underground. Secondly, the water system is not characterized by normal surface runoff and lakes like in most humid regions but mostly underground water systems with lakes and rivers being held in fissured rocks. The third parameter is intensely eroded surface forms that only appear in karst areas. Worldwide 20% of the land surface is covered with soluble limestone (Pfeffer, 2009). Some of these regions are located in Southeast Asia, namely Laos, Thailand, Vietnam, Philippines, Malaysia and Indonesia. One karst region in Indonesia is the approximately 1 400km² large Gunung Sewu ("land of thousand hills") in the south of Java.

The Gunung Sewu is part of an administrative district called Gunung Kidul in the province Yogyakarta. The geology of this karst area is characterized by compact reef limestone, which is, due to the high temperatures and the high humidity, intensely eroded. The geomorphology of the Gunung Sewu is dominated by a highly eroded tropical karst formation, the cone karst. The cones are mostly between 30 and 70m high and represent the characteristic landscape form. Neighbouring the Gunung Sewu in the north is the Wonosari Plateau, another geomorphologic unit that consists of soft oolite limestone. Compared with the hilly surface of the Gunung Sewu, the Wonosari Plateau is plane and on lower altitude. The third big geomorphologic unit in Gunung Kidul is the Baturagung massif in the north western part of Gunung Kidul. This mountain chain has the highest elevation of Gunung Kidul and consists of volcanic deposits (Neumann, 2009).

Gunung Kidul has an average precipitation of approximately 2000mm per year, with highest rainfall rates in January and February and lowest rainfall rates in August. The high precipitation is strongly coupled with the low pressure area above Indonesia. The pressure gradient force along the equator is named after its discoverer, the Walker Circulation. Walker found out that there is a negative correlation between the air pressure over the east Pacific near the equator and Indonesia: "By the southern oscillation is implied the tendency of pressure at stations in the Pacific […], and rainfall in India and Java […] to increase, while pressure in the region of the Indian Ocean […] decreases." (Walker, 1924). The differences in sea level atmospheric pressure between the Indonesian low and the Pacific high are indices to characterize the Southern Oscillation. At an El Niño event the trade winds become weaker and the Walker Circulation is reversed. El Niño events refer to the appearance of high positive anomalies in sea surface temperature and extreme heavy rainfall in the eastern Pacific as well as extreme low rainfall in Indonesia. Anti-El Niño events are also known as La Niña events and refer to abnormally low sea surface temperature and intense rainfall over Indonesia (Quinn et al, 1978, Rasmusson and Carpenter, 1981).

The alternation of wet season and dry season is attended by the movement of the Intertropical Convergence Zone and the trade winds. Boerema recorded that Indonesian climate is characterized by seasonal variation. He wrote in his studies about rainfall types in Indonesia: "NE-trade, doldrums (zone of monsoon changes) and SE-trade, as it exists above the oceans, is predominated in the Netherland Indies by the monsoons… the monsoons are indicated as east- and westmonsoon according to their principal directions; the eastmonsoon is the dry, the westmonsoon the rainy season […]…". For the area of Gunung Kidul he observed a maximum of precipitation in February and a minimum in July (Boerema, 1927).

Due to the lack of surface runoff and streams, the people of Gunung Sewu have to deal with limited water availability during the dry period. Even though there is a water scarcity caused by the soluble limestone, a karst area presents as well a big potential since it has a large underground reservoir, which can be utilised for drinking water.

In 2002 a joint research project was initiated by the Institute of Water and River Basin Management at the Karlsruhe Institute of Technology (KIT). The project is supported by the German Federal Ministry of Education and Research (BMBF) and is carried out in cooperation with scientific institutions as well as industrial partners. The objective was the construction of a pilot hydropower plant to pump up the water from a cave named "Gua Bribin" to a high-elevated reservoir for further distribution. At full capacity this facility is able to provide 80.000 inhabitants with 70 litres per person per day (Nestmann, *et al.,* 2011). During the construction of Bribin hydropower plant a significant reduction of the discharge of river Bribin was detected, in contrast to previously recorded data. This phenomenon can be analyzed from different points of views, among others from the hydrological perspective. Furthermore, the investigations concerning the hydrological conditions are also required because currently in Gunung Sewu there is a second hydropower plant in planning.

Background - Data and Methods

Data from 34 different rainfall stations in Gunung Kidul, owned by various facilities, forms the basis for the current hydrological analysis. The facilities recording rainfall data are as follows:

- Dinas Tanaman Pangan dan Hortikultura Wonosari (Agricultural Office, AO)
- Dinas Pekerjaan Umum Wonosari (Office of Public Works)
- Dinas Pekerjaan Umum Yogyakarta (Office of Public Works)
- Department Pekerjaan Umum Yogyakarta (Department of Public Works, DPW)
- Universitas Gadjah Mada Yogyakarta (UGM)
- Karlsruhe Institute of Technology (KIT)

Moreover, there is some rainfall data of Gunung Kidul recorded by Dutch scientists, namely Berlage and Boerema, between the years 1909 and 1941.

The Agriculture Department measures the precipitation with 17 analogue gauges, type OBS. These Gauges are calibrated by the Badan Meteorologi Klimatologi dan Geofisika Yogyakarta (Bureau of Meteorology, Climatology and Geophysics, BMKG) and located nearby local agricultural offices in rural settlements. Nowadays the AO has one gauge in every administrative district (Kecamatan); some old gauges have recently been replaced by new ones. The Office of Public Works Wonosari has currently only two ordinary analogue gauges, which are fixed on the roof of authority buildings in the settlements of Wonosari and Rejosari. The Department of Public Works is the only authority with rainfall stations including two different kinds of measurement instruments: In each of the five stations there is one analogue (type Hellmann or OBS) and one automatic pluviograph (type Hellmann or tipping bucket). The gauges of the DPW are placed on agricultural land, mostly in the middle of farmed fields. There are hourly values available, measured by the automatic stations, and daily or monthly rainfall data from the analogue gauges. In the Karst area Gunung Sewu, all the precipitation gauges belonging to local authorities is located in valleys of the karst cone hills.

For this research precipitation data was mainly used from the Agricultural Office. The AO provided data of 18 rainfall gauges from the years 1952 to 2009 (Fig. 1). This period of 58 years represents the longest time period of rainfall data that could be received. Rainfall data of other gauges and facilities mentioned above was used in the error analysis for comparison and in some cases for replacement of missing data. For the statistical analysis monthly or annual rainfall data from the AO was used. In fact, the latest data available is more complete than the data before 1981. Especially in the 1960s the recorded data of some stations is intermittent or not available at all. For the new established districts Gedangsari, Saptosari, Girisubo and Tanjungsari, rainfall data is available from the late 1990s to mid 2000s. For district Purwosari the data availability was not adequate for this research. As a conclusion, the data available from 17 gauges was used for the current research.

The methods applied are mapping the rainfall stations and basic statistical analysis such as rainfall probability analysis, time series analyses, correlation and regression analyses as well as geostatistical interpolation.

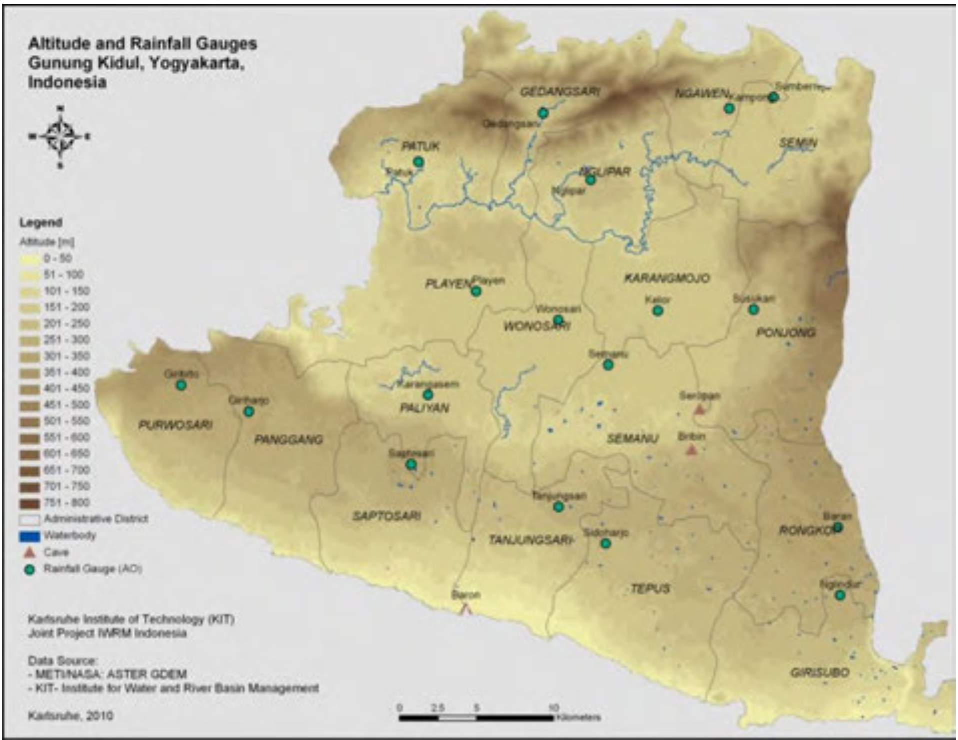

Fig. 1, Altitude and rainfall gauges of the agricultural office in Gunung Kidul

Characterization of the rainfall in Gunung Kidul

Rainfall probability analysis. As already mentioned above, daily and alternatively monthly rainfall data since 1952 recorded by the Agricultural Office was used for the analysis. The daily data had to be summarized to monthly and annual data in order to carry out long-term rainfall analysis. To keep the results valid, the annual data had to be calculated from years with complete monthly data; for that reason the station average method allowed to supplement missing monthly data and correct noticeable anomalies in monthly data. The station average is the simple average of those gauges where monthly data is available. As there are also differences in the spatial distribution of the rainfall in Gunung Kidul, only the gauges with similar geomorphologic and hydraulic conditions are considered for the individual station average. Furthermore, this method was only adopted if a sufficient amount of precipitation data for the year with missing or unrealistic data was available. As a result, 486 annual rainfall values for 17 gauges during the period of 1952 until 2009 and a mean annual precipitation of 2017mm were detected. The standard deviation for the different stations, referring to the mean precipitation in Gunung Kidul area, is 284mm.

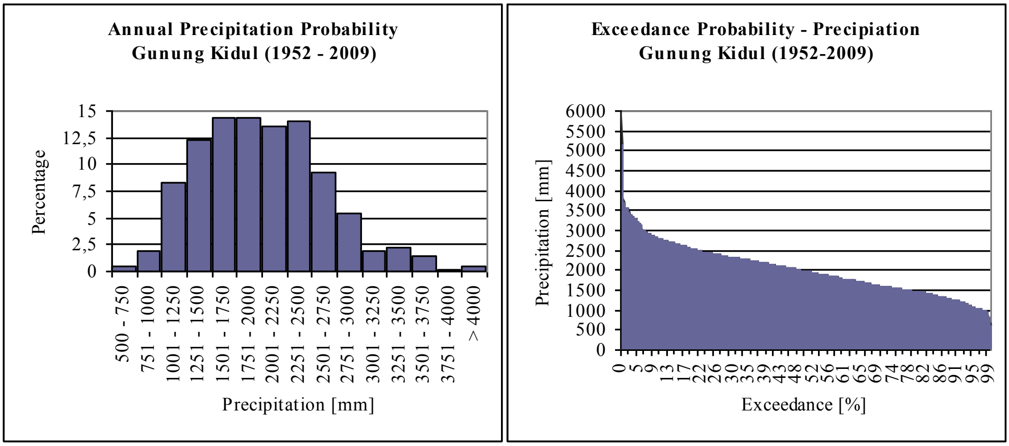

Fig. 2, left: Probability of annual precipitation values in Gunung Kidul for the years 1952 to 2009; right: Exceedance probability of the annual precipitation values in Gunung Kidul for the years 1952 to 2009

The annual rainfall probability (Fig. 2) proves that annual rainfall appears mostly (69%) in the intervals of 1251 to 2500mm. Extreme low or high annual rainfall values (lower than 750 and higher than 4000mm) do also appear, but they show up infrequently and only in individual regions. However, the exceedance probability (Fig. 2) shows that for a probability of 75%, 50% and 25%, annual rainfall quantities of 1530mm, 1968mm and 2416mm, respectively, will be exceeded.

The graphs of the rainfall probability analysis (Fig. 2) illustrate significant variation in annual rainfall numbers. In most cases the annual precipitation data ranges between 1250 to 2500mm. Nevertheless, rainfall values even smaller than 1000mm or bigger than 4000mm, which means a deviation of more than 200% of the mean value, can occur. There could be several reasons for this big variation in precipitation data over the years. The regularly occurring El Niño events have their influence on the Indonesian climate as already discussed in the introduction. Furthermore, there has recently been a lot of discussion about the Climate Change phenomenon. To have a more detailed look on these phenomena and their influence on the climate in Gunung Kidul, time series of annual rainfall with respect to differences in rain and dry seasons as well as an investigation about the influence of the El Niño phenomenon on the rainfall in Gunung Kidul will be described in the following chapters.

Annual rainfall distribution. The annual rainfall distribution, as shown in Figure 3, reflects the monsoon climate with its separation into rain

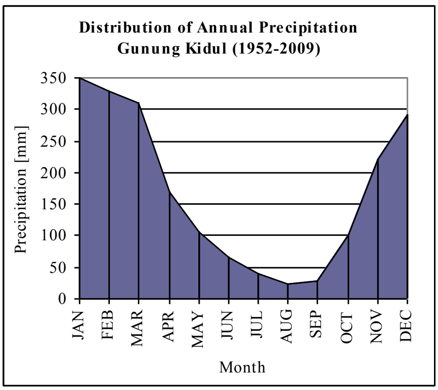

Fig. 3, Monthly distribution of annual precipitation in Gunung Kidul for the years 1952-2009 season and dry season. The rain season lasts from November until April with monthly precipitation above 150mm and a maximum of precipitation in January (349mm). Boerema refers these months of rain to the west monsoon, which brings moist air from the sea. Whereas from May until October the east monsoon brings dry air from the Australian continent (Boerema, 1927). The dry season has monthly rainfall less than 150mm and a minimum of precipitation in August (24mm).

Spatial rainfall diversity. The spatial rainfall diversity analysis over Gunung Kidul was carried out with the kriging method. As a criterion for the spatial analysis the availability of at least 20 annual rainfall values per rainfall station was applied. Hence, the analysis was based on rainfall data of 13 rainfall gauges from 1952 to 2009. The result can be seen in Figure 4. The precipitation station in Tepus, in the south of Gunung Kidul, has recorded the highest numbers of precipitation with a mean value of 2613mm. Precipitation of approximately 2200mm are recorded in the stations of Panggang, Playen, Patuk and Ponjong. Nglipar, Ngawen and Semin in the north of Gunung Kidul have a mean precipitation of about 2000mm over the time period of 58 years, which is conform to the mean precipitation of the whole Gunung Kidul area. The stations in Karangmojo, Wonosari, Paliyan, Semanu and Rongkop have an amount of precipitation under this average. Except for Rongkop, which is located in Gunung Sewu, the last mentioned rainfall gauges are all situated in the geomorphologic unit called the Wonosari Plateau.

The result of the spatial rainfall analysis reveals that rainfall values on the coast as well as in the Baturagung Range and Panggung Massif are on average or even above-average. On the Wonosari Plateau, with low altitudes compared to the mountain ranges and some parts of Gunung Sewu, the precipitation is under-average. Consequently, it can be assumed that spatial rainfall diversity depends on the distance to the sea and the altitude.

Rainfall variability in Gunung Kidul since 1952

The big variation of annual rainfall during the period of 58 years has already been discussed in a previous chapter. In order to see some kind of pattern in the data diversity a time series analysis was performed, using the precipitation data of the whole Gunung Kidul area, calculated as an average value of the 17 single rainfall stations, belonging to the Agricultural Office. In addition, the moving average of 10 years was plotted in the graph (Fig. 5).

Fig. 4, Distribution of precipitation in Gunung Kidul; based on annual data from 1952-2009

From 1952 to 2009 a continuous up and down of precipitation values can be observed. To see some significant patterns of a 10 year mean, some even longer time series would be useful. Even though, clearly noticeable is the progress of rainfall variation since 25 years. As a matter of fact these years are of special interest for the Integrated Water Resource Management (IWRM) joint project, since the first studies in the Gunung Sewu karst area took place in the early 1980s, carried out by MacDonald and Partner, and the feasibility study for the actual project has been accomplished from 2000 to 2002. In the period from the mid 1980s to the early 2000s the annual rainfall is in most of the year"s above-average, whereas the rainfall from 2002 to 2009 is continuously under-average. To see any trend in long-term precipitation variability the rainfall data of 58 years was divided into two periods. The first period contains the years 1952 to 1980 and the second period the years 1981 to 2009. Additionally, it should be considered that the amount of available data in the second period was higher than in the first period. The results indicate a slight decline in precipitation with an average of 2050mm for the first period and 2007mm for the second period.

In order to gain more insight into precipitation variability, the variability analysis was divided into dry and rain seasons. Monthly data from May to October was summarized to get the amount of precipitation in dry seasons. The rain season is the total of monthly rainfall data from November until April. Figure 6 shows three time series: The annual precipitation for the hydrological year from November to October, the precipitation in the rain period and the amount of rainfall in the dry period. To identify a secular trend in the data, a 10 year mean as well as a trend line was added in the figure.

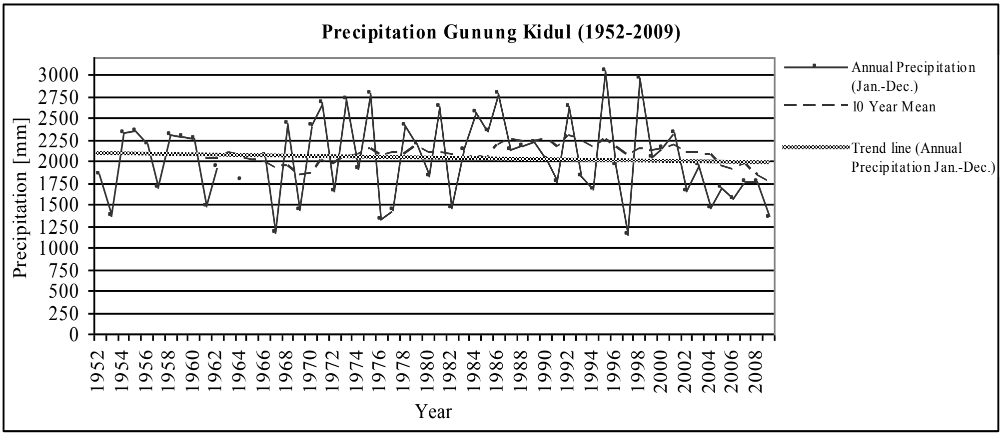

Fig. 5, Time series of precipitation data in Gunung Kidul for the calendar years 1952-2009

Corresponding to Figure 6 the trend of precipitation in the rain season is increasing, while the precipitation trend in the dry season as well as the annual precipitation is decreasing. Hence, it can be assumed that the months with decreasing rainfall dominate over the ones with increasing rainfall. For more information in changing rainfall distribution a detailed study about the characterization of monthly time series was of interest. Therefore, the averaged rainfall data for Gunung Kidul was split into monthly data. A time series analysis for every single month, plotted in four diagrams, as well as an analysis of annual precipitation distribution in three periods (1952-1980, 1981-2009 and 2002-2009) was reviewed. The results can be seen in Figures 7 and 8.

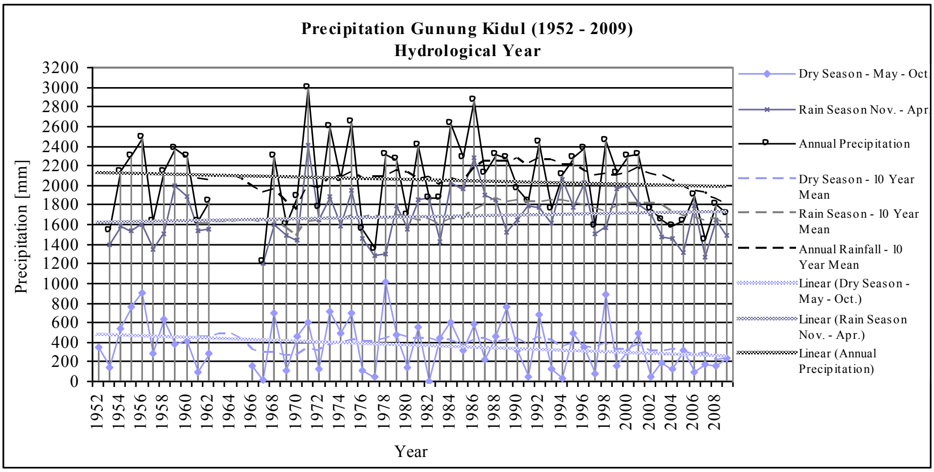

Fig. 6, Time series of precipitation data in Gunung Kidul for the hydrological years 1952-2009

A positive gradient of the trend line is noticeable in the months December, January, February and April, which means an increasing trend of precipitation in these four out of six months of the rain season. The most considerable rise in rainfall is, according to the trend lines, in February and the smallest rise is recorded in April. In March, but even more in November, the trend of precipitation decreases. In every month of the dry season the trend line gradient is negative. May turned out to be the month with the highest decrease in precipitation. Notable for May is also a sudden break in precipitation data since 1990; since then, rainfall never exceeded 140mm. The comparison of the annual rainfall distribution of the three different time periods confirms the results of the monthly time series analysis (Fig. 7). Even though the eight years in the interval from 2002 to 2009 have an average annual precipitation of 1650mm, there is still an increase in precipitation in December. If only the periods 1952-1980 and 2002-2009 are evaluated, an increase in precipitation is also noticeable in February. In the remaining months the amount of monthly rainfall in 2002-2009 is decreasing in contrast to the periods 1952-1980 and 1981-2009.

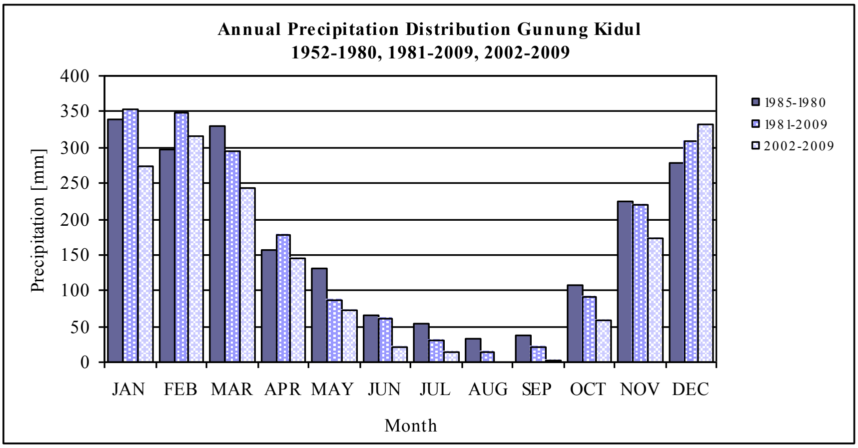

Fig. 7, Monthly distribution of annual precipitation in Gunung Kidul for the periods 1952-2009, 1981-2009, 2002-2009 a).

b).

c).

d).

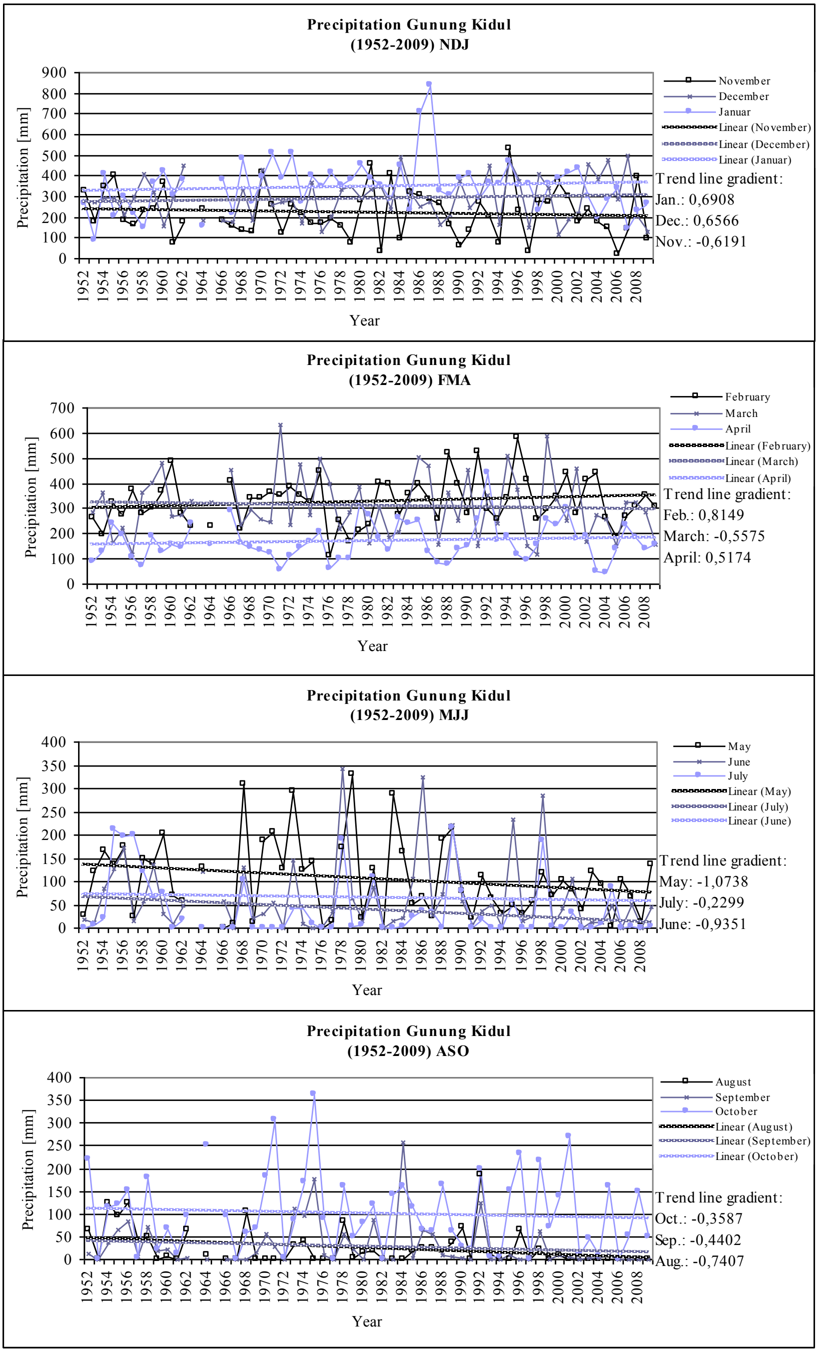

Fig. 8, Time series of monthly precipitation data in Gunung Kidul for the years 1952-2009; a) November, December, January b) February, March, April c) May, June, July d) August, September, October

These facts lead to the conclusion that especially in December, January and February the rainfall gets more intense, while there is a lesser amount of rainfall in the dry season. The tendency towards an extended dry period is observably, whereas the rain season concentrates on fewer months. Aldrian came to the same conclusions in his climatological studies in East Java where he found out that the accumulated rainfall has a negative trend. His findings showed also an increase of rainfall ratio during the rain season and an extension of the dry spell period (Aldrian, 2008). The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) also predicts a decline of rainfall for the southern regions of Indonesia. Moreover, for some monsoon climate regions in Asia, a rise of flood events during the rain season was expected as well as a decline in precipitation in the dry season (Cruz *et al.,* 2007). Since no specific regional differences were given, this conclusion cannot be adopted without any restriction for the research area. Nevertheless, the predictions still reflect the given results of the present investigations.

The El Niño climate phenomenon

When analysing the climate of Indonesia it is indispensable to take a closer look at the influence of El Niño. As it was discussed earlier, in some years the rainfall numbers show significant deviations. The question has been raised what kind of influence the El Niño climate phenomenon has on these rainfall variations. Quinn et al and also Rasmusson and Carpenter wrote about the Indonesian droughts occurring during El Niño events (Quinn *et al.,* 1978, Rasmusson and Carpenter, 1981). Due to the fact that the air pressure and the sea surface temperature in the Pacific Ocean are indices for the weakening Walker Circulation, which is equivalent to the El Niño phenomenon, the sea surface temperature (SST) was chosen for a correlation with the precipitation data of Gunung Kidul. More precisely, the SST anomalies of Nino Region 3.4 (90°W-150°W, 5°S-5°N) were adopted for the investigation. The Sea Surface Temperature Data was provided by the US Climate Prediction Centre.

The correlation between single months or seasons and the SST anomalies has been analysed. The results show an obvious correlation between the SST anomaly data in the dry season and the corresponding precipitation data. Figure 9 demonstrates the SST of Niño Region 3.4 and the seasonal precipitations, both for the dry season. A correlation of these two factors occurs especially in the years with a positive or negative SST anomaly of more than 0.5°C. However, the two parameters, precipitation and SST, were plotted in a scatter diagram (Fig. 10). A correlation coefficient for the SST anomalies and rainfall data in the dry season has been calculated, finding a negative linear correlation of 0.57 ($r = -0.57$) and a coefficient of determination of $r^2 = 0.32$. This implies that 32% of the precipitation scattering is relied to the sea surface temperature anomalies.

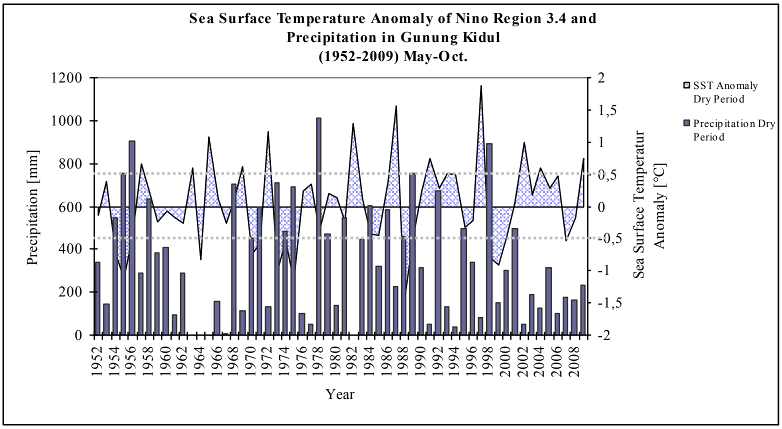

Fig. 9, Long-term analysis of sea surface temperature anomalies of the Nino Region 3.4 and precipitation in the dry period in Gunung Kidul; based on monthly data from the years 1952 to 2009. For the years 1963, 1964, 1965 no data were available

Figure 11 shows in particular the influence of El Niño on the annual rainfall distribution. Diagrammed are the very strong El Niño years 1982 and 1997 as well as the La Niña year 1989. The annual precipitation was 1460mm in 1982, 1162 mm in 1997 and 2229mm in 1989. The graphs illustrate as well that the biggest influence of El Niño and La Niña events can clearly be seen in the dry season.

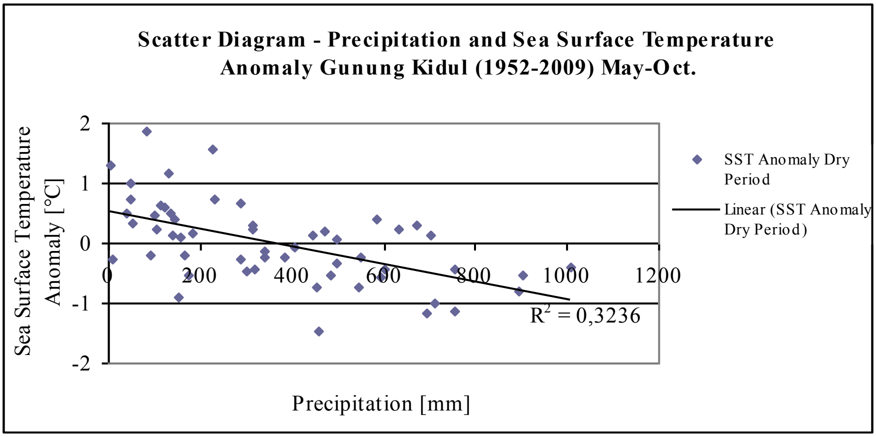

Fig. 10, Scatter diagram of the SST anomalies and precipitation in Gunung Kidul for the dry seasons from 1952 to 2009

With these results it could be demonstrated that El Niño or alternatively La Niña events have an influence on the rainfall in Gunung Kidul. Nevertheless, the sea surface temperature anomaly is not always the explanation for the variation in annual or seasonal precipitation amounts. In order to find out more about the reasons for rainfall variations other global and local climate phenomena have to be studied.

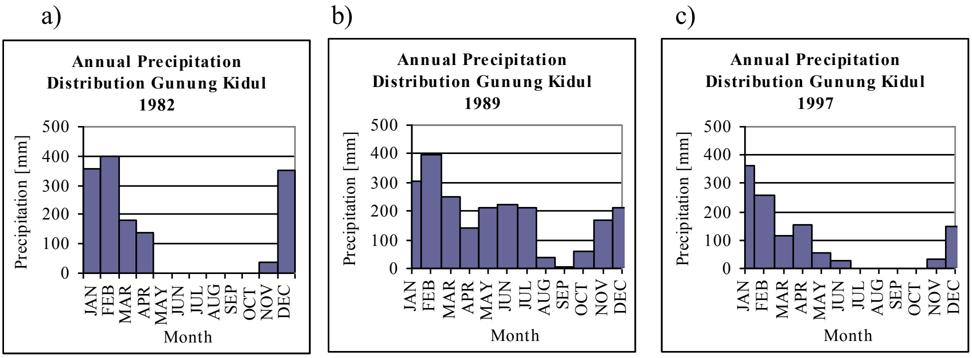

Fig. 11, Monthly distribution of annual precipitation in Gunung Kidul a) El Niño year 1982 b) La Niña year 1989 c) El Niño year 1997

The influence of precipitation variability on the Bribin Underground River

According to the study of Sir MacDonald and Partners in the early 1980s, the discharge of the underground river Bribin never falls below 1m³/s (MacDonald & Partner, 1984). Besides, during the feasibility studies in the years 2000 and 2001 a mean discharge of 1.35m³/s was measured in the months July and September. In the following years the amount of discharge decreased unexpectedly. More precisely, the mean discharge from 2006 until 2009 during the months July until October was 0.88m³/s. This test result is based on measurements by the KIT. As shown in Figure 5, the precipitation data has also decreased since the year 2002.

Adji analysed the dynamics of the Bribin karst aquifer. In order to find out how fast the karst aquifer system, and therefore the recharge of the underground river, reacts on the rainfall, he calculated the time to peak. With an average of 5.5 hours it is proven that the karst aquifer system responds quickly to rainfall (Adji, 2010). Adji´s results clarify even more that a connection between the decline in precipitation data and the decreasing discharge is definite. Despite the amount of precipitation also other parameters, such as the geology, have an influence on the discharge rates in the underground rivers. Due to the current data availability further investigations in discharge precipitation analysis have not been performed yet, but might be of interest and will be carried out in the near future.

Concluding remarks

It has been revealed that there is a spatial and temporal variation in rainfall in Gunung Kidul, southern Java. While the spatial variation depends on the proximity to the sea and the altitude, the temporal variation in rainfall is regulated by climate phenomena. Long-term rainfall declines only slightly, whereas there was a clear decrease in precipitation from 2002 to 2009. The intensity in rainfall increases in December, January and February but is decreasing in most of the other months. Even a tendency towards an extended dry spell period could be detected. Furthermore, the El Niño and La Niña events have influences on the rainfall variation in the dry period with either year of extremely low or high rainfall rates.

The variation in precipitation has also consequences on the discharge of the underground river Bribin that has its catchment area in Gunung Kidul. The figures show a decline in discharge since 2002.

Because of the trends in precipitation rates as presented, it can be assumed that the water shortage in the dry period is getting a bigger problem in Gunung Kidul. The karst area Gunung Sewu in the south of Gunung Kidul has hardly any surface runoff and reservoirs, and a decrease in precipitation is affecting the limited water availability even more. Nevertheless, there are still many water reserves in the soluble rocks of the limestone. Therefore, an improved water supply system, which guaranties a permanent water supply for the local people, is even more required.

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HYDRODYNAMIC PROPERTIES OF TWO MAIN KARST SYSTEMS OF ZAGROS RANGES IN IZEH, SOUTHWEST IRAN

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Abstract
Time series analysis was applied to the precipitation, spring discharge and piezometric head data of two representative karst systems of Zagros Ranges (Ilam-Sarvak and Asmari Formations) in order to study the function, hydrodynamic behavior and hydraulic properties of the karst aquifers in Izeh, southwest Iran. Results obtained through analysis of piezometric head and spring hydrograph data showed that the Asmari karst system of Kamarderaz Anticline has a large storage capacity. Base flow dominates while quick flow is low contribution due to the lack of a well-organized karst network. On the other hand, unlike the Asmari karst system, the fractures and small diameter conduits in the Ilam-Sarvak karst system are more dominated producing a better developed karst network, but contrary to the typical karst systems, diffuse flow and conduit flow coexist.

Keywords: Time series analysis, Karst, Quick flow, Iran

Introduction
The typical karst aquifer is distinguished by extremely heterogeneous properties, a well-organized network of karst conduits, so that it drain the aquifer swiftly after heavy rainfalls as a result of which the karst spring discharges strongly over a short period of time (Padilla and Pulido-Bosch, 1995). As many researchers have confirmed, however, there are karst aquifers different from the typical cases. Here the main difference lays in the fact that, due to the significant storage capacity, baseflow dominates at the expense of quickflow. This status could be found in poorly developed karst systems which lack a considerable karst network. In this case, water is stored during the recharge period and release later during the dry season (Larocque *et al.,* 1998). In order to find out the function and hydrodynamic behavior of karst aquifers, the relevant studies have been focused on the analysis of the spring hydrograph (Bonacci, 1993) or the recession curves (Padilla *et al.,* 1994). Another method is time series analysis in which rainfall is regarded as an input and spring discharge and/or piezometric head as an output. Time Series Analyses deal with the global hydraulic response of karst systems to a succession of rainfall events. Univariate time series analytical methods are capable of identifying cyclic variations. Bivariate time series analyses are very suitable for analyzing the relation between the input (recharge) and output (discharge) parameters of different karst systems (Kovacs, 2003).

The Zagros karst system is mainly comprised of the limestone of Asmari and Ilam-Sarvak Formations. The karst aquifers in Izeh area are the only source of drinking water supply of the city. Hence, the exploration, production, and quantitative and qualitative protection of karst aquifers are of essential importance in these areas. In this paper, we tried to find out the hydrodynamic and hydraulic properties of the karst aquifers, applying time series analysis to the precipitation, spring discharge, and piezometric head data.

The study area is located in the southwest Izeh in Khuzestan Province, southwest Iran (Fig. 1), within Zagros Ranges. The area consists of a very gently dipping Oligocene-Miocene age limestone and marl limestone (Asmari Formation in Kamarderaz Anticline) and Upper Cretaceous limestone units (Ilam-Sarvak Formation in Tanush Anticline) (Fig. 1). The Sarvak Formation consists of argillaceous and thin limestone, as well as dark grey marly limestone. Ilam Formation overlay on Sarvak Formation consisting of grey argillaceous thick limestone. The two formations are not easily separable and, therefore, they are known with the single name Ilam-Sarvak. In Izeh basin the extent of Ilam-Sarvak Formation is more than other formations and it outcrop as the core of Shavish and Tanush Anticlines. The primary porosity of Ilam-Sarvak formation is very low, but it has a high secondary porosity due to containing several faults and fractures as well as the development of karst process. Asmari Formation contains fully fractured thick limestone with interbedded marly lime, being outcropped at Kamarderaz and Chalkhoshk Anticlines, southwest Izeh.

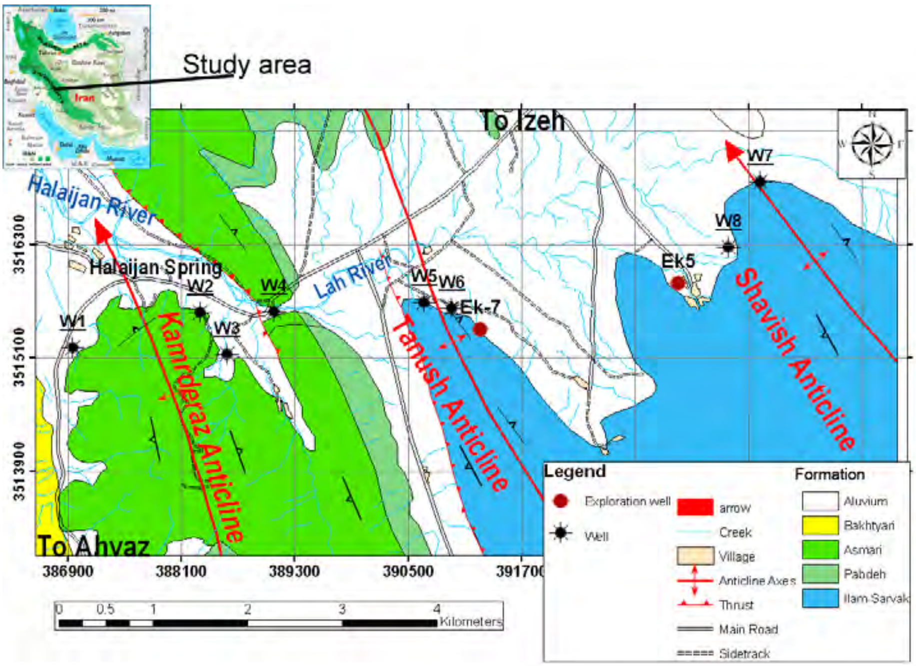

Figure 1. Geological map of study area

Kamarderaz karst aquifer has one main discharge system (Halaijan spring) located at northwest nose of the anticline. The karst water of Halijan spring is of good quality with an electrical conductivity ranges from 450 to 500 micromhos/cm. The total discharge of three outlets of Halaijan spring varies between 200 to 1200 l/s in years with average precipitation, but occurrence of two consecutive drought years made the springs dry in August 2008 for the first time over recent years. While Tanush Anticline was discharged through a seasonal spring with a discharge of at most 30 l/s in 2006, the spring dried out because of recent drought years and intense drawdown of karst water surface (about 110 m) in Ilam-Sarvak limestone.

In order to supply drinking water of Izeh city, four wells were drilled in Ilam-Sarvak formation at Shaivsh and Tanush Anticlines in 2006 and 2007 (W5 to W8 in Fig. 1). Moreover, two exploration wells were drilled at anticlines of Tanush (EK7) and Shavish (Ek5). After two successive drought years in 2007 and 2008, the depth of groundwater fell from 25m down to 135m in wells W5 and W6 at Ilam-Sarvak at the nose of Tanush Anticline. Three wells were drilled in Kamarderaz karst aquifer and one in Chalkhoshk (Fig. 1). After two drought years, the wells W1 and W2 at Kamarderaz anticline in Halaijan area (Asmari karst aquifer) underwent a slight drawdown (about 1m).

Methods

Time series analysis was applied to two karst aquifers, those of Asmari and Ilam-Sarvak formations. The daily precipitation measured in Izeh synoptic station was considered as input data of both karst systems. For time series analysis, this research utilized daily data of groundwater level in piezometer P1, Halaijan spring discharge (representative of Asmari Formation at Kamarderaz Anticline), exploration well Ek7 (representative of Ilam-Sarvak Formation at Tanush Anticline), and exploration well Ek5 (representative of Ilam-Sarvak Formation at Shavish Anticline). The total length of time series was about 2.7 years, extending from May 2007 to December 2009, and consists of 999 values. During the research, we installed a one parameter probe in data loggers which daily measures the water surface. Most of the studies done in relation to the time series analysis have been conducted considering the spring discharge as the output data.

However, several researchers demonstrated that the piezometric heads may be used as well, since they are influenced by precipitation and water losses from the rivers (Larocque et al. 1998; Lee and Lee, 2000; Panagopolous and Lambrakis, 2005). Therefore, the piezometric data could be used to provide information about the dynamics of the water table fluctuations as well as the origin and dynamics of infiltration.

The research examined two representative karst systems, i.e. Asmari and Ilam-Sarvak limestones at the anticlines of southwest Izeh. While having been subject to same tectonic and climatological conditions, the two studied karst formations show different hydrodynamic behavior due to the diversity of the karstification processes. Time series analysis were applied for describing Izeh karst systems with a focus on both univariate (auto-correlation, spectral analysis) and bivariate (cross-correlation and coherency function) methods. The individual structure of the time series has been characterized using univariate methods, while bivariate methods interpreted as the transformation of an input function into an output function. Theoretical details of the functions could be found at Jenkins & Watts (1968), Mangin (1984), Box et al. (1994), Padilla & Pulido-Bosch (1995), Larocque et al. (1998), and Panagopolous & Lambrakis (2006).

Results and Discussion

The average annual precipitation at Izeh area is 620 mm. The value of precipitation at Izeh station is 636 mm (around the average) for hydrological year 2006-2007, 351 mm (57 percent of average) for 2007-2008, and 388 mm for 2008-2009 (62 percent of average). Precipitation of Izeh station was 351 mm (57 percent of annual average) in autumn 2009. The hydroghraph of three representative piezpmeters of karst aquifers at southwest Izeh shows the intense drawdown of groundwater in Ilam-Sarvak Formation and the rather stable trend of water table in Asmari limestone after two successive drought years (Fig. 2). Halaijan spring, which discharges the dynamic storage of the Asmari karst system, dried out along two periods, one extended from August 2008 to January 2009 and the other from May 2009 to December 2009.

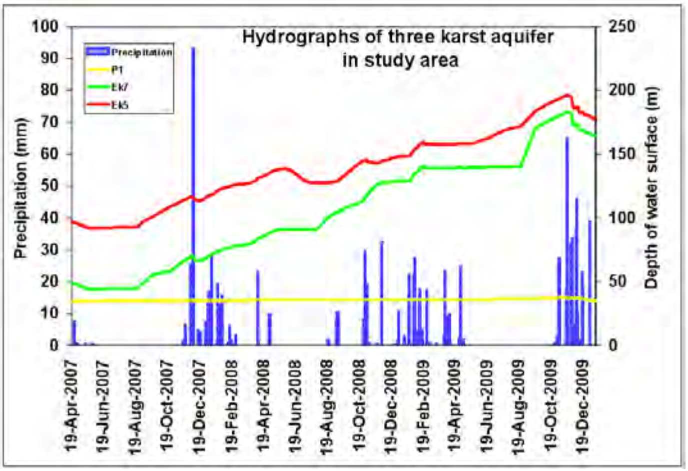

Figure 2. Hydrograph of the representative wells in karst aquifers of southwest Izeh (P1 is representative of Asmari limestone at Kamarderaz Anticline and Ek7 and Ek5 are of representative of Ilam-Sarvak limestone at Tanush and Shavish anticlines, respectively)

The autocorrelation function of the piezometers of the Ilam-Sarvak Formation is the same in the anticlines of Shavish and Tanush (Fig. 3). The decrease of the autocorrelation function is non-uniform and the slope of the correlogram is high. The delay time is short, about 35 days. In the two modes, the value of autocorrelation function exceeds 0.2. The difference indicates the duality of the behavior of the Ilam-Sarvak karst aquifer. The influence of large karst conduits which quickly drain the aquifer as well as that of smaller conduits may be the case in Ilam-Sarvak aquifer. The piezometric plot P1 in Asmari limestone aquifer had a steep slope in the early time and it corresponds to a low memory system of karst conduits at the upper part of the aquifer. After almost a month, however, the autocorrelation function came to less than 0.2, and this represents the high storage capacity of the aquifer. The autocorrelation function of Halaijan karst spring displays a great inertia, and this means that the system properly filters the precipitation input. Unlike the piezometers of Ilam-Sarvak limestone, the correlogram of Halaijan spring has gentler slope and its shape is uniform without any remarkable change. A physical interpretation of this fact is that, in comparison with Ilam-Sarvak karst Formation, the karstification degree of Halaijan is lower and its storage capacity is larger.

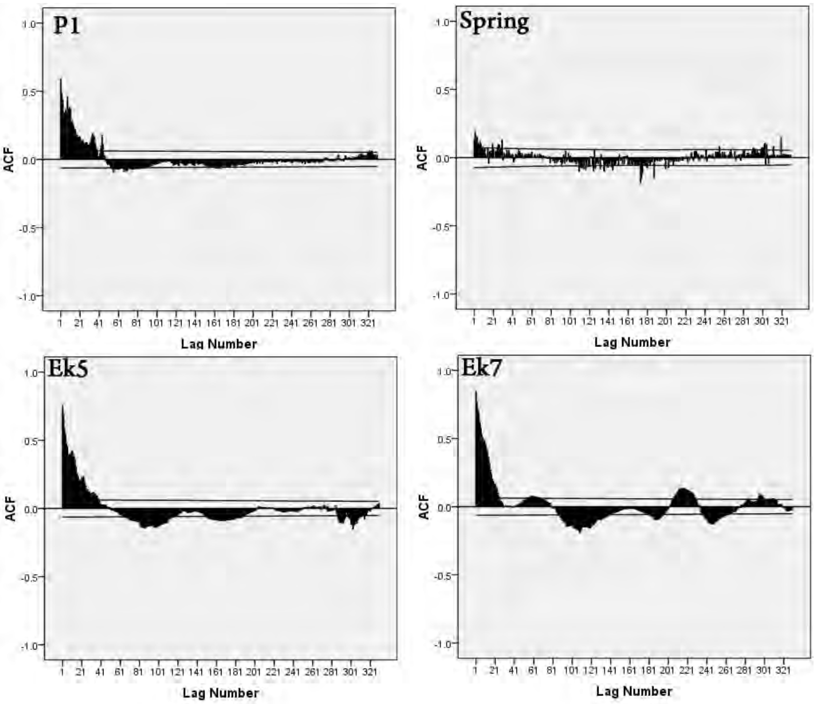

Figure 3. Autocorrelation function plot of representative wells of karst aquifers at southwest Izeh and Halaijan Spring

Fig. 4 displays Spectral density functions for Halaijan spring discharge as well as water table representative piezometers of the karst of the study area. A large peak at the frequencies less than 0.004 (250 days) confirms the presence of an annual cycle for aquifers recharge. Spectral density plot of piezometer P1 indicates the noticeable regulation effect, the greater inertia of the system, and the absence of the quickflow component. Draining the conduit system of the upper part of Asmari limestone (dynamic storage), Halaijan spring, just like Ilam-Sarvak wells, presents a relatively large spectral band, so that there is a good filtering effect at frequencies higher than 0.2 (a period less than 5 days). In the case of Ilam-Sarvak limestone this fact represents quickflow in conduits, and in the case of Halaijan spring it represents dominant baseflow in which quickflow is implied.

The cross-correlation function (CCF) (Fig. 5) in is symmetrical in Ilam-Sarvak karst system and dissymmetrical in Asmari karst system. CCF plot displays a clear peak with regard to none of the piezometers. The long response at Halaijan spring implies the powerful memory of the system. Contrary to the situation of Ilam-Sarvak limestone piezometer, the CCF plot is homogeneous and has a gentle slope, typical of a system in which quickflow is absent. The low CCF values of Halaijan spring suggest that the precipitation signal is remarkably reduced between the time of its entry in the system and the time when it reaches the water table through the unsaturated zone. This fact can be ascribed to the larger storage capacity of the system, compared to Ilam-Sarvak limestone system. While the precipitation is transmitted through the primary and secondary porosity to Asmari limestone aquifer, in the case of Ilam-Sarvak karst system, the pressure pulse is quickly transmitted through the karstified conduits.

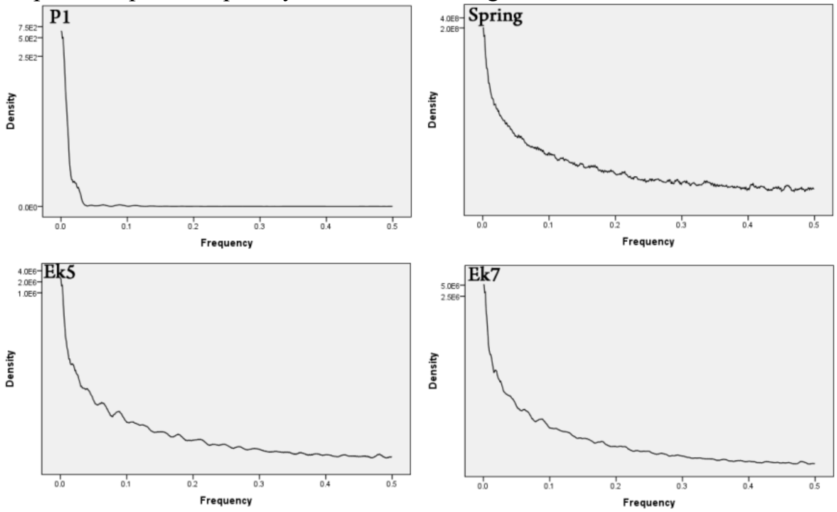

Figure 4. Spectral density plot of representative wells of karst aquifers at southwest Izeh and Halaijan Spring

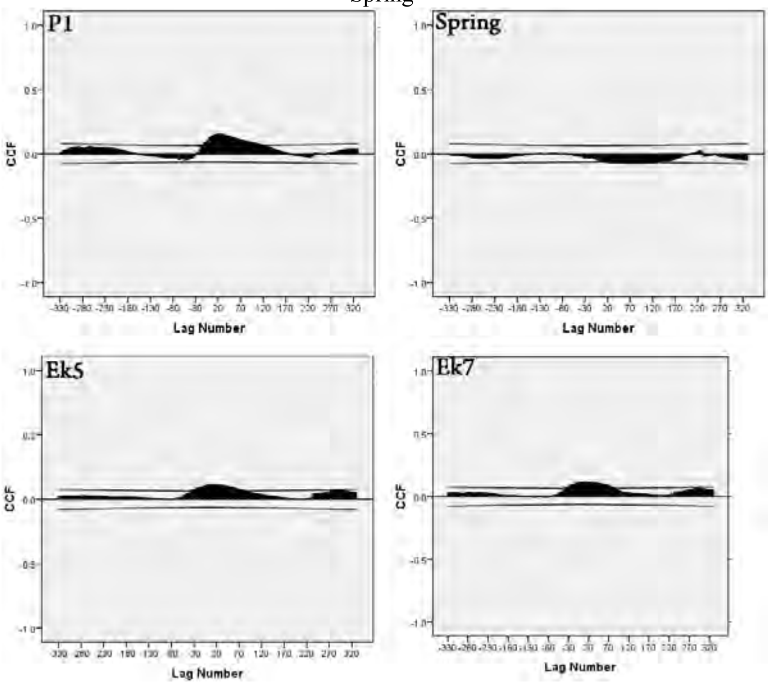

Figure 5. Cross-correlation function plot for representative wells of karst aquifers at southwest Izeh and Halaijan Spring

The coherence function (COF) (Fig. 6) represents the linearity of the input–output relationship. The COF fluctuations between 0.1 and 0.8 are variable in all frequencies. This means that there is not a fully linear relationship between rainfall and water table data and spring discharge in the both karst systems. In case of piezometers EK5 and EK7 at Ilam-Sarvak Formation, low storage capacity of the limestone and the large distance between recharge and discharge points caused the precipitation–karst system relationship to be non-linear with regard to low and medium precipitation and almost linear with regard to high precipitation. Based on coherency function, the regulation effect of Asmari and Ilam-Sarvak karst systems could be sufficiently determined. The linear coherency function for Asmari karst system was attained in a separate model using water table piezometer as input and Halaijan spring discharge as output (Fig. 9). Thus, it was found out that the karst water table–spring discharge relationship in the Asmari limestone with a COF about 0.8 exists in most frequencies (regardless of the periods when Halaijan spring is completely dry).

Based on the results obtained by time series analysis of two karst systems (Table 1), Asmari karst was identified as a system with high storage capacity as well as a dominated baseflow, and Ilam-Sarvak karst as a system with intermediate quickflow along with low storage capacity. Fig. 7 shows the conceptual models of the two main karst systems in Izeh area.

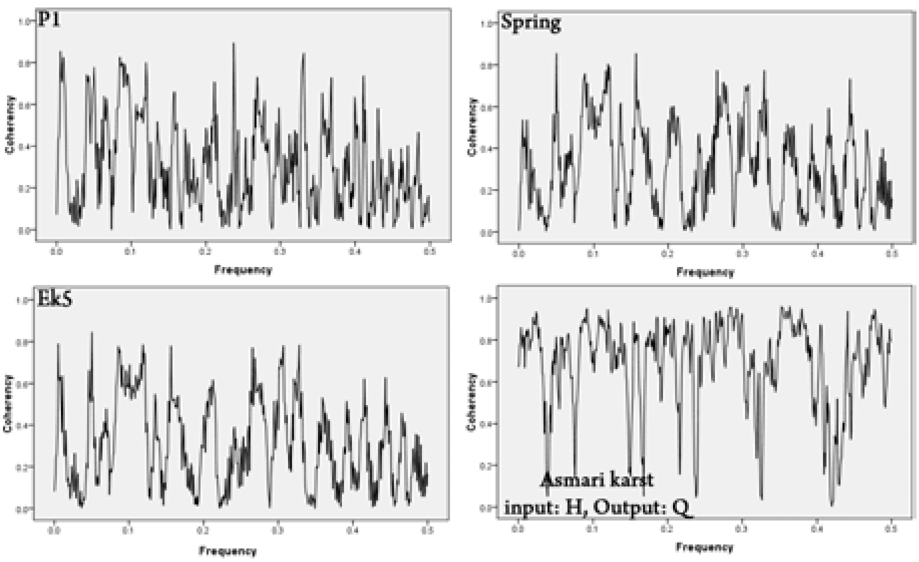

Figure 6. Coherency function plot for representative wells of karst aquifers at southwest Izeh and Halaijan Spring

Table 1. Summary of time series analysis of the karst systems in Izeh area

Formation	Autocorrelation	Spectral Density	Cross-Correlation	Coherncy Function
Asmari (Halijani Sp.)	High storage capasity	Base flow	Intermediate	Linear relationship with precipitation
Asmari (P2)	High storage capasity	Good filtration	Base flow	Linear relationship with precipitation
Ilam-Sarvak (Ek5, Ek7)	Quick flow	Quick flow	Quick draining	Linear to non-linear relationship with precipitation

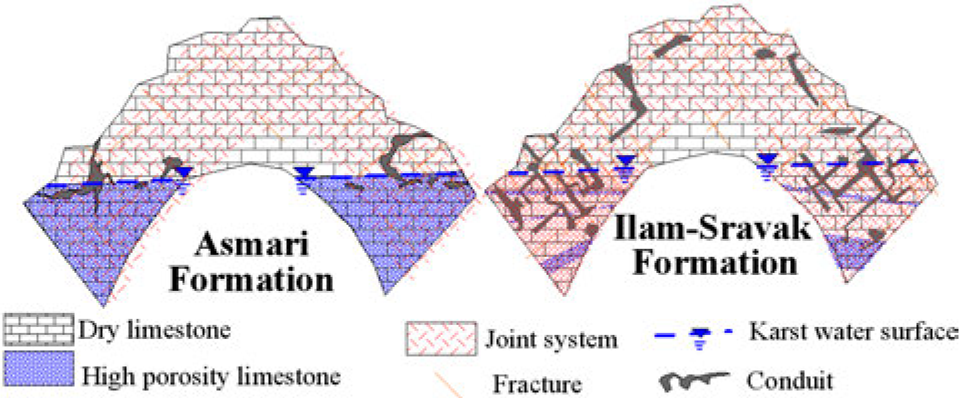

Figure 7. Conceptual models of Asmari karst system (dominant baseflow and high storage capacity) and Ilam-Sarvak limestone (dominant quickflow and low storage capacity)

Conclusions

The groundwater flow in a typical karst system does not follow the Darcy law, because it dominates the regime of preferential flow through the karst network. As a result, these aquifers have an appreciable quickflow component in favor of the baseflow. The typical cases excepted, many karst aquifers can be considered as an equivalent porous media, to the effect that the groundwater flow follows the law of Darcy. These karst systems have poorly-organized karst network as well as high matrix porosity in which both fracture and conduit porosity are rather low. The main hydrodynamic characteristic of these non-typical karst aquifers is that the baseflow component dominates, while quickflow is absent. In contrast to the typical karst aquifers, the storage capacity of baseflow karst systems are high and the matrix can also transmit horizontal flow. The results obtained by time series analysis of two karst systems in Zagros area, southwest Izeh, shows that the karstificatiomn of Asmari Formation bring about a dual-porosity karst aquifer, where fracture and conduit porosity coexist, but unlike Ilam-Sarvak karst systems, the matrix could also easily transmit horizontal flow. In general, Asmari Formation in Izeh area characterized by dominant baseflow in saturated zone (which probably is near Darcy conditions), despite there being some discrepancies. Although the existence of cavities in unsaturated zone of Asmari limestone is evident, the conduit network in the lower part of the karst aquifer is poorly developed, and groundwater is stored in a matrix having a high storage capacity. Ilam-Sarvak karst system in study area lies between two extremes, one highly karstified and the other slightly karstified, and thus the groundwater system is influenced by two factors, quickflow and baseflow.

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COP METHOD MODIFICATION FOR GROUNDWATER VULNERABILITY ASSESSMENT FROM CONCENTRATION OF FLOW ASPECT: BRIBIN CATHMENT AREA CASE, GUNUNG SEWU KARST-INDONESIA

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Abstract

Karst groundwater is one of the potential natural resources in the Gunung Sewu karst area. On the other hand, karst aquifers are highly vulnerable to contamination. Bribin underground river has become the main water source for the local people, especially during dry season. The purposes of this research are: 1) to know the characteristics of the swallow hole recharge area through identifiying vulnerability variables (swallow hole condition, slope, vegetation, soil and rock), 2) to know the level of groundwater vulnerability to contamination which is assessed by COP method, 3) to modify the C factor (concentration of flow) for the assessment of groundwater vulnerability to contamination that is suitable for the study area. Swallow holes, caves and doline are identified by census, while soil sampling are done by purposive sampling using soil series unit. The data processing method is based on COP, which is an acronym of C (concentration of flow), O (overlaying layer) and P (precipitation). Each variable and sub-variable has value at each class, and then is performed with the operation of multiplication and addition. New variables from the C factor are analyzed statistically through factor analysis. The aims of analysis are to identify the smallest number of common factors which has the best explanation or link correlation among indicator variables. The results show that characteristics of swallow hole recharge area vary from aspects of the number, dimension, location, and condition of swallow holes, slope and vegetation, soil and rock thickness. The level of groundwater vulnerability to contamination in the research area is mostly very high. The factor that has a large contribution is the variable of flow concentration. It is the number of swallow holes as a point recharge of surface flow that makes it very vulnerable. Statistical test results in three major factors that correlate with each other. Factor 1 includes size and number of sink hole variables, factor 2 includes sink hole and vegetation-slope condition variable, and factor 3 covers distance to sink holes and sinking stream. The total variance which is formed by the model can give a value of 62.26% and the total score variation value of C can provide a more diverse C class, especially in the area and the number of sink holes.

Keywords: COP, vulnerability, contamination, concentration of flow, swallow hole

Introduction

Karst is an area that has unique characteristics in geomorphology and hydrology. Ford and Williams (1989) defines karst as a field with the characteristics of karst hydrology and landforms which are caused by a combination of rock dissolving easily and having a well-developed secondary porosity. Some factors that characterize karst are: the presence of closed valleys which have various sizes and shapes, absence or scarcity of surface drainage or river, and the presence of caves of the underground drainage system (Summerfield, 1991).

The characteristics of karst aquifer are complex and natural which makes it different from another aquifer, such as: high heterogeneity, a large channel, high-speed flow, high flow rate (Bakalowicz, 2005). Groundwater in karst areas has a high chance to be developed as a source of drinking water, because the amount is very abundant. Gunung Sewu karst regions in Gunungkidul district actually have potential of groundwater to support the water supply in the dry season since this region is known as a hard water area. The problem is that it is difficult to access the groundwater as the depth varies between 50-100 m below the surface (McDonald & Partners, 1984). To solve this problem, local government has made efforts to pump Bribin underground rivers, Seropan, Baron, and Ngobaran (Baron-Bribin system) and distribution network development.

On the other hand, karst aquifers are particularly vulnerable to contamination due to thin soil, the flow concentration within epikarst, and concentrated recharge through sink holes. As a result, contaminants may easily reach the groundwater and be rapidly transported in karst conduits over large distances (Goldscheider, 2005). Therefore, it needs good management to protect groundwater from contamination. One of the important efforts to protect the karst groundwater is zoning of groundwater vulnerability to contamination. One method used is the COP (Vias *et al.,* 2006), which is one result of the development of the previous methods i.e. EPIK (Doerfliger and Zwahlen, 1998) and PI (Goldscheider, 2002). There are three variables, namely: concentration of flow, overlaying layer and precipitation. This study focuses on the C factor as one of the variables to determine the vulnerability of groundwater to contamination. Through this research, it is hoped that the details of sink hole recharge area in the study area will be obtained. The results serve as a basis to modify the COP method especially C factor (concentration of flow). As consideration, the variables of C factor in COP method are only based on the distance to sink holes and sinking stream. In fact, swallow hole condition is not always open, but is also covered by sediment and filled with water as a doline is. These conditions will affect the criteria for assessment of groundwater vulnerability to contamination. Therefore, there is an opportunity to develop the methods according to the research conditions. Based on some of these considerations, the purposes of the study are to characterize sink hole recharge areas through identifying vulnerability variables (sink hole condition, slope, vegetation, soil and rock); to know the level of vulnerability of groundwater to contamination using COP method; to modify the C factor (concentration of flow) for assessment the groundwater vulnerability to contamination that is available for the study area.

Cop Method Review

Daly *et al.* (2002) has distinguished two classes of vulnerabilities: intrinsic and specific vulnerability. Intrinsic vulnerability is based on the hydrogeological characteristics of an area, but independ on natural contaminants and artificial contaminants. Specific vulnerability takes into account the physical-chemical properties of contaminants and their relationship to the physical and chemical properties of the hydrogeological system. The concept of groundwater vulnerability is based on origin - pathway - target model (Goldscheider, 2002). Origin is assumed as a place of release of the contaminant, pathway is a potential contaminant flow path from the release to the point or place that must be protected, and the target is water that must be protected (resources - aquifers, sources - wells/springs). There are four factors to consider here, including: overlaying layer (O), concentration of flow (C), precipitation regime (P) and karst network development (K) (Drew, 2003). Factor O, C and K reflect the internal characteristics of the karst system, while P is the external factor. For aquifer vulnerability mapping, the factor O, C and P should be considered, while for mapping the vulnerability of wells and springs, the K factor should be added. The flow stream for the protection of the aquifer consists of most of the vertical part of the protective layer (protective cover) and for the protection of wells/springs also includes horizontal flow in aquifers. COP method is one of intrinsic vulnerability assessments for carbonate aquifer proposed by COST

620 (Zwahlen, 2003). The COP acronym comes from the three initials of the factors used: Concentration of flow, Overlaying layer, Precipitation (Vias, *et al.,* 2006)

Each of these factors serving as determinants of vulnerability of groundwater to contamination at the COP method is explained as follows (Vias *et al.,* 2006). The C (concentration of flow) factor reflects the degree to which precipitation at or near aquifer outcrop is concentrated into swallow hole, by passing unsaturated zone. Two scenarios of C factor are differentiated: 1) swallow hole recharge area and 2) the rest area. Scenario 1; this describes the situation within catchment covered by low permeability layer, where suface runoff flows either into a swallow hole or an area of concentrated infiltration such as the foot of a slope. The evaluation of the C factors considers four variables: the distance from the recharge area to swallow hole (dh) and to the sinking stream (ds), the influence of slope (s) and vegetation (v). Scenario 2; this describes the situation in areas where autogenic recharge occurs but not as concentrated infiltration into a swallow hole or at the foot of slope. The C score is evaluated by the combination of only three variables: surface features (sf), slope (s) and vegetation (v). The O (overlaying layer) considers the protection provided for the aquifer by the physical properties and thickness of the layers above the saturated zone. The O factor is evaluated by taking into account two layers with important hydrogeological roles: soils (O_S) and the litholocical layers of the unsaturated zone (O_L). Several variabels of soil sub factor are texture, grain size and thickness. Meanwhile, litological sub factor assesment criteria are rock type and the degree of fracturing (ly), the thickness of each layer (m) and any confining conditions (cn). The P (precipitation) factor (Daly *et al.,* 2002) includes quantity of precipitation and factors which influence the rate of infiltration, i.e. frequency, temporal distribution, duration and intensity of extreme rainfall events. These factors determine the ability of precipitation to transport contaminants from the surface to groundwater. The P factor is evaluated by two sub factors: quantity of precipitation (P_Q) and temporal distribution of precipitation (P_I). The COP Index represents the level of vulnerability which is obtained from three factors by performing multiplying operation.

Swallow Hole (Point Recharge) Characteristics

Swallow holes, caves and doline. Based on the results of aerial photo interpretation and field checks, it is found out that the condition of each swallow hole recharge area is very diverse. Field survey results indicate that the distribution of swallow holes/caves/doline in the study area is found in 87 locations. In Semanu, there are 19 sinkholes, 7 caves and 14 telaga (doline), whereas there are 26 swallow holes, 2 caves and 19 dolines in Rongkop. Basically, swallow holes, caves, doline are a unity. Doline is a closed basin, round or oval within the size of a few meters to more than 1 km (Ford and Williams, 1992). Doline in the various literatures on karst is often called a sinkhole, sink, swallow hole, cenote and blue hole (Haryono and Adji, 2004). Each doline or closed basin is composed of three components (White, 1988), namely: drainage, the altered zone by the solution process, and covered soil or sediment. Related to the assessment of groundwater vulnerability to contamination, each condition (sink holes, caves, doline) gives a different effect or meaning to the assessment. Therefore, the following is the description of each condition.

a. Swallow holes and caves

The various conditions of swallow holes which are encountered in the field can be summarized in the following categories. Sink hole dimension of width: < 1 m, 1 - 5 m, > 5 m, and depth: < 10 m, 10 - 100 m, > 100 m. Swallow holes are connected to the underground drainage system. They are not always located in the middle of basin, but are also located at the edge of the basin on foot slope of hillsides. In one swallow hole recharge area, the number of sinkholes is not always single, but more than one. Sinkhole conditions vary: 1) the mouth of swallow hole is left open as it is but others are arranged by stones , 2) some sinkholes are filled with water and utilized by residents for domestic purposes, 3) those which are closed by residents may be used for agricultural land. In each catchment area, the number, shape, and area of sinkholes are diverse. It will affect the ratio of the sinkhole number toward sinkhole recharge area. The ratio of the sinkhole number is divided into three classes, i.e.: 0.003 to 0.049, 0.049 to 0.134, and 0.134 to 0.219. From the classification, it can be seen that in general, the study area belongs to in the first category (low). The result shows that there are many large catchment areas with single sinkhole. Some of swallow holes in the areas of research are found in Balong, Sindon, Jurang Jero, Bendo, Karang Lampar, Ngrinjing, Ledok, Jomblangan, Wedi Utah, Ombo, Pucung, Towati.

In the study area, caves are mostly located in Semanu, while in Rongkop only two caves are found. Their conditions are generally watery except Pace Cave which is a horizontal cave. The water potential found in the cave is used by residents to meet water needs. Especially for Bribin, the water management is done by PDAM. MacDonald and Partners (1984) have also traced the cave. Some of them in the study area are: Ngreneng, Bribin, Sodong, Semuluh, and Jlamprong caves. The cave channel is formed by groundwater flow that moves from place to place at low height which becomes the output. Symptoms explain why the channel is always associated with resource augmentation collected on the conduit. The location of these conduits is influenced by several factors of geology (geological structures: faults, open fracture) that spur the process of dissolution. Open fractures (1 mm) in general can be passed to the water that moves laminar, while the open gap (10 cm) traverse the turbulent water. This gap is the development of fractures, while the conduit is initially small cavities which then have enlarged because of the solution process.

b. Dolines

As previously described, that doline is a closed basin where the surface flow accumulates. The results of field survey show that 33 dolines in the study area are not always filled with water. This condition is controlled by the presence or absence of sinkhole, the basic sediment thickness, making the foundation surrounding the doline, doline volume, vegetation on the hillside in the sinkholes catchment area. Some of these factors will affect rainfall and runoff to fill doline. From the observation in the field, variations of dolinw conditions are indicated, namely:

1) dry doline, it is because the water seeps into the system directly beneath the surface through both internal dolines itself which flow into the system and other swallow holes. Another factor is the manufacture of stone embankment around doline which can also make the dry doline so that local recharge of water added to the doline obstructed. Many things are informed by the residents to clarify this conditions. The dry conditions of doline also result in the small volume of doline and the level of evaporation.

2) the stagnant water in doline quite varies, namely: the perennial and intermittent. The intermittent doline quite varies: <1 month, 1 -3 months and 3-6 months of water stagnantation. Resident time of water in the perennial doline is affected by sedimentation in the sinkhole, the thickness of sediment and high carrying capacity or volume doline.

Examples of dolines in the research area are Telaga Karangtritisan, Widoro, Wuluh, Ngepung, Gesing, Sriten, Jurug, Wunut, Tileng, etc.

Slope and Vegetation

a. Slope

Slopes in the study area are strongly influenced by geomorphological processes that will determine the appearance of the surface or karst. Landform of study area includes a closed basin, cone karst, karst valley and karst terrain. The variation of slopes was determined by the landform. Slope classification refers to the method of COP for assessment of groundwater vulnerability to contamination. There are four slope categories : 8%, 8-31%, 31-76% and > 76%. The slope distribution spatially includes four classes in the study area. Most of the slopes belong to the second and third category, while for the first and fourth are only in a small part. Settlements located at the slope belong to the first class and fourth classes, especially at cone karst.

b. Vegetation density

Vegetation density is obtained from the calculation of t NDVI (Normalized Difference Vegetation Index) value which is derived from Aster image. Based on NDVI analysis, most part of the study area belong to a moderate level. It may be understood that the facts show that most part of the land is covered by bushes (without vegetation cover), as well as settlements. There is no very dense vegetation such as forests. The vegetation density will affect the interception of rain before it reaches the surface. The function of vegetation is inhibiting the rate of runoff. The more vegetation dense the smaller runoff rate. If there are sources of contaminant, the runoff will carry contaminant into the subsurface system through point recharge or diffuse infiltration.

Nevertheless, based on previous research (Setyahadi *et al.,* 2001) note that low runoff coefficient, which is 4% for low-level solusional, 7% for the moderate class solusional, and 26% for high solusional class. It has also been emphasized by McDonald, *et al.* (1984) that the value of runoff coefficient is 4-27%. The low value of surface runoff due to the influence of other factors which is the number of water loss is controlled by the intensity of rock fracture. More fractures, the greater water loss.

1) Soil

Description of soil focusws on the thickness and texture. The results of grains size analysis indicate that most of the textures included are clay material. The thickness of the soil are identified based on the depth of the hand drill that can be done for soil sampling. It also considers the classification of the existing COP method. From the results of hand drilling, it is found out that soil thickness is also influenced by the landform of the study area. The thickness of the valley or basin areas is more than a hill top or hillside regions. The depth of the valley area can be achieved with hand drill range of 2 m, while for the slope is less than 1 m.

2) Lithology

Lithology in the study area is almost the same since all of them are a part of the Wonosari Formation. Limestones in this formation are mostly composed of coral limestone, although there are also layered limestone, limestone, marl, and conglomerate (Surono *et al.,* 1999, Samodra, 2005 in Adji, 2009). The thickness of the lithology is considered a layer of rock above the underground river. This is one difficulty in this study, which is to estimate the thickness of the rock accurately. The complexity of the underground river network is still the subject of discussion and review of the increasingly complementary. This is taking into account the watery caves that had been surveyed by previous researchers (McDonald & Partners, 1984), with detailed cave morphometry. It can be calculated from the height of the roof of the cave to the surface topography. Based on these surveys, the average thickness of rocks in the study area is 25-225 m dpal. This method still needs to be addressed with geophysical methods, particularly the VLF-EM-vGRAD (Very Low Frequency Electromagnetic Gradient vertical) which is the development of VLF-EM method. This method is intended to get a clearer picture of the underground river network system (Bahri, *et al.,* 2008).

Factor Analysis For Proposed Concentration Of Flow (C)

Factor analysis to determine variables of C (concentration of flow) factor is as follows: 1) the distance to swallow hole (dh), 2) sinking stream distance (ds), 3) the condition of the vegetation-slope (sv), 4) area of swallow hole recharge (La) , 5) the number of swallow hole (Qty), and 6) swallow hole conditions (KND). The following will be given an explanation of SPSS output for factor analysis. Table 1 informs the associations between 6 variables with each of 5 variables. High correlation values ('+' or '-' more than, 60) means that there are common factors and will be combined by factor analysis. Determinant value of 0.693 which means low colinearitas.

Tabel 4. Correlation Matrix

		La	Jml	knd	Dh	ds	sv
Correlation	La	1.000	.526	.069	.068	.010	-.077
	Jml	.526	1.000	.043	.084	-.044	-.038
	knd	.069	.043	1.000	-.014	-.023	-.102
	dh	.068	.084	-.014	1.000	-.058	.076
	ds	.010	-.044	-.023	-.058	1.000	-.013
	sv	-.077	-.038	-.102	.076	-.013	1.000
Sig. (1-tailed)	La		.000	.112	.116	.432	.088
	Jml	.000		.222	.068	.219	.250
	knd	.112	.222		.403	.340	.036
	dh	.116	.068	.403		.155	.090
	ds	.432	.219	.340	.155		.406
	sv	.088	.250	.036	.090	.406	

a. Determinant = ,693

Table 5 informs the adequacy of data or samples which can be identified through the Kaiser-Meyer-Olkin (KMO). Value Kaiser-Meyer-Olkin (KMO) is 0.514, which means in theory a group of data which meets the assumption of the adequacy of the data (Hair, *et al.,* 2006). While the value of Sig. 0:00 which means that the correlation matrix is significantly different (less than 0.05) to explain the correlation among variables.

Tabel 5. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.514
Bartlett's Test of Sphericity	*Approx. Chi-Square*	113.555
	Df	15.000
	Sig.	.000

Table 6 describes the number of factors that can be determined based on the eigenvalue of the correlation matrix between variables and grouping variables. Eigenvalue is taken to determine how many factors causing the eigenvalue greater than one (Sharma, 1996). The total factor is formed by three factors. The total variance of the three factors is 62.269%.

Tabel 6. Total Variance Explained

	Initial Eigenvalues			*Extraction Sums of Squared Loadings*			*Rotation Sums of Squared Loadings*		
Component	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*
1	1.571	26.182	26.182	1.571	26.182	26.182	1.542	25.697	25.697
2	1.138	18.975	45.157	1.138	18.975	45.157	1.127	18.789	44.486
3	1.027	17.112	62.269	1.027	17.112	62.269	1.067	17.782	62.269
4	.922	15.363	77.631						
5	.873	14.544	92.175						
6	.469	7.825	100.000						

Extraction Method: Principal Component Analysis.

Table 7 shows the loading factor after varimax rotation. Loading factor values below or equal to [0.4] is not displayed. Loading factor of the orthogonal rotation has a range -1 and 1. Negative values can be interpreted as a reversal, such as the second factor that is influenced by the condition of swallow hole and conditions of slope and vegetation showing the higher value of vegetation and slopes that will reduce the value of the swallow hole. Based on the three factors, it can be concluded that variables on the first factor consist of the area of swallow hole recharge area (La) and the number of swallow hole (Qty). The second factor consists of the swallow hole conditions (KND) and slope-vegetation conditions (sv). The third factor consists of swallow hole distance (dh) and the sinking stream distance (ds).

Table 7. Rotated Component Matrix

	Component		
	1	2	3
La	.866		
Jml	.860		
knd		-.703	
sv		.692	
ds			-.822
dh		.	.551

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 5 iterations.

Interpretation that can be obtained from the factor analysis to the first factor is a variable size and number of swallow hole theoretically show the existence of a relationship where the more extensive a swallow hole will be supported by increasingly large number of swallow hole. The second factor which is determined by the condition of vegetation-slope (sv) and the swallow hole conditions (KND) indicates if the higher value of sv, which means the condition of the ramps and the denser vegetation whether it is covered or not would encourage swallow hole condition for being opened or flooded. The third factor is affected by distance to swallow hole and sinking stream which indicates that the further the distance to swallow hole, the more not supported the closer river valley formation. This is consistent with the characteristics of karst material which will not necessarily form a surface flow. Water that fall in the sinkhole will be directly drained into the underground river through swallow hole without any form of surface flow. Variables that make up the overall flow concentration factor (C) contribute 62.26%. In this case, the loading factor values are used to compile the new C score for each predetermined variables as the result C score for each factor. The result of the total flow concentration can indicate a variety of classes, with the rise in value - of extreme value to swallow hole which has an area large enough with a lot of swallow holes. Testing results of the statistical model is still necessary to validate the condition of the field and include the other influence variables to vulnerability such as P and O factors. In broad outline, it can be determined that there are differences in the statistical model value of C theoretically in previous research with the research done today, i.e. area of swallow hole recharge area and the number of swallow hole variables.

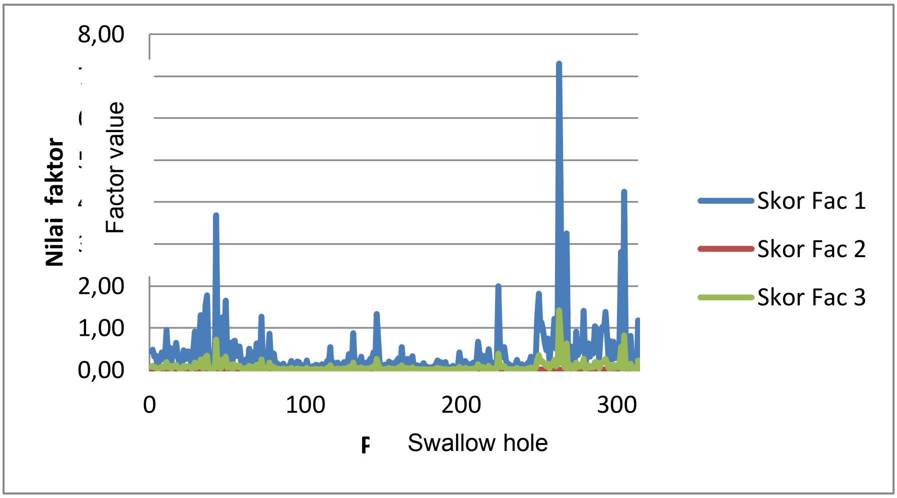

Figure 1. C value based on the loading factor 1, 2 and 3

Groundwater Vulnerability To Contamination

a) *Concentration of Flow* (C)

The C factor is a modifier of the O variable (Daly, *et al.,* 2002). If the cover or the overlaying layer (O) describes the vulnerability of groundwater to contamination which is infiltration process through the unsaturated zone diffusely. Concentration of flow represents the rain into the subsurface system through point recharge at unsaturated zone. Based on COP method, there are two scenarios of C factor: 1) swallow hole recharge area and 2) the rest of area. The first scenario describes the situation within catchment covered by low permeability layer, where suface runoff flows either into a swallow hole or an area of concentrated infiltration such as the foot of a slope. The evaluation of the C factors considers four variables : the distance fromthe recharge area to swallow hole (dh) and to the sinking stream (ds), the influence of slope (s) and vegetation (v). The second scenario describes the stuation in areas where autogenic recharge occurs but not as concentrated infiltration into a swallow hole or at the foot of slope. The C score is evaluated by the combination of only three variabels: surface features (sf), slope (s) and vegetation (v).

Based on the results, it is found that that the sub-variables is influenced at the first scenario. The distance to swallow holes, mostly is in the first criteria i.e. < 500 m (value 0), 500-1000 m (value 0.1), while the distance 1000 - 1500 m is limited. The distance to the sinking stream is not available so for ds is given value 1. Variable sv is a combination of the slopes and vegetation. Slopes in the study area vary depending on landform, while vegetation density is relatively homogeneous. By merging the two variables, it is known the overall dominance on the 2nd slope class (8-31%) with low vegetation (value 0.90). The third slope class (31-76%) with moderate vegetation cover is with a value of 0.85. Since the vegetation classification is not available in the table of the COP, the assessment is included in the high category. The assessment results in the finding that the C factor of the first scenario is very high (0 - 0.2). The second scenario is classified into the developed karst area and a permeable layer. Slope and vegetation are similar to the first scenario. The results of the second scenario of C factor belong to moderate class (0.4 - 0.5). The result of C factor can be understandable since the number of swallow holes spread in the most of the research area. It means that infiltration through the point recharge is the dominant process, other than the diffuse infiltration process.

b) *Overlaying Layer* (O)

The O (overlaying layer) considers the protection provided for the aquifer by the physical properties and thickness of the layers above the saturated zone. The O factor is evaluated by taking into account two layers with important hydrogeological roles: soils (O_S) and the litholocical layers of the unsaturated zone (O_L) (Vias *et al.,* 2006). Several variables of soil sub factor: texture, grain size and thickness. Meanwhile, litological sub factor assesment criteria are rock type and the degree of fracturing (ly), the thickness of each layer (m) and any confining conditions (cn). The grain size of soil is mostly clayed. The soil thickness variation depends on the landform, namely: the valleys, slopes and hills. The soil sample takes into consideration the series unit of soils in each landform. The result of filed survey shows the thickness of the soil layer: less than 0.5 m on hill top (value 3), between 0.5 - 1 m at the hillside (slope) (value 4); while the thickness of valley varies from 0.5 to 1 m (value 4) and more than 1 m (value 5).

The lithology of study area is karst rocks (karstic rock). The determination of value is a combination of lithology and fracturing (ly), the thickness of each layer (m) (as an index layer) and the confining condition (cn) via multiplication process. The classification of layer index shows the value between 0 - 250 (value 1). Furthermore, the O score by sum operation of Os and OL results in the value of the medium and high level. It is caused by clay texture of soil and the thin thickness of layer.

c) *Precipitation* (P)

According to Daly et al. (2002), rain includes quantity and a number of factors that influence the infiltration process such as: frequency, temporal distribution, duration, and intensity of rainfall events. These factors will help identify the ability of rainfall in bringing contaminants from the surface into groundwater. The rainfall data in the study area is measured in three limited rainfall stations: Tambakromo (upstream), Karangasem (middle), and Bribin (downstream). If there are more rainfall stations then the better result will be obtained. The annual rainfall in wet month is divided into three classifications: > 1600 mm/year (value 0.4), 1200 - 1600 mm/yr (value 0.3) and 800-1200 mm (value 0.2). Temporal distribution of rainfall is calculated based on the number of annual rainfall by day event of rainfall. The temporal distribution belongs to the first and second classification : <10 (value 0.6) and 10-20 (value 0.4). By combining PQ and PI, the value of P (precipitation) factor is obtained. There are three classifications: very low, low and medium. This result indicates that the precipitation ability in bringing contaminants includes very low to moderate categories.

d) The level of groundwater vulnerability to contamination

The result of groundwater vulnerability to contamination assessment in a part of Bribin underground river (down stream) using the COP method suggests that the majority of the research area belongs to a very high degree of vulnerability. However, there is a part of the region which belongs to a low level to moderate vulnerability (Figure 2). The high level vulnerability is controlled by several things. Firstly, the C factor shows a very high value caused by the dominant process of infiltration through point recharge and supports the shortest distance to swallow hole. It is also clarified by previous studies that the surface runoff coefficient is in the low level because of the large water loss through the fracturing. Secondly, the index layer is classified into a low level because of its lithology type and its thickness. It will reduce the level of protection to contaminants. However, the variable of protective layer of soil conditions is in fact mostly clayed texture which is actually inhibiting the rate of water due to low permeability. However, due to the dominant infiltration process which is through sinkhole, it becomes vulnerable. A small area of research has vulnerability levels from low to high level. Low vulnerability is found in the rest of area where infiltration process occurs diffusely. Therefore, the level of vulnerability in this region is controlled by the layer of unsaturated zone and rainfall both amount and temporal distribution. It is similar to the classification level of moderate to high vulnerability.

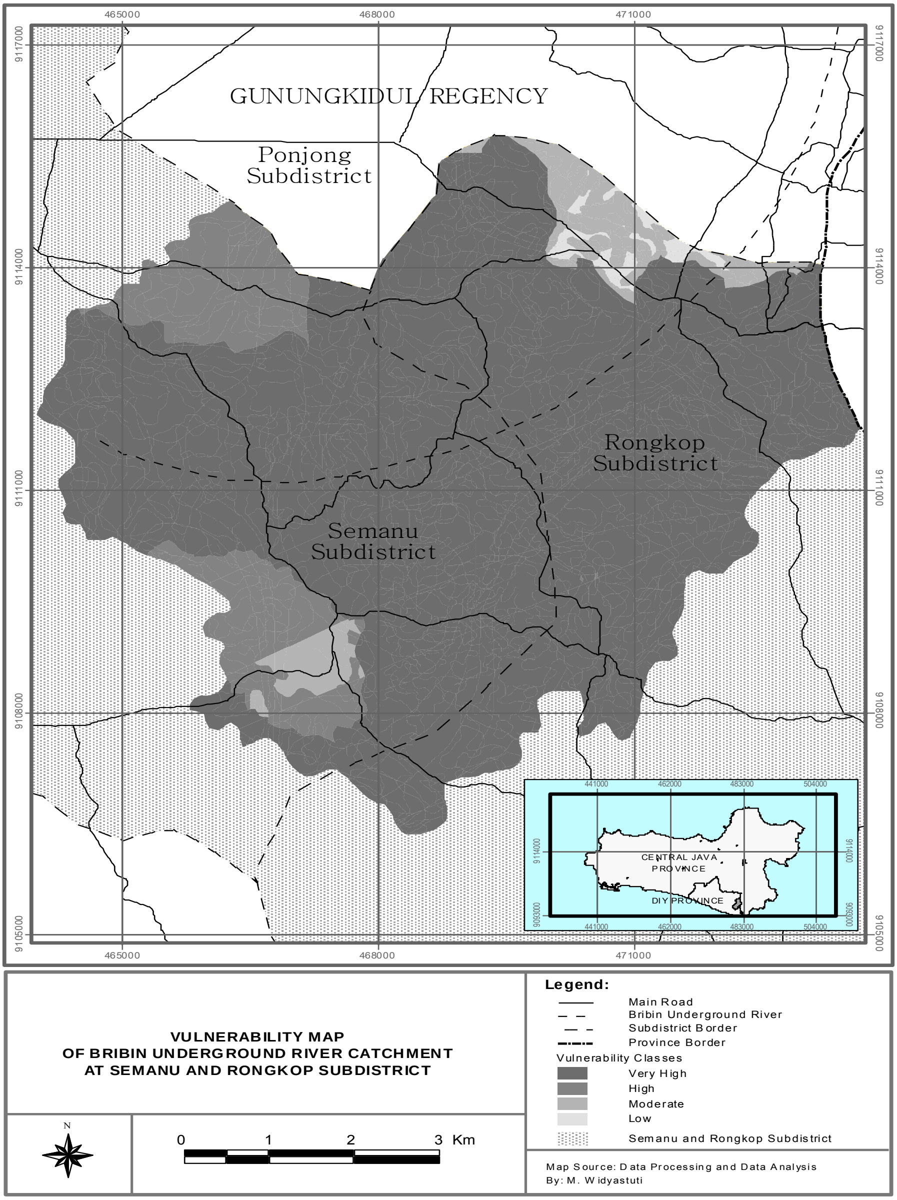

Figure 2. The Map of Groundwater Vulnerability to Contamination using COP Method

Conclusion

The conclusion of the research results is as follows. Swallow hole recharge area is characterized by: a) the variety of swallow hole condition according to the dimension, location, number and swallow hole condition; most of the caves are watery caves and the people use them to fulfill their domestic needs; some dolines are in dry conditions, temporary filled with water and perennial, b) vegetation density is low to moderate criteria with the dominant 8-76% of slope; c) the dominant soil texture is clayed by varying the thickness of the soil layer (valley, slope and top of the hill); type of lithology is karstic rock with a variety of unsaturated zone thickness (<250 m). Concentration of flow (C) factor belongs to the high level, the overlaying layer (O) factor belongs to the medium and high categories, whereas for the P (precipitation) factor, there are three classifications: very low, low and medium. Based on the three factors (C, O and P), it is found out that most of the research area belongs to the very high degree of vulnerability. It is determined by the number of swallow holes as a place of concentration flow. Statistical test using factor analysis suggests three main factors that correlate with each other. The first factor includes the area and the number of swallow hole variables. The second factor includes the swallow hole conditions variable and vegetation-slope condition. The third factor includes the distance to swallow holes and sinking stream. The total variance which is formed from the model can give a value of 62.26% and the total score variation value of the C factor can provide a more diverse class of C factor, more specifically, it is the area of swallow hole recharge area and the number of swallow holes.

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THE ROLE OF STRUCTURAL ELEMENTS IN RECONNAISSANCE OF KARST HYDROLOGY IN THE LAR CATCHMENT'S, IRAN

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Abstract
Information on karst hydrology is needed to develop water quality and quantity management strategies. Karst aquifers are characterized by high heterogeneity and spatial variability of hydrological parameters. one possible approach to study them is investigation of relation ship between geostructural element and hydrological elements In this study various types of assessments, have been carried out, including analysis of karst related features from aerial photo, satellite image, geological map and fieldwork. Water quality and quantity characteristics were investigated with respect to catchment characteristics and integrated in GIS. And hydrograph analysis was done to estimate ground water contribution to stream flow. The regression results indicated that occurrence of karst water resources were highly correlated to geological structural elements.
Demonstrated is the importance of structural geological elements, such as lineaments and faults, in reconnaissance of karst hydrology.

Keywords: Karst, structural element, hydrology , Lar

Introduction

Detailed knowledge of hydrological and structural elements in karstic area is of utmost importance in order to understand interaction between structural and hydrological elements. Fracture distributions involving orientation, continuities, densities, intersecting and fault types provide a key to understanding the hydrology of karstic area. However in study area there are good outcrops of the fracture, faults and also so many ground water discharge point. Fracture system in the region have been characterized through field survey, geological map, interpretation of aerial photo graph, remote sensing of satellite images and integration in GIS.Tectonics element such as faults, syncline and anticline axes, joints, lineaments and their analysis have provided new insights into a vast array of hydrogeology. Lineament is natural simple or composite-pattern linear or curvilinear features discernible on the Earths surface, In the geologic sense, these features my depict crustal weakness. These originate mainly from strains that arise from stress concentrations around flaws, heterogeneities, and physical discontinuities, largely reflected in the form of fault, fractures, joints sets, or dykes (O Learly *et al.,* 1976). In the last two decades structural elements have been widely practiced by Neven Kresic (1995) and Ozkaya and Minton, (2007), Solomon and Ghebreab (2008), and Pirasteh *et al.* (2006). Krishnamurthy and Srinivas (1995), Lattham, L.H. and Parizek, R.R.(1964). This paper studies the geostructural and hydrological elements in the Lar region, in the central Alborz mountains ,some 85 km North East of Tehran (capital of Iran) ,which are extracted and interpreted from geological map, aerial photo, Land sat imagery and DEM data. The propose of this research was to improve the understanding of the role of structural element in reconnaissance of karst hydrology in the Lar catchment.also establishing relationships between remote sensing data and hydro geologic setting in the area.

Materials and Methods

Study Area. Approximately 11 percent pf the territory of Iran is covered by carbonate rocks (Afrasiabi, 1998) and within the study area 33 percent is occupied by exposed karstified carbonate rock, in which sinkholes, caves and karstic springs occur locally .The research was conducted within the Lar catchment located in upstream of Lar dam, southern part of Alborz Mountains and 85 km far from Tehran city, Iran. The study area, about 750 km^2, located in the coordinates of between 35, 48 to 36, 04 N and 51.32 to 52.04 E and at the elevations of 2400-5670 m above sea level, as a part of Lar river catchments, has been shown in Fig. 1. Lar River flows from North West to south west and has 6 main tributaries. The area covers the middle sector of the Alborz Mountains. The Alborz Mountains are a continuation of the Alpine Type Mountains, which are a complex asymmetric belt of folded and faulted rocks (Stoklin, 1974). The area is mainly underlain by limestone, volcanic beds and lake deposits. The limestone units consist of medium bedded limestone of upper Jurassic age (Lar formation) and a massive fine grained limestone of Early Cretaceous age (Tiz-koh formation) and marly limestone of Middle Jurassic (Dalichai formation). The volcanic rocks include mainly trachy- andesitses, formed by the activities of Damavand Mountain which is of Early Pleistocene age and also Tuff of Miocene age (Karaj formation). The lake deposits consist of two units informally named as lower and upper deposits (Stoklin *et al.,* 1964).

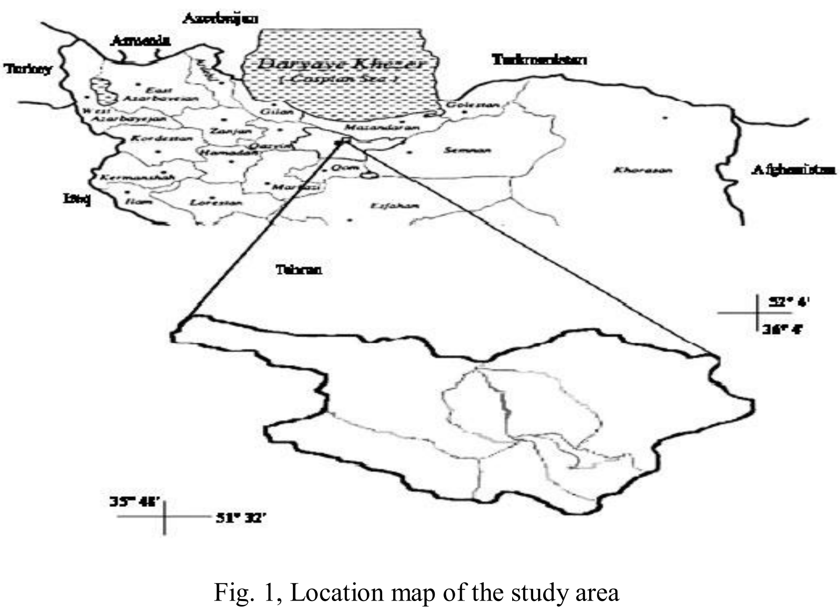

Fig. 1, Location map of the study area

This research was accomplished using ILWIS 3.1 (Integrated Land and Water Information System), PCI EASI/PACE 8.2 and Microsoft Excel software at Research Institute for Water scarcity and Drought in Agricultural and Natural Resources (RIWSD). Land Sat TM 2002 satellite images and 1/50000 scaled topographical maps, geological maps and black and white

1/20000 aerial photos used in this research were supplied from Geological Survey of Iran and Iran Remote Sensing center.

Method of Investigation. The extraction of the tectonic elements that have deformed the rocks is one of the important tools for determining of the direction of the most opened fractures. The most elementary approach is to make rose-diagrams of structural elements and to expect to find out some relation between them and hydrological data. To aim the role of structural elements identification, in karst hydrology a karst potential map were prepared and then based on geological and hydrological and remote sensing data, different thematic layers like, tectonic element .lineament, litho logy, spring, slope and elevation class, drainage network and density, and shallow ground water map were prepared and integrated in a GIS to investigate relationship between geostructural and hydrological data. To find out the role of karst systems, in sustainable base flow, a river and spring discharge monitoring survey carried out during the dry season and also daily flow analysis were down.

Karst related features and the main thematic layers. Tectonics elements such as, faults, joints, folds and bedding pattern play an important role in the karstification and lineaments derived from remotely sensed data can be correlated with vertical or near vertical zones of fractures concentration which can act as conduits for transport and storage of ground water. With this hypothesis different thematic layer were prepared as an indication and reflection of karstification .They are as fallow;

Lithology map: The lithology layer was compiled from the geological map and using false color composite of the area, by extracting only the boundaries between the main litho logical sequences (limestone, dolomite, tuff, volcanic beds,). This layer was used in G.I.S. to segment the area in rock-units with different degrees of karstification, and in non-karstic units with different permeability‟s.

Karst potential base map: The Concept of karst potential map is provided to establish an indicator of where karst might occur and what level of karst development might anticipate. This is carried out by analysis of the geology map, images and aerial photo.Criteria were used to evaluate karst potential within a particular polygon were the likelihood that karst forms on soluble bed -rock (e.g. massive and thickly bedded limestone, Dolomite). The proportion of soluble bed -rock based on litho logy, unit thickness and stratigraphic information and position. Of course there are other important factors that control karst potential (e.g. secondary porosity, mineralogical composition, etc…), but that type of information was not available at this scale of mapping and data collection. Karst potential base map is shown in (Fig2). In the base map Strong-karstic were used to identification of area that have maximum soluble –bed rock with maximum karstic feature .Moderate-karstic is related to area with low surface karstic feature and moderate soluble bed rock, Non-karstic low permeable were used to identify area that have not limestone and surface karstic features wit some low discharge springs, Non-karstic- permeable were used to show area with non carbonate litho logy and so many low discharge springs.

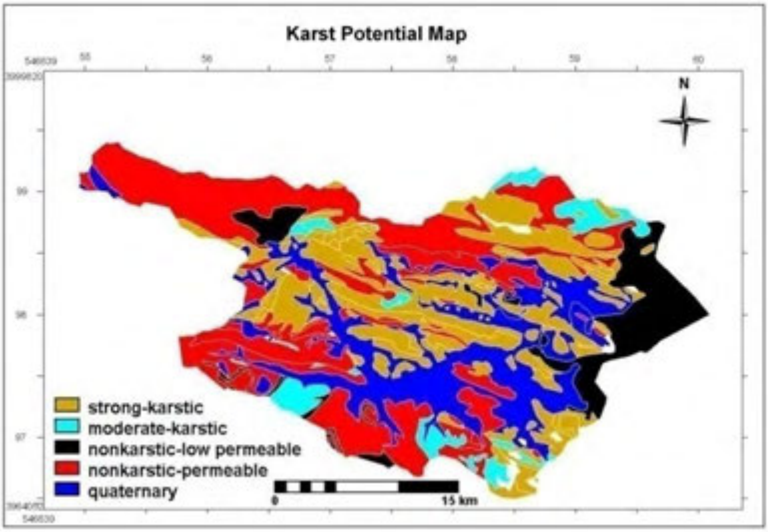

Fig. 2, Karst potential base map of the study area

Tectonic element map: (fault, folds and bedding pattern this is prepared from elements shown on the geologic map and was compiled by adding some elements which extracted by visual stereoscopic analysis of 1/50000 scale, black and white aerial photo.

Lineament map: The Land sat imagery was acquired on July; this time of year is suitable because vegetation has developed after the spring period when water in the form of snow melt and rain are available. In July it can be assumed that vegetation possibly response to soil moisture in fractures. Furthermore vegetation responses could be related to soil as a function of litho logy. For lineament extraction different techniques have been used which are suggested by Suzen &Toprak (1997), Moore &Waltz (1983) and also automatic lineament extraction by PCI EASI/PACE software is experimented .The most effective method was found to be image enhancement by different filter operations and visual extraction of lineaments. Optimum bands, for lineament extraction used are a summation of band 4, 5 and 7.

Rose diagram: in order to find out tectonic stress, lineament patterns were summarized in a rose diagram (Fig.3,)

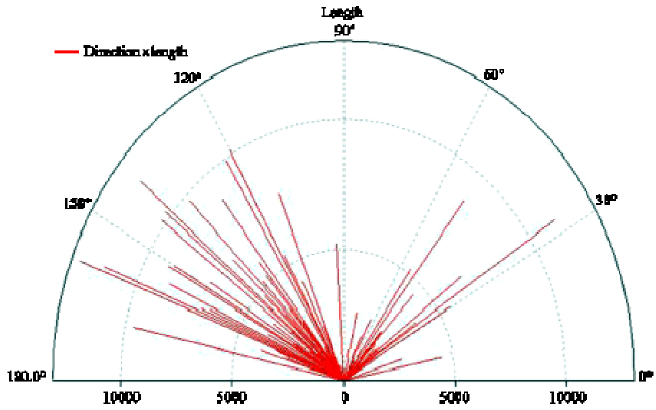

Fig.3, Rose diagram for the lineaments showing major trends of lineaments occurring in the study area

Drainage network: In geologically active region drainage is a function of tectonics elements and generally high drainage is expected in regions of high faults and folds

Lineament, drainage network and tectonic element density map: In general, low drainage density is favoured in regions of highly permeable and resistant rocks and high drainage density is a favoured region of weak or impermeable subsurface materials (Chow, 1964). Relationship between drainage density and lineament density is used by Ahmed (1984) for assessing hydrological condition. With above assumptions, relationship between tectonics elements length over drainage length and number of springs, in different units investigated, it is expected initial condition for karstification in area with high correlation

Shallow ground water map: This is generated from NDVI (normalized difference vegetation index) by selecting area with high values of NDVI, with this assumption that most of the shallow ground water is associated by high vegetation density that are not in valleys. Vegetated area, in valleys shows presence of base flow. From overlying stream network on shallow groundwater layer, area that is not on the valley is distinguished.

Springs location map: Topographic map shows a large number of ground water discharge points such as spring and seeps, observed at the time of the topographical survey. data of the field work have been added to the initial map, this is generated to investigate relation ship between structural element and ground water discharge points.

Slope and elevation map: These were created to investigate the role of local geologic controlon in hydrology of karstic area.

Distribution of springs in different lit logical units. Investigation of spatial distribution of groundwater discharge points in different litho logical unit will help us to find out hydrology of karstic area. The differences in number of springs in the class strong karst to moderate karst and to impermeable formations are in line of expectation. Interesting is the large percentages of springs in non-karstic permeable rocks. It is likely that those springs have low discharges and conversely, the springs in the karst area have high discharge as the karst development favors tunneling. The large numbers of springs in the alluvial area are due to the intersection of the valley bottom with the sub-regional groundwater body. Fig.4

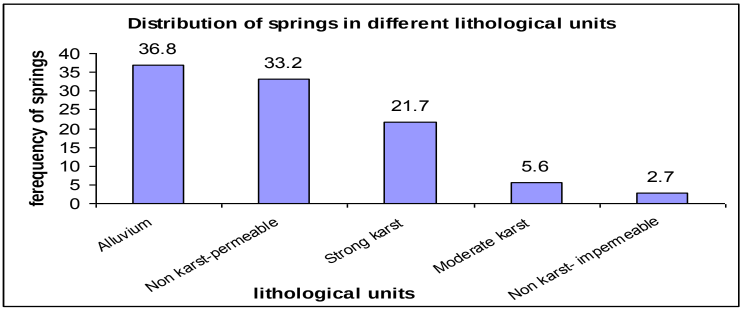

Fig. 4, Distribution of springs in different litho logical units

Data management and processing

In this phase, first, all data were converted to digital format and then different layers, such as tectonic elements, lithology, lineament, karst potential, water quality and quantity , integrated in GIS. Results are shown in Tble.1. Flow component separation and recession curve analysis were carried out, fallowed by analysis and interpretation of the results.

Table 1. Relationship between geostructural and geomorphologic elements with frequency of springs

The parameter of investigated	**Regressions**
Relationship between slope class and frequency of springs	R2 = 0.9449 y = 42.714e-0.3238x
Relationship between elevation class and frequency of springs	y = -6.2732Ln(x) + 21.926 R2 = 0.7204
Relation ship between frequency of springs and distance from tectonics elements	y = 0.8848x + 14.867 R2 = 0.8971
Relationship between frequency of springs and distance from stream network	y = -6.9x + 40.7 R2 = 0.8532
Relationship between frequency of springs and distances away from lineaments.	y = -1.9083x + 19.208 R2 = 0.9776
Relationship between tectonic elements length and frequency of springs in sub catchments of study area	y = 0.8245x + 13.026 R2 = 0.6213
Relationship between tectonic elements length and drainage length	y = 0.2462x + 23.89 R2 = 0.8758

Relationship between drainage length and frequency of springs	y = 0.2477x + 25.931 R2 = 0.8111
Relationship between ratio of tectonic elements density over drainage density and frequency of springs	y = 0.0861x + 0.3643 R2 = 0.8801
Relationship between internal relief and discharge of springs	y = 0.0354x + 334.22 R2 = 0.0079
Relationship between discharge of springs and catchments size	y = 23.895x + 103.94 R2 = 0.4541
Relationship between EC and discharge of springs in study area	y = 0.2053x + 90.428 R2 = 0.0265

Hydrologic setting

The data available for study area are rainfall and time series records of stream flow discharge, Supplemented with base flow measurements made during the fieldwork. Hydrograph analysing, and interpretation of the base flow is all that is available for studying possible effects of karst.

The study area is a mountainous area influenced by air masses of Mediterranean and Caspian Sea origin and climate is classifies as cold arid or cold-semi arid, variation of monthly discharge, precipitation and mean daily temperature is shown in Fig 5, The mean annual precipitation over the catchment is about 697mm calculated from the data of 10 stations, within and close to the study area.

There are three hydrometric stations within the area, including Dalichai, Sefid Ab, and Lar. Only stream flow data from Lar station is used for analysis, due to lack of precise data of the other stations.

For the period of interest, variation of annual and 3 year moving average of rainfall is shown in Fig.6,.As it is shown there was a decreasing trend in annual rainfall over the study area. Variation of minimum, maximum, and mean daily temperature of Lar polor station at catchment outlet is shown in Fig.7, It should be noted that for north of the catchment, the mean monthly temperature is less than zero for about half November to April. Precipitation accumulates in the form of snow.

Flow duration curve

The flow duration curve is the empirical cumulative frequency distribution function of the entire daily stream recorded at a site, and describes the fraction of the time over the entire record that different daily flow levels were exceeded (Midment, 1993). The flow duration curve is a useful tool for illustrating the flow characteristics of a catchment and ground water contributions (Sharifi, 1995). In this research daily flow duration data for three years (dry, wet, normal) and whole period of study, were compared in order to determine the drying trends and ground water contribution to stream flow, Fig 8, shows interesting data. The short duration flows are clearly influenced by the precipitation, but there is not much difference in the long duration flow. This indicates strong buffering characteristic of a permeable catchment with a substantial ground water contribution.

Base flow index (BFI)

The base flow index (BFI) is a dimensionless ratio developed by Lvovich (1972) and the Institute of Hydrology (1980). This index can present some information about the proportion of the runoff that originates from stored sources (Sharifi, 1995). Fig.9,.Shows variation of BFI and annual runoff in period (1967-1976), higher runoff years experience higher and low runoff years experience lower BFI value and high value of base flow index shows that a major portion (60 % to 80%) of the stream flow of Lar river comes from the ground water.

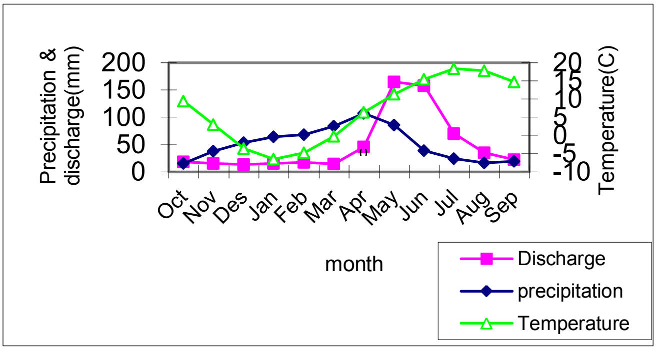

Fig. 5, Variation of monthly average discharge, precipitation and mean daily temperature

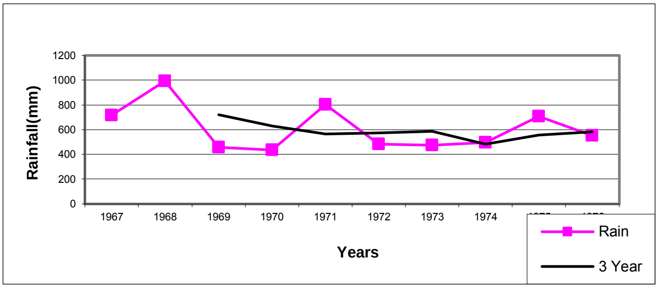

Fig. 6, Variation of annual rainfall in study area

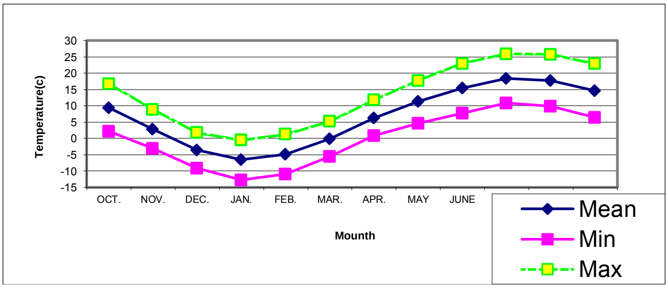

Fig.7, Variation of average daily temperature in study area

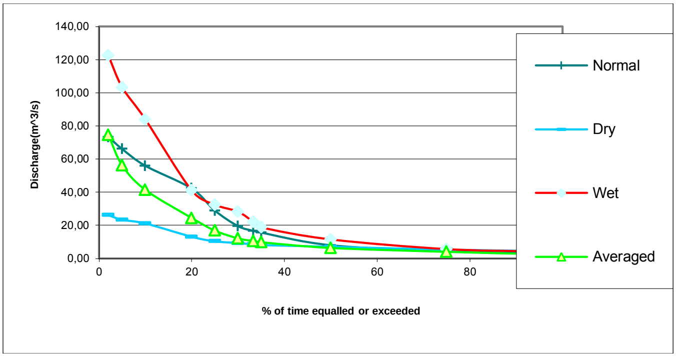

Fig. 8, Flow duration curve of the Lar River

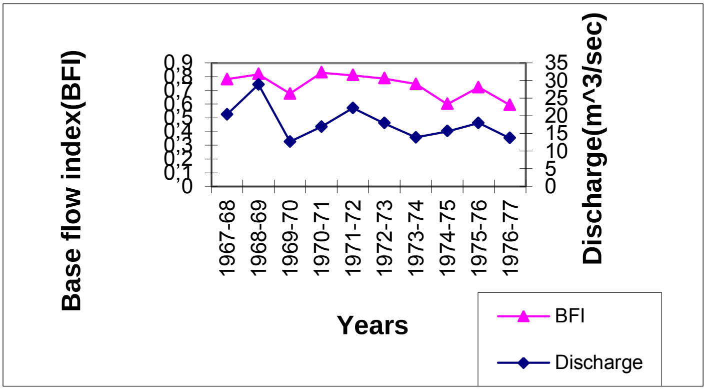

Fig. 9, Variation of base flow index and runoff in study catchment

Recession curve analysis

The recession curve tells in general way about the natural storages feeding the stream. Accordingly, it contains valuable information concerning storage properties and aquifer characteristics .The recession curve has traditionally been separated into the linear components of surface, unsaturated and saturated flow. The components are thought to represent different flow path, in the catchment (Tallaksen, 1994, Felton, G.K. *et al.,* 1994).

Base flow recession curve of Lar River

According to Vogel and Levoll (1991) the start of the recession period was considered to be the day when a 3-day moving average began to decrease and then different hydrograph is plotted on semi-log paper. By sliding the first point of inflection over the other, different base flow recession curve of Lar River is constructed in one graph. As is shown in Fig.10, There are three main recessions, overland flow, direct runoff, flows near the surface (inter flow), termed delayed flow here and ground water flow recession .The recession of base flow is similar from year to year but there is a considerable variation in the recession rate that can be caused by difference in climate or according to Laurenson (1961) it can be the result of several aquifers.

In the Lar catchment there are two conceptual reservoirs:

1) Relatively shallow system with permeable conditions causing a recession from a bout 50-60 m^3/sec to a bout 20 m^3/sec in a period of 100 to 110 days. The physical reservoir could be the thick scree slope, shallow karst, perched water table and river terraces. There is same annual variation.
2) A deep system consisting of a coherent ground water body. Annual variation is minor

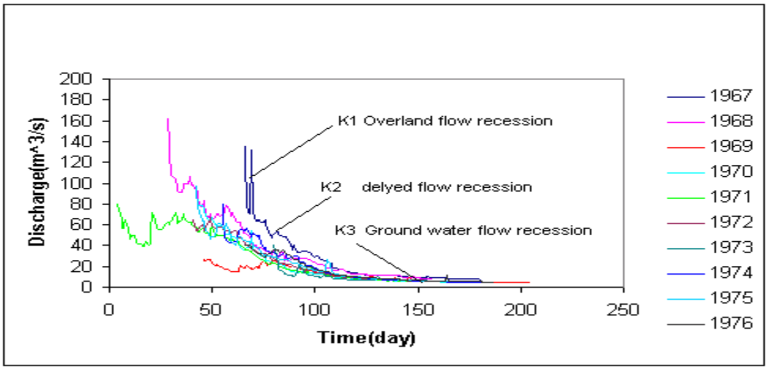

Fig.10, Annual recession curve for 10 consecutive years for Lar River (1967-76)

Lapsed variation of the recession constant

The recession constant, interpreted in literature as a representative of the residence time or the turnover time of the ground water (Wittenberg, 1999). Fig.11 shows variation of the recession constant in the study catchments for 10 years. Physically based variation in the recession rate is caused in climate during the time of recession, but also determined by the conditions prevailing prior to the start of the recession (Tallaksen, 1995). Recession constant in this study period shows variability. Reducing recession constant in 1973 can be interpreted as the result of reducing rain fall ,for the period of 1968-72 there is decreasing trend in rain fall but there is no large fluctuation in recession constant, this can be the result of ground water contribution from the karst system, to stream flow.

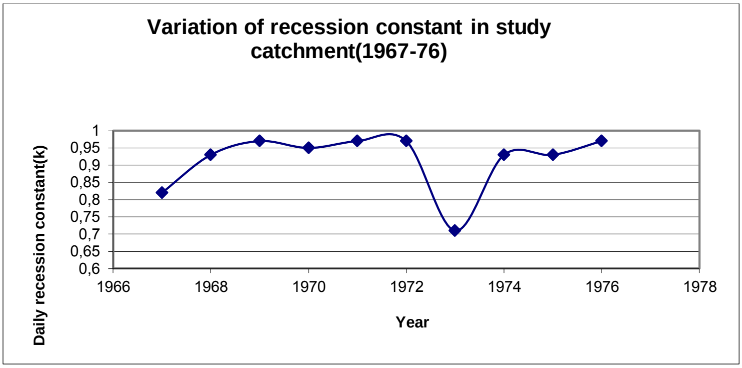

Fig.11, Variation of recession constant for 10 consecutive years

River and springs discharge monitoring

A river and spring discharge monitoring survey carried out during the dry season shows high contribution of the big springs to the stream flow.

Of 24 springs measured in the study area, 18 had a finite flow during the summer of 2002.The 9 largest springs account for approximately 76% of the spring discharge.

The 6 large springs that directly enter Lar River account for approximately 68% of the total river discharge, during the dry season, this high value shows high ground water contribution to stream flow. Different discharge measurement along the river, were carried out and after delineating catchments boundary and calculating area covered by different units, is plotted, Relationship between, non-karstic permeable and impermeable area, with specific discharge shows increasing trend, whilst, limestone area and alluvium shows some scatter, this is not in line of expectation and it could be the result of existence of different, karstic aquifers and ground water emergence in the alluvium.

Results and discussion

One of the most useful methods in karst water resource evaluation is comprehensive analysis of karst related features (lineament, fault, joint) from aerial photo, satellite image, geological map, fieldwork data and also hydrological data processing in karst potential map (Fig.2) generated based on previous described criteria a continuous body of karst units bounded by non-karstic terrains was distinguished, also there is a small discontinuity in north west, north and south of the study area. From the dominant trends of lineament extracted from satellite image and the tectonics elements map (Fig.2, Fig.3) and the location of discontinuity, it is likely that underground passageways and exchange of ground water occurs between adjacent catchments and sub catchments within the Lar catchments. This is also confirmed by presence of large and active sinkholes in the Lar catchment and known underground water losses to the reservoir.A rose diagram generated for lineaments, extracted from satellite image (Fig.3.), suggest that the dominant lineaments orientation is between 140-170 N-W degrees that can be related to the main structural direction .The second lineament trend lies between 140-110 N-W shows cross folding or shear zones. The third class of lineaments is orthogonal to the first directions and is consistent with the counterclockwise rotation of compressive stress. This study has led to the valuable in sights regarding the properties of structural elements and lineaments and their hydrological significance.

From the relationship between Frequency of springs and distance away from lineament (Table.1.1.) signifies the role of lineaments in conveying water.

Relationship between Frequency of springs and distance away from main tectonic elements (Table.1.1) shows a tendency for springs to occur at short distance from tectonic elements, it can be concluded that tectonics elements are conduits of water.By comparing the Frequency of springs with the distances away from main tectonic elements (Table.1.1) and lineaments only a minor difference was found and this supports the significance of the lineament interpretation. From the good correlation between Frequency of springs and tectonic elements length (Table.1.1) and also the concentration of springs close to the lineament and tectonic elements, It was concluded that fractures, indicate zone of enhanced porosity and conductivity, thus can have a positive influence on the ground water occurrence and they act as transmission routes in the limestone bodies.From suitable relationship between the tectonic elements length and number of springs, (Table.1.1) the relationship between drainage length and number of springs and the relationship between tectonic elements and drainage length, it is concluded that number of springs and drainage length are a function of tectonic elements. Thus tectonic elements influence the hydrogeology of the study area. From the association of the ratio of tectonic elements over drainage density and number of springs (Table.1.1) it was found that a high value of this ratio can show ground water occurrence in study area, concentration of springs is found in the lower slope class. Springs occurring on steep slopes indicate local geological control. The same is true for the relationship between elevation class and percentage of springs. Resulting from crossing and distance operation between stream network and springs shows a tendency for springs to occur at short distance from stream network. This is expected because of the way ground water flows in ground water flow systems. Distribution of springs in different lithological units (Fig.4,) shows a decreasing trend from strongkarst to moderate karst and non karst impermeable units that were in line of expectation, fairly large percentage of springs in non karst but permeable units can be the result of fracture flow. The relationship between number of springs in karstic area and distance away from limestone contact (Table.1.1) shows a tendency for springs to occur at short distance from limestone contact, this can bet he result of ground water escaping from the karstic area through the shear zone near contacts of competent and incompetent rocks.

From overlaying stream network on the shallow ground water layer derived from NDVI, it can be concluded that existence of vegetation that is not in the valleys, indicates, wet soils or shallow groundwater. Such area could be recharge area.

The poor relationship between quality and quantity of springs with each other and with catchments characteristics (Table.1.1) were not in line of expectation, it is due to geologic controls.

From the relationship between rainfall-runoff and delay in response to rainfall, high permeability of the catchment can be concluded. Recession curve analysis shows that there is an intermediate and a deep reservoir; the latter correspond to a coherent ground water body in a considerable part of the catchment's. Recession constants, base flow indexes and flow durations all indicate an important contribution of ground water from a coherent ground water body to the runoff. It is likely that these are carry – over effects from one water year to another, because annual rainfall variations have little effect. This study has led to the valuable in sights regarding the properties of structural elements and lineaments and their hydrological significance.

Acknowledgment

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KARST GROUNDWATER RESOURCE IN KARANGBOLONG, KEBUMEN, CENTRAL JAVA

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Abstract
The presence of karst areas in Indonesia, today considered to have strategic value, because it is a region as a supplier and reservoir water for domestic purposes. Research Area (Mountain Karangbolong) administratively located in the area Gombong, Kebumen district. groundwater zones in the study area can be divided into 3 groups; lowland groundwater zone, groundwater zone hills, and karst groundwater zone. Non-depressed groundwater table on limestone in the mountains of Karangbolong ranged from 3 to 40 m under the soil surface, with the fluctuation of ground water level is very influenced by the local rainfall conditions. Depressed groundwater on areas geologically composed by the rocks which old age and consist of several layers which to function as of water bearing layers (aquifers) and water-retaining layer functioning (impermeable layers) such as clay and marl and rocks fine grained

Keywords: Karangbolong, Groundwater Resources

Introduction

The existence of karst areas in Indonesia, today considered to have strategic the value.. Throughout the territory of Indonesian archipelago, area of Karst the region reach almost 20% from the total area. A strategic the values of referred, in addition to the region as a suppliers and the reservoir water to domestic use (United Nations estimates the water supply about 25% of the world population is a source of of Karst water, (Ko 1997), as well have the natural resources that can be used increase state income such as of tourism, minerals in mining, producers swallow nest, and even strongly linked too with the field enforcement, defense / military, and the intelligence. In addition several a strategic values above, by researchers / Scientist, of Karst regions considered as a natural laboratory full of the objects that can be studied / investigated. Many of the results the research theses, or dissertations, has been produced by this region at a variety of disciplinary. Every year there's always the karstolog, both foreign and domestic the visited to do the research. From the this statement can be be seen how much the contribution of Karst regions in the scientific world. The uniqueness of the region is the presence of of Karst caves and underground rivers and the the movement water in shaping the river in a caves. (figure 1)

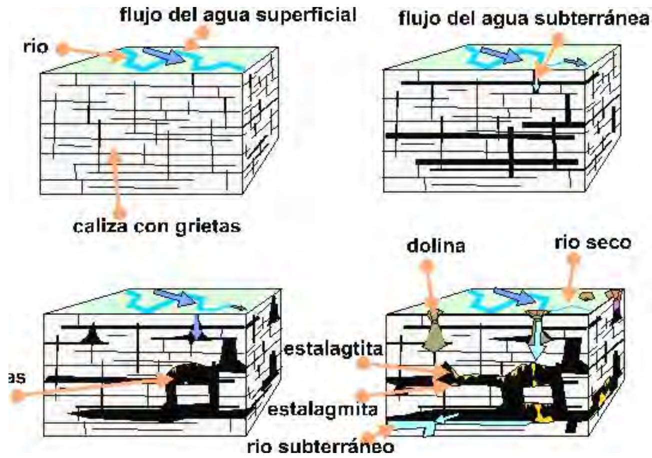

Figure 1. Subsurface drainage of the in karst areas
(Source : http://www.eccentrix.com/members/hydrogeologie/hidrogeol/karst.gif)

Figure 1, shows that the nature of carbonate rocks that have a lot of cavities and easily soluble in water, the surface drainage system is not developed and more dominated by the subsurface drainage system. For example is a cave system that is sometimes known as the river water and underground. In this discussion will be described more karst groundwater .Surface runoff in karst regions are difficult to identify because of more development under surface. The fact that there are many hall of his results solusional process and very least runoff. Karangbolong Mountains has long recognized as a source of water for satisfy of daily needs people nearby, especially when the dry season. In recent years the activities of the mining industry agriculture and animal husbandry, and tourism is growing rapidly, so does the population also increased. Along with these developments, the need for clean water for various purposes is increasing. In fact, according to records, since a few years ago there is groundwater tapped through several wells drilled as a source of water supply for irrigation in this area. The purpose of this groundwater investigation was to inventory and analyze groundwater data and other supporting data, especially in the border area, either directly through a special point of hydrogeology that visited by during in the field surveys as well secondary data of gathered from the related institutions.

Regional Overview of Research

An administrative Kebumen district consists of 26 subdistricts with total area of 128,111.50 hectares or 1281.11 km ^{2}, with condition of the flat area,, mountains, and beaches, more than 50% is lowland. This research area is a section downstream of the Mountain South Serayu and is a southern coastal plains of Java. The morphology of the upstream region is a series of mountains and hills homoklinal Melange Complex Karangsambung of them is G. Gupakan (125 m) and G. Kendil (1040 m) above sea level. In this area arise varied igneous rock, sedimentary rocks and metamorphic rocks. Region the middle of is on alluvial plains, while the downstream area (the south) is a coastal area.

Kebumen Geographically located at coordinates 07o 27 '- 07o 50' latitude and 109o 22 '- 109o 50' east longitude. Climatic conditions in Kebumen, 2125 mm annual rainfall, rainy days 87 days, with average monthly rainfall ranges from 6 to 490 mm. Minimum temperature ranges from 14.2 up to 23.5 o C, humidity ranged between 75 up to 85%, wind speeds ranged from 0.24 up to 1.47 km / h, solar irradiation ranged between 30 up to 84% and evaporation ranges 2.6 up to 5.12 mm.

Research Area (Mountain Karangbolong) administratively located in Gombong, Southern Kebumen district. Karang Bolong Mountains formed by two the main lithologies, that is limestone and volcanic rock product. Both groups of rocks these have physical properties and characteristics are very different, mainly from effect of water, where the limestone is more easily dissolve in water, resulting in well-developed rivers in the limestone just of the under gound river.

Hydrogeological Conditions. Hydrogeological conditions whole in Karangbolong Mountains is detail can be seen from the condition of each watershed which there are by assumption that climate system affecting are considered same in each watershed. It is primarily for to control water flow on the main River (Gb.2.1) and branches of River. Control of flow River should be sustained by the institutions associated so as to soon known if there disruption hydrological system in the area. Changes in the hydrology conditions will interfere with availability of water, both on the surface, or under surface resulting in fewer of underground water reserve. This case will be observed clearly in the spring, if occur that sharply changes in water discharge, means that infiltration the water in area reduced.

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Photo 2.1. Condition and quality of the water in the main River (K. Ijo)

Rock Types. Karangbolong Mountains formed by two the main lithologies, which is the limestone and volcanic rock product. Both groups of rocks these have a physical properties and characteristics are very different, especially of the influence of water, which the the limestone is more easily dissolve in water, while the rocks of volcanic products is much more resistant. This resulted in the flow River well developed in volcanic lithologies, while the in the limestone be found only short rivers and there are water rainy season. Activities in the limestone dissolution causes rain water that falls in the rock surface will absorbed downward rapidly, so that the channels was not growing the surface of stream, but under surface of underground river (photo 2.2) is growing very well.

Photo 2.2 Hole cave where the entry of water into the ground surface

Absorption / recharge water. For the determine the condition of absorption / recharge water into the soil can be seen from the springs that be found in the concerned of watershed, with the decrease spring discharge which there are significant decreasing the number of water absorption into the ground, and this means that many more flows a surface water. In general the process of water flow in the study area as the shown in the figure 2.3.

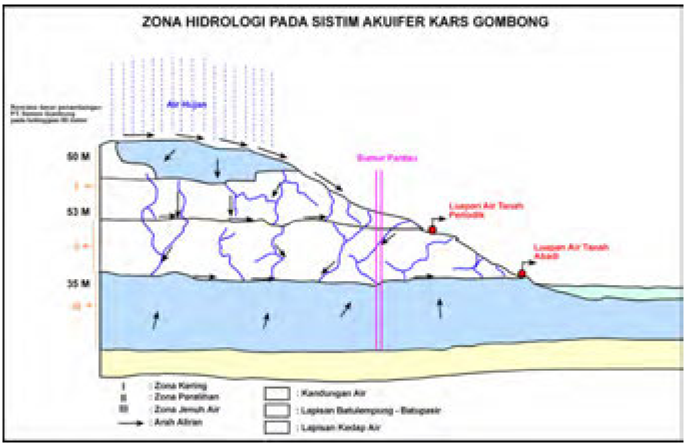

Fig 2.3. Process the flow of water under the surface in the study areas
(source: PT. Cement Gombong, 1996)

Change of Land Use. The changes of land use that is in the watershed areas will be very affect the hydrological conditions, absorption / recharge water and rate erosion and sedimentation. These factors of the above would be interrelated from each others so that in the management of this area should be done in an integrated and the involves variety of aspects.

Zone of karst groundwater in the research area

Karst region-specific character of the disappearance of of the river water absorbed into the rock surface, so that of the river flows is not well developed. For the areas Karangbolong the middle is a region is almost of all the rain which falls surface of the ground will absorbed bottom hrough a fractured areas, a small river or the cave where entry of water. Based on the morphology in the region are often found cup-shaped valley that large (Dolina) and do not have a flows for drain the rain water except for bottom surface of the earth.Based on the morphological features, geology Karangbolong Mountains can be divided become 3 (three) zone of that is groundwater: groundwater zone of lowlands, hilly zone of groundwater, and karst groundwater zones. In this case, karst groundwater zone of that have a large enough distribution in the border areas will be discussed in more detail.

Lowland Groundwater Zones. Groundwater zones is found on the plains in beside west of and eastern Karangbolong Region, this zones is composed of clays, sands, pebbles and gravel which nature separated. Based on field observations of this zones adjacent to west of the hills extends Karangbolong far as the border to the Oyo River Cilacap District, includes the Village A.yah, Candirenggo, Bulurejo, Demangsari, redisari, and Rowolele village. As well as of this zone includes the area east of the hills Karangbolong like a Puring Village, Rangkah, Buayan Village, and Village Kuwarasan. Potential of ground water in the of this zone in the form shallow of groundwater with a of high ground water level is very varies depending on season and based on the population information depth of their wells various between 5 to 8 meters (gb.3.1) under the local ground level.

Photo 3.1. Ground water zones the lowlands

Groundwater Zone Hills. Groundwater zones are found in hilly areas (undulating and the steep). The lithology composer is the volcanic breccia, lava, lahars, and sand. The rocks of Tertiary age which is generally have been weathering, as viewed at backgrounds Fig. 3.2. In the hilly zone of groundwater it much springs flow arise a limited. Meanwhile, from the observations at people dug wells, ground water level indicates the depth of shallow groundwater level varies depending on at the condition and lithology of rock composer. In several the steep peaks are found limestones, and can be keep water time when rainy season and dry season flows gradually. Volcanic Breccia rock weathering very potential as an agricultural area, while the limestones has the potential to save the water, which boundary the region second types of rocks such develop in settlement and agricultural areas

Fig. 3.2. Morphological appearance of Groundwater Zone Hills

Karst Ground Water Zone. Karst groundwater zone occupies the northern part Karangbolong Mountains consist of coral limestone, coral, and clastic limestone karst morphology and shape. This zone has distinct characteristics, namely the process of dissolution by water shown by the cavities' lapies ", and other karst appearance.

Based on field observations, and data from Bappeda, the zone of karst groundwater is often found the appearance of spring with a discharge that varies. The appearance this spring will be discussed in detail in Tataan Groundwater. In the zone of karst groundwater is very rarely found around residential areas except sumberair which spread around the area. Appearance of karst groundwater zone as shown in Fig. 3.3

In addition to springs, cave water and shallow wells, the existence of Dolina in karst areas is very important, Dolina formation is closely linked to the physical properties of limestone rock, which formed the valley between the hills that do not have "outlets" so that the rain water that falls flowing into the surrounding dipebukitan valley, carrying material which is generally the result of weathering of clay, and precipitated based valley, clay has low permeability, so as to cover the surface of limestone which have high permeability. And eventually the water will be collected in a closed basin, the land will slowly seep into the limestone which is underneath.

Fig 3.3. Morphological appearance of plateau karst groundwater zone Karangbolong

Aquifer system

Based on the field observations, the aquifer system in upland areas Karangbolong can be differentiated into two groups: sediment uncontined and badrock unconfined

Sediment uncontined. Sediment uncontined found in lowland areas and the results of weathering and soil basin between hills that are included in the sediment alluvial geology and sediment plains are as follows: Kali Oyo low-lying areas in the west.Lowlands Cicingguling time. Basin between the hills.

1. Lowland Kali Oyo
   This area is a floodplain Kali Oyo, which is composed of the alluvial sediments, with silt-sized material, clay to coarse sand. The deepest groundwater level found in the slopes of hills composed of limestone and marl, To the west of the shallow groundwater table. Upstream of K. Oyo there are the plains that was formed by deposition of alluvial material derived of the reworked materials of volcanic rocks, and limestones that come of the hills on top. This plain stretches in the Village Ayyah, Candirenggo, Bulurejo, Demangsari, redisari, and Rowolele village. The deepest groundwater level be found in the area at the foot of hills and undulating hills north - east. The measurement results population a well during the field work in this area has a depth of 10 m,. This indicate the groundwater level in this region is not depends on topography, but on ability of rock hills to supply water.

2. Lowland K. Cicingguling
   Groundwater conditions in the lowlands K. Cicingguling as to that there in lowland K. Oyo, separated only by height Karangbolong, which was established by alluvial deposits destruction of material derived from volcanic rock materials, and limestones derived from the hills above it. This plain is extends Puring Village, Village Rangkah, Buayan Village, and Village Kuwarasan.

3. Hills Inter Basin
   In the hills inter basin formed of sediment transport the results than around it hills, In some location of limestone and volcanic rock hills to keep water, and to supply water into alluvial deposits inside of valley. Much too are found basin is the contact between limestones with volcanic breccias, so that the water seeped get out from the field boundary.

Badrock Aquifer. Based on lithologic constituent species as has been noted in the discussion of Geology, and is supported by observations during the field data, indicate that the limestone karst mountains in the area Karangbolong a bedrock aquifer lithology primary.

1. Aquifer parameters
   Assessment of the aquifer in Karangbolong Mountains conducted with the pumping test data analysis that have been done by the Public Works Department P2AT, industrial companies which take advantage of groundwater through a bored wells

2. Aquifer deposition surface
   Shallow groundwater aquifer be found in the alluvial deposits which to spread in the lowlands, highlands and inter-basin hills As be found in lowland to the west and east Karangbolong Mountains, with a limited to the spread and not constantly in a vertical or horizontal, on the general, the shallow groundwater flow is less of 5 liters / sec (A. Tabrani E. 1985)

3. Badrock aquifer
   At the Mountains of northern Karangbolong main aquifer is limestone, calcareous sandstone, with a high productivity aquifer and its wide distribution, while in the south of

primarily volcanic breccias with a low to moderate akifernya productivity and widespread distribution (A. Tabrani. E 1985). Even so, considering that the some places are found underground streams and springs (Banyumudal) with a discharge reach more than 10 l / sec, it can be concluded is also in the local aquifer continuity possible the presence of which reach of thousands m2/day.

Groundwater Governance. The position of groundwater level can be determined by measurement of ground water level in dug wells, while the depressed groundwater level is known by measurement through borehole. To have a clear description of ground water level in the some areas of the mountains of Karangbolong was still rather difficult because the data can be collected very limited. This is due to a lack of dug wells and drilled wells are located in this region. However, according to the existing data depicted attempted the limits of groundwater table depth lines which can be used to guide drilling wells.

1. Groundwater Not Depressed

   Based on measurements of ground water level in dug wells conducted during the field work, it is known that in general the position of groundwater level following the general pattern of topography. Groundwater in the plain (alluvial deposits) are generally less than 5-7 m below ground level local and regional groundwater flow was depressed following the hydro-static system that runs from the hills toward the plains. Non-depressed groundwater table is also found on limestone karst aquifer, but the position of ground water level is very diverse. This is due to groundwater flow in the limestone takes place through the cracks and through the pores that exist in the manner and depth of that is different from one place to another. This is which causes some measurements of ground water level in dug wells and drilled wells are formed by limestone difficult or impossible to drawn a line in common such as ground water level in the sedimentary rock that groundwater flow through the spaces between the grains. Non-depressed groundwater table in the limestone in the mountains of Karangbolong ranged from 3 to 40 m under the ground level, with fluctuations in ground water level is very influenced by local rainfall conditions.

2. Depressed groundwater

   Depressed groundwater in areas geologically composed by the rocks which old age and consist of several layers which function as water bearing layers (aquifers) and water-retaining layer functioning (impermeable layers) such as clay and marl and rocks fine grained and so can not pass water. While on the rock which is composed by the limestone, in which there is groundwater be controlled by the cracks a result dissolution and structure (fault and fracture), the holes in the limestone karst region especially as a place to get into the flow of water so that the the flow which can be appears as springs . Processes such as this is what the possibility of on spring Kiskendo, Teken (hamlet Merangi), in the hamlet of Coral Gendeng teba Lor.

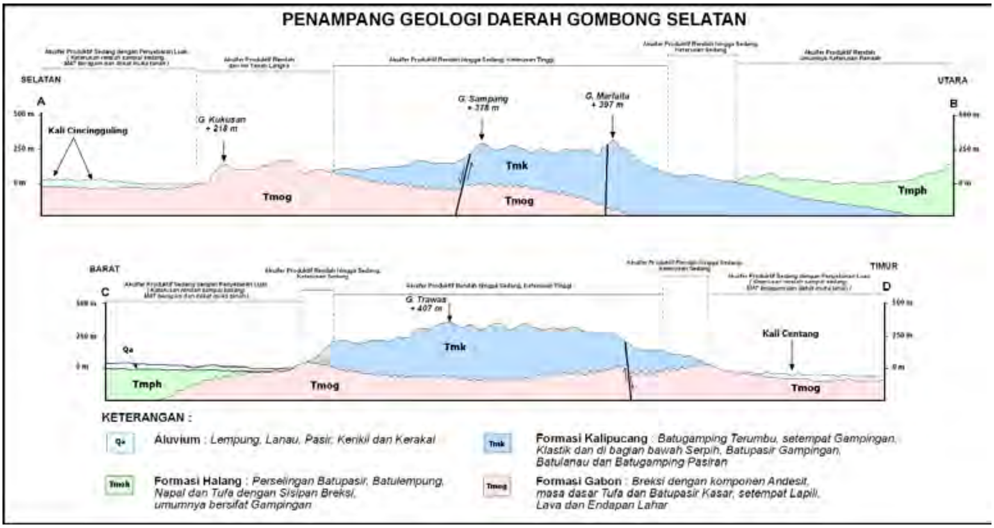

Fig 4.1. The existence of the aquifer in the Formation Kalipucang
(compilation Sukendar A., 1992, with A. Tabrani E, 1985)

Karst is limestone which is characterized by a scarce surface drainage, soil solum thin and only locally, the presence of a closed basin-basin (dolin), and the presence of underground drainage system (Summerfield, 1991). Ford and Wiliam (1996) The main characteristic of karst areas is the presence of hollow-closed basin called dolin. If dolin fused together to form Uvala. In some places, dolin can be filled with water to form lakes dolin. Surface appearance than doline karst areas and are Uvala Polje, Ponor, Pinnacle, tower karst, karst or dome. Combination dome dolin and cause to be unique with panoramic karst hills that lie at large. Another uniqueness of the region is the presence of karst caves and underground rivers. Caves are generally graded by size of less than one meter to hundreds of square meters with a vertical tilt and horizontal. Karst caves almost all of them decorated with ornaments (speleothem) that are very diverse ranging from very small (helectite) to very large (column) with a variety of shapes and colors.

In karst basin, under the surface can be identified by looking for relations between the underground river (swallow holes) and springs. Basin beneath the surface of the basin can be correlated with surface flow (DAS) if the corridor routes solusional on its main subsurface based on the surface of the river entering through Ponor. But, in general, the boundary between surface and subsurface watershed is not the same. Subsurface systems, especially those with a low slope of the groundwater table can have many channels and outlets (springs). Furthermore, because the continued development of prosespelarutan, groundwater, springs and underground rivers paths in karst aquifers can also vary according to time.

Jankowski (2001) says that there are three main components in the system karst hydrology, namely: aquifer systems, surface hydrology, and hydrologic system under surface. In karst, the basin below the surface can be identified by looking for relations between the underground river (swallow holes) and springs. Basin beneath the surface of the basin can be correlated with surface flow (DAS) if the corridor routes solusional on its main subsurface based on the surface of the river entering through ponor.Tapi, in general, the boundary between surface and subsurface watershed is not the same. Subsurface systems, especially those with a low slope of the groundwater table can have many channels and outlets (springs). Furthermore, because the continued development of process dissolution, groundwater, springs and underground rivers paths in karst aquifers can also vary according to time.

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UPPER CATCHMENT OF BRIBIN UNDERGROUND RIVER HYDROGEOCHEMISTRY (GUNUNG SEWU KARST, GUNUNG KIDUL, JAVA, INDONESIA)

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Abstract
This research was conducted within Bribin underground river, the primary river in the Gunung Sewu karst area, Gunung Kidul, Java, Indonesia. The main purpose of this study is to describe hydrogeochemical processes that occur at the upstream of Bribin River. In addition, this study also differentiates hydrogeochemical dominant processes, which come about in rainy season and dry season. Study area boundary is the upper rainfall catchment of Bribin River that is focused on three locations: Pentung River (surface), Luweng Jomblangan, and Gilap Cave. Discharge measurements for one year period are conducted to define discharge hydrograph. Furthermore, baseflow separation analysis is conducted to determine the percentage of base flow (PAD) throughout the year. Water sampling for hydrogeochemical analysis is taken every month to represent dry season and rainy season condition. To describe the hydrogeochemical processes, scatter plot analysis with small sample size is conducted. The result shows that within dry season, dominant hydrogeochemical process is water rock interaction that indicates by: achieving maximum level of Ca^{2+}-HCO_3^- ; strong relationship between discharge increment and PAD reduction; strong relationship between increasing of Ca^{2+}-HCO_3^- and increasing of PAD. In addition, strong relationship between the increase in Ca^{2+}-HCO_3^- and reduction of carbondioxide in water as well as minimum level of carbondioxide gas in water at the peak of dry season, is also present. (abstract terdiri dari 150-200 kata)

Keywords: Bribin, undergroundriver, hydrogeochemistry.

Introduction

Bribin Underground River is firstly published by MacDonalds and Partners (1984). It is located within Gunung Sewu Karst area, which is initially introduced by Danes (1910) and Lehmann (1936). This karst is characterized by the development of conical hills (*kegelkarst*), the positive formation of blunt, and no steep or often termed as sinusoidal dome. *Kegelkarst* by Sweeting (1972) is categorized as part of tropical karst type. Several other geomorfologist strengthen Lehmann opinion i.e. Flathe and Pfeiffer (1965); Balazs (1968, 1971); Verstappen (1969), and Waltham *et al.,* (1983). In fact, Balazs (1968) confirms that the number of hills in this region amounted to more than 40,000 hills with a density of about 30 hills/km^2. Recent publications related to this karst region are conducted by Haryono and Day (2004), Ahmad *et al.,* (2005), and Urushibara-Yoshino and Yoshino (1997).

The largest underground river systems in this karst region is Bribin-Baron system, which reached discharge amounted to 8000 liters/sec (MacDonald and Partners, 1984). This underground river system is the most important river systems in the Gunung Sewu karst (Figure 1). Meanwhile, the Bribin River on the upstream system performs the largest discharge and a focus for the fulfillment of local domestic water. Demographically, the number of people who depend on this water supply system is more than 200,000 people. In addition, Bribin River catchment was firstly defined by Fakultas Kehutanan (1993) bounded on the upstream (north) by a massive old-volcanic mountain, in the west by the ancient Ponjong- Polje (Srijono and Aldilla, 2006), while the southern and eastern boundaries have not undefined yet. This paper reports on result of the first detail-quantitative evaluation of karst aquifer hydrogeochemistry within the upper part of Bribin River, with the primary focus on identifying the relation between hydrochemical parameters to provide understanding of aquifer characteristic and behavior in this area.

Climate and Hydrogeological Setting

Bribin River catchment is administratively located in Gunung Kidul Regency, DIY Province, Indonesia. As it is located on a tropical region, the knowledge of climatic conditions, especially rainfall and temperature impinge on the water input component associated with the karst hydrogeochemistry condition. Not so much research related to climate conditions in the Gunung Sewu. The most recent researches on global climate conditions in Gunung Sewu are conducted by Verstappen (1997) and Urushibara-Yoshino and Yoshino (1997). Previous studies related to climate in the Quaternary period in the vicinity of the study (Java Island) performed by Urushibara-Yoshino (1995) and Verstappen (1975, 1994), Dam (1994), Morley (1982), and Budel (1975). Meanwhile, information about climate conditions in Bribin River catchment are found in publications by Adji and Nurjani (1999), Suryanta (2001), MacDonalds and Partners (1984), BMG (2000), Sutikno and Tanudirjo (2006), and Fakultas Kehutanan (1993).

These studies show the monthly average temperature in Bribin River catchment area ranged from 22.12 ^{o}C to 26.97 ^{o}C. Meanwhile, the annual rainfall in Gunung Sewu ranges from 2000 to 2500 mm/year from data obtained at 12 rain gauge station in the period of 1947-2000. The research brief that take place by Adji (2010) indicates that the air humidity in Bribin River catchment ranges between 60-90% with temperatures between 24-28 ^{o}C.

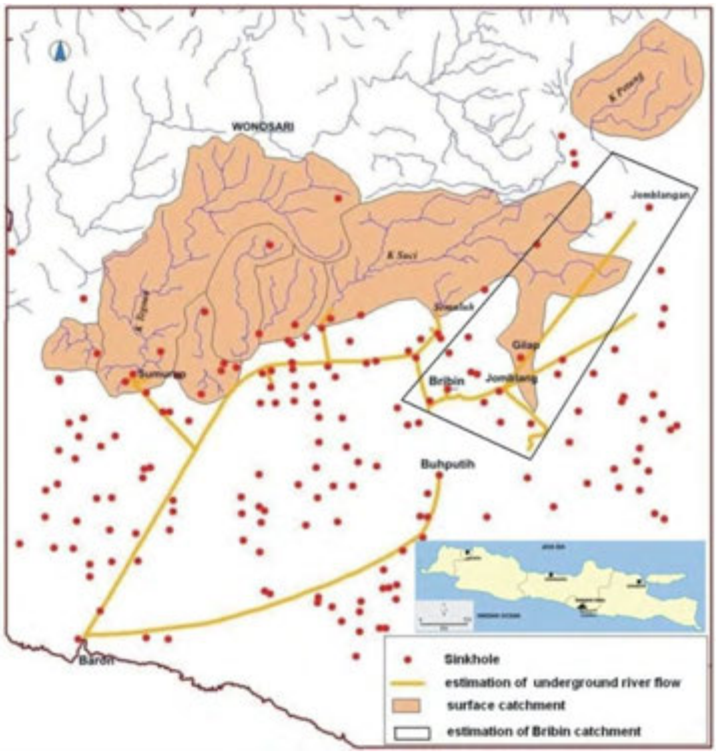

Figure 1. Bribin River Catchment and Bribin-Baron System (MacDonalds and Partners, 1984)

Geologically, the study area is dominated by Miocene limestone of the Wonosari Formation, which consists of massive coral reef limestone in the south and bedded chalky limestone in the north (Balazs, 1968; Bemmelen, 1970; Waltham *et al,*. 1983; Surono *et al.,* 1992). The results of 1:50,000 scale aerial photo interpretation and image of 1:1,000,000 scale ERS conducted by Kusumayudha (2005), shows that the moment structure consisting of thick cracks, faults, and fractures in Gunungsewu have a general direction moves the structure fracture or fault northwest-southeast and northeast-southwest. The existence of regional structure is then divided the area into blocks bounded by faults that also set the hydrogeological system since the creation of low-level and high-level configuration (Kusumayudha, 2005). The catchment of Bribin River included in the Wonosari-Baron Subsystems of hydrogeology that have bedrock configuration (volcanic rock) as graben that has direction around the northeast-southwest (Figure 2).

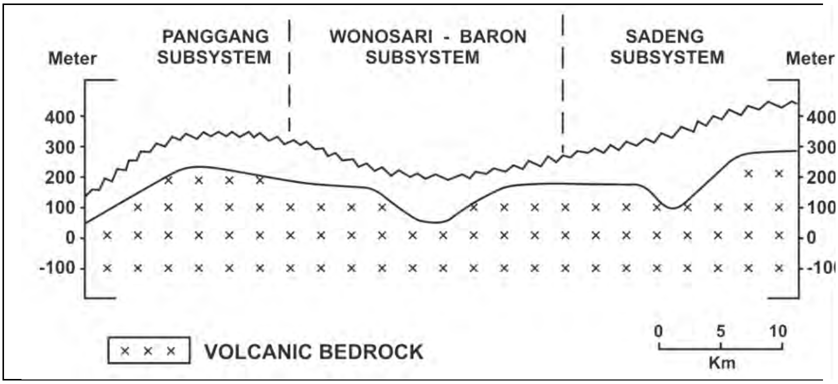

Figure 2. Hydrogeological Conceptual Model of West-Eastern region Gunungsewu (Kusumayudha, 2005)

Bribin River describes by the MacDonalds and Partners (1984) starts from a surface (Pentung River) that disappears to some sinkholes in Sawahombo area. This river then emerges as a cenote in Luweng Jomblangan, which then emerges again in Gilap Cave, Luweng Jomblang Banyu, Luweng Jurangjero, and last appeared in Bribin Cave before comes out as a large resurgence at Baron Beach. In the segment between Luweng Jurang Jero and Bribin Cave, it leaks out to Ngreneng Cave, which also flows into the Beach Baron afterwards (Figure 3). In this study, the Pentung River, Luweng Jomblangan, and Gilap Cave regarded as the upper area of Bribin River catchment. According to Adji (2010), Pentung River is intermittent due to the lack of baseflow supply from the old-volcanic aquifer. As a result, large runoff occurs after rain events and the river discharge is very low during the dry season. This river then disappears into the underground river which later appeared in Luweng Jomblangan. Luweng Jomblangan is a cenote which is located only about 500 meters from the sinkhole loss of the Pentung River that consequence to similar discharge fluctuations between these two points. In addition, Luweng Jomblangan minimum discharge is about 80 liters/sec (Fakultas Kehutanan, 1993). Second occurrence of the River Bribin after Luweng Jomblangan is Gilap Cave point. The entrance of this cave is in a collapse doline with 200 meters of diameter. Gilap Cave is always watery throughout the year (perennial), with minimum discharge is about 6 liters/sec, while the maximum discharge of approximately 350 liters/sec.

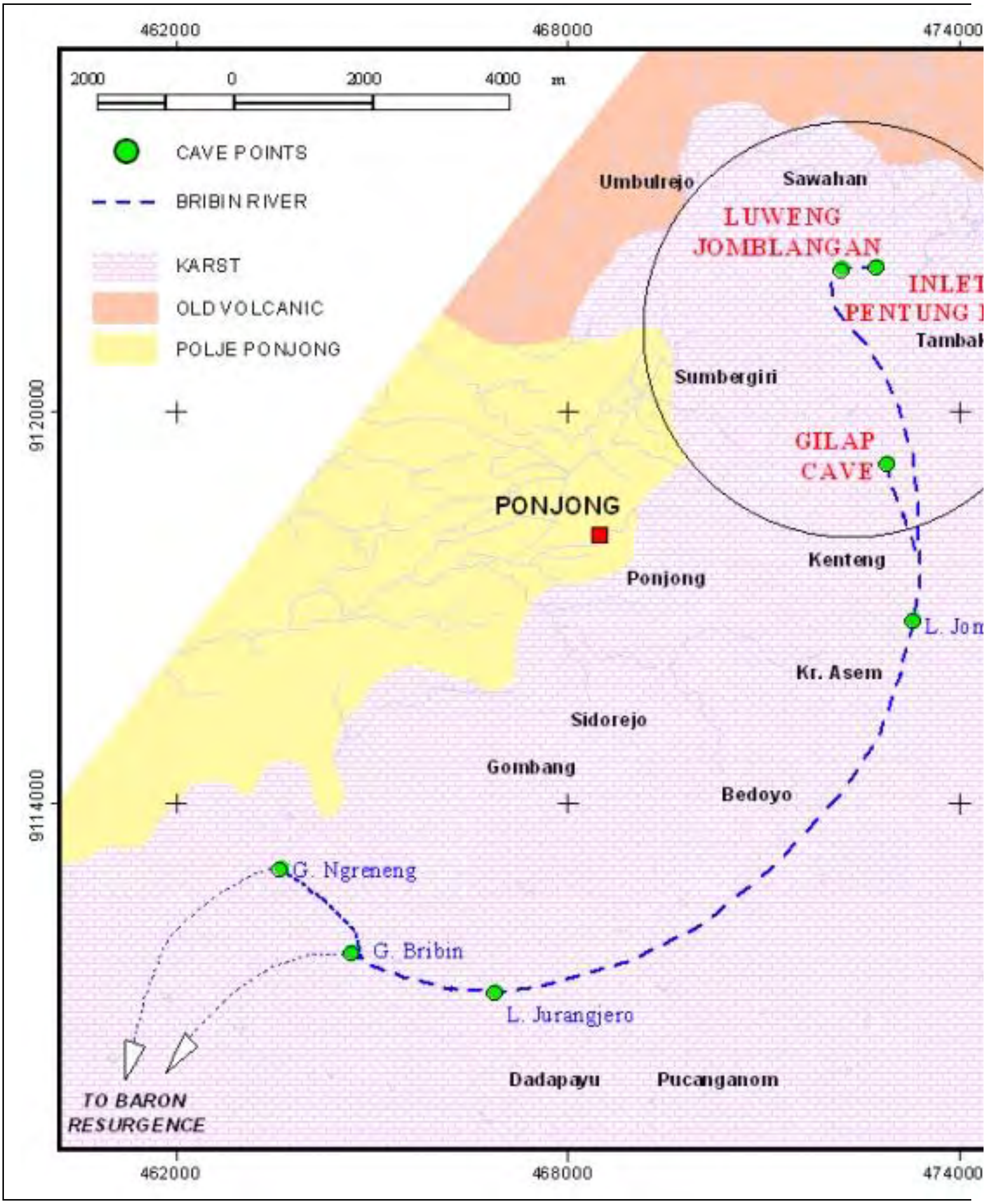

Figure 3. Bribin River System

Methods

The boundary of study area is the estimated surface area of Bribin River rainfall catchment, and the research focuses on the three locations within upper area of catchment, which are Pentung River, Luweng Jomblangan, and Gilap Cave. Furthermore, recording of water level fluctuations and discharge measurement is carried out to obtain the discharge hydrograph throughout the year. Separation of base flow is conducted using the *automated base flow separation by digital filtering method* (Eckhardt, 2005), on the basis of a recession constant value in the hydrograph, which is then correlated to the value of Base Flow Indices (BFI) within karst aquifer, the formula used are:

$$q_{b(i)} = \frac{(1 - BFI_{\max})aq_{b(i-1)} + (1-a)BFI_{\max} q_i}{1 - aBFI_{\max}}$$

where $q_{b(i)}$ is the baseflow at time *i,* $q_{b(i-1}$ is the baseflow at the previous time *i-1*, q_i is the total flow at time *i*, *a* is the recession constant and BFI_{max} is the maximum baseflow that can be measured or performed. To find the constant of recession used the formula:

$$Q_t = Q_0 e^{-\alpha t}$$

where Q_t is the flow rate at time *t*, Q_0 is the initial discharge in recession segment, and α *is a constan.* Furthermore, $e^{-\alpha}$ may be replaced by *k*, which is known as a recession constant or depletion factor. This constant is often used as an indicator of the continuity of baseflow (Nathan and McMahon, 1990). Then, the value of *k* compared with the classification of karst underground river recession by Worthington (1991, in Giliesson, 1996). In this research, due to the difficulties of field conditions, water level data logger could not be installed at Luweng Jomblangan point, so that the baseflow proportion is not calculated.

Water sampling is conducted one time/month during a year to cover two seasons (rainy and dry seasons). Chemical analysis of samples in the laboratory include the cations Ca^{2+}, Mg^{2+}, Na^+, K^+ and anions Cl^-, SO_4^{2-}, dan HCO_3^-. . Volumetric method is used for the element of Ca^{2+}, Mg^{2+}, CO_3^- and SO_4^{2-}; spectrophotometric method for HCO_3^-, and flamefotometri for Na^+ and K^+. Furthermore, analysis of Saturation Indices (SI) is conducted to determine the nature of water to the level of carbonate rock dissolution with respect to $CaCO_3$ mineral, assisted with software Netpath (Plummer, *et al*, 1991) with the formula as follows.

$$SI\ CaCO_3 = \log_{10} \frac{[CO_3^-]\ [Ca^{2+}]}{Ksp\ CaCO_3}$$

Where $[CO_3^-]$ is the carbonate ion activity, $[Ca^{2+}]$ is the calcium ion activity; Ksp is the solubility product of $CaCO_3 = 10^{-8,48}$. Another analysis is the calculation of PCO_2 (partial pressure of carbondioxide), which is assumed to have reached equilibrium of water samples (Stumn and Morgan, 1981; Drever, 1988; White, 1988) in all samples, assisted with software Wateq-4F (Ball and Nordstrom , 1991), is determined.

$$P_{CO2} = [HCO_3^-]\ [H^+]\ /\ K_1\ K_{CO2}$$

Where PCO_2 is partial pressure of carbondioxide gas in water; $[HCO_3^-]$ is the activity of bicarbonate ions, $[H^+]$ is hydrogen ion activity; K_1 is the equilibrium constant reaction solvent at 25°C, and K_{CO2} is the equilibrium constant of CO_2 in water at 25°C. To describe the hydrogeochemical processes, scatter plot analysis with small sample size (non-discrete parameters) is conducted, including: (i) discharge-major ion concentration, (ii) specific conductivity-calcium and bicarbonate, (iii) sodium-chloride, (iv) discharge-baseflow, (v) baseflow-log PCO2, and (vi) baseflow-calcium and bicarbonate.

Result and Discussion

Pentung River as a surface river performs the characteristic of dissolved elements temporal variation be different compared to an underground river, which generally characterized by obvious fluctuations between dry and rainy season. However, in Pentung River, fluctuations encountered are not too strict in the dry season and during the rainy season. The same condition also found in Luweng Jomblangan due to its location closes to Pentung River. Here, conductivity and dissolved elements fluctuations similar to those found in the Pentung River. The conductivity value during rainy season is very low (200 μmhos/cm), even if during dry season it reaches peak value of almost 500 μmhos/ cm, similar to those found in underground river. Just as that found in the Bribin Cave (Adji, 2010), when the rain towards the end of the dry season, Luweng Jomblangan and Gilap Cave shows declining of discharge leading to the dominance of baseflow (diffuse flow), which is characterized by increasing of dissolved elements constituent in water due to diffuse flow recharge as saturated water infiltration from karst aquifers. When entering a period of rain, the dominance of the baseflow is reduced and fluctuates depending on the period of flood events to occur. Similar pattern found in the Bribin Cave (Adji, 2010), which is also shown on the temporal variation of dissolved calcium and bicarbonate that tend to increase slowly in the dry season and then dropped dramatically at the peak of the rainy season and then increased again at the end of the rainy season 2007.

Table 1. One-year hydrogeochemistry of three major points within upper Bribin River

Pentung River (river as surface input)														
time		conductivity (μmhos/cm)	pH	T (°C)	Eh (volt)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	Q (l/sec)	PAD (%)
date	hour													
21/3/06	10:00	187	7.57	26.20	-0.060	45.30	3.30	4.10	1.70	143.01	9.20	6.50	887.44	10.1
28/4/06	14:00	288	7.84	25.00	-0.051	50.30	11.90	7.10	2.80	169.01	16.00	13.70	168.78	82.9
22/5/06	15:50	268	7.92	26.3	-0.055	52.10	14.00	3.80	1.50	207.01	7.40	11.90	87.36	100.0
21/6/06	10:15	324	8.05	24.8	-0.064	50.30	10.70	10.80	2.20	222.01	5.50	13.80	62.22	100.0
20/7/06	10:30	330	8.07	23.8	-0.06	52.30	12.70	11.50	2.90	233.02	6.50	14.90	23.25	100.0
23/8/06	10:00	358	8.08	24.1	-0.062	59.50	13.40	12.10	1.50	236.02	9.20	10.40	4.06	100.0
21/9/06	10:00	505	8.42	26	-0.095	65.60	11.40	8.40	1.50	237.02	9.30	12.40	2.25	100.0
16/11/06	12:45	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	0.0	0.0
21/12/06	10:30	239	7.96	26.3	-0.05	32.00	6.90	3.00	0.80	125.01	7.90	8.40	3.32	100.0
1/2/07	14:30	300	8.21	30.8	-0.07	49.10	15.40	4.60	1.10	231.02	7.60	8.80	5.50	100.0
22/3/07	10:30	246	7.75	25.2	-0.052	42.70	12.50	5.00	1.40	155.01	22.50	3.50	147.00	40.8
20/4/07	10:00	146	6.95	25.7	-0.018	45.00	11.60	3.60	1.50	156.01	20.60	7.20	513.70	17.5

Jomblangan Cave (underground river as a cenote)														
21/3/06	14:40	215	7.10	26.6	-0.021	44.66	4.50	3.20	1.70	158.01	9.20	4.00		
28/4/06	13:30	312	7.09	26.6	-0.014	59.30	3.10	10.80	4.10	197.01	7.40	6.40		
22/5/06	16:00	478	7.09	26.3	-0.006	62.10	9.60	3.80	1.50	247.02	7.40	11.90		
21/6/06	10:35	484	7.1	26.6	-0.005	71.90	10.70	4.60	1.20	286.02	5.50	10.30		
20/7/06	11:00	500	7.11	26.3	-0.011	73.50	11.80	4.70	1.40	291.02	7.40	11.40		
23/8/06	10:30	504	7.13	26.2	-0.013	76.90	11.60	4.60	1.90	304.02	7.40	11.20	No measurement	
21/9/06	10:30	506	7.37	26.4	-0.047	139.01	1.40	4.60	1.30	395.03	7.40	15.40		
16/11/06	11:00	508	7.38	26.4	-0.048	140.01	3.40	4.60	1.30	397.03	7.40	15.40		
21/12/06	11:00	408	6.63	25.8	0.018	110.01	5.80	4.30	1.20	356.02	9.50	10.40		
1/2/07	15:00	463	6.99	27.7	-0.009	98.20	15.40	3.90	1.30	334.02	3.80	10.50		
22/3/07	11:00	292	6.62	25.9	0.001	74.40	11.30	4.60	1.20	232.02	19.20	5.40		
20/4/07	11:00	238	6.55	25.4	0.002	42.80	11.70	2.90	1.70	154.01	10.80	7.20		

GilapCave (underground river)														
23/3/06	16:30	471	7.06	26.4	-0.006	50.56	3.50	2.50	1.40	178.0	7.80	7.00	343.8	73.5
28/4/06	18:30	493	7.18	26.4	-0.011	52.68	6.50	13.60	5.20	204.0	11.20	7.80	294.1	78.8
23/5/06	12:50	501	7.23	26.2	-0.016	54.11	16.20	2.90	1.20	217.0	5.50	11.80	74.4	80.5
21/6/06	12:15	502	7.42	26.0	-0.027	55.50	13.00	3.00	0.90	223.7	7.40	13.50	57.3	80.8
20/7/06	12:40	503	7.48	26.0	-0.062	57.01	7.60	3.10	1.30	228.2	7.40	11.20	34.7	82.1
23/8/06	13:30	504	8.16	25.9	-0.064	58.11	8.90	2.80	1.00	232.0	5.50	11.80	15.7	82.5
21/9/06	13:30	505	8.42	26.0	-0.095	63.65	4.80	3.60	1.10	242.2	9.30	11.80	8.5	82.7
16/11/06	12:45	505	8.42	26.2	-0.097	68.08	6.80	3.60	1.30	265.0	3.70	10.40	6.6	83.3
21/12/06	13:00	489	7.12	25.9	-0.008	39.20	5.00	3.20	1.10	8.50	8.50	145	5.43	84.22
22/1/07	18:00	345	6.84	25.8	-0.015	33.80	4.00	2.80	1.00	7.40	6.70	122	50.42	47.98
26/2/07	21:30	273	6.52	25.5	-0.016	31.80	3.10	1.70	1.00	7.20	5.80	110	180.77	62.65
22/3/07	13:00	485	7.01	26.1	-0.019	36.90	6.10	2.10	1.00	8.10	2.80	131	74.07	81.75
22/4/07	14:30	482	6.85	26.0	-0.015	42.70	6.30	2.20	1.80	8.60	6.30	154	121.0	88.50

* conductivity are expressed in µmhos/cm; major elements in ppm; Q= discharge in lt/sec; PAD= (baseflow/total discharge) in %

Scatter plot of conductivity- calcium and bicarbonate

Scatter plot of conductivity, calcium and bicarbonate in Pentung River, Luweng Jomblangan, and Gilap Cave are shown in Figure 3, 4, and 5

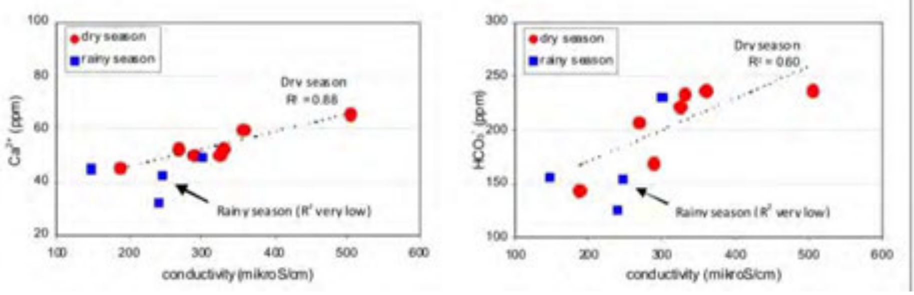

Figure 4. Linear relationships between specific conductivity versus calcium (left) and specific conductivity versus bicarbonate (right), along the year for Pentung River

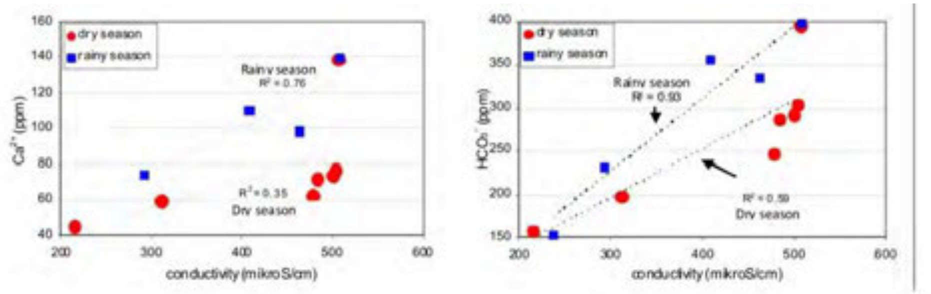

Figure 5. Linear relationships between specific conductivity versus calcium (left) and specific conductivity versus bicarbonate (right), along the year for Luweng Jomblangan

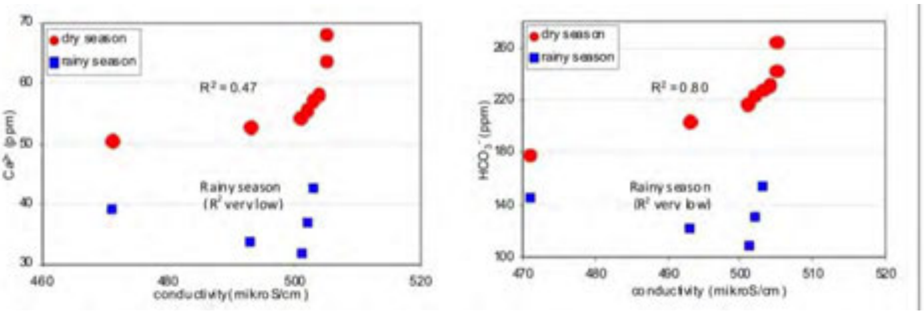

Figure 6. Linear relationships between specific conductivity versus calcium (left) and specific conductivity versus bicarbonate (right), along the year for Gilap Cave

According to Figure 3, 4, and 5, it seems that the relationship between specific conductivity and calcium or bicarbonate generally has a positive relationship in the dry season, with correlation value (R^2) by 70%, even more. Conversely, R^2 value in rainy season is small or negative. This indicates that the positive relationship related to water-rock interaction process to occur predominantly during the dry season, i.e. when there is dominance of diffuse flow than during the rainy season that is affected by the flow of the conduit system, resulting in a mixing process and also it may be by the process of dilution by precipitation. From the pictures it is also seen that the values of dissolved calcium and bicarbonate as well as specific conductivity during the dry season is much greater than that occur during the rainy season. Different characteristic found in Luweng Jomblangan, that the value of dry season R^2 value is very low. This occurs because the flow component in Luweng Jomblangan is a mixture of surface streams and karst aquifers that have different carbonate mineral saturation.

Scatter plot sodium-chloride

Scatter plot of sodium-chloride in Pentung River, Luweng Jomblangan, and Gilap Cave are shown in Figure 6. Analysis of scatter plots between Na^+ and Cl^- indicate that there is a clear separation of plotting position, i.e. samples of rainy season and early dry season has a relative position close to the 1:1 line, while the samples from September and November 2006 (drought peak) shows the position which is utmost from the line ratio of 1:1. It shows strong water-rock interaction process due to the weakening of the dominance of rain and is replaced by the diffuse flow component from karst aquifer.

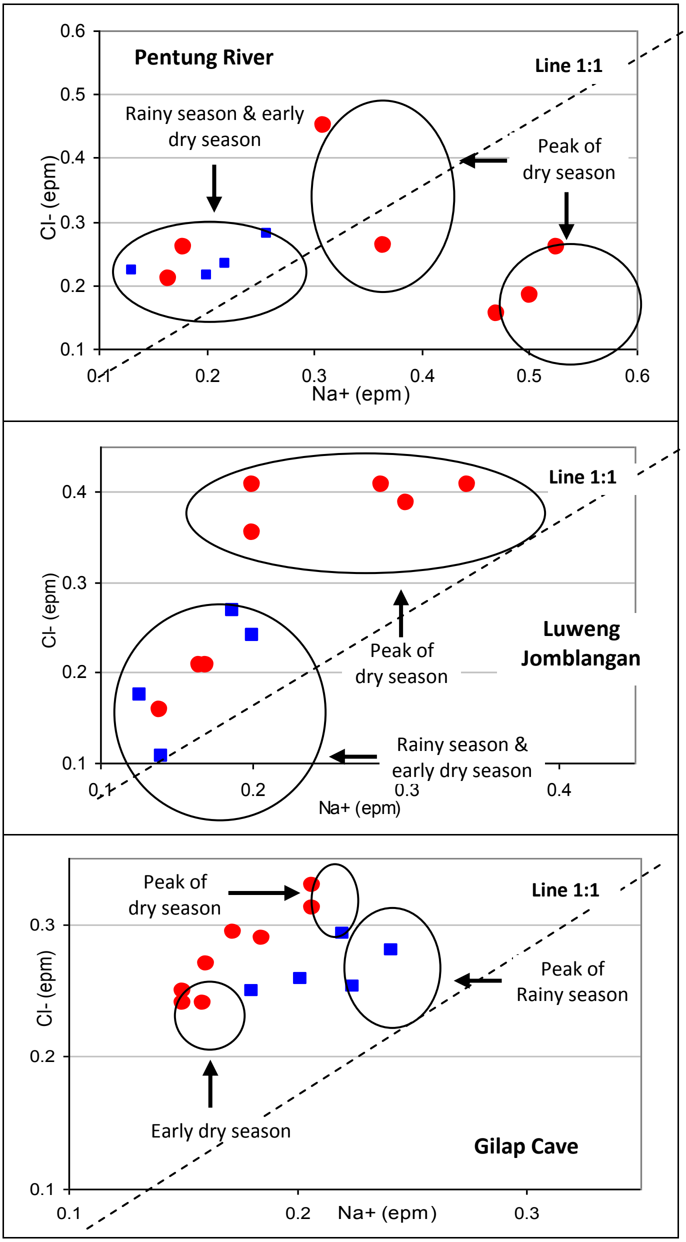

Figure 7. Scatter plot of sodium-chloride along the year for Pentung River (above), Luweng Jomblangan (middle), and Gilap Cave

Scatter plot PAD-discharge

Scatter plot of PAD-discharge in Pentung River and Gilap Cave are presented in Figure 7. Meanwhile, discharge measurement is not conducted in Luweng Jomblangan in order that PAD is not calculated. In general, decreasing in discharge related to increasing of diffuse flow percentage (PAD). This negative correlation also occurs in rainy season, although the correlation is relatively somewhat smaller. However, in Gilap Cave, there are two rainy season samples put in close proximity to the discharge-PAD linear line of dry season. These two samples are taken during the rainy season rather than during flood events (beginning and end of rainy season), thus indicating the existence of water-rock interaction process. Next, Pentung River performs a strong relationship between decreasing of discharge and PAD increasing (negative relationship), especially during the dry season (R^2=0.99). Furthermore, because of the influence of surface runoff, which is controlled by rainfall, the correlation between discharge and the PAD during the rainy season decreases slightly (R^2 = 0.84).

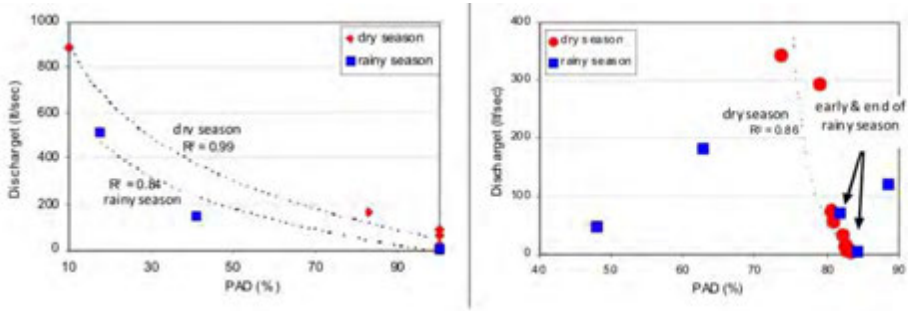

Figure 8. Scatter plot of Discharge-PAD (baseflow percentage) in Pentung River (left) and Gilap Cave (right) along the year

Scatter plot calcium and bicarbonate –PAD

Scatter plot of calcium and bicarbonate -PAD in Pentung River and Gilap Cave are shown in Figure 8 and 9.

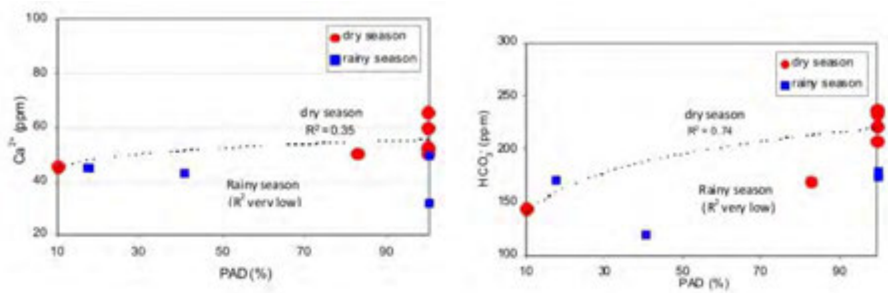

Figure 9. Scatter plot of PAD-Calcium (left) and PAD-Bicarbonate (right) in Pentung River along the year

The relationship of calcium and bicarbonate-PAD within rainy season in Pentung Rivers shows positive relationship with very small correlation or negative (Figure 8). During the dry season it turns into positive relationship, but the correlation is not as big as that found Cave Gilap. This is caused by the differences in flow composition and fluctuation that recharge into river. Also, it is caused by conduit flow characteristic, which performs time lag longer than the overland flow occurs to recharge Pentung River from its catchment area. According to Figure 9, it seems that the PAD in Gilap Cave during the rainy season varies between 47-88%, whereas during the dry season the range is between 73-83%. This suggests that conduit channels exist in the system to contribute conduit flow during rainy periods. This positive correlation between PAD-calcium and bicarbonate during rainy and dry season indicates that PAD in Gilap Cave controls to calcium and bicarbonate constituent.

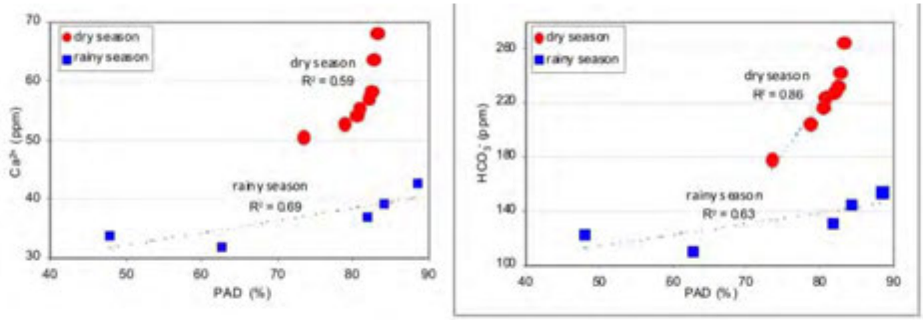

Figure 10. Scatter plot of PAD-Calcium (left) and PAD-Bicarbonate (right) in Gilap Cave along the year***Scatter plot PAD-log PCO_2***

Scatter plot of PAD-log PCO_2 in Pentung River and Gilap Cave are shown in Figure 10.

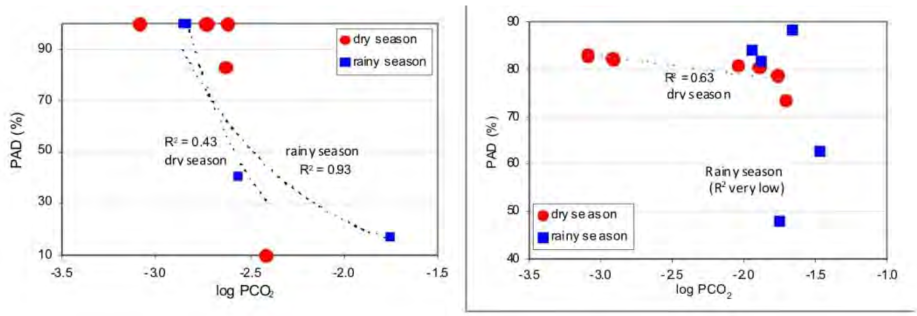

Figure 11. Scatter plot of PAD-log PCO_2 in Pentung River (left) and (right) in Gilap Cave along the year

Correlation of log PCO_2 -PAD in the Pentung River have R^2 values of about 0.9, because the system of air-water-interface in Pentung River is open, so every time there is transfer of carbondioxide gas into the water. In Pentung River also no carbon dioxide gas that is used to dissolve the limestone as found in Gilap Cave aquifer. In Gilap Cave, value of log PCO_2

variations shows a declining trend and reaches its lowest level during the peak of dry season (September-November), which then rises when the rainy season comes, and fluctuates depending on the variation of flooding that occurred. When, it is correlated to PAD, it performs negative relationship, meaning that the value of log PCO_2 decreases while the percentage of baseflow (PAD) in Cave Gilap increases (Figure 10). During the dry season, there is a more significant relationship between the PCO_2 and PAD in Gilap Cave compare to that within rainy season (R^2 value of 0.63 compared with 0.15 in the rainy season). This indicates that the process of water-rock interaction occurs predominantly during the dry season. Several other processes that occur during the rainy season are the dilution by precipitation as indicated by the falling value of PAD and the supply of carbondioxide gas through conduit system.

Scatter plot of calcium and bicarbonate-log PCO_2

Scatter plot of calcium and bicarbonate-log PCO_2 in Pentung River and Gilap Cave are shown in Figure 11 and 12.

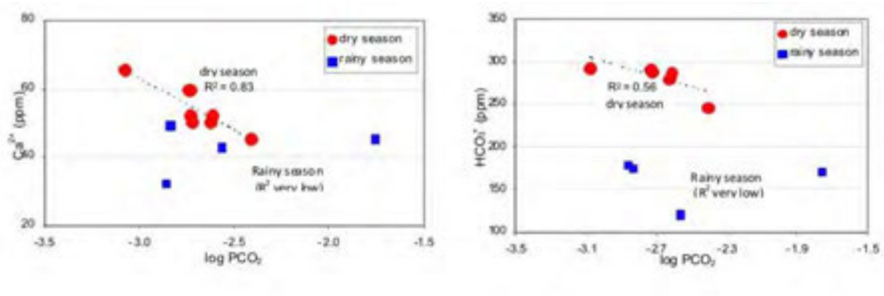

Figure 12. Scatter plot of calcium (left) and bicarbonate (right)-log PCO_2 in Pentung River along the year

Negative correlation is also found in the relationship between calcium and bicarbonate-log PCO_2. R^2 value low during the rainy season shows the dominance of fast-changing flow conduit, when floods supplies water from karst surface to recharge underground streams and reduce PAD (baseflow). Conversely, the value of R^2 is quite high during the dry season, indicates that the effect of carbondioxide gas is more likely to occur during the rainy season and decreases the influence of water-rock interaction process. This is supported by the facts in Ngreneng Cave as described by Adji (2010). In Ngreneng Cave, the immense of direct runoff supplies Ngreneng Cave during the rainy season through its conduit system decreases the relationship between calcium and bicarbonate-log PCO_2.

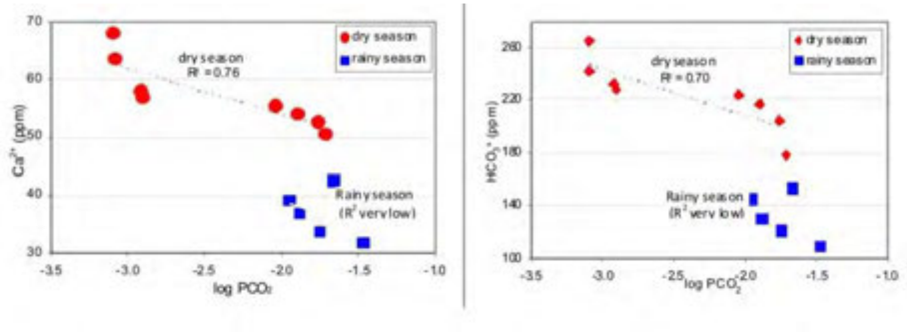

Figure 13. Scatter plot of calcium (left) and bicarbonate (right)-log PCO_2 in Gilap Cave along the year

Conclusion

From the scatter plot discussion of relationship between hydrogeochemical parameters within the upper part of Bribin River catchment area, spatially and temporally, it is concluded that:

(1) in dry season, there is a strong relationship between the percentage of baseflow (PAD) with the calcium and bicarbonate dissolved in water. It can be perceived from the high correlation between DHL and calcium-bicarbonate which specified strong water-rock interaction process. Another thing that indicates strong relationship between hydrogeochemical characteristics and baseflow condition is the high correlation between PAD and calcium-bicarbonate. In addition, the level of correlations value during the dry season also influenced by the sampling point‟s position along Bribin River.

(2) in rainy season, hydrogeochemical process shifted from water-rock interaction process to dilution by precipitation process due to the rain water supply through conduit system channel. This fact indicated by the declining value of correlation between the PAD and calcium-bicarbonate and DHL- calcium-bicarbonate. Another factor to affect underground river hydrochemistry is the difference in spatial position and flow characteristics along Bribin River. Then, the summary of hydrogeochemical processes within rainy and dry season of Bribin River upper catchment is shown in Table 2.

Table 2. Summary of hydrogeochemistry of three major points in upper catchment of Bribin River

Season	Hydrogeochemical processes	Hydrogeochemistry characteristics parameters
Dry	water rock interaction	▪ Ca^{2+} dan HCO_3^- constituent increase to reach its peak during dry season ▪ strong relationship between discharge increment and PAD reduction ▪ strong relationship between increasing of Ca^{2+} and HCO_3^- and increasing of PAD ▪ minimum level of carbondioxide gas in water at the peak of

		dry season ▪ the chemical composition of the dry season peak dissimilar to early dry season ▪ strong relationship between the increase in Ca^{2+} and HCO_3^- and reduction of carbondioxide in water
Rainy	▪ dilution by precipitation ▪ water-rock interaction ▪ difusion of carbondioxide gas	▪ the dominance of conduit flow during floods, and domination of diffuse flow during non-flood and recession period ▪ the declining in Ca^{2+} dan HCO_3^- when discharge increase, and increasing Ca^{2+} dan HCO_3^- when discharge decrease ▪ rising of carbondioxide gas when discharge increase ▪ low correlation of spesific conductivity vs Ca^{2+} and HCO_3^- ▪ low correlation of PAD vs Ca^{2+} dan HCO_3^- when discharge increase ▪ high correlation of PAD vs Ca^{2+} dan HCO_3^- when discharge decrease ▪ a strong correlation between declining in PAD by increasing of CO_2 in the water during the rainy season

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THE EFFECTS OF LAND-USE TYPES ON NITRATE CONCENTRATION AND $\delta^{15}N$ OF GROUNDWATER IN NANDONG UNDERGROUND RIVER SYSTEM, CHINA

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Abstract

To examine the effect of different land-use activities on nitrate contamination, 36 groundwater samples were collected from springs in rainy and dry season of 2008 in the Nandong Underground River System, located in Southeast Yunnan Province, China, with different land-use and analyzed for the concentration and N isotopic ratios (δ15N) of nitrate. The characteristics of nitrate contamination clearly differed with land-use types. The significant spatial disparities and discrepant seasonal variations for the nitrate concentrations and δ15N values of groundwater were observed depending on the land-use types in the NURS. The nitrate concentrations of groundwater showed a systematic control on land-use characteristics and tended to increase in the following order in both seasons: grass, forested, cultivated and construction land. The δ15N-NO3 of groundwater from different land-use types in the NURS showed a wide range from -3.7605 to 23.3335‰ with a mean value of 5.6529‰ in summer, and from 1.7508 to 24.1457‰ with a mean value of 7.3717‰ in winter, respectively. The consistently higher δ15N-NO3 of groundwater in both seasons was observed in the residential area, while δ15N-NO3 of groundwater in the other areas showed lower and wider ranges. The combination of concentration and isotopic composition of nitrate can provide the evidence for the identification of a nitrate source. Crossplots of δ15N values versus nitrate concentration clearly showed the impact of land-use activities on nitrate contamination of groundwater, of which the δ15N values > 9‰ regardless of nitrate concentration in groundwater suggested domestic waste water, sewage or manure are the predominant sources of nitrate, the nitrate concentrations <5 mg/l with δ15N values of 2-5‰ in groundwater indicated nitrate derived from soil resources, and the nitrate concentrations >5 mg/l with δ15N values of -4-6‰ in groundwater indicated nitrate mainly derived from fertilizers.

Keywords: Land-use; Groundwater; Nitrate concentrations; δ15N-NO3−; Nandong; China

Introduction

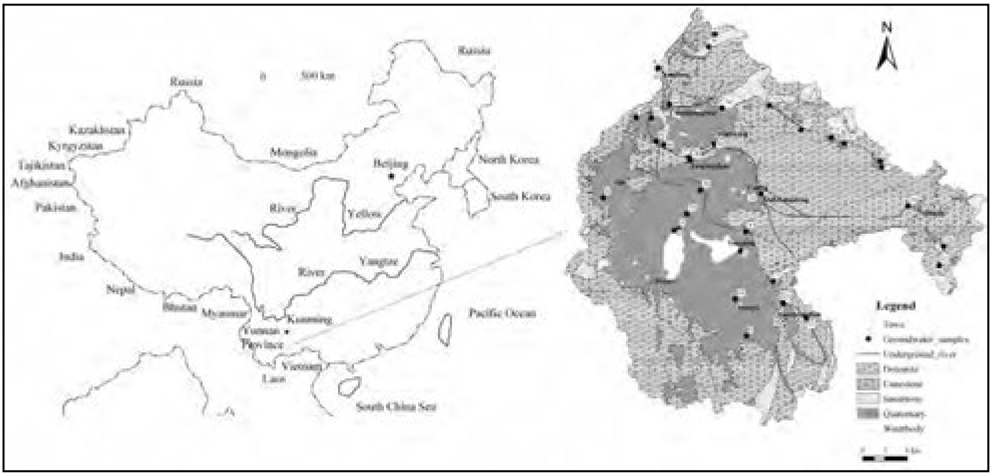
Nitrate (NO_3^--N) is one of more common contaminants of natural environment. It is a wide-spread pollutant of both surface and groundwater‟s worldwide. The over-application of nitrogenous fertilizers and poorly treated or even untreated human sewage and animal waste contribute to an accumulation of nitrate in the hydrological environment. Nitrate is a potential human health hazard. Consequently, nitrate pollution of drinking water has been a matter of great concern throughout the world in recent decades. Karstic aquifers and their associated springs systems or underground river systems are particularly vulnerable to nitrate contamination from various anthropogenic activities because of their unique hydrogeological characteristics. Over the past two decades, the increasing environmental pollution as deliberate or unintentional consequences of human activities has to a great extent destroyed sensitive karst ecosystems in many parts of China. There are a myriad of potential sources of groundwater containments, including point sources (e.g. storm overflow, industrial effluents and domestic sewage), non-point sources (e.g. atmospheric deposition, agricultural practices and construction works), and liner sources (e.g. sewer system and road). Concentrations of nitrate increase notably as a result of intensive land-use and the employment of N-based fertilizers in agriculture, and untreated human sewage and animal waste in rural regions or even in urbanization in southwest karst areas, China (Jia Y and Yuan D, 2004; Zhang and Yuan, 2004; Liu *et al.,* 2006; Jiang *et al.,* 2008; Jiang *et al.,* 2009; Jiang and Yan, 2010). Karst groundwater surveys showed that nitrate concentration exceeds the national drinking water standard at numerous locations, although the impact of human activities on karst groundwater quality is gaining increasing attention in China (Yuan, 2003; Jia Y and Yuan D, 2004; Zhang and Yuan, 2004; Liu *et al.,* 2006; Jiang *et al.,* 2008; Jiang *et al.,* 2009; Jiang and Yan, 2010). To prevent the contamination, it is crucial to discern the major sources of nitrate contamination.

The stable N isotope of nitrate has been successfully used to trace the sources of nitrate in aquifer systems (Heaton, 1986; Katz *et al.,* 2004; Li *et al.,* 2007; Choi *et al.,* 2007; Singleton *et al., 2007*), because nitrate may have distinct isotopic signatures depending on its sources. Atmospheric deposition exhibits a large variation in nitrogen isotopic composition, ranging between −15 and +15‰ (Kendall *et al.,* 1995, 2007; Kendall, 1998; Elliott *et al.,* 2007). The nitrogen isotopic composition of synthetic fertilizers ranges from −6 to +6 ‰ (Kendall, 1998; Deutsch *et al.,* 2006; Silva *et al.,* 2002; Bateman and Kelly, 2007; Singleton *et al.,* 2007; Xue *et al.,* 2009), and the range of the nitrogen isotopic composition of organic nitrogen in natural soil ranges from −3 to +8‰ (Kendall, 1998; Bedard-Haughn *et al.,* 2003; Spoelstra *et al.,* 2007; Singleton *et al.,* 2007; Xue *et al.,* 2009), while nitrate-nitrogen derived from manure or sewage is isotopically distinct from nitrogen in both synthetic fertilizers and natural soil organic matter and is usually characterized by high $\delta^{15}N\text{-}NO_3^-$ values of +9 to more than +20‰ *(*Heaton, 1986; Widory *et al.,* 2004, 2005; Choi *et al.,* 2007; Xue *et al.,* 2009*)*. Recently, a dual approach employing both $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ has been introduced to trace the nitrate resources in the groundwater (Silva *et al.,* 2002; Pardo *et al.,* 2004; Seiler 2005; Singleton *et al.,* 2005; Deutsch *et al.,* 2006; Liu *et al.,* 2006; Lee *et al.,* 2008; Savard *et al.,* 2010) because of overlapping of N isotopes signature between fertilizers and soil origin. However, some of the studies (Aravena *et al.,* 1993; Mengis *et al.,* 2001; Xue *et al.,* 2009*)* based on the dual isotope ($\delta^{15}N\text{-}\delta^{18}O$) approach in agricultural areas reported no significant differences in $\delta^{18}O$ values of NO_3^-, and this approach could yet not distinguish between the various possible nitrate sources. The $\delta^{15}N\text{-}NO_3^-$ values can be considered to be a semi-quantitative or qualitative index for the identification of nitrate sources, although the $\delta^{15}N\text{-}NO_3^-$ values alone cannot readily differentiate between fertilizers and natural soil organic matter as nitrogen sources. Meanwhile, combined use of the nitrate concentration and $\delta^{15}N\text{-}NO_3^-$ values of groundwater could be useful to trace the sources of nitrate contamination, because the concentration and $\delta^{15}N\text{-}NO_3^-$ values in groundwater tend to show seasonal variations due to seasonal changes in agricultural activities (such as fertilizers application) and rainfall. Therefore, we hypothesized that a seasonal investigation of the variation in nitrate concentration and $\delta^{15}N\text{-}NO_3^-$ values of groundwater would provide more valuable and reliable information on the impact of land-use activities on groundwater contamination. The objective of this study was to characterize the impact of various land-use activities on nitrate contamination of groundwater in karst underground river system comprising different land-use patterns by conducting a seasonal monitoring exercise of the concentration and N isotope ratio of groundwater nitrate.

Study Area

Nandong Underground River System (NURS) is located at the southeast of the Yun-Gui Plateau in Yunnan Province, China. The underground drainage area of the system is about

1618 km^2 (Fig. 1). The climate condition is primarily subtropical monsoon type with a mean annual precipitation of 830 mm which 80% of total precipitation occurred during the June – September period and mean air temperature of 19.8℃. In 2007, the total population in the area was about 0.4 million, about 60% of which (0.24 million) lived in rural areas. The gross domestic product (GDP) in 2007 was about 9.1×10^8 USD, about 1/3 of which (3.1×10^8 USD) was from agriculture production.



Geology and hydrogeology. The geology of the study area was shown in Fig. 1. The entire area is mainly underlain by Mesozoic Triassic strata. Carbonate rocks cover about 950 km^2 (58.7%) of the total area. Limestone and dolomite each is about 50% in the carbonate rock area Fig. 1. The central basin is covered by the Quaternary Mal lateritic clay, which is underlain by Triassic Gejiu formation. The length of the main underground river from the Mingjiu cave to Nandong is about 75 km, and the other two branch underground rivers are about 40 km long. The average discharge of the Nandong Underground River is 9.4 m^3/s. Figure 1 Location, geological map and the distribution of groundwater samples in the NURS

Land-use pattern. There are 5 major land use categories, i.e., forested land, grassland, cultivated land (dry and paddy land), water bodies, and construction land (towns and other urbanized areas) in the NURS (Fig. 2). Land use data was obtained by interpreting 2007 Thematic Mapper (TM) images. The percentages of land-use for each type are 29.5 for cultivated land, 27.5 for forested land, 37.7 for grass land, 2.8 for construction land, and only 2.5for water bodies in 2007, respectively.

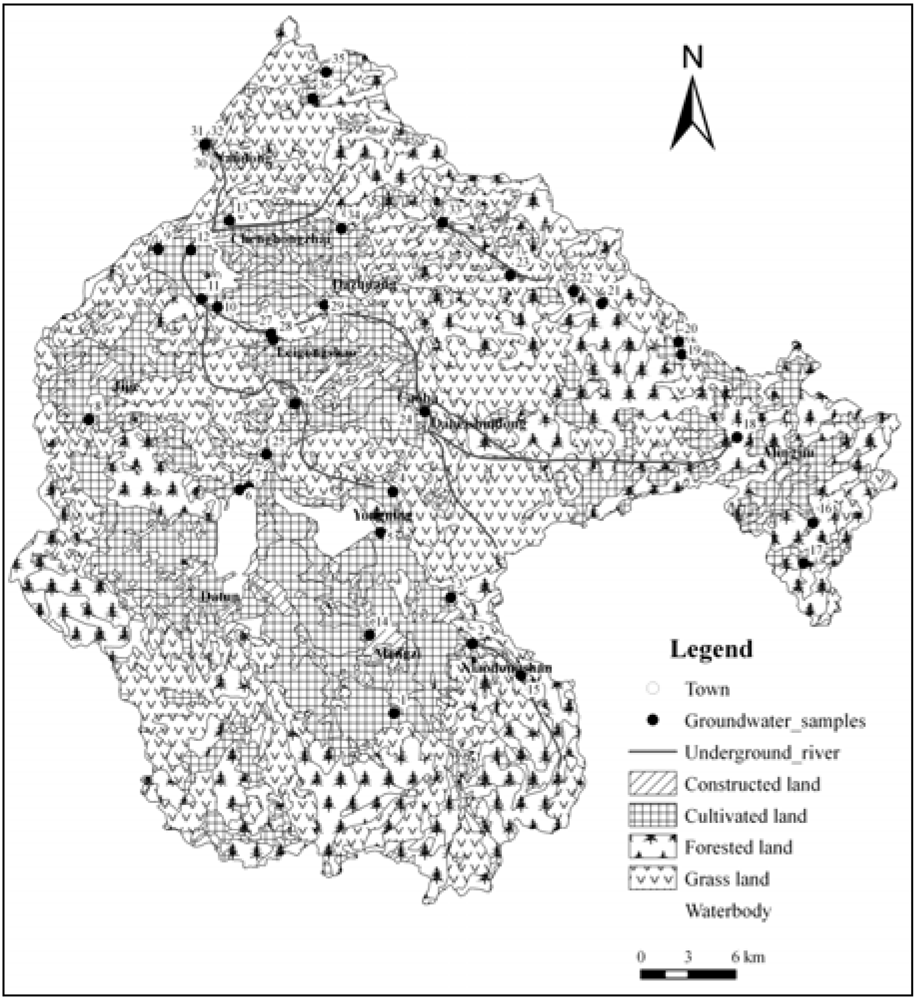


Figure 2. The land-use patterns and the distribution of groundwater samples in the NURS

Sampling and analytical methods

To take human activities into consideration and to investigate seasonal and spatial variations of the contents and nitrate isotopic composition in the NURS, a total of 36 groundwater samples, of which 6 are from the outlets of underground river and the rest are from epikarst springs, from representative springs at different land use background (6 from forested area, 5 from grass area, 17 from cultivated area and 8 from residential area, respectively) were collected in July (rainy season) and December (dry season) of 2008 (Table 1). Sampling locations are shown in Figs. 2 and 3. The water temperature, pH, electrical conductance (EC, at 25°C) were measured in situ using a multi-parameters probe of WTW model (Multiline P3 PH/LF-SET), and the level of the dissolved oxygen (DO) was determined in situ using a probe of WTW type (Oxi330/SET). Samples for chemical and isotopic analyses were passed through a 0.2 μm cellulose-acetate filters and kept refrigerated at approximately 4℃ until analysis. Eluted SO_4^{2-} was precipitated as $BaSO_4$ by addition of 10% $BaCl_2$ solution, and then thermally decomposed to yield SO_2 for ion chromatography analysis. Aqueous SO_4^{2-} was converted to $BaSO_4$ by addition of a large excess of $BaCl_2$ solution (100 g L^{-1}) following adjustment of sample pH to ～2.5 and heating to 70℃. Samples were kept warm overnight to coarsen the precipitated $BaSO_4$ before recovery by filtration. Concentrated $HgCl_2$ solution was added to water samples for the determination of nitrate-nitrogen isotopic composition to prevent microbial activities, which can cause significant N isotopic fractionation of nitrate during storage of samples. Concentrations in the water samples were measured by ion chromatography for NO_3^- (uncertainty 5-10%) at the water environmental laboratory of Southwest University. The $\delta^{15}N$ values were determined by isotope ratio mass spectrometer (Thermo Scientific Finnigan MAT Delta Plus) at the Isotope Geochemistry Laboratory of Southwest University, using the sample preparation method ($AgNO_3$), and the analytical precision was ±0.15‰.

Table 1 Analytical result for groundwater in the NURS

Sample point	NO_3^- (mg/l)		$\delta^{15}N$ ‰		DO (mg/l)		Land-use
	Summer	winter	summer	winter	summer	winter	
1	65.46	57.45	4.9485	5.3652	5.4	9.01	cultivated land
2	3.78	2.49	1.1475	4.8522	7.09	7.72	grass land
3	1.95	1.59	3.4155	2.6077	11.98	6.47	grass land
4	64.54	71.18	9.5995	18.3223	7.78	8.10	construction land
5	273.43	288.26	20.6245	21.7734	4.29	6.16	construction land
6	7.48	6.22	-1.8815	3.5765	4.77	2.39	cultivated land
7	213.85	246.88	23.3335	24.1457	2.80	3.01	construction land
8	31.92	18.56	2.3515	4.6805	6.07	6.27	cultivated land
9	5.34	3.72	2.8935	3.8493	19.83	4.88	grass land
10	54.61	42.44	-3.7605	2.4786	9.28	7.43	cultivated land
11	268.98	287.47	21.4355	21.8264	3.76	3.76	construction land
12	14.34	39.82	13.7635	14.2163	5.94	3.02	construction land
13	33.36	22.18	-0.8795	1.7508	5.30	5.42	cultivated land
14	34.71	41.61	16.3945	18.2972	2.45	1.23	construction land
15	32.57	36.23	9.1035	13.6854	2.35	1.36	construction land
16	5.27	3.05	1.9735	2.0946	3.35	7.89	forested land
17	4.57	3.45	3.4665	4.2605	7.12	7.92	forested land
18	7.66	6.74	5.5745	5.6118	7.15	8.55	cultivated land

19	7.12	6.67	1.8265	4.4776	3.69	6.28	cultivated land
20	7.67	2.96	5.4755	5.9638	7.49	7.06	cultivated land
21	0.69	0.63	0.5150	2.4692	11.50	10.05	forested land
22	14.67	8.87	3.7060	3.9528	7.68	7.90	cultivated land
23	0.35	0.31	2.0005	3.8124	2.09	2.31	forested land
24	1.23	1.22	3.7310	3.3286	7.68	6.24	grass land
25	27.47	24.43	4.8230	4.8768	6.60	8.29	cultivated land
26	36.97	27.55	4.5935	5.2256	6.80	5.82	cultivated land
27	37.45	30.91	-1.5625	2.4593	8.07	4.17	cultivated land
28	236.65	248.26	21.5655	21.5335	9.98	3.06	construction land
29	103.28	44.22	4.0995	4.2567	6.40	7.04	cultivated land
30	10.63	5.69	2.7135	4.6343	6.46	6.92	cultivated land
31	10.62	5.64	2.1725	4.4142	6.14	6.93	cultivated land
32	10.31	5.52	1.3185	4.5293	6.49	7.00	cultivated land
33	3.27	2.26	3.7335	4.1406	7.49	7.84	grass land
34	6.23	4.67	1.2053	3.5843	4.37	7.09	forested land
35	43.44	26.87	4.9270	5.1326	6.87	6.46	cultivated land
36	8.21	4.01	3.1565	3.1935	2.26	1.90	forested land

Results and Discussions

Seasonal and spatial variation of concentration of nitrate in groundwater. As shown in Table 2, the nitrate concentrations in groundwater from NURS exhibited strong spatial variation and a systematic control on land-use characteristics, which tended to increase in the following order in both seasons: grass, forested, cultivated and construction land, suggesting that the distribution of the nitrate concentrations in groundwater likely reflects the dominant land-use characteristics around each spring. Nitrate concentrations of groundwater collected from the grass and forested land showed a relatively consistent concentration of < 9 mg/L in both seasons. However, the nitrate concentrations of groundwater in the cultivated and construction land differed between springs of the same land-use type (Table 1).

Table 2 N isotopes, NO_3^- and DO compositions of groundwater in the NURS

Land use		NO_3^-(mg/l)		DO (mg/l)		$\delta^{15}N$ ‰	
		summer	winter	summer	winter	summer	winter
Forested land (6)	Min	0.35	0.31	2.09	1.90	0.5150	2.0946
	Max	8.21	4.67	11.50	10.05	3.4665	4.2605
	Mean	**4.22**	**2.69**	**5.12**	**4.26**	**2.0529**	**3.2357**
Grassland (5)	Min	1.23	1.22	7.09	4.88	1.1475	2.6077
	Max	5.34	3.72	19.83	7.84	3.7335	4.8522
	Mean	**3.11**	**2.26**	**10.81**	**6.63**	**2.9842**	**3.7557**
Cultivated land (17)	Min	7.12	2.96	3.69	2.39	-3.7605	1.7508
	Max	103.28	57.45	9.28	9.01	5.5745	5.9638
	Mean	**30.01**	**20.17**	**6.51**	**6.64**	**2.3792**	**4.3168**
Construction	Min	14.34	36.23	2.35	1.23	9.1035	13.6854

land (8)	Max	273.43	288.26	9.98	8.10	23.3335	24.1457
	Mean	**143.38**	**157.46**	**4.92**	**3.71**	**16.9775**	**19.2250**

Also as shown in Table 2, the nitrate concentrations in groundwater from different land-use types in the NURS showed discrepant seasonal variation. The nitrate concentrations of groundwater collected from grass and forested land were slight higher in summer in winter, suggesting that it is in favor of decomposing of soil organic matter in the grass and forested land due to higher temperature and humidity in rainy season. Meanwhile, the nitrate concentrations of groundwater collected from cultivated land were higher in summer than in winter, indicating that more nitrogenous fertilizers were used in cultivated land in summer. While the nitrate concentrations in groundwater collected from construction land showed higher concentrations in the winter samples instead due to the result of dilution effects by rainwater during rainy season and concentration effects in dry season.

Overall, high nitrate concentrations were observed in groundwater from construction land both seasons, and from cultivated land in summer season, respectively. Such spatial disparities and seasonal variations observed for nitrate concentrations in groundwater indicated that the hydrochemistry of groundwater in the NURS could be controlled by various hydrochemical processes, such as anthropogenic inputs and natural soil origins. Nevertheless, it is limited in terms of real discrimination of the anthropogenic and natural sources.

Seasonal and spatial variation of δ^{15}N- NO_3 of groundwater. The δ^{15}N- NO_3 of groundwater from different land-use types in the NURS showed a wide range between -3.7605 and 23.3335‰ with a mean value of 5.6529‰ in summer, and between 1.7508 and 24.1457‰ with a mean value of 7.3717‰ in winter, respectively (Table 2), which fell within the widely accepted δ^{15}N rangs of nitrate derived from natural soil-N, fertilizers and manure-based organics. The δ^{15}N- NO_3 of groundwater collected from grass, forested and cultivated areas, which ranged between -3.7605 and 5.5745‰ in summer, and between 1.7508 and 5.9638‰ in winter, respectively, were distinctively lower than those of groundwater collected from construction areas, which ranged between 9.1035 and 23.3335‰ in summer, and between 13.6854 and 24.1457‰ in winter, respectively (Table 2). And fives samples from construction areas showed highly ^{15}N-enrich δ^{15}N values above 20‰ in both seasons (Table 1).

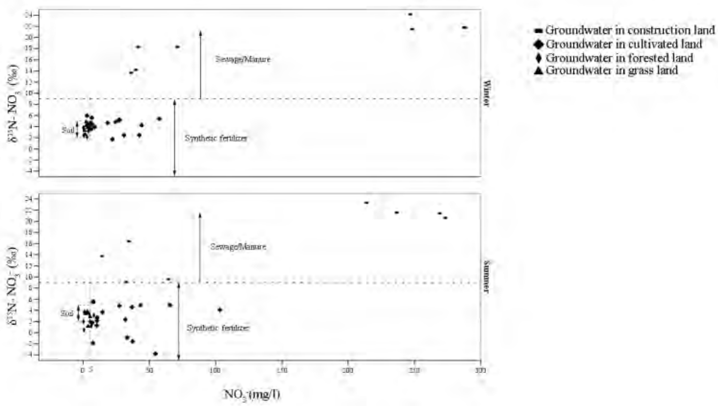
Also as shown in Table 2, the δ^{15}N- NO_3 of groundwater from different land-use types in the NURS showed discrepant seasonal variation. Overall, the δ^{15}N-NO_3 of groundwater from different land-use types in the NURS was higher in winter than in summer. Especially, the δ^{15}N- NO_3 of groundwater from cultivated areas were obvious higher in winter than in summer, presumably reflecting different sources of nitrate in groundwater in summer and winter season. Such spatial disparities and seasonal variations observed for δ^{15}N- NO_3 of groundwater indicated that nitrate sources of groundwater derived from natural soil-N, fertilizers and manure-based organics in the NURS. The δ^{15}N-NO_3 of groundwater from construction areas showed isotopically distinct from nitrogen in grass, forested and cultivated areas and was characterized by high δ^{15}N-NO_3 values of 9 to more than 20‰. However, it is impossible to distinguish the nitrate sources of groundwater from grass, forested and cultivated areas using nitrogen isotope data alone because of overlapping of N isotopes signature between fertilizers and soil origin.

Nitrate sources in groundwater. NO_3^- and DO (ranging from 2.09 to 19.83mg/l in summer, and from 1.90 to 10.05 mg/l in winter, respectively)of groundwater showed higher concentrations in both seasons, but with obviously higher concentrations of NO_3^- in the groundwater collected from construction land in winter than those in summer (Table 2), indicating that the karstic groundwater system is sensitive to the influence of point and non-point pollution and it could be assumed that de-nitrification, which causes increasing $\delta^{15}N$ values in groundwater (Heaton, 1986), would not be significant.

Crossplots of $\delta^{15}N$ values versus nitrate concentration clearly showed the impact of land-use activities on nitrate contamination of groundwater (Fig 3). In the residential area, the consistently higher $\delta^{15}N$ values (ranging from 9.1035 to 24.1457 ‰) regardless of nitrate concentration (ranging from 14.34 to 288.26 mg/l) in both seasons suggested that domestic waste water, sewage or manure are the predominant sources of nitrate in the study area. The nitrate concentration and $\delta^{15}N$ values of groundwater in the residential area were lower in summer than in winter, presumably reflecting the dilution of the nitrate concentration and $\delta^{15}N\text{-}NO_3^-$ from sewage or manure by rainwater during summer.

Figure 3 Crossplots of $\delta^{15}N\text{-}NO_3^-$ vs. nitrate concentration of groundwater in the NURS

During the base-flow period (winter season), groundwater samples from grass and forested



land showed a relatively consistent concentrations of < 5 mg/L, indicating those groundwater were not affected by anthropogenic resources, and the nitrate concentration could reflect the main contribution of nitrate derived from soil resources. Meanwhile, $\delta^{15}N$ values of groundwater from grass and forested land ranged from 2.0946 to 4.8522‰, which fell within the range for soil-N reported by other studies (Kendall, 1998; Bedard-Haughn *et al.,* 2003; Spoelstra *et al.,* 2007; Singleton *et al.,* 2007; Xue *et al.,* 2009). Therefore, it can be assumed that $\delta^{15}N$ values for soil ranged from 2 to 5‰ in the study area. In the rainy season, the nitrate concentration of groundwater from grass and forested land showed a relatively wide range from 0.35 to 8.21 mg/l, and $\delta^{15}N$ values ranged from 0.5150 to 3.7335‰, indicating that most of the nitrate contributed by soil-N, while part of the nitrate derived from fertilizers.

In the cultivated area, nitrate concentrations and $\delta^{15}N$ were distributed a wide range in both seasons (Fig 3), which ranged from 7.12 to 103.28 mg/l for the nitrate concentrations and from -3.7605 to 5.5745‰ for $\delta^{15}N$ in summer, and from 2.96 to 57.45 mg/l for the nitrate concentrations and from 1.7508 to 5.9638 ‰ for $\delta^{15}N$ in winter, respectively. The nitrate concentrations of groundwater from the cultivated area were higher than 5 mg/l in summer, which was the nitrate level assumed to indicate non-contamination by anthropogenic sources, suggesting that the nitrate mainly derived from fertilizers, supported by its $\delta^{15}N$ values, which fell within the range for fertilizers (Kendall, 1998; Deutsch *et al.,* 2006; Silva *et al.,* 2002; Bateman and Kelly, 2007; Singleton *et al.,* 2007; Xue *et al.,* 2009). However, disparate $\delta^{15}N$ values and NO_3^- concentrations of groundwater from the cultivated area indicated the nitrate derived from the mixing sources of soil-N and fertilizers in winter.

Therefore, as indicated by the fig. 4, the nitrate sources of groundwater can be distinguished by the combination of concentration and isotopic composition of nitrate in the NURS, of which the $\delta^{15}N$ values > 9‰ regardless of nitrate concentration in groundwater suggested domestic waste water, sewage or manure are the predominant sources of nitrate, the nitrate concentrations <5 mg/l with $\delta^{15}N$ values of 2-5‰ in groundwater indicated nitrate derived from soil resources, and the nitrate concentrations >5 mg/l with $\delta^{15}N$ values of -4-6‰ in groundwater indicated nitrate mainly derived from fertilizers.

Conclusions

The seasonal and spatial variations in both concentration and isotopic composition of dissolved nitrate of groundwater in the Nandong karst underground river system of Yunnan, China, were examined via rainy and dry seasonal groundwater sampling. The significant spatial disparities and discrepant seasonal variations for the nitrate concentrations and $\delta^{15}N$ values of groundwater are observed depending on the land-use types in the NURS. The nitrate concentration of groundwater showed a systematic control on land-use characteristics and tended to increase in the following order in both seasons: grass land (average 3.11 and 2.26 mg/l in rainy and dry season, respectively), forested land (average 4.22 and 2.69 mg/l in rainy and dry season, respectively), cultivated land (average 30.01 and 20.17 mg/l in rainy and dry season, respectively), and construction land (average 143.38 and 157.46 mg/l in rainy and dry season, respectively). The $\delta^{15}N\text{-}NO_3$ of groundwater from different land-use types in the NURS showed a wide range from -3.7605 to 23.3335‰ with a mean value of 5.6529‰ in summer, and from 1.7508 to 24.1457‰ with a mean value of 7.3717‰ in winter, respectively. The groundwater samples from residential area showed consistently higher $\delta^{15}N\text{-}NO_3$ (>9‰ in both seasons), while the groundwater samples from grass, forested and cultivated land showed a wide range of the $\delta^{15}N\text{-}NO_3$ (from -4 to 6‰ in summer and from 1 to 6 ‰ in winter, respectively).

Such seasonal and spatial variations of the nitrate concentrations and $\delta^{15}N$ values of groundwater in the NURS can be attributed to the various controls of natural and anthropogenic inputs, including soil, agricultural fertilizers, sewage or manure. The combination of concentration and isotopic composition of nitrate can provide the evidence for the identification of a nitrate source. Crossplots of $\delta^{15}N$ values versus nitrate concentration clearly showed the impact of land-use activities on nitrate contamination of groundwater, of which the $\delta^{15}N$ values > 9‰ regardless of nitrate concentration in groundwater suggested domestic waste water, sewage or manure are the predominant sources of nitrate, the nitrate concentrations <5 mg/l with $\delta^{15}N$ values of 2-5‰ in groundwater indicated nitrate derived from soil resources, and the nitrate concentrations >5 mg/l with $\delta^{15}N$ values of -4-6‰ in groundwater indicated nitrate mainly derived from fertilizers.

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WATER RESOURCE MANAGEMENT IN KARST

KARST GROUNDWATER MANAGEMENT: MEASURES TOWARDS SUSTAINABLE CONSERVATION OF GROUNDWATER IN ROTE ISLAND, INDONESIA

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Abstract

Groundwater is a very significant water source for inhabitant living in karstic Rote Island, Indonesia. People depend on groundwater provided by karst springs for different purposes. In order to efficiently maintain its capacity to supply water, community practices traditional groundwater management called Mamar System. However, several potential trades-offs, namely land use change, abandonment of customary knowledge of water management, increased emigration rate and global climate change could pose threat to the capability of the springs to supply adequate water for the whole communities in the island. Those factors may have direct and indirect implication to the state of water balance variables that govern hydrologic process in this karstic island. As inhabitants depend on Mamar springs for water supply needs, the ultimate implication to society is water insecurity. This study aims to develop recommendation based on the analysis on hydrogeology, the existing indigenous practice of groundwater management and local economic potential towards sustainability of groundwater use. This paper concludes several conservation strategies to conserve karst groundwater in the framework of sustainable groundwater management that suits Rote Island‟s physical and societal conditions.

Keywords: karst groundwater trade-offs, karst groundwater conservation, sustainable conservation strategies

Introduction

Water issues are considered as the primary and indispensable problem in East Nusa Tenggara Province (NTT). Each year society suffers from water-related disaster such as frequent drought. The alarming disaster occurs in the dry-hot period of the year ranging from June until November. Characterised by minimum rainfall, drought crests on October resulting in some major detrimental consequences such as water shortage, harvest failure, and environmental destruction. The regional planning and development in NTT is always impeded by this indisputable fact.

However, in some areas in Rote Island people practises local water management rules called “Mamar”. Mamar is a small pocket of forest around natural springs. It also occurs along permanent streams and rivers or on land irrigated by these water sources. Mamar is the hub of the village community. This indigenous institution perhaps was the embrio of community engagement, which would advance into territory authorisation since traditionally people developed their social relationship around water resources. This unique customary is ran for centuries in the way supplying water needs for daily consumption, agriculture, livestock, food, medicine, material for weaving and manufacture of households utensils and others. Regarded as the main source of livelihood, the Mamar develops society‟s behaviour towards sustainable water conservation as well as environment-friendly agriculture and livestock practices.

The main characteristics of Mamar springs is karst which describes the important geological component of Rote Island. According to Ford & Williams (2007), karst is a form of landscape which consists mainly of soluble carbonate rocks such as limestone, marble, gypsum and dolomite. The springs provide water for communities living surround it throughout the year. However it is indicated that there are several factors threatening the main functions of the springs, such as population growth, land-use change, global climate change and abandonment of local knowledge. The main consequence is food insecurity due to potential water depletion. Therefore it is recommended to analyse the problems before building recommendations towards sustainable water management in Rote Island.

Methodology

Methods used in this study were literature review and survey using interview, discussion, and questionnaire in Rote Island, NTT.

Result

Location of Study. Geographically, Rote Island is located between $10^{o}25^{"}$ and $11\ ^{o}00^{"}$ South Latitude and between $121^{o}49^{"}$ and $123\ ^{o}26^{"}$ East Longitude (Figure 1). The total area of this island is approximately 978.5 km^2 with elevation ranges mainly between 0 and 150 m above sea level (68.6%). Topography of this island is dominated with a highly undulated landscape that forms a very complex drainage system. Distribution of slope surface is varied where flatter areas are primarily found in both west and east ranging from 0.20 to 0.35 %. The slopes then substantially become stepper (11 – 28%) towards the middle north of the island.

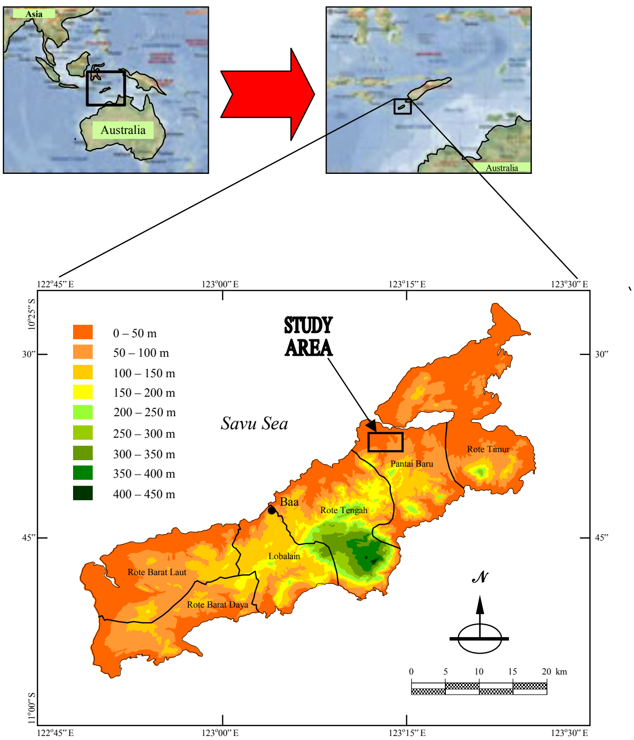

Figure 1 Figure 1. Study Area

Administratively Rote Island consists of six sub-districts. The total population of this island based on 2009 census was about 113,000 people. In general, from census data collected in 2002 and 2009 (BPS, 2003, 2010) population in Rote Island annually tends to increase by approximately 7.87%. The most notable rise appears in Lobalain Sub-district situated in the middle of the island where the growth reaches 15.79%.

The major change in demography in Lobalain Sub-district reflects population boom due to migration right after the shift of level of government from sub-district to regency. In the new administrative category, Rote Island has its own local government and legislative body. It also receives more allocation of funds from the central government in Jakarta. Therefore there was a significant demand for both infrastructures and human resources which already drove people to migrate to this island. Nevertheless, the distribution of migration is uneven. Migrants mostly resides in the capital (Baa) which is situated in Lobalain Sub-district in where people may enjoy quantitatively more and better facilities such as telecommunication, education and entertainment. Most of inhabitant rely on agriculture sector, from which about 45% of the economic revenue comes (BPS, 2010) while other sectors such as service and trade play minor role in building the economy of this island.

Potential trade-offs

Mamar spring is the main source of water in Rote Island. The typical karst characteristics of the land that covers over 60% of Rote Island as well as a short period of wet season that is only last for about four months which are December to March preclude the availability of surface water such as river and lake. Therefore, together with other one-quarter of the world"s population that is fed by or live in karst groundwater areas (Ford and Williams, 1989), people living in this island heavily rely on the perennial supply of groundwater that emerges as Mamar springs.

However, there are some factors that pose threats to the capability of Mamar spring to supply adequate water for the whole communities in Rote Island. An increase in population in the form of augmented immigration and birth rate could trigger a rise in basic demands i.e. food, water and housing. This increase could consequently put an immense pressure on natural resources that are already limited in this island. Higher demand of natural resources may subsequently trigger land use change that converts natural recharge area of for groundwater to agriculture and settlement areas. Meanwhile, amplified demand on water as a coherent consequence of increased population may exacerbate the problem, as water might be overused beyond its physical capacity that is directly linked with recharge performance of the land.

The relationships of the potential factors that pose threat to Mamar are presented in Figure 2. In this flowchart, the connections among each factor are described in arrows by which it is explained that one problem occurs as a result of preceding factor. It is shown that all factors have direct and indirect implication to the state of water balance variables that govern hydrologic process in this karstic island. Anthropogenic factors have direct correlation with water balance parameters, i.e. rainfall, infiltration, run-off and evapotranspiration. Furthermore, a potential of hydrologic impact of global warming may contribute to the change in water balance of Rote Island. Any changes occurs in the state of water balance of the karstic groundwater may result in a reduced water recharge capacity to karst aquifer, by which water is stored and conveyed to Mamar springs. As a result, the capacity of spring to supply water for the community is degraded as groundwater supply from karst aquifer is depleted. This condition may also to some extent has potential to reduce the functions of Mamar System which is developed as water institution that manages the Mamar karstic springs. And ultimately, as water supply from Mamar springs declines water scarcity may be intensified and ends in water insecurity in the communities of Rote Island.

a. Population growth

Increase of population gives additional burden to natural resources such as water. Total water requirement in term of quantity is magnified as population grows. Therefore, demand for bigger water consumption soars as population growth rate rises. A projection by Gardner-Outlaw & Engelman (1997) shows that a direct correlation is present between population and water withdrawals. In their report, within the last sixty years world population tripled while rate of water abstraction follows the same trend. The United Nations has predicted the acuteness of threat on water as by 2050 there will be 7 billion people in sixty countries suffering water shortage (UN, 2003).

Urbanization might be the potential threat to the availability of water in Rote Island. The recent census between 2002 and 2008 shows of that population grew significantly due to immigration in Lobalain Sub-district in where the capital of the regency is situated. Unlike other five sub-districts, Lobalain experienced this irregular growth rate since a transfer of the governance status of Rote Island took place in 2002. In that year, Rote Island gained a new authority as regency replacing the previous status which was sub-district. The shift in governance level in this island brought direct changes in economic and administration settings. Nevertheless, its new “governmental cloth” has attracted more people to emigrate from other island. Migrants mainly come and settle in Rote Island as public servants and traders. Contributing to an increase in total annual population growth rate from 1.5% to 2.33% between 2002 and 2008 respectively, this trans-island migration brings a heavy strain as settlement areas expands and so does water demands in Rote Island. This situation can be clearly seen in the capital of the regency where water problems that were previously severe have become even more acute, especially when it deals with drinking water service provided by the local Water Agency.

b. Land-use change

According to Turner, Moss, & Skole (1993) land use change is categorized as land cover conversion and land cover modification. The difference between the two categories is that the earlier denotes total replacement of land cover with another type while the change in land use in the latter category does not transform the main type of land use. However, despite the level of change described in the two categories, land use change contributes to the modification of hydrologic characteristics of a particular area.

Any changes to soil-atmospheric behaviour may lead to environmental problems. Ford & Williams (1989) suggested that compared to other type of landscape, karst areas are more vulnerable to numerous types of environmental problems, especially those that relate with water. Unlike non-karst aquifers that are generally covered by overlying or less-permeable rock formations or soils, those in karst terrain are often exposed directly to surface without a low permeability cover (Kaçaroğlu, 1999). Therefore, the only protective coverage of the karst surface is vegetation. Consequently, any conversion or modification on land use that lead to removal of covering vegetation in a karst area may result in the surface being uncovered and as a result the overall karst system may be prone to water loss due to run-off (Gillieson, 1996). As vegetated areas being anthropogenically transformed to impermeable areas such as settlement, roads and buildings, land capacity to let water infiltrates decreases. Consequently, there is little supply to karst aquifer from both allogenic and autogenic areas through recharge process. Thereby, karstic springs may experience water shortage throughout the year.

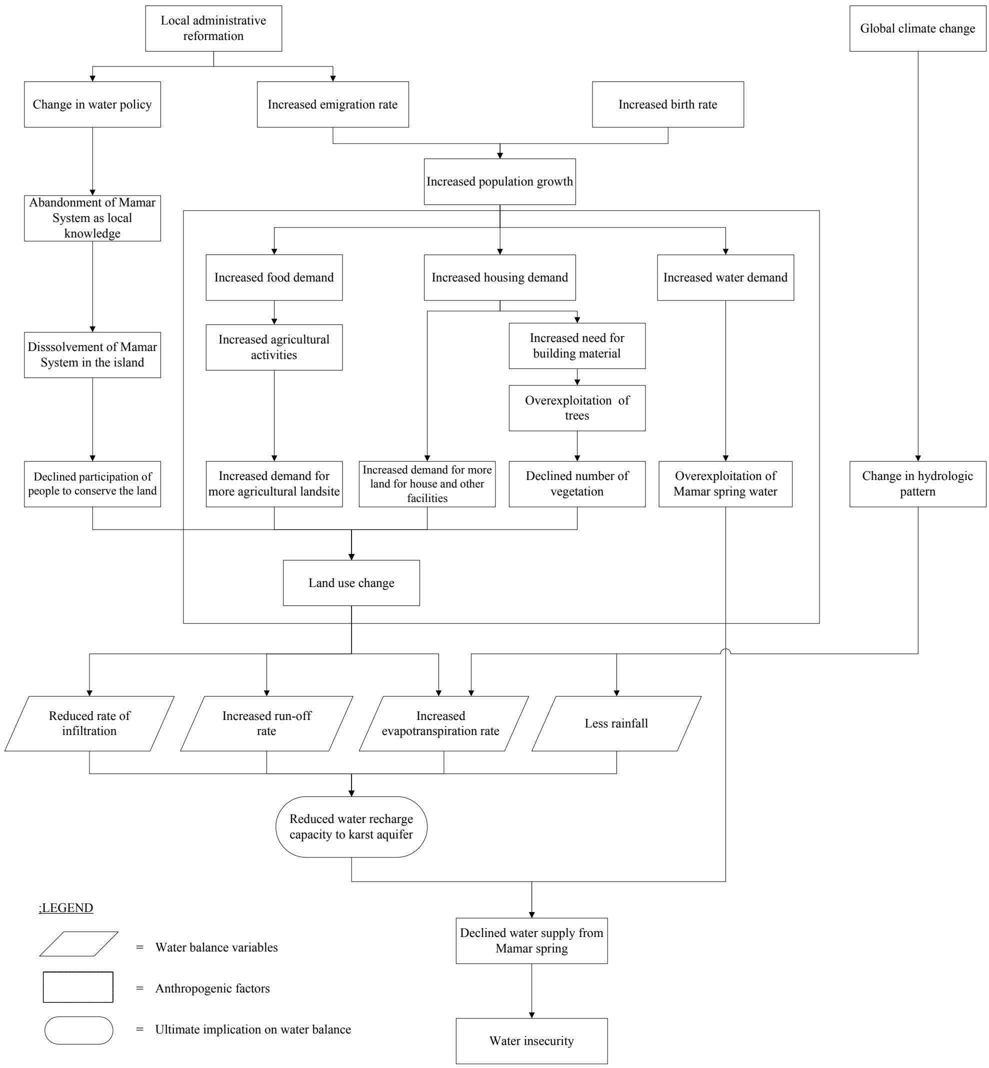

Figure 2. Potential trade-offs over water provision from Mamar springs

c. Global climate change

According to the climate projection by Intergovernmental Panel on Climate Change (IPCC, 2007a) that employs seven scenarios the global average sea surface temperature will increase by 0.6 to 4.0 ^{o}C between 2090 and 2099 relative to temperature in 1999. Locally, Rote Island is projected to experience a 1.5 to 2 ^{O}C temperature increase in the same time framework (IPCC, 2007c). It is also expected that mean rainfall in Rote Island between December and March will increase by 0.2 mm/day however during dry period it decreases by 0.1 mm/day (IPCC, 2007b).

The change in climate condition in Rote Island apparently will change the recharge pattern with regards to karst environment. The increased temperature leads to an increase of evapotranspiration, thus reducing the recharge rate on a watershed scale. Although there is an increase in rainfall in wet season it is argued that without any conservative precaution on land coverage in recharge area most water may become runoff rather than infiltrate into karst. It is also possible that the increase in precipitation is presented as intense and extreme rainfalls that suggests an increased chance of flash flooding rather than as steady rain which helps maximize infiltration (IPCC, 2007b).

d. Abandonment of local knowledge

Incorporation of indigenous knowledge on managing natural resources such as groundwater is crucial for building a strong foundation that in the long-term serves as a basis for conservation. As noted by Burke & Moench (2000), the step to acknowledge local context is an efficient way to better manage groundwater resources. A case study from the Andean Region of Ecuador (Cremers *et al*., 2005) shows that when policy makers fail to recognize and embrace the significant value of local water rights and knowledge access to water by all users is endangered. Bridgewater & Arico (2002) underlines that preservation of biodiversity requires a cultural control that shares its manifestation in the form of indigenous knowledge.

Conservation strategies

Water insecurity in many places of the world has become a problem that without any cure could trigger other problems such as health, sanitation, poverty and food insecurity problems. It is predicted that 25% of world population live in countries that are affected by lack of freshwater (Gardner-Outlaw and Engleman, 1997). People living in karst area are more likely to be susceptible from water shortage due to physical characteristics of carbonate rocks in which water stored in its porous media may evaporate quicker than that of impermeable soils. Other factors such as rapid economic growth and increased population rate could put tremendous pressure on karstic water sources to supply enough water to the society. Consequently, without appropriate conservation strategies the provision of water from karst landscape that covers 7-12% of the earth terrain (Drew, 1999) is at stake.

In order to protect karstic groundwater in the framework of sustainable water management in Rote Island several proposed measures are recommended. These measures that are presented in Figure 3 are designed to encourage an integrated approach in watershed scale in order to facilitate sustainability in the area. The formulation of proposed measures takes into account characteristics of karst areas in Rote Island, existing indigenous practice of natural resource management called Mamar System and potential trade-offs. Each measure correlates with others to an extent that one supports others, thus all components of the proposed measures are linked in an integrated relationship as described below.

a. Determination of Protective Karst Area (PKA)

Establishment of protection zones is the first option undertaken in several cases in karst areas in the world (Escolero *et al*., 2002, Afrasiabian, 2007). The concept of protective karst areas, that is often called vulnerability and risks map (Nguyet and Goldscheider, 2006), has been widely used to become a foundation of policy formulation of karst protection in several European countries (Goldscheider, 2005, Andreo *et al*., 2006, Gogu *et al*., 2001). In the context of Rote Island, PKA is determined using the concept described above towards which hydrogeological characteristics of the karst landscape is used. Here, it is concluded that the karst system is governed by a mixture of autogenic and allogenic karst. Therefore, the area where both types of karst that initiate infiltration occur is described as PKA (Figure 4).

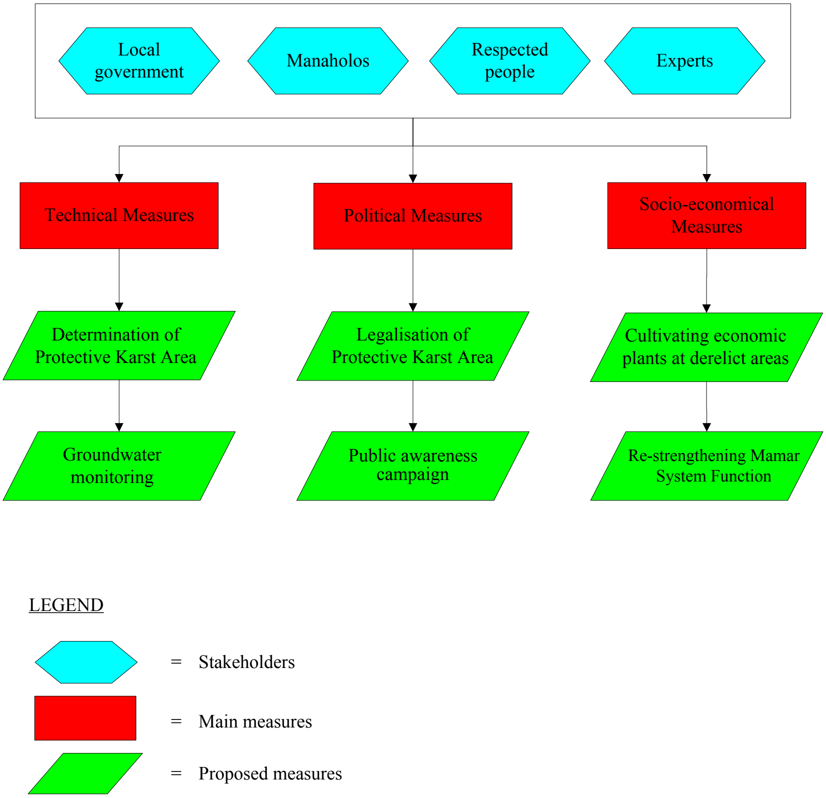

Figure 3. Proposed measures for sustainable water management in Rote Island

b. Groundwater monitoring at Mamar springs

Knowledge of hydrogeological system of a specific area is a precondition for appropriate conservation strategies (Nguyet and Goldscheider, 2006). The knowledge is built upon thorough analysis of a set of data available for pertinent area. In karst areas, several places i.e. springs, cave streams, and wells, are the only suitable location to monitor the quality and quantity of groundwater (Quinlan and Koglin, 1989). Data such as springs" water discharge taken from continuous groundwater monitoring is important to determine characteristics of groundwater recharge process.

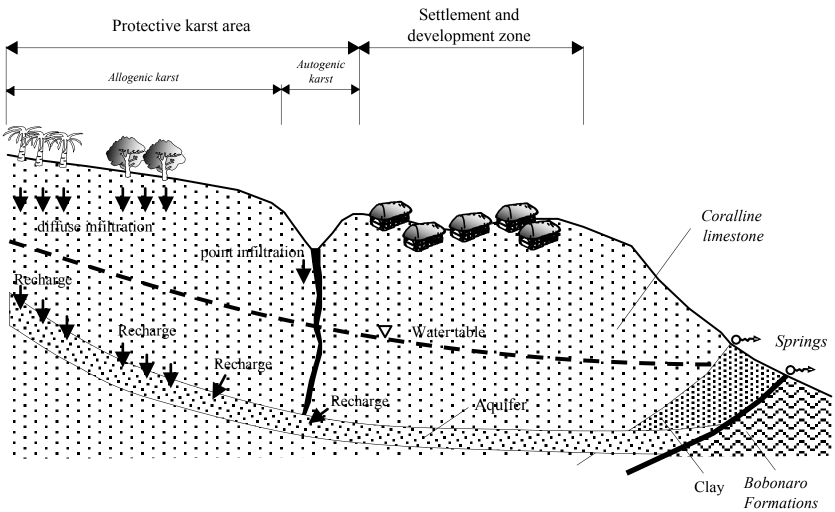

Figure 4. Concept of protective karst area (PKA) in Rote Island

c. Legalisation of protective karst area (PKA)

After being confirmed by all stakeholders, it is recommended that the final draft of PKA be implemented with legal means. The government, through its Regional BAPPEDA (Regional Development Planning Agency), who mainly works as a coordination agency in regencial platform, can adopt PKA into its regional strategic plan (*Rencana Strategis Daerah*). This plan projects and integrates overall development strategies from all agencies in Rote Island. The plan is then translated in a formal-legal language as Perda (Regional Regulation).

d. Cultivating economic plants at diffuse recharge area

Ecologically, reforestation measure is a method to conserve the land by which it accommodates more water to penetrate the earth, thus entering the aquifer during recharge process. Therefore, the absolute benefit of reforestation in hydrologic cycle is that it accentuates infiltration by increasing the quantity of water percolating down to the water table (Allen and Chapman, 2001). The selection of local vegetation needs to take into account the concept that the improvement of inhabitants" livelihood is the most important long-term objective in efforts to enhance natural resources management in developing countries (Merrey *et al*., 2005), such as coconut (*Cocos nucifera*), Palm (*Borassus flabellifer*), betel palm (*Areca catechu*), banana (*Musaceae*) and mango (*Mangifera*), which in turn can strengthen local"s economy.

Conclusion

There are several points concluded in this study:

a. The local knowledge by which the community manage the spring water and its ecosystem is called Mamar System developed and maintains a system which is locally acknowledged as Mamar System which is, in this study, defined as a local knowledge and practice of water management in Rotenese society in Rote Island to conserve karstic groundwater spring in order to primarily provide sufficient water for plantation and drinking water for the community living surrounding it.

b. It is concluded that all factors that pose threat to Mamar have direct and indirect implication to the state of water balance variables that govern hydrologic process in this karstic island. Any changes occurs in the state of water balance of the karstic groundwater may result in a reduced water recharge capacity to karst aquifer which end at reduction of capacity of spring to supply water, thus creating water insecurity in the communities of Rote Island. Therefore conservation strategies, which in this are drawn in the framework of sustainable water management, need to be designed and implemented in order to overcome the potential tradeoffs.
c. The finalization of legal aspect of Protective Karst Area (PKA) is important through appropriate administrative means in Rote Island in order to strengthen the preservation of the recharge area. Wider participation of the community to support the overall measures is suggested to be achieved through dissemination of information that encourage better understanding of the karst characteristics in Rote Island.
d. Coordination of all Mamar System in Rote Island is recommended through regular meeting that discusses economic, social and technical issues regarding Mamar Spring to strengthen Mamar System‟s capability to manage the spring and its ecosystem. It is recommended to perform reforestation at recharge area with profitable plants that could improve inhabitants‟ livelihood in order to gain continuous participation of inhabitants to conserve the Mamar ecosystem.

Discussion

In order to achieve an enhanced understanding of karst characteristics which govern the recharge process to Mamar springs, the following potential studies are considered suitable for further research: a detailed geological study that aims at identifying the actual geological stratum over the Rote Island and a thorough water balance analysis of the island.

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DEVELOPMENT OF UNDERGROUND HYDROPOWER SYSTEMS FOR KARST AREAS – PILOT STUDY JAVA, INDONESIA

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Abstract
This article describes an Indonesian-German joint project for the development of an underground hydropower pilot plant in a karst region on Java, Indonesia, which is from German side supported by the German Federal Ministry of Education and Research (BMBF). At the end of 2008, after years of construction works and several setbacks due to earthquake and flood events, test storage and first operational tests of the facility had been successfully carried out. At the beginning of 2010 the hydropower plant has been handed over to the Indonesian government for operation. The pilot plant will assure future water supply for 80.000 people and serves as an initial of multiplication measures for similar situations worldwide. Within this cooperation on German side seven institutes from Karlsruhe Institute of Technology (KIT) and University of Gießen as well as several industrial partners were involved. On Indonesian side governmental and scientific institutions, enterprises as well as non governmental institutions were involved in this project.

Keywords: Karst, Hydropower, Pump as Turbine

Introduction
According to WHO/UNESCO (2004) more than 1.1 billion people throughout the world are affected by water shortages and the vast majority of these people are living in developing countries. This situation of water shortage is even more severe in karst regions. Karst is related to the occurrence of carbonate and gypsum rock. Approx. 20 % of the world‟s population lives on carbonate rock. More than a quarter of mankind depends on karst aquifers as their source of water. However, due to the absence of surface water storage possibilities, people living in karst regions are likely suffering from acute water shortage, especially during dry seasons.

On the other hand in many karst regions networks of underground rivers exists which lead water continuously, also during dry season. Nevertheless, very often there is limited accessibility to these rivers due to their location deep underground. This high difference of altitude causes significant operational costs for water extraction using conventional techniques such as diesel or electric driven pumps. In addition, due to high infiltration rates, the situation is even more complex because of the vulnerability to contamination e.g. from agriculture or from diesel fuel leaking engines used for conventional water supply.

As a consequence, for an exploitation of the underground rivers, adapted and innovative solutions for management, distribution, usage as well as protection of the water are required in order to assure the sustainability of the development. Based on this situation an interdisciplinary research group from Karlsruhe Institute of Technology (KIT) was established. In cooperation with German industrial partners this research group intensively worked on the development and implementation of concepts and technologies for adaptive water resource management in karst regions in Southeast Asia (e.g. Indonesia, Thailand and Vietnam). The aim was to establish a long-term integrated water resource management (IWRM) concept which can be used as a basis for further research and development work with global relevance.

Fig. 1 Java Island and location of district Gunung Kidul

The present paper focuses on the karst region Gunung Sewu in the district of Gunung Kidul which is situated within the Yogyakarta Special Province along the southern coast of the Indonesian island Java (see Fig. 1). The south eastern region of Gunung Kidul is called Gunung Sewu ("land of 1000 hills"), an area of approx. 1400 km^2 geomorphologically defined by cone formations of karst formed by tropical erosion. Due to a high infiltration rate and a lack of natural storage possibilities, Gunung Sewu faces acute water shortage especially during the dry season (see Fig. 2). On the other hand there are enormous underground water resources which are currently not being optimally used, flowing through the underground caves and into the Indian Ocean. Over the years the Indonesian government has been taking many steps to make this underground flowing water accessible. However, no sustainable solution is in place so the acute water shortage problems have not been solved yet. During the dry seasons, many households have to live with less than 10 liters per person per day (Scholz *et al.,* 2004).


Fig. 2 Gunung Sewu during rainy seasons (left) and during dry seasons (right)

In the year 2002 KIT and University of Giessen initiated a German-Indonesian joint project to exploit the underground rivers. Under the coordination of the Institute for Water and River Basin Management (IWG/KIT) and in cooperation with German companies and Indonesian partners such as governmental institutions (among others Government of Yogyakarta Special Province, Department of Public Works, National Nuclear Energy Agency - BATAN), universities (among others Universitas Gadjah Mada, Universitas Sebelas Maret), enterprises (among others PT. Wijaya Karya) and NGOs (among others ASC speleological club), innovative technologies were developed and implemented, associated with the usage of renewable energy.

Innovative and Sustainable Technologies for Water Supply

Within the frame of a feasibility study, which was conducted by IWG in the year 2000, basic concepts for sustainable underground water resources exploitation had been developed - one concept is “water storage with reinforced concrete dam (barrage)”. In this concept, the barrage will close the whole cave cross section to store the continuously flowing water in order to produce the necessary pressure head to pump the water partially to the surface through a hydropower-driven pumping system. The advantage of this concept is an appropriate water management depending on the amount of water stored underground. The geological conditions in the target area have to be analyzed extensively prior to the construction of such a hydropower plant in order to assess the risks of water losses due to gaps and porosity of the surrounding rock formation.

For the pumping system, reverse driven centrifugal pumps (widely known as “Pump as Turbine” – PaT) were used instead of complex turbines due to their high availability, low investment costs, good maintainability and good operating efficiency at peak load. The generated mechanical energy is transmitted via a gearing to the feed pumps for water transport to a high-elevated reservoir. Optimization studies for various pump types had been conducted by IWG in cooperation with German pump manufacturer KSB AG (Fig. 3). The results show that with a suitable pump selection the PaT efficiency can reach over 80 % (Singh, 2005).

Fig. 3 Test rig to optimize Pump as Turbine (PaT) at the Theodor-Rehbock Water Laboratory, IWG (left) and module 1 (volute casing pump in PaT mode, gearing and multistage centrifugal pump) at the test facility of KSB AG (right)

A substantial disadvantage of a PaT compared to the original "turbine" is the absence of an adjustable mechanism to regulate the PaT due to water discharge variations. However, this can be solved by parallel installation of several modules which can be operated separately. Therefore a broad discharge spectrum can be covered in order to achieve a high efficiency of the facility. In case of high discharge (e.g. during rainy seasons), which cannot be managed by the PaTs and feed pumps, the flow will additionally be controlled and released through two flood relief lines.

Gua Bribin as Pilot Plant and Cave Laboratory

For the implementation of the proposed concept into a pilot-plant, a cave named "Gua Bribin" was found to be particularly suitable. The river Bribin can be reached through a narrow entrance passage (see Fig. 4) with a length of approx. 350 m. The cave strand has an overall length of about 3 km with an associated total volume of approx. 300.000 m³. Based on the study of Sir MacDonald and Partners (1984) and on initial field studies of KIT in the early 2000s, during dry seasons the discharge can still be higher than 1.0 m³/s: During the rainy seasons this value can increase dramatically. A current study which is conducted by KIT shows that the discharge conditions have slightly changed in the mid 2000s, among others, affected by the changes of the hydrological characteristics in the region, the first results will be also presented during the Asian Trans-Disciplinary Conference 2011.

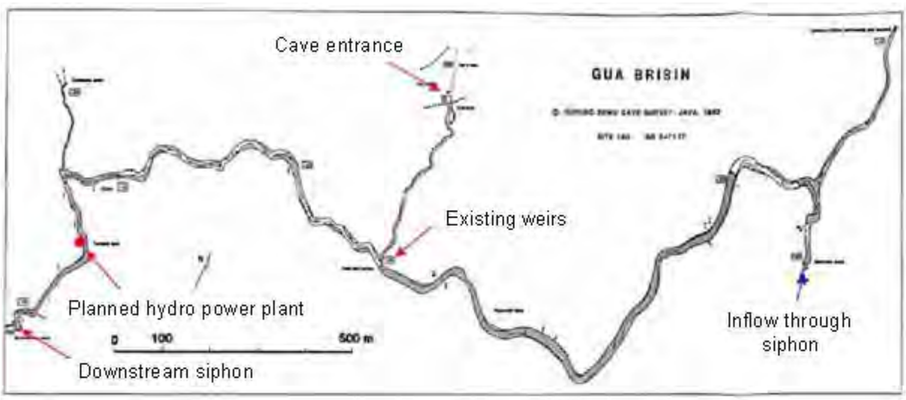

Fig. 4 Layout of Gua Bribin [Sir MacDonald and Partners, 1984]

In upstream and downstream direction the cave is bounded by siphons. Before entering the downstream siphon the water accumulates to a natural lake with a length of approx. 300 m. The cave cross section at the location of the hydropower plant has a width of approx. 10 m and a height of 6 m and was defined as suitable based on the existing geometrical boundary conditions and the results of a preliminary geological analysis. Due to the barrage the needed pressure head can be provided. The water of Bribin River is stored up to a level of 10 to 15 m above the downstream water level (Fig. 5). The needed calculated discharge for full operation of the entire plant is about 1.9 m³/s. At full capacity 65 l/s of water can be supplied to a reservoir at 220 m height. From this reservoir the water will be distributed to the communities mainly by the impact of gravity. Due to the fact that cost intensive external energy will not be needed, this facility can be operated 24 hours a day to supply theoretically 80.000 inhabitants with 70 litres per person per day (lpcd).

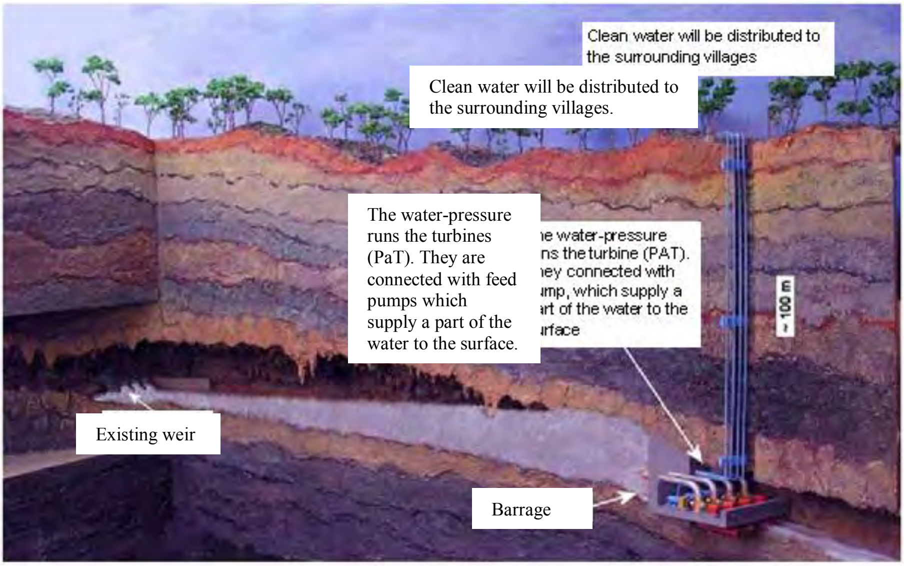

Fig. 5 Basic outline of the underground hydropower plant for water supply (source: Batan / IWG-KIT)

Plant layout. The dimensioning and design of Bribin hydropower plant were carried out based on the hydrologic and geodetic boundary conditions in Gua Bribin. In cooperation with KSB AG standard machines were selected as system components (Nestmann *et al.,* 2009). The optimal efficiency of the entire plant can be achieved through parallel operation of 5 modules, each consisting of PaT, gearing and feed (supply) pump (Fig. 6). Additionally, one smaller module with lower capacity was implemented to run a three-phase synchronous alternator for the power supply of the plant (isolated operation). The electrical energy is used e.g. for the supply of the control system for the valves in each module and the two flood relief lines.

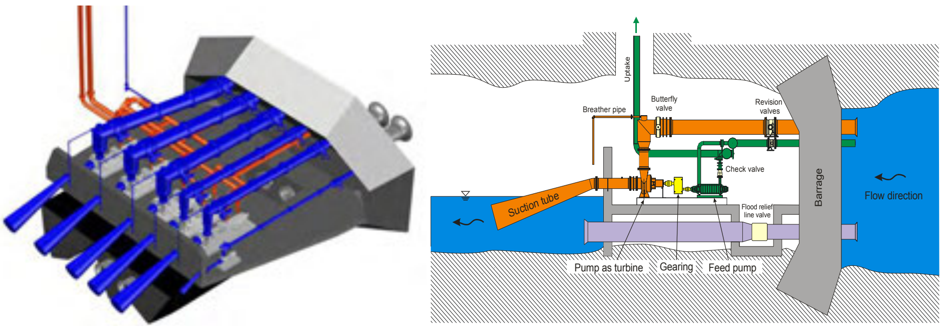

Fig. 6 Modular layout of the hydropower plant

Initially, the first type of module was tested at the test facility of KSB AG, consisting of PaT (ETA 300-340), transmission and 9-stage centrifugal pump (Fig. 3). The modified PaT possesses a flow capacity of 375 l/s with 15 m pressure height and an efficiency of 81 %. The rotation speed for PaT and feed pump are 1200 rpm and 2200 rpm, respectively, synchronized through the gearing. These operational conditions empower each feed pump to deliver 17 l/s to the 220 m elevated reservoir.

Shaft construction. For the construction of the plant, the establishment of a shaft as a vertical entrance was necessary to bring building materials, pipes, pumps, etc. into the cave. Furthermore it is also needed for the operation and maintenance works. For the development of this shaft, the German company Herrenknecht AG had developed an appropriate drilling machine, which can be operated under the local conditions (Meyer, 2005). With this drilling machine a shaft was drilled to a depth of approx. 100 m with a diameter of about 2.5 m (Fig. 7). In July 2004, the shaft drilling activity began. The drilling work was accomplished by Herrenknecht AG in cooperation with the Indonesian construction company PT Wijaya Karya (WIKA). The shaft breakthrough into the cave took place at the beginning of December 2004 - a further important milestone was accomplished.

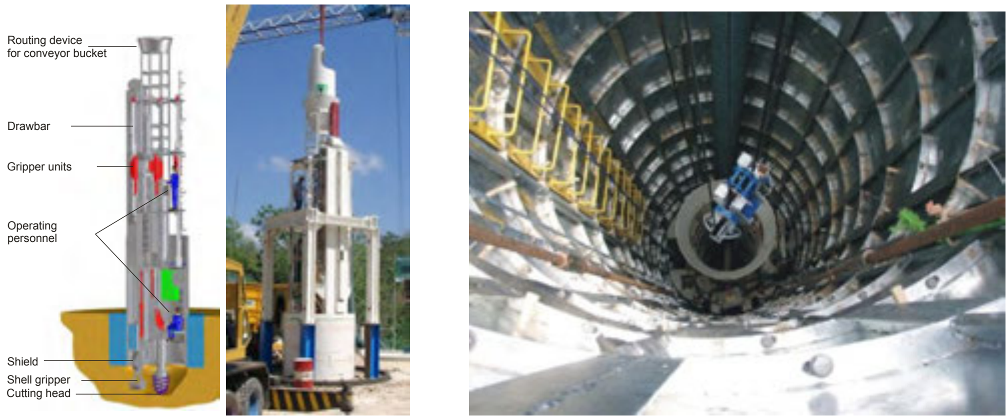

Fig. 7 Application of the vertical drilling machine (left) and view into the developed shaft with a depth of 100 m (left)

Dewatering, excavation works and platform construction. After finishing the shaft, the construction works in the cave began with the implementation of the two flood relief lines with a length of 18.6 m each to convey water from upstream to downstream (DN800; DN600/900). 250 m^3 rock materials were excavated with pneumatic chisel tools in order to expand the cavern and the rock abutment area. Furthermore, 150 m^3 of mud and rubble deposits were removed. A total of 310 rock anchor drillings for the platform foundation were accomplished, drainage pipes were installed and concrete reinforcements were prepared. At the beginning of November 2005 the construction of the platform and the valve chamber was finished (Fig. 8).

At the beginning of December 2005 several rainy days with high intensity occurred unexpectedly early. These high rain intensities caused a flooding of the underground construction site due to a flood wave with a peak flow of 10 m^3/s. Due to safety reasons, all project partners agreed that the construction works should be postponed until end of rainy season 2005/2006.

Fig. 8 Flood relief lines (left) and status of the construction site in November 2005 (right)

The effects of severe earthquake in May 2006. The construction activities were planned to be continued at the beginning of the dry season 2006 (April-May). Unfortunately, in May 2006 a severe earthquake with an intensity of 6.3 Richter scale hit Yogyakarta region. This earthquake had caused 6.000 casualties and had ruined more than 100.000 houses. Moreover after the earthquake it was detected that the water level at the construction site rose up to 1.5 m. Explorations to the downstream siphon to determine the causes of the high water level had been carried out by German professional divers in July 2006. They found out that more than 1.000 m^3 rock downstream of the siphon had been released by the earthquake. This rock fall had partially blocked the river and caused the backwater to the construction site (Fig. 9).

Fig. 9 Rock fall after downstream siphon (left) and open channel after blasting (right)

In the 2nd half-year 2006, most of the activities were concentrated to the blasting activities with the objective to remove some part of this rock falls and reduce the backwater at the construction site. With a cooperation between German professional divers and Indonesian partners, in November 2006 and April 2007 the blasting activities had been carried out successfully and a sufficient part of the rock fall could be removed (Fig. 9).

Construction of the barrage. The construction activities were continued in June 2007. In order to improve the establishment of the barrage foundation, 42 micro piles were installed with a mean distance of 0.7 m and a depth of 4 m. The construction of the monolithic barrage was divided into six sections with several days" intervals for the forming, reinforcement and concreting works.

In January 2008, the construction of the underground barrage was finished (Fig. 10). In July 2008, the contact injection between the barrage and the rock had been carried out. A detailed description of construction material and technologies as well as the construction processes of the barrage can be seen in (Bohner *et al.,* 2009) and (Mutschler *et al.,* 2009).

Fig. 10 Construction of the barrage with wall pipes (left), transportation of concrete in the cave (right)

Installation of the machinery. The first KSB pump module was installed directly after the finishing of the barrage construction. In a second step the VAG controlling valves at the flood relief lines were installed at the end of the rainy season 2008 (Fig. 11). For the installation of the controlling valves, each flood relief line was briefly closed with pipe sealing bags at the upstream and downstream side. During the installation of each controlling valve, the total incoming flow was conveyed through one flood relief line. In total both relief lines have a capacity of 10 m^3/s (maximum monitored peak discharge during flooding) with a pressure head of 20 m. The barrage was designed for a maximum static head of 30 m. In order to avoid solid-waste materials flowing through the flood relief lines, wire cages have been installed at the inlet of the flood relief lines.

Fig. 11 First installed KSB-Module (left), Installation of VAG-valves at flood relief lines (right)

Test storage and first operational test. In August 2008 the first test storage with a river discharge of 1.2 m^3/s has been carried out. Considering the geological conditions and the risk of water losses through the karst cavities, the expected duration for the water storage to a sufficient height for further tests was approx. 1-2 weeks. However, the storage level of 16 m was reached within about 2 1/2 days. These results of all the intensive investigations show that damming water in karst caves is possible. With this successful storage test, the first KSB-module was taken into operation for test reasons. A water flow of 20 l/s has been pumped to the surface though a 100 m vertical pipeline (Fig. 12). Based on these positive test results the final selection and installation of four further modules could be done. Due to the given boundary conditions it was decided that all further installed modules should be identical to the previously installed one, namely the ETA 300-340, gearbox and 9-stage centrifugal pump.

Due to high water pressure from the upstream side of the barrage, seepage water finds its way through the rocks to the platform. In order to reduce the amount of seepage water as well as to avoid a hydraulic breakthrough, grouting injections around the barrage were necessary. These activities had been carried out in 2009 and 2010. Detailed description of the grouting injection activities will be presented in parallel paper in the Asian Trans-Disciplinary Conference 2011.

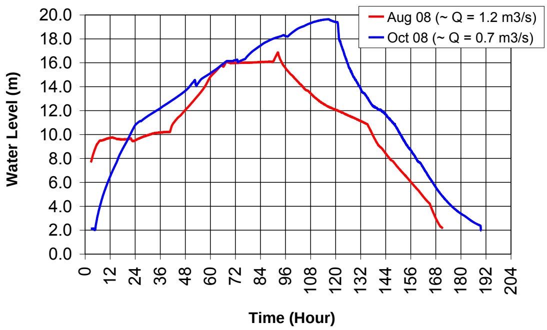

Fig. 12 Successful first storage and operational test in August 2008 (left) and storage curve (right), note: for monitoring purposes, the water level had constantly been held at several heights through partial opening of the controlling valves

Outlook

As the continuation of water resources management in the karst area, in 2008 both Indonesian and German sides agreed to extend the cooperation with the follow-on project Integrated Water Resources Management (IWRM) in Gunung Kidul. The main objective of IWRM is not only to explore the underground water resources but also to manage the water resources (including wastewater and sanitation) in order to increase the life quality of the communities (Oberle *et al.,* 2005). The IWRM should contain all aspects of research and development of water resources covering infrastructure (civil works), water distribution, water quality regulations and wastewater treatment and disposal. Additional to operational and economical aspects the hydrological, hygienic, ecological, social and cultural boundary conditions must be taken into consideration. Within the IWRM project, the development of an underground hydropower plant with a wood-stove pipeline in a cave named “Gua Seropan” is planned (Fig. 13). Actual information regarding the state of the development and the activities in Gunung Kidul can be found in: www.iwrm-indonesien.de

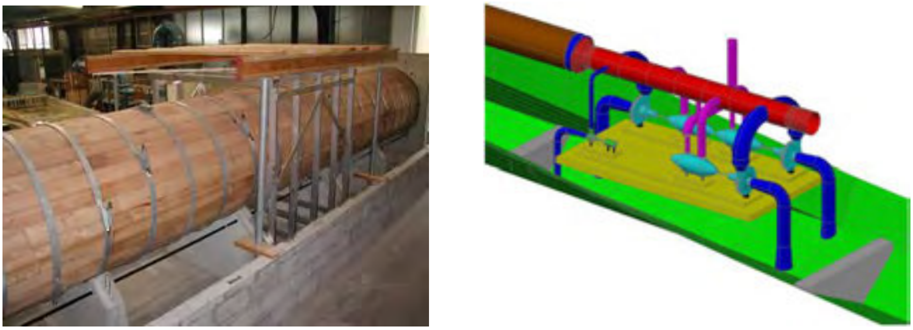

Fig. 13 Experimental investigation of wood-stave pipeline at KIT (left) and illustration of the planned underground hydropower plant in Gua Seropan (right)

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CONCEPT OF APPROPRIATE WATER TREATMENT IN THE KARST REGION GUNUNG KIDUL, SOUTHERN JAVA, INDONESIA

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Abstract
The district of Gunung Kidul in Southern Java is located above a big karst formation, the Gunung Sewu. Due to the underground drainage system of the Gunung Sewu, rainfall rapidly seeps into the ground and is discharged to the sea. This leads to acute water shortages during dry season. The deficient waste water treatment results in a contamination of the groundwater that is impaired by the poor filtration capacity of the karst underground. During several sampling campaigns, the reservoirs and pump stations along a water distribution network have been examined. The focus has been primarily on microbial contamination, especially on fecal bacteria. While every sample was found to be contaminated by coliforms, the bacterial count rose within the distribution system. This circumstance probably results from the dilapidated pipelines and the fact that they run mostly above-ground and are heated up by the sun. Further monitoring results showed that the contamination by coliforms during dry season was relatively low but increased dramatically in the beginning of wet season. The reason for this increase can be found in the high rainfall and resulting washing of bacteria from the surface in addition to the poor filtration capacity of the karst underground.

Keywords: water treatment, microbiological monitoring, appropriate technology, Southern Java

Introduction
In the province of Yogyakarta in Java, the district of Gunung Kidul is considered one of the poorest areas in Indonesia. It is located above a big karst formation, the Gunung Sewu. Due to the underground drainage system of the Gunung Sewu, rainfall rapidly seeps into the ground and is discharged to the sea. This leads to acute water shortages that greatly affect the population, especially during dry season, which lasts from May to September (Nestmann *et al*., 2009).

A lack of sufficient water treatment and the partially dilapidated water distribution system make the situation even worse. Not only is the water highly contaminated by fecal microorganisms, it also contains a lot of pathogens (Oberle *et al*., 2005). This is why consumers are forced to use barely sustainable methods like boiling, to disinfect the water and avoid illnesses (mostly diarrhoea). Within the scope of the research project IWRM-Indonesia, appropriate and sustainable treatment concepts shall be developed, to supply water in sufficient quantity and quality. Therefore, a thorough water treatment system is essential.

Material and Methods
During several sampling campaigns, the reservoirs and pump stations along the Bribin distribution network as well as the Gua Bribin and a second cave (Gua Seropan) have been examined. Although several physiochemical parameters were measured, the focus has primarily been on microbial contamination, especially fecal bacteria. Apart from the sampling campaigns for the distribution network, the two caves have been sampled once a month for one year.

The microbial analysis was mainly done by using the ColiLert-System from IDEXX Laboratories following the manufacturer‟s instructions. The quantitative detection of *E.coli* and total coliforms is based on an enzymatic cleavage of synthetic substrates (Product information, IDEXX).

For this analysis 100 ml samples were taken from each sampling point, transported in a cooling box for protection against the sun and analysed within 6 hours.

Results and Discussion

The ColiLert analysis of the sampling campaigns in October 2009 and July 2010 clearly showed a development of the coliform contamination within the course of the Bribin distribution system (Figure 2). While every sample was contaminated by coliforms, the bacterial count rose within the distribution system and reached a maximum at the end of every branch.

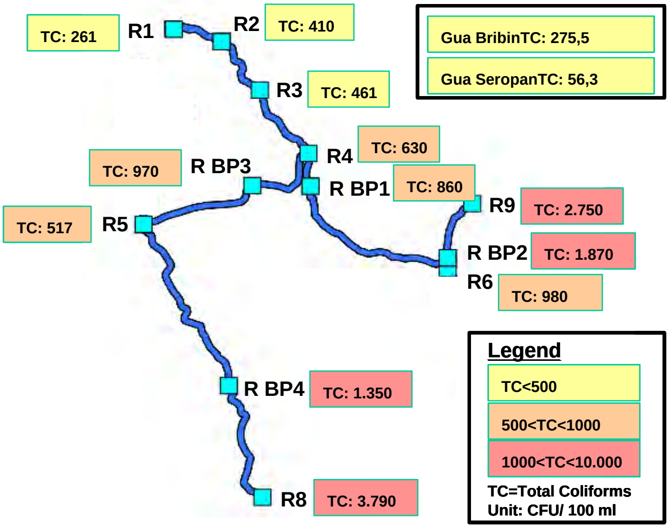

Figure 2. Distribution of total coliform data in July 2010
R1-R9 = reservoirs, R BP1-4 = pump stations

In the first reservoir (R1) only 261 CFU[1]/100 ml could be detected, but the total coliform count reached 2,750 CFU/100 ml at the reservoir R9 and even 3,790 CFU/100 ml at the reservoir R8. This circumstance probably results from the dilapidated pipelines and the fact that they run mostly above-ground and are heated up by the sun. The relatively high temperatures in tropical Java then contribute to a better growth of bacteria.

The monthly analysis of the two caves (Figure 3) showed that during dry season the contamination by coliforms was unsteady, though relatively low in comparison to the values for the beginning of wet season, where the coliform count suddenly increased dramatically.

[1] Colony forming units

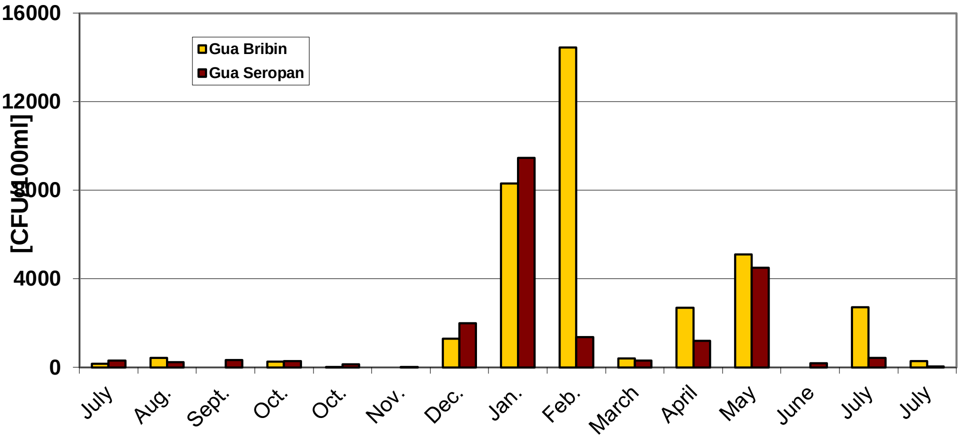

Figure 3. Total coliform data from July 2009 to July 2010

The average value for total coliforms in dry season was about 250 CFU/100 ml. In December wet season began and coliform count began to rise. For the Gua Seropan total coliform values reached a maximum of 9,500 CFU/100 ml in January 2010. The maximum of 14,500 CFU/ 100ml total coliforms in the Gua Bribin could be detected in February 2010. The reason for this increase can be found in the high rainfall and resulting washing of bacteria from the surface in addition to the poor filtration capacity of the karst underground.

Conclusion and Forecast

The monitoring results proved that water quality is deficient and even decreases within the course of the Bribin distribution system (Figure 2). The detected contamination with fecal bacteria is caused by the poor waste water treatment and the washing of resulting contamination into the groundwater through the karstic underground. This fact is underlined by the dramatic increase of contamination in the beginning of wet season (Figure 3).

Based on the monitoring results the water treatment concept was divided into three parts. Right after the cave, a central sand filtration will be implemented to eliminate turbidity and bacteria. As the contamination increases within the distribution network, a second treatment step shall be established central, but close to the consumer. In order to find the most appropriate treatment for this hygienisation, several disinfection techniques will be compared in a field laboratory, using different water sources. The third treatment step will be a point-of-use ceramic filtration.

As the project runs until 2013, the monitoring will go on until the end of the project. Different water hygienisation techniques will be investigated in a field laboratory that will be implemented in the project region in beginning of 2011. Based on the results of these experiments in combination with the monitoring results, a sustainable and appropriate water treatment concept will be developed.

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STUDY OF THE POTENTIAL OF KARST REGION IN NORTH KENDENG, THE DISTRICTS OF GROBOGAN AND PATI

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Abstract
The hilly region in North Kendeng is a karst region spreading from the district of Grobogan in the south to the district of Pati in the northern part of the range of hills of North Kendeng. The geomorphology of the karst region is a structural karst range of hills with a series of conical hills and dolenas, while the geomorphology of the endokarst is a system of caves and their ornaments as well as rivers flowing under the surface. The developing flow pattern (hydrological system) is a pattern of parallel flow controlled by geological structure and the process of dissolving in the region. The juxtaposition of karst springs in the north and south of Sukolilo range of hills comes out at the revolution rate of 5 - 150 mdpl, with the radius of 1 - 2 kilometers from the range of hills. In the karst region of Grobogan, the emergence of karst springs is at the revolution rate of 425 - 450 mdpl and in the southern zone they reach the height of 300 - 450 mdpl. The springs and underground river system in the karst region of North Kendeng is perennial in nature. The karst regions of Sukolilo and Grobogan are water-deposit regions for all karst regions in Pati and Grobogan; consequently, the government of the districts Grobogan and Pati need to establish this region as protected karst region in order that its function be maintained, in order that the risk of draught for more than 8,000 households and 4,000 hectares of cultivated land in the future can be prevented.

Keywords: karst, spring, exokarst, endokarst, conical hill, cave, the risk of draught.

Introduction

The southern part of Pati District includes a mountain range, more commonly called North Kendeng Mountains. The mountains is a spread-out of limestone hills that undergone the natural processes in the geological limit of space and time. The product of earth dynamics that takes place from the past to the present has produced a unique natural phenomenon, known as karst landscape.

The phenomenon of karst landscape North Kendeng is reflected by the many conical hills, the emergence of springs in rock cracks, and the flow of underground rivers with cave trails as corridors. It is not rare to find very dry land surfaces during the dry season in the parts of the hill because the rivers flowing in the surface are very rare to find. The flow of water goes into the cracks of limestone and dissolves it, unlike the lower part of this region, which contains springs coming out through rock cracks.

Geologically, karst region can be formed by dissolvable stones and react with water, moreover if the water is acid. This kind of stone generally contains more than 50% carbonate ($CaCO_3$) from the total of minerals in the stones. The more carbonate it contains, the more perfect the process of karst formation. The most ideal karst is formed in limestone, i.e. stones whose composition is more than 90% calcium carbonate ($CaCO_3$). The other carbonate stone that can form karst is dolomite $CaMg(CO_3)_2$. Beside on carbonate stones, karst can be formed on evaporated stones, such as gypsum and halite and on silicate stones such as limestone and quartzite, as well as on some basalt and granite as long as condition allows (Gillieson, 1996).

Karst in general forms a landscape marked by closed depressions with various sizes and structures, troubled surface drainage, as well as caves and underground drainage system (Bambang Prastistho, 1995). While according Esteban (1996), karst is a system of exodemic phenomenon that involves water that make the structure of stone mass dissolve easily, and changes continuously. Karst formation happens on the stone of a stone, beginning with its surface, i.e. the part having direct contact with the atmosphere, reaching the depth of 200 - 250 meters (Milanovic, 1992). This process of its continuity produces an environmental order that in general complex with unique hydrogeology and geomorphology. Beside due to dissolving, landscapes such as karst can be caused by corrosion, the result of hydrological activity for example erosion, tectonic movement, and liquefaction of ice and lava evacuation. Since its main process of formation is not due to dissolving, such landscape is called pseudokarst (Gillieson, 1996). While the karst formed by dissolving is called truekarst.

It is true that limestone has the characteristic of being easily dissolved in rainwater that contains acid. Rainwater dissolves limestone, gets into stone cracks or holes and forms cave systems and underground river, and later when it is overfull in a lower region, it will emerge in the surface as springs. It is these springs that is naturally used by the community in karst regions as one of their living resources. The community in general uses the water for drinking, cooking, public bathing, washing and toilet facilities and if the water debit is high will be used for irrigation.

Following the Decision Letter of the Minister of Energy and Mineral Resources No. 0398 K/40/MEM/2005 on the establishment of Sukolilo karst region, establishing the karst region of North Kendeng that includes both the districts of Pati and Grobogan as karst regions its classification of karst region has not been established based on the government decision in “Decision Letter of the Minister of Energy and Mineral Resources No. 0398 K/40/MEM/2005”. In the management of a karst region it is necessary to conduct a study and survey in advance. If in the establishment a karst region has the criteria as level 1 karst region (Article 12), the protection of karst region should be main concern in deciding the continuity of the ecology in the region. This status makes this region potential to be cultivated beyond the proper ways. The management of karst region that is not oriented to the principles of sustainable development will cause potential disaster against assets of life and livelihood. Dealing with this matter, information on the existence and value of the karst region is not necessary to be dug and informed to various parties so that good policy and practice of development in the region.

Physiography and Geomorphology

The island of Java is physiographically divided into four main parts (Van Bemmelen, 1949), i.e. West Java, Central Java, East Java as well as Madura Strait and Madura Island. The region of Central Java is formed by two ranges of mountains: North and South Serayu Ranges. North Serayu Ranges of Mountain borders on Bogor Ranges in West Java and Kendeng Ranges in East Java. While South Serayu Ranges is a continuation of Bandung Depression in West Java. Based on this physiography, the karst regions of Grobogan and Sukolilo in Pati are situated in Kendeng Mountain Range (anticlinorium of Rembang-Madura). To be exact, they are situated in the North Kendeng Mountain Range that constitutes a fold of hill that lies longitudinally from the west to east and its wing fold stretching from north to south.

Regionally, the morphology of the karst region of North Kendeng is located in the structure of the fold range of hills. After the hill folding underwent dissolving process, on the top of the range of hills the morphology of conical hills, dolenas, and sinkholes as well as karst springs and ponds were found below. In the endokarst morphology of the karst region there is a formation of cave and underground water system. The northern and southern parts of the limestone are dry lands.

The highest top of this karst hill area is about 300 - 530 mdpl. In the southern part of the hill there is a steeply sloping hillside located in a long stretch from the west to south with a vertical or steep slope. This part is a block of fault structure of Grobogan karst range of hills formed in the process of elevation of South Kendeng range of mountains.

Geology

The stratigraphy of North Kendeng Karst Region, according to Pringgoprawiro (1983), belongs to the formations of Wonocolo, Bulu, Ngrayong, Tawun and Tuban. The establishing formation of North Kendeng Karst region was formed during the period of Middle Meosen - Upper Meosen about 25 million years ago according to geological time scale. Wonocolo formation was formed by the sandy clay rich in plankton. There is insertion of calcarenite with the thickness around 5 - 20 centimeters. Its spreading is relatively from west to east, beginning from Sukolilo (in the west) – Sedan – Wonosari – Kedungwaru – Metes Banyuasin – Mantingan – Bulu, Anticline of Ledok, Anticline of Kawengan, continues to the direction of Manjung – Tawun, Jojogan – Klumpit, becomes less and less to the direction of Tuban in the east. The thickness of this unit is 89 - 600 meters, formed in early Last Meosen up to the middle of Last Meosen (N15 – N16). It was settled in the open sea (outer neritic) to upper batial. The relation with Ledok Formation above it is harmonious. The Bulu Formation was formed by a massive limestone that contains coral, alga and the vain of limestone that contains sea elements in the form of coral, orbitoid and alga, sometimes alternated with quartz sand which is carbonate in nature and is alternated with limestone. Its spreading begins from Ngrejeg – Klumpit – Rengel to Purwodadi, and disappears in Pati alluvial sediment. The thickness of this unit is 54 - 248 meters. Based on small fosils, the Bulu Formation was formed in early Last Meosen (N14 – N15). It was settled in the open sea (outer neritic) to upper batial. The relation with Wonocolo Formation above it is harmonious. Under this Bulu Formation Ngrayong Formation it was formed by the alternating of quartz sands, stony limestone, and clay. Stony limestone was formed by alga and shells of sea animals. Later is the older layer is Tawun Formation formed by clay, alternated with inserted quartz sandstone and carbonate sandstone, in some place layers of clay stone containing gypsum is found. The lower layer there is Tuban Formation, formed by clay stone and inserted with limestone. The folded side is found in Sirwula, Drajat village with the thickness of 144 - 665 m.

The geological structure developing in the karst region of North Kendeng is a folded structure. The part of Bulu Formation being karst region is part of sink link with the direction of folded wing leading from north to south. The sink link is found in the top of the karst range of hills located longitudinally from Beketel to the region of Wonosari, the border with Blora. There is fault structure relatively in the direction of northeast and southwest. The fault structures happen due to the folding process of this North Kendeng Mountain Range. Such condition of geological structure makes limestone, functioning as base stone for the formation of North Kendeng Karst Region, have many cracks, both minor and major. These cracks are the origins of the formation and development of cave system in the karst region after experiencing the process of dissolving in geological space and time.

Speleology

Grobongan Karst Region constitutes a karst region being on the highest top of the karst region of North Kendeng, which is located at the height of 500 mdpl. The process of karst formation in the karst regions of Grobogan and Pati has taken place when North Kendeng Range of Hills was formed by limestone as base stone had been revealed. Then dissolving process has been taking place until now. The fact of this process is still happening until now is proved by the many cave systems and underground rivers that are still active. The development of this process has produced cave trails, both horizontal and vertical.

Beside the intensive dissolving process of limestone, the controlling factor of cave system and underground rivers in this region is the developing geological structure. In elevation process, North Kendeng Range of Hills formed a folding geological structure and faults. The process of folding and fracture produced many limestone cracks. These cracks then developed and formed active cave trails in the process of karst formation.

Cave openings in this region are revealed into two types, i.e. ruins and dissolving from the surface. Surface type generally form vertical cave opening, for example Kembang Cave in Wates Village, Lowo Misik Cave, Kalisampang Cave, Tangis Cave, Telo Cave, Ngancar Cave and Jolot Well in Kancil Sub-village, Sumber Mulyo Pati Village. This type has the characters found mostly in stone chunks falling from the roof of these trails. This is proof that this cave system was formed in the relatively weak crack line so the base stones are not stable and are easy to fall apart. Besides, sinuous trails like stone cracks are also found. Another proof that structure control affects cave formation is the juxtaposition of cave ornaments in the roof formed out the carbonate sedimentation of the dissolving process.

Beside the dominant structure control in North Kendeng Karst Region in the formation of cave systems, dissolving process originating from surface water is also found in this region. Some caves whose openings are located in valley bases are found in the caves of Urang (in the sub-village of Guwo Kemadoh Batur Grobogan), Bandung, Serut, Gondang and Banyu in the village of Sukolilo and Wareh in the village of Kedungmulyo, the district of Sukolilo as well as Pancur Cave in the district of Kayen. In the rainy season, the cave openings constitute periodical river lines that go into the caves and also function as main rivers going out from the caves. Generally, horizontal caves in this region develop by following a covering pattern of stone bases the slope of layers directing to the north with the result that the accumulation of surface rivers will be centered in lower regions that go out through springs of cave openings.

During the process of karst formation, hydrological system has very important role in the formation process of the accumulated cave systems in its saturation zone to undersurface stream and underground water. Caves function as corridor connecting systems between the process of exokarst on the surface and endokarst under the surface. The corridor is a functional structure in landscape and becomes basis for the prevention of fragmentation becoming fragments or on the contrary to intensify the penetration of foreign creatures. Corridors can be formed by topography such as hydrological cycle like river layers and by human beings like forest opening.

Karst and cave ecosystems are very unique. The landscape and physical characteristics of one region is different from another. Almost every karst hill in North Kendeng region has a giant reservoir with underground river as the system of its capiler pipes. The cave area is a unique and special area with a total and never-ending dark condition. A cave area is usually divided into four zones, i.e. cave opening, transitional zone (obscure zone), dark zone and eternally dark zone. Each zone has different (non-biotic) characteristics of are as well as its fauna (Howarth, 1983; Howarth and Stone, 1990; Howarth, 1991).

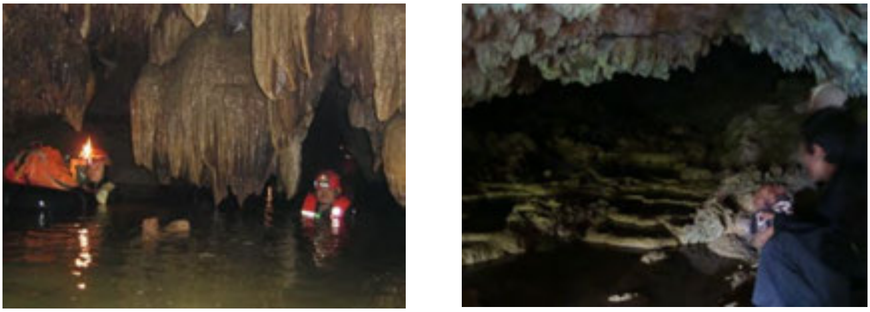


Figure 1. Left: The opening of Gondang Cave showing rimestone pool as a result of flowstone stream of water resulting from the process of karst formation, located in Sukolilo Village, Sukolilo Sub-district and Pati District.
Right: The appearance of undersurface river and the ornaments of the caves of Urang and Jemblong Kembang, Tawangharjo Sub-district, Grobogan District

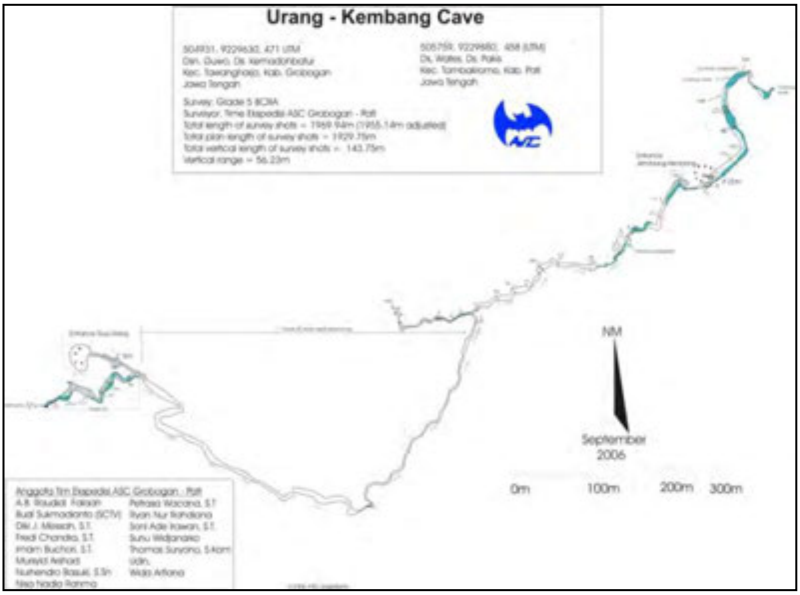


Figure 4. Map of Urang – Jemblong Kembang Cave system, Grobogan karst Tawangharjo Sub-district, Grobogan District

The caves in North Kendeng Karst Region stretch from the west to east. The lining of the caves follows a pattern of faults, cracks and layers. The development of these cave trails is controlled by a geological structure indicated by the appearance of a stretching trail which is formed as a result of dissolving through cracks and areas of faults as well as the development of dissolving in the areas of stone coating influenced by the existence of cracks following a pattern of stone coating.

Karst Hidrology

Regionally the hydrological pattern of North Kendeng Karst Region follows a pattern of parallel flow where there is a line of springs and it following an existing geological structure. Such a flow pattern is a reflection that the flow pattern of rivers in the karst regions of Sukolilo-Pati and Grobogan is influenced by a developing geological structure (Map of Flow Pattern is attached). The flowing rivers are divided into two zones, i.e. north and sout flowing zones. Both north and south zones are rivers coming out from the cracks of limestone in the region or karst springs with a type of spring called fracture springs. The formatin of fracture springs is due to the formatin of faults in this region in the process of elevation and folding.

The zone where the line of springs is found is a former saturation zone. In the northern zone the karst springs are found in areas with lower relief down to the areas with the height of 20 - 100 mdpl and in the southern region at around 100 - 350 mdpl. Another proof that the process of karst formation in this region still continues and its hydrological function is the discovery of undersurface rivers that form surface streams through the corridors of cave openings located in the region of Sukolilo. This proof is seen from the underground water found in the caves of Wareh, Gondang, Banyu, and Pancuran. These four caves are both active cave and underground river systems. Such a phenomenon gives a picture that the range of hills in North Kendeng Karst Region functions as recharge area and then the absorbed water is distributed through the springs emerging in the part of settlement and the flat areas around the karts region of Pati.

In North Kendeng Karst Region there are 33 springs sorrounding Grobongan Karst Region and 79 springs sorrounding Sukolilo Pati (North Kendeng) Karst Region. All these springs are parenial, meaning water flows in a constant rate of flow even during the dry season. From the calculation it is known that the emergence of water changes along the season. During the dry season based on the calculation of 38 springs found in Sukolilo water reaches the rate of 1,009 lt/second, and fulfils the need for water of 7,882 households in Sukolilo District. From the 18 springs in Tawangharjo District the rate of water reaches 462.796 lt/second and suffices for 5,000 households in the districts of Tawangharjo and Wirosari, in Grobogan District. This calculation will go up drastically during the rainy season.

Function of Region

The principal function of Sukolilo Karst Region Kawasanis hydrological, meaning it is useful for the continuity of karst region ecosystem. Many issued outlets on springs indicate that Sukolilo Karst Region is an active karst region that is in the process of karts formation. The water flowing through undersurface rivers and spring has important function for every living asset and the livelihood in the karts region, both for the living creatures in the caves, the flora and fauna in the surface, as well as human being as the main component that has important role in an ecosystem. This region of limestone hill range has the characteristics of a karst region.

The important characteristics of peculiar formed hills and valleys due to dissolving process are caves, undersurface river flow and springs. The rainwater falling in the hills will penetrates into the land, goes into the cracks and the pores of limestone become conduit flow. Furthermore, water flows to a lower place through cracks and slope of stone layers forming cave trails, becoming undersurface river flow. And eventually water will go up again to the land surface in a lower place and becomes spring.

The physics and geological structure of this range of hills has perfectly keep water and maintain water in an ideal amount and mass. As a result, there is fulfillment of water for local people in the dry season until the coming for the next rainy season. Generally karst hill and epikarst zone have been able to keep water up to three or four months, until the end of the rainy season with the result that most underground river and springs flow all year long with a better quality" (Haryono, Eko, 2001).

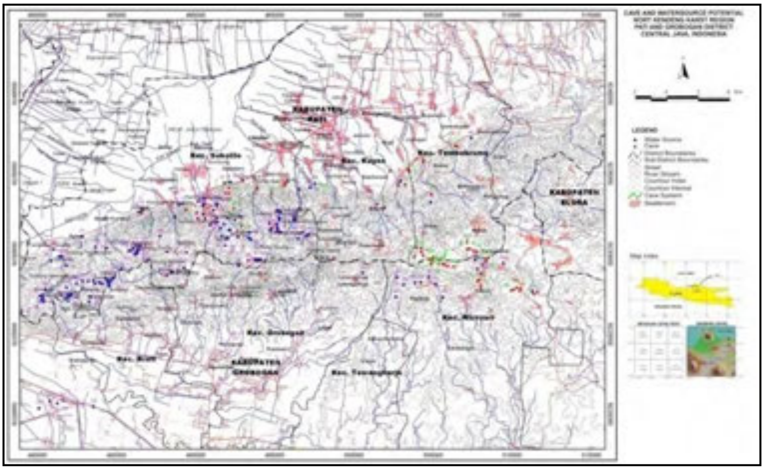
Epikarst springs, according to the study of Linhua (1996), are known to have superiority in the matter of:

1. Quality of water. The water coming out from epikarst springs is very clear because the existing sediment is trapped in filled materials and cracks.
2. Stable rate of flow rate. The srpings coming out of epikarst zones can flow even two or three months after the rainy season with stable rate of flow.
3. Easy to manage, epikarst springs are generally found in the foot of a hill range so it can be retained without pumping.

This karst region becomes a giant natural reservoir for all springs located in the two districts. This unique aquiver makes the water resources in the karst region as undersurface, spring, lake, and resurgence. Karst region is pointed out as aquiver that functions as the fourth largest reservoir after alluvial plain, volcano, and coast.

Figure 3. Sumber Lawang being the largest spring in North Kendeng Karst Region is used to fulfil the need of water for 2,000 households in two villages, both for daily needs, agriculture and husbandry, in Tengahan Sub-village, Sukolilo Village, Sukolilo Sub-district, Pati District.

Figure 4. Map of cave and springs distribution in North Kendeng karst region



Besides the potential water resources, some caves in North Kendeng Karst Region in Pati are home for bats. Bats are very important in controlling the population of insects that becomes pest and vector of the spreading of contagious diseases.

"*Bats with the average weight of arround 17 grams and can eat insects whose weight is a quarter of their body weight, certainly have important in controlling the population of insects so that there will no population explosion, meaning it will become pest",* says Sigit Wiantoro (bat researcher of LIPI, in Wijanarko 2008). The loss of hydrological function as the main system in karst region will have big impact on the life persistence of living creatures in the caves, which have many creatures not found in dry land, such as bats living in caves in day time. Caves are a space of endokarst ecosystem and in night time the bats living in the caves become balancing power of insects in the surface. Bats also function as bearers of plant types due to their flying activities where every one hour they throw away food waste and carry seeds to be spread. Beside bats, cave creatures also function as a cycle of food chain in the cave ecosystem. This is very useful to maintain biological diversity; therefore, it is necessary to wholly protect karts region in order that the existing system continues and useful for the life of living creatures, including human being.

Use of Water Resources

Water resources in karst region is a valuable asset for people around the karst region. More than 100 years ago the springs found in this karst region had been used by the communities around this region to fulfill the basic needs such as cooking, public bathing, washing and toilet facilities and irrigation for agricultural areas in alluvial plains. Beside land material coming from the volcano of Muria in the northern part of this karst region, materials originating from corrosion and sedimentation of limestone that bring contents of lime for the lands in the low parts contribute to the very high fertility of the land. It can be seen from the condition around the region, which is still green.

Almost all communities in North Kendeng Karst Region comprises the sub-districts of Sukolilo, Kayen, Tambakromo, Pati District and the sub-districts of Brati, Tawangharjo, Tanggungharjo, Wirosari, Ngaringan, Kedungjati, Grobogan, Kradenan, and Pulokulon, Grobogan District use the springs coming from the karst region of Sukolilo and Grobogan because 90% of water suply is from North Kendeng Karst Region. Almost every sub-village in the villages of Sukolilo (19 springs), Gadudero (3 springs), Tompe Gunung (21 springs), Kayen (4 springs), Kudumulyo (1 spring), Mlawat (1 spring), Baleadi (3 spring), Sumbersuko (24 springs) located in the sub-district of Sukolilo have springs with varying rate of flow from 1 liter/second up to 178.90 liter/second and those found the villages of Dokoro (12 springs), Kemadoh Batur (15 springs), Grobogan District have springs with the rate of flow ranging from 6 liter/second up to 64 liter/second. The largest spring is Sumber Lawang located in the sub-village Tengahan, the village of Sukolilo, Sukolilo District with the rate of flow in the dry season reaching 178.90 liter/second. This source can meet the need of water of more than 2,000 households in the sub-district of Sukolilo, because this source is the main one whose surface flow join with some springs around them to become a surface river that has the largest flow and is used to fulfill the daily needs such as washing, public bathing, washing, and toilet facilities, living stocks, basic daily needs and as irrigation for more than 4,000 hectares of rice field in the village of Sukolilo. Besides, Sumber Lawang has also been used as micro-hydro electric power station to fulfill the needs of electricity in the sub-village of Tengahan.

From some springs in the sub-district of Sukolilo, the lowest rate of flow is 0.06 liter/second, i.e. Sumber Ngowak in the sub-district of Tompe Gunung, the village of Tompe

Gunung, in the sub-district of Sukolilo. This rate of flow does not include the pipe flow that has been used on this source. This source can fulfill the need of 40 households around the sub-village of Tompe Gunung. Every spring in Sukolilo Karst Region can fulfill the average of water used to meet the need of water for 200 households in every sub-villages and villages. The use of water per day for each person is around 15 to 20 liters, so it can be calculated that one household can use 100 liters to meet daily needs. This can indicate that water resources in Sukolilo Karst Region exceed the capacity of water needs of the community, and water from other sources is also used for larger agricultural areas and husbandry.

Hazard and Disaster Risk

The threat of draught in karst regions often happens yearly especially in the region of Grobogan comprising nine sub-districts: Brati, Tawangharjo, Tanggungharjo, Wirosari, Ngaringan, Kedungjati, Grobogan, Kradenan and Pulokulon. This is caused by the physical characteristics of the limestone region where water tends to go beneath the surface of caves, vertical holes (sinkhole) and undersurface rivers, with the result that the community uses the available water resources to fulfill daily needs. Mismanagement of this region can have impact on the disturbance of hydrological system.

The less control of local policies to manage karst region can cause threat for the biological persistence of living creature in karst ecosystem. Sustainable development should have the perspective of disaster risk reduction. Can development reduce disaster risk or can it add new risks? The loss of hydrological function due to the damage of environment and excessive exploitation of natural resources can damage the existing ecological system, which can cause new vulnerabilities. This can have impact on the happening of draught and other ecological disasters.

Disaster is a phenomenon or a series of happenings the threathens and disturbs community life and livelihood caused by both natural or non-natural factors and human factors so that it causes casualties, damage of environment, loss of properties and psychological impacts (Law No. 24 on Disaster Addressing, article 1, clause 1). Disaster is a social phenomenon being collective consequence of hazard component in the form of natural and/or manmade phenomenon on one hand, and with vulnerability on the other hand. Disaster happens if the community has lower capacity compared to the level of threat that can affect it. Every individual, both community and larger social units develops capacity of coping system in responding threat (Paripurno, 2002). The response is short-term and is called coping mechanism or a longer term known as adaptive mechanism. The mechanism in facing changes in short term principally aims at accessing basic life needs: security, clothing, food, while the long term mechanism aims at strengthening life resources (Paripurno, 2002).

The threat of draught is a yearly cycle for some regions in North Kendeng Karst Region especially in Grobogan Karst Region as the highest area in this region. Development with the perspective of disaster risk reduction can give positive input for the continuity of karst region so that it can reduce the risk towards the existing assets. If development is not in the perspective of disaster risk, it will give negative input that can give threat to the continuity of a region, both ecologically and physically especially to the living assets found in karst regions like existing water sources. This can threaten more than 13,000 households and more than 4,000 hectares of agricultural areas and plantation that make use of existing springs so that it can have high risk towards the communities in the vicinity of the region in a long period of time and can cause disaster.

Regional Management

The environmental management of disaster risks is related to the participative management of all assets of life and living in Sukolilo Karst Region are amongst others: (1) Natural assets: natural resources, water, area and environment; (2) Physical assets: infrastructure, road, facilities and so forth; (3) Economic assets: agriculture, hustandry, property; (4) Human assets: way of thinking, human resources, knowledge and so forth; (5) Socio-cultural Assets: social order, environmental wisdom, culture and tradition, belief, mutual community help and local institutions. In management, karst regions should be wholly paid attention to in order to maintain the existing system at the surface or under the surface. In order to keep the assets in karst regions should be protected against the existing hydrological system, as agent of control, maintaining the persistence and continuity of the process of karst formation in a karst region. The persistence karst region is an entrusted object for grandchildren in the future. Therefore, there should be law force that can adjust and protect the karst region.

The management of karst region must be implemented by every party especially the local government and the community living in the region in a participative way. The increase of population in the future will give emphasis on karst region ecosystem and will have impact on environmental degradation. The strategy of karst region management is basically efforts of conservation of ecosystem functions in karst environment and controlling ecological function that can urge for balance, harmony, and persistence of the region by involving all parties.

The integrity of regions in North Kendeng Karst Region comprises the sub-districts of Grobogan, Pati, and Blora in order to achieve the same objective in reducing vulnerabilities that can cause disaster risks. Environmental management should be holistic and comprises biotic, abiotic, economic and socio-cultural aspects. Lay-out planning has to be optimized karst region potential in order to accomodate the dinamics of the development that has sustainability and pespective about disaster risk reduction. Strategic role in community-based management of karst region by making the community in this region as main actor who plays important role for government policy in order that legal protection of a region can be guarantee for a region that gives profit to all parties.

Conclusion

Based on the outcome of study it is concluded that:

1. The area of hill range in North Kendeng constitutes a karts region with the process of karst formation in this region is still active and continues until now, and this is proved by the many springs coming out from spring outlets through limestone cracks as well as undersurface rivers going out through cave openings.
2. The geomorphology of Sukolilo karst region is a structural karst region with surface morphology in the form of conical hills, long fault slopes, dolena, and karst springs. In the endokarst morphology structural cave systems and underground rivers developing in a crack pattern.
3. The developing flow pattern (hydrological system) is the pattern of parallel flow controlled by geological structure and the process of dissolving in the region. The juxtaposition of karst springs in the north and south of Sukolilo range of hills come out at the revolution rate of 5 - 150 mdpl, with the radius of 1 - 2 km from the range of hills. In the karst region of Grobogan, the emergence of karst springs is at the revolution rate of 425 - 450 mdpl and in the southern zone they reach the height of 300 - 450 mdpl. The springs and underground river system in the karst region of North Kendeng is parennial in nature.

4. The springs and underground river system in the karst region of Sukolilo (North Kendeng) is parennial in nature.
5. The cave complex in North Kendeng Karst Region has the potential of water resources for the basic household needs and agriculture. Besides, there are cave creatures that control pests.
6. North Kendeng Karst Region functions as recharge area and then the absorbed water is distributed through the springs emerging in the part of settlement, both in the north and south of this region.
7. More than 8,000 households living around Pati region, especially in the sub-district of Sukolilo and another 5,000 households in Grobogan, especially in the sub-districts of Tawangharjo and Wirosari are very dependant on the springs and underground water coming out from the caves located in North Kendeng Karst Region as their living resource. Settlement in the region follows a pattern, where they are close to the springs, especially the upper regions.
8. The many springs coming out from stone cracks and undersurface rivers are very important for land fertility and the productivity of agricultural lands located in the lower parts or in the plains and the areas of plantation as well as the forest in the upper parts as living assets and livelihood of the local community.
9. The management and use of water resources in Sukolilo Karst Region still use conventional methods; however, it use can meet the basic needs for clean water in the region.
10. Hydrological function in North Kendeng Karst Region is the main controlling factor of ecological sistem that comprises the relationship of abiotic components (land, stone, river, water, etc.), biotic components (cave creatures as well as flora and fauna in the karst region), cultural components (social domain, community, culture, and customs) that interact each other to an ecosystem where karst becomes the main controlling factor.

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GROUTING OF AN UNDERGROUND CONCRETE BARRAGE IN KARST LIMESTONE

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Abstract
By means of a case study, a successful implementation of a grouting curtain in pervasively karstified limestone is presented in this paper. Within the scope of a German-Indonesian joint project, the grouting curtain was constructed under difficult climatical, spatial and geological boundary conditions. It has to assure the durable water storage of an underground barrage with a hydropower plant in the region of Gunung Sewu in central Java, Indonesia. Based on geological mappings, exploration drillings, Lugeon tests and an extensive test grouting, the mix compositions of the cementitious grout suspensions were adjusted continually to the conditions of the karstified rock mass. The sealing success was demonstrated with test storage, revealing a reduction of seepage water by approx. 95 % compared to the initial status. From a technical and economical point of view, the rheological behaviour of the injection material is the key factor to achieve the best possible sealing of porous karst rock. In this regard, the authors‟ works revealed an enormous optimisation potential which is currently investigated with the objective to develop novel, cementitious grouting suspensions.

Keywords: barrage, grouting, suspension, cement, rheology, karst

Introduction

The reliable and durable sealing of hydraulic engineering structures in karst areas has an outstanding significance for their serviceability and structural safety. Usually it takes extensive efforts to prevent or minimise seepage. The ambitious project is demonstrated in this paper by means of a case study, where a grouting curtain in pervasively karstified limestone was successfully constructed under difficult climatical, spatial and geological boundary conditions. It has to assure the durable water storage of an underground barrage with hydropower plant.

Within the scope of a German-Indonesian joint project, funded by the German Federal Ministry of Education and Research (BMBF), a hydropower plant with an underground concrete barrage was initialised, planned and built during the years of 2002 to 2006. During the dry season, it provides an urgently required water supply for the karst region Gunung Sewu in central Java, Indonesia [Müller *et al*. 2008; Nestmann *et al*. 2008]. In the meantime the plant situated in the Bribin cave near the city of Wonosari has been successfully tested and operated and was commissioned to the Indonesian government in March 2010 [Nestmann *et al*. 2011].

Within an ongoing German-Indonesian follow-up project funded by the BMBF, the hydro power plant is planned to be embedded into the frame of an "Integrated Water Resources Management" (IWRM), which couples all aspects of water supply, distribution, usage and treatment in an overall concept [Oberle *et al*. 2005]. The authors‟ objectives are the development and provision of appropriate technical engineering concepts for the model region of "Gunung Kidul". Subproject 5 (IMB) focuses in particular on the warranty of durable watertight and functional hydraulic constructions and Subproject 4 (IBF) on the short and long time behaviour of karstic rock mass near hydraulic pressurised underground constructions.

The present paper focuses on the optimisation of cementitious injection materials for a reliable grouting of porous karstic rock and the adaption of the working procedures to the encountered karstic rock conditions. The objective of the works described in detail below was the effective and economical sealing of the karstic rock surrounding the concrete barrage in Bribin to minimise the incidental seepage water and to guarantee the secure and durable long time operation of the plant consequently.

State of The Art

Seepage problems occur in hydraulic structures all over the world, in particular in karst areas [Foyo 1997; Kreutzer 1997]. For a reliable sealing of those structures (e.g. excavations or dams), special injection procedures are used which can be applied according to the respective present conditions in concrete, rock, masonry or soil [Akinrogunde 1999; Westendarp 2006]. Injection materials can be divided into three main groups: polyurethane resins, highly elastic, soft gels based on acrylates or methacrylates as well as cementitious suspensions and mortars [ASTM C845-2004]. The advantages of cementitious injection materials compromise low costs, deformation properties similar to solid rock, a high durability as well as the toxicological innocuousness.

While the reliable injection of cracks in concrete or masonry meanwhile may be assumed as state of the art [RILI-SIB 2001], the injection of rock still must be considered as a challenge of the injection techniques [Kreutzer 1997; Linortner 2009]. In particular fillings of karst cavities with highly argillaceous marls or clays are extremely problematic, as those can not be displaced or consolidated without additional measures. Nevertheless these fillings may be washed out under a permanent flow of pressurised water because of regressive erosion, which can lead to increasing infiltrations especially in continuous joint systems.

Numerous case studies show that the difficulties of karst rock injections can be dealt with in different ways [Foyo 1997; Kreutzer 1997; Linortner 2009]. Mostly, the optimisation of the grouting materials is done based on empirical approaches, e.g. the study of relevant literature, the experience of the executing engineer and own, often extensive preliminary explorations and tests. The raw adjustment of the viscosity of the injection material is usually carried out by an adjustment of the water/cement-ratio while retaining mostly constant amounts of bentonite to guarantee the suspension stability. If necessary, the addition of admixtures and additives such as fly ash or superplasticisers for further control of the viscosity of the suspension or of sand to fill larger cavities with mortar is recommended. Lugeon tests are a suitable measure to estimate the feasibility of the respective rock mass for an injection a priori and to characterise its permeability respectively.

Initial Situation

Concrete barrage. Compared to common barrage dimensions the present concrete barrage is small. It has a height of 8.5 m and a width of 15.0 m. Its depth varies between 1.5 m and 2.5 m (Fig. 1). The multiangular shape of the barrage comprises good load-bearing properties and a minimisation of production and formwork complexity in the narrow cave environment.

The curvature in vertical direction is explicit higher as in horizontal direction, so that the water pressure during the operation is mainly transferred by the cave roof and bottom. The design water level for the operation of the plant is limited to 20 m hydraulic head (maximum storage height), for accidental high water situations to 30 m. During the long time operation 80

000 people of the circumjacent region are planned to be supplied with 70 liters of water for drinking and domestic use per capita and day (lpcd) [Nestmann *et al*. 2008].

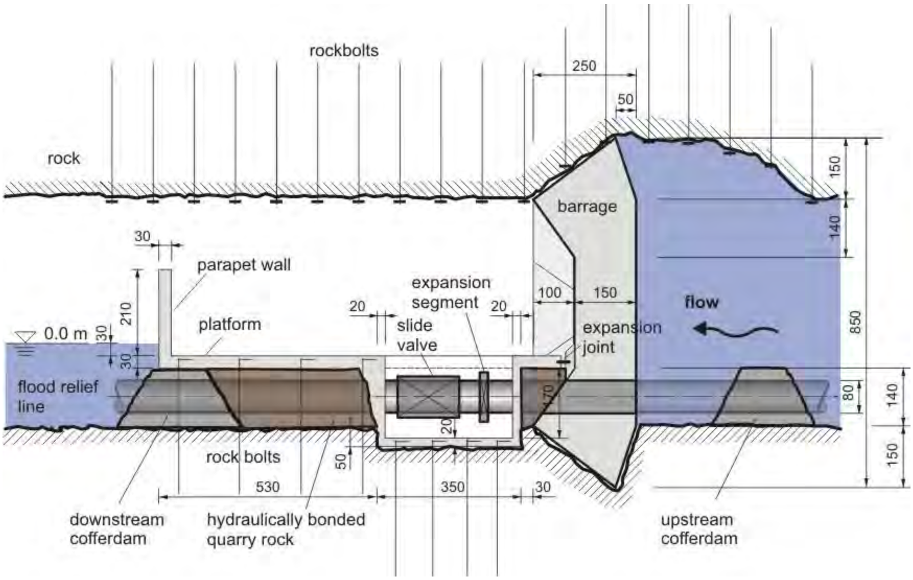

Figure 1. Drawing of the plant (longitudinal section, without components of the hydraulic power plant) with the functional elements cofferdam, flood relief line, barrage and platform with sliding valve chamber [Bohner *et al*. 2009]

Geology

The geological situation at the location of the barrage was initially investigated by surface mappings during speleological explorations. When the access for heavier equipment was given by the shaft, core drillings, 10 m long, were made in the cave. Three drillings were executed in the top (vertical) and both side walls (horizontal). Five more drillings were made in the bottom (vertical). Figure 3 shows the geological surface mapping of the construction area [Mutschler and Berner 2005]. The reef limestone was subdivided in four homogenous areas. HA1: massive banked limestone HA2: cavernous reef limestone HA3: collapsed cavernous reef limestone HA4: breccious limestone in a smooth clay matrix.

Laboratory tests of rock specimens from cores and hand pieces revealed porosities between 5 and 20 % by volume, bulk densities between 2.2 and 2.6 g/cm³, moduli of elasticity between 2 000 and 10 000 MPa and compressive strengths between 10 and 80 MPa which approved the first impression of a strongly varying rock quality. Rock mass properties were assessed by experience as well as rating procedures and gave deformability moduli in the range from E_v = 5 MPa (HA4) to E_v = 5 000 MPa (HA1). The rock mass strength varied from very poor (behaviour of soft clay (HA4)) to good (c > 5 MPa, φ > 40° (HA1)).

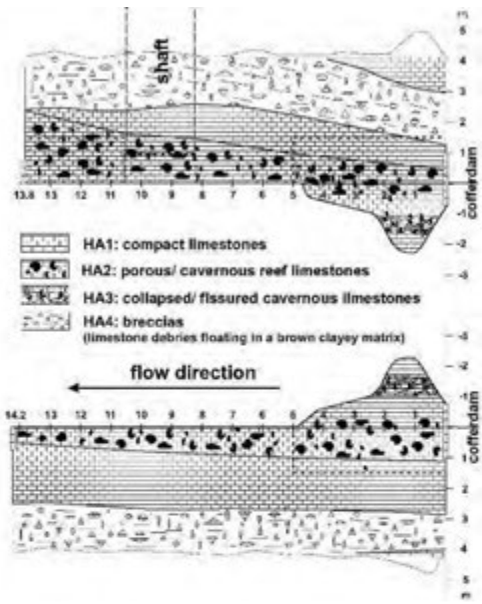

Figure 2. Result of the surface mapping and of the analysis of a vertical drilling in the bottom of the cave [Mutschler and Berner 2005]

Seepage water

In order to quantify the permeability of the surrounding karstic rock mass and to assess the seepage potential, constant and falling hydraulic head tests were performed before the construction of the barrage [Müller *et al*. 2008]. They allowed for first evaluations and indicated problem areas with a rather high permeability. The cave roof showed a very low permeability even though noticeably increased permeabilites were measured in areas more than 4 m above the cave roof. In the lateral rock areas with poor rock quality as well as in the bottom area higher permeabilities were indicated, which may even increase with time because of regressive erosion processes. Thus, the option of a 15 m deep circumferential grouting curtain was already intended in the pre-design.

Its necessity became apparent during the first successful test storage after the finalisation of the barrage construction. The surrounding karstic rock mass was able to bear the water pressure for a limited time before a hydraulic breakthrough occurred in the breccious formation (HA4). The seepage water amounts accumulated to 1366 l/h at a hydraulic head of 19.6 m.

Design of the grouting curtain

Together with the Indonesian project partners it was decided to realise the pre-designed grouting curtain to reduce the existing seepage water amounts. Furthermore the risk of a hydraulic breakthrough should be overcome already prior to the permanent operation of the plant, even though the serviceability or the structural safety of the concrete barrage were not endangered at any time.

The development of the grouting material compositions was previously laboratory-confirmed in Germany on an empirical basis. The draft design for the execution of the grouting works was projected by the authors and discussed with the Indonesian authorities. Test injections in the cave formed the basis for the detailed implementation planning, the material selection and for the estimation of the material amounts. The layout of the grout curtain is illustrated in figure 3.

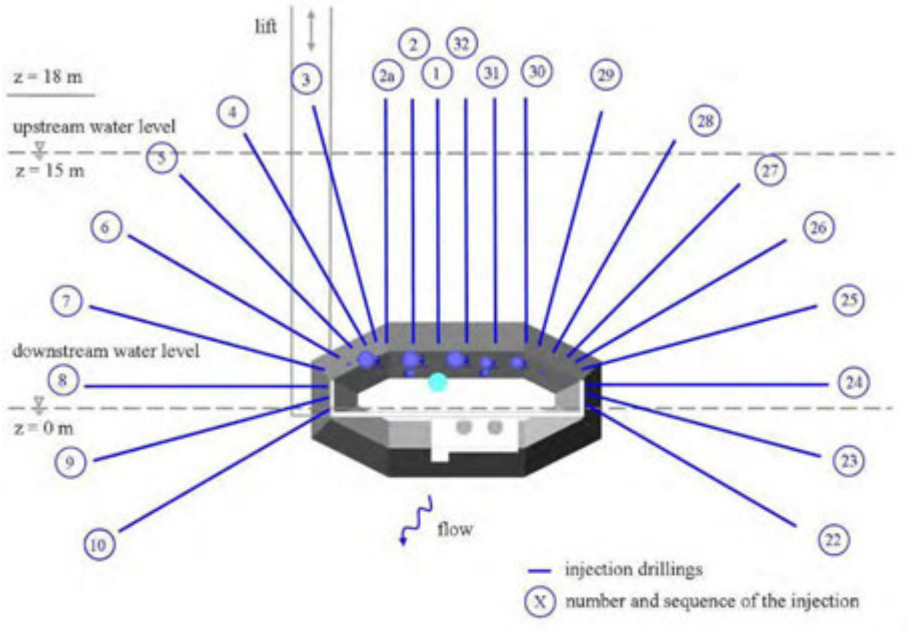

Figure 3. Design of the grouting curtain surrounding the barrage

The grouting curtain was planned as a single-layer, fan-shaped injection curtain with the option to be supplemented by a second layer. The length of all drill holes should amount up to 15 m from the cave roof to exceed the storage height of the planned long-time operating conditions. In addition to the orientation in the vertical plane (Fig. 3), all drill holes have an inclination of 10 degrees towards upstream. The drilling and grouting works took place at the downstream face of the barrage.

Construction of the grouting curtain

Construction materials and mix design. The application of *cementitious* injection material is basically known in Indonesia and the respective equipment and technology for grouting exists. The main restriction for planning and construction was to use only locally available source materials. Their selection and their properties are discussed in the following.

Cement. Numerous cement plants exist in Indonesia being controlled by worldwide operating cement producing companies. However, no fine cement is available and in practice only Portland cements (OPC Type I) and so-called Portland puzzolanic cements (PPC) are used. Preliminary experiments and investigations at the IMB substantiated to favour OPC type I for the injection works in Bribin. The cheaper PPC held a substantial amount of indissoluble components, had a lower grinding fineness and was consequently excluded.

Bentonite. By means of x-ray diffraction analysis, the bentonite used in the cement paste could be indentified as sodium-bentonite. Using x-ray fluorescence analysis, which was performed together with the Institute of Mineralogy and Geochemistry (IMG), the quantitative composition of the material was determined. To activate the bentonite, it was prehydrated at least 15 minutes prior to its use in the grouting process.

Additives and Admixtures. Super plasticiser was not used in order to ensure an economic injection mix. Admixtures like fly ash do not exist in Indonesia or they are available as expensive import products only. Locally available ashes from the hillsides of Merapi volcano were investigated but unfortunately did not show any hydraulic properties, which were necessary for a qualified use in the injection process.

Aggregates

During the exploration of numerous digging and excavation facilities for sand and rock as well as gravel and concrete plants in the region of Yogyakarta, important information for the selection of concrete aggregates in Indonesia was gained. The sand used for construction measures in Yogyakarta and the Gunung Sewu exclusively comes from the Merapi area. It can be described as raw volcanic sand with a moderate porosity and a comparatively high dry density. As no bigger cavities were detected in the cave during the test drillings and injections respectively, the usage of sand was abandoned.

Water

The Bribin underground river water was used as addition water. The investigation of its chemism in cooperation with the IMG revealed a good applicability.

Mix design

Based on Lugeon tests and an extensive test grouting, the mix compositions of the cementitious grout suspensions were adjusted to the conditions of the karstified rock mass. The material behaviour was studied and optimised in situ to achieve optimal grouting results. To control the viscosity of the cement suspensions, the respective water/cement-ratio was varied according to the injection success between 1.5 ("very pourable") and 0.6 ("slightly plastic") following the known, empirical approaches from literature. The amount of bentonite in the process was kept constant at 3 % by mass of the cement weight to control the sedimentation behaviour of the suspension and to act as lubricant for the pumping operation. Table 1 summarises the material properties.

Table 1. Summary of the material properties

Material	cement	bentonite
Type	OPC Type I	Sodium-type
Density	3.08 kg/dm³	2.70 kg/dm³
Grinding fineness	2846 cm²/g	2563 cm²/g
Remarks	-	3 % by mass of the cement, 15 min. prehydrated
w/c-ratio	between 0.6 and 1.5 depending on the rock permeability	

Execution

The grouting works were executed by the Indonesian company PT Geoteknika, located in Bandung, Java, Indonesia. Their technological knowledge and equipment determined the site facilities, the logistics and the construction process. Technical support, supervision and the evaluation of the works were provided by the authors on-site.

As a result of the spatial restrictions in the Bribin cave, the construction of the grouting curtain was realised with simple equipment, which could be easily disassembled and thus be transported into the cave (Fig. 4, left). However, no reliable logging of the injection pressures and amounts of grout was possible. The flow rate could be measured only by estimating the filling level of the agitator.

Figure 4. Drilling and injection equipment (left) and drilling cores providing detailed information on the karstification of the rock mass (right)

Grouting works

At first the drill holes were carried out having a length of approx. 15 m and a diameter of 63 mm each. Since the drillings were performed with the core drilling technique, an exact evaluation of the geology was possible on-site (Fig. 4, right). Apart from the documentation of the core samples, the notable karstification of the surrounding rock was also approved by several implications during drilling like the strong varying drilling rates or clayey discolourations of the flushing water. The mean progress of drilling amounted to 1.5 to 2 m per hour.

After drilling, the holes were flushed with water to remove loose and unconsolidated clay and marl fillings. Lugeon tests were performed to judge the rock permeability on the basis of pressure-flow rate correlations. The cement suspension was mixed in batches of 200 litres and stored in an agitator. A reciprocating piston pump kept the suspension constantly in motion around a circulation line to the injection hole and back to the agitator if only little grout take prevailed. The packer consisted of two thermoset pieces with a length of 10 cm and a diameter similar to the drilling hole diameter. They were mechanically braced against each other to tighten the drilling hole. The grouting was executed step-by-step from top to bottom in sections of two or three meters according to the particular porosity of each section.

The injection was performed at each packer position until a predefined intake criterion was reached. This was defined either as the gravity filling of 400 litres of injection suspension or a grouting pressure increase exceeding 12 bars. The first intake criterion was followed by a reduction of the water/cement-ratio to reduce the viscosity of the cement suspension whereas the second criterion defined the end of the injection for the respective grouting stage. These two criteria were intended to limit the amount of suspension volume on the one hand and to prevent the fracture of rock by application of an ultimate pressure on the other hand.

Difficulties during the construction works

The inhomogeneous karstic rock mass was often challenging the injection works. Problems like sudden injection pressure decreases, the uncontrolled flow of suspension due to widening joint systems or the partial loss of suspension due to connections with other holes or leakages in the rock had to be overcome. Cavities, filled with clay, which could not be flushed away or consolidated completely, prevented a complete bonding of the injection material with the surrounding karstic rock. It became evident that from a technical and economical point of view, the rheological behaviour of the injection material is the key factor to achieve the best possible sealing of porous karst rock. Apart from these geological problems, the narrowness due to the meanwhile installed hydraulic equipment, power blackouts and floodings complicated the works and extended the construction time.

Results

The main grouting activities took place from April to May 2009. During these primary injections, all in all 52 tons of cement and 1.5 tons of bentonite were injected which corresponds to a mean grout take of 222 litres per meter drilling hole. The grouting curtain was completed in spring 2010 when nine secondary injection drillings and some water-bearing drainage holes were grouted subsequently. In the course of the secondary injections, 6 tons of cement and 200 kg of bentonite were used, which corresponds to a mean grout take of 61 litres per meter drilling hole.

Seepage water

To judge the efficiency of the grouting curtain, the seepage water amounts may be compared at the different stages of the construction process. By means of test storages of the karst water reservoir, each time an operating state of the plant was simulated. The water dropping out of the drainage holes was collected and measured in regular intervals. The reference value was the seepage water amount in the stationary case, i.e. after the saturation of the surrounding rock mass due to the present hydraulic head (Fig. 5, left).

Without the injection curtain, the measured amount of seepage water summed up to 1366 litres per hour at a hydraulic head of 19.6 m. The primary injections already led to a considerable decrease of almost 50 % to 724 litres per hour at a hydraulic head of 21.3 m. By means of the secondary injections the volume of seepage water could be significantly reduced to a value of approx. 70 litres per hour at a hydraulic head of 15.2 m. This corresponds to a reduction of 95 % compared to the initial status (Fig. 5, right). This impressive result was obtained by performing a selective and efficient injection with comparatively small amounts of suspension and can be considered as a proof for the effective implementation of the grouting curtain.

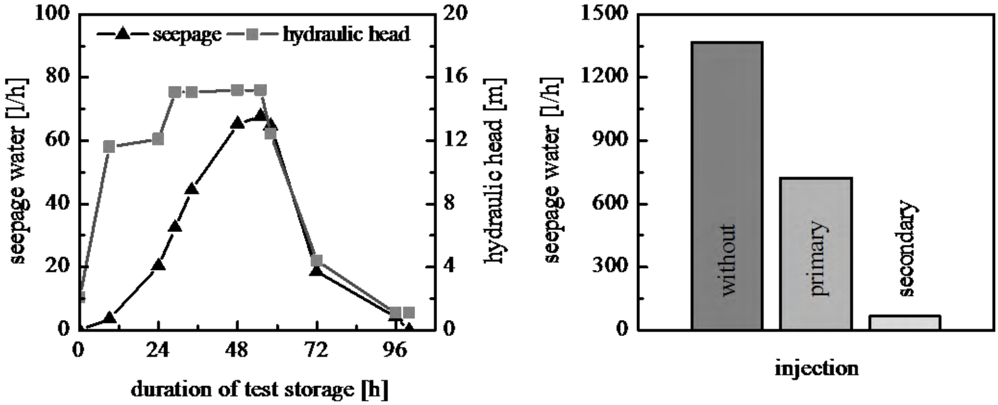

Figure 5. Exemplary graph illustrating the result of a test storage after the secondary injection measure (left) and comparison of seepage water amounts at different stages of the construction process (right)

Conclusions

Following Linortner *et al*. (2009) a seepage water amount of 1 % of the mean annual design discharge forms a maximum acceptable value for the permeability of a hydraulic barrage construction. In Bribin this value is only about 0.0013 %. However, it has to be kept in mind, that water, which possibly passes underneath the barrage, can not be detected. Nevertheless, the efficiency of the grout curtain can be named as excellent, which assures the serviceability and the operational safety of the plant even in the case of a long-time maximum hydraulic head.

The hydro power plant Bribin is planned to start its regular operation in spring 2011. Even though the seepage water amounts were significantly reduced, a permanent seepage water monitoring is foreseen.

Outlook

The rheological behaviour of the injection material turned out to be the key factor to achieve the best possible sealing of porous karstic rock mass. In this regard, the authors" works revealed an enormous optimisation potential which is currently investigated with the objective to develop novel, cementitious grouting suspensions within the BMBF joint project “Integrated Water Resources Management” (IWRM).

Based on the experiences in Bribin, the academic identification and investigation of the relevant parameters combined with the application of the latest knowledge in building materials rheology and novel measurement techniques will form the next step of the ongoing research. Newly designed injection materials with optimised properties may reduce the perfusion of karst joint systems and may lead to a stabilisation of clay layers against regressive erosion. Consequently, the use of underground water resources as water reservoirs could be a groundbreaking alternative in many regions throughout the world.

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OPTIONS FOR DECENTRALIZED WASTE WATER TREATMENT IN RURAL KARST AREA IN GUNUNG KIDUL: SOCIAL ACCEPTANCE

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Abstract

To overcome water scarcity in rural karst area of GunungSewu, water which flows through the caves, namely Bribin cave, is retained by an underground dam and distributed to the people. Karst aquifers are often considered as highly vulnerable to contaminations from human activities, since the water from the surface, including pollutants, penetrates to the ground almost without filtration. Therefore the potential problems caused by current sanitation and hygiene practices in Bribin‟s recharge area have to be well anticipated in order to protect Bribin‟s water sources. This paper presents results of community acceptance research on decentralized sanitation options for rural karst area in Bribin‟s recharge area, which is conducted by KIT-ITAS and the Faculty of Geography, GadjahMada University in Yogyakarta, within the joined Indonesian-German research project IWRM in GunungKidul, Yogyakarta, Indonesia. The options analyzed include: (i) composting and urine diverting toilette, (ii) communal bathing-washing-toilet facility, (iii) anaerobic treatment for biogas recovery and (iv) grey water reuse. As comparison, the most common sanitation technology applied in the area -classical siphon toilette equipped with septic tank- will also be considered. The preliminary results achieved from the survey reveal that the acceptance of the existing system (septic tank) is still high, namely 91.4%. The concept of resource recovery is still new in the community; nevertheless the interest is quite high. Around 61% of the respondents are interested to use human manure as fertilizer and 62% of them would like to use urine as fertilizer. The acceptance of using biogas from human feces is rather low (25%), compared to biogas from animal manure (53%). Public facilities such as communal washing, bathing and toilette do not gain much interest like in the past time. Only 46% of the respondents are still in favor for having public facilities.

Keywords: karst area, decentralized sanitation, composting toilet, urine diverter, biogas, grey water reuse.

Introduction

The southeastern region of GunungKidul, Yogyakarta, Indonesia, namely GunungSewu is suffering from seasonal water scarcity due to its karst structure. To overcome this problem, the water which flows through the caves, namely Bribin cave, is retained by an underground dam and distributed to the people. From a hydrological and hydrogeological point of view, karst aquifer is characterized by the domination of underground stream that leads to the lack of surface drainage pattern (Adji and Sudarmadji, 2008). Therefore, karst aquifers are often considered as highly vulnerable to the contamination from human activities since the water from the surface, including pollutants, penetrates to the ground almost without filtration (Kacaroglu, 1999).

Due to this fact, sanitation in karst area should be appropriately managed. Currently the local government of GunungKidul tries to formulate the sanitation strategy. According to the Sanitation White Book 2010 of the Local Planning Agency *(Bappeda)* in GunungKidul, a centralized off site system for wastewater treatment is considered inappropriate for the region, due to topography and demography conditions. Karst GunungSewu refers to the uncountable conical hillocks and dolines, 0-400 m high, and with 8°- 40° slopes (Bappeda, 2010). Compared to the population density in Java Island which reaches 1000 inhabitants/km^2, the GunungKidul population density is relatively low, namely 462 inhabitants/km^2 (Statistic

Bureau, 2009). Hilly region, scattered settlement and relatively low population density lead to high construction and maintenance costs for any offsite treatment. Wastewater cannot be transported only by gravity system and it needs long distance sewerage. Due to these facts the planning agency prefers onsite systems, such as well constructed septic tanks or communal wastewater treatment.

This paper presents results of community acceptance investigations on decentralized sanitation options for rural karst area in Bribin"s recharge area, which are conducted by KIT-ITAS and the Faculty of Geography of the GadjahMada University in Yogyakarta, within the joined Indonesian-German research project IWRM in GunungKidul. The options analyzed include:

(i) Composting and urine diverting toilette,
(ii) Communal bathing-washing-toilet facility,
(iii) Anaerobic treatment for biogas recovery and
(iv) Grey water reuse.

As comparison, the most common sanitation technology applied in the area -classical siphon toilette equipped with septic tank- is also presented.

Methodology

The methodology of this research is based on questionnaires, interviewsand field observation. The questionnaire is structured in five parts: (i) social and economic conditions, (ii) water sources, (iii) sanitation and solid waste, (iv) role of agriculture and industry, and (v) degree of environmental awareness. The main focus is on community"s acceptance concerning water management; therefore questions referring to water and sanitation were prioritized. The questionnaire consists of closed questions. Before starting the questionnaire, the interviewer has explained the technology options to the respondents, so that they have information on how the technology functions. In village Gombang, a workshop on technology options has been held before the questionnaires started.

Selection of research area

Since the main goal is to protect Bribin"s water source, the management and control has to be started from its catchment area. Therefore the research area is focused within the catchment area, whose boundary has been identified by previous research of Adji and Sudarmadji (2008).This survey focuses on four villages which are located in the southern part of the catchment area, which are the closest areas to Bribin"s water source (Fig. 1)

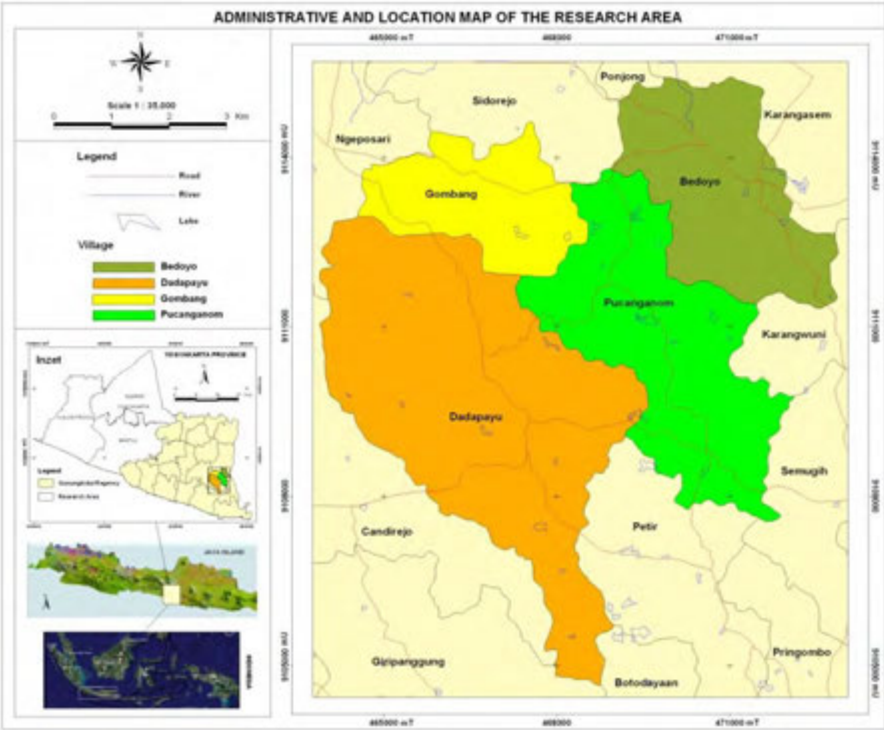

Figure 1. Administrative Map of Research Area

Selection of respondents

The number of households in the area is 4657. The number of respondents is defined based on arithmetic method, namely 355. The sampling method is based on proportion random sampling.

Findings Social economic condition related to water.

Around 65% of the total respondents work as farmers. Most of the farmers do not receive income in cash, but many receive income in the form of harvest, loan, mortgage and support from their relatives. In this questionnaire income is estimated from respondents‟‟ monthly expenditure. Monthly expenditure for water varies greatly, depending on the water supply conditions in each village. In the four villages investigated the main water supply comes from cave Bribin and cave Seropan. Water is pumped and distributed in pipeline by water provider *(PDAM)*. The other water sources are rain water from cistern, bore wells, springs and lakes *(telaga)*. When there is no access to such sources or access is limited, a household has to buy water from vendors/tankers, which costs approximately IDR 120,000-160,000 (USD 13-USD 18) for 5000 liter - 6000 liter. This becomes a burden for the households since it influences greatly monthly expenditure, as it is depicted in Table 1 and Fig. 2.

Table 1.Water supply condition related to water expenditure

Village	Number of sub villages *	Number of households *	Water condition in village level*	Average total monthly expenditure/ water expenditure as % from monthly expenditure **
Dadapayu	20	1790	15 sub villages supplied by Bribin daily; 1 sub-village supplied by Bribin and Seropan irregularly; 4 villages are connected to Bribin but never receive water (tankers are needed).	IDR 757,570 (USD 84)/ 11.2%
Gombang	10	769	10 sub villages are all connected with Seropan and receive water daily.	IDR 780,549 (USD 88)/ 9.7%
Bedoyo	9	926	8 sub villages connected with Seropan and receive water daily and 1 sub village supplied by Bribin daily.	IDR 1,032,545 (USD 115)/ 9.7%
Pucang anom	12	1172	1 sub village connected with Seropan and receive water daily; 4 sub villages connected with Seropan only during dry season; 4 sub villages supplied by Bribin daily; 3 sub villages not connected to any scheme (tankers are needed).	IDR 680,911 (USD 76)/ 20.4%

Source:
* UGM-ITAS Survey, 2010 based on data in village level
**UGM-ITAS Survey, 2010 based on questionnaires

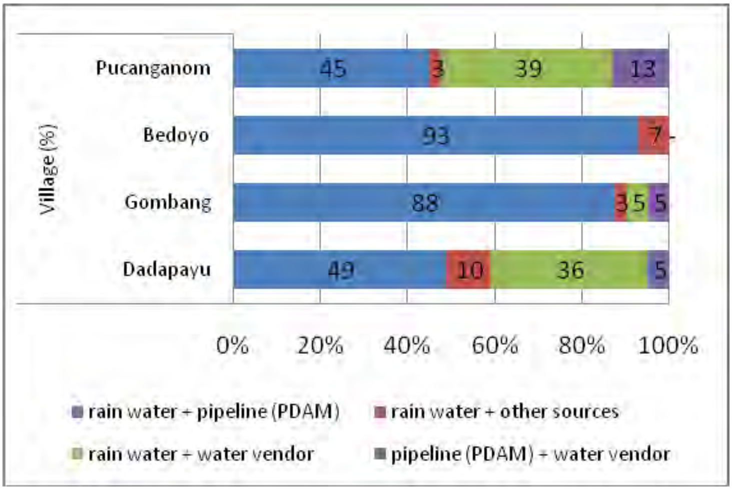

Figure 2.Water sources in survey area (household level)

Figure 3. Rain water cistern

Cisterns (see Fig. 3) or any other form of water containers play important roles:

1. In some areas in Dadapayu and Pucanganom which never receive water from pipeline, rainwater becomes the main source.
2. In some areas in which pipeline water does not come regularly, most of the respondents mix rainwater with pipeline water. Rainwater becomes an additional source. Once the pipeline water comes, cistern/containers serve as water storage for future water consumption.
3. Since pipeline water is very turbid during the rainy season, cisterns and containers function as settlement tank as well. Water should be stored for 4 days, before it can be consumed.

Sanitation condition

The discussion in this paper is limited to domestic wastewater, which means water that originates from the household. In the research areas, black water (feces and urine) is treated by using private siphon toilettes connected to a "septic tank" (68%), private simple pit latrine (30%) and shared toilette- either siphon or simple pit latrine (2%).

Simple Pit Latrine (SPL)

Simple pit latrine (SPL) is the simplest technology found in the region. The latrine is approximately 1-2 m deep and the upper part is sometimes cemented or covered by wood (Fig.4). SPL is used by communities with low income and/or with limited water supply in the region. Once the economic condition and water supply improve, people will shift to siphon toilette. Among all SPL users, 40% are not satisfied with the performance of their latrines and the rest never experiences any problems. Most of SPL (44%) will be full after 4-5 years. The rest takes longer than 5 years (24%), 2-3 years (10%) and never full (22%). Once the SPL is full, different follow-ups will be done by the respondents as depicted in Fig. 5. Due to the fact that some of the full pit latrines are used for planting (13%) and some are taken up for fertilizer (1%), the concept of resource recovery has been in practice for a long time almost in about one fifth of the households.

Figure 4.Simple pit latrine

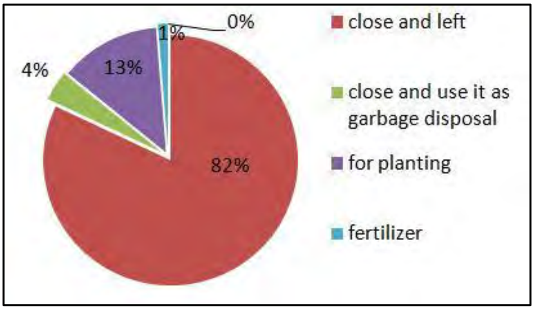

Figure 5. Follow up after SPL is full

Septic Tank

In Indonesia, it is compulsory for each household to treat its waste water using a septic tank. Indonesian National Standard (SNI): 03-2398-2002 provides a standard set of procedures for the construction of a septic tank, including the size and the minimum requirements of the tank facility. Based on this standard, a septic tank must be a strong, acid resistant and waterproof construction. Therefore, no seepage should come out of the tank.

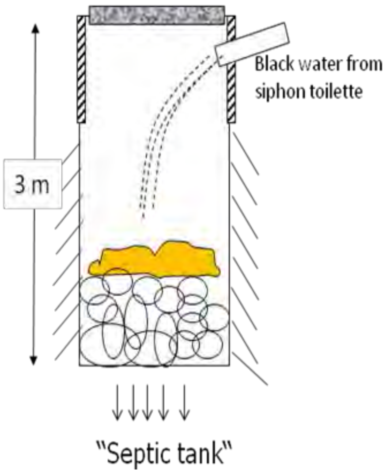

Figure 6. "Advanced infiltrationpit"

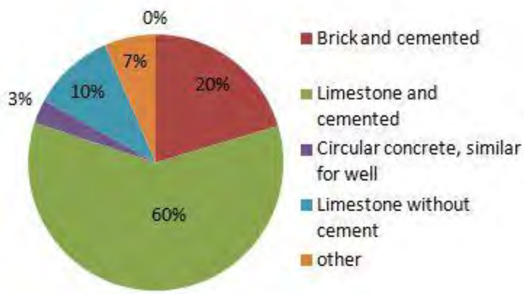

Figure 7. Material for septic tank construction

In the survey area, 68% of the respondents use pours flush siphon toilettes. Among these respondents, 96.3% equipped their siphon toilette with a so called „septic tank". To their opinion, a septic tank is a single permeable hole connected by a pipe to the siphon toilette. Therefore, a so-called „septic tank" in the survey area is actually an „advanced infiltration pit" (Fig. 6). According to 58.2% of the „septic tank „owners, the permeability are considered to be important for enabling the black water infiltrates to the ground. Therefore, most „septic tanks" (89%) are not waterproof, as the bottom parts are not cemented. Moreover, the material selected to build a „septic tank" is mostly porous stone, such as limestone which can be easily found in the region (Fig. 7). Due to this improper construction, 92.5% „septic tanks" are never full due to leakage, which will lead to ground water and soil pollution. Incomplete anaerobic digestion of organic matter may cause the drop of pH. This is particularly common in clay or loamy soils, where oxygen supply is insufficient due to physical closure of the pores in the soil by suspended soil. Furthermore, soil pollution poses a threat because of washout effect that harms both surface and groundwater (Ulrich *et.al*, 2009).

Among the respondents whose „septic tank" is ever full, only 18.2% desludge the „septic tanks" and the others just leave it or do nothing. In the research area, „septic tank" is well accepted, as 91.4% of the current users are satisfied with such a system.

Grey Water

Most of the grey water is left untreated and simply discharged to the surface (86%) and only 14% of the respondents reuse their grey water. Among those who reuse grey water, 53% reuse it for watering the plants, 38% for feeding the cattle or fishery and the rest for toilet flushing or cleaning their cattle. Since most grey water is discharged to the surface, it causes unpleasant smell and muddy condition (see Fig. 8) as mentioned by 55% respondents. The existing grey water is left untreated and unused due to several reasons as it is depicted in Table 2.

Figure8. Existing grey water discharge

Table 2.Reasons for not reusing grey water

Reasons	Percentage
No need, water is enough	25.5
Do not want to use, dirty	37.8
No facility for grey water collection	13.6
Do not know	18.0
Other	5.1
Total	100

Sanitation Options

During the interview, the following sanitation options were asked to the respondents:

Composting and Urine Diverting Toilette. Domestic wastewater contains nutrients that would be valuable for agricultural purposes (Esrey et al. 2001). About 94% of the nitrogen, phosphorus and potassium in domestic wastewater emanates from the urine and feces, together with abundant micronutrients in balanced concentrations (Lind *et al.*, 2000). Those nutrients would not be obtainable if they are diluted with large amount of wastewater (Malisie, 2008). Moreover, when urine becomes mixed with feces, this mixture is much more difficult to handle hygienically (Tanski et al., 2007). Most of human manure is treated by composting process. Both urine separation and the composting process can be obtained with urine diverting (UD) and composting toilet. Apart from the „natural" feelings of disgust that most people express towards human excreta which result in anal cleansing, Islam requires ritual cleaning after being in contact with materials that are considered to be *najis*(religiously unclean). However, the use of water for anal cleaning also appears to be a cultural habit as non-Muslim Indonesians also use water for anal cleaning (Water and Sanitation Program, 2010). To consider this need, an alternative extended compartment for cleaning is added to such toilette. During the interviews, a picture of a squatting urine diverter and composting toilet (see Fig. 9) was introduced to the respondents with adequate explanation about its functions.The acceptance of the respondents is divided into some steps as depicted in Table 3.

Figure 9. Squatting urine diverter

Table 3. Acceptance of respondents

Steps	Acceptance	
	Yes (%)	No (%)
Using composting and UD toilette	73	27
Processing urine	60	40
Processing feces	55	45
Using urine fertilizer	62	38
Using humanure	61	39

Most of the respondents (73%) are in favor of using UD and composting toilettes. For those who are not in favor, the arguments are depicted in Fig. 10. Many of those respondents are mothers representing their children, and old people, who will have difficulties to shift position when using the toilette.

The biggest hindrance in implementing UD and composting toilette consists in the processing of feces and urine. Only 55% respondents are willing to do the composting process of the feces and 60% will process their urine due to religious reasons, *najis/najassa*and health reason. According to the Water Sanitation Program 2010, based on their interviews with the staff of two leading Muslim organizations in Jakarta, it is indicated that there is no specific ruling (*fatwa*) on this issue, and in their view the selling and buying of urine and feces processed as fertilizers and hence valuable substances is allowed. The argument is that the price is charged not for the *najis* itself, but for the human work of processing the *najis*, and for the transportation involved. Although the processing is considered as an unpleasant step and *najis,* more respondents are interested to use the end product (61-62%). The price of mineral fertilizer is considered too high by 58% of respondents. Therefore 66.5% of the respondents would prefer to use organic fertilizer, as long as the supply is enough. Only 23.7% prefer to use mineral fertilizer, which brings better yield in their opinion. The rest of the respondents (9.8%) do not really experience the differences between these two types of fertilizers in their yield. In general, the main reasons for not doing the processing and/or using the end products are described in Fig. 11.

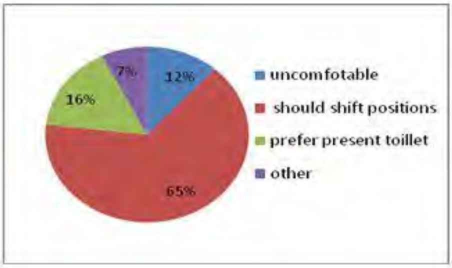

Figure10. Reasons for not using composting/UDT

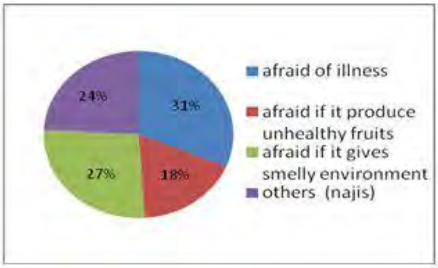

Figure 11. Reasons for not processing/using composting/UDT product

Public Facility

Public facility (washing, bathing and toilet) does not gain as much interest as in the previous decades of 80‟s-90‟s (50.3% respondents), although some respondents (49.7%) still wish to have one. Around 82% of the respondents who are not in favor mention that privacy is important. Therefore, they would like to have their own bathroom and toilet at home. The rest (18%) thinks that public facility is not attractive, since they have to walk and queue. There are several reasons why people still want to have public facilities. For communities who have to carry water to their houses, they wish to save their own water at home (53.5%) by using public facility. Around 21.7% wish to use a better facility which they cannot obtain at their own expense. The rest (15.9%) wishes to have public facilities for their guests/relatives, because they feel ashamed with their own bathroom, and some would like to meet neighbors during the stay in the public facility (8.9%)

Biogas

Most of the respondents (53%) are interested in using biogas from cattle waste, but only 25% are willing to use biogas from human feces. Around 22% of the respondents are unsure to use biogas from both sources. Among those who are unsure, 51% cannot imagine using biogas, 40% think that biogas might be improper due to bad odor, and the rest (9%) refuses due to religious reasons *(najis).*

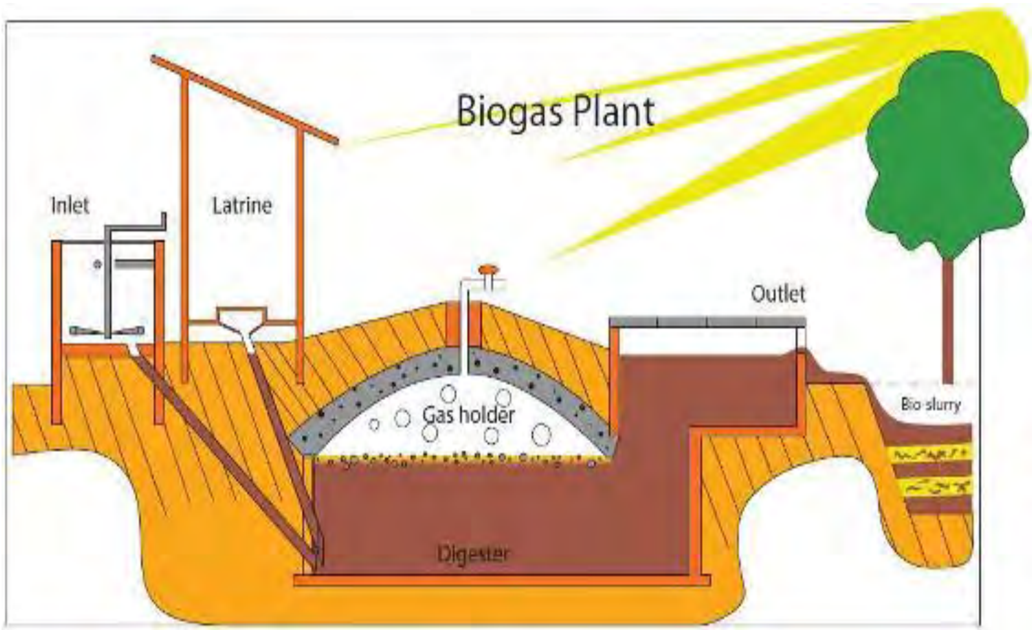

Fig. 12 Typical biogas plant for domestic wastewater

Conclusion and Recommendations

In the research area the nutrient cycle is not closed. Black and grey water is almost untreated and discharged to the ground for free, while organic waste is mostly burned. Actually the raw material is available and the demand on fertilizer, water and energy exists. But the concept of resource recovery is not yet known or even applied.

Most siphon toilette users are already satisfied with the performance of their toilette. This toilette also represents wealth in the society. The major failure of this system is the poor constructed septic tank, which leads to groundwater and soil contamination. Having a well constructed septic tank might not solve the problem as well, due to the difficult access for the desludging truck. In this case, biogas in 5-10 households" level might be a feasible solution. Biogas is one solution, which accommodate resources recovery. Cattle or human manure or even organic kitchen waste, which is currently not well managed, can be fed to the biogas. The gas can be used for cooking or lighting and the slurry can be used for agriculture purpose. During the operation no direct contact with human feces is needed, therefore *najis*can be avoided. Considering the amount of untreated kitchen waste in the region, biogas can actually be fed by kitchen waste as well.

Most SPL users (60%) do not see their latrine as a problem. They will keep the system due to less water usage. Some of current SPL users (14 %) have already practiced resource recovery and use the old SPL"s soil for planting or fertilizer. As advancement of SPL, composting and UDT in household level, which requires less water, is feasible to be used. Feces can be stored in an outside compartment for 3 years and will be ready to use as organic fertilizer. The 6 month urine storage is needed before it can be applied. In this case, direct contact with unprocessed feces and urine is avoided and will not lead to any *najis.*

Public facility in the region with direct water connection in household level will not be acceptable. In the future, when economic situation is getting better people will tend to build their own facility. The need to have social gathering with neighbor in a public facility is not as high as in two decades ago.

Depending on the discharge flow, grey water can actually be collected and treated or even reused. A simple vertical bed might filter the grey water before it is discharged to the ground. If the flow is adequate for reuse, a simple horizontal bed and a small pond might be an alternative.

Acknowledgement

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CARBON CYCLE AND CLIMATE CHANGE ARCHIEVE

ATMOSPHERIC CARBON DIOXIDE SEQUESTRATION TROUGH KARST DENUDATION PROCESSES
Estimated from Indonesian Karst Region

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Abstract
The important of karst denudation in term of climate changes lies on the ability of karst ecosystem in regulating atmospheric carbon. Karst denudation consumes CO_2 either from atmosphere and soils. This paper is intended to describe the karst denudation related to CO_2 sequestration and apply the concept to calculate carbon gain through karst denudation process in Indonesian. Estimated from the carbonate rock outcrops, the Indonesian karst region is approximately 140,000,000 km^2. Previous work suggested that average denudation rate of Indonesian karst is 82.9 m^3/year/km^2 or equivalent to 218,856 kg/year/km^2. Since 120 kg of atmospheric carbon is absorbed during the removal of one ton calcium carbonate removal and Indonesia karst area is 140.000 km^2, Indonesian karst area up takes 3,677 Gg/year atmospheric carbon. This amount is equivalent to 13.482 Gg CO_2/year. This figure is merely from denudation processes, considering carbon dioxide sequestration by karst vegetation covers will inevitably gains much higher number. The role of karst denudation therefore needs more attention in carbon flux calculation and developing climate change mitigation measures

Keywords: Karst denudation, karstification

Introduction

CO_2 is one of the important green house gases of which has big contribution to global warming. In recent decades, emissions of CO_2 have continued to increase (Dawson and Spannagle, 2009; Mackenzie, 2004; Parry et.al., 2007). The increase is mainly caused by fossil fuel and land use changes. Global annual fossil CO_2 emissions increased from an average of 6.4 ± 0.4 GtC/yr in the 1990s to 7.2 ± 0.3 GtC/yr in the period 2000 to 2005. Estimated CO_2 emissions associated with land use change, averaged over the 1990s, were 0.5 to 2.7 GtC/yr, with a central estimate of 1.6 Gt/yr (Parry *et.al.,* 2007).

Terrestrial and oceanic carbon sequestration potentials therefore are needed, to counter balance the increase of CO_2 emission. Karst ecosystem is one of the carbon sink potentials. Karst landscape systems, composed primarily of limestone and dolomite, cover some 12% of the earth's land surface, and weathering of these rocks on the continents has been recognized as a sink term for atmospheric CO_2. (Ford and Williams, 2007; Gornitz, 2008). It owes its important not only because it stores carbon binding rocks but also because karstification itself is a carbon dioxide sequestration process.

Karst processes are part of the world carbon, water and calcium cycles that occur at the interfaces between lithosphere, hydrosphere, atmosphere and biosphere. The CO_2-H_2O-$CaCO_3$ reaction is kwon as karst dynamic system which is useful in explaining the important of karst in carbon cycle (Yuan, 2002; Grove, 2001; Liu and Zhao, 2000; Liu *et al.,* 2010). Karst study has an important role in understanding the global carbon cycle, and thereby can contribute more to an understanding of global climate change.

The important of karst denudation in term of climate changes lies on the ability of karst ecosystem in regulating atmospheric carbon. Karst denudation consumes CO_2 either from atmosphere and soils. Thereafter this paper is intended to describe the karst denudation related to CO_2 sequestration and applying the concept to calculate carbon gain in Indonesia Karst Region through karst denudation process. Calculation was based on data from previous works.

Indonesian Karst Region

Karst areas of Indonesia develop mostly in limestone outcrops, small areas develop in dolomites and marble. It covers an area of 140.000 km^2 from 95^{o}21‘ to 140^{o}96‘ East Long; and from 10^{o}37‘ South Lat to 5^{o}57 North Lat. No karst area is reported to develop in non carbonate rocks. Carbonate rock distribution of Indonesia is controlled by tectonic frameworks of Indonesia archipelago resulted from colliding Hindia-Australia in the south, Pacific Plate in the east, and Philippine Plate in the north to the Eurasia plate (Hall and Blundell, 1996; Hamilton, 1979; Verstappen, 2000). Those four plate interaction have brought about orogenetic processes that made carbonate rocks to outcrop. Most carbonate outcrops are associated with convergence margin. Only Papua karst areas (easternmost part of Indonesia) are not related to convergence margin.

Figure 1. Indonesian karst areas compiled from geological map of Indonesia
(From: Indonesian Geological Survey)

Most limestone and dolomite formation are deposited during Tertiary. However, small areas of Cretaceous limestone formations are also discovered in the high mountain of Papua. Quaternary carbonate outcrops are quite common in Indonesia archipelagoes, especially along cost lines and small islands as a result of neo-tectonically uplift. Due to subject to high intensity of tectonic deformation, carbonate outcrops are severely fractured giving a better prerequisite for karst development. Karst areas of Indonesia are distributed either slightly or in the high mountain ranges up to more than 4,000,000 meters above sea level.

Karst Denudation

Denudation of karst areas in Indonesia is significantly favoured by the high yearly precipitation and the existence of overlying forest coverage. Though rainfall is varies in some localities, 2000 up to more tjam 3000 mm annual rainfall is quite common in the area. Torrential rainfall of monsoonal climate and tropical climate has very important roles in denudation processes. The high fractured carbonate rocks as mention earlier is the other factor make possible denudation of Indonesian karst is quite intensive. Forest cover (although in some areas have been deforested) on the other hand provides high concentration of soil CO_2 and furthermore resulting in more aggressive water to dissolve limestone. Those circumstances should be the explanation why karst morphology in the forms of cockpits, conical karst, and tower karst are easily encompassed throughout Indonesian archipelago, though most of Indonesian karst areas have just been subject to kartification since Late Pliocene. Compared to Dinaric Karst, Guilin Karst, and Mammoth Cave, Indonesia karst is much younger.

Denudation rate of Indonesian karst was first calculated by Balazs (1971) by using Corbel‘s method. He investigated five sites of Indonesian karst, i.e Gunung Saribu Karst (Sumatra), Kalapanunggal Karst (Java), Gunung Sewu Karst (Java), Nusa Barung Karst (Java), and Maros Karst (Sulawesi). Denudation rates of those areas are summarized in Table 1. With the same method, Balazs (1971) calculated denudation rate of temperate karst of Hungary for comparison of which the result was 20.4 m^3/year/km^2. Balazs‘s estimate clearly shows that denudation rate of Indonesian karsts is considerable high. This should be the reason accounts for the well developed karst landforms within young karst rocks of Indonesia. Further research (by Karst Reseach Group-Faculty of Geography UGM) is still ongoing to elaborate Balazs estimate, especially in understanding temporal variability of dissolved carbonate brought from Indonesian karst and its relation to carbon cycle.

Table 1. Denudation rates of some Indonesian Karst Areas

Karst Area	Denudation rate	
	m^3/year/km^2	mm/year
Seribu Karst	> 63	
Nusa Barung Karst	No data	No data
Kalapanunggal	99	0.099
Gunung Sewu Karst	86	0.086
Maros Karst	83	0.083
Average	**82.9**	**0.0829**

(From Balazs, 1971)

Carbon sequestration

Since karst areas develop under soluble rock, the major denudation process in the area is dissolution. Dissolution is of paramount importance in developing karst compared with its relatively minor role in other lithologies. The dissolution is incorporated by the absorption of atmosphere carbon dioxide. Atmosphere CO_2 along with rain enters the karst system acting as dissolve agent and generating denudation processes. Carbon dioxide is the most soluble of the standard atmospheric gases, e.g. 64 times more soluble than N_2. The dissolution process is started through reaction between water and CO_2 in the form of H_2CO_3. H_2CO_3 is unstable and breaks down in H^+ and HCO_3^-. H^+ ion then replaces Ca in the limestone ($CaCO_3$) producing Ca^{2+} and CO_3^{2-} to the bulk solution. $Ca^{2+}$and CO_3^{2-} ions released from the surface of the mineral must be transported away into the bulk of the solution by molecular diffusion. On the other hand, CO_2, H_2CO_3, and H^+ must migrate from the bulk to the mineral‘s surface. Thus one molecule of CO_2 is consumed to dissolve one $CaCO_3$ unit (Figure 2).

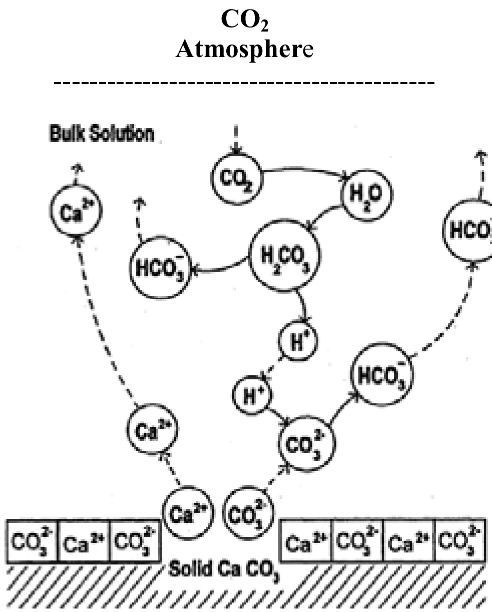

Figure 2.
Sequestration of CO_2 in karst denudation trough carbonat dissolution (Modifed from Dreybroadt, 2004)

Carbonate rock dissolution have assumed that half of the dissolved inorganic carbon leaving a given catchment comes from the mineral and half from the atmosphere. Hence 120 kg carbon is absorbed from atmosphere during the removal of 1000 kg carbon through karst denudation. As mentioned earlier, karst denudation rate in Indonesia is 82.9 m^3/year/km^2. Considering average limestone specific gravity of 2,640 kg/m^3, carbon uptake from atmosphere during karst denudation equals to 218,856 kg/year/km^2. Since the area of Indonesian karst is 140,000 km^2, thus total carbon sequestration during karst denudation is 3,677 Gg/year or equivalent to **13,482 Gg** CO_2/year. To give general figure on the important karst ecosystem in atmospheric carbon sequestration, DHG emission is presented in Table 2 for comparison.

Table 2. Summary of GHG emission and removal (in Gg)

Source/Sink	**CO_2 Emission**	**CO_2 Removal**	**CH_4**	**N_2O**	**CO_2 Eq**
Energy	305,983		1,221	6	335,540
Industry	31,938		104	0	34,197
Agriculture	2,178		2,419	72	75,419
Land Use Change and Forest	1,060,766	411,593	3	0	649,254
Peat Fire	172,000				172,000
Waste	1,662		7,020	8,05	151,578
TOTAL					**1,415,988**

From : MoE, 2009

Compared to green house gas (GHC) emission of Indonesia (Table 2), the role of karst denudation seems very important in atmospheric carbon dioxide sequestration. Karst denudation from Indonesian is able to up take a half of CO_2 emitted from industry. Considering carbon sequestration through biomass production, Indonesian Karst ecosystem, which covers approximately 8 percent of Indonesian landmass, must have much higher carbon sink potential.

Concluding Remarks

General figure from karst denudation in Indonesia obviously indicates that greater attention should be devoted to understand karst ecosystem in climate change mitigation. The important of karst denudation in term of climate changes lies on the ability of karst ecosystem in regulating atmospheric carbon through denudation processes. Karst denudation up takes CO_2 both from atmosphere and soils. Considering carbon sequestration through biomass production, Indonesian Karst ecosystem accordingly owes considerable role in climate change mitigation Therefore, attempts should be made to ascertain comprehensive carbon cycle mechanism in karst ecosystem including carbon cycle from biomass production and other biological activities.

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PALEOCLIMATIC INVESTIGATION USING CAVE SPELEOTHEMS IN SOUTH KOREA

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Abstract
More than 1,000 limestone caves are estimated to be extensively developed in South Korea. A potential to use soda straws as regional paleoclimate proxy was investigated. Monsoonal climatic variations can be detected from the soda straw in Seopdong Cave, which grew for five years (July, 1999 ~ July, 2004). This soda straw is ca. 20 cm long, and this implies that the growth rate is 4 cm/yr. Excess ^{210}Pb variation coincides well with the amount of precipitation during its growth, and the values are high during rainy summers and low during dry winters. Carbon isotope contents are relatively more depleted from 2000 to 2001, and this was probably due to the smaller amount of precipitation during this interval. Two stalagmites from Gwaneum and Daeya caves revealed that carbon isotopic compositions indicate East Asian Summer monsoon intentisites during MIS 5a and Eemian and Middle Holocene. Textural and geochemical investigation was carried out to delineate the paleoclimatic variations from the late Pleistocene stalagmites of the Eden cave. Based on U-series age dating, the stalagmite of Eden Cave started to grow from 537 ka BP and the growth ceased at 96 ka BP. Based on the frequency and density of growth laminae, the stalagmite shows five orders of cycles, and each cycle reflects various climatic changes with different periods of growth intervals. Two stalagmites of the Yongcheon lava tube cave shows that the oxygen isotopic variation clearly shows the period of the Little Ice Age and coincides with the instrumental records of Northern Hemisphere temperature variation during the last 1,300 years. High resolution, textural and stable isotope analyses revealed the termination of Little Ice Age and transitional period from LIA to global warming period. Studies on fine scale variations in the isotopic composition of speleothems along with age control using U-series and ^{210}Pb excess methods from the speleothems in Korean caves promise a great potential for the reconstruction of climate and environmental changes in East Asian monsoon system during the geologic past. Also, it is emphasized here that textural data can provided invaluable information on paleoclimatic history in addition to geochemical data.

Keywords: Paleoclimate, Cave speleothems

Introduction

Speleothems have been used as a useful terrestrial proxy for paleoclimatic information due to several advantages such as their wide distribution, precise dating result, and continuous growth intervals for long periods of time compared to other paleoclimate archives (e.g., ice cores, loess and lake sediments) (Fleitmann and Spötl, 2008). Numerous information has been revealed from all over the world (e.g., McDermott, 2004), however speleothem records from northeastern Asian region including Korea have not yet been reported. Therefore, it is the objective of this study to firstly report textural and stable isotopic records of a speleothem from South Korea to reconstruct the paleoenvironmental changes in eastern part of the Korean peninsula as well as to understand the evolutionary changes of East Asian monsoon system in northeast Asia. Also, we will make an emphasis on the use of $\delta^{13}C$ records to delineate East Asian monsoonal changes despite the fact that most previous studies for the same purpose have mainly used $\delta^{18}O$ records only.

Setting

Located at the middle latitude (ca. 34 ~ 43 °N) in the northeast margin of Asia, Korean peninsula is strongly affected by the East Asian monsoon system with pronounced seasonal fluctuations in humidity, temperature, and atmospheric circulation. Major air masses that influence the climate of the Korean peninsula are the Northern Pacific air mass, Siberian air mass, Yangtze River air mass and Okhotsk sea air mass. A low pressure cell above the central Eurasian continent during summer is associated with southwesterly winds that carry warm and moist air masses from the northwestern Pacific Ocean towards Japan and Korean peninsula. During winter seasons, reversed pressure gradients with prevailing northwesterly winds carry dry and cool air masses from the Eurasian continent towards the Pacific Ocean. When both Siberian and North Pacific highs are weak, Yangtze River and Okhotsk sea air masses control the climate of Korean peninsula during spring and autumn season. In early summer, heavy rainfall front (so-called ‗Jang-ma') pass through from south of the Korean peninsula to north by contact between Okhotsk sea air mass and Northern Pacific air mass. The westerly winds, blowing from west to east high up in the atmosphere at the mid-altitude, also contribute to the climate conditions in Korea. Path of the westerly jet is changed between summer and winter by 15 degree in latitude. Every year, the Korean peninsula is affected by typhoons several times between June and September. The long stretching mountain ranges have had great influence on climates in the eastern part of Korean peninsula. That is, for winter season temperature in same latitude, the eastern part of the peninsula represents higher temperature than western part. It is because the mountain ranges block cold and dry northwesterly during the winter resulting in the higher sea surface temperature (SST) of the eastern coast in Korean peninsula. The prevailling climate in the eastern part of the peninsula is characterized by a mean annual temperature of 12.9 °C with the mean annual maximum and minimum temperature of up to 17.4 and 8.9 °C, respectively, from 1971 to 2000 (Korea Meteorological Administration, http://www.kma.go.kr). The average annual precipitation in Korea is approximately 1402 mm, and more than 3/4 of the annual precipitation takes place during the rainy season.

Methods

Samples were collected from limestone and lava tube caves. To check growth patterns such as growth laminae, hiatuses, and possible diagenetic alteration, the samples were cut in half along the growth axis and polished. One half was thin-sectioned and examined with a polarizing microsope for textural description, and the other half was stained with Alizarine Red S and Feigl's solution to determine carbonate mineralogy (Friedman, 1959). Subsequently, acetate peels were prepared in order to supplement thin-section examination and to examine the internal growth texture and the characteristics of growth laminae under a binocular microscope). Oxygen and carbon isotope ratios were analyzed. For each measurement, approximately 100 µg of powder samples were drilled along the growth axis of the speleothem and analyzed with an on-line, automated, carbonate preparation system (Kiel III), linked to a Finnigan MAT-253 ratio mass spectrometer. Samples were calibrated against the NBS-19 standard and are reported as per mil (‰) relative to the Vienna Pee Dee Belemnite (VPDB) standard. Duplicates were analyzed every 10 to 20 samples, all of which were replicated within 0.15‰ for oxygen and 0.20 ‰ for carbon. The sub-sampling interval is 1 mm. Sub-samples were prepared for ^{230}Th dating following procedures similar to those described by Edwards *et al.,* (1987) and Dorale *et al.,* (2004). Approximately 300 to 400 mg of calcite powder was drilled out from along the 7 selected growth horizons. ICP-MS analyses were made at the Minnesota Isotope Laboratory on a Finnigan-MAT Element equipped with a double-focusing sector-field magnet in reversed Nier-Johnson geometry and a single MasCom multiplier. All reported ratios are activity ratios with 2σ errors given.

Results and Discussion

1. A soda straw from Seopdong Cave

A five year-old, 20 cm-long soda straw (SD-1) was analyzed geochemically to delineate the relationship between the geochemical record and climatic behavior. The growing tip of the soda straw was marked on July 18 1999, and the sample was collected on July 16 2004, thus the growth period of this speleothem is well constrained. During the five years the soda straw grew about 20 cm, a mean growth rate of about 4 cm/year. Fast growth rate of this speleothem enabled not only to understand seasonal variations of geochemical data but also to compare these data directly with outside climatic variations near the cave. $^{210}Pb_{ex}$ (excess or unsupported ^{210}Pb) results suggest that the overall pattern of $^{210}Pb_{ex}$ changes as well as the frequency and relative intensity of their peaks show a strikingly similar pattern to that of the amounts of precipitation in the study area. This suggests that $^{210}Pb_{ex}$ was transported into the cave with infiltrating rainwater mostly during rainy summers because $^{210}Pb_{ex}$ is a particle-reactive element. Controlling detailed growth rates by the $^{210}Pb_{ex}$ fluctuations, it can be noticed that $\delta^{18}O$ compositions vary very little in spite of significant droughts and typhoon events, whereas $\delta^{13}C$ values clearly display impacts of a severe drought from 2000 to 2001. The Sr/Ca, Ba/Ca, U/Ca and Mn/Ca ratios coincide with the $\delta^{13}C$ trends and show anomalies during the drought period. These coeval trends strongly indicate that hydraulic factors in vadose zone that were directly controlled by the amount of rainfall, influenced on the geochemical imprints of the SD-1. This study illustrates the behavior of an atmospheric radionuclide ($^{210}Pb_{ex}$), the O and C stable isotopes and trace elements in calcite speleothems and, furthermore, implies that they can be used to detect short-term climatic behavior, including climatic extreme events, as well as the long-term climatic fluctuations in the past.

2. A stalagmite from Gwaneum Cave (GE-1)

Textural and stable isotopic records of a composite-type speleothem from Gwaneum Cave in the eastern part of the Korean peninsula show prominent paleoenvironmental changes since the MIS (Marine Isotope Stage) 5a. Based on $^{230}Th/^{234}U$ dating, the speleothem had grown from 90.9±6.5 ka (BP) to 1.2±0.5 ka with several hiatuses. This speleothem appears to contain more than one type of speleothem formations involving four growth phases (A, B, C & D), depending upon the speleothem type and texture. Phases B and C (cave coralloids) which formed from the MIS 4 to the MIS 2 are mainly composed of spherulitic fibrous calcite crystals, while columnar calcites of stalagmites (Phases A and D) grew during the MIS 5a and the late MIS 1, respectively. Growth laminae in Phases B and C are very irregular and discontinuous laterally, that may indicate that the cave coralloids (Phases B and C) grew over the stalagmite (Phase A) while the supply of dripping water became limited. However, as the supply rate increased again, the stalagmite (Phase D) continued to grow over the cave coralloid (Phase C). This interpretation can be supported by the enrichment of $\delta^{18}O$ and $\delta^{13}C$ for Phases B and C showing the kinetic growth fractionation. Phase A provides the $\delta^{13}C$ time-series that exhibit millennial-scale fluctuations of the East Asian monsoon intensity during the MIS 5a.

Considering that $\delta^{13}C$ values reflect the isotopic composition of soil-derived CO_2, the results clearly show monsoon driven-changes in terrestrial primary productivity above the cave during the MIS 5a. These results can be correlated with different records from the North Atlantic and Mediterranean regions, indicating that the East Asian monsoon system in the Northeast Asia are clearly connected with oceanic processes of the Northern hemisphere. Our reconstruction reveals that the significant changes in East Asian monsoon occurred as a response to sea level changes and/or oceanic circulations during the transition period from the MIS 5a to MIS 4.

3. A stalagmite from Eden Cave (ED-1)

Textural and geochemical investigation was carried out to delineate the paleoclimatic variations from the late Pleistocene stalagmite of the Eden cave (ED-1) in Korea. Based on U-series age dating, the stalagmite started to grow from 537ka (BP) and the growth ceased at 96kaBP. The inside of the stalagmite can be divided into 5 units (A, B, C, D & E) according to the growth rates, and the growth rates of each unit are 0.26, 5.30, 0.10~0.36, 0.30, 0.70 mm/ka, respectively. Especially, Unit C shows the different texture compared to other units. This unit is characterized by fibrous and spherulitic calcite crystals with a minor contribution of fibrous aragonite. Also, growth laminae in the Unit C are very irregular and discontinuous laterally. This textural difference indicates that cave corals grew in this interval as the dripping water ceased to be supplied from the ceiling. However, as water started to drip again, the stalagmite continued to grow over the cave corals. Based on the frequency and density of growth laminae, the stalagmite shows five cycles, and each cycle reflects various climatic changes with different periods of growth intervals. Stable isotopes of carbon and oxygen were analyzed from the texturally distinctive Unit C. Oxygen and carbon isotope values range from -8.7~-2.6 ‰ (PDB) and -9.9~-5.6 ‰ (PDB). The enrichment of these stable isotopes strongly suggest that the cave coral grew out of equilibrium (kinetically controlled) with respect to supplying seepage water, mainly controlled by rapid degassing of carbon dioxide and evaporation. Also, relatively enriched values represent cold and dry glacial period, whereas depleted ones are interglacial signatures. Comparing with Marine Isotope Stage (MIS), the Unit C belongs to the MIS 8. Also, MIS 6 and MIS 10 are characterized by the change of the growth axis within the stalagmite. This study suggests that the stalagmite of the Eden Cave contains significant textural information on several glacial periods in the past, and also suggests that a variety of paleoclimatic evidences can be revealed from the speleothems in the future.

4. A stalagmite from Daeya Cave (DY-1)

Textural and stable isotopic records from the absolute-dated stalagmite of the Daeya Cave (DY-1) provide new insights into the climatic evolution of the Korean Peninsula during the Holocene and Eemian climatic optima. The stalagmite yielded ages of 8,572±227 to 5,907±158 and 123,456±535 to 119,837±1,089 years, which coincide with the Holocene and Eemian climatic optima, respectively. The stalagmite's $\delta^{13}C$ record closely resembles previously reported Chinese speleothem $\delta^{18}O$ data. Thus it can be suggested that textural and geochemical results of the DY-1 reflect East Asian monsoon intensity, which is forced by summer insolation patterns in the northern hemisphere. Lighter carbon isotopic compositions, well-developed fibrous calcite crystals, and their relatively faster growth rate in the stalagmite sample are interpreted to reflect the warmest and wettest climate conditions of the Holocene and Eemian interglacials. Both climatic optima took place when insolation was decreasing from its maximum level, temperature in Greenland was highest, and sea level approached its maximum level. These climatic optima also coincide with decreasing Antarctic temperatures. Compared the DY-1 data to other proxies, it is suggested that the Holocene and Eemian climatic optima developed through a balance among boreal insolation, monsoon intensity, and sea level (also continental ice volume), which are the main climatic forcing factors in the northern hemisphere. These trends also follow the bi-polar seesaw mechanism as previously described.

5. Two stalagmites from Yoncheon Cave (YC-1 & YC-2)

Yongcheon Cave is located on Jeju Island, the southernmost part of Korea. The island is under the strong influence of East Asian monsoon climate. The Yongcheon cave which contains numerous carbonate speleothems was the typical lava tube cave that probably formed between 0.2~0.4 Ma ago. A 6.8cm- and 11cm-long stalagmites (YC-1 & YC-2) were collected in its growth position in 2005 and 2008, respectively. The age of the stalagmites were determined by ^{210}Pb dating, radiocarbon dating and U/Th dating for the YC-1 and by counting growth laminae for the YC-2. Age dating revealed that the stalagmites are about 3,300 and 287 years old. High resolution stable isotope analyses were carried out for two stalagmites. The YC-1 clearly shows Dark Age Cold Period, Medieval Warm Period, Little Ice Age and Global Warming. The YC-2 supports the data by the YC-1 and shows that textural data coincide well with geochemical data. Also, the YC-2 shows well defined transitional steps from Little Ice Age to present-day Global Warming Period. This study suggests that textural characteristics of speleothems can be used as a proxy to reconstruct paleoclimatic variations in addition to geochemical proxies.

Conclusions

Paleoclimatic investigation using speleothems in natural caves in South Korea suggest that they will provide significant information on climate changes for the past 500,000 years. Also, speleothems can be used as a proxy to trace natural disasters. It is especially notable that carbon isotope compositions of speleothems are more useful to interpret paleoclimatic variations than oxygen isotope values for Korean speleothems.

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ATMOSPHERIC CO_2 SINK: SILICATE WEATHERING OR CARBONATE WEATHERING?

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Abstract
It is widely accepted that chemical weathering of Ca–silicate rocks could potentially control long-term climate change by providing feedback interaction with atmospheric CO_2 drawdown by means of precipitation of carbonate, and that in contrast weathering of carbonate rocks has not an equivalent impact because all of the CO_2 consumed in the weathering process is returned to the atmosphere by the comparatively rapid precipitation of carbonates in the oceans. Here, we show that the rapid kinetics of carbonate dissolution and the importance of small amounts of carbonate minerals in controlling the dissolved inorganic carbon (DIC) of silicate watersheds, coupled with aquatic photosynthetic uptake of the weathering-related DIC and burial of the resulting organic carbon, suggest that the atmospheric CO_2 sink by carbonate weathering may previously have been underestimated by a factor of about 3, amounting to 0.477 Pg c/a. This indicates that the contribution of silicate weathering to atmospheric CO_2 sink may be only 5%, while the other 95% is by carbonate weathering. Therefore, the atmospheric CO_2 sink by carbonate weathering might be significant in controlling both the short-term and long-term climate changes. This questions the traditional point of view that only chemical weathering of Ca–silicate rocks potentially controls long-term climate change.

Keywords: Atmospheric CO_2 sink; carbonate weathering; silicate weathering; aquatic photosynthetic uptake of DIC; organic carbon burial

Introduction

It is widely accepted that chemical weathering of Ca–silicate rocks could potentially control long-term (50-100 My episodicity) climate change by providing feedback interaction with atmospheric CO_2 drawdown by means of the precipitation of carbonate ($CO_2+CaSiO_3 \Rightarrow CaCO_3+SiO_2$), and that in contrast weathering of carbonate rocks has not an equivalent impact because all CO_2 consumed in dissolution of carbonates is returned to the atmosphere by the comparatively rapid precipitation of carbonates in the oceans ($CaCO_3+CO_2+H_2O \Leftrightarrow Ca^{2+}+2HCO_3^-$) (Urey, 1952; Berner *et al.,* 1983; Elderfield, 2010). Thus, the proportions of silicate and carbonate weathering at the earth‘s surface are important in long-term global CO_2 balances (Berner *et al.,* 1983).

However, for short time scales $<10^4$ years, the role of carbonate weathering in the global CO_2 cycle and thus in short-term climate changes cannot be ignored due to the much faster kinetics of dissolution (Plummer *et al.,* 1978; Dreybrodt, 1988; Liu & Dreybrodt, 1997; Kump *et al.,* 2000), and the much greater solubility of carbonates (Holland, 1978; Hurd *et al.,* 1979; Dreybrodt, 1988; Van Cappellen & Qiu, 1997) compared to silicates. Moreover, the presence of the ―biological carbon pump" in natural aquatic ecosystems (e.g., oceans, lakes, rivers, reservoirs) diverts carbon into the lithosphere by sedimentation and burial of organic carbon produced by the aquatic photosynthetic uptake of weathering-related dissolved inorganic carbon (DIC) ($Ca^{2+}+2HCO_3^- \Rightarrow CaCO_3+CH_2O+O_2$) (Smith, 1981; McElroy, 1983; Maier-Reimer, 1993; Einsele *et al.,* 2001; Lerman & Mackenzie, 2005; Smith and Gattuso, 2010**).**

This has been neglected in all modern global carbon cycle models, partly because the identification of negative feedbacks of the organic carbon cycle in controlling the climate has been elusive (Berner, 1983; Boucot & Gray, 2001). Therefore, the atmospheric CO_2 sink due to carbonate weathering may have previously been greatly underestimated.

Further Exploration on Recent Key References

Though rich in carbonate rocks, calcite is also commonly associated with shales (Hurd *et al.,* 1979), metamorphosed gneisses and schists, hydrothermal altered granitic rocks (Blum *et al.,* 1998), and pristine granitoids, which probably form from CO_2-rich fluids associated with the final cooling of batholiths as well as during later periods of hydrothermal activity (White *et al.,* 1999). Therefore, the CO_2 consumed in silicate areas does not necessarily result primarily from silicate weathering: it may mainly be due to the contribution of rapid calcite dissolution in the silicate rocks (Blum *et al.,* 1998; White *et al.,* 1999, 2005). For example, Blum *et al.* (1998) investigated the major element and Sr isotope geochemistry of surface waters, bedrock, and river sands in the Raikhot watershed within the High Himalayan Crystalline Series (HHCS) of northern Pakistan. Mass-balance calculations of mineral-weathering contributions to the dissolved flux of ions from the watershed indicated that 82% of the HCO_3^- flux is derived from weathering of carbonate minerals and only 18% from silicate weathering, even though the bedrock in the watershed is predominantly quartzofeldspathic gneiss and granite with only ~1% carbonate. This study demonstrated the importance of small amounts of bedrock carbonate in controlling the water chemistry of glaciated silicate watersheds. It also suggests that the flux of Sr with a high $^{87}Sr/^{86}Sr$ ratio in the major Himalayan Rivers may be derived in mainly from weathering of low amounts of calcite within the HHCS silicates. Therefore, models using the flux of radiogenic Sr from the Himalayas as a proxy for silicate weathering rates may overestimate the amount of CO_2 consumption attributable to reactions with silicates there. Similar results were obtained by Jacobson *et al.* (2002b), who showed that the conventional application of two-component Ca/Sr and $^{87}Sr/^{86}Sr$ mixing equations has overestimated silicate-derived Sr^{2+} and HCO_3^- fluxes from the glaciated Himalaya. They found that carbonate dissolution provides more than 90% of the weathering-derived Ca^{2+}, HCO_3^-,and Sr for at least 55 ka following initial exposure of rock surfaces, although carbonate may represent only ~1.0 wt% in fresh glacial till (Jacobson *et al.,* 2002a): this significantly increases the Ca^{2+}/Na^+ and HCO_3^-/Na^+ ratios in the so-called ‗silicate end member reservoir'. This finding may explain why Gaillardet *et al.* (1999) obtained such high CO_2 consumption estimates by silicate weathering despite the fact that the weathering rates are 10^2 to 10^8 times lower than those of carbonates. They calculated the CO_2 consumption by silicate weathering from the bulk chemistry of large rivers and made no allowances for the contributions of carbonate weathering that occur in predominantly silicate areas.

To summarize, the contribution of carbonate weathering to the atmospheric CO_2 sink may have been greatly underestimated in these previous studies (Amiotte-Suchet *et al.,* 1995; Gaillardet *et al.,* 1999).

In a new attempt to estimate the atmospheric CO_2 budget, by considering the combined effects of carbonate dissolution, the global water cycle and photosynthetic uptake of dissolved inorganic carbon ($DIC=CO_2(aq)+HCO_3^-+CO_3^{2-}$) by aquatic organisms (see Fig. 1), Liu et al.(2010) found that the net atmospheric CO_2 sink by carbonate weathering on the continents (including dissolution of CO_2 in non-carbonate areas) could be as large as 0.477 Pg C/a (CFR+CFA in the Fig. 1). This is much larger (with a factor of about 3) than the estimate of 0.148 Pg C/a obtained by Gaillardet *et al.* (1999), who considered neither the carbonate weathering sink in silicate areas nor the photosynthetic uptake of DIC by continental aquatic organisms and burial of the resulting organic matter (CFA=0.233 Pg C/a, see Fig. 1). This latter value of 0.233 Pg C/a has been confirmed by the independent work of Dean and Gorham (1998), Einsele *et al.* (2001), and Cole *et al.* (2007). They estimated that about 0.2 to 0.3 Pg C/a, mainly of autochthonous origin, is buried in aquatic sediments in inland waters (lakes, reservoirs and rivers). Therefore, the atmospheric CO_2 sink due to carbonate weathering has previously been greatly underestimated. If the value by Jacobson *et al.* (2002a) (i.e. less than 10% of HCO_3^- originates from silicate weathering) is applied to the case of Gaillardet et al. (1999), then the atmospheric CO_2 sink by silicate weathering will decrease from 0.104 Pg C/a (Gaillardet *et al.,* 1999) to about 0.0104 Pg C/a, and correspondingly, the atmospheric CO_2 sink by carbonate weathering will increase from 0.148 Pg C/a (Gaillardet *et al.,* 1999) to 0.1948 Pg C/a (0.148+(0.104-0.0104)*0.5=0.1948, where the factor 0.5 results from the fact that in the case of carbonate dissolution only half of the HCO_3^- is of atmospheric origin). Therefore, the atmospheric CO_2 sink by carbonate weathering is 18.73 times that of the atmospheric CO_2 sink by silicate weathering. In other words, the atmospheric CO_2 sink by carbonate weathering contributes about 95% to the atmospheric CO_2 sink, while only 5% results from silicate weathering.

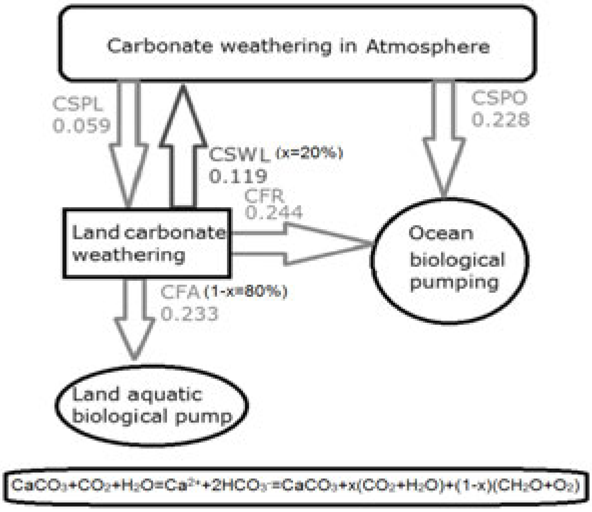

Fig. 1, Atmospheric CO_2 sinks (in Pg C/a) by carbonate weathering (i.e., carbonate dissolution, coupled with aquatic photosynthetic uptake of the resulting dissolved inorganic carbon). CSPL: carbon sink by precipitation on land; CSPO: carbon sink by precipitation in oceans; CSWL: carbon source from waters on land; CFR: carbon flux to oceans by rivers; CFA: carbon flux by aquatic plants to organic matter burial sites. (Modified after Liu *et al.,* 2010).

Conclusions

We have shown that the rapid kinetics of carbonate dissolution and the importance of small amounts of carbonate minerals in controlling the dissolved inorganic carbon (DIC) of silicate watersheds, coupled with aquatic photosynthetic uptake of the weathering-related DIC and burial of the resulting organic carbon, suggest that the atmospheric CO_2 sink by carbonate weathering may previously have been underestimated by a factor of about 3, amounting to

0.477 Pg c/a. This indicates that the contribution of silicate weathering to atmospheric CO_2 sink may be only 5%, while the other 95% is by carbonate weathering.

Our new findings on the magnitude of the carbonate weathering-related atmospheric CO_2 sink (Liu *et al.,* 2010) are significant in three respects.

First, we must question the origin of carbonates in oceans and lakes. Is it mainly due to the silicate weathering reaction?

$$CaSiO_3+CO_2 \Rightarrow CaCO_3+SiO_2 \qquad (1)$$

Or is it mainly due to the carbonate weathering reaction?

$$CaCO_3+CO_2+H_2O \Rightarrow Ca^{2+}+2HCO_3^- \Rightarrow CaCO_3+CH_2O+O_2 \qquad (2)$$

Because of the much faster kinetics of carbonate weathering, the carbonates in oceans and lakes may originate mainly from (2), the carbonate reaction.

Second, we must reassess the atmospheric CO_2 sinks by rock weathering. It appears that the atmospheric CO_2 sink in chemical weathering rests chiefly on carbonate dissolution and subsequent aquatic photosynthetic uptake of the resulting DIC (Liu *et al.,* 2010). However, for accurate quantification, the consumption of CO_2 by silicate and carbonate weathering, the balance between the production/burial and respiration/oxidation of organic matter, and the fluxes of CO_2 release from the aquatic ecosystems must all together be taken into account in future studies.

Third, the presence of a ―biological carbon pump effect" in natural aquatic ecosystems which diverts carbon produced by the reaction $Ca^{2+}+2HCO_3^- \Rightarrow CaCO_3+CH_2O+O_2$ to the lithosphere by sedimentation and burial of the organic carbon (Lerman & Mackenzie, 2005), implies that the atmospheric CO_2 sink in carbonate weathering might be also significant in controlling long-term climate change. This questions the traditional point of view (Berner *et al.,* 1983) that only chemical weathering of Ca–silicate rocks could potentially control long-term climate change by providing feedback interactions with atmospheric CO_2 drawdown due to the precipitation of carbonate.

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CARBON FLUX IN SOIL ALONG KARST HILLSLOPE TOPOSEQUENCE ABOVE WONOSARI FORMATION AT GUNUNGKIDUL DISTRICT

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Abstract
The objectives of this research are to estimate carbon flux in soil, to evaluate loss carbon from soil, and to evaluate carbon input to the soil from litter and fertilizer. This research was carried out in karst Gunung Sewu Gunungkidul regency. A survey method is used for this research. Soil samples were collected by purposive sampling method. The parameters to select toposequences representative are including land use, and slope position. Soil organic carbon was analyzed with Walkey and Black method. Soil redistribution was analyzed with stocking and Murnaghan method, and soil respiration was analyzed with titration method. The research result is average of carbon input to soil in crest slope position are 5,74 tons/ha/year derived from plant litter, 14,26 tons/ha/year in back slope, and 16,18 tons ha^{-1} $year^{-1}$ in foot slope. The major source of carbon in back slope and foot slope is harvest residue and organic fertilizers. Total emissions of carbon in crest slope are 0,16 tons/ha/year, 0,073 tons/ha/year in back slope, and 0,13 tons/ha/year in foot slope. Total carbon transported through soil redistribution in crest slope is 0,03 tons/ha/year, and in back slope is 0,016 tons/ha/year. Total carbon lost form crest slope is 1,604 tons/ha/year, and from back slope is 11,35 tons/ha/year. Carbon flux in foot slope is different with the other position. Carbon output occurs through respiration. Total carbon emission from soil in foot slope in amount of 0,13 tons/ha/year. Total carbon lost from foot slope is 11,92 tons/ha/year. Total carbon lost from soil in karst toposequence is 24,88 tons/ha/year.

Keywords: Carbon flux, soil carbon

Introduction

Carbon is the main element of life. In the world, carbon can be found in the atmosphere plants, animals, organic matter, fossil fuels, rocks, and dissolve in the ocean. Transformation of carbon molecules in the world called carbon cycle (Lal, 2007). Karst ecosystem is one of the carbon sink potentials. Karst landscape system, composed primarily of limestone and dolomite, cover some 12% of the earth land surface, and weathering of these rocks on the continent has been recognized as sink term for atmosphere CO_2 (Haryono and Day, 2004).

A karst dynamic system involves the transfer of energy and matter within the carbon, water and calcium (and magnesium) cycle. It occurs at the interfaces of the lithosphere, hydrosphere, atmosphere and biosphere and controls the formation and evolution of karst, but is moderated by formed karst features (Daoxian, 2002). The importance of karst denudation process in term of climate change lies on the ability of karst ecosystem in regulating atmospheric carbon (Haryono et. al., 2009).

The objectives of this research are to estimate carbon flux in soil, to evaluate carbon loss from soil through erosion and respiration, and to evaluate carbon input to soil from litter and fertilizer use by farmers and its influence on carbon flux and distribution along the slope.

Materials and Methods

The research was carried out at Gunung Sewu karst on Gunungkidul District of Yogyakarta Special Province, Java Indonesia between $7^0 52‘48”$ to $8^0 12‘36”$ South latitude and $110^0 19‘48”$ to $110^0 50‘24”$ North longitude (Figure 1). The Gunung Sewu karst is adjacent to the India

Ocean on the south central coast of Java. The elevations range is start from zero to 512,5 m a.s.l. Chemically composition of limestone is presented on Table 1.

Table 1. Limestone minerals content

No	Compound content	percentage		
		I	II	III
1	CaO	54,04	54,78	55,03
2	MgO	0,03	0,10	0,10
3	SiO_2	0,78	1,55	1,05
4	Al_2O_3	0,03	0,74	0,53
5	Fe_2O_3	0,12	0,38	0,27

Source: Haryono, 2008

Average rainfall recorded from 4 rain gauged station on 1999 to 2008 is 1941,8 mm with annual temperature approximately 24,3^{0}C. Research area has classified on tropical climate with index TE more than 128 according to Thornwhite. It indicated that there are high evaporation and evapotranspiration rate in Gunung Sewu. Highly evaporation rate on tropical region has caused high soil weathering process.

Soil Sampling: Soil samples has collected along a longitudinal transect from top of karst dome to the valley or doline. We chosen 3 representatives transect base on land use type (natural and cultivated land), and slope position. Slope profile has separated on 3 positions such as crest slope (top of hill), back slope (slope), and foot slope (doline or valley). A Transect was determined on the slope profile from crest slope to the foot slope laterally to collect the soil sample. We make 3 point on along transect. One point is representative of 100 m2. Soil samples were collected from ceret slope, foot slope, and back slope. Samples of plant litter, necromass, and macro fauna were taken with the plot system. At each slope position made a 200 m2 of plot, on each plot there are 4 small plots with size 0.25 m2. Erosion rate was analyzed with Stocking and Murnaghan (2000) methods. Erosion processes is indicated by soil surface feature such as rill, gully, and pedestal. Another erosion indicator is solution notches. Our research has used solution notches on limestone as erosion indicator. Land use, land morphology, and soil depth were observed on the field. Interview was conducted to get information about type of fertilizer that used by the farmers and plant litter management on harvest. The parameters analyzed in the include laboratory soil respiration, C organic by Walkey and Black method, and bulk density with wax method.

Results

Karst toposequence characteristics

	Crest slope	*Back slope*	*Foot slope*
Slope Rocks exposure	6 – 13% 25 – 35%	14 – 55% 25 – 30%	0 – 5% (2 – 5%
Processes	Erosion : 0,465 ton/ha	Erosion : 0,495 ton/ha	Deposition : 0,963 ton/ha
bLand use	bushes, cultivation forest	Agricultural land	Agricultural land, paddy field
Permeability	Moderate	Moderate	Moderate
Soil type Soil depth Color	Mediteran 0 – 30/50 dark reddish brown	Mediteran 0 – 20/40 reddish brown	Mediteran 0 – >50 dark reddish brown
Texture pH	Clay actual = 6 Potential = 6	Clay actual = 5 Potential = 6	Clay Actual = 5 potential= 6
Litology	Wonosari formation limestone	Wonosari formation limestone	Wonosari formation limestone
C organic Organic matter	5,34% 9,21%	3,17% 5,47%	3,65% 6,31%
C sequestration	3,92 ton/ha	2,82 ton/ha	4,09 ton/ha
Total N Ratio C/N	2,86% 27,1	1,23% 29,63	1,63% 22,77

Figure 1. Terrain analysis of karst toposequence

Soil depth varies from zero usually on crest slope of steep slope, up to several meters on depression area. Thick soil will increase erosion processes and reduce it productivity. Soil texture is dominated by clay and easily eroded. Erosion process resulted to displacement soil from the crest slope and back slope towards depression area or doline (Figure 1). This is affect to the distribution and flow of soil carbon at each slope position. Soil Color Munsel Chartz shown that soil color in Gunung Sewu is dominated by dark reddish brown (2,5 – 5 YR). Organic carbon content has influenced of soil color, high organic carbon content is indicated by darkest color.

Soil organic carbon input agriculture land is strongly influenced by human activities. Fertilization and cultivation processes contribute to organic carbon content in soil. The recapitulation of carbon input to soil is presented in Table 2, and soil carbon flux model are presented in Table 3.

Table 2. Recapitulation of input carbon to soil

Input carbon	Crest slope		Back slope		Foot slope	
	kg/ha	ton/ha	kg/ha	ton/ha	kg/ha	ton/ha
Plant litter	5714,13	5,71	0	0	0	0
Harvest residue	0	0	1476,5	1,48	1402,92	1,4
Organic fertilizers	0	0	12758,5	12,76	14773	14,78
Total	5714,13	5,71	1426	14,26	16175,92	16,18

Source : research data, 2010

Table 3. Carbon fluxes matrix in toposequence

Parameters	Crest slope		Back slope		Foot slope		total	
Input C (ton/ha/year)	5,71	15,81%	14,26	39,45%	16,18	44,74%	36,15	100,00%
C sequestration (ton/ha)	3,92	10,85%	2,82	7,81%	4,09	11,31%	10,84	29,97%
Emission (ton/ha/year)	0,16	0,45%	0,07	0,20%	0,13	0,35%	0,36	1,01%
Transportation (ton/ha/year)	0,02	0,07%	0,02	0,04%	0,04	0,10%	0,08	0,21%
Processes	Erosion		Erosion		Deposition			
Missing C (ton/ha/year)	1,60	4,44%	11,35	31,40%	11,92	32,98%	24,88	68,81%

Source: research data, 2010

Carbon fluxes. Total input carbon to soil is 5,714 tons/ha/year. Total soil carbon sequestration on crest slope is 3,92 tons/ha. Major output carbon from soil on crest slope is occurring in 2 processes such as respiration, erosion and leaching. There are 0,16 tons/ha/year of carbon dioxide released to the atmosphere through respiration by microorganisms. Respiration process has influenced by organic carbon and nitrogen content in soil. Figure 3. Shown the respiration rate related to N and C content in soil.

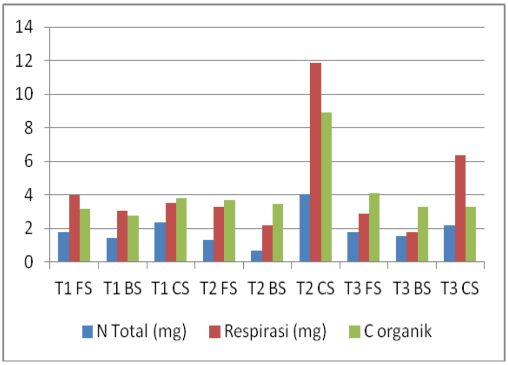

Figure 2. Respiration, N and organic C diagram

Soil carbon transported from crest slope is higher that back slope, it indicated that the erosion process in crest slope more intensive than back slope. Total carbon transported from crest slope is 0,025 tons/ha/years. The high level erosion is occurred in crest slope caused by making the terraces on land management has not been done even high vegetation density. Carbon lost from soil amounted to 1,6 tons/ha/year.

Total carbon input to soil is 14,26 tons/ha/year, with details 1,48 tons/ha/year derived from plant litter, and 12,76 tons/ha/year derived from organic fertilizers. Soil carbon sequestration is 2,82 tons/ha. There are 0,02 tons/ha/year of carbon transported through soil redistribution processes, and 0,07 ton/ha/year is total CO_2 emitted to the atmosphere. Carbon emission on back slope is lowest because the organic matter content lower than crest slope and foot slope. Total C loss from soil amounted to 11,53 tons/ha/year.

Input carbon from agricultural activities amounted to 16,18 tons/ha/year, with details 14,78 derived from organic fertilizers and 1,4 tons/ha/year derived from plant litter. Carbon input through soil deposition amounted to 0,04 ton/ha/year. Soil depositions that occur in foot slope are coming from some toposequences nearby. Soil carbon sequestration amounted to 4,09 tons/ha. The high content of organic carbon causes soil carbon sink high as well.

Total CO_2 emission from soil is 0,13 tons/ha/year. This number is highest compared with back slope and crest slope. Carbon output through erosion does not occur in this position, but there was soil deposition from back slope and crest slope. Carbon loss from soil in foot slope is occured through leaching, ponors, and dissolution process. Total carbon lost from soil on foot slope is 11,92 tons/ha.

Soil carbon fluxes model

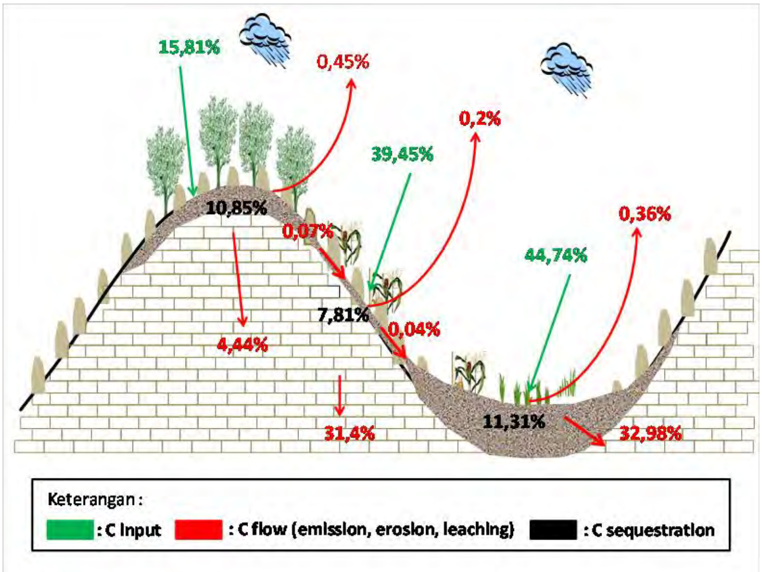

Figure 3. Soil carbon fluxes model in karst system (research data, 2010)

Figure 3. presented that the soil carbon flux in karst is different with the others landform. In watershed system, soil carbon loss from terrestrial to oceanic carbon pool is occurring through erosion process. Carbon flow from soil to water system in karst though hydrogeology system. Soils are transported through runoff to the depression area, and some of them are flowing to the underground drainage system or cave through ponors or sinkholes. Erosion occurring at the crest slope and back slope flow area of depression, and fill the dolins with soil material so that the soil layer is thicker in depression area than soil in crest slope and backslopes.

Discussion

Soil carbon flux in karst is unique. It is different with previous study that conducted on watershed system where carbon flows from terrestrial system to oceanic system occurred through surface erosion. Carbon flow from soil to water system in karst is occurred through surface erosion that flowing in to the ponors of sinkholes. There are 3 main processes in carbon flux in soil that occur in karst system such as input carbon, output carbon, and carbon sequestration. Input carbon is mainly derived from plant litter and organic fertilizers. The output carbon consists of two forms through respiration by microorganisms‘ activity and through soil redistribution (erosion and deposition processes).

The result has indicated that there is different carbon flux processes on each slope position. Largest input carbon to soil is at the foot slope, then on the back slope, and the last on the foot slope. Carbon input in crest slope mainly comes from plant litters, while in back slope and foot slope derived from harvest residue and organic fertilizers. Plant litter, microorganisms, macro-micro fauna, and organic fertilizer are an organic material that became the source of C organic in soil. According to Zhuang *et al.* (2007), the concentration of soil organic C depends on the balance between input and output of organic matter in soil. Plant litter that falls to the soil and turn of the fine roots are major input of soil organic C. Organic and chemical fertilizers is also input of carbon organic to soil in agricultural ecosystems.

Soil carbon sequestrations in each slope position are different. Carbon sequestration at the crest slope is 3,92 tons /ha, in back slope of 2.82 tons/ha, and at the foot slope of 4.09 tons/ha. A difference in soil carbon sequestration at each slope position is influenced by the amount of carbon input in soil, surface erosion, and soil respiration. C sequestration in soil is higher at crest slope than the back slope because the land use at the crest slope is dominated by forest and shrubs so that the input C of the litter is larger and land cultivation by farming activity almost non-existent.

Agricultural activities such as plowing and ploughing have impact to the soil carbon sequestration rate. Land management in crest slope is without cultivation processes, so that the number of soil carbon sequestration highest. This is related with research conducted by Rothon, *et al.* (2006). Rothon found that the highest organic C content in a single toposequences are at the foot slope and toe slope, this reflects the contribution from the slopes above it. Other researchers are Moormoan, *et al.* (2004) suggests that (a) soil cultivation system has an important role in reducing erosion and carbon conservation in surface soil (topsoil). Loss of carbon through erosion processes is more common in the disk tillage system, but the largest soil loss is through decomposition processes and microbial respiration regardless of the tillage system, (b) soil cultivation caused a decrease in soil carbon, which is followed by a period decrease gradually toward equilibrium, (c) soil on the back slope where this area is more susceptible to erosion have 50%C organic content lower than foot slope. Soil at the foot slope and soil on the basis of watershed position derived from the deposition of sediment has an average content of C is greater than the soil at the crest slope.

Precipitation and temperature not only affected to the soil carbon sequestration but also to the decomposition of organic matter by microorganisms. According to Zhuang, *et al.* (2007) climate conditions influence soil biological and physical processes driving soil organic matter dynamic change. In the process of soil organic carbon formation and decomposition, temperature and precipitation are the main influencing factors.

Soil carbon exchange in karst is influenced by input of organic matter as a source of soil carbon and the nitrogen availability in soil as an energy source for microorganisms on decomposition process. Soil moisture also have important role. Soil in crest slope have higher moisture than the other positions, it caused respiration processes in crest slope largest. The crest slope area is covered by canopy and without tillage processes so that the soil moisture is highest. The effect of temperature and moisture on organic matter decomposition process in soil to the carbon emission from soil has been proved by Bajracharya, *et al.* (2000). They showed that the CO_2 evolved from the soil surface varied significantly among seasons ranging from 0 g C/m^2/day in the winter to 1,6 g C/m^2/day during the summer. Soil erosion phase had no direct effect on C flux from soil, but it affects to the soil moisture and soil temperature.

The result indicated that the natural land use and no-tillage land on crest slope has highest of organic carbon and nitrogen content. While C : N ration is highest at the back slope. Yao *et al.* (2010) found that organic carbon and nitrogen total in soil has influenced by land use. That research indicated that there was a positive correlation between clay content and soil organic carbon as well as nitrogen content.

The flow of carbon in soil from crest slope toward the back slope and foot slope is occurs through soil redistribution. Soil carbon will be transported during the soil erosion process. According to Kimble *et al.* (2001) Erosion caused displacement and redistribution of soil organic carbon may accentuate mineralization and release of C to the atmosphere. Erosion breaks down aggregates, exposes soil organic carbon locked in them, and increases mineralization through increased microbial decomposition. Some of the soil organic carbon transported by erosion may be buried in depositional sites and aquatic ecosystems.

In the research site, loss of organic matter through erosion is not all the way into aquatic ecosystem, but rather deposited in depressed area such as doline, uvala, and polje. Result of field measurement showed that the carbon loss through soil redistribution is different at each slope position. Yumi (2001) showed that the soil sedimentation rate in karst is slightly with the largest value is 30,6 tons/ha/year and the smallest is 14,6 tons/ha/year as measured from the calculation of suspended materials in doline.

The organic matter decomposition will produce CO_2 and acid organic compounds. Carbon dioxide and acid organic compound will react with water forming acid solution HCO_3. According to the soil carbon flux model, there are 68,81% of soil carbon are missing. We estimated that the missing carbon is happen in three processes. The first process is transports of carbon vertically from top soil to subsoil through leaching. Second process is transports carbon to the underground drainage system through ponor of sinkhole, and the last process is loss through dissolution processes. According to Liu, *et al.* (1997), the carbon dioxide in soil is drives the karst processes under soil layer. Shengyou and Shiyi (2002) explained that the seasonality increase of carbon dioxide in soil profile is influences of limestone dissolution, According to Haryono, *et al.* (2009), carbon dioxides sources in limestone denudation processes are from atmospheric carbon dioxide and soil carbon dioxide. They estimated that the number of carbon sequestration through denudation processes is 72.804.16 tons.

Conclusion

The inputs of organic matter as a source of carbon to soil karst toposequence are difference between crest slope, back slope, and foot slope, and it influence to the soil carbon sequestration. The missing carbon is happened through leaching and flowing into the ponor/sinkhole.

The number of carbon emission through microbial respiration is influenced by land use, fertilization, and nitrogen availability in soil. Carbon flow from crest slope and back slope is occurred trough soil redistribution. Erosion processes has transported soil content of organic carbon from crest slope and back slope that accumulated on foot slope.

Input carbon to soil on crest slope is 5,71 tons/ha/year derived from plant litter only; on back slope is 14,46 tons/ha/year derived from organic fertilizers and harvest residue; and on foot slope is 16,18 tons/ha/year derived from organic fertilizers, harvest residue and carbon deposition from crest slope and back slope. Input carbon on back slope and foot slope is influenced by agricultural activities.

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CARBONATE ROCK DISSOLUTIONAL RATES IN DIFFERENT LANDUSES AND THEIR CARBON SINK EFFECT

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Abstract

Research on karst processes is very important for karst carbon sink estimation, and the carbon source/sink assessment precisely of terrestrial ecosystem in karst area as well. In this article the solutional denudation rates in the soil of different landuses of three karst spring watersheds using limestone standard tablets were studied, furthermore, carbon sinks were estimated. Solution rates show a distinct landuse control, with generally higher rate being recorded in the forest. The mean values of tablet solution in cultivated land, shrub, secondary forest, grassland and primary forest are 4.02、7.0、40.0、20.0, 63.5 t/km2.a respectively. Accordingly, in the proceeding of karsr carbon sink estimation in regional scale, landuse difference should be taken into account other than climate, hydrogeology and geological conditions. Vegetation evolution could improve karst carbon sink remarkably, carbon sink result from karst processes under the soil is 3 times higher in primary forest than in secondary forest, 9 timeshigher than in shrub, that is to say, carbon sink result from karst processes will increase 5.71-7.02 t/km2.a, 24.86-26.17 t/km2.a from cultivated land or shrub to secondary forest and to primary forest respectively. Carbon sink of terrestrial ecosystem increases with vegetation evolution or reforestation, it was proved that similar process caused by karst dissolutional denudation will happen under the earth simultaneously.

Key words: Carbonate rock, dissolutional rate, landuse, carbon sink, southern China

Introduction

In early stage on study of karst processes, the estimation of carbonate rock dissolutional rate was mainly done by means of mathematical method or empirical equation, for example, Pulina calculated and composed the potential dissolutional rate chart in scale of Poland, Europe, temperate and subtropical region of Asia, and the world respectively (Pulina, 1971; Pulina, 1974). Thereafter, a world correlation programme on dissolutional rates was conducted by International Union of Spelaeology in the framework of limestone standard tablet method. As a resolute of the programme 101dissolutional rate data in different soil depths from 25 correlation sites with different climate conditions around the world were collected and analysed by Gams (1981). The data from other karst areas showed that the more the precipitation is in a given study area, the higher the disolutional rate is (Drogue *et al.,*1987). Accordingly, before 1990s scientific research related to karst carbon sink were mainly focus on simple karst processes and their influencing factors, in which many of them are single factor analysis, such as air temperature or precipitation.

Since 1990s until the turn of the century it entered into an integrated study stage, with emphasize of associated impact of climate, hydrology, geology etc. on karst processes. It also was introduced into global change research area during the implementation of the IGCP 379 ―karst processes and carbon cycle(1995-1999)”, and aimed at the estimation of carbon sink intensity in regional(such as China (Jiang *et al.,* 1999)) and global scale. World correlation of carbon cycle of epikarst dynamics system was also carried out, and it was estimated that the carbon sink from global karst processes is (1.1-6.08)$\times 10^8$ tC/a (Yuan, 1999; Yoshimura *et al.,* 1997; Liu *et al.,* 2000; Liu, 2000), about 5.5%-30.4% of ―missing sink”. Moreover, carbon sink of atmospheric CO_2 result from epikarst processes in different karst region of the world was also investigated and monitored, for example, after 18 years monitoring of catchments in different landscapes in Spitsbergen near polar region, it is proved that the chemical denudation rates obtained from continuous recordings of water stages and detailed chemistry of water are quite different in different catchments. The amounts of carbon used for carbonate rock dissolution during weathering processes in glacier basin, permafrost terrace are 53.09×10^5 gC/km^2.a , $20.4\text{-}23.5\times10^5$ gC/km^2.a respectively, while the estimated removal carbon in a typical small karst catchment was high ranging $94.43\text{-}109\times10^5$gC/km^2.a (Krawczyk, 1999) in polar glacier region.

Currently karst processes has been involved in the research field of combating climate change considering the impact of human activities, such as landuse change, especially vegetation variation impact on karst carbon sink. The results from some typical studies showed that vegetation recovery and area increase of allogenic water in a catchment can improve karst processes remarkably (Zhang *et al.,* 2008; Ford *et al.,* 2007), as well as biological processes and soil carbonate anhydrase (Li *et al.,* 2004).

So with the deepen of disciplinary research and improvement of estimation method and accuracy, the percentage of karst carbon sink in “missing sink” could be much higher than it is. On the other hand, debate and argument are still remained on long-term/short-term process of karstification. There are several key scientific problems in the study of karst carbon sink potential, including how to distinguish partial sink which is related to human activities, such as reforestation and acid rainfall (Liu *et al.,* 2008); the stability of bicarbonate in underground water (Liu, 2007) when it flows out and turns into surface water.

It seems to be more important in temporal(seasonal) and spatial(landuse) variation of karst processes owing to the sensitivity of karst dynamics system to environmental change and the heterogeneity of karst and karst water (Zhang *et al.,* 2005; Yuan, 1993). In this paper, taking three small catchments in Fengcong depression area of Nongla, Guangxi, and karst valley of Jinfo mountain, Chongqing as an example, the author discussed the subsoil dissolutional rates and carbon removals‘ variation under the different land-use patterns, i.e. till land, shrub, secondary forest, and primary forest, using standard limestone tablet method. Furthermore, karst carbon sink potential with the evolution of vegetation was analyzed. The study will help understand the impact of different land-use patterns on karst processes. It also provides some basic information for more accuracy estimation of karst carbon sink result from carbonate rock chemical denudation, thus potentially improve carbon cycle model used for terrestrial ecosystem in karst region.

Study Area

1. Nongla, Mashan County, Guangxi

Nongla is a typical karst Fengcong (depression) mountainous area, which is situated at Guling Town, Mashan County, Guangxi, China (Fig.1). Air temperature ranges from 8°C to 30°C with annual average 20 °C. Annual precipitation is about 1750 mm. The main lithology is thick marl-silica dolomite of Donggangling Formation of middle Devonian with gentle dip angle (Zhang *et al.,* 2003). Soil thickness is about 1-2m, generally 0.5m. Soil CO_2 contents at 20cm and 50cm depth are 4500×10^{-6}-17000×10^{-6}, 8000×10^{-6}-35000×10^{-6} respectively.

Secondary forest is the main vegetation cover in the study area, which account for 51.94% of the total land area, orchard, shrub and tilled land constitute 31.59%、9.26%、7.21% respectively(Tab. 1).

Table 1. Landuse covers and their areas in the year of 2003

landuse	forest	orchard	tilled land	shrub	total
area(km^2)	0.684	0.416	0.095	0.122	1.317
percentage(%)	51.94	31.59	7.21	9.26	100

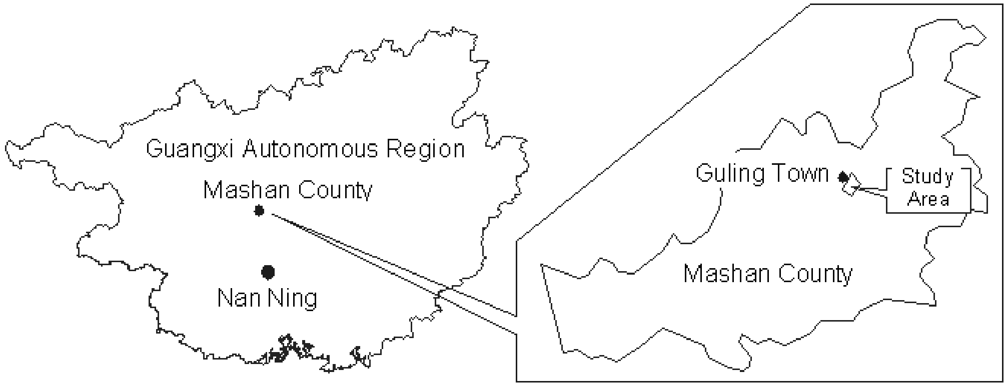

Figure 1. Geographic location of Nongla, Mashan County, Guangxi

2. Jinfo mountain, Chongqing

Jinfo Mountain (Jinfo Mt.) National Nature Reserve is located at the south of Nanchuan County, Chongqing Municipality, China (Fig.2). The area of main scenic attractions in Jinfo Mt. occupies about 441km^2. The plateau surface is underlain by Permian limestone (P1) in the upper part with about 2000m a.s.l. Meanwhile, karst forms in large scale(dolines and caves) on the surface or underground are well developed; The shale and sandstone of Silurian lay in the middle part of Jinfo Mt. from 1000m to 1500m asl.; The lower part of Jinfo Mt. is composed of limestone and dolomite of Cambrian and Ordovician, plenty of small- and micro-forms of karst are formed in this area. Overall, Jinfo Mt. sits in the subtropical humid monsoon climate zone with rainy season from April to October. The vertical change of climate and vegetation is very notable from the mountain foot to the top. The lower part of the mountain has subtropical humid monsoon climate, typical in Southwest China, with annual average air temperature of 16.6 ºC and annual mean rainfall of 1,286.5mm. However in the upper part of the mountain, it exhibits similar characteristics usually observed in temperate climates with annual average air temperature of 8.2 ºC, annual mean rainfall of 1,434.5mm(Zhang *et al.,* 2006) .

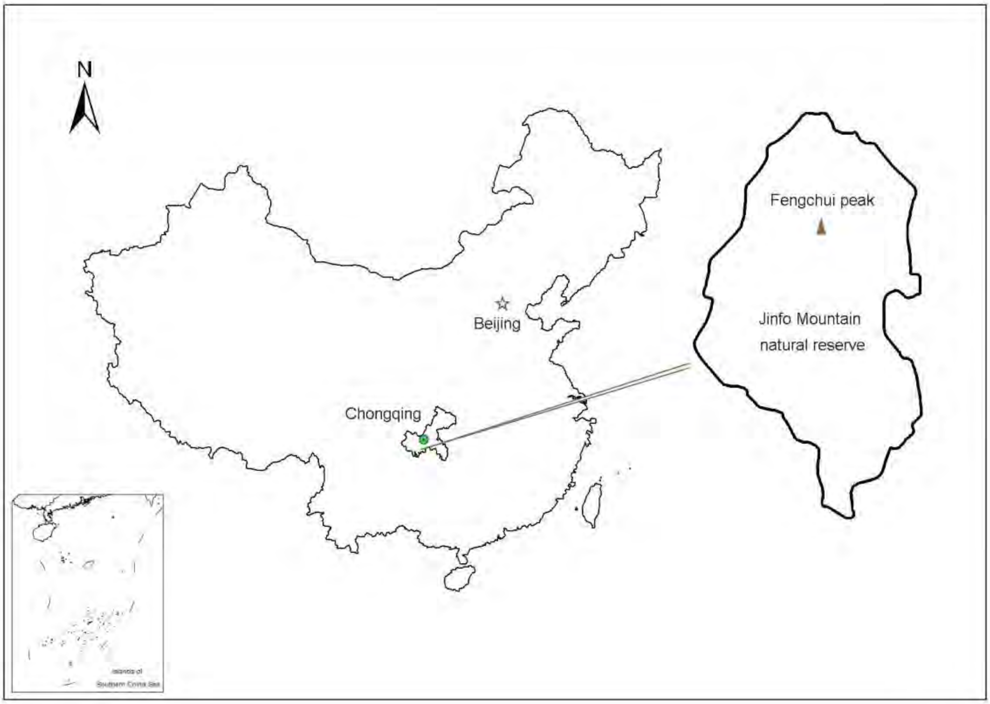

Figure 2. Geographic location of Jinfo mountain, Chongqing

In this study, two epikarst springs at different elevations were selected as study sites: Bitan Spring (BS, 700m a.s.l.); and Shuifang Spring (SS, 2,000m a.s.l.). The former (BS) represents the lower part of mountain with karst ecological environment typical in subtropical climate zone while the latter (SS) represents temperate karst ecological environment on plateau surface and mountain top.

The lower part is composed mainly of the limestone and dolomite of Cambrian and Ordovician and soil thickness is 20~60cm in this area. Secondary shrub is the main vegetation with 70% of coverage. It belongs to low-mountain gorge karst in geomorphology under the good condition of water and heat. The plateau surface at the mountain top is underlain by Permian limestone and soil thickness is 30~120cm. primary forest and grass land are the main land use patterns in this area.

Driving forces of soil for karst processes in study catchments are listed in Tab.2, including two key controlling factors: soil CO_2 and organic carbon content. The data showed that with the evolution of vegetation (from tilled land, shrub to secondary forest, and to primary forest), pH value decreases, the contents of soil organic carbon and soil CO_2 increase gradually. The soil CO_2 content in Nongla, Mashan is higher than that in Jinfo mountain which is probably related to higher air temperature during the summer and much intensive soil respiration. It was proved by average spring water temperature (approximating to local average air temperature)(Tab. 3)。

Table 2. Driving forces of soil for karst processes in study catchments

Study area and land uses		pH	Av. Soil $CO_2(\times10^{-6})$	Av.Soil Org. C(%)	note
Nongla, Mashan	Secondary forest	7.28-7.40	16100	3.43	Soil CO_2 was measured in raining season, ”/” means no data
	Orchard land	7.2-7.49	/	3.39	
	Shrub land	7.98-8.40	9100	2.00	
	Tilled land	8.33-8.44	/	3.19	
Bitan spring, Jinfo Mt.	Secondary forest	6.68-7.67	4700	5.54	
	Shrub land	8.04	2000	1.91	
Shuifang spring, Jinfo Mt.	Primaryforest	6.3-6.94	7000	11.28	
	Grass land	/	6000	2.72	

Table 3. Main hydrochemical parameters of epikarst springs in study catchments

Study area	Epikarst spring	Land use	Av.Temp. (℃)	Av. pH	$[Ca^{2+}]$ (mg/L)	$[HCO_3^-]$ (mg/L)	EC (μs/cm)
Nongla, Mashan	Landiantang spring	Secondary Forest	19.7	7.54	73-90	317.2-451.4	599-603
	Dongwang spring	Shrub land	19.4	7.70	52-83	311.1	435-460
	Nongtuan spring	Tilled land	19.8	7.91	39-42	164.7-268.4	293-360
Jinfoshan Mt.	Bitan spring	Secondary forest	14.7	7.97	34-54	180.3-205.0	226-351
	Shuifang spring	Primary forest	9.9	7.67	20-50	97.2-121.0	189-223

Study Methods

The measurement and calculation of solutional denudation rates of limestone manly include hydrochemical-runoff method (Ellaway *et al.,* 1990), Corbel formula calculation (Corbel, 1959), weight loss measurement of standard limestone tablet, DBL chemical-dynamics method (Dreybrodt, 1991), micro-erosion meter (High *et al.,* 1970; Trudgill *et al.,* 1981), Karrentische (measurement of bare-rock surface irregularities), and cosmogenic chlorine-36 measurement (Bogli, 1961; Peterson, 1982). The last two are mainly used for long-term average estimation(>10ka). Hydrochemical-runoff method should be based on at least one hydrological year monitoring of discharge and Ca^{2+} content of the water; when the data are limited, Corbel formula is an appropriate method for obtaining a first-order estimate of dissolutional denudation using runoff and the average $CaCO_3$ content of the water; DBL approach can predict hydraulic control to precipitation rate, it is useful for better understand of micro-denudation mechanism but scaring adequate on-site data support, furthermore, it is still questionable for simulation of regional micro-processes. Standard tablet method needn‘t have long time monitoring, rock tablets of standard dimensions and lithology can be easily prepared.

The area of emphasis should be mentioned is the spatial-scale converting problem (from a site to a region/catchment). This method was used in the paper to determine carbonate rock dissolutional rates and their carbon sink effect in catchment scale.

Typical land uses (forest, shrub, grass land, orchard, and tilled land) in two spring catchments were selected for tablets bury at various soil depths, soil CO_2 and soil moisture are also measured on site using GASTEC-CO_2 meter and SM-2 portable meter.

Standard tablet method was introduced into Chinese karst community by Yuan Daoxian in later 1980s (Yuan *et al.,* 1988), and was used widely during the implementation of the IGCP 299 project "Geology, climate, hydrology and karst formation" (1990-1004), which aimed at the correlation of karst processes intensity and differences under different geological, climatic and hydrological background. For the results comparable, tablets used for different sites all are from Guilin and same lithology, pure limestone of Rongxian Formation of Devonian, with standard dimension. tablets are rather rounded in shape with a diameter of 40mm, and a thicknss of about 3mm.

Standard limestone dissolutional tablets were placed on rock surface and at different soil depth (-5cm, -20cm, -50cm). 3 tablets were placed at each layer and each land-use cover. Tablet annual dissolutional rates (DRs) were measured after one hydrological year's buried using following formula (Yuab *et al.,* 1988):

$$DR=(W1-W2)\times 1000\times T/365/S$$

where：DR—dissolutional rate (mg/a.cm^2)

W1—tablet initial weight(g)

W2—tablet weight after buried(g)

T—buried time(d)

S—surface area of tablet(approximately 28.9cm^2)

Results and Discussion

In Nongla Fengcong (depression) area, four representative sites were selected in different land use covers (woodland, shrub, orchard, tilled land), and a total of 48 pure limestone tablets were placed. Buried time is from 1 April 2004 to 6 April 2005. 46 tablets data were obtained (2 lost). The results showed that DRs are quite different in different sites and at different soil depth. Maximum absolute DR is 145 mg/a, at the depth of -50 cm in orchard. Most of DR is larger than 20 mg/a in woodland and orchard, more higher than that of shrub and tilled land. Average annual DRs at various soil depth and unit-area DRs in different land uses are listed in Table 1.

Table 1. Under-soil dissolutional rates in different land uses in Nongla

Land uses	Under-soil DRs (mg)				Unit-area DRs (t/km^2.a)
	-5cm	-20cm	-50cm	Av.	
Tilled land, Nongtuan	9.5	11.0	14.9	11.8	4.02
Shrub, Dongwang	1.4	0.5	2.6	1.5	0.51
Woodland, Landiantang	88.1	68.7	18.7	58.5	19.97
Orchard, langdiantang	82.0	87.7	120.1	96.6	32.97

In general, DR in descending order is orchard, woodland, tilled land and shrub(Table 1). DR in shrub is one order of magnitude less than those calculated from other land uses, it means that vegetation degradation is unfavorable for karst process. On the other hand, less rate also represents less developed and shallow epikarst zone in this section, which was proved by the occurrence of a seasonal epikarst spring in the vicinity of tablet buried site. Accordingly, relative under-soil DR indicates the development characteristics of karst aquifer in some degree. Under-soil DR in woodland is 40 times of that in shrub, 5 times of that in tilled land. The results showed that land use has a remarkable impact on karst processes, in which soil organic matter(OM) and soil CO_2 are two major controlling factors (Zhang *et al.,* 2006).

DR seems directly dependent on soil OM under the secondary forest and orchard conditions, OM content of surface layer of soil is always high in woodland due to the thick litter and intensive microbe activity. OM content is generally high in orchard caused by organic fertilization and results in an increase tendency of OM from surface to deep soil, as well as DR.

Under the tilled land and shrub condition, soil OM content is relatively lower, and deceases with depth, results in slower under-soil DR, and seems to have a slight rise with depth, corresponding to the variation of soil CO_2 concentration. It showed that soil CO_2 is a key controlling factor during karst processes (Xu *et al.,* 1996). Moreover, enlarged porosity resulted from the surface soil disturbance in tilled land is in favor of soil CO_2 release, thus unfavorable for karst process; in shrub area sparse vegetation, steep slope, much more solar radiation absorption, and intensive transpiration, which unfavored for moisture preservation, are also important factors that can impact on DR.

In Bitan spring and Shuifang spring catchments of Jinfo mountain, four representative sites were selected in different land use covers (woodland, shrub, grass land, tilled land), and a total of 34 pure limestone tablets were placed. Buried time is from 24 January 2007 to 27 March 2008. 34 tablets data were obtained. Maximum absolute DR is 218.15 mg/a, at the depth of -20 cm in woodland of Shuifang spring and minimium 3.9 mg/a, at the depth of -50 cm in grass land of Bitan spring. Most of DR is higher than 40 mg/a in woodland, more higher than that of shrub and tilled land(less than 30 mg/a). Generally, in rainy season weight loss in various landuse decreases from woodland, grass in Shuifang spring; and from woodland, tilled land to bush-grass in Bitan spring. Average annual DRs at various soil depth and unit-area DRs in different land uses are listed in Table 2.

Table 2. Under-soil dissolutional rates in different land uses in Jinfo mountain

Land uses	Under-soil DRs (mg)				Unit-area DRs ($t/km^2.a$)
	-5cm	-20cm	-50cm	Av.	
Rock desert land	Rock surface			32.6	10.38
Woodland, Bitan	106.9	41.6	39.8	62.8	20.0
Shrub, Bitan	50.6	11.6	3.9	22.0	7.0
Woodland, Shuifang	187.8	218.2	191.8	199.3	63.5
Woodland, Shuifang	Rock surface			67.1	21.4
Grass land, Shuifang	94.3	105.1	177.1	125.5	40.0

Data in table 2 showed that annual weight loss of tablets in Shuifang spring both placed in soil and on the surface under different land uses is generally higher than that in Bitan spring, especially in primary forest of Shuifang spring, DR is 3 times of that in secondary forest of Bitan spring.Yearly average under-soil DRs in Shuifang spring all are higher than 120 mg(equivalent to 38.0g/m^2·a), moreover DR in the soil is generally greater than that on the surface at a given site. The value of DR from secondary forest in Bitan spring, 3 times of that from nearby shrub measurement site, is quite close to that from secondary forest in Nongla. It indicates again that vegetation degradation is unfavorable not only for soil quality, but also for karst processes.

Generally DRs both in the soil and on the surface at the upper part of the mountain are greater than that at the lower part of the mountain, and DRs in forest are higher than that in grass land. However, DR of grass land in Shuifang spring is higher that that of forest in Bitan spring, it may be caused by lower CO_2 content (Table 2) and higher $CaCO_3$ content, ranging 0.81-3.26% in the soil of Bitan spring, while Soil $CaCO_3$ in Shuifang spring ranges 0.01-0.07%. alkaline barrier is unfavourable for the dissolution of limestone tablets. On the other hand, the distinct values of DR also show the heterogeneity of karst. Moreover, soil CO_2 and soil moisture characteristics are two major controlling factors which influence the weight loss in tablets placed in the soil (Zhang, 2010).

Soil CO_2 shows distinct temporal and spatial variety. In rainy season mean CO_2 content at Shuifang spring is as high as 7000×10^{-6}(July, 2006), whereas 4700×10^{-6} at Bitan spring and 3900×10^{-6} at vicinity (tilled land)(Tab. 2). In dry season the normal CO_2 is about 1000×10^{-6}, average values of soil CO_2 in Shuifang and Bitan are 1200×10^{-6} and 970×10^{-6} respectively.

Soil water content from different landuse soil profiles near Bitan spring is less than that in Shuifang spring, most content in Bitan is smaller than 30%W, while larger than 40%W in Shuifang spring. And the water content of soil profile has relative stable distribution near Shuifang spring owing to more precipitation recharge and lower air temperature favored for moisture holding. Soil water of surface layer in tilled land is very low, which showed that vegetation degradation or human activities can influence remarkably the soil water content and water holding capacity.

The area of Shuifang spring catchment is about 0.54km^2, based on monitoring data of monthly discharge and Ca^{2+} contents of spring in the year of 2004, the estimateion of $CaCO_3$ removal from this catchment by chemical dissolutional denudeation is 18.26 t or 33.81 t/km^2.a. the rate value calculated from water hardness and runoff data is less than those derived from tablet weight loss in the soil of woodland or grass land, but quite close to average DR of the catchment(41.6 tkm^2.a). So DR calculated from single land use pattern can not be used for regional scale estimation.

CO_2 removal calculated from unit-area $CaCO_3$ dissolutional denudation is listed in table 3. the data showed that CO_2 contents up taking from atmosphere(carbon sink) by karst processes are quite different in various land uses owing to the heterogeneity of karst with a maximum of 27.94 t/km^2.a(7.62 tC) at primary forest in Shuifang spring of Jinfo mountain, and a minimum of 0.224 t/km^2.a (0.061 tC) at shrub in Dongwang of Nongla, Guangxi.

In general, carbon sink caused by karst processes in descending order is primary forest, grass land, secondary forest, shrub and tilled land. Values from secondary forest both in Landiantang and Bitan are relatively close, about 8.8 t/km^2.a(2.4 tC), three times of that in degradation shrub, five times of that in tilled land nearby. Furthermove, carbon sink in primary forest is three times of that in secondary forest, i.e. in typical Fengcong areas of southweat China karst, carbon sink increase caused by carbonate weathering process is about 5.71-7.02

t/km^2.a and 24.86-26.17 t/km^2.a from tilled land/shrub to secondary forest and primary forest respectively. The data also showed that under-soil DRs have a distinct variation in different land uses, so land use patterns should be taken into account for regional scale carbon sink estimation more precisely, besides other background conditions, including climate(air temperature and precipitation), hydrology(runoff and allogenic system) and geology etc.

Table 3. Carbon sink related to karst processes in different land uses

Location	Land use, site	Unit-area DR (t/km^2.a)	Unit-area CO_2 removal(t/km^2.a)	Carbon sink (tC/km^2.a)
Nongla, Mashan, Guangxi	Tilled land, Longtuan	4.02	1.769	0.482
	Shrub, Dongwang	0.51	0.224	0.061
	Woodland Landiantang	19.97	8.787	2.396
	Orchard, Langdiantang	32.97	14.507	3.956
Jinfo Mt. Nanchuan, Chongqing	Rock desert	10.38	4.567	1.246
	Woodland, Bitan spring	20.0	8.80	2.40
	Shrub, Bitan spring	7.0	3.08	0.84
	Woodland, Shuifang spring	63.5	27.94	7.62
	Grassland, Shuifang spring	40.0	17.60	4.80

CO_2 removed during weathering processs could be both from atmosphere and soil respiration. Whereas soil respiration is a very important component in terrestrial carbon cycle, and its accurate assessment could have crucial influence on terrestrial carbon source/sink estimation (Zhou *et al.,* 2008) . CO_2 result from soil respiration may be involved actively in carbonate weathering processes in karst region, thus essential to consider karst processes in the research of carbon cycle potential and assessment of karst region.

Forest is the largest carbon pool in terrestrial ecosystem, Dixon et al. reported that global forest area is about 4.1×10^9 hm^2 (Dixon *et al.,* 1994), which can sequestrate 1,196 $\times10^9$ t CO_2 annually (Zhang *et al.,* 2008). Total carbon sequestration capacity in China is 4.5×10^9 t CO_2 for forest, 1.2×10^9 for grass land, 0.5×10^9 for sparse forest and shrub, 0.1×10^9 for crop, 0.2×10^9 for desert (Fang, 2000).

Unit-area carbon sequestration capacity of grass land is less than that of forest, average carbon sink of grass land in China is one tenth of that of forest (Fang, 1981) . From the view of vegetation's carbon sequestration capacity, the largest contributor is forest, the second one is grass land and wet land, and the smallest one is crops. As mentioned above there is a similar variation for under-soil karst carbon sink, which indicates that forest can improve karst processes remarkably.

Karst processes is a part of global carbon cycle, in recent years geological processes (including karst processes) were neglected in global carbon cycle study, one important reason for this is that the geological processes in carbon cycle model was regarded as a medium- to long-term processes, whereas biological processes as short-term processes. Thus the carbon flux parameters for geological processes are 2 to 3 orders of magnitude less than those for various biological processes in the model (Mackenzie *et al.,* 1995), for example, carbon fluxes for marine biological processes and terrestrial ecosystem are about 45 billion T/a and 60 billion T/a respectively. Whereas 0.2 billion T/a for weathering processes, 0.16 billion T/a for carbonated precipitation, and 0.06 billion T/a for volcanic processes. Neglect of geological processes may be one of the key factors result in unbalance between source and sink of atmospheric CO_2.

Soil CO_2 and HCO_3^- of underground water are two factors related closely to karst processes in epikarst dynamics system. Many years monitoring data showed that these two parameters have distinct seasonal multi-year variations and a positive relationship (Liu *et al.,* 2000) , i.e. soil CO_2 increase can improve carbonate chemical dissolution, thus the increase of HCO_3^- contents. Changes are also affected by air temperature and rainfall events (Liu *et al.,* 2004). The results indicate that karst processes is very sensitive to environmental change, and varies simultaneously with various climatic change (rainfall, air temperature), biological processes (soil CO_2 rise result from decomposition of organic matter) which means no remarkable time lag (Yuan, 1997) [6]. The results of this paper proved this point and karst processes is also sensitive to vegetation change.

Karst carbon sink was commonly considered as a revertible process, nevertheless, the result from paper which is newly published in volume 326 of Science (12.18.2009) showed that aquatic CO_2 is much more stable than our understanding of processes (Adamczyk *et al.,* 2009). This provides a basic support for determining the stability of HCO_3^- of surface water, which circulated from underground karst water, and for estimating net carbon sink.

Conclusion

Karst processes intensity is related closely to climate, hydrology, geology, as well as land uses. Comparison between karst systems with different elevations in southwest karst area showed that DR is generally dependent on precipitation, other than on temperature, positive evolution of vegetation can improve under-soil DR remarkably, thus the increases of CO_2 carbon sink of terrestrial ecosystem and of karst processes.

The results of this paper proved that carbon sink caused by karst processes can increase 2 up to 8 times during the vegetation evolution from shrub to secondary forest, and further to primary forest. Unit-area carbon sequestration capacity of karst processes may be less than that of forest ecosystem, but exposed karst is distributed widely in southwest China with an outcrop area of 907 thousand km^2 (Yuan *et al.,* 2002). With the deepen of rehabilitation of rock desertification and ecosystem restoration, there will be a huge karst carbon sink potential. On the other hand, it is essential to obtain more data to verify the increase amplitude of carbon sink from karst processes with vegetation restoration, thus the results could be applied for large regional scale carbon sink estimateion.

Data from monitoring and experimental sites showed that karst processes, as a low-temperature geochemical open system, is very sensitive to environmental change, and is a kind of special geological processes which involved in short-term carbon cycle. Carbon sink of terrestrial ecosystem increases with vegetation evolution or reforestation, it was proved that similar process caused by karst dissolutional denudation will happen under the earth simultaneously.

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BIOSPELEOLOGY AND BIODIVERSITY

BIOSPELEOLOGY OF JAVA CAVES, INDONESIA: A REVIEW

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Abstract
Java Island is the most densely populated island in Indonesia, which has limestone karst extending from west to east forming a unique landscape. Each karst formation has an extensive cave development to form underground habitat for many organisms. Although some cave explorations have been done in the island, biospeleological knowledge of the island is still poorly understood. Several new troglobitic species were discovered in many caves from the island. Unfortunately, the knowledge of their ecology, biology, and the conservation issues of the species are remained unknown. During the extensive fieldwork in almost all karst areas, more than a hundred species from 17 families were discovered. Of those, more than 50 species were believed to be a troglobitic species and most of them are remained undescribed. The most remarkable cave species discovered is the cave spider from Menoreh Karst, Central Java, which shows troglomorphic features with very small eyes, pale coloration and legs elongation. Java caves are proved to be home of various endemic and unique cave invertebrate species. The recent knowledge of the biospeleological studies in Java can be used to manage the karst ecosystem specifically to protect the cave faunas and its habitats.

Keywords: conservation, troglomorphism, endemism, biodiversity, arthropods

Introduction

Java Island is the most densely populated island in Indonesia and about 4 percent (5500 km^2) of present day surface cover with karst areas. Each karst area is separated by alluvial sediment forming island-like karst ecosystem. The vast cave development occurs in the karst forming underground habitat for many organisms. Caves as a habitat are unique and specific due to the stability of the environment such as stable darkness, stable in temperature, high humidity and low-energy resources because the lacking of green plants. Biospeleology, the science to study the cave life, is poorly understood in the island. However, Java Island proves to be a home of several new species. The paper is aimed to understand the current knowledge of biospeleology in the island, and its important role for caves and karst conservation to ensure the protection of cave faunas and its habitat.

Methods

Eleven karst areas in Java were surveyed, and about 60 caves were explored to collect cave fauna especially cave invertebrates. The distribution of the karst areas in the island was shown in Figure 1.

Several different fieldworks in April, August and December 2007, April and August 2008 were done to study the diversity of cave faunas especially cave invertebrates. Cave invertebrates were collected using various methods: pitfall traps and direct collecting. The pitfall trap method was aimed to study soil surface-dwellings arthropods in cave floor. About 65 pitfall traps were set up in five different caves in four different karst areas for 72 hours. The direct collecting were applied using a small brush, forceps, nets and specimen bottles to collect the cave invertebrates that live under stones, on the cave walls, under dead woods, in the small puddles, ponds, and underground river. The cave invertebrates were preserved using ethanol 70% and 98% for further studies. The identification of the fauna was based on the morphospecies which based on morphological characters and further detail identification to species level was done when it possible.

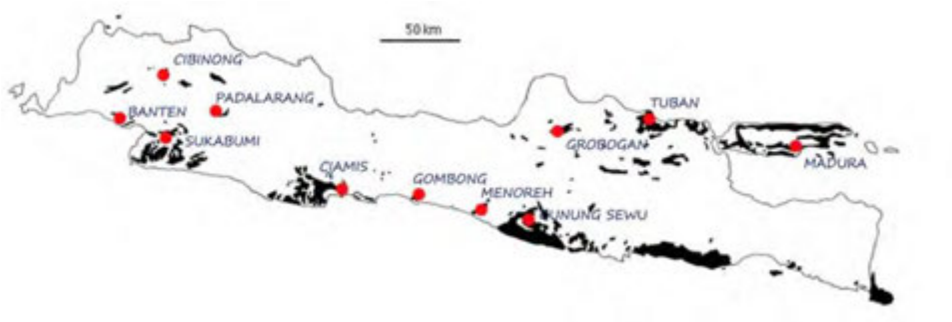

Figure 1. The distribution of the karst areas in Java and showing areas studied

History

The discovery

The first cave invertebrate was reported from caves in Gunung Sewu, Yogyakarta by the finding of first cave crab, *Karstarma jacobsoni* (Ihle, 1912), previously belonging to the genus *Sesarmoides*. Burr (1912) described one species of Dermaptera which is known as guanophilic species from lava tube (Gua Lawa) near Banyumas namely *Arixenia jacobsoni* Burr, 1912 which was currently placed in the genus *Xeniaria* forming combination *Xeniaria jacobsoni*. From the same cave, Gua Lawa, Tullgren (1912) described a new species of cave false-scorpions, *Stygiochelifer cavernae* (Tullgren, 1912) and recognized as guanobitic species. In 1915, Gravely (1915) reported one new species of whip spider namely *Phrynichosarax javensis* Gravely, 1915 from Bogor (as Buitenzorg) which was currently belonging to the genus *Sarax* forming combination *Sarax javensis*. A new species of crickets was described by Chopard (1924), *Arachnomimus jacobsoni* Chopard, 1924 from Gua Jatijajar (Karst Gombong, Central Java). Karny (1924) also described cave crickets, *Rhaphidophora dammermani* Karny, 1924 which was collected from Ciampea (Bogor) and Gua Nglirip (Tuban). Later, Roewer (1928) added one new species of whip spider collected from several caves in Bogor (as Buitenzorg), *Stygophrynus dammermani* Roewer (1928). Brist (1935) described one tenebrionid species from Banyumas namely *Tenebrio antricola* Brist, 1935 (Coleoptera). In 1951, one species of tineids moth is described from lava cave in Mount Tengger, namely *Wegneria cavernicola* Diakanoff, 1951. Since then, no cave species has been described from the island. The emerging periods of biospeleological researches in Java was started again in 1984 with the description of cave prawns from Gunung Sewu *Macrobrachium poeti* Holthuis, 1984. Two species of philosciid isopods were described from two caves in Gunung Sewu by Schultz (1985) namely *Tenebrioscia antennuata* Schultz, 1985 and *Javanoscia elongata* Schultz, 1985. The most recent cave obligate species from Java, *Stenasellus javanicus*, was described in 2006 (Magniez and Rahmadi 2006). The species was found in small puddle in small caves near limestone‘s quarry in Cibinong.

General studies

A brief overview of biospeleological studies in Java have been reported by several authors (Dammerman, 1932; Suhardjono *et al.,* 2001; Rahmadi *et al.,* 2002, 2005; Lips, 2003;

Rahmadi & Suhardjono, 2007). Several studies of cave fauna were reported by several students (Notowinarto, 1986; Palawa, 1988; Sutrisno, 1987; Matalabiogama, 1987, 1999). Some fieldwork reports of the cave faunas in Java were remained unpublished. In 2000, the French scientists in collaboration with Indonesian scientists made exploration in several caves and reported the results in the International Symposium of Biospeleology in Brazil (Suhardjono *et al.,* 2001)

Cave Invertebrates

During several fieldworks in Java caves, more than a thousand of specimens consisting more than a hundred species of cave invertebrates from 71 families belonging to arachnids, myriapods, crustaceans and hexapods including springtails and insects were discovered (Table 2). Of those, about fifty species were suggested to be cave obligate species. The detail of the diversity of each group as follow

Table 1. Number of cave invertebrates from Java caves

TAXA	Number		
	Family	Species	TB/SB
Annelida			
Hirudinea	1	2?	0
Crustacea			
Decapoda	6	10	5
Isopoda	5	20	12
Myriapoda			
Chilopoda	3	4	0
Diplopoda	3	6	3
Arachnida			
Acari	3	9	0
Opiliones	3	9	0
Schizomida	1	6	6
Pseudoscorpiones	1	1	1
Amblypygi	3	7	1
Uropygi	1	1	0
Araneae	10	25	1
Hexapoda			
Thysanura	1	1	0
Diplura	1	2	2
Collembola	9	21	15
Coleoptera	6	22	0
Dermaptera	2	4	1
Dictyoptera	2	5	3
Diptera	4	10	0
Hymenoptera	2	6	0
Thysanoptera	1	1	0
Trichoptera	1	2	0
TOTAL	**69**	**174**	**50**

Annelida

Hirudinea. Hirudinea was found on the cave roof and walls with reddish coloration. The group was collected from Gua Buniayu (West Java) at about 800 m asl., and Gua Sekantong (Menoreh Karst, Central Java) at about 700 m asl. Hirudinea was found in Papuan caves and sporadically found in Sumatran caves (Deharveng *et al.,* 2006). In Java, the group was known only in caves with the altitude more than 700 m asl.

Crustacea. Crustacea is a common group to live in cave both terrestrial and aquatic habitat. They have the highest diversity of cave obligate species. In Java, about 30 species from 11 families were recorded and 17 species are believed to be cave obligate species.

Decapoda. Brachyura is represented by four families (Sesarmiidae, Parathelphusidae and two other families). The first cave species of decapods from the island is *Karstarma jacobsoni* (Sesarmiidae). The species is known only in Gunung Sewu karst from several caves in the Bribin Cave System such as Gua Jomblang, Gua Ngingrong, Gua Jurang Jero (Adji pers.comm), Gua Gilap, Gua Sodong Dadapayu and Luweng Towati (Hidayat pers.comm). They live in percolation water and very rare found in main rivers from surface water. Other species of crab is *Parathelphusa convexa,* which was reported from Gua Ngingrong (Ihle, 1912) and several underground rivers in Gunung Sewu and other areas. *Parathelphusa* sp. was collected from Gua Urang in Grobogan and two unidentified species were collected from Gua Cilalay and Gua Lauk (Banten).

The cave prawns consist of two families (Atyidae and Palaemonidae). Family Atyidae was found in Gunung Sewu, *Caridina* sp.1 and *Caridina* sp.2 with small eyes and white coloration. These two species can be distinguished by its length of rostrum (Wowor pers. comm.). They were found in Gua Gilap, Gua Bribin and Gua Jomblang and might be a new to science. The cave prawn, *Macrobrachium poeti* Holthuis, 1984 (Palaeomonidae), was collected for the first time from Gua Sodong Mudal, Luweng Tong Pocot and Gua Ngingrong (Holthuis, 1984). The species was also recorded from Gua Gilap share the habitat with *Karstarma jacobsoni*. Other stygophilic species were found, such as *Macrobrahium lar* and *Macrobrachium pilimanus*. These species were commonly found in some underground water in several karst areas such as Gombong and Banten. In Grobogan karst, one species of *Macrobrachium* sp. which has eyes reduced in size, white and elongate antenna and suggested to be a second stygobitic species for Java.

Isopoda. The group consists of several families both terrestrial and aquatic species. The aquatic species were represented by two species, *Stenasellus javanicus* (Cibinong) and *Stenasellus* sp. (Sukabumi). These species were found in the percolation water in the small pools with drips water from the stalagmite in very low population.

Stenasellus javanicus was collected from single cave in Gua Cikaray (Cibinong). The cave located on karst area on altitude about 110 m asl., densely populated and highly disturbed due to limestone mining activities. So far, the small number of individual was observed in different parts of the caves in various visiting in 2008 and 2009.

A second record of *Stenasellus* sp. was found in Gua Buniayu (Sukabumi) about a 100 km away from Cibinong at the altitude about 800 m asl.. The species lives on the small pools in fossils passage and in small inlets in phreatic passages.

Terrestrial isopods species are dominated by family Philosciidae, Porcellionidae, Trichoniscidae and Armadillidae. The family Armadillidae was collected only from Gua Cikaray (Cibinong) and caves of Menoreh karst. Trichoniscidae is family with white body and in each segment equipped crest and possible to roll. The family was found only in Gua Buniayu. Porcellionidae have some species and mostly epigean species. The most diverse is

Philosciidae with 12 species encountered. They show a high adaptation into cave environment showing troglomorphic features. Two caves species were described by Schultz (1985) namely *Tenebrioscia antennuata* and *Javanoscia elongata*. They were collected from caves in Gunung Sewu. Other species were also found in other karst areas and show highly adapated to cave environment.

Arachnida

Schizomida. About six species of schizomids were recorded. Two species were found in Tuban, and one species in Grobogan, Gombong, and Banten. Several unidentified female specimens from Sukabumi and Cibinong were also collected. Each species can be easily distinguished by the shape and seta arrangements on the male flagellum. The species of schizomids belong to family Hubbardiidae, in which widely distribute in the world. In Java, the schizomid is only represented by a single species *Javazomus oculatus* (Cokendolpher and Sites, 1988) from forest habitat in Cibodas West Java. None of the specimens from caves has been described. The morphological characters show high degree adaptation to caves, a pale coloration and no eyes spot.

Amblypygi. A cave whip spider is represented by three genera i.e. *Charon*, *Stygophrynus* and *Sarax* from two families (Charontidae and Charinidae). All of these genera have specific distribution in Java caves. *Charon* species in caves occur in the eastern part of Java started from Gunung Sewu (Yogyakarta) to farther east to Madura.

The first *Stygophrynus* species in Java was described by Roewer (1928) namely, *Stygophrynus dammermani* distributes from Bogor eastward to Nusakambangan Island and Menoreh Karst (Rahmadi and Harvey, 2008). The species was also recorded in Krakatau Island on epigean habitat (Rahmadi and Harvey, 2008). Other species of the genus was also found Grobogan and Tuban caves, which is closely related to epigean species from Ujung Kulon, *Stygophrynus sunda* (Rahmadi and Harvey 2008).

Genus *Sarax* is small-sized species of whip spider that commonly live under stone or dead wood on cave floor. The first species of *Sarax* was described by Gravely (1915) namely *Sarax javensis* (Gravely, 1915) (Charinidae) from Bogor (as Buitenzorg). The habitat of this species was not reported by Gravely (1915). *Sarax* species was found in Gunung Sewu and Tuban. There are two different species of *Sarax* based on the number of spine on dorsal pedipalpal tibia.

Uropygi. Uropygi is a group of arachnid, which has a tail on the end of abdomen. In Java, there are four species of uropygi. These species are *Thelyphonus caudatus* Linnaeus, *Thelyphonus asperatus* Thorell, *Thelyphonus linganus* C. L. Koch and *Hypoctonus javanicus* Thorell. These four species, only one species is known to live in caves, *Thelyphonus caudatus*. This species was found in Banten, Sukabumi, Cibinong, Gombong, Grobogan, Tuban and Madura. They live under stones and crawl on the cave walls. They are an active predator of other arthropods such as crickets and cockroaches.

Pseudoscorpiones. Group of false-scorpiones is less diverse in Java caves. The first species from Java was described by Tullgren (1912) namely *Stygiochelifer cavernae* from lava caves near Banyumas, Gua Lawa and live in guano piles. During the survey, the species was collected from Gua Petruk (Gombong). The survey in Gua Lawa (lava cave) in April 2007 was unsuccessful to collect the specimens from the type locality.

Opiliones. Opiliones is arachnids group that commonly live on the leaf litters and several species were found in caves. We found at least three families (Assamiidae, Epedanidae and unidentified family). Family Assamiidae is represented by one species collected from Gua

Jomblang (Gunung Sewu). Family Epedanidae is the most diverse family found in Java caves with six species collected from Gombong Selatan, Grobogan, Menoreh, Gunung Sewu, Ciamis and Tuban.

Araneae. Araneae is large group of arachnids and several species are known as cave species. In Java, only one species was known described by Deeleman-Reinhold (1995) namely *Athelphus javanensis* collected from caves in Gua Jatijajar. Twenty-five species of spiders from several families (Tetrablemmidae, Pholcidae, Sparassidae, Salticidae and several unidentified families) were discovered. The sparassids spider, *Heteropoda* sp. was found in Gua Buniayu, Sukabumi. The discovery of the cave spider from Menoreh Karst was remarkable. The cave spider was collected from several caves in Gua Nguwik, Gua Anjani and Gua Seplawan.

Myriapoda

Diplopoda. Diplopoda is dominated by family Cambalopsidae (*Hypocambala* sp.) that commonly found on guano habitats. They are represented by single species that indicated by number of eyes. A second group is Polydesmida that commonly live on the oligotrophic habitats. They have white in color and no eyes. Doratodesmida is also found in caves, but it might not be a cave species due to the present of eyes and reddish in color.

Chilopoda. A common group of chilopods in Java caves is *Scutigera* spp.. They were found in Banten, Cibinong, and Grobogan. They are an active predator for cave crickects, cockroach and other arthropods.

Hexapoda

Diplura. Diplura is only represented by single family, Campodeidae. The family is suggested a cave adapted species. None species has been described from Java. The described species were only known from caves in Maros Karst.

Collembola. A large number of collembolan species are found in the caves and most of them are adapted into cave habitat. They are mostly dominated by family Entomobryidae, Paronellidae, Isotomidae, Neanuridae, Sminthuridae, Neelidae and Hypogastruridae. The most diverse family is Entomobryidae, they are represented by at least ten species and mostly are cave adapted species especially form genus *Pseudosinella* spp. The paronellids species are represented by species of *Cypoderopsis* sp. and found in Gombong and Nusakambangan (Suhardjono *et al.,* 2001; Deharveng, 2003).

Insecta. Fifty species belonging to 21 families in seven orders were collected from caves in Java. They consist of Coleoptera, Dermaptera, Dictyoptera, Diptera, Hymenoptera, Orthoptera, Thysanoptera and Trichoptera. Coleoptera is the most diverse in caves represented by 22 species. Several species were newly recorded from caves such as *Xeniaria jacobsoni* (Burr, 1912), *Rhaphidphora dammermani*. One species of Gryllidae, *Arachnomimus jacobsoni,* was not collected during the survey, which is known only from Gua Jatijajar (Gombong Selatan). Other groups are less diverse in caves. A small-sized cockroaches belonging to the family Nocticolidae were also collected from various localities. Several specimens show a troglomorphic adaptation to cave life. Some of carabids beetles are not cave species largely they have eyes and with strong coloration. One species of Trichoptera was recorded from Gua Buniayu and Gua Rengganis namely *Diplectrona fasciata* they live in the cave near the entrance (Lupiyaningdyah pers. comm.).

Comparison between karst areas

A comparison of species number between karst areas is showed in Table 2. The number of species among the karst area was varied. The highest number of cave arthropods species was found in Gunung Sewu (46 species) and Gombong (43 species) (Table 2). In contrast, the low number of species was found in Padalarang, Ciamis and Madura, since the number of cave survey was very low. The number of species was varied between 5–9 species. Others areas have a moderate number such as Banten, Cibinong, Grobogan, Menoreh and Tuban. The number of species was varied between 19-32 species.

Table 2. A comparison of number of cave arthropod species from eleven karst areas

Karst	Number of		
	Species	Orders	TB/SB
Banten	22	15	3
Cibinong	19	12	7
Sukabumi	32	15	8
Padalarang	5	4	0
Ciamis	7	6	0
Gombong	**43**	20	9
Grobogan	11	10	4
Menoreh	22	17	6
Gunung Sewu	**46**	17	16
Tuban	28	17	4
Madura	9	8	0

Composition and diversity of cave arthropods

Species diversity

The diversity index was based on two different indices, Shannon Diversity and Simpson Diversity (Fig. 2). Shannon Diversity is most sensitive to changes in the rare species in the community samples and Simpson Diversity is most sensitive to changes in the more abundant species (Krebs, 1989). In Figure 2 shows that Gua Sodong has the highest diversity both Shannon Diversity (2.03) and Simpson Diversity (10.5). The lowest diversity is found in Gua Buniayu both Shannon Diversity (1.46) and Simpson Diversity (3.23).

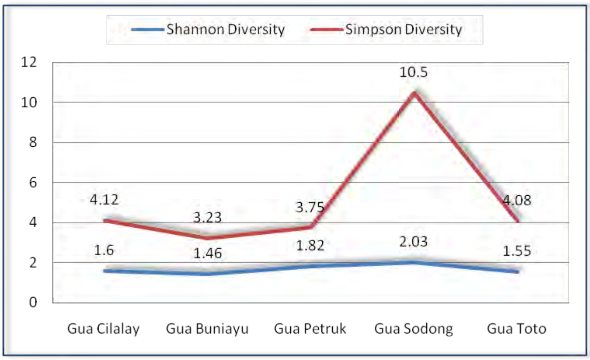

Figure 2. The diversity indices (Shannon and Simpson Diversity) of cave arthropods in five different caves

Species abundance and composition

The composition of arthropods is dominated by Acari (30%), Coleoptera (21%) and Collembola (18%). These groups are the most common arthropods live on the cave floor especially on energy-rich habitat such as guano and rotten woods. Acari is major group, which dominate in guano habitat and they live in large number of individuals (Fig. 3). Staphylinidae (Coleoptera) is also commonly live on the cave floor. They are also dominant in guano habitat. Diptera was found mostly on energy rich habitat such as guano and flood debris.

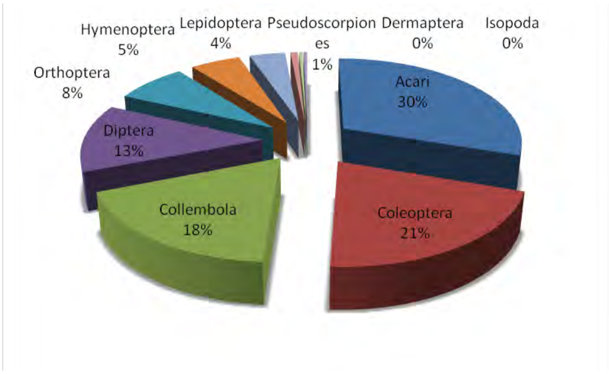

Figure 3. The composition of cave arthropods collected by pitfall traps in five caves studied.

Biogeography and endemism

The biogeography of cave fauna in the island is worth to discuss. Some cave fauna in Java depict unique distributional patterns. The cave aquatic isopods from Cibinong, *Stenasellus javanicus* and from Sukabumi(*Stenasellus* sp.) were known only from karst areas in western part of Java. The genus is absent in Central Java eastward to East Java and Madura Island or even farther to Sulawesi and eastern Indonesia. This pattern is worth for the study of biogeography in the island (Magniez and Rahmadi 2006). The extensive collections effort in the island have been done and failed to make any findings for the presence of stenasellids in eastern part of Java. The stenasellids are known from Thailand, Cambodia, Sumatra (Magniez 1989, 1992, 1995), Borneo (Magniez, 1982; Rahmadi and Suhardjono, 2004) and western part of Java (Magniez and Rahmadi, 2006). The genus is never observed in the Sangkulirang caves during the expedition in the region in 2004.

Springtails show a similar distributional pattern whereas the genus *Cyphoderopsis*, a cave adapted genus (Paronellidae, Collembola), is absent in the eastern Java farther east to Sulawesi and distribute from the southern Kra Isthmus to Sumatra and western part of Java (Deharveng 2003).

The distributional pattern of the cave whip spider especially the genera *Stygophrynus* and *Charon* likely show a similar pattern with other groups. The giant cave whip spider from the genus *Charon* is known from Gunung Sewu caves where the western most record extending eastwards to Tuban, Madura farther east to Sulawesi, Philippines, Taiwan, Moluccas, New Guinea, the Solomons Island and northern Australia (Rahmadi et al. in prep). The epigean species of the genus are known from Pogung Village in Yogyakarta and several specimens in the collection of Naturalis (Leiden) from Batavia (Jakarta) (Rahmadi unpublished data), Benkalis and Singapore (Harvey, 2003). The *Charon* species never occupy the cave habitat in western part of Java. During the fieldwork in western Java, *Charon* species is never observed.

In contrast, the typical cave species from the genus *Stygophrynus* especially *Stygophrynus dammermani* is extensively occurs in the west Java caves from Banten, Bogor, Nusakambangan to Menoreh Karst for the eastern most record of the species (Rahmadi and Harvey, 2008). Thus, a species of the genus was known from Grobogan (Gua Pawon and Gua Urang) and Tuban (Gua Putriasih, Gua Lawa, and Gua Nglirip). In Tuban caves they occur especially in the southern part of the karst and none of the genus was observed in northern part on coastal margin except those the related genus *Charon*.

Stygophrynus species is likely absent in the southern east of the island from Gunung Sewu to Blambangan Peninsula. The genus is confirmed to be absent in Gunung Sewu from Gunung Kidul to Pacitan. The absent of the genus in southern Java display whether its a real distributional pattern of the genus or only lacking collecting trips in Malang Selatan to Blambangan Peninsula (East Java).

The most recent cave species described from Java, *Stenasellus javanicus* is known only from single cave in Cibinong (West Java). The male and female specimens were collected in single small puddle in Gua Cikaray (Rahmadi and Magniez, 2006). The recent records, they were observed in small pool with only five specimens (2007) and two specimens in 2009. They strictly live in the small pool with percolation water and never found in water bodies of underground rivers. The species is highly threatened by mining activities in the area and caving activities in the cave. The species is believed to be site-endemic species and presumed no epigean species exists.

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STUDY OF GUNUNGSEWU KARST BIODIVERSITY IN GUNUNGKIDUL REGENCY

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Abstract

Indonesia is a beautiful archipelago country. It has some habitat types and ecosystems. The most interesting area is karst. By its special characteristics, karst area has specific and unique ecosystem. Here, organism is not only life in surface area (eksokarst) but also in underground area (endokarst). Gunungsewu is the largest karst area in Indonesia that becomes our consideration to study biodiversity there. To do the study, we use observation and interview method. In temporally result (research still on progress), we get more than 200 species of bird, 21 species of Mammal, 17 cave species, and 38 species of tree (unintroduce). From that result, we can conclude that conservation in Karst of Gunungsewu is needed. It must be done soon because some tree species will be extinct. Besides, Gunungsewu karst is a habitat for Javan Leopard (*Panthera pardus melas*), Crested Serpent Eagle (*Spilornis cheela*), Barn Owl (*Tyto alba*), Java Sparrow (*Lonchura oryzivora*), and many more. Here, in doing the conservation, we can use local wisdom to do the conservation. It is used to make survive some endangered tree species. Here, we make a meeting for all of the stakeholders to solve the problems in getting the best plan to conserve Gunungsewu karst as soon as possible.

Keywords: bird, cave, ficus, carnivor, mammal

Introduction

Karst is a unique area. It is not only for the geomorphology but also for the biodiversity of flora fauna. The specific area with a high concentration of calcium (Ca) and low water concentration in the surface area make animals and plants develop their capability. In this case, plants try to adapt their metabolism to survive in the high concentration of calcium, animals adapt their skin in the high temperature and low moisture, animals and plants adapt their morphology to survive in minimum water resources. This process is called an adaptation. The adaptation of animals and plants in karst area that is done in long period of time can bring speciation process. Here, it is not surprised if we find many new varieties of plant and animal, new structure of geomorphology, new physiology process, new behavior, and probably new species in the karst area.

Karst is not only has an eksokarst ecosystem, but also an endokarst ecosystem. Endokarst has more specific characteristic and specific biodiversity. Therefore, with zero lux of light, there is no plant or phytoplankton can survive and no one animal uses eyes as a dominant function in their life. Here, some animals are blind. They develop their sense of touch just like arthropod that lengthens their antenna to be eyes complement equipment. Endokarst has constant temperature, high moisture, and few organic resources. It makes animals have to decrease their metabolism, use more effective activity, and become more efficient in their power use.

Karst of Gunungsewu is the largest karst in Java. Some parts of this place ought to be conserved. It must be done because when the environment change, some animals and plants in the karst area that can not develop their adaptation will dead. It becomes the cause of the extinct of some biodiversity in the karst area. In fact, natural tropical karst forest cannot be found anymore in this area. It happens because of human activities, such as mining, farming, residencing, introducing, and tourism that can change microclimate and microhabitat in karst area. In this case, some sensitive species will be extinct. Those are the reason why I and all my friends in PPA-GK are interested to study the biodiversity in ecosystem of Gunungsewu karst area. By the result of this study, we expect to collect the data of biodiversity of plant and animal before some of them become extinct and we expect for the society to be more carrying the area.

Materials and Method

The data collection of this biodiversity research is done in the karst area of Gunungkidul administrative area. It happens because of human resources and other resources that are not enough to cover all of Gunungsewu karst. This study is started on July 2003 till now. We start the study in unintensive one because all of us are still senior high school students. This study is started by collecting ordinary plants and simple animal like mammal and bird, then in 2008 till now we collect the data in a more intensive one by using social partitipation.

In this study, we use binocular to see far objects, spesific form, herbarium kit, camera, sample kit and plastic clip to collect the data, and alkohol 75% for the preservation. All of this equipments are placed in one bag. This bag is always ready in our basecamp to make it easy if there are some of us who want to collect the data.

We divide Gunungsewu karst in Gunungkidul in four parts, those are west, east, south, and middle area. In the first study, we eksplore all places one by one. After that we observe some specific places and collect the report from the society. Therefore, in this study we make a mix between field observation and interview. This research is still in progress. Here, some places such as Panggang, Girisubo and Tanjungsari are difficult to be observed. It is not only caused by the resources, but also the topography and our capability in science field method.

Results and Discussion

From the observation, we get 61 species of plant and 516 species of animal. Those are not conclude all of data which caused by the difficulty to invent and identify some data, especially plants. For the plant we just take big trees. It is because of our assumption that big trees have lived in the karst area in a long time so that big trees are more endemic than other tress. For the animals, we collect 9 kinds of animal data. It is not conclude all of the animals yet which are caused by some animals like arthropods that are difficult to get and to identify. A neritic organism is a mix between plants and animals.

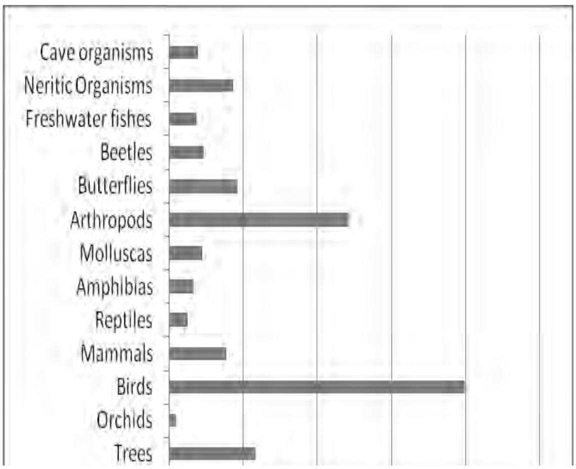

Figure 1. The number of species in the result of biodiversity research in Karst of Gunungsewu, Gunungkidul

The data are collected from some beach organism inventory. Generally, because we collect the data in the morning until afternoon, so we can only get a few nocturnal species.

From the figure 1 we know that this study get 58 species of trees and 4 species of orchids. Karst area is not only having trees and orchids as the endemic species but also shrub, herb, and grass. The problem here is that grass, herb, and shrub are difficult to identify whether it is an endemic species or introduce species. In our observation, we get four species of orchids those are *Dendrobium capra, Phalaeonopsis* sp., *Aerides* sp. and *Pecteilis suzannae*, where all of them are found in the southern area except *Pecteilis suzannae* that is found in the Northern area. All of the orchids that are found in the line area between farm area and unused area, though some of them are found in unused area. The orchids are very special that the flowers are very beautiful. The weakness is that the flowers are rarely in flowering. It is only *Pecteilis suzannae* that flowering every year.

From the observation, we get 58 species of tree. We collect the data by fragmenting the places such as outer of the cave entrance, local wisdom forest, surround area of water source, and steep of conical hills. It is difficult to observe and identify the area that is caused by too many introducing species. Here, we know that the endemic trees do not have any advantages if it is looked from economic side, that is why the greater part of them are cut down and changed into economical introduce trees such as *Tectona* sp., *Switiena mahagoni*, etc. It is difficult to find a real karst forest as the result of that condition. Thus, to know about karst forest information, we are collecting from endemic species trees and local information. Some of the endemic trees are found in the middle of human activities. They are conserved by local wisdom. They can survive because of animism and dynamism human believed. Therefore, it is needed to collect the data as soon as possible before local wisdom is disappear which is caused by modernism. As it is known that some of the places are cutting down their local wisdom trees that are caused by modernism such as build the houses, road, mining, etc.The action of cutting down the trees can give extinction effect in a greater part of the (*Ficus* spp.). This case is interesting in relation to the fact that this species needs specific insects for their reproduction process where some of them need some birds to distribute their seeds. Thus, some of them are not reproductive with the prediction that it is caused by the insects that have been extinct.

Figure 2.A. Flower of *Pecteilis suzannae* (Doc. Edi)
B. Local Wisdom tree in karst area (Doc. Edi)

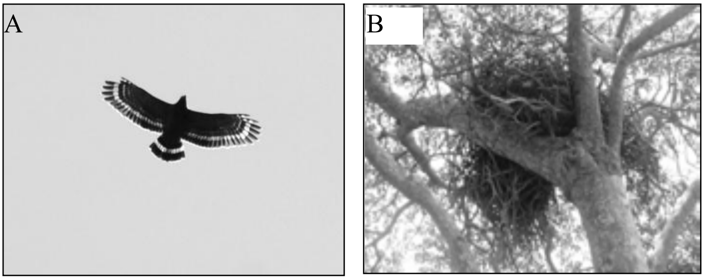

Figure 3.A. Crested Serpent Eagle (*Spilornis cheela*) was soaring (Doc. Edi)
B. The nest of Crested Serpent Eagle (*Spilornis cheela*) (doc. PPA-GK)

In all research side, we get 201 bids species. Some of them are passerines bird and beach bird. It is interesting because we never predict to find the species until the number of 201 species. Here, it is known that the weather in karst area are hot and dry, thus it is surprised to find bird areas there. It is found three species of raptor birds in the karst area those are Crested serpent eagle (*spilornis cheela*) found in Southern and northern karst area and Changeable Hawk Eagle (*Nisaetus chirratus*) found in Northern side of Gunungsewu karst, fish eagle (*Haliaeetus* sp.) found in southern where this area is near the beach. Besides, we get three species of migratory raptor pass Gunungsewu karst. It is known that Oriental Honey Buzzard (*Pernis ptilorhynchus*) stay and residence in northern side of Gunungsewu karst. Here, some nests of the birds are broken by human act and some of the trees that are used as nest are cut down to make a building. From the data, it is known that some of birds, especially raptor bird are very sensitive with environment change. Thus, it is consider doing conservation in gunungsewu karst area.

Gunungsewu karst has many species of mammals. It has species Javanese endemic such as java porpucine (*Hystrix javanica*) and Javanese little bat (*Nycteris javanica*). Here, half of the mammals species are bat. The cause is that karst has many caves to be home for range of bats. It is not only cave, but also trees such as banana tree (*Musa* spp.) as a home for Vespertilionidae like *Myotis muricola*, big trees as a home for Megachiroptera like *Rousettus* sp. and *Pteropus vampyrus*. The most important thing of the mammals data which is found is that the evidence of the carnivors existence. In this area, it is found some feces and footprints of Leopards. From civilians, we get information that there are two sub-species of Leopards live in Gunungsewu karst, those are Spot Leopard (*Panthera pardus pardus*) and Black Leopard (*Panthera pardus melas*). Some scientists say that Black Leopard is an endemic in Java. Moreover, from the Society assessment, we know that before 1980, Gunungsewu karst become a habitat corridor of Javanese tiger (*Panthera tigris sondaica*), though it still needs more research. Besides, in the area, it is found many population of wild cat (*Felis bengalensis)* that live in the line between unused land and farm field.

Figure 4. The feces of wild cat (*Felis bengalensis*) that find in South zone of karst Gunungsewu (Doc. Edi)

Figure 5. Big lizard (*Varanus salvator*) in Middle zone of Karst of Gunungsewu (Doc. Edi)

Amphibians in Gunungsewu are very near with human live. There are many interactions between them that make the collection of the data easy to do. Tree frog, toad, and ground frog are living this area although some of the places in this karst area are dry. Some of the frogs use doline and river in dry season for their reproduction where some of doline and surface rivers are still have waters. Besides, there are lizards that live in the area. The lizard is from the little lizard (*Eutrophis sp.*) till the big lizard (*Varanus salvator*). There are big snake (*Phyton reticulatus*), poisonous snake like cobra (*Naja* sp.), green viper (*Chlipteliptrops albolabris*) and Black-white snake (*Bungarus* sp.) that also live in Gunungsewu karst. In this case, we are not really sure why in dry area like karst can have many species of herpetofauna. Here, we predict that it is caused by the prey and the need of place to hide such as cave and stone pores that become important factors to survive. Besides, minimum water supplies can be the reason that makes herpetofaunas adapt their physiology and morphology that must be done to survive in dry and high temperature area like karst.

The greater part of Mollusks in Gunungsewu Karst is gasthropods. They live in beach, freshwater, ground till gardens and farm fields, but there are many people who do not care with those animals. Farmers are only care with introduce species of gasthropods like *Acatina fulica* and *Phila* sp. that this species destroys their harvest. This case is not only happens in Molluks, but also in fish. Many endemics fishes are lose in their competition with introduction fishes. There are many fishes that interesting such as local river fish (*Pangasius* sp.), and snakehead little fish (*Channa* sp.). Unfortunately, some of them are under pressured and live only in a little population. *Anguilla* sp. uses the surface and the underground of the river to stay after their sea travelling. Here, the most interesting fish for scientists is cave fish. From this species the scientists study about adaptation till evolution. In this case, some scientists find new species in Karst of Gunungsewu.

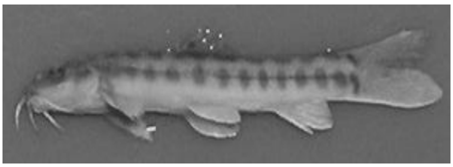

Figure 6. *Nemacheillus* sp. the new distribution record in Karst of Gunungsewu (Doc. Edi)

Arthropod has a big number of members. There are many arthropods that are found in Gunungsewu karst. The data that we have about arthropod can not cover all of Gunungsewu arthropods. There are many species that can not found by our team, especially nocturnal arthropods and underground arthropods. The cause of this problem is our limitation knowledge about arthropods sampling. But, from the data we get a great result. We know that arthropods have an important function in karst ecosystem. Some of them live in a specific habitat and make socialization with specific organisms. There are many ficus spp. can not finish their reproduction process. It happens because of some Ficus spp. that need specific insect to help their reproduction process. From this case, we can make a hypothesis that some of arthropods

Figure 7. Troides sp. The endangered butterfly in karst of Gunungsewu. (Doc. Edi)

in Gunungsewu karst area were extinct. Gunungsewu karst has some exotic species like member of beetle and butterfly. There are found some endangered species of butterfly like *Troides* sp.. This species needs specific habitat and plant. It needs more research especially to conserve this species.

In the neritic zone between karst of Gunungsewu and Indonesia Ocean there are many organisms that we found, those are coral, seaweeds, mollusks, crabs, lobsters, and many more. Besides, there are also some species of sea snake and jelly fish that can be harmful. The present of the harmful species is not worrying the civilians. They keep looking for some species of sea weeds as their regular activity in neritic zone to be eaten and sold. It is not only in the spring tide, but also in the regular sea weeds and jelly fish blooming.

Figure 8. *Octopus* sp. Their population decrease because habitat detruction (Doc. Edi)

Neritic zone is very interesting in their beauty of tourism, richness and phenomena. In neritic zones, we can study about population dynamic, association and symbiosis on complexity organisms, adaptation, ecosystem, interaction between sea water and fresh water, etc. From the observation, it is known that some area in neritic zone is destroyed by overexploitation. It is a problem that needs to be solved quickly. The case here is not only about economic factors, but also habit and tradition of local society. In fact, the civilians have a good local wisdom to support the conservation of the ecosystem, but modernization make it lost step by step.

The most of interesting point in karst is the caves. Adventurers can be challenged by cave exploring. Besides, many scientists can study about all science aspect in the cave such as geology, cave faunas, hydrology, speleogenesis, etc. Biodiversity in cave are interesting. It is looked from their adaptation, their metabolism, their behavior, their morphology and their physiology. The specific characteristics of cave like constant temperature, high moisture, and zero lux of light intensity make cave fauna do an adaptation for their life to survive in the cave. Some species do the adaptation for their organs like depigmentation, blind eyes, skin or antenna (arthropods) development as a dominant organ to complement the eye. This is what we call speciation process. It is not surprised if some scientists find some new species in the caves. This research not finds fauna where all of their life cycle in the cave (troglobion).

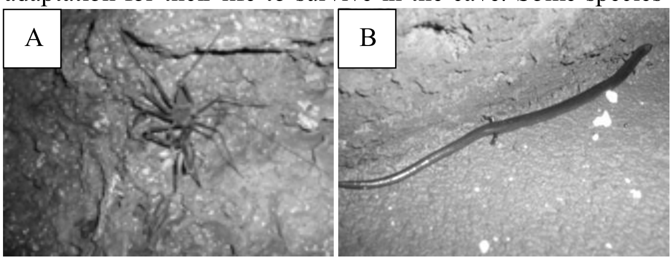

Figure 9. A. Amblipigy eat Raphidophoridae in Senen Cave, Tepus. B. Unidentified cave species in Sawahlor, Banyusoca, Playen. (Doc. PPA-GK)

A great part of cave fauna in Gunungsewu karst use cave as a part of their habitat (troglophile) and some of them come to the cave as a guest or lose (trogloxene). There is a possibility that troglobion species are there, but it is not observed because this research does not explore all of cave in Gunungsewu. Thus, there are many caves in Gunungsewu karst are unexplored.

By this research, we know that Gunungsewu karst has so many unique species and interesting point in biodiversity. But some of them are extinct that caused by human activities and the environment changes. Generally, we can say that Calcium mining and Phosphat mining destroy the karst ecosystem, but the greater factor of the damage is garbage. There are civilians in Wonosari (a center city in Gunungkidul) throw away their garbage into the river then the current of the river bring the garbage into Sumurup cave and it is stop in Baron beach. Besides, introduction foreign species destroy karst ecosystem too. Some introduction species are pressured endemic species and make it extinct. Here, we can say that introduce species are useful in economics side. Moreover, human activities like over exploration, hunting, logging, tourism, ineffective water management, etc. are also destroying karst ecosystem in Gunungsewu. This is our duty to solve this problem and to take a middle way, to make a win-win solution between human activities and ecosystem.

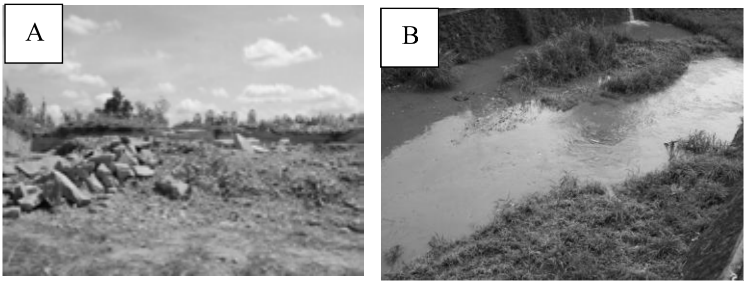

Figure 10. A. karst mining in Gunungkidul.
B. Garbage in river, after pass Wonosari and before enter Sumurup cave
(Doc. Edi)

I and my friends as Gunungkidul civilians try to collect the potential of biodiversity and local wisdom. We try to make sample of environment management with society participation in such area of Gunungkidul, those are Purwodadi and Tepus. Together with local civilians, we try to make field management and ecotourism. I and my friends with local civilians try to make miniature of karst forest using personal approximation and local wisdom issue. Unfortunately, we can not conclude all of our effort in making the miniature of karst forest because it is still on progress.

Conclusions

This research finds 58 species of tree, 4 species of orchids, 201 birds, 38 mammals, 12 reptiles, 14 Amphibians, 23 mollusks, 121 arthropods, 23 Beetles, 47 butterflies, 16 species of freshwater fishes, 44 neritic organisms (non fish), and 19 cave organisms. From the data we know that Gunungsewu karst is very rich in biodiversity that becomes the consideration of the importance to do the observation in the area. Here, we can use local wisdom to help the conservation and socialize karst ecosystem to the civilians so that some of them can be participated to the conservation of Gunungsewu karst. The case here is that some of human activities are destroying karst ecosystem. It is necessary to be solved as soon as possible by make some alternative job for the miner or make the management of ‗true ecotourism'.

This research is unfinished yet. There are still many uneksplored places that we think have a very potential data in which we predict that the area are very comfortable for the animals and plants that is caused by minimum human activities. Therefore, this research is still on progress as we can.

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THE DIVERSITY OF SMALL MAMMALS IN GUNUNG KIDUL KARST REGION

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Abstract
The Gunung Kidul karst region is the largest area of the Pegunungan Sewu's karst system (65%; surface area 1300 km^2) and is categorized as cone or kegelkarst type. The tropical limestone karst region is often called a centre of biodiversity as it contains a high endemic wildlife, which is yet under pressure. For karst regions in Indonesia, identification of faunal diversity and its function constitutes a first step toward biological hotspot determination in a typical ecosystem. The purpose of this study was documenting the diversity of small mammals in Gunung Kidul karst region. The study was conducted using Rapid Biodiversity Assessment technique, by collecting flying and terrestrial mammals, combined with the observation of any signs of mammals. For bats, relative population number was conducted through evening emergence counts technique. Small mammals were captured by mist net for 16 mist net nights and life trap for 324 trap days. The result of 11 caves being explored showed 18 mammals species were noted. The biggest mammal found was long tail crab macaque (*Macaca fascicularis)* and the majority bats being caught were *Miniopterus* and *Hipposideros*. The highest sympatric species number among bats' cave was found in Gua Gilap and Plarar with four species. Evening emergence counts from Gua Jelamprong was found 400 individuals/minute of *Miniopterus schreibersii*, which lasted approximately 30 minutes.

Keywords: Gunung Sewu, karst, bats, *Miniopterus*, *Hipposideros*.

Introduction

The three largest limestone karsts areas in Southeast Asia are found in Thailand, Vietnam and Indonesia (Clement *et al.,* 2006). In Indonesia, the karst region spreads in almost every large and small island, with the majority centralized between altitudes of 200-600 m a.s.l, except in Papua region where it can be found to a height of 1,000 m a.s.l (Balazs, 1968). It is also been reported that the majority of existing types of karst is conical karst (kegelkarst).

Karst region in Gunung Kidul is the largest area (65%; surface area 1300 km^2) within the Pegunungan Sewu karts ecoregion, which belongs to cone type or kegelkarst (Balazs, 1968; Haryono & Day, 2004), in a group of Miocene limestone (Balazs, 1968). However, this categorization is thought to be excessive simplification (Haryono & Day, 2004), considering the overall formation of karst areas in the Pegunungan Sewu is very diverse. Subsequently, it was reported that for Pegunungan Sewu karst region is a mixture of labyrinth cone karst type, polygonal karst and residual cone karst with conical shape (cone/ kegel) reached 30 hills/km^2 (Haryono & Day, 2004).

The climate of Pegunungan Sewu is categorized as humid tropical karst group. Dry season runs from May to August, with August as the driest period. Rainfall was high in February, reaching up to 310 mm and the lowest of 14 mm in August. Highest rainfall days were only 16.7 days in January and the lowest 1.2 days in August (Balazs, 1968).

The limestone karst area is often referred as the center of endemic biodiversity region (Clements *et al.,* 2006), but very depressing (Elliot, 2005). Three aspects that make the karst areas in the tropics threatened for its biodiversity conditions are due to socioeconomic aspects, politics and lack of scientific data in the biodiversity potential other than mineral exploitation. Socio-economic factors through the mineral exploitation are the highest threats anywhere in the karst regions of Asia. On the other hand, Balazs (1968) stated that the fastest process of destruction of karst areas in Indonesia is through deforestation.

Cave is the most preferred habitat by many species of bats compared with other natural formations as a re-side location (roosting) (Hutson *et al.,* 2001 in Clements *et al.,* 2006). Of the 143 threatened species of fauna that live in karst regions of Asia, 31 species live in the karst regions of Southeast Asia. Therefore, identification of biological hotspots (areas with high endemicity levels but with high levels of habitat loss, Meyer *et al.,* 2004 in Clement *et al.,* 2006) in karst areas is urgent. De Harveng (2002) stated that tropical karst area actually save so much diversity of fauna species, but only very few are well-documented. Attention to the availability of information by geographic distribution, baseline data on flora or fauna through ecology and taxonomy perspective in Asian karst regions has been initiated since 1980s. For the karst areas in Indonesia, the identification of fauna diversity with its function in a karst region and the ecosystem is the first step in the search for hotspot of biological diversity region. The aim of this study was to document the diversity of small mammals in the area of Gunung Kidul karst, Pegunungan Sewu region, in Gunung Kidul Regency.

Materials & Methods

Research was conducted in the karst area of Gunung Kidul, Pegunungan Sewu, Gunung Kidul Regency, and its adjacent karst region, from July 16, 2007 to August 6, 2007. Rapid Biodiversity Assessment was done in this survey. Caves were selected by random and were assessed for the possibility of high species number judging from the present of river, the size of the cave entrance, cave system or the present of avent. Judgment was supported by interviewing local villagers on the cave conditions. Collections of mammals were focused to small mammals, for both land and flying groups. The presence of other mammals was done through observation of track, dung, sighting or information obtained from the local villagers. Small mammals are defined as any mammals that have adult weight of less than five kilogram.

Collection technique for flying mammals were mist nets (hole size 36 mm, four pockets) of 6 and 12 meters long, and two sweeps net with 40 cm in diameter. For terrestrial mammals, small (24 x 12 x 25 cm) and large (50 x 24 x 50 cm) wire collapsible Kasmin live traps were used, apart from Sherman traps (Bookhout, 1996; Kuntz *et al.,* 1996). Calculation of the relative populations of bats emerging from cave was done using Emerging Counts Method (Kuntz, 2003).

Mist net placements were done in two layers, two to five meters from the cave entrance and followed by 10 meters behind the first mist net toward the outside of the cave, at a height of 2-6 meters from the ground. On several occasions, mist net was placed in the cave, diagonal to the cave canal system. Sweep net was performed sporadically in the cave. Due to tendency of high number of individual flying mammals, mist net was placed only for 2-3 nights per site. Live traps (small & big sizes) were placed nearby (2-20 m) cave entrances or any suspected entrance, 3 x 10 small traps/line or in a zigzag form and 19 big size traps. Ten Sherman traps were placed adjacent to the small Kasmin traps. The distance between traps was 5-10 meters and traps were placed for a maximum of three days per site.

Body measurement of any captured specimens was performed after animals were out in deep sleep and finally killed using excessive chloroform (Kuntz *et al.,* 1996). Body weight was measured using digital scales at the accuracy of one gram (Hitachi, Japan). Reproductive status was observed following the guideline of Semiadi & Nugraha (2005). After all field measurements were completed, the specimens were fixed in 8% formalin solution and then processed and preserved according to Museum Zoologicum Bogoriense standards (Suyanto 1999) in mammals laboratory at the Research Center for Biology LIPI Cibinong. Identification of collections was done through morphology and morphometry, follow Corbert & Hill (1992), Wilson & Reeder (2005) and Suyanto (2001, 2006) and reconfirmed through specimen comparison at Museum Zoologicum Bogoriense (MZB) LIPI Cibinong.

Results and Discussion

Overall, 11 caves (10 horizontal & one vertical) were visited, in which 82% of the caves were active caves; where river was flowing at all time (Table 1). Typical for Pegunungan Sewu karst formations, the survey areas were dominated by mixed bare land and local agriculture with a majority of plants such as teak, cassava, peanuts, corn, local fruit trees (mango, orange), legume trees, sengon, papaya and banana trees.

Nearly all caves which have river system were used by the local people for their daily livelihoods. A pipeline system was also present where water was channeled away from to much further area from the cave entrance. Given the survey was conducted in mid-dry season, almost all river caves were at the lowest discharge conditions, except in Gua (Cave) Bribin and Gua Plarar.

Gua Lawa was the only dead cave, where no river with short cave system, yet the cave has a high commercial value for local villagers through guano production. Interviews with the local guano collectors, indicated there are three classes of commercial guano produced from this cave, namely the super class, class two and class three. Guano of super class is relatively fresh guano, which is not yet decomposed; second class is the guano that has decayed, also known as black guano. Third-class or the lowest class is the guano that has decomposed for long time and almost decayed due to weather influences and is easily identified by its whitish dry color. Generally, the first and second grades guano is harvested from inside the cave, while the third grade guano usually harvested from the entrance or almost outside the cave entrance. This may happen when the cave‘s ceiling collapsed, thus result guano to expose to open climatic change. Daily production of black guano was the majority, reaching approximately 70-100 bags of urea size of 25 kg/day/collector. The fact that first grade guano was so scarce indicated that the cave was no longer inhabited by large population of bats. This can be inferred from the thick layer of black guano, reaching 30 m deep, stretching along the cave floor up to 150 m in length. At the time of the visit, the cave was only inhabited by around 300 bats.

Gnaspini and Trajono (2000 in Molds, undated) states that in the tropics, bats inhabit the cave are settled throughout the year, although there is a tendency for some groups to be nomadic, using the cave as temporary roosting site. This makes the size of bat populations dynamic changes, thus making the guano buildup highly variable. The nomadic nature is believed not to have an annual cycle, as found in temperate regions.

A total of 18 mammal species were collected within the duration of 26 mist net nights and 324 trap days (Table 1 & Figure 1). The dominance mammals being caught was bat with 13 species and the rest was rat, shrew, squirrel, primate and porcupine (1 species, respectively). Primates (*Macaca fascicularis*) were noticed from sighting at several places, nearby Gua Gilap, in a small flock (1, 3 & 5 individuals), whilst porcupine (*Hystrix javanica*) was detected from the burrow and tracks nearby banana plantation close to Gua Kali Suci. A plateau was reached in the number of species being caught at day 12 (Figure 1). Several species which were not detected from this study compared to previous survey were bats *Hipposideros ater, Chaerephon plicata* and civet *Paradoxorus Hermaphroditus* (Puslit Biologi 2006).

Table 1. Cave locations surveyed in the study

No	**Cave (Gua)**	**Location**		**Nature of river & cave**	**Collection site**
1	Gua Kali Suci	E 08^{0}00‘31.4”, S 110^0 38‘19.8”; 175 m asl	Pedukuhan Jetiswetan, Desa Pacarejo, Kecamatan Semanu, Kab. Gunung Kidul.	Active, horizontal	Cave entrance
2	Gua Gilap	E 07^{0}57‘56.4”, S 110^0 45‘16.”; 451 m asl	Pedukuhan Lumpit, Desa Kenteng, Kecamatan Ponjong, Kab. Gunung Kidul.	Active, horizontal	200 m
3	Gua Jelampron g	E 08^{0}00‘42.7”, S 110^0 40‘32.3”; 443 m asl	Desa Mojo, Kelurahan Ngeposari, Kecamatan Semanu, Kabupaten Gunung Kidul.	Active, horizontal	200 m
4	Gua Lawa	E 07^{0}56‘56.3”, S 110^0 43‘49.2”; 263 m asl	Dusun Seladi, Desa Umbul Rejo, Kecamatan Ponjong, Kabupaten Gunung Kidul.	Dead cave, horizontal, guano,	210 m
5	Gua Seropan	S 08^{0}00‘56.5”; E 110^0 40‘56.0”; 174 m asl	Desa Kenongo, Kecamatan Ponjong Kabupaten Gunung Kidul.	Active, horizontal	Cave entrance
6	Gua Kali Banjar	S 08^{0}07‘38.5”; E 110^0 58‘57.5”; 174 m asl	Desa Wareng, Kecamatan Punung, Kabupaten Pacitan (Jatim).	Active, two entrances, horizontal	210 m & 80 m
7	Gua Kiut	S 08^{0}07‘48.5”; E 110^0 59‘24.0”; 235 m asl	Dusun Klepu, Desa Wareng, Kecamatan Punung, Kabupaten Pacitan (Jatim).	Active, horizontal	265 m
8	Gua Plalar	S 07^{0}55‘57.9”; E 110^0 43‘35.9”, 285 m asl	Dusun Plalar, Desa Umbulrejo, Kecamatan Ponjong. Kabupaten Gunung Kidul.	Active, horizontal	220 m
9	Gua Tlogo	S 07^{0}56‘07.9”; E 110^0 43‘23.5”, 283 m asl	Dusun Plalar, Desa Umbulrejo, Kecamatan Ponjong. Kabupaten Gunung Kidul.	Active (lowest condition), horizontal	210 m
10	Gua Sodong-Dadapayu	S 08^{0}03‘35.8”; E 110^0 42‘45.8”,	Dusun Sendang, Desa Dadapayu, Kecamatan Semanu.	Passive, horizontal	210 m

No	Cave (Gua)	Location		Nature of river & cave	Collection site
		266 m asl.	Kab. Gunung Kidul.		
11	Gua Bribin	N/A	Desa dadap Ayu, Kecamatan Semanu, Kab. Gunung Kidul	Active, Vertical	Depth 100 m

Figure 1. Profile of species number collected during the survey

The majority of bats being caught in the cave was in 20-200 m from cave entrance, with some were caught at 265 m from the entrance. In Gua Bribin, a vertical cave, at the depth of 100 m, five individuals‘ bats were noticed flying around the cave system. The bats were thought to enter the deep cave system somewhere from the pothole entrance with a diameter of 1.5 m. So far, this is the deepest site where bats was ever been recorded to be present in a vertical cave.

The dominant bats caught from the present survey were *Miniopterus* and *Hipposideros*. High numbers of sympatric bats found in the cave was in Gua Gilap and Gua Plarar, with four species, whereas in Gua Sodong and Gua Kiut was only three species, respectively (Table 2). Gua Jelamprong harbors the highest number of individuals and mostly dominated by *Miniopterus schreibersi*, followed by Cynopterus *brachyotis*. Success rate for rat collection was relatively low, with species being caught was *Rattus tiomanicus* with three individuals noticed to be lactated. For bats, 98% of the individuals were noticed not in pregnant neither at post-partum conditions.

Table 2. Mammals found during the survey

No.	Location	Species	Number of specimens	Number of sympatric species
		Flying mammals		
1	Dusun Jetiswetan-area of Gua Kali Suci	*Cynopterus brachyotis*	1	

		Rhinolophus canuti	1	
2	Gua Kali Suci	*Myotis muricola*	1	2
		Rousettus leschenaulti	1	
3	Gua Gilap	*Hipposideros larvatus*	1	4
		Miniopterus australis	10	
		Miniopterus schreibersii	4	
		Rhinolophus borneensis	1	
4	Gua Jelamprong	*Miniopterus schreibersii*	136**)	
5	Gua Kali Banjar	*Coelops frithii*	1	
6	Gua Kiut	*Hipposideros larvatus*	4	3
		Miniopterus schreibersii	11	
		Rhinolophus canuti	4	
7	Gua Lawa	*Rousettus amplexicaudatus*	2	
8	Gua Plalar	*Hipposideros diadema*	4	4
		Hipposideros larvatus	12	
		Miniopterus schreibersii	2	
		Rhinolophus lepidus	1	
9	Gua Seropan	*Myotis horsfieldi*	1	
10	Gua Sodong	*Hipposideros diadema*	3	3
		Hipposideros larvatus	2	
		Rhinolophus borneensis	7	
11	Gua Tlogo	*Rhinolophus lepidus*	7	
		Terrestrial mammals		
1	Dusun Jetiswetan- area of Gua Kali Suci	*Rattus tiomanicus*	1	
		Suncus murinus	4	
		Hystrix javanica	1	
2	Gua Gilap	*Rattus tiomanicus*	2	
	(outside)	*Macaca fascicularis*	12*)	
3	Gua Kali Banjar	*Rattus tiomanicus*	3	
4	Gua Jelamprong (outside)	*Tupaia javanica*	18*)	

Note: *) sighting, **) 19 specimens were collected.

Suyanto & Struebig (2007) reported for the karst in Sangkulirang peninsula area (East Kalimantan), which is characterized by well established and high variation of flora of intact secondary forests type species, the trend of bats dominance were *Hipposideros larvatus*, *Rhinolophus creaghi* and *R. Pussilus*. They also reported that those species are karst type dependent. In the area of Gua Batu, Malaysia, *Rhinolophus* group (2 species) and *Hipposideros* (4 species) are the dominant species. In total 10 bat species were found in that karst region (McClure *et al*., 1967). Price (2000) also reported that at Gua Batu, Malaysia, as an open karst region, there were 17 bat species, whilst in the limestone area in Laos, up to 41 bat species can be found, where the highest threat is sporadic capture for protein consumption source (Robinson & Webber, 2000).

Results from emerging count indicated that bats from Gua Jelamprong can reach up to 400 individuals/ min. and lasted for 30 minutes, starting at 17:30 pm (Figure 2). From Gua Seropan the emerging count was only 110 individuals/ min., which lasted not more than 12 minutes. At Gua Gilap, the number was 20-30 individuals/min., and lasted for 27 minutes. Overlap in roosting between species in the present survey showed that species with low number of population tend to roost in non selective area, whilst those high population number (>50 individuals) were scattered in several locations within one area/site.

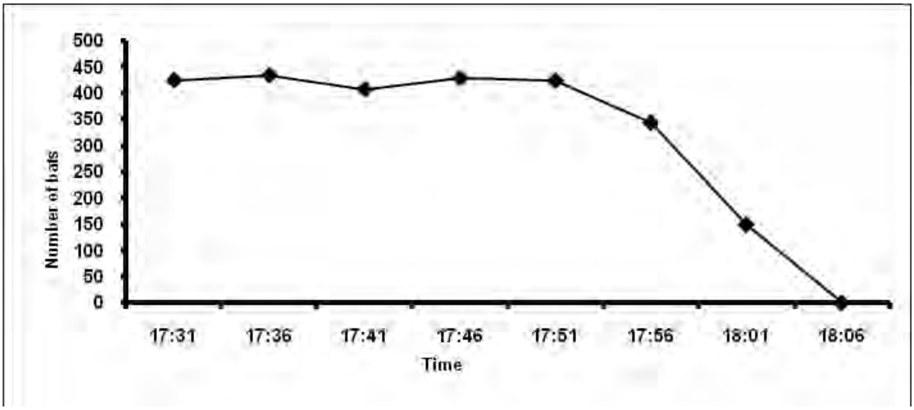

Figure 2. Number of Miniopterus schreibersii emerges from Gua Jelamprong

In Gua Plarar, the *Miniopterus schreibersii* roosting site tended to interchange with *Hipposideros larvatus*. An apparent trend suggested that the deeper into the cave system, the smaller body size bats, such as *Miniopterus schreibersii,* would increases progressively for its populations size (15-80 individuals/ roosting site), compared with the bigger body size species (*Hipposideros larvatus*) where only 30-40 individuals/roosting site. However bigger body size bats was noticed to inhabit much deeper cave‘s region (220-300 m from the entrance). Rodriguez-Duran & Soto-Centeno (2003) stated that roof cave temperature condition is the main criteria for site selection by bats to form a multi species association (sympatric).

From this study it shows that Gunung Kidul cave areas were dominated by two bat species, with very low number of terrestrial mammal species. Sympatric conditions of bat species tend to be found in a large cave canal system reaching to four species per area.

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THE LAST FRONTIER IN FRESHWATER BIODIVERSITY RESEARCH: GROUNDWATER

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Abstract
Groundwater fauna has very specific characteristics that set it far apart from taxonomically related freshwater organisms in surface environments. In spite of some regional advances groundwater biodiversity remains poorly studied on a world wide scale. There is certainly a huge knowledge gap with regard to Asian groundwater fauna. Although scientific investigation already has revealed a very high biodiversity especially in Southeast Asian surface water environments, knowledge of subterranean aquatic fauna still remains scarce. Investigative efforts so far seem to have focussed on relatively few sites, mostly caves. Based on experience from Ireland, surveys of rural dug wells and boreholes could be a cost effective alternative that would rapidly advance the knowledge of biodiversity in Asian groundwater fauna in large areas.

Keywords: Biodiversity, biogeography, subterranean fauna, Crustacea, Niphargus

Introduction

Groundwater biodiversity exhibits several peculiarities including high proportions of either phylogenetic or distributional relics (―living fossils”) and a high proportion of endemic species (Gibert & Deharveng, 2002). Constraints like scarce food resources and often quite low oxygen levels have forced groundwater animals to evolve remarkable adaptations in their physiology and life cycles. These features rank aquatic subterranean fauna among the most precious biological heritage on Earth and increase the risk of species extinction due to anthropogenic disturbances.

Several of the major taxonomic animal groups commonly encountered in surface water habitats also have a strong subterranean presence (Sket, 1999). For the whole world Botosaneanu (1986) listed about 7000 known aquatic subterranean species, with crustaceans representing more than 40%. Using nested regional estimates Culver and Holsinger (1992) predicted that with complete exploration the world‘s number of subterranean animal species is likely to total 50,000 to 100,000. Perhaps comparable to the challenge of deep sea research in oceanic exploration, groundwater represents the ‗last frontier‘ with regards to freshwater biodiversity research. The exploration of regions like Southeast Asia with enormous potential for a very high subterranean biodiversity has only just begun.

What makes groundwater animals special?

The space occupied by our planet‘s groundwater aquifers has been shaped by a long and eventful geological history. It is not only vast, but also of a very heterogeneous nature. Any individual animal species, which solely depends on this subterranean environment, would therefore have to overcome many natural barriers in order to attain a wide geographical distribution. Hydrological, geological, hydrogeochemical and other aquifer features can severely impede faunal migration from one groundwater body to another. Where such barriers may result in a high degree of biogeographic isolation for subterranean environments, groundwater ecosystems tend to be characterised by high numbers of endemic species, i.e. species that are unique to the particular area where they have been found. Some groundwater species are also rare, because they represent the last survivors from taxonomic groups, which have disappeared from surface waters a long time ago. Species from the ancient crustacean group of Syncarida (in Ireland: *Anthrobathynella stammeri*) for example are ―living fossils”; earliest fossilised records from this group have been found in carboniferous strata. Being rare and unique unfortunately also implies that some endemic groundwater species would be particularly vulnerable to extinction, if habitat degradation or contamination were to occur.

Adaptations and strategies for survival

Animals may find living conditions in groundwater ecosystems very challenging. But a long history of adaptation and evolution has made them masters of survival. Complete darkness has rendered pigmentation and eyes unnecessary (Figure 1) and life in confined spaces favors slender body shapes. Amazing physiological adaptations enable them to survive periods of extremely low oxygen concentrations, yet they still do need some oxygen to survive.

Fortunately, undisturbed groundwater does not tend to be a very productive environment. Otherwise, aquifers with low recharge rates would soon be completely void of oxygen due to microbial heterotrophic activity, which would thus render them uninhabitable for groundwater animals. Contrary to stream environments with a potential for relatively quick recovery, such groundwater environments would remain depleted of oxygen after any substantial pollution event with easily biodegradable organic substances because of the much longer water residence time.

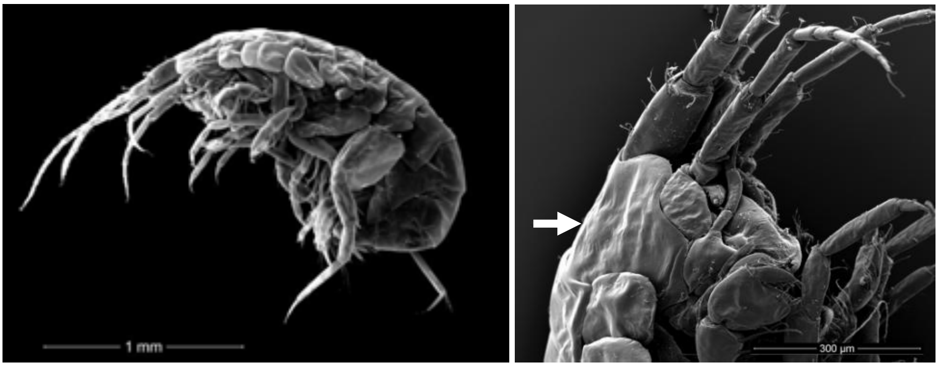

Figure 1. Left: *Niphargus kochianus irlandicus*, an Irish groundwater amphipod. The picture shows a very small specimen of 2.5mm length, large animals can be 10mm long.
Right: Ventrolateral view of a *Niphargus kochianus irlandicus* head. Remnants of eye structure are still visible (arrow), but have no function for sight due to lack of pigmentation. (Quanta SEM scans by Barry o‘Hagan)

Low ecosystem productivity has an obvious drawback for animals, as it means a lack of food resources. Groundwater animals rely on a highly efficient metabolism in order to cope with their resource poor environment. They also have to feed on anything they can find, and scavenging is common.

Table 1. Comparison of life cycle data for surface and subterranean species of Copepoda, Isopoda and Amphipoda (adapted from Preuß & Schminke, 1994 and Mösslacher, 2003 with data from Murphy & Learner, 1982 and Økland, 1978) a= years; w=weeks

		surface	subterranean	subterranean	surface	subterranean	surface	subterranean
		Bryocamptus zschokkei	Antrocamptus catherinae	Parastenocaris phyllura	Asellus aquaticus	Stenasellus sp.	Gammarus sp.	Niphargus virei
Life expectancy	a	0.75	2	2.5	<1	>12	<2	>12.5
Embryonic stage	w	1	7	-	-	-	<3	12
Juvenile state	w	4	14	22	14	> 260	<12	130
Reproductive interval	w	1	3	2	5	104	4	52
Number of eggs		23	6	2	-	-	-	-

As trade off for their slow and efficient metabolism groundwater species take a long time to reach the maturity required for reproduction (table 1). Mature female groundwater animals tend to have fewer but larger eggs than taxonomically comparable surface water species. If such a low fecundity is sufficient to ensure a species survival, predation risk in groundwater must be low. The large egg size suggests that the scarcity of food sources in groundwater environments forces females to equip offspring with a larger ‗initial survival ration‘ for a successful recruitment.

Finding partners for reproduction is quite a challenge, considering the complexity of aquifer interstices and the animals‘ low abundance. The comparatively long life spans of groundwater species (table 1) increase their chances of successful reproduction.

The groundwater environment in Ireland

The main aquifers found in Ireland comprise Quaternary deposits and Palaeozoic bedrock formations including Carboniferous limestone and sandstone, Devonian Red Sandstone and Ordovician volcanics (EPA, 2005). Palaeozoic limestone and sandstone underlie more than 50% of the country (Fitzsimons & Misstear, 2006). Even though Ireland has a rather complex geology, groundwater often contains a large percentage of calcium, magnesium and hydrogen-carbonate (Daly *et al.,* 2000), because limestone bedrock and limestone derived sub-soils are very common. Yet on a worldwide scale, absolute ion concentrations are quite low in Irish groundwater (sulphate, sodium and chloride), suggesting that the monitored groundwater bodies contain relatively shallow and young groundwater. Electrical conductivity values rarely exceed 800µS/cm. With few exceptions, e.g. in some coastal aquifers, the mostly low manganese concentrations provide evidence for predominantly oxic conditions in many Irish groundwater bodies; pH values are not extreme with percentiles 10-90 ranging from pH 5.6 - 8.4 (EPA, 2008).

Predominant groundwater flow horizons in Ireland are situated within the top 30-40 metres below ground (Daly, 1995); extensive karstification in some limestone aquifers has produced conduit systems with very rapid groundwater flow rates (Coxon & Drew, 1999). Most Irish bedrock aquifers are dominated by fracture flow; there is only one important sandstone aquifer representing porous groundwater flow; sand and gravel aquifers with intergranular flow underlie only two percent of the country (EPA 2005).

Warm springs due to geothermic activity are rare in Ireland; the warmest recorded average spring temperature is 25 ^{O}C (Reynolds *et al.,* 1998). Therefore, the existence of hot shallow groundwater is unlikely and temperature of shallow groundwater is close to the mean annual soil temperature. For Ireland Garcia-Suarez and Butler (2006) reported annual mean soil temperatures at 100cm depth, which range between 11^{O}C (Armagh) and 12.7 ^{O}C (Valentia observatory).

Exploration of subterranean aquatic fauna in Ireland

First records of subterranean animals date back to 1899, when the first *Niphargus kochianus irlandicus* was discovered from a well. Soon afterwards more specimens were recorded from the bottom of a lake with groundwater influx (Kane 1904, cited in Proudlove *et al.,* 2003). From the late 1930's and onwards knowledge of Irish subterranean fauna has greatly increased due to the sampling efforts of the Cave Research Group of Great Britain (CRG) led by Audrey Glennie and Mary Hazelton (Hazelton, 1974) and due to pioneering work by Mary Crichton for the Irish Biological Records Centre. Biogeographic patterns of Irish subterranean fauna have however largely remained obscure, because of accessibility issues and an imbalance in sampling effort with the majority of historic sampling sites situated in karst areas. Figure 2 provides a representation of the geographic distribution of caves in Ireland. Clearly, these features are strongly clustered. Any exploration of subterranean fauna, which was mainly to focus on caves in order to pursue classical biospeleology would therefore have a large bias towards these regions. In Ireland this is indeed a likely cause for the higher density of historical *Niphargus. kochianus irlandicus* records in a few counties.

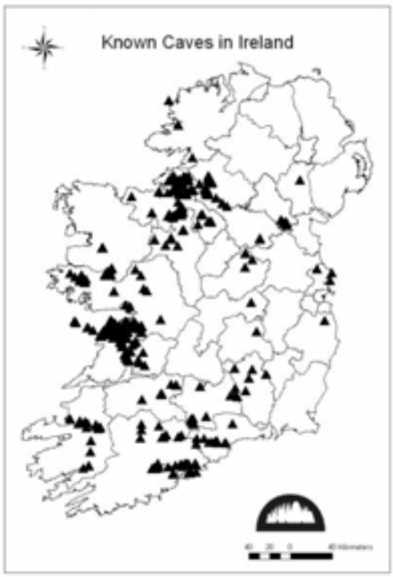

Figure 2: Distribution of known caves in Ireland based on Drew (2007) and Jones *et al.,* (1997)

Recent island-wide surveys aiming to achieve a more balanced coverage, have therefore adopted a non cave oriented sampling approach, which targeted dug wells and boreholes. The sampling method takes advantage of the tendency of groundwater organisms to get trapped in wells and boreholes, because once they are inside those structures they tend to sink to the bottom sediments, where they seem to remain alive for considerable time. Using net samplers to catch those animals is classified as a passive sampling method as opposed to sampling which involves pumping groundwater and retaining the animals by filtration over gauze (Malard *et al.,* 2002).

Passive sampling with a modified Cvetkov net sampler (Cvetkov, 1968; Fuchs, 2007) has been the method of choice for the Ireland surveys due to its ease of use. The inexpensive equipment is light weight, comfortably fits into a backpack and is thus even ideal for sampling sites that can only be reached on foot. The sampler can be operated from a fishing rod for wells up to 200m deep. The sampler consists of a small 63µm net with an aperture diameter of 47mm for the smallest nets, for larger wells nets with wider aperture diameters increase sampling success.

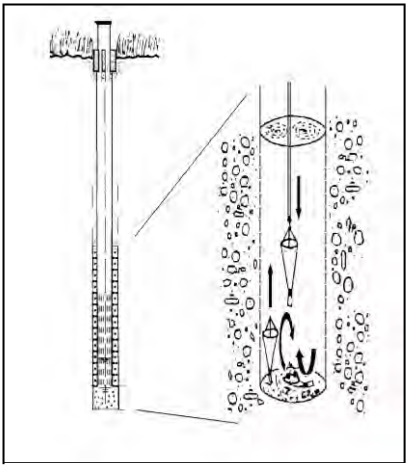

Figure 3: Modified Cvetkov net sampler, Fuchs (2007)

The net is funnel shaped and is attached to a centrifugation tube. The tube carries lead weights at its lower end, which serve to suspend sediment and the organisms within it (Fig. 3). Moving the net up and down through the water filters suspended organisms from the water column to be finally concentrated in the centrifugation tube. The tube is the sample reservoir. After sampling the tube is exchanged and closed with a screw cap for sample storage. For a pilot survey 106 sites were sampled and a more intensive survey has now added more than 240 sites, a subset of which has been sampled repeatedly to investigate short term trends. As a result, biogeographical patterns are starting to emerge. *Niphargus kochianus irlandicus*, the most frequently encountered groundwater amphipod, seems to be absent from the most Northern part of the island (Figure 4). The currently known Northern limit of its range does however extend far into the area covered by ice shields during the last glacial maximum. Investigations have resulted in first records for subterranean species of amphipods and ostracods (Arnscheidt *et al.,* 2008) and will most likely result in describing species new to science. Furthermore, the gathered specimens provide the foundation for current genetic investigations. The survey method has thus proved to be very effective. Contrary to surveys in Germany, which can take advantage of a well documented array of standardized monitoring boreholes (Steenken, 1998, Hahn & Fuchs, 2008) the Irish surveys had to rely on non-standardized wells and boreholes. Drilling records for older boreholes can only rarely be obtained. As a consequence, there cannot be absolute certainty on whether the absence of groundwater organisms from a particular site may be caused by the furnishing of the borehole. In this respect there will be improvements in the near future, as new meticulously documented monitoring sites are being established by the Irish EPA. However, with increasing centralization of water provision in rural areas, traditional wells, which used to serve villages or individual houses, are disappearing fast, thereby reducing the overall number of sites for future surveys.

Figure 4: Records of *Niphargus kochianus irlandicus* from all Ireland surveys since 2006

The potential for exploration of subterranean fauna in South East Asia

The potential of karst formations in Asia for biodiversity, particularly in the continent‘s South East became apparent with the faunistic exploration of the Mulu caves in Malaysia (Chapman, 1984). While most of the species discovered there were non-aquatic cave habitats, this investigation sparked of a series of similar explorative undertakings and soon aquatic subterranean species were reported from similar environments, e.g. Deharveng & Bedos (2000) reported that a quarter of the retrieved species from the Gua Salukkan Kallang—Towakkalak underground river system was aquatic, including two fish species. More species new to science have since been found by dedicated researchers in other karst cave sites, e.g. the blind isopod *Stenasellus javanicus* (Magniez & Ramadhi, 2006), which is now known from several sites in Java. Clements *et al.* (2006) have summarized the importance of karst sites throughout South East Asia as arks of biodiversity, because they are habitats for many species, which represent ‗living fossils‘.

In areas with karst or other geological formations which form aquifers, a large part of the village population tends to rely on small wells for water supply. Stiebel & Surjadhi (1985) for example reported on the inventory of 1,200 dug wells in the Solo River catchment, where groundwater abstraction from alluvial deposits and from limestone aquifers is common. The recent drive towards an installation of more powerful pumps, mainly for irrigation, has occasionally led to excessive abstraction, occasionally resulting in salinization of shallow near coastal groundwater resources. Yet, in regions where there still are many wells with low pumping activity, well sites provide excellent opportunities to sample subterranean aquatic fauna. Even in countries like Ireland with a fauna that is believed to have lost much of its diversity due to several glaciations (Proudlove *et al.,* 2003) such investigations lead to first recordings and to the discovery of species new to science. How great must the chances be for exciting discoveries in regions like South East Asia! If the few explored cave sites are anything to go by, a systematic survey of wells will yield many new species. Biogeographic patterns for Asian groundwater fauna would soon emerge, if the research effort could be undertaken in collaboration with hydrogeologists. A passive sampling method like one described for the Irish surveys make this a low cost enterprise, which could cover large areas in a short time scale.

We are certain that the science of subterranean aquatic ecology has much to gain from an intensive research in subterranean of Asia, with a particular focus on the continent‘s South East. Such an exploration could also have benefits with regard to biomonitoring. Berkhoff *et al.,* (2009) and several other studies have suggested that faunal analysis of wells can be a low cost indicator of surface water intrusion and thus risks of contamination.

Acknowledgement

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RESTORATION OF THE NATIVE SPECIES OF GUNUNGSEWU KARST HILLS FOR BIODIVERSITY CONSERVATION

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Abstract
Forest restoration in Gunungsewu karst hills is one of the reforestation efforts, in to the previous condition before the degradation and the anthropogenic impacts came in the area. Restoration needs pre-condition to acclimate by manipulating environment to provide the condition that proper for plants to grow. Geomorphological approach for karst native species restoration based on *theory of uniformity*. Karst landform characteritics are lack of soil nutrition, thinly solum, high calsium, and lack of water surface. Those become special habitat for special flora.The native species restoration in Gunungsewu karst hills is based on the pollen invention. The validation of the pollens was using seed deposit growing test to evaluate the viability and their survival. There are four types of flora in the Gunungsewu karst hills since 2500 years BP. Those are mountain flora found in 2500 years BP with the characteristic species of Pinaceae and Hammamelideae; wet tropical forest flora with the characteristic species of Ulmaceae, Podocarpaceae, dan Sapotaceae in 2000 years BP; and Bombacaceae rose in 60 years ago, and low land with the characteristic species of Palmae, Euphorbiaceae, Leguminoceae, and Moraceae in 1400 years BP. Fall forest type that we can find now, is formed of one of the migrant groups such as Meliaceae. Based on the current climate condition, so that today they have two types of flora, which are low land forest and fall forest. Seed deposit growing test was successfully grow the seedling until the age of the sediment is about 2500 years BP, although it is dominated by grasses, shrubs, and pioneer plants like *Grewia sp*. The seeds that had been deposited for a long time needs more time to awake from their dormancy. Therefore, they needs more time to sprout. It is needed to validate the truth, pollen identification as the source of information for native plants restoration.

Keywords: Gunungsewu, pollen invention, conservation.

Background

Gunungsewu Karst is one of the southern mount hills of Java Island, Indonesia, known as a dry area although it has enough rain and the climate type is B and C based on Schmidt and Ferguson. But, the permeability of the stones in the karst make the rainfall is directly absorbed to the deep soil and filling the ground river. The Gunungsewu karst hills is dominated by cone and sinusoid shapes (Samodra *et al.,* 2005), with its underground river and water, stalagtit and stalagmit. The ideal forming of karst is in tropic and middle latitude with the rainfall from middle to high and covered by a dense forest (Sutikno and Eko Haryono, 2000).

The ideal karst is hard to find in the recent time because of land degradation and deforestation. But, identifying from the recent physical condition of the Gunungsewu karst hills, it can be assumed that the area was having a dense forest. Anthropogenic factor is believed to be the cause of unnatural change acceleration of the karst landform. Gunungsewu was created during the Miocene to mid Plestosin (Forestier, 1998), thus there‘s a lack number of karst area due to its long creation time, and its need of high rain intensity and deep forest coverage. Those characteristics are worldly recognized so that Gunungsewu karst is known as the world heritage. Hence for supporting the mentioned attribution, there should be a forest restoration.

―*The present is the key to the past*" is a geomorphologic approach which can be used for underlying native species historical study as forest restoration interest. Regarding to the high environmental degradation, there should be an area precondition for creating acclimatization with growing the seeds deposition and presenting pioneer plantations. Aclimatization using shrubbery plants are usually applied at the begining of forest restoration. This idea contributes innovation for biodiversity conservation in karst, for avoiding species extinction. The result of this forest restoration will be a reference for designing Karst Nature Reserve, of which main characteristics are fragile ecosystem and full of anthropogenic factors intervention.

Identifying Karst Native Spesies as Reference For Karst Forest Restoration

Pollen and Seeds Deposit Identification.

Karst native species identification was applied through the introduction of deposit pollen and seeds in the ground. Pollen and seeds were stored in the ground as an evidence of the past plants history. Many pollen and seeds that were stored in the special sediment can inform the actual environment condition associated with the flora. (Sukandarrumidi, 2008). In the forestry world, known various associated vegetation such as Pine (*Pinus Merkusii*) forest that is naturally associated with Rasamala (*Altingia excelsa*) dan Puspa (*Schima walichii*); while in teak forest usually associated with Kesambi (*Schleicera oleosa*), Ploso (*Butea monosperma)*, Walikukun (*Schoutenia ovata*), Pilang (*Acacia leucophloea*), Kepuh (*Sterculia foetida*), Wild Randu (*Ceiba petandra*), Wild Jambu (*Eugenia* sp). Pollen and seed deposit collected by *undisturbed sample method* (Morley, 1991; Kaars and Dam, 1994), and those ages were predicted by C-14 radiocarbon soil analysis. The approachment was also used to get the environmental characteristic of sediment and reconstruct the old environment condition related with appearance explanation and geomorphic process.

Vegetation in some spesific area is reflecting the combination process of many environment parameter in that place. In karst area, forest vegetation is one of the eksokarst component that defined the geomorfik process. The good forest condition will bring a good karstification. The lost of vegetation in that area will affect the quality of the karst ecosystem (affect trough solutional and hidrogeological process, also erosion and sedimentation).

Based on the pollen discovery to be identified as a sample from alluvial karst valley in Kanigoro, found the pollen distribution pattern from the upstream to the downstream with the index around 0,83-0,93. The data describes that the Gunungsewu karst hills was highly enough diverse of flora. The five accumulated soil layer structures in the downstream are in modern class age, while in the middle and upstream, the modern class is only at the first layer. The predicted old soil layer was found in the fourth layer of the middle (soil age 2318±110 BP), and gradually in the upper middle part and north is getting younger (Tabel 1). Based on that approachment, it can be identified that predicted age of the first layer of north-middle-south part is in modern age class. The five layers in the southern part are modern, this is probably because the area is lowest, so that it could trap and accumulate the sediment from north and middle (upper land). This information also indicates that in more or less 200 years around the supply of sediment from the upper land is intensive so that they formed enough thick layers in south (downstream). But, based on the soil structure in every stratum that is almost uniform (heavy clay) shows that the sediment process in those areas is following the principle of stratigrafi the law of supersition (Summerfield, 1981) the lowest layer is the first sediment accumulated and the age is older than the first layer on it.

Table 1. Vegetation identification based on the pollen discovery in Kanigoro alluvial karst valley

No	Location	Soil Age	Structure	Associated flora based on hierarchy cluster analysis
1	North layer 1	Modern	Heavy Clay	Pteridophyta, Gramineae, Pandan, Polygonaceae, Euphorbiaceae, Podocarpaceae ,Hamamelidaceae, Ulmaceae
2	North layer 2	213± 15	Heavy Clay	Pteridophyta, Gramineae, Pandan, Polygonaceae, Chenopodiaceae, Compositae, Palmae, Ulmaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Sapotaceae, Leguminosae, Moraceae,
3	North layer 3	373± 20	Heavy Clay	Pteridophyta, Pandan, Gramineae, Cyperaceae, Balsaminaceae, Polygonaceae, Compositae, Euphobiaceae, Podocarpaceae, Hamamelidaceae, Leguminosae, Palmae, Ulmaceae
4	North layer 4	1305± 75	Heavy Clay	Pteridophyta, Gramineae, Cyperaceae, Polygonaceae, Chenopodiaceae, Compositae, Polygalaceae, Ulmaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Leguminosae, Palmae,
5	North layer 5	1863± 95	Heavy Clay	Pteridophyta, Gramineae, Pandan, Cyperaceae, Polygonaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Pinaceae, Casuarinaceae, Leguminosae, Palmae, Ulmaceae
6	Middle layer 1	Modern	Clay	Pteridophyta, Gramineae, Pandan, Polygonaceae, Compositae, Polygalaceae, Ulmaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Sapotaceae, Casuarinaceae, Palmae, Leguminosae, Moraceae
7	Middle layer 2	1046±75	Heavy Clay	Pteridophyta, Gramineae, Pandan, Balsaminaceae, Polygonaceae, Chenopodiaceae, Polygalaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Casuarinaceae, Leguminosae, Palmae,Moraceae, Ulmaceae

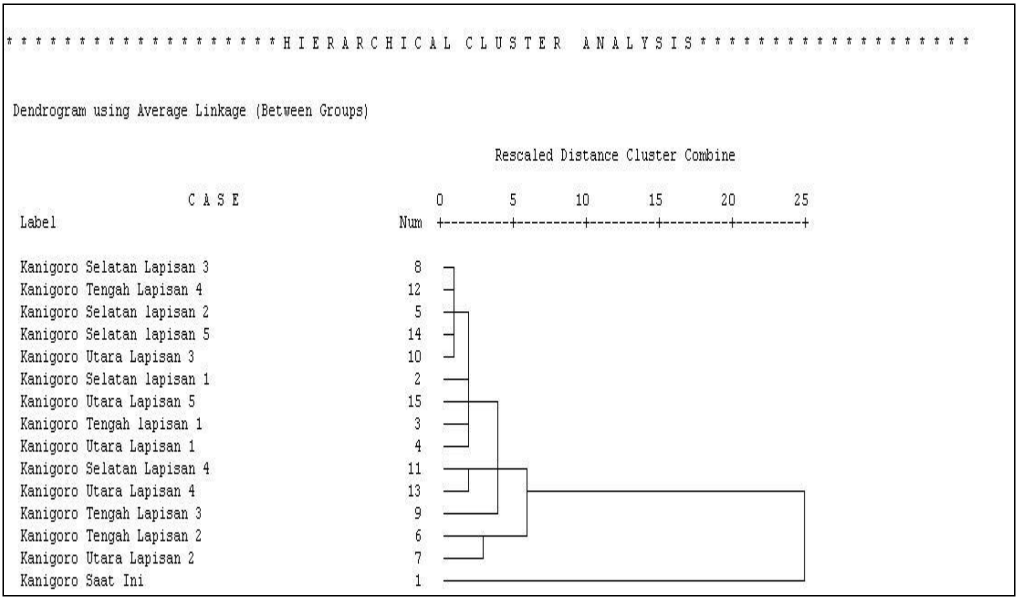
8	Middle layer 3	1149±80	Heavy Clay	Pteridophyta, Gramineae, Pandan, Polygonaceae, Chenopodiaceae, Compositae, Cyperaceae, Polygalaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Leguminosae, Palmae, Moraceae, Ulmaceae
9	Middle layer 4	2318±110	Heavy Clay	Pteridophyta, Gramineae, Pandan, Polygonaceae, henopodiaceae, Euphorbiacaeae, Hamamelidaceae, Leguminosae, Palmae, Ulmaceae
10	South layer 1	Modern	Clay	Pteridophyta, Gramineae,Pandan, Polygonaceae, Chenopodiaceae, Compositae, Cyperaceae, , Ulmaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Sapotaceae, Pinaceae,
11	South layer 2	Modern	Heavy Clay	Pteridophyta, Gramineae,Pandan, Polygonaceae, Chenopodiaceae, Compositae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Pinaceae, Casuarinaceae, Leguminosae, Bombacaceae, Palmae, Ulmaceae
12	South layer 3	Modern	Heavy Clay	Pteridophyta, Gramineae, Pandan, Polygonaceae, Chenopodiaceae, Euphorbiaceae, Podocarpaceae, Hamamelidaceae, Casuarinaceae, Leguminosae, Palmae,
13	South layer 4	Modern	Heavy Clay	Pteridophyta, Gramineae, Polygonaceae, Chenopodiaceae, Compositae, Cyperaceae, Balsaminaceae, Euphorbiaceae, Hamamelidaceae, Palmae, Ulmaceae
14	South layer 5	Modern	Heavy Clay	Pteridophyta, Gramineae, Polygonaceae, Chenopodiaceae, Euphorbiaceae, Hamamelidaceae, Leguminosae, Bombacaceae, Palmae,
15	Kanigoro, this day		**Clay**	Burseraceae, Sapindaceae, Leguminoceae, Tiliaceae, Moraceae, Sapindaceae, Meliaceae, Lauraceae, Ebenaceae

Note: the color indicates the similarity of the vegetation association.

There is various plants finding in Kanigoro, from the beach, marsh, lowland, and mountain. That is unique and specific, even possibly only found in the area. Sudihardjo (1998) found the volcanic matters in Gunungsewu, based on the analysis it is 2010±80 BP from the eruption of Gunung Panggung, even the volcanic matters from Gunung Lawu eruption is also found with the age of 3090±90 BP. This finding becomes the base concept of *the present is the key to the past*, that the volcanic materials indicate Gunungsewu karst was probably ever got volcanic materials from eruption of the volcanic mountains around it in the past. The volcanic mountain around the area, might invite the flora from mountain to the karst, through spores, fruits, seeds or any other vegetative parts. The evidence of the mountain flora aggregation to the karst hills is shown by the finding of group pollen of Pteridophyta (Lycopodium, Cyatea, and Osmunda), Pinaceae (Pinus) and Hamamelidaceae (Altingia).

The presence of mountain flora in karst hills indicates that the climate in tat time was proper to live (even though with minimum condition). This statement is strengthen with the information of climate distribution by Verstapen (1994), that during period 3000-5000 BP the climate condition is very wet from today, beside the volcanic soil supply that contributed to soil fertility, so that the mountain flora and Pteridophyta can grow. Pteridophyta, has became the evidence that wet tropical climate was happened in that area. The history of the plants could describe the succession process in the Gunungsewu karst, which is shown by the changes of the community time to time. There is also possibility that the presence of mountain flora in the karst hills caused by dispersal factor, indicating that the pollen mass is so light and easy to disperse by the wind.

The reforestation in Gunungsewu karst hills that had been nudated trig the primary succession process. Indriyanto (2006) described nudasion as the condition without vegetation or empty caused by the vegetation communities were disturbed, both because human activity caused or natural factor. Based on Euwsie (1980) primary succession happened because the native community was being disturbed until the total native was lost and made them found a new habitat. At the end, there is no left organism of the old community, so that they have to grow without them and only some pioneer that can tolerate that extreme condition (Resosudarmo *et al.,* 1993).



Picture 1. Cluster Analysis to test the non similarity of vegetation association

Based on hierarchical cluster analysis (Picture 1), the recent flora type is so different than the past. Today, there is associated plants dominated by a groups of low land species (Moraceae, Palmae, Leguminoceae, Ebenaceae) and semi arid (Meliaceae). The Moraceae Group even is a symbol/flagship as the specific plant in Gunungsewu karst hills today. From the pollen analysis found that the mountain flora type and wet tropical forest in karst hills that temporary various but still have similarity one to each other. Pinaceae and Hamamelidaceae Groups found in the upstream is about 2000 BP indicates that the climate is possible for mountain flora to grow in the location. But, in the next time Pinaceae was lost and only Hamamelidaceae is still exist and adaptable as the mountain flora. The change of climate type became wet tropic indicated by the presence of Moraceae group around 1500 BP, and then Bombasaceae was appearing in the next period. Casuarina as the characteristic of coastal forest in 225 BP indicates that the flora ever filled the formation of coastal forest in the karst hills.

Based on that information, It can be concluded that the mountain flora ever did invasion to the Gunungsewu karst hills, although at the end it is disappear because the change of climate that led to the new association from tropical forest type to fall forest type. Today, the flora type is direct to antropogenic consideration, especially for commercialization and forestation (*Tectona grandis*, *Swetenia macrophylla*, *Acacia auriculiformis,* and *Anacardium occidentale*). There are only some tolerant native plants that adaptable to the recent condition such as Leguminoceae (*Tamarindus indica*), Moraceae (*Ficus* sp.), Euphorbiaceae (*Acalypha* sp), Bombasaceae (*Ceiba petandra*), Sapindaceae (*Schleicera oleosa*), Tiliaceae (*Grewia paniculata*), Burseraceae (*Feronia lucida*), Meliaceaea (*Dysoxylum amoorodes*), Lauraceae (*Litsea chinensis*), Ebenaceae (*Diospyros kaki*), and Palmae (*Arenga pinnata*). Flora restoration in the karst hills is directed to develop the source of gene of the groups of the plants, beginning with seed deposit growing test stored in the ground.

Seeds Deposit Planting Trial

Seed deposit in the ground could be the authentic evidence to the truth of pollen discovery as the source of information of plant groups in karst hills. Suginingsih, *et al.,* (2009) had proofed that seed deposit biji can be stored in the ground for long time, and the deeper it is stored, the variation and number of seeds decrease. The grassed group is a dominant group in that growing test. The same result also happened in the soil deposit in Kanigoro, that after 3 months seedling, the grasses are growing (Picture 2). There are two probabilities of the long time stored seeds, those are the seeds died or these could still life in their dormancy time.

			
1st layer Kanigoro the age of 0 BP – This day	2nd layer Kanigoro the age of 1000 – 600 BP	3rd layer Kanigoro the age of 2001 – 2900 BP	4th layer Kanigoro the age of 12000 -4000 BP

Picture 2: Survival deposit seeds test after 3 months seedling, the grass is the first group to grow

The growing of grasses group in the test indicates that seed or grass seed are highly survive although had been stored for long time in the ground. Therefore, in the open areas grasses dominate as the pioneer. Suginingsih, *et al.,* (2009) succeeded sprouting the seed deposit of 30 centimeters depth with the time length is about 3-6 months. It informs that soil can be good media of seed storage. Peter (1893) in Justice (2002) reported his research about many kinds of seeds in the forest soil, which was a meadow long time before. He found *Hypericum humifusum, Juncus bufoius* and *Stellaria* in the layer depth with the age of 20 to 46 years, he found many kinds of species of open land, and concluded that meadow and marsh seeds can be survive for more than 50 years. The longest survival period is reported by Ohga (1923) in Justice (2002) that is seeds in the 2 feet depth buried humic layer, together with dust sediment of Pulantien river valley in South Manchuria, that almost 100% still can sprouting. The layer is in 40 feet height above the river level. Based on the age of **weeping willow**, the trace of the lake bottom and the evidence of the water level getting lower can be concluded that the seed is about 120 years minimum. However, after the checking by some experts applying Carbon-14 showed that the seed is 1.040 ± 210 years.

The discovery of Paleobotany, pollen or macro fossil is useful to study the history of the flora and vegetation development in an area. In the formation of Tarsier time especially Sumatera found the fossil of *Palmae, Moraceae, Annonaceae,Anacardiaceae, Sapindaceae*, *Sapotaceae, Ebenaceae dan Dipterocarpaceae* (Van Steenis, 1936) Dipterocarpaceae fossil is the clearest one, and been maintained good in the peat layer that having the ability to preserve. The fossils are Dipterocarpus, Shorea, Shereoxylon, Hopea, Dryobalanop and Vatica. It can be concluded that low land rain forest in Indonesia is not changing a lot until today.

The observation result in Gunungsewu karst hills is similar with the discovery of the paleobotany, so that the possibility to restore the extinct vegetation is forming the wet micro climate for microflora and microfauna. It supposes to make those microspecies‘ can help to degrade the organic materials so that it becomes humic and instantly becomes anorganic materials to be able to absorb by plants roots that will come later on.

The first step to do is forming the micro climate with planting some Leguminoceae. The experience of planting legume is in Wanagama I using *Acacia villosa*, this plant has intensive roots and relatively short so that it is proper to make new spaces between rocks and stones. The spaces will be deepen by the next flora and ease the organic material and soil to fill the spaces. The next process is creating a conducive environmental condition with based on the pollen sediment discovery in the Gunungsewu karst hills and seeds can sprout, so we can plant those species‘ until they can survive, and the last step is restoration with groups of Moraceae, Anacardiaceae, Annonaceae, Sapindaceae dan Dipterocarpaceae.

Conclusion

1. There are four flora types in Gunungsewu karst hills since 2500 years BP, which are mountain flora that could be found 2500 years BP with the characteristic species of Pinaceae and Hammamelideae, the wet tropical flora with the characteristic species of Ulmaceae, Podocarpaceae, dan Sapotaceae in 2000 years BP and the appearance of Bombacaceae since 60 years ago, and low land forest with the characteristic species of Palmae, Euphorbiaceae, Leguminoceae, and Moraceae in 1400 years BP. The fall forest type can be found in the present time, and it is one of the migrant groups (Meliaceae). Based on the recent climate condition, (Type C and D; Schmidt and Ferguson) so that today there are two flora types, which are low land forest and fall forest.

2. Deposit seeds growing test succeeded to grow the seedlings of 2500 years BP of sediment age, although it is still dominated by some grasses, shrubs, and pioneer like *Grewia sp*. The seeds can be stored for a long time in the ground and needs more time to be able to awake from the dormancy, so they need more time to sprout to validate the truth of pollen identification as the source of information of the native species.

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CAVE NECTAR BAT (*EONYCTERIS SPELAEA: PTEROPODIDAE*) CRUCIAL POLLINATOR OF TROPICAL CROPS: ISSUES OF HABITAT MANAGEMENT AND CONSERVATION PROBLEMS

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Abstract
Caves and karsts are the important biodiversity hotspots. Most of the species of bats (Chiroptera: Mammalia) are cave dwelling. Bat spends almost seventy percent of their daily life bat inside the caves that indicates the importance of cave ecosystem maintenance for biological welfare. Tropical rainforest is mainly found depending on animal for their seed dispersal and pollination success. Chiropteophily is one of the evolutionarily evolved phenomena and bat plant relation is believed as one of the pollination syndrome to certain plants. Cave Nectar bat (*Eonycteris spelaea*) is found one of the principal pollinator for their food plants. *Durian* and *Parkia* like tropical crops were found crucially dependent on these fauna for their pollination success. We are assessing their pollination effectiveness on these floras. The study sounds important since the bat pollinating crop stands as the major cash crops to the region and production increment or decrements have considerable socio-economic importance. The human induced threats to cave and fruiting garden around the cave has found the major challenging to bat conservation.

Keywords: Bat pollination, effective pollination, conservation threats, Habitat management

Introduction

Bats are a group of mammals that are very specialized for their unique life styles. It represents more than 20% of global mammal (Mickleburgh *et al*. 2002). However, the country wise diversity reputation can rank higher than this global rank. Ecological knowledge acquired by the bat scientists after their long attempt, is now succeeded to change the people‘s negative perception in bat as harmful. Bat rather has benefited to human, controlling insect pest of crop and insect vector of several disease, key seed dispersal and pollinator of tropical forest. Bat pollination is often rarely discussed phenomena in the world because majority of plant pollination services reserved with bee like insect pollinator. The review on vertebrate pollination (Fleming and Muchhala, 2008) reported 58 families of plants in about 24 orders; 43 families by *Phyllostomid* (restricted to New World tropics) 26 families by *Pteropodid* bats (restricted to Old World Tropics) associated to the phenomena. Bat pollination is a phenomenon restricted to the tropics and subtropics since approximately 90% plant in tropics are animal dependant for pollination (Bawa, 1990). Bat plant interaction is often described as the specialized mutualism in which one questions the existence of other on their absence. Flower visiting bats belonging to the family *Pteropodidae* (Old world distribution) while that at new world to family *Phyllostomidae* (New world distribution). Bats are appreciated to their long distance foraging movement from their diurnal roost. Mobility of bat like pollinator influences the pollen quality throughout- crossing the distant vigor of pollen to maintain the genetic diversity as a long distance pollen vector (Baker 1973, Elmqvist *et al.,* 1992,). Animals that move genetic material i.e. pollen or seeds between isolated fragments of vegetation can reduces the negative effects of habitat fragmentation (Young *et al.* 1996).

South East Asia is popular part for chiropterophilous interaction where *Durian* and *Parkia* like popular fruits including several other valuable plants with ecological and economical significance, have found dependant to bat pollination (Bumrungsri, 2008, 2009). Reductions of durian production due to inadequate fruit set (Subhadrabandhu *et al.,* 1991) pull the attention of durian growers to national to regional scale. Pollination biology of durian has confirmed having different level of self- incompatibility (Soepadmo & Eow, 1977; Chen and Chang, 2008) and Bat pollinated durian has found better fruit set in latest experiment in Thailand (Bumrungsri, 2008). Similarly there are many other plants like *Oroxylum* (Srithonchuay, 2008) and mangrove flora.

True Nectar bat in SE Asia – cave host the main population

Southeast Asia has good diversity of fruit bats, but few of them are specialized to nectar diet. *Eonycteris spelaea, Macroglossus sobrinus and M. minimus* are three truly nectarivore bat in the region. Specialized pollinator are assumed to be comparatively more effective and convenient pollinator in comparison to diet generalist. All three bat species are equipped with basically identical morphological feature (long and protrusible tongue with elongated muzzle). However, they are differing in their roosting and foraging habitat selection. The species belongs to genera *Macroglossus* roost in tree foliage with solitary living and small in size. While *E. spelaea* is colonial cave roosting nectarivore and bigger than the earlier two.

Through ecological perspective, Solitary animal governs its activities in small home range in comparison to colonial living. Animal sociality is benefited to reduce the predation, increase foraging efficiency with trapline movement though the cost to compete the resource can exist. Our speculation to this nectar bat is also based on the same background. Cave Nectar bat (*Eonycteris spelaea*) has been accepted as the main and probably the most effective bat pollinator to the region. Since, pollination is the output of polllinator‘s movement along the conspecific neighborhood of plants; our project is dealing about the foraging behaviour of bat in the region.

Pollination effectiveness has been defined as the relative contribution to plant fitness by different flower visitors. The contribution consists of two multiplicative components – pollination efficiency of pollinator and visitation rate by pollinator of pollination effectiveness (Herrera, 1987, 1989). Furthermore, pollination efficiency described as the amount of pollen deposited on stigma (Inouye *et al.,* 1994).

Methods and Methodologies

Study Area. The study is carried out at peninsular Thailand. *E. spelaea* colony from Sekeysoune cave, Tambon Khaophra, Rattaphum district of Songkhla Province (07 °04‘ 29.3‘‘N, 100° 10‘ 07.4‘‘, 65m Elevation). The foraging behaviour of bat and pollen load experiment was carried out at agro-forest system around the cave.

Methods. Live bats were captured with the help of mist net with various sizes and made on spot release after recording their morphological information. Flower visitation rate by bat has surveyed using infrared camera trapping and the bat visiting strategy to flowering plants was observed using infrared video observation. Transmitters were applied to neck collar to individual *Eonycteris* bat with feasible body weight (5-7% rule of biotelemetry). The bats were tracked to at roosting to feeding level with the help of receiver and 3 Yagi antennas. The close and far signal range were adjusted using attenuator. Foraging behavior of the bat will be enumerated with the help signal received in the foraging areas. Pollination effectiveness index has been measured with the help bat visitation rate to targeted flower and the no. of pollen load on stigmatic surface (*Durian*) no. of stigma with pollen load (on *Parkia spp.*)

Result

Bat Survey. Bat captured for 3 nights at Durian blooming garden results *E. spelaea* 80% (44 of 55), *Rousettus spp.* 14.4% (8 of 55), *Macroglossus spp*. 3.6 % (2 of 55) and remaining insect bats. *Rousettus* bats were captured frequently in one Durian garden. While in Parkia garden, two night capture deployed 4 mist net night, results 96.6 %(28 0f 29) while 3.4 %(1 of 29) *Macroglossus spp.*

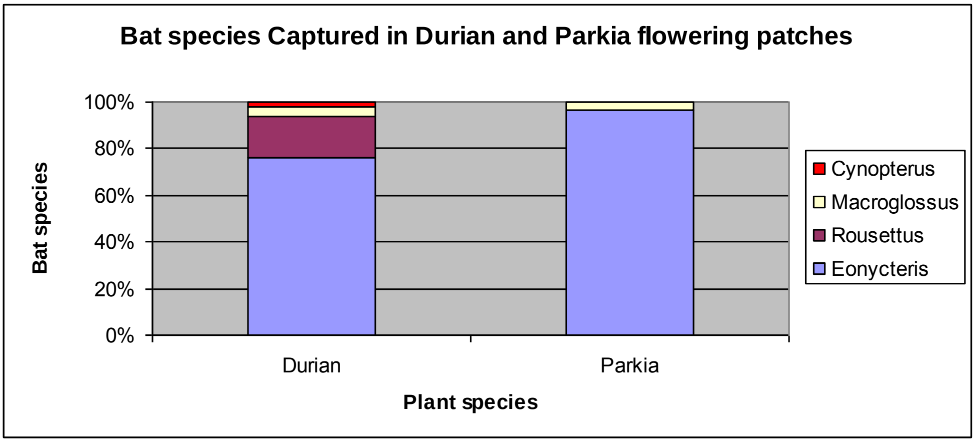

Figure 1. Bat species captured in Durian and Parkia flowering patches

Foraging Behavior. Among 4 individuals of *E. spelaea* (2 mature male and 1 female), There is no significant difference in foraging distance (1.94km from cave – 1st mature male, 2.59 km from cave- 2nd male and 1.8km for sub adult female). But there is remarkable difference in foraging duration. Adult male bats were found foraging about 4 hours duration while female and bachelor male bat was found foraging significantly longer duration of about 6.5 hour.

All of the three tracked bat possessing identical feeding range. Their feeding activity was found limiting to 1 square kilometer distance from their nightly resting roost. Our record shows – 0.68 sq km for sub adult female, *0.33 Sq.km* for adult male (with harem feature) and *1 Sq.km* for adult male. All bats were found feeding on same feeding range with no change in change in feeding areas.

Fig. 2, Diagram a. - Roosting site and feeding area utilized by Radio tracked E. spelaea.

Habitat Use

The habitat use survey of mature Male *Eonycteris spelaea* and sub-adult female shows of current tracking ba (Diagram b.) can be compared with the following notes –

a. **Night roost** by male is very close (5m – 30m) to one feeding area which is the main feeding place to it, however, distant feeding site also frequently visited by bat. While the night roost of female is quite away (100m) from the feeding place. Both individual use the dense canopied rubber vegetation for night resting.

b. **Female selected habitat** is found quite resourceful than male in terms of trees available to flowering stage.

c. **Female selected feeding** area is quite undisturbed than the male (adjacent to human settlement)

Fig. 3, Diagram b. habitat use by radio tracked Female and Male E. spelaea

d. Flower visitation rate to Durian flowering patch. Flower visiting rate by bat on Durian blooming inflorescence has been derived through infrared camera trap fixed on target flower bunch. Following result has been achieved. It shows, maximum bat visit to Durian flower at the first hour of feeding (1900hrs – 1800hrs, 1.7 N=12) secondly on departure hour (0200hrs- 0300hrs, 1.45; N = 12). Similarly, the least visit on early morning that follow on mid foraging time period (1000 hrs – 1100hrs, 0.6, N=12).

e. Feeding Strategy by Radio tracked *E. spelaea* (Based on Parkia). All tracked bat found having direct flight to their feeding area after emergence. First landing they has found to their nightly resting area, after a transient landing, they travel around their feeding range thoroughly and back to resting area. Feeding trip begins immediately. In each feeding trip the bat was found visiting more than one flower tree. After every feeding trip, it found resting proportionately longer time to night roost. Night roost has found temporarily permanent until bat utilized the same feeding area.

Pollination Effectiveness Index

PEI in Durian has found as 405.082unit (Average visitation rate – 8.6, N = 12, average pollen load – 47, N = 20) in *Durio zibethinus*. Similarly Parkia results PEI 341 unit (Average visitation rate – 22, Average stigma with pollen load due to bat visit – 15.5 floret).

Discussion & Concluding remarks

To date information of *E.spelaea* contribution to pollinate this valuable plant is now being the established agenda for discussion in pollination biology.

Current study is the follow up step to prove further guided by previous literature. This research evident how the cave dependant fauna is servicing the nature in terms of pollination success valuable floras with regional mankind. Production rate such fruit set in terms of quantity and quality is extra controlled by the pollinator‘s population. Durian production decrement is occasionally reported in Thailand (Honsho *et al.,* 2004). Hence, population status of such key pollinator is in the need of management. Prime threat has found in roosting level – due to human induced disturbances – improperly managed cave tourism and Mining.

Similar threats have been seen in foraging areas. Direct killing is an unwanted treats still existing commonly in fruit orchards. The indirect threat message to sustain *E. spealea* population is seems the habitat management. Cultivation of all kind of bat plant to ensure the year round availability of resources for proper supply of diet to nectar bat can benefit to maintain bat‘s reproductive potentiality in one hand, to supply the conspecific pollen to the plants via pollinator‘s movement in another way. Lastly, Cave based economics is the matter to discuss throughout the region. *E. spelaea* could be one of the most convenient to disseminate the ecological message of cave benefit to human well being throughout the region

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CAVE WHIP SPIDERS (ARACHNIDA: AMBLYPYGI) OF INDONESIA

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Abstract
Whip spiders, Amblypygi, are bizarre animals with flattened body, strong pedipalps with spines, and elongate antenniform legs. Whip spiders live under stones and rotten logs in the forest, and in the caves. Indonesian whip spiders contain more than nine species from four genera (*Stygophrynus, Charon, Sarax, Phrynus*) in three families (Charontidae, Charinidae, Phyrnidae). The first whip spider from the cave is *Stygophrynus dammermani* from Bogor caves and distribute eastwards to Menoreh caves (Central Java). It is a troglophilic species, which also reside on epigean habitat in Krakatau Island and various localities. Most of *Stygophrynus* species are easily found in caves from South Sumatra, West Java, and Central Java to northern east of Java. None of *Stygophrynus* species in Indonesian caves shows troglomorphic adaptation to cave environments. The second genus, *Charon*, is also common to live in most of Indonesian islands from Kalimantan, Java, Sulawesi and eastward to Papua region. The *Charon* species are troglophilic species, and no cave-adapted species is reported. The third genus, *Sarax*, is known from several localities in Indonesian island. Most of the species members occur on cave floor, but some species are also found on epigean habitat. Recently, two *Sarax* species are discovered from Sangkulirang caves (Kalimantan) and exhibit troglomorphic characters with small eyes, elongate legs and pale in coloration. Several un-described *Sarax* species from Nias (Sumatra), Maros (Sulawesi) and Madura caves are believed to be new to science. The fourth enigmatic genus, *Phrynus*, is known from caves in Flores Island, and reported living on epigean habitat. The distribution of the whip spiders species is restricted to certain areas or even only single cave with high level of endemism. The biogeography and the evolution of the whip spiders species still need further studies.

Keywords: Charontidae, Charinidae, Phrynidae, troglomorphy, biogeography, distribution, diversity, endemism.

CAVE AND KARST MANAGEMENT

CRITERIA AND NEW TECHNOLOGIES FOR THE DEVELOPMENT OF SHOW CAVES

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Abstract
Before a proposal to develop a wild cave into a show cave becomes a physical project, it is necessary to carry out a careful and detailed study to evaluate the benefits and risks, by taking into account all pertinent factors such as the access, the synergy and possible conflict with other tourism related activities in the surrounding area, the availability of funds and many other related factors. The conversion should only take place if the results of the studies are positive. The materials used for the development should have the least possible impact on both the aesthetics of the cave and its underground environment. Once concrete is cast it is extremely expensive and difficult to modify or decommission. Stainless steel has the distinct advantage that it lasts for a long time and requires little, to no, maintenance but it is expensive and requires special techniques to assemble and install. Some recently developed plastic materials have the advantage of a very long life, are easy to install and are relatively easy to modify. The energy balance of a cave should not be modified beyond its natural variations. Lampenflora is typical problem of show caves, because the light that is necessary for the visitors supplies enough energy to some plants, mainly algae and mosses, which may grow to the point of defacing and damaging seriously the cave itself. Sustainable development means that the environment meets the needs of the present without compromising the ability of future generations to meet their own needs. Such a principle aims to consider ways and means by which show caves can achieve sustainable development, and to propose long term plans by which the world‟s show cave community can deal more effectively with the achievement of sustainable development.

Keywords: Management Guidelines, pathways, lighting, lampenflora, sustainable development

Introduction

Sustainable development means that the environment meets the needs of the present without compromising the ability of future generations to meet their own needs. This concept must obviously be applied to any activity and, therefore, also to the show caves whose number sometimes increases beyond a level compatible with the principle of sustainable development. (Cigna & Summers, 2009).

There is a global need to achieve sustainable development of show caves. In many ways our subterranean worlds are sensory monitors of what is occurring above ground. In any show cave, environmental matters must rank as the highest consideration. The often-touted need for economical profit pales against environmental considerations. If the environment of the cave is not good, then its economical future will not be good. Conversely, of course, if the economics of the show cave are not good, then the environmental quality will suffer.

Clearly the item that must always be at the top of the list is the protection of the cave. This must always be in the highest echelon of the priorities of a show cave. It will be futile to implement any new methods of operating or developing a cave if the foremost obligation of protecting the cave is not achieved.

In addition to the protection of the environment the safety of the visitors must be assured. Show caves are where the public needs to be directed in order to enable them to see the incredible underground spectacle that exists in our underworld. The general public does not belong in wild and unimproved caves. Caves are inherently dangerous places if the lay visitor is not properly trained and equipped.

In accepting the general visitor into their caves, the show cave operator must be aware that the average visitor is becoming more educated and will also have a greater awareness and appreciation of the environment.

The owners and operators of show caves, have a responsibility to ensure that show caves are operated with the absolute highest environmental standards. The matter of need becomes fundamental. In assessing “need”, the economic impact that a show cave can have on a locale must always be remembered. Not only are there more obvious economic advantages arising from direct benefits to be considered, but also the less obvious benefits arising from a show cave must also be taken into account.

The notion that a show cave must be economically successful in order to support the environmentally sound practices is alive and well. Find a cave that is not performing well economically and it will follow that there are insufficient funds available to support the environmental needs. While the owners and operators of show caves are generally working hand in hand with the environment, there clearly is a need to be cognizant that this can always be improved (Cigna & Summers, 2009).

Materials

Pathways. Any undue source of harm to the visitors must be avoided. This means that the pathways must be strong enough to withstand the very high humidity and, sometimes, also floods. In the past wooden structures were often used, but they had to be replaced frequently; presently some "green" people would still use wood because this material is natural. Nevertheless the rather short life of a wooden structure in the cave environment implies an additional cost which is not justified by any advantage. On the contrary the rotten wood supplies large amounts of food modifying the equilibrium of the cave life.

In particular at present, the criterion to use only structures, which can be easily decommissioned, is substantially wrong because, once it is no longer convenient to manage a show cave, no one will spend any money to take out any structure inside the cave. Only when show cave managers will be obliged to deposit a given amount of money to assure the future decommissioning of any structure, it is possible to use structures to be easily disassembled.

In the meanwhile, it is preferable to use a material, which is compatible with the cave environment and will not release pollutants also in the long run. A material with these characteristics and not expensive is concrete. It may be conveniently used for pathways in general but it implies sometimes a high cost to carry it in place.

The handrails in stainless steel are also a convenient solution, particularly when they are also used as pipes to provide water in different parts of the cave to wash out the pathways. In fact, a higher cost of stainless steel is justified by a lack of any maintenance also after many years of operation (Cigna *et al.,* 2000). Sometimes plastic may be used under the condition that it does not contain any contaminant (e.g., heavy metals or organic compounds which may be released) (Cigna, 2005). The use of plastic material in caves is subject to some constraints. E.g. if the plastic, which is in principle rather chemically inert, is added with wood debris mould will develop easily in the cave environment and their mechanical characteristics are quite poor (Knox, 2004).

Recently plastic structures have been used in caves to build pathways. Presently the best material available on the market is a fibreglass reinforced plastic. Its key product features are that it is lightweight, corrosion resistant, non-conductive, low maintenance, slip resistant, fire retardant, etc. In addition this material has a high strength-to-weight ratio with one-third the weight of steel, allowing easy installation, with no heavy equipment, and less manpower. In fact simple tools easily work such materials and the different parts of the structure are assembled with stainless steel bolts. Another interesting advantage is the possibility of modifying any pathway very easily.

Lamps. In the past the so-called "cold light lamps" have been proposed for cave lighting. Such lamps are currently used where ice cream and other cold foods are displayed. The infrared part of the spectrum is scattered backwards so that the lamp does not heat the objects. Obviously from a global point of view such lamps do not provide a real advantage for the cave environment because the heat release into the cave environment is not decreased.

In the last years the incandescent lamps (where only the 5% of the energy supplied is released as light) have been replaced by other devices with a much higher efficiency. The High Pressure Metal Halide lamp (HPH) have a higher efficiency but cannot be switched on frequently because they take some time to reach the full power. The Cold Cathode Lamp (CCL) may be manufactured with different emission spectra and can be switched on and off without problems. The Light Emitting Diodes (LED) have a very long life (50,000-100,000 hours) and a good efficiency. In Table 1 the characteristics of some kinds of lamps are summarized.

Table 1. Characteristics of some kinds of lamps (indicative)

Lamp	Efficiency [lm/W]
Incandescent, tungsten	15
Incandescent, halogen	24
Cold cathode (CCL)	70-80
Light Emitting Diode (LED)	50 - 90
Fluorescent	60 - 100
Gas discharge (HPH)	65 - 115

Energy balance: visitors and lighting

A cave is an environment with little contact with the outside. For this reason its equilibrium may be easily changed when additional energy is introduced (Cigna, 1993). Obviously such changes may occur more frequently when the whole energy budget of the cave is small, but in case of show caves the energy budget is often not very small, because of their size which is generally large. A river or a subterranean lake plays an important role in keeping the natural equilibrium because they may absorb more easily than rock any further input of energy.

There are different ways to keep the additional energy input into the cave as low as possible. A limit of the number of visitors is given by the so called "visitors' capacity" which is defined as the maximum number of visitors acceptable in a time unit under defined conditions which does not imply a permanent modification of a relevant parameter. Otherwise, instead of reducing the number of persons, the time they spend into the cave may be reduced. This result may be easily achieved when people enter the cave through one entrance and exit along another passage, instead of returning along the same pathway when they got in.

Using high efficiency lamps can reduce the contribution by the electric lighting system. A further reduction can be obtained if the lamps are switched on only when visitors are in the vicinity.

Another perturbation of the cave environment is also due to the lint (hair, dry-flaking skin, dust from shoes and lint form clothing) left by visitors. In caves visited by a large number of people the accumulation of lint becomes a real problem to be solved by an accurate removal. In fact it would cause deterioration of formations and reduce their pristine white beauty to a blackened mess.

Lint released into a cave might be reduced by means of air curtains at the entrance. Such a solution would wash people entering the cave and, at the same time, isolate the cave environment from outside since an air curtain acts as an invisible door and avoid airflow through it.

The protection of the environment of a show cave is fundamental both from the point of view of avoiding any damage to a not-renewable patrimony and the conservation of the source of income for the cave management. Therefore such a common interest may have an important role in the implementation of any action aiming to the safeguard of the cave environment.

Visitors release also carbon dioxide as a result of their breathing. Until few years ago such carbon dioxide was considered as a threat to the cave formations since it could have increased the water acidity and, consequently, the corrosion instead of the deposition of new formations. Further accurate studies (Bourges *et al.,* 1998) have shown that in many instances the carbon dioxide produced by natural processes (oxidisation of organic matter in the soil above a cave) may introduce through the water percolating into the cave amounts very much larger than the carbon dioxide released by visitors.

When the water, with a relatively high concentration of carbon dioxide, reaches the cave environment it releases immediately part of such carbon dioxide, which is not in equilibrium with the carbon dioxide in air. Therefore the chemical reaction moves towards the deposition of calcium carbonate and the formations continue to grow. In general, rather small caves with a high visitor' flux and without any input of natural carbon dioxide might have formations corroded because the chemical reactions would be reversed when the carbon dioxide of air dissolves into water, particularly when water vapour condenses on the cave walls.

In a show cave both the visitors and the electric lighting system release energy into the environment. A person who is walking release nearly as much energy as a 200 watt bulb at a temperature of about 37°C. Therefore the total energy released by hundreds or thousands of visitors in a day is not negligible as an absolute amount. The heat released by the electric lighting system has the same order of magnitude.

Lampenflora

Another form of environmental pollution may occur through a joint contribution by visitors and light. Persons release into the cave spores or seeds of plants and they may grow in the vicinity of lamps if the light flux is high enough. The result is the so-called "lampenflora" i.e. green plants (generally algae, fern, moss) developing on cave walls or formations close to a light source. Such plants cover the surfaces with a greenish layer, which can become included into the calcite deposition and no longer removable. In fact the lampenflora may be washed away by bleach or hydrogen peroxide if it is not covered by any calcite. Special care must be paid to avoid any nuisance to the cave fauna.

The growth of lampenflora can be avoided by the employ of light sources with a very low emission of light useful for the chlorophyllian process and low light flux at the rock surface.

Nowadays in tourist caves a great care is paid to avoid damages to the environment. One of the main sources of possible damage is due to the lighting system, which may promote the proliferation of algae, mosses and other plants. The whole category of these plants is normally called "lampenflora" a German word meaning "plants of the lamps", because this phenomenon was firstly studied mainly by Austrian scientists (Kyrle, 1923; Morton & Gams, 1925) and, later, in France (De Virville, 1928).

The damage due to the lampenflora has a double aspect. Plants detracts from the beauty of the formations and the organic acids released by them produce corrosion, both of rock and formation, which may attain a rather high level.

A light source supplies energy as heat and, obviously, light. Only a small fraction of the energy released by incandescent lamps is light (around 5%) while the remaining part is heat. Modern lamps are more efficient and the heat released to the environment may be reduced to 50-70% of the whole energy budget.

Nevertheless, the photosynthesis process, which is fundamental for the development and the growth of the green plants, is based on the absorption of some wavelengths mainly around 440 and 660 nanometres. Therefore, there is the possibility to decrease the amount of energy useful for the plant growth by installing lamps with an emission spectrum without peaks at the wavelengths reported above.

Obviously it is not always possible to apply this rule for aesthetic reasons. In fact the light colour may result not acceptable in some cases and a compromise between aesthetics and algae proliferation must be found.

Lamps should be chosen among those with the highest efficiency possible and the lighting network should be divided into sections to be switched on only when tourists are present. In any case the lamps should not be placed close to the rock to avoid that a given amount of energy (both as light and heat) be delivered to a small area.

Algae are the most widespread plants of lampenflora and, therefore, any action aiming to clean and restore the cave environment has been directed mainly against this kind of plants.

Both Kyrle (1923) and Morton & Gams (1925) in their important books on speleology and cave plants do not make any reference to lampenflora because at that time it was not considered a real problem since the light sources used in show caves delivered too little energy to the cave environment.

When electric lighting started to be used in caves, lampenflora spread out as well as the efforts to avoid it. In addition to a better installation of lamps, as it was reported above, the proliferation of lampenflora was avoided with the employ of herbicides and water scrubbing (Caumartin 1973; 1994).

The experience achieved in some show caves (as, e.g. the Grotte di Frasassi, Ancona, Italy) where many systems were tested, reached the conclusion that herbicides must be avoided for their toxicity to both other cave organisms and humans. On the other hand, sodium hypochlorite (at the concentration normally used for bleaching) and hydrogen peroxide solution (3 to 10%) applied to the formation or the rock wall covered with algae and successively brushed away and rinsed with water was the most efficient procedure to destroy safely the lampenflora.

It must be emphasized that algae may survive and diffuse also outside of the vicinity of lamps (Claus, 1955; Giordano *et al.,* 2001). In most cases this fact has a scientific interest only without any further practical consequence on the cave environment. But when suitable conditions exist (temperature, humidity, nutrients, etc.) algae may spread away from the light source until they cover a large surface of the cave. Such a phenomenon is quite evident, e.g., in different locations of the Cango Caves (Outdshoorn, South Africa) where entire walls and ceilings, also very rich of small formations, are covered with algae turning the original colour into a deep green. This is a heritage from light sources installed in the past, because at present there are no lamps close to the algae colonies.

Negative aspects only of algae and mosses in caves have been reported above, but it should be mentioned that sometimes they may play a positive role in the development of formations in the threshold zone, i.e. in the vicinity of entrances where some light from outside is available. In fact, through the binding action of algal mats, stalagmites with a rather irregular shape, called stromatolites, may form. A similar process is found sometimes on mosses, and an eccentric formation develops on the older parts of the moss.

Economy

It is evident that the economy of a region around a show-cave-to-be can be radically modified by the cave development. Therefore strenuous opposition to any tourist visitation appears to be rather unfair towards the local people, particularly when a suitable compromise between strict conservation and a sound development can be found. But in any case, as it was previously reported, a cave development cannot be accepted if it is not supported by appropriate preliminary research.

A recent evaluation of the number of show cave visitors all around the world (Cigna & Burri, 2000), based on data obtained for about 20% of all show caves, estimate a global number of more than 150 million visitors per year. By assuming a budget per person as reported in Table 2 the total amount of money spent to visit the show caves is around 3 billion US $ (2008). The number of the local people directly involved in the show cave business (management and local services) can be estimated to be up to several hundred per cave, i.e. some hundreds of thousands of individuals in the world.

By taking into account that there are several hundred other people working indirectly to each person directly connected with a show cave (Forti & Cigna, 1989), a gross global figure of about 100 million people receive income from the show cave business. Therefore, it can be roughly assumed that for each tourist visiting a show cave there is about one other person directly or indirectly connected who is earning income from the visit.

Table 2 - Rough estimation of the annual direct and local budget of a show cave per each visitor (US $, 2008).

Source	US $ (2008)
Direct income	6.5
Other local income:	
Souvenirs & snacks	2.0
Meals	6.5
Transportation	2.5
Travel agency	2.5
TOTAL	20.0

In addition to show caves, the existence of karst parks, which include a cave within their boundaries, must also be considered. As reported by Halliday (1981) the number of visitors to the top three karst national parks in USA (Mammoth Cave, Carlsbad Caverns and Wind Cave) amounted to about 2,500,000 tourists each year. Therefore karst parks give a further increase to the number of people involved in the whole "karst" business.

There are many other human activities that involve a larger number of people; nevertheless the figures reported above are not negligible, and give an indication of the role that show caves play in the global economy.

Conclusion

There is an overwhelming need to make informed choices. The need to adopt sound sustainable development practices is upon us. The transition to sustainable development can be achieved. Part of our environmental management practices must be focussed on after the fact repairs of damage and restoration of natural habitats. We must accept that change will happen. We must produce more with less.

There is a clear challenge facing the world of show caves. We must protect, conserve and preserve our incredible displays of the earth"s natural systems. Show caves are not simply curiosities but very important vehicles to aid and promote public awareness. The last component that we must meet is the need to remain viable. We are charged with a very fragile and delicate world, a world that requires a co-joining of economy and science.

These guidelines were obtained as the result of wide cooperation between the International Show Caves Association (ISCA), the Union Internationale de Spéléologie (UIS) and the International Union for Conservation of Nature and Natural Resources (IUCN) and are intended to set minimum standards, while recognizing that many existing show caves may not initially be able to comply with the specified guidelines.

Recently "Management Guidelines for Show Caves" should have received the final agreement during the 6th ISCA International Congress held in Liptovsky Mikulas, Slovakia, 18-23October 2010 (Cigna, 2010). During the General Assembly objections were raised against the recommendations to avoid both the use of wood in caves and the determination of the visitors capacity; as a whole the guidelines were also considered dangerous since they could be endorsed in local laws. Unfortunately the position of cave managers, who put the profit before the protection of the cave environment, prevailed and the guidelines were not endorsed. Therefore they are now promoted by the Union Internationale de Spéléologie (UIS).

Such "Management Guidelines for Show Caves" are here summarized in an Annex.

We do not have a resource that we can rebuild, if it is damaged, within periods of time that are less than thousands of years into the future. We are all aware that once something in a show cave is lost, it is effectively lost forever. The future need not be threatened if collaboration among scientists, cave managers and cavers is assured.

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Annex

MANAGEMENT GUIDELINES FOR SHOW CAVES

1 Development of a wild cave into a show cave

1-1 A careful study of the suitability of the cave for development, taking into account all factors influencing it, must be carried out, and must be carefully evaluated, before physical development work commences.

2 Access and pathways within the cave

2-1 Any new access into a cave must be fitted with an efficient air lock system, such as a double set of doors, to avoid creating changes in the air circulation within the cave.

2-2 Any development work carried out inside the cave should avoid disturbing the structure, the deposits and the formations of the cave, as much as possible.

2-3 Only materials that are compatible with the cave, and have the least impact on the cave, should be used in a cave. Cement, concrete, stainless steel and plastics are examples of such materials.

2-4 Organic material, such as wood, should never be used in a cave unless it is an ice cave where, if necessary, it can be used for pathways.

3 Lighting

3-1 Electric lighting should be provided in safe, well-balanced networks. The power supply should preferably be non-interruptible.

3-2 Adequate emergency lighting should be available in the event of a power outage.

3-3 Lighting should have an emission spectrum with the lowest contribution to the absorption spectrum of chlorophyll (around 440 nm and around 650 nm).

3-4 Lighting sources should be installed at a distance from any component of the cave to prevent the growth of lampenflora and damaging the formations and any rock paintings.

3-5 Lighting should be installed in a manner to enable only the portions of the cave that are occupied by visitors, to be illuminated.

4 Frequency of visits and number of visitors

4-1 A cave visitor capacity, per a defined time period, should be determined and this capacity should not be exceeded. Visitor capacity is defined as the number of visitors to a given cave over a given time period, which does not permanently change the environmental parameters beyond their natural fluctuation range. A continuous tour, utilizing an entrance and another exit, can reduce the time that visitors spend in a cave, compared to the use of a single entrance/exit.

4-2 When visits to wild parts of a cave are arranged, they must be carefully planned. In addition to providing the participants with the necessary speleological safety equipment, the visitors must always be guided by a guide with good experience in wild caves. The pathway, where visitors are to travel along, must be clearly defined, for example with red and white tape, and the visitors should not be allowed to walk beyond this pathway. Special care must be taken to avoid any damage to the cave environment, and the parts beyond the pathway must be maintained in a clean condition.

5 Preservation of the surface ecosystem when developing buildings, parking, removal of surface vegetation and waste recovery

5-1 Any siting of buildings, parking areas, and any other intervention directly above the cave, must be avoided in order to keep the natural seepage of rainwater from the surface in its original condition.

6 **Monitoring**

6-1 Monitoring of the cave climate should be undertaken. The air temperature, carbon dioxide, humidity, radon (if its concentration is close to or above the level prescribed by the law) and water temperature (if applicable) should be monitored. Airflow in and out of the cave could also be monitored.

6-2 Specialized cave scientists should be consulted when there is a situation that warrants research in a cave.

7 Cave managers

7-1 Cave managers should be competent in both the management of the economics of the show cave and its environmental protection.

8 Training of the guides

8-1 Cave guides should be trained to correctly inform the visitors about the cave and its environment.

A CONCEPT OF WATER RESOURCES-BASED ZONING SCHEME FOR KARST NATIONAL PARK (STUDY CASE IN MANUPEU TANADARU NATIONAL PARK)

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Abstract
A national park is managed with zoning system mainly for ecosystem conservation and recreation. Under the current management paradigm, a national park must benefit not only the biodiversity and landscape that it contained, but should also enhanced the social conditions of neighbouring people as well as maintained environmental services. One type of environmental services that a national park provides is water and one giant reservoirs of fresh water is limestone caves, found in many karst areas. A newly developed national park with a significant karst area is Manupeu Tanadaru National Park in East Nusa Tenggara Province. Sources of water supply for the local communities come from areas outside the national park, but during dry periods, they often experienced lack of water. Although some great water resources could be found within the national park, unfortunately the area is restricted. A national park should be managed with and for the people, providing sufficient welfare. This article provides zoning concept based on water-resources, unlike regular national parks zoning scheme where mostly based on biodiversity and/or landscape potentials. With the existing underground river system, zoning management in national park with extensive karst area should consider the hydrological values of the area to local communities.

Keywords: zoning, national park management, Manupeu Tanadaru National Park, water resources, karst

Introduction

National parks are protected areas with pristine ecosystems, managed by the zoning system and utilized for the purpose of research, science, education, as well as supporting aquaculture, tourism, and recreation (Dephut, 1990). National Park serves as the protection of life support systems, preservation of plant or animal species diversity and sustainable use of natural resources and their ecosystems. According to Soekmadi (2003), the new paradigm of conservation area management focused on consideration of aspects of the benefit and accommodating local interests. Therefore, a national park is managed in accordance with the potentials and characteristics of its natural resources for the benefit of the protection and conservation and utilization to meet human needs in a sustainable manner (Purnama, 2005). This management system is known as the zoning system.

According to the Minister of Forestry Regulation (Permenhut) P.56/Menhut-II/2006, national park zoning system requires the park to comprise of at least core, wilderness, and utilization zones. In line with the explanation in this Permenhut, these least requirement zones are associated with protection zone, thus biodiversity potentials is one of the most used consideration in determining criteria for zoning. While the welfare of the surrounding people are much related to the availability of environmental services.

One of the important environmental services of national parks is as a provider of water resources which is non-living natural resources that are absolutely necessary for human survival. In primitive cultures, water were used only to satisfy some very important needs such as for household and agricultural needs, but on a much more contemporary world, water is used more for industrial needs as well as mechanism agriculture and human convenience (Lee 1988).

Some national parks are catchment areas that provide water during rainy and dry seasons. Utilization of water resources in national parks is not only to meet the needs of communities around the park, but also the resources used by communities who are living quiet a distance from the national park. According to IUCN (2008), Jakarta gets its clean water requirements from Mount Gede Pangrango National Park located in Bogor and Cianjur Districts. In addition, some springs and the upper catchment areas of this national park are managed by water companies to meet the water requirements of Sukabumi, Cianjur and Bogor areas (Widarti 1995). Another example of the hydrological benefits of national parks can be seen by Halimun Salak Mountain National Park which, according to Herlianto (2005), the water resources flow throughout the year with a relatively constant flow through the flow of surface and underground rivers. The high potentials of water resources in national parks provides opportunities to be utilized in meeting the needs of the community. Unfortunately the current zoning system does not regard important hydrological areas as criteria for determination of the established zones.

One of the landscape that has a high hydrological value as a provider of fresh water resources is karst. Karst received inputs from infiltration of water into the soil and runoff that flows directly into the endokarst. Karst water will flow through the gap-fracturing and tunnel underground (caves) as a source of spring water. The flow of underground water is often very complex thus water from one source could emerge in several springs (Ford and Williams, 2007).

Zoning Concept in Indonesia National Park

Act no. 5/1990 defines a national park as an area designated to protect natural ecosystems and managed by the National Park Agency using a system of spatial zoning. A national park is to be used for research, education, cultural needs, tourism or recreation. This definition complies with the IUCN classification for national parks as Category II protected areas, established to (a) protect the ecological integrity of one or more ecosystems for present and future generations; (b) exclude exploitation or occupation inimical to the purposes of designation of the area; (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible. The zoning of national parks is regulated through Ministerial Decree P.56, which defines zoning as the spatial arrangement of the park in different zones. Zones are differentiated according to function and existing ecological, socio-economic and cultural conditions. Decree P.56 also states that the designation and management of zones is to be based on: (a) potential of natural resources and the ecosystem; (b) level of interaction with local people; (c) importance of the area.

Unfortunately, the current system often lacks to take into account the human population despite the above criteria for zone designation. The existing zones, which put more emphasized on biodiversity protection purposes, have in turn limited the community access to get direct benefits from the national park. For example in Tesso Nilo National Park, the communities lose important source of income from collecting honey within the park since the area is now designed as a core zone to protect elephant habitat, which is obviously contradictory to the purpose of national park management zoning system.

Incompatability of Regular Zoning System for Karst National Park

Water resources are one of the benefits that can be enjoyed by the communities from a karst area and hence required to be managed for sustainably. Globally, the world's largest springs are karst springs (Jennings, 1985 *in* Sunkar, 2009). In Indonesia, the Karst region of Maros-Pangkep in South Sulawesi is the giant fresh water tank that is able to provide fresh water to surrounding society. Furthermore, Maros is one of large rice-producing region, in which its existence depends on the availability of fresh water. In other areas of the world, Manavgat Springs in Turkey, which collectively are the largest karst springs in the world, have a total discharge of 150-130 m3sec-1. The water of the Fore-Alps in Italy, with a total discharge of about 40 m3sec-1, represents one important resource that is still comparatively clean (Sauro, 1993 *in* Sunkar, 2009). Chingsui Spring, one of the largest in China has a mean discharge of 33 m3sec-1. One of the most famous springs in Europe occurs in a karst area, at Timavo, with a mean discharge of 26.25 m3sec-1 (Jennings, 1971 *in* Sunkar, 2009), while Silver and Blue Springs, the largest in Florida, have discharges of 14-15 m3sec-1. Indeed, the Austrian cities of Vienna and Salzburg, are dependent on karst waters and both Paris and London obtain much of their water from karst sources. In Indonesia, limestone ranks third in importance as a water-bearing formation after volcaniclastics and alluvial deposits (Soetrisno, 1997 *in* Sunkar, 2009). Ironically however, the abundant deep groundwater is sometimes inaccessible to those who need it.

According to Kurniawan (2010) there is an option for management of karst areas as protected areas. However, the management of karst areas requires special design that is different from the current national parks management in general. According to Sunkar (2007) the presence of karst areas should be a concern because the term geological diversity (geodiversity) is parallel to biological diversity (biodiversity). Apart from zoning criteria, on national parks with regular zoning scheme, zones are divided above the land with clear boundaries whereas karst areas possesses challenges because it often have irregular boundaries due to the presence of underground river system as well as cave systems. Furthermore, karst aquifers are particularly susceptible to contamination due to the lack of filtration of water entering the aquifer. Contaminants thrown into sink holes can flow directly into the aquifer without filtration, exposure to sunlight, or adequate dilution. In addition to their extreme vulnerability to contamination, karst aquifers are extremely difficult if not impossible to remediate. Other important issues to consider in karst national park include:

1. The exact total area of the karst that is part of the national park
   The management plan can be prepared by clarifying karst boundaries inside a national park area.
2. Location of missing rivers and springs.
   Potentials of water resources are of primary consideration in classifying karst region, therefore information on water resources and catchment area are necessary.
3. Utilization of water by the people living in and around the national park.
   Form of water utilization can provide insights into the level of water requirements by the local populations. Benefits received by the public will assist managers in protecting the national park.

Due to the unique physical landscape and hydrological system of a karst area, the incompatibilities stated above should point at a new zoning scheme for national parks with extensive karst landscapes. Since a national park must benefit the communities who live in and around the park as well as people-centred national park management is the new paradigm in managing a national park, national parks managers whose areas comprised of great karst landscape must take into consideration the water necessities of the local population. This is especially true if most of the great river discharges exist within the national park and since it is the responsibility of the park authority to protect water quantities and qualities that are used by the local population especially if the upper catchment is in the national park.

Water-Based Zoning System for Manupeu Tanadaru National Park

Indonesia has the largest karst areas in Southeast Asia with a total area of 145.000 km^2, where about 22.000 km^2 are protected areas (Day and Urich, 2000). This role becomes very important especially after the appointment of karst areas by IUCN as one area that deserves protection (Watson *et al.,* 1997). However, karst ecosystems, both in Indonesia and the world, have not been much considered in the determination of protected areas.

So far, there are no specific forms of karst area management that are also protected areas. All still influenced by the broad categories of protected areas, as a National Park, Nature Reserve, Wildlife Sanctuary and Nature Park. Data showed that many karst areas belong to national park category and many are also World Natural Heritage and World Cultural Heritage. Williams (2008) recorded as many as 45 regions, of which 25 of them have a universal value, including the Lorenz National Park in Indonesia.

One national park in Indonesia that has extensive karst landscape and is in the process of preparation stage of establishing its zonation is Manupeu Tanahdaru National Park (MTNP) located in the Province of Nusa Tenggara. Manupeu Tanadaru National Park is the main catchment area that is use to transport water for fulfilling clean water needs and agriculture purposes for the people living around the national park. Many of Sumba people faces difficulties in getting adequate amount of water. In MTNP, the distribution of water within the national park is not evenly spread. This was suggested by observation that showed that some villages dependent on wet-rice agriculture while others dependent on dry-field agriculture. Most of the villages around the MTNP obtained their water supplies from water sources that are occurred outside the park. Unfortunately due to long dry season, very often the water sources experienced decreasing discharge. The people said that some large discharge springs occurred within the national park, but unfortunately they are not allowed to access it since the location if restricted for human passing

The People at Kanabuwulang Village hoped that the existing water sources in Kanabuwulang can be managed by the national park to be channelled into people's homes due to lack of water resources within the area. Once there was a plan to build water facilities from this cave but is inhibited by shortage of fund. Although close by, there is Lake Wundut, but the water can not be used as a source of clean water because the lake is used as a place to bathe or wallow by animals such as horses, cows and buffalo. In addition, some of the people in other areas, i.e. Kambatawundut Village even wished that the existence of the cave around their area could be further developed as tourist attractions because of the activities are expected to improve the welfare of the community.

One of the great spring that is used by another village, the Watumbelar Village, is spring water in Waikangguruk where the water comes from Ramandu Cave and Nangga Cave (the people stated that there are about 67 caves in this village). At first, the water from this spring was expected to provide water supply for 6 villages namely Watumbelar, Bidipraing, Kangeili, Leilahu, Kambatawundut and Umamanu. However, the plant has not been carried out yet. On the other hand, the people here felt that water is the main problem since the quantity is very low. The people used to build wells but during dry periods, the well collapsed.

Due to the high demand of the people for better water availability, the park authority should be able to better manage the national park so that it will provide better livelihood for the surrounding local population. With regard to the potentials of water supplies within the national park, the park authority should establish a map showing distribution of potential spring water, swallow rivers as well as underground rivers with their water discharge. Some options for water-based zoning system could be based on the area of underground river flow with great discharge and especially vulnerable to pollution; areas with swallow hole (missing rivers) and areas with springs. Therefore the zone might look different since these areas can be randomly distributed and thus the zoning design may not follow a fix form.

Conclusion

It is clear that biodiversity is more dominant in setting designated zones within a national park that are more directed to the tourism and science. Yet, some karst formations are found within national parks. Unfortunately the zoning system that is use to manage national park in Indonesia overlooked the importance of its hydrological values. Furthermore, the existing underground cave and river systems possess certain challenges in delineating boundaries of designated zones, since it required a deep study of the relationship between endokarst and eksokarst components. Another important thing to consider is that national parks must provide welfare benefits especially for the surrounding community. Karst as a natural giant water tank plays an important role in providing fresh water for the community. Therefore a national park with extensive karst landscape such as Manupeu Tanadaru National Park should consider the existence and distribution of water resources over the whole park. The park manager should take into account and mapped locations having water flow all year round, especially if the discharge is quite large, and easily accessible. This information should be used to design the zoning system within the park.

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THE AWRAMAN GEOPARK: AN APPROACH TO PROTECT KARST GEOHERITAGES IN NORTH-WEST OF KERMANSHAH, WESTERN ZAGROS

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Abstract

Karst carbonate formations cover about 11% of Iran‟s land area (185,000 km2) and 55.2% of the total karst carbonate in Iran is located in the Zagros ranges . 33% of Kermanshah province area covered by karst terrains. Zagros is one of the most important locations for geological and archeological research either to study the pre-historical or historical eras in Iran. The western Zagros' Ravansar and Shahu high karst plateau which are generally called “Awraman”, are located in the north west of Kermanshah. Diversity of karst phenomena, liner, surfacial and other karst structures and landscapes in the high karst plateau (2500-3339 m asl) illustrate the geological history of zagros' karst and at the same time prove the importance of natural conditions for the traditional human settlements and the cultural development of Awraman society in the course of several thousand years in western of Zagros. Abundance of water resources and its rich biodiversity have acted as effective agents to establish prehistoric setting, the emergence of pastoralist and nomadic life styles and the enhancement of sedentary life in the Zagros. Rock materials and karst water specially in high mountains or karstic high lands of west of Zagros (shahu , Sirwan River basin and Ravansar high lands) have created unique dry wall stones and rock architectural landscapes. The notion of Geopark tourism is a kind of tourism which emphasize on the features of geopark of a tourist site. The features are related to the human, historical and cultural factors of the local community. The valuable geological features and geoheritage of the geopark is under direct threat from pastoralists and nomadic societies which have been established in the karst terrains where water and grass are abundant to be used and grazed. Establishing Awraman karstic geopark is a plausible and a suitable idea to protect and conserve this unique karst and its related socio-cultural, environmental, geomorphological phenomena. In another word, visitors to the Awraman geopark can appreciate the scientific, aesthetic, historical and cultural elements of the geopark which has been evolved during the last 5000 years dating back to the cretaceous-pleistocene karst evolution era. This paper attempts to present Awraman‟s karst attractions as tourist potentials and proposes to establish the Awraman geopark. Education and sustainable tourism policy are necessary for the protection and conservation of cave and karst landscape and related geo-cultural heritages in this region.

Keywords: Geopark, karst protection,geoheritages ,Zagros, Shahu,Awraman

KURDISH KARST LITERATURE AND RESOURCE USE IN THE AWRAMANAT KARST LANDS OF WESTERN ZAGROS, IRAN

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Abstract
The Awraman karst lands is a high-plateau karst which is situated in the Western Zagros, west of Iran, on the border of Iraqi Kurdistan. The karst region consists of approximately 900 square kilometers of carbonate rocks including all of the karstic phenomena such as doline, ouvalla, ponor ect. the indigenous karst resources such as rock, water, vegetation ect are employed by traditional human settlements and rural ecosystems to produce many cultural and archaeological artifacts . The traditional occupations of the people in this area have been influenced by the bio-geo-diversity of the region and the influence of the late Pleistocene era continues to the present day). This makes the region very rich in archaeological remains which is a timeline record of occupational history dating back to Middle Paleolithic time. In more recent times, Kurdish herders and nomads seasonally moved between valley floors to the top of the Karstic plateau in search of pastures and other resources. Long time human settlement of this rugged mountainous region allowed Kurdish people to adapt their material culture to the region‟s resources. This is, for instance, expressed in their simple architecture and buildings made from dry stone walls, their clothing, as well as other cultural behavior. More fascinating is the is Kurdish karst literature which provides an attractive prospect of this region suchTerms such as Kawreg or Ashkawt, Noor, Ma, Kani, Bele, Khemkhora which are applied as cave, sinkhole, karstic cliff, karst spring, small karst spring and ponor respectively are used in Awraman karst lands. The aim of this paper is to explain and document Awraman's karst literature and geoheritage and to propose a protection plan for its conservation.

Keywords: Karst resources, kurdistan, Kermanshah, awramanat, zagros, karst literature

LOCAL KNOWLEDGE OF GEOHERITAGE VALUES OF DONG VAN KARST PLATEAU GLOBAL GEOPARK - SOME FIRST FINDINGS

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Abstract
Dong Van Karst Plateau (DVKP), which covers an entire area of 2356km^2 of the 4 districts: Quan Ba, Yen Minh, Dong Van and Meo Vac of Hà Giang Province, has for long been well known as a remote, rugged, dangerous and poor mountainous area. It is, however, also famous for its long-lived local knowledge on all kinds of heritage, including geoheritage values. Thanks to the work of generations of international and national scientists, many more heritage values, especially geoheritage ones, have been discovered, studies and assessed. This contributes to the recent set up of a geopark - the optimal way for the rational use of natural resources, environmental protection, nature conservation, poverty reduction and hunger eradication in the area. Many geoheritage concentrations in DVKP geopark appear to be echoed by many other types of natural and cultural heritage. They are either "sensed intuitively" or interpreted by local people in their own way, in the form of myths, legends, fairy tales etc. Such geoheritage concentrations are abound in DVKP geopark, just to name for example, Quan Ba valley, Lung Cu Flag, Ma Pi Leng Pass and Nho Que Canyon, Khau Vai-Lung Pu Love Fair, Sa Phin-Lung Tao with Vuong Family"s Castle and Dong Van Ancient Town etc. Interpreting such "local knowledge" scientifically and using it to convey scientific interpretation of heritage values is probably the best way to raise awareness of local people and tourists, and in so doing, to develop the geopark.

Keywords: Local knowledge, Rocky Culture, Cutural heritage, Intangible Geopark, Ethnic groups

Introdution
In general, natural conditions and heritages create the basis, on which human cultural values can be developed. "*As the tree, so is the fruit*": in the ancient time, to struggle for survival, people from different regions of the globe kept learning how to adapt themselves to the surroundings. In order to win in this struggle, people needed to study the environment. Meanwhile, there was a need to explain all objects and natural phenomena happening around them. However, ancient people with their limited range of perception were not able to explain the nature of the phenomena, which is why they fabricated legends, fairy tales, and so on.

The story about geoparks told us the same. Inhabitants in the geoparks" areas, which were characterized by exceptional natural conditions, had to find the way to adapt themselves to the environment. Then, being surprised by unique features of the geoheritages, they explained spontaneously the formation of those geoheritages to satisfy their longing of discovering the surroundings, from which, a treasure of plentiful cultural heritages in the multi-geoheritage areas were produced. From this, we can also explain the origin of the proverb: "sacred land, prominent men" and "non-physical geoparks", which were mentioned by A.Katerina and F. Charalampos (2010). In fact, that is local knowledge of geoheritages of inhabitants in geoparks.

Content
I. Local Knowledge Of Geoheritage Values Of Dong Van Karst Plateau Global Geopark – Initial Findings

At the 9th European Geopark Conference held in Lesvos, Greece on October, 2010, Dong Van Karst Plateau Geopark was recognized as an official member of the Global Geopark Network (GGN). This success was achieved by great efforts of local authorities in cooperation with Vietnam and Belgium scientists during those years.

Up to now, around 139 geoheritages have been established in Dong Van Karst Plateau (DVKP) Global Geopark in accordance with the local, national and international levels. They

all have been presented in the Scientific Dossier of DVKP Geopark, which was submited to UNESCO on the November, 2009 and has been being highly appreciated.
However, besides the geo-values of the heritages, this region is characterized by plentiful non-geological values in terms of biodiversity, archaeology, history and culture. Natural landscapes and cultural treasures of 17 local ethnic minorities can attract anyone who comes here. The optimal choice to preserve and exploit the overall values of heritages in this area is to investigate and define the natural and cultural heritages (including local knowledge of geoheritages) and make this area into a geopark.

What is “local knowledge of geoheritage”? That is the local treasure of knowledge and living skills that are related to means of production, military arts, local rules and beliefs, folklores of the community. They are also related to natural conditions and features of geoheritages. Local knowledge of geoheritage includes intellectual and cultural treasures which reflect the perception of the community about their surroundings. This awareness results in high adaptation and harmonization between the human beings and the nature. It also explains the human‟s desire to discover their surroundings, including geoheritages.

Here are some typical examples of local knowledge of geological heritage in Dong Van Karst Plateau:

- The legend about the origin of the Fairy Bosom Mountain and some geoheritages in Tam Son Valley:

Fairy Bosom Mountain is a tectonic – morphological heritage, and is a famous scenic spot locating at the gateway of the Dong Van Karst Plateau Geopark. The ancient people have probably ever seen and been enthralled by the scenic beauty of the mountain, so they have created many legend versions to explain the origin of the Fairy Bosom Mountain and many other geoheritages in the region. The legends are long, lyrical, compelling and humanitarian, showing almost instinctive desire to explore the origin of many beautiful and unique geological heritages. However, in any version of ancient human remains which they ended by giving an explanation for the origin of geological heritages, such as Fairy Bosom, Tam Son Mount clusters, The Gigantic Man‟s Shoulder Pole Mountain Range, 9 lakes karst system, etc., that today in the light of the Earth sciences, they have been explained clearly. Although these geological heritages have been scientifically explained, the legendary treasure of folklore keep all its values. That is the local knowledge of the geological heritage of the local community, which has existed for thousands of years. They should be respected and preserved. The significance will be mentioned in Section III.

Fig.1. Tam Son Mount clusters and The Gigantic Man‟s Shoulder Pole Mountain Range in Quan Ba.

Fig.2. Fairy Bosom Mountains in Tam Son Valley – the origin of many lyrical legends.

- Lung Cu area:

Lung Cu area is very rich in such geoheritage types as paleontology, stratigraphy, tectonics, geomorphology and karst caves. This area also has many non-geological heritages, including archaeological value of the bronze drum of Lo Lo ethnic group, historical value of the Lung Cu Flag Tower and the folklore treasure of the residents.Every place of the region is closely related to attractive legends such as the legend of Dragon Mountain, the Dragon Eyes, which actually are two ancient karst sinkholes that have been sealed at the bottom with clay that makes the lake run out of water etc. Then numerous legends about dragons hiding in the spacious water in the heart of the limestone mountain etc. We all know that these limestone areas are constantly scarce in water because rain water runs very fast on the ground-surface and then quickly escapes to the fissures and caves system underneath. On the Dong Van Plateau, water scarcity is particularly severe in Dong Van and Meo Vac districts. Is there any likelihood that the desire for water redundancy and the metaphysical sense capability helped the ancient people imagine a "sea" inside the vast limestone? We can say without exaggeration that the ancient people had supernatural “knowledge of hydrogeology", because as we all know today, although surface water in the limestone areas is scarce, the underground water in the cave is sufficient. It is also true even for Lung Cu region – the birthplace of legends. Currently, Vietnam Institute of Geosciences and Mineral Resources is working with the German experts to develop a technology that has the capacity to exploit underground water. The method is to use the energy of the water flow in the cave to pump water that will serve the community life in the Dong Van Plateau Geopark. It is clear that the "local knowledge on geological heritage" of the residents is remarkable!

Fig.3. Dragon Eyes - actually two ancient karst sinkholes have been sealed at the bottom with clay.

- Ma Pi Leng Pass - a place of highly metaphor about geoheritage‟s characteristics:

Ma Pi Leng mountain pass is a place of plentiful highest ranked geo-heritages of Dong Van Karst Plateau. Among those, Tu San abyss is 700-800 m deep and 1.7km long, cliff slope is 70-90^0. It is considered the most gigantic attraction on Karst Plateau, the deepest abyss of Vietnam and perhaps also of Asia South East area. This geomorphology techtonic heritage was named "De Nhat Hung Quan" (which means "first rank gigantic wonder") and was ranked as an international heritage by scientists. However, in this article, the authors would like to introduce only the highly metaphorical place, "Ma Pi Leng" moutain pass. The name "Ma Pi Leng" has existed for a very long time, and this Pass has been a well-known toponym on the Karst Plateau since earlier than the time these geo-heritages were established. Before the road "Hanh Phuc" (Happy) was opened passing here, this area is extremely steep and sheer, looking down to the abyss of Nho Que river below. The name "Ma Pi Leng" is explained by the local people in many ways: first, it is "hold the horse‟s tail", which means that everyone has to hold the horse‟s tail to get by this pass because the pass is so steep and dangerous; second, it is "horse nose covered by white snow", because it is high and cold there, and the steam from the breaths of the horse is frozen immediately on their nose; third, it is "cold wind on horse nose" with the similar explanation; fourth, it is "Horse killing pass", because the topography is so dangerous and tottery, when horses climb over here, they may be exhausted and plummet into the abyss and die; fifth, and extremely impressive "Mau Pi Leng", in dialect of H„mong, which means the emotion of a rat lying in the mouth of a cat. Overall, all of these explanations describe the extreme fear of people who have to pass this pass.

Fig.4. Some geoheritages in Ma Pi Leng Pass - Tu San Canyon: one highly metaphorical toponym of geoheritage"s characteristics in Dong Van Karst Plateau Global Geopark.

- The Vuong Family's Castle:

The Vuong Family's Castle, which locates in Sa Phin, Dong Van district, was ranked among national historic-artistic and architectural heritages in 1993 by Ministry of Culture, Sports and Tourism of Vietnam. Its beauty and value can be compared to "an emerald within the Karst Plateau". However, in geo-heritage aspect, the Castle is the intersection point of northeast - southwest and northwest - southeast fault systems and it is also a karst sinkhole. At the heart of the valley, there is a rising hill in tortoise shell shape, which actually is a mount remained after the fault of the valley and the formation of the giant karst sinkhole. In front of the castle, there is a couple of mountains, which symbolizes wealth and power. The back of the castle leans against an arc mountain range, which is said to be a "favourable position" according to "feng shui". This reflects knowledge of the local people in terms of choosing land for Home of the King of the Karst Plateau.

Fig.5. Cultural heritage: The Vuong Family's Castle was build on the hill in tortoise shell shape in Sa Phin giant karst sinkhole.

2. The Role Of Researching On The Local Knowledge On Geoheritage For Developing Dong Van Karst Plateau Global Geopark

Local knowledge on geoheritage is part of the natural and cultural heritages of the Dong Van Karst Plateau. A place which contains geological heritages is also the cradle of natural and cultural heritages that contain values of biodiversity, archaeology, history, culture, society and so on. Currently, although it has been recognized as an official member of the Global Geo-parks Network - GGN, the Dong Van Karst Plateau Geopark has still not satisfied all criteria stipulated by the GGN, including raising public awareness of geological heritage and geopark. The research, preservation and exploitation of local knowledge treasure of geo-heritage will help to solve the above mentioned shortcomings.

In fact, an extremely rich treasure of "local knowledge" of 17 local ethnic groups had existed in DVKP before the geologists set foot on this place to discover, interpret, assess and rank local geological heritages according to the scientific criteria. Even without any notion of the so-called "geological heritage", local inhabitants felt the "spiritual air" of heaven and earth by their own ways. Then they started to gather in the areas of geological heritages, and created plenty of cultural values. Surprisingly, their presence did not harm the Nature in such a way that "civilized human being" is doing, but contributed actively to preserving the natural heritage values. Therefore, the preservation and promotion of the overall value of all types of natural and cultural heritages, including "local knowledge on geoheritage on DVKP, was chosen to develop a geopark.

Conclusions

1. Besides the decisive values of geoheritage and biodiversity, Dong Van Karst Plateau owns a big local knowledge treasure of 17 ethnic groups;
2. Generally, local knowledge of the ethnic groups in Dong Van Karst Plateau Geopark has been controlled by natural features as well as geoheritages;
3. The local knowledge expresses the awareness of the community on geoheritages in terms of living skills and legends that explain the origin of geoheritages;
4. The abundant treasure of local knowledge is the product of the close relationship, adaptation, and integration between people and nature;
5. *"Scientific knowledge"* is usually accurate but always difficult to understand, meanwhile local knowledge is very vivid, poetic, and easy to learn;
6. Establishing a Geopark is the NEW and OPTIMAL way to effectively exploit natural resources and development sustainably, which contributes to the conservation of all kinds of heritages and the environment. In order to succesfully convey the knowledge to people, we need to use "scientific knowledge" to explain "local knowledge", and use "local knowledge" to convey *"Scientific knowledge" to the community as well as every tourist. That is the best way to conserve* all kinds of heritages and complete the 3 goals of Geopark in Dong Van Karst Plateau.

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NATURAL AND ANTHROPOGENIC HAZARDS IN THE KARST OF BOHOL, THE PHILIPPINES

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Abstract
About 40% of the island of Bohol is karst landscape, and karstic hazards affect much of this area, which contains about 75% of the population of 1.1 million. The inland karst consists of broad, alluviated valleys or poljes punctuated by isolated residuals (mogotes) and separated by uplands which are dissected by underdrained and abandoned dry valley systems, themselves dismembered by polygonal enclosed depressions (cockpits) and bordered by sinuous residual interfluvial ridges, which adjacent to the enclosed depressions have been reduced to isolated or connected residual hills. With population and urbanization increasing, and as infrastructure is developed, karstic hazards are becoming more prevalent and risks are increasing. One major natural hazard is seasonal drought, which disrupts water supplies, particularly in upland areas where groundwater resources are poorly developed and residents depend on rainwater and springs. Conversely, seasonal flooding, particularly that associated with tropical storms and extreme events, causes property damage and human death, injury and displacement in the valleys. Ground surface subsidence and collapse threatens developing infrastructure, dwellings and livestock, but the potential for catastrophic karstic failure appears to be limited. Slope failure also occurs, but is not often recognized as a hazard and has not been studied in detail. Human impacts include quarrying, groundwater abstraction, groundwater contamination, urbanization, agricultural development and tourism. Less than ten percent of the karst area is within protected areas and the karst is the setting for contemporary civil strife.

Keywords: Bohol, karst, hazards, drought, flooding, human impact.

Introduction

Approximately 40% or 2000 km^2 of the Philippine island province of Bohol is karst landscape. Approximately 75% of the province"s 1.1 million people reside in the karst and therefore karstic hazards pose a considerable and ever increasing risk. The inland karst is variable in nature, but includes broad, alluviated valleys or poljes punctuated by isolated residuals (mogotes) and separated by uplands which are dissected by underdrained and abandoned dry valley systems, themselves dismembered by polygonal enclosed depressions (cockpits) and bordered by sinuous residual interfluvial ridges, which adjacent to the enclosed depressions have been reduced to isolated or connected residual hills. With population growing at 2.95 percent per year in the period 1995 to 2000 and urbanization increasing, and as infrastructure is developed, karstic hazards are becoming more prevalent and risks are increasing.

The Bohol Karst

Bohol is a roughly circular island, centrally located in the Visayan island group of the Philippine archipelago. Covering nearly 5000 km^2, the island consists of two approximately equal sized components divided between the north and the south. The north consists mainly of gently rolling fluvial topography, flanked to the east by a range of higher hills, and in the west by more heavily dissected terrain. The south consists of two areas of about equal extent in the east and west. In the former, a narrow coastal plain borders a series of east to west trending limestone mountain ranges. In contrast, the southwest consists of wider coastal plains flanking an extensive karstified plateau-like interior.

The Bohol karst is part of the Philippine Mobile Belt, which extends from northern Luzon to southern Mindanao and represents tectonic blocks accreted to a volcanic arc terrane associated with the Philippine-Eurasian Plate boundary (Day and Urich 2000). The Cretaceous basement complex contains limestones and marbles; the extensive Tertiary limestones which give rise to the karst represent part of an intravolcanic arc or forearc basinal depositional sequence, with discontinuous karst landscapes developed on the highly variable carbonates. Throughout the region, most of the presently nonactive islands and atolls are blanketed by Quaternary reef limestones.

Pliocene-aged limestone underlies most of the coast and interior of southwestern Bohol. Raised shore platforms and marine terraces characterise the shore and near-shore environments (Sison, 1954; Hillmer and Voss, 1987), and the interior is a dissected karst plateau ranging from 100 to approximately 600 metres above sea level. Two topographic elements dominate the plateau. First are three broad, alluviated valleys or poljes trending northeast to southwest and punctuated by isolated limestone residuals (mogotes) from 10 to 80 metres in height (Voss, 1970). These three main valleys are separated by distinctive blocks of dissected and karstified limestone anticlinal uplands rising up to several hundred metres above the surrounding plains. The limestone uplands are themselves dissected by remnants of now underdrained and abandoned dry valley systems, which are themselves dismembered by polygonal enclosed depressions (cockpits) developed by surface dissolution. The valley remnants are bordered by sinuous residual interfluvial ridges, which adjacent to the enclosed depressions have been reduced to isolated or connected residual hills. These conical karst hills, which are aptly called Chocolate Hills for their dry season appearance, are the most widely-known features of the karst landscape. The limestone surface is pitted by dissolution and is extremely rough where soil cover is minimal. Surface water is rare except during and after heavy rainfall (Quiazon 1979). There are abandoned vadose caves close to the surface beneath the uplands, many with entrances via collapsed pits, with more extensive and active cave systems at greater depth (Day *et al.,* 1989; Reeder *et al.,* 1989; Urich, 1996b; Naraglav, 1997).

The limestone itself is highly variable in lithology, structure, hardness and permeability. In particular, resistant lenses of less permeable limestones, conglomerates and sandstones influence groundwater hydrology and the local agro-ecozones (Urich, 1990a,b, 1996a,b), and complex contacts between the anticlinal uplands and the lowlands, plus impurities within each lithological unit further complicate the geomorphology and hydrological situation (Day, 1982). Broadly, the karstified anticlines are areas of recharge, whereas the valleys are areas of discharge. The water-table below the uplands is at depth (>30 metres) whereas in the valleys the level of saturation is close to the ground surface. Water is discharged from the uplands via valley edge springs, and smaller springs debouch from the peripheries of the residual hills within the valleys.

Rainfall is extremely variable across southern Bohol. Coastal areas generally receive between 1500 and 1800 mm per annum, and elevations between 100 and 300m receive between 1800 and 2200 mm per year, while at 300 to 600m annual rainfall may total 3500 mm depending on exposure to the southwest and northeast monsoons. Rainfall is highly seasonal, with a markedly drier season from March to June, followed by a slightly wetter period until August, which is marginally drier. Peak rainfall occurs between September and February. Longer-term and cyclical variations in climate result in periodic droughts, often associated with approximately decadal El Niño events.

Ecologically, the interaction between the wet lowland valleys and the dissected karst uplands is critical (Urich and Reeder, 1999). Differentiation between the soils of the lowlands and those of the uplands becomes particularly important during periods of drought, when the upland soils maintain higher moisture levels and are increasingly exploited. The distribution of water resources also limits most wet rice production on the island to areas above two hundred metres in elevation and several kilometres from the coastal plain. Much of the agricultural and associated history of Bohol has, for this reason, been focused on the interior karst of the island"s southwest (Urich, 1996a, 1997), and approximately 75% of Bohol"s 1.2 million people live in the southern half of the island.

Natural Hazards in the Karst

Beyond the overall roughness of much of the upland limestone terrain, which makes access and construction challenging in general, one major problem remains that of drought and water supply within the karst, particularly in rural areas where groundwater utilization is limited by finances and logistics and there is still considerable dependence on rainwater and springs. The perennial problem of the paucity of surface drainage assumes even greater seasonal dimensions throughout Bohol because rainfall itself is sparse and/or temporally unreliable. Short-term dry season drought, such as extended through June in 1988, is a recurrent problem in the Bohol karst, but more intense droughts may extend over longer periods and become severe, such as during the El Nino events of 1998, 2002 and 2004-05 (Urich *et al.,* 2006). El Nino-induced droughts affect the karst severely, leading to crop and livestock losses, economic losses, bush fires, and emergency distribution of water supplies. Agricultural economic costs of recent El Nino droughts have been estimated at P120m (1998, 12 months), P443m (2002, 8 months) and P61m (2004-05, 6 months), with the last figure reflecting improved preparation by Bohol"s El Nino Task Force (Urich *et al.,* 2006).

Although considerable progress has been made throughout the Bohol karst in the provision of reliable urban water supplies via wells and pumps, much of the rural water supply still relies in large part upon collection of rainwater in tanks from roofs and gutters. These collection systems, although simple and environmentally-friendly, have their limitations. Storage capacity is limited, and supply is unreliable, being characterized by periods of deficit or surplus. Storage may be further compromised by evaporation and leakage, or by accidental contamination, and the water may be deficient in minerals such as calcium which would otherwise be dissolved during percolation.

Springs remain the other important source of rural water supply, particularly around the periphery of the uplands and around individual mogotes. Major perennial springs, such as Ujan Spring in Cortes (daily capacity of 3500m^3), are the most reliable, but other communities also utilize seasonal and ephemeral springs when discharge is adequate.

Karst springs play a critical role in Boholano rice or individuals to bring in water by trucks from non-karst areas or from remaining sources within the karst itself. Such drought conditions have a secondary impact in the form of increased probability of bush fires, resulting from either natural or anthropogenic causes.

Conversely, and perversely, flooding poses a greater hazard than drought and has more serious short-term consequences, including human death, injury and displacement, and damage to homes and other structures. Flooding of the karst landscape is an integral component of the natural karst hydrology, and is to be expected on a seasonal or intermittent basis, although it does not occur everywhere throughout the karst landscape and it remains problematic to predict. Flooding in the karst has been documented throughout the history of its study, dating back to the nineteenth century, and flooding of the Loboc River has culminated in disastrous floods dating back to at least 1876. Twentieth century studies regularly note temporary flooding of the poljes, with upwelling via estavelles – basal sinks which later act as drains for the floodwaters (Urich, 1990a 1996a). Previously this caused only minor disruption disruption in sparsely settled areas, but this hazard is now accentuated by increasing population and settlement within the karst (Urich, 1990a, 1996ac).

Flooding within the karst occurs through a number of distinct, but often complementary mechanisms, and affects only certain parts of the karst landscape. First, heavy and/or prolonged rainfall, such as that associated with tropical storms, especially typhoons, may produce significant overland flow when surface and epikarstic infiltration capacities are exceeded. This is rare on exposed limestone surfaces where flowpaths are generally short and drainage sinks rapidly into open fissures, but it does occur occasionally. Such surface flow is more common where the surface is mantled by regolith or alluvium, and is often indicated by rills or gullies. Surface flooding of this nature poses potentially greater hazards, particularly where natural drainage paths are provided by normally dry valleys.

Second, flooding of the karst may occur where rivers carrying increased allogenic drainage from adjacent non-karst terrain exceed the intake ability of the karst drainage system and overflow their channels. This is particularly likely along the non-karst borders of the poljes, where such occurrences are sufficiently frequent as to be predictable on a broadly seasonal basis. Poljes, whose flat surfaces are essentially a product of alluviation during such overbank floods, also flood more locally and unpredictably via dispersed estavelles.

Third, local flooding within the karst may result from filling and overtopping of the epikarstic reservoir, which lies close to the surface within the upper portion of the vadose zone. Such flooding is unpredictable and uncommon, but is usually localized and temporary. Fourth, flooding on a broader scale may result from elevation of groundwater levels and upwelling of groundwater via estavelles. This again occurs on a more-or-less predictable seasonal basis in the poljes and other larger, low-lying depressions. It is this regional groundwater upwelling that represents the most serious flooding hazard, particularly in more densely populated, low lying areas. Increased groundwater levels and volumes may also lead to increased spring output, which may in turn lead to stream flooding on the downstream sides of the karst. Finally, normally dry valley systems within the karst may become activated after prolonged or heavy rainfall, through a combination of groundwater elevation, epikarstic overflow, increased spring output and/or allogenic inputs.

In recent decades, serious floods in the Bohol karst have occurred in March and August through December 1982, February and September 1984, July 1987, June 1999 and December 2003. The 1999 floods claimed four victims, and damage was estimated at P7m. Flooding associated with typhoons in 1996, 2002 and 2003 resulted in 14 deaths and caused damage estimated at over P22m. Predisposing geomorphic conditions include the following:

1) The poljes are large, synclinal, locally fault-bounded depressions, floored by alluvium or terra rossa clays.
2) At shallow depth, less permeable limestone deflects water laterally into the poljes.
3) Within the limestones there is locally low sinkhole density and restricted water transmissivity.
4) Sinkholes are blocked by sediment.

Early ideas about the development of tropical karst stressed the role of surface collapse, but more recent studies suggest that this is of only secondary significance, with epikarstic dissolution being the primary formative mechanism. This notwithstanding, occasional surface collapse and subsidence does occur within the karst, although it has yet to cause more than minor localized damage and inconvenience. Subsurface dissolution, cavity formation, surface subsidence and collapse represent major hazards in many karstlands (Waltham et al. 2005), but Bohol has not yet suffered their effects as catastrophically as elsewhere.

Despite these relatively low probabilities, both ground surface collapse and subsidence represent an increasing threat to developing infrastructure, such as highways and public service facilities, plus a minor hazard to rural dwellings and livestock. Minor cavitation problems have recently been encountered during construction as part of the P1.856 billion Bohol Circumferential Road Improvement Project (BCRIP).

Slope failure also poses a hazard to buildings, roads and other structures, although one that is greatly underestimated. Although karst slopes are often considered to be stable, localized failure does occur, particularly along weathered planes of weakness, such as joints, and through shifting of talus. Karst bedrock failure may occur as slab failure, rock collapse or rockfall, the precise mechanism depending essentially on the configuration of the planes of weakness and the internal structure of the rock itself (Day, 1978). Slab failure is uncommon, but does occur in locally more crystalline beds where near vertical joints are undercut, for example by fluvial erosion of tower bases within poljes. Most of the Bohol limestones are rubbly and internally variable, and here rock collapse and individual rockfall are the principal failure mechanisms. Locally, talus, which is potentially unstable, particularly when disturbed, represents a potential threat to construction projects. More significantly, major collapses, such as that near Jagna in 2005, threaten individuals and infrastructure. The Jagna event involved failure of approximately 1.5m m^3 of limestone, covering an area of 70 hectares, with daily rates of movement in excess of 23 meters. The soil and rock extended 1.75 km from the ridgetop. The landslide ruptured the main highway, approximately 70 houses were destroyed, and almost 600 individuals from 160 families were displaced. The monetary cost of the landslide in terms of lost houses, crops and other infrastructure has been estimated at P15,849,500 (US$1 = P 55). P1,132,684 was provided in terms of government assistance (Republic of the Philippines, 2005).

Anthropogenic Hazards in The Karst

As throughout Southeast Asia, human impact on the Bohol karst has been long-term and is increasing, particularly via increased groundwater abstraction, urbanization, agricultural development and quarrying (Restificar *et al.,* 2006; Urich, 1989, 1993, 1996c). Human impacts on the karst may be schematized by reference to a broad impact-process-consequence model involving human activity, geomorphic process change and landscape response, and problems for human occupancy and activity. This can be illustrated by reference to the Bohol karst hydrology. Through time, human activities have increasingly disturbed this system through forest clearance, soil utilization, groundwater abstraction, and modification of surface drainage courses. This disturbance has resulted in process changes such as increased runoff, decreased infiltration, increased surface sediment transport, and decreased spring discharge. In turn, this has impacted the human population through increased flood susceptibility, desiccation of springs, accelerated soil erosion, and surface subsidence (Urich, 1990a, 1996c).

Forest clearance and agriculture have had a profound effect on Bohol"s karst landscape. By the 1990s, about 75% of the Bohol karst was utilized for some form of agriculture, mainly rice cultivation in the lowlands and grazing on the uplands, and these activities are increasing rapidly, with increasing decline of traditional agricultural systems and increased outside investment in crops such as oil palm (Urich, 1996a). Sediment eroded from agricultural lands frequently has blocked sinkholes and other karst drainage features. Flooding in the karst may be exacerbated by human activities, such as infilling of sinks and depressions. Seasonal drought results in serious localized agricultural losses and increased fire hazard.

Limestone quarrying has also had pronounced impacts on the Bohol karstlands, although the exact extent of this is difficult to quantify. Nationally, the production of limestone for cement manufacture and construction uses dominates the Philippines industrial minerals sector (Lyday, 2000). National limestone reserves total about 4b tonnes. Nationally, the annual production of limestone, excluding that for road construction, averaged about 22m tonnes in 1998-2002 and annual crushed stone production for the same period averaged 2.3m m^3 (Lyday 2002). For 1998-2002, annual cement production was nearly 11m tonnes and annual lime production was about 5000 tonnes (Lyday, 2002). According to the Mines Bureau, as reported by George *et al.* (1999), national agricultural limestone production was 6860, 2612, 4346, and 3206 tonnes during the years 1995 to 1998. Such production is negligible compared to the estimated reserves, and to production for non-agricultural purposes, and the average producers" price of agricultural limestone is about twice as much as for industrial limestone, P243 vs. P123 t^{-1} (George *et al.,* 1999).

Limestone quarrying for roadbed and general construction has had an impact both locally and nationally, but the most significant quarrying, that for cement production, has been minimal in Bohol itself. The main quarry is the 640 hectare Bohol Limestone Corporation mine at Garcia-Hernandez, from which limestone is exported to Taiwan. There are numerous smaller operations, many of which are poorly documented or monitored. In 2006, illegal limestone extraction was discovered in barangay Montesuerte, Carmen town (Bohol Chronicle, 2006). There is also a limited amount of small-scale mining of bat guano from caves, although less than in previous centuries.

Ground and surface water contamination is also an increasing hazard, particularly where domestic effluents and urban runoff enter underground drainage systems via point recharge. Groundwater contamination occurs sporadically throughout the Bohol karst where urban and other effluents enter the underground flow system, but there has been no comprehensive monitoring of this problem. For example, a major diarrhea outbreak occurred in the coastal municipality of Loon in Southwest Bohol in December 2006. Forty-four of the town"s 67 villages were affected. Thousands were infected and twelve people died. The outbreak was linked to heavy rains and the contamination of the water supply with *Shiegella flexneri* bacteria (Office of the Mayor, Municipality of Loon, 2007).

Other, less recognized and less documented anthropogenic hazards also characterize the Bohol karst. Although substantial improvements in the road network have been made since the 1990s, roads within the karst remain relatively few and many of those are in poor condition (Granert *et al.,* 2004). The first phase of the P1.856 billion Bohol Circumferential Road Improvement Project (BCRIP), extending 124.4 km beween Calape, Buenavista, Talibon and Candijay was completed in 2002. The second phase, covering 136.02 km, is now under construction. Traffic accident rates in Bohol are generally high, and roads through the karst are no exception.

The Bohol karst also has a long history of military conflict, which continues to this day (Day and Urich, 2007). During 1744-1829, the Boholano resistance pitted technologically and numerically superior Spanish colonial forces against native guerrilla fighters under the leadership of Francisco Dagohoy in the classic tropical karst of Bohol"s Chocolate Hills and environs. In this complex landscape of conical hills, narrow valleys and sinkholes, Spanish efforts to engage and subdue their antagonists were largely unsuccessful, while they suffered mounting casualties from guerrilla attacks. Following numerous efforts to dislodge the partisans, the Spanish adopted a strategy of containment and negotiation, terminating with a futile military assault in 1828-29.

A similar situation prevailed during 1942-1945, when the Boholano resistance cooperated with US forces against Japanese invasion. The strategic position of the island within the wider island group was critical to the monitoring of marine vessels, while the karst uplands provided excellent conditions for broadcasting clandestine radio reports of Japanese movements to other resistance forces. The symmetrical alignment of the Chocolate Hills was exploited by American pilots navigating bombing runs over Cebu City during the Allied liberation of the islands.

Since the 1980s, militias of the New People"s Army (NPA) have also made extensive use of the Bohol karst for military purposes, establishing temporary bases, harassing Philippine armed forces and conducting raids in surrounding urban centres. The karst terrain has been an essential element in much of the rebellion and, until very recently, the command for all guerrilla forces in the Central Visayas was situated in the karst terrain of Central Bohol.
Rebel activity continues to this day across the interior karst of Bohol, although government and non-governmental response has, over time, become much more coordinated and effective in reducing the level of rural poverty which has been at the root of much of the civil unrest. Rural development projects, such as rural electrification, small water impounding projects for irrigation and reforestation programs, were initiated in the karst after pacification, but many of these projects have proved to be poorly conceived and of limited effect. In fact, over time the nature of some projects, including the designation of large areas of karst lands across the interior as protected areas, have become rallying points for the continuing rebel movement (Urich *et al.,* 2001).

Discussion and Conclusions

A wide range of natural hazards exists within the Bohol karst, potentially affecting 40% of the land area and 75% of the human population. Although much of the karst area is currently rural, urbanization and other development is increasing rapidly, with the increasing probability of karst hazards having greater impacts both socially and economically. Seasonal drought and the provision of reliable water supply remain problematic and are becoming more so as domestic, agricultural and industrial demands increase. Periodic flooding has a long history of causing property damage and human death, injury and displacement, and new development in the karst needs to be acutely aware of vulnerable locations and situations. Ground surface subsidence and collapse also increasingly threaten developing infrastructure, but the potential for catastrophic karstic failure can be reduced considerably by appropriate site investigation and engineering practices (Waltham *et al.,* 2005). Slope failure is not often recognized as a hazard in the karst and warrants further investigation.

Human impacts on the karst presently include groundwater abstraction and contamination, urbanization, agricultural development and quarrying. All of these are increasing in scope and impact, and there is a real need for a comprehensive assessment of these activities, their consequences and their future sustainability. Failing this, anthropogenic hazards can only continue to increase exponentially.

The karstlands are also increasingly involved in ecotourism activities, and the Chocolate Hills are the most famous tourist destination in Bohol. Nevertheless less than ten percent of the Bohol karst area is afforded recognition in protected areas (Day and Urich 2000; Restificar *et al.,* 2006). Cave and karst conservation throughout the Philippines is in the early stages of organization (Day and Urich 2000; Restificar et al. 2006), with 29% of the karst under some form of protected area designation but only a handful of caves and karst sites afforded any meaningful protection. Illegal logging, farming, hunting and trapping for the pet trade remain local problems.

In Bohol, karst is protected in the Chocolate Hills National Monument, which covers an area of about 1,776 hectares and was inscribed as a National Geologic Monument in 1988 by NCGS, and as a protected area under the National Integrated Protected Areas Act (NIPAS) in 1997. The Rajah Sikatuna National Park is one of the most recent additions to the Philippines' list of protected karst areas, established in 1987 with an area of 9,023 hectares (Urich & Bliss, 1992; Granert *et al.,* 2004). In 2000, the area was de-listed as a National Park and was designated a Protected Landscape instead. This change was made because the large number of people resident within its boundaries prevented the area meeting the criteria of a National Park. The area of the Rajah Sikatuna Protected Landscape is currently about 10, 452 hectares.

To date, stakeholder reaction to natural and anthropogenic hazards within the karst has been mixed. International attitudes to hazard mitigation and landscape conservation, particularly those of NGOs, have been generally positive. Likewise, national NGOs, such as the Soil and Water Conservation Foundation, have been supportive of hazard awareness and reduction. Local residents are most directly affected, but their attitudes are sometimes ambivalent. Some people recognize the hazards and seek to avoid or minimize them either individually or through broader societal action, but others are unaware or unable to do so, and others may actually benefit in various ways from the hazardous conditions and activities. Similarly, business and industrial concerns may benefit economically from activities which cause hazards, but they also incur losses when hazards disrupt facilities or productivity, so they too need to be informed and aware. Boholano society as a whole stands to benefit from sustainable and rational development within the karst. However, the risks need to be understood and assessed as part of a comprehensive management strategy similar to that instituted in the Rajah Sikatuna area by the Soil and Water Conservation Foundation (Granert et al. 2004). "Bohol's 500-year history of sustained karstland occupation is seriously threatened today by the pressures of population, inappropriate application of agricultural technologies, and civil strife" (Urich, 1993).

In this context, government agencies have sent mixed messages, some supportive of hazard reduction and karst conservation, others aligned with developments which underestimate hazards or increase them. Overall, however, the Philippine government appears to be gradually recognizing explicitly the need to protect karst landscapes. The establishment of the National Caves and Cave Resources Management and Protection Act in 2001 and the inclusion of karst water resources in the country"s National Action Plan (NAP) under the United Nations Convention to Combat Desertification (UNCCD) are significant steps towards explicit protection of karst areas (Restificar *et al.,* 2006). Ultimately, the Bohol karstlands require their own comprehensive management plan, the formulation and implementation of which is becoming ever more urgent.

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THE MANAGEMENT OF KARST AREAS IN INDONESIA

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Abstract

Karst areas have specific and unique ecosystem both physical aspect (natural landscape, geology, hydrology) and biotic aspect (flora and fauna). Natural landscape in the form of conical hill, tower, drainage valley (dolin), caves system and underground river which have potency as water resources, and various properties of flora, fauna and also properties of past culture. Its makes karst areas have important to human life. However, on the other side, karst areas have much of natural resources, especially mining materials (mineral resources). Many of mining activities in various karst areas in Indonesia have caused karst areas damaged. Management of karst areas in Indonesia has a new era after the government published of Government Regulation Number 26 Year 2008 regarding National, Provincial and Regental/Municipal Layout Plan (RTRWN). This government regulation published as mandate of Law Number 26 Year 2007 regarding Spatial Planning Article 20 paragraph (6). In Government Decree Number 26 Year 2008, natural landscape of karst is one of the criterions of the unique natural landscape area. The unique natural landscape area is part of the geology natural preserve area, its represent the part of geology protected area. Geology protected area is a part of national protected area. Therefore, with the Government Regulation Number 26 Year 2008, all of karst natural landscape is protected area. Stipulating natural landscape of karst as geology natural preserve area will make consequence in management of karst, because existence of karst areas spread both on public (state) land and on private land, spread both on forest area and on outside forest area. Base on government administration, some karst areas spread on more one regental area and more one provincial area. Considering complexity parties on management of karst areas needs the existence of integrated management plan. The integrated management plan will be base to manage karst area. The integrated management plan will accommodate of importance all parties to manage karst area, such as central government (Energy and Mineral Resource Ministry, Forestry Ministry, Environmental Ministry, Cultural and Tourism Ministry), local government (provincial, regental and municipal), local society, scientific society (Indonesian Institute of Sciences, college/university), as well as corporate society (business). However, the one of main key in management plan of karst area is management plan that accommodate the local community importance and aspiration who is live in surrounding karst area and their participation on its implementation. The important problem on management karst area, not only on management plan of karst area, the other problem is institution model to executed management plan. Institution model to manage karst area in any region may be same or may be different with the other region. Institution model in West Sumatra will be different with institution in East Kalimantan and even in Java. Many factors must consider to developing the institution to manage karst area such as social factor, culture factor and political factor. The exactly institution model will be able to execute management plan by effectively and efficiency. Therefore management plan that develop from basic or local level (local community) become management of area of karst more strength.

Keywords: karst areas, management, protected area, integrated management plan, institution model.

ART, HISTORY, MEDICINE, PHILOSOPHY, AND SOCIAL SCIENCE

EARTH COLOR FROM HAEMATITE FOR BATIK: A FIELD STUDY OF THE PREHISTORIC ROCK ART SITES IN SUBIS KARST SARAWAK MALAYSIA

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Abstract

The research utilities natural elements such as the hematite can be found locally in the production of art material. This product has very high potential for commercial production, as this will identify. Haematite (Fe_2O_3) the value for new product. This technique does not need any high trough put our expensive equipment and can be used in any laboratory. The underlying idea is the extraction of mineral materials like hematite. In this project, the researcher chooses earth color for art material as it is related to Rock Art Conservation based on art science and technology. The researcher used the term "Geoarkeoseni" combining geology, archeology, and art. The area of study consist of a district prehistoric site in Kain Hitam cave, Subis Karst area, Niah, Sarawak, Malaysia. Hematisol is product developed for the treatment of user-friendly and environmental-friendly, causes no side-effects, and easy to use. The active ingredient of Hematisol is an extract from haematite. It is the first product to be produced in the form of color. The color from the earth‟s core of local in the lime stone sequence in tropical region.The result colors from haematite has a great potential in contributing to the continuity of the global civilization. It is a form of coloring agent that is to preserve the batik have now come of age with new discoveries contribution to our understanding of the past. My discovery concerns color extracting from the mineral haematite, mixed and formulated into an batik cloth, and an alternative to hazardous chemical dyes. It is interesting to note the extraction of these minerals were quite similar to a common natural phenomenon. The next step is to translate the spirit of environmental awarenes into contemporary works of batik.

Keyswords : Cave painting, Subis karst, Haematite, Hematisol, Batik

Introduction

When did the last time you see a karst? Can you think of the ways the karst were used in the past? Cave paintings represent a more natural and rural past which is fast disappearing. What are other lifestyles disappearing too? Why do you think the artist draw a hematite and not another material, like lime stone, rock and karst area.

This article present findings of batik dyes obtained from rock minerals, including discovery and description of hematisol, an eco friendly and user friendly substance. It all began on 2001 when I was invited as a writer at a book "Lukisan Gua di Malaysia" initiated by the National Art Gallery Malaysia. In 2001, archaeological research was conducted at Gua Kain Hitam, Niah by the National Art Gallery Malaysia with the cooperation of the Sarawak Museum Department, Kuching and Department of Mineral and Geoscience Malaysia, Kuching, Sarawak. The research was conducted in order to obtain new dates and data on the prehistory of Gua Kain Hitam , which is located in the Niah-Subis limestone complex, about 110 km southeast from Miri, Sarawak. Results of the archaeological research at Gua Kain Hitam revealed evidence of prehistoric painting cave associated with earthenware sherds, haematite remains and shell ornaments, dating possibly from the Late Neolithic to Early Holocene period.

According Velat Bujang (2010), archaeological research carried out since the 1950‟s in Sarawak has revealed evidence of early human occupation, dating from around 43,000 BP until 1,300 A.D., in the limestone complex of Niah-Subis, Niah. The prehistory of Sarawak, in particular the Niah Caves, therefore shows a long and continuous period of human occupation from the Late Pleistocene (Paleolithic) to the Late Holocene (Harrisson, 1958, 1959; Zuraina, 1982; Cranbrook, 2000; Barker, 2005; Barker *et al.,* 2001, 2007).

Ancient Colors from the Earth's Core.

While traveling to the "Land of The Hornbill". I was introduced to a prehistoric cave site in Subis karst. Niah, Sarawak. Crossing the archaeological site feels like looking through the life and culture of the past. The beauty of ancient color site with the background of cave painting – represented, reconnect, mixing the batik as inspirations to present the style in any different occasions. An astonishing karst formation, the midday sun creating the most intricate composition of lines and shadows. a sudden wind that improvises new ornaments on the sand while hunter, like ancient painters, draw mysterious lines in ever changing patterns. The sight of ancient painter"s creations is sometimes so overwhelming it leaves me breathless. The karst, the cave painting, and past time. Erosion on a piece of rock in the karst area. Creation and expression heritage and civilization. It"s rather like something touches me deep down on my core and I feel warmth in my heart. As if ancient painters. Nature"s creative power, had lifted her for a split second and let me know that.

Ancient painters is there always, mysteriously the painting caves of life. The hunting expertise of the prehistoric community at Gua Kain Hitam B was not limited to hunting terrestrial and arboreal animals. They were also adept at catching and exploiting aquatic animals as evident by findings of fish, hard and soft-shelled turtle carapaces, as well as mollusc remains. One of the techniques that could have been employed is the bamboo fish-trap (Adi, 1985:65; Datan, 1993:114). Angling could also have been practiced as evident by the finding of a fish hook, in addition to stone sinkers (Fig. 16). Fish hooks are usually used to attach worm, crab or mollusc meat baits (Voeum and Driash, 2004: 409). Wood or bamboo spears could have also been used to catch fish and soft-shelled turtles. Simple pointed bone tools are probably indications of spear manufacturing (Piper *et al.,* 2008: 94). According to Voeum and Driash (2004), fish and soft-shelled turtles are caught using spears in shallow rivers. It is also possible that the prehistoric communities caught freshwater fish using plant poison. In fact, plant poison is still used by indigenous communities in Sabah, Sarawak and Peninsular Malaysia (Zulkifli, 2001: 213; Chia, 2003: 202; Velat Buang, 2010: 1).

The elegance of the ancient cultural. The un-matching beauty of the ancient colorbride shows in the elegance with a noble meaning inside. I here focusing the art, science, and technology, yet still applying the modern touch, this style will fulfill programs. The application of warm colors, such as terracotta, earth brown, or red. The atmosphere, certainly, looks different. The contemporary traditional decoration is formed by classic color. These combines with the natural dyes in harmony composition. The combination of ancient formula and more modern elements materialized. Now days, there are more objects can be exchange in ancient color, with various color innovations. Hematite, has similarity with red stone. It is very useful in every part of it, become a color trend inspiration for the work. The shining of Hematisol is presented in three activities. Haematite giving touch to the unique and attraction in red, and brown. Also, red stone are collected from local site and inspired by the exoticism of painting cave coming in exotic colors.

Crossing the land of one thousand prehistoric caves, flying the mind to embrace the sky. There, the history past was carved, able to write its footsteps to be enjoyed as today arises. Telling us the rich of ancient culture give inspirations like the boundless ocean. Inspired by the unique prehistoric painting, presenting the contemporary art. Showing the up most beauty. My Work synergizes with the beauty of local wisdom with the story then become the archaeological site bring out the amazement to the grand culture of today"s era. This workshop combining multiple discipline which is Geology, Archaeology and Art. This study is intended to give a picture of the significance of karst, with emphasis on cave painting in the Subis karst, Niah, Sarawak, Malaysia. However, considering the present state of researching and documenting in this field. Ancient color is product developed for the treatment of user-friendly and environmental-friendly and easy to use. The methodology of field study, observation, experiment, analysis of the condition of cave painting. Its is the first product to produce in the form of design. A significant contribution of the research is development of sense of belonging and an appreciation of our cultural heritage.

Colors from haematite have a great potential in contributing to the continuity of the global civilization. It is a form of coloring agent that is to preserve the batik has now come of age with new discoveries contribution to our understanding of the past. My discovery concerns color extracting from the mineral haematite, mixed and formulated into an batik cloth, and an alternative to hazardous chemical dyes. It is interesting to note the extraction of these minerals were quite similar to a common natural phenomenon. The next step is to translate the spirit of environmental awareness into contemporary works of batik.

It is hoped that society will be able to interpret nature not in the frameworks of exploiting natural resources, but how to view and think about the well-being of nature in the future: how to process the raw material using high technology. Sophisticated technology today has made it possible to analyze the formulas and recipes of mineral rock dyes material. With the help of microscopic "Nanostructure" and "Nanocomposit" the color density scheme of dark red to dark brown, can be identified, and lies between 4,9- 5.26. The chromatic color of haematite in various rocks is located on the IOR/ 8 (Munsel Soil Color Chart) between 6 and 2,5. The archaeo-chemical haematite is dominated by iron oxide (Fe2O3) frequently found in the massif lime stones. The following is a composition of the hematisol according to the geo-archaeo laboratory test. However, as a sedimentary, it may be mixed in with other minerals depending on how clear the water is when it forms. - Oxide of iron (Fe2O3), crystal hematite system-Hexagonal, but rarely seen as good crystals. Hardness- 5.5-6.5, varieties- specular iron, black crystals. Kidney ore, fibrous radiating structure like a kidney. Both valuable iron ores. Occurrence, in pockets in lime stone. Mineral Data Hematite, Chemical Formula: fe203 Composition: Molecule weight 159.69 gm, Ferum 69.94% , Fe 100.00%, Fe203, Oxygen 30.06% 0 O 100.00%, Total Oxide 100.00%, Empiric Formula Fe3 + 203. Origin name: In Greek "HAIMATITES". "BLOODLIKE:" refer to the color of the stone. Synonym: ICSD 64599, Kidney Ore, Martite, PDF 33-664, Specularite, Dougal Dixon (1992).

In hematisol most artist choice to work with five main colors that are made using natural materials. The yellow color comes from the rock, red from hematite, found in land along the river in Subis karst, white comes from lime stone. The raw materials are founded and cooked with sticky rice powder, skin cow to produce the paint. Produce the paint that is use to spraying colors the picture on the wall cave. The picture are produced one color at a time, using a spraying technique. Hematisol, as a natural resource for batik industry, attests to good performance and high quality. Extraction processes are environmental: haematite (iron oxide, water) from mineral and renewable origin, more than 100 % of solvent recycled, valorization of by-product, biological treatment of waste water for these processes are ISO 9001 certified.

Earth color was created in 1987 after a 23-year R&D project. The aim is to provide industrial product of mineral dye and pigments for batik industrial or public uses. Efficient processes for dye-extracts and mineral pigments production are carried-out in a laboratory through selective extraction and spry-drying. As they are standardized water soluble powders, the products can be used for dyeing natural or synthetic fibers. They are specially developed for cosmetic formulation (body painting), paints and inside decorative coatings, colored fine arts and crafts. Mineral pigments are carried out to fit technical requirements of batik and these pastes may also be used for several innovative colored products. Emphasis is given to research which has relevance to ancient time, provides information that can be used in policy formulation and which may be expected to lead to an improvement in the quality of public life. The research is intended to give a picture of the significance of hematite as an alternative media for batik industrial, with the emphasis on cave paintings in the Malaysia

I just come back from the Tesob Madai Cave, Sabah, Sarang Cave and Sirih Cave, Sarawak where I was doing a field study of the prehistoric rock art in Malaysia. It was in 2001 and I visited Subis Karst, Niah Sarawak Malaysia, a village full of beautiful memories, before my five years stay in Peninsular Malaysia. It was through my friend Mr. Ipoi Datan, Director Museum Sarawak in Kuching, Sarawak Malaysia. As far as I"m concerned it was a historic meeting. Meeting Ipoi Datan and being able to call him a friend has been a great pleasure and enrichment in my life, particularly when I was presented with cave paintings in Kain Hitam caves using hematite pigment on cave walls. The research section is the main focus for the research activities at the prehistoric sites as priority areas. Hunting and gathering were the main subsistence activities in order to obtain protein and fat from terrestrial, arboreal and aquatic animals. The variety of animal species hunted indicates the expertise and technology employed in hunting and gathering. Not only were the hunted animals a source of diet, but they were also manipulated into bone tools and ornaments. The bone tools and ornaments displayed grind marks and polishing, which provide clues on the manufacturing technology. Based on morphology, pointed bone tools probably functioned as borers and picks. On the other hand, shell remains were modified into beads and pendant. The manufacturing of these shell ornaments indicates that they were regarded as valuable items (Pookarjorn, 1994). Beads and pendant were made of marine shells such as *Nassarius sp*., Cypraeidae and *Conus sp*. The manufacturing of bone tools and ornaments also imply the high level of expertise, technology and creativity of the prehistoric community at Gua Kain Hitam B. In addition, the prehistoric community at Gua Kain Hitam B also hunted animals for burial and ritual purposes as indicated by the findings of faunal remains associated with human burials (Velat Bujang, 2010: 2).

The color is from local cave paintings in the lime stone sequence in Seseng, Tana Toraja Indonesia or other tropical region and the study was carried out in a prehistory site in Subik karst area, which is also known as the painted cave because of hematite found on the cave wall. The research utilizes natural elements such as the cave paintings and other items that can be found locally, as an alternative dyestuff in the production of batik, handicrafts and art materials. This product is very highly potential for commercial production. After long contemplation, research, and conjectures. I present images of ancient and varied rock art, symbols of the temperaments, connections, contradictions, attitudes, behaviors, and judgment that we deal with in our daily lives. The significant contribution of the research is to develop sense of belonging and an appreciation of our cultural heritage. Hematisol has great potential in contributing to the continuity of global civilization. It is a cultural heritage with social-cultural and socio-economic prospects. Industrial Batik has now come of age, with new discoveries contributing to our understanding of the past. From the natural environment and ancient time comes my inspiration in transforming and reviving the use of tradition towards natural color in contemporary artwork. To achieve the goal, Sopandi has directed its art work development programs to renewable resources developing innovative and creative development programs for the batik community so that the local economy growth may increase. In the due course, the art communities are expected to be sustainable and self-sustained from chemical product.

I interest natural dye began in the early 75‟s, thinking that there must be something special in the art of cave painting triggering foreigners to come to visit from far away in order to study it. From that time on, began to study several cave painting techniques and also to conduct experiments. During the past 35 years there has been a shift of focus from the initial exclusive concentration on research into natural dye made from hematite to matters of contemporary concern and practical application including projects on the impact of environment-friendly and user-friendly products. Becomes more enchanted by cave paintings. Many unexpected possibilities as a result of intricate processes turn into challenges that aroused his creative passion. He makes journeys to several prehistoric sites in foreign countries to see the cave paintings of the world and the cave painting-artists and designers with their magnificence have inspired him to continue on his work. The art work seeks to explain and illustrate the ancient and contemporary artworks that have been inspired by the Indonesian landscape and its living natural environment.

There is a spiritual and magic energy that cave painting grows in him, but he needs time to head there, to explore, and to reveal the essence of the works. He has been ignorant and faces many obstacles, weaknesses, and mistakes. However, he later discovered new things, and finally revealed new prospects. In cave paintings there are a journey of culture and magic to avoid disaster and life that keeps going on. The artwork has soul and life to tell a story of history and livelihoods full of symbols.

This paper is a part of the attempts to introduce the significance of contemporary art and new dimension. Close to the cave paintings stored in Niah area is a big rock formation of Subis, the largest mountainous area in Malaysia and it is located in the northern part of the main island of Borneo. Some limited fieldwork was carried out in specific areas of the cave paintings a heritage art that has long existed in Indonesia especially among the ancient community. Cave paintings started more than 10.000 year ago. The ancient people were known to have outstanding artistic paint cave skills. They were also famous for their strong belief system, animism. In many ancient cultures and religious traditions, cave painting symbolizes truth, life or a spiritual presence. Cave painting is created from hematite rock having been domesticated since ancient times. It is the oldest painting and was an important and deep symbol in different societies of caves, as well as in ancient tribal societies. It is symbolically significant for most cultures, and the creation of the color is imbued with a sense of mystery according to Zuraina Majid (2003) recently discovering art rock in Madai Caves, Sabah. This spread shows several styles- charcoal human figure with oar boats, a white peacock against a hematite background, and human and animal figures in hematite. The pink shades are all hematite, not the original rock color.

Subis karst area, now surrounded by a lush nature reserve, contains some of South-East Asia‟s earliest traces of *Homo sapiens hunter,* associated with stone tools of the same period. Pottery fragments have been found in most parts of the Niah complex. Of course there is no recorded history of Niah. A set of fascinating wall paintings conveyed a message from former artists and their audience but no longer leaves us the key to interpret the signs. Niah men, who lived as nomadic hunter-gatherers in the Subik area had developed considerable skills in grinding stone and splashing color and within the next 4.000 years they learned to paint the wall. Color from the core was used to apply decorations to the cave surfaces or it was embellished with incised patterns. In the painted cave, a number of human figures were found on the cave ceiling, animal and human figures dancing or hunting accompanied by some unintelligible symbols or was applied to the wall in bold strokes of hematite (Achmad Sopandi, 2003).

The people of this region painted pictures of the animals they hunted like bison, along the walls of caves. Forms of natural mineral dye like red ochre, were used as paint (Robert Muir Wood, 1996). They entrusted their life fully to nature as hunter communities. The tendency of most the hunter-gathered cultures is to maintain continuity of the traditional value from generation to generation.

The Use of Mineral Dyes for Batik Industry

"Think globally Act Locally", "Green Industry", "Preservation of Local Culture", "Organic Farming", " Eco Green", "Eco friendly" and the like have been bandied around globally. Firstly, these issues were an appeal to mankind, but gradually they began to regulate human life, specifically in the industry which was directed towards increasing the quality of life and at the same time being conspicuous of and caring for the environment. Besides the use of organic dyes, most of batik artisans use chemical dyes such as Remasol, Indigosol and Napthol, all containing the toxic component , azo.

Current sophisticated technology has opened doors and the possibility to analyze complex dye formulas based on ancient recipes handed down from generation to generation. Organic dyes are derived from "Haematite". Studies on natural dyes are now applied to restoration and conservation prehistoric painting. To use the mineral as a dye, Sopandi"s Earth colors are mixed with water, plant resin, seaweed and gelatin to from a dye bath to immerse uncolored cave painting, or to dye wax drawn batik cloths. Design for batik industry is based popularly on natural elements. Coming with creative fresh design is usually difficult and time consuming. The availability of diverse rock types (haematite) in this country provides an opportunity for other scope of study besides its conventional use as aggregates on the energy industry. This project involves the utilization of rock as a source of dyestuff for batik industry. The grinding stones can readily be used to produce designs for all kinds of fabric (batik textile). Each rock thin sections produces different texture and colors depending on its mineral composition. Haematite is a sedimentary rock, usually biogenic or chemical in origin. It forms in the shallow water of shelf seas and so it tends to cover very large areas. Haematite is, basically, a rock, made of lime stone.

In carrying out the project, we plan to make temporary settlement in the archaeological sites in the world. Yet, there is much more of the painted caves than archaeology. Therefore, the programs of this documentation include the aspects of natural science, art and technology. And programs are offered in diverse specializations such as batik materials and textile coloring matter. Our rough materials are from renewable sources. Cultures participate in the biodiversity preservation. Improved are checked for the resource protection.

The paint which was used throughout the world gives a deep red color and lasts longer on the wall which it paints, for it never fades. There are varieties of hematite and later researchers show that there are more than ten varieties of rock material. Earth color is a mineral product developed for the treatment of art material. The active ingredient of earth color is an extract from the rock mineral of a local mineral found growing wildly in the bushes of Indonesia and tropical regions.

Sometimes ago, the mineral used for the dyes obtained the ISO 14100 for excellent quality. In addition, various test of color quality such as British standard scale test: Xenotest 150 S (scratch test of color fastness, fading and running), Rubbing Machine and Coloring Matching Cabinet (sampling of color grading) also proved to be outstanding. Furthermore, machine extracted powered hematite was acquired to test the contents of the minerals. These are done using X-ray fluorescence spectrometer (XRF), atom absorption spectrophotometer, X-ray diffraction spectrometer (XRD) and the high-powered scanning election microscope (SEM). This equipment can also be used to analyze the structure of stones (Zurina Majid, 2003).

The reinvention of natural dyes also manifested in the presentation of various research outcomes from many national and international academics focusing on the development and use of natural dyes in the Indonesia textile industry, (Achmad Sopandi, 2010: 17). Current sophisticated technology has opened doors and the possibility to analyze complex dye formulas based on ancient recipes handed down from generation to generation. Studies on mineral dyes are now applied to modern textile production such as batiking cloths. The medium was found on 2001, Mouth west Niah Cave, Subik, Sarawak, Malaysia. Extracted color and part used hematite to product to color red, red Brown, Ochre, and Yellow. Method of the extractions is by drying the rock, grinding it into stones, pounding it until a fine dusk or powder produced. The powder can be stored for a long time. The dye stuff can be stored only in its dry form at room temperature, moisture free for a long time, especially of the real batik with natural coloring agents and their genuine smell. Because the hematite became ever more colorful, attempts were made to find additional techniques to get all the colors on to the cloth in a correct way. This was obviously done with such a high degree of skill that this additional technique is certainly not considered a counterfeit method. The colors from these archeological sites are especially associated with cave painting. The fabric is now ready to be submerged in the red dye. This process is frequently repeated until the desired result has been achieved, sometimes no less than 5 times for a top quality product. The dyeing agent is hematite. The remarkable thing about hematite is that its characteristic color does not become apparent until it is left to dry. This implies that the use of one type of dye has resulted in one color. This process takes a long time which eventually gives us haematite. It was found in 2010, in Sesean, Tana Toraja Indonesia.

Conclusion

The conclusion is, from my presentation I hope that I can share my knowledge about a color from mineral changing into the use of natural color for today. What I do now is to break the ancient mystery by reconnecting the prehistoric artifact in Subis karst area. The creative process and sensibility of cave painting are derived in part from the equisetic heritage of ancient, well known for their sense of aesthetic beauty and their real and symbolic ties with nature. Their intimacy with their natural milieu, together with their beliefs and their proclivity for the supernatural thing has inspired cave painting. Environment-friendly life and welfare are common goals of all human beings throughout the world today, as we are suffering from environmental pollution and getting more isolated by the development of technology and science. Currently, the writer collaborates with Batik, on educational program combining art, science, and technology specifically on the preservation and sustainability of natural color for the future generation.

It is hoped that this article is useful for conservation prehistoric painting in the world in their work and encourage them to re-think the value and importance of age-old wisdom and indigenous practices of our ancestors in making use of nature without harming it. By reviving and reintroducing indigenous wisdom and practices in expressing our creativity, we can meet the demands of our time and at the same be kind to our environment and safeguard our health and well-being.

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CONSERVING CULTURAL AND BIOLOGICAL RESOURCES OF PASIR PAWON AS SACRED NATURAL SITE

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Abstract
Historical artefacts and field evidences have been discovered in Pasir Pawon, Citatah Karst West Java Province, Indonesia, with the most striking discovery being an ancient human fossil- thought to be the forefather of Sundanese people. It is expected that Pasir Pawon still covers much more cultural and biological resources waiting to be revealed. Unfortunately, the great number of limestone industries in surrounding areas, forms a great threat to the sustainability of this exceptional cultural area which may hold the key to understanding Sundanese (West Java) culture. Although local efforts have been started to decrease the devastating negative impacts, further urgent actions are required to boost this effort. With so much history and culture tied to this area, protection effort could start by recognizing Pasir Pawon as a **Sacred Natural Site**, which is defined as areas of land or water having special spiritual significance to peoples and communities. Pasir Pawon Sacred Natural Site would provide dual protections in conserving cultures, being a place of reference for cultural identity, and protecting nature. It is expected that with the designation of Pasir Pawon as Sacred Natural Site, awareness and understanding of the cultural evolution of Sundanese people can be recognized, protected and studied.

Keywords: conservation, Pasir Pawon, sacred natural site

Introduction
According to Coon (1969), human civilization comprised of four historical phases. In the first phase, *i.e.* between 600 thousand - 50 thousand years ago, humans learned to make tools, communicate, and discovered fire and used it to cook. In the second phase, more than 20 thousand years ago, humans had started to use clothing, hunt with the accompany of animals and had studied the art of craft. In the third phase, which is about 7000 years ago, humans had been able to construct buildings, known to use stationery and has been known to have culture. The fourth phase is the current human beings. Overall, these phases are related to the evolution of food production systems through hunting activities, food gatherings and farming. For such reasons, human beings required a living space as a centre of activity as well as shelter.

An area used as a living space must have a lot of social aspects considerations due to the development of human civilization and culture that occupy it. Early human habitation have certain characteristics such as easy access, close to creeks or other water sources, not far from food sources, close to source of equipment materials, and has a large enough space to be occupied by a flat surface, circulation of good air, sufficient light, and not too humid (PTKA and UGM, 2003). One place that possesses these characteristics is cave because it can be used as a shelter, resting place as well as gathering place, although not all caves meet the criteria of an ancient living space. A cave, which was chosen as a shelter, should have a fairly broad view as it relates to the ease in observing game animals.

One of the ancient cave dwellings in the area of West Java is a cave located in the Pasir Pawon area in Citatah Karst region, located in Padalarang. This area is the oldest karst area in West Java. In line with the theory of cave formation, (Mohr and Poulson, 1966) Pasir Pawon area was a shallow ocean floor, which then formed Pawon Cave after experiencing a very long process. This was indicated by the limestones, which were formed from fossilized colonies of living seabed creatures (Suganda, 2004).

The valuable historical remains found in Goa Pawon such as bones and fragments of ancient stone were impressive with an estimated age of 10 thousand years. Apart from the artefacts, the most striking discovery was an ancient skeleton of 9,500 years old belonging to Homo sapiens. This ancient skeleton is thought to be the ancestor of the Sundanese people (people of West Java). These have lead to the establishment of Pawon Cave as a Cultural Reserve. Unfortunately, the surrounding area of Pasir Pawon has not received similar treatment, meaning that it has not been given a legal protection status. On the other hand, the discoveries of other pre-historic objects outside Pawon Cave area indicate that there are opportunities that many more prehistoric objects would be found. In addition to its ability to record human development in this area, Pasir Pawon is also very important as a place to study the condition of biodiversity in the past, since human livelihood depend on the interactions between human and nature as nature provides the essential requirements to survive. However, the existence of these important historical evidence is threatened by the presence of massive limestone quarrying that are gradually destroying the surrounding area within the vicinity of Pasir Pawon.

For these reason, not only Pawon Cave that must be given legal protection status, but it is also important to include a broader region of protection for traces of histrory that can tell us more about the past environment as well as the cultural identity. Currently, the local communities including academics, government and others are making efforts to protect the broader Karst Region of Citatah, where they are developing a master plan for the management of Citatah Karst. This paper is aimed at giving some considerations for early management option for Pasir Pawon area. Since Pasir Pawon is a place of cultural identity and thus has spiritual and cultural significance, it is important to regard the area as a Sacred Natural Site, since there are times when cultural heritage is closely linked to sacred sites apart from the fact the some people use Pawon Cave to meditate. Through a Sacred Natural Site, it is expected that Pasir Pawon will be able to preserve its cultural resources as well as biological resources and hence awareness and understanding of the cultural evolution of Sundanese can be recognized, protected and studied.

General Conditions of Pasir Pawon

Pasir Pawon Prehistoric Site and Its Environment. Karst Region of Citatah comprised of hills formed by the uplift of limestone from the time of Oligo - Miocene around 20-30 million years ago (Brahmantyo, 2004). This karst stretches westward from Tagogapu on the north of Padalarang to the south of Rajamandala, which includes the oldest heritage in West Java, including Pawon Cave and Pasir Pawon.

The peak of Pasir Pawon has a place called stone garden (Fig. 1a) which is a collection of randomly arranged stones with different heights. On one area of the stone garden, there are two stones that are vertically inline called the Stone Gate (Fig. 2b) that are considered sacred by the local people because it is believed as a door separating the two worlds. Whereas, on one of the stone, some marine animal fossils were imbedded on the rock (Fig. 2c) indicating the region was used to be part of a shallow sea.

(a) (b) (c)

Figure 1. View from top of Pasir Pawon: (a) stone garden, (b) stone gate, (c) marine fossil

Not far from the stone garden, an obsidian rock could be observed which derived from magmatic rocks resulted from volcanic eruptions. According to Budi Brahmantyo (KRCB, pers. comm), such rock were not supposed to be found in Citatah Karst since the area is quiet a distant from the territory of volcanic eruptions, hence he assumed that that the obsidian rock was brought in by early human from outside the karst area. Not far from the location where the obsidian rock was found, a large rock surrounded by smaller rocks arranged in a circular formulation could be observed. This place is thought to be a gathering place for the early humans, or perhaps a worship area (sacred place).

Pasir Pawon itself consisted of three caves, namely Pawon Cave, Poek Cave or Peteng Cave, and Barong Cave. The position of Pawon Cave which is higher than the surrounding region made it a strategic location for prehistoric humans to allow them to see the game. The discoveries of artefacts such as fractions of shells, as well as foreign stones like obsidian, chalcedony, and andesite, broken bones of various kinds of vertebrates, freshwater mollusc shells, fossils of ancient animals skeleton in 2000 (KRCB, 2006) and the prehistoric human skeleton aged around 9500 years ago (Fig. 3) in 2003, provided proofs that Pasir Pawon was used as an ancient living area (Arif, 2004) rich in historical values.

Figure 3. Ancient human fossil found in Pawon Cave

Limestone Quarrying Activities in and around Pasir Pawon. Some forms of landscape destruction can still be observed in the vicinity of Pasir Pawon (Fig. 4) as well as vandalism in the Cultural Reserve area. The quarrying activities were already existed prior to the establishment of Pawon Cave as a Cultural Reserve. Unfortunately, the existing limestone quarrying is increasingly widespread.

Figure 4. One of the devastating destruction of Citatah Karst

Dredging is done almost every day. Some people who deliberately took the rocks from the Pair Pawon were also observed. The intense cleared area due to limestone quarrying has resulted in the gradual reduction of the number of springs (Budi Brahmantyo, pers.comm), whereas the swamp areas have been replaced by a residential population and agriculture. With such alarming threats, the government must make urgent action to preserve what is left of Citatah Karst especially Pasir Pawon area.

Legal Aspects of Pasir Pawon. Of the whole Karst Citatah area, only Pasir Pawon that is relatively safe from quarrying activities (although some cave vandalism could be observed). This was possible because the caves in this area and some parts of Pasir Pawon area were considered sacred.

Pawon Cave was designated as a Cultural Reserve based on Indonesian Act No. 5/1992 on Cultural Reserve Object. According to this law, objects of cultural heritage is a national wealth that are important to the understanding and development of history, science, and culture that needs to be protected and preserved for the sake of national identity and awareness of national interests. Pawon Cave served as objects of cultural heritage as it relates to the development of human culture, especially the Sundanese. Furthermore, the discovery of ancient fossils can be used as study materials and research in addition to describing about the past biodiversity. Pawon Cave is also protected under the West Java Government Regulation No. 2 of 2006 Article 62 on Protected Areas Management.

Based on the Decree of Ministry of Energy and Mineral Resources No. 1456K/20MEM/2000 on Guidelines for Karst Area Management, Citatah Karst is classified as Class I, because it has archaeological remains that have the potential to be developed into tourist and cultural objects that meets the meaning and function of socioeconomic, cultural, and development of science. Under this category, mining activity is not allowed. Citatah Karst is also protected under West Java Government Regulation No. 2 of 2006 and the importance of karst ecosystem conservation is also confirmed by Act No.32/1990 on Protected Area Management Chapter VI, Article 57.

The legislations above indicated the importance of protecting Citatah Karst region, but currently only Pawon Cave that receives protection status. Bearing in mind the cultural and ecological values as well as the alarming destruction threat by mining activity, urgent actions to provide clear legal status for the protection of the wider region is required. The protection of Pawon Cave should be strengthened with the protection of the surrounding area.

Rationales for Designation of Pasir Pawon as Sacred Natural Site

Some parts of Pasir Pawon area are considered sacred by the people and this would provide justifications on the sanctity of the area and can be used as a basis for protection. The religious or cultural designation of an area as sacred, especially those which are relatively natural, may either intentionally or coincidentally promote the conservation of its associated biodiversity. According to Suryadarma (2009) the presence of a sacred site would eventually manifest in various areas of sacred artefacts with associated restrictions. Restrictions on access and use of such areas, and especially for sacred places in nature, may reduce or even eliminate human environmental impact and thereby help protect species in the area. The pattern of sacredness can be established as an effort to protect the diversity of species and to investigate the background norms and strengthened by formal rules. Samodra (2001) also stated that caves have historical as well as legend, mysticism and beliefs values that are recognized by residents of the region for generations.

Sacred Natural Site is one form of protected areas recognized internationally as defined by Oviedo and Jeanrenaud *in* Wild and McLeod (2008) as "areas of land or waters that have spiritual values important to people and their communities" (p. 7). Sacred Natural Site is very important for the protection of nature and culture as it relates to biodiversity, habitats, ecosystems, landscape and geology. In fact, it is one of the oldest forms of culture-based conservation. Sacred Natural Sites is also associated with cultural identity. With regard to Pawon Cave, the cultural identity was expected to be Sunda since the ancient human fossil found in Pawon Cave was suspected to be the ancestor of Sundanese.

Cultural resources are physical features, both natural and man-made, associated with human activity. These may include such physical objects and features as archaeological sites and artefacts, buildings, groups of buildings, street furniture, signs, and planted materials; in short, almost anything that connotes man's past presence (Sponsel, 2008). Many sacred places in nature are associated with indigenous cultures. However, within the context of Pasir Pawon, it is more associated with a prehistoric culture that is thought to be the ancestor of an important culture. No culture can hope to understand its present or to forecast its future if it fails to recognize its past. For by tracing the past, a culture can gain a clear sense of the process by which it achieved its present form and substance; and, even more importantly, how it is likely to continue to evolve. For these reasons, efforts directed to identifying and preserving Pasir Pawon historic and archaeological resources - with their inherent ability to evoke the past - are most advisably pursued.

Pasir Pawon is more than a landmark and territory, more than mountain, forest and geologic wonder. It represents a piece of the Sundanese soul. The remarkable landscape and features of the nature preserved in Pasir Pawon have the power to awaken an extraordinary sense of wonder. They tend to evoke a feeling of some awesome, mysterious, and transcendent power that merits special reverence and treatment. Individuals may experience a sacred place in different ways as a site of fascination, attraction, connectedness, danger, ordeal, healing, ritual, meaning, identity, revelation, and/or transformation (Sponsel, 2008). Pasir Pawon hold special value and attraction for people wanting to dwelve more into prehistoric site as well as Sundanese culture. Establishing Pasir Pawon as a Sacred Natural Site may not be on the agenda of the political and environmental agencies that is currently working on developing a Master Plan for Citatah Karst, but this can be taken into consideration as a management option.

Sacred natural sites and cultural landscapes cannot be understood, conserved and managed without taking into account the cultures that have shaped them and continue to shape them.

Educating the Community. Education is an element of building close and cooperative relations between this prehistoric site and the communities. Historic site of Pasir Pawon is a critical tool in creating an understanding of past lives and cultures in every successive generation. If youngsters are given a first-person experience with the actual places, buildings and artifacts of lives and events gone by, they will get a much richer understanding and appreciation of the past.

Conclusion

As a prehistoric site with significant spiritual, cultural and ecological values, Pasir Pawon required further protection action beyond Pawon Cave. Areas outside Pawon Cave within the vicinity of Pasir Pawon should be protected under legal protection status. Bearing in mind the sacred values that the people have on Pawon Cave and some parts of Pasir Pawon area, as an early management option, the cultural landscape of Pasir Pawon can be designated into a Sacred Natural Site that would be an intangible heritage. This would allow the protection of the discovered historical remains as well as those yet to be discovered. Collaboration among religious, governmental, scientific, and/or conservation agencies may be desirable for the protection of sacred sites and landscapes as well as such site can complement other protected areas established by governments.

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POTENTIAL OF GEOTOURISM OBJECT DEVELOPMENT AT SOUTH GOMBONG KARST AREA, KEBUMEN

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Abstract

South Gombong Karst Area (SGKA) with 559,98 hectare has highly scientific and economic value. The importance for ecosystem and human life, this area those set in minister regulation (Kepmen ESDM No. 961.K/40/MEM/2003) as karst conservation area with three zone. At SGKA there are 171 active and fossil caves, at zone 2 there are mass tourism object like Jatijajar and Petruk cave. The other location are Logending, Menganti, Pasir and Karangbolong beach.

Besides mass tourism object, this area has potential for special interest tourism like ecotourism, geotourism, agrotourism and spiritual tourism. Development of geotourism attraction had an effect on knowing ecotourism genetic object and other special tourism. Geotourism priority are unique of rocks, morphology and earth structure. It‟s can be develop at all natural object destination. Karst topography from Tugu village, Jatijajar cave, Petruk cave, Barat cave, morphology from Argopeni, Logending beach, Karangbata beach, Pasir beach, Karangbolong beach and Sendang Pelus has good potential to arrange as geotourism object. Development geotourism object no reconstruction of settled tourism object but must be inventetory of attraction object, support capability object, packaging, guidance book and promotion. To packaging and promotion object at SGKA can attributable to geotourism attraction object at Karangsambung Geological Park.

Keywords: SGKA, geotourism, inventory, attraction object, packaging.

Overview

Recreation is universal and fundamental requierement for human life. The aim of recreation is mental and physical rebound after hard work. Tourism is full or part of voluntary journey to enjoying natural attraction like forest, cave and geotourism or human made like budist temple, palace and museum for temporary time (Anonim, 1977). In recent time, there is blooming tourism all the wold as main devisen. Economic globalisation and market liberalisation with information technology and transportation development, encourage blooming wold tourism.

Geotourism is special tourism utilising geologist resources like morphology, rocks, mineral, rock stucture and earth history with the focus of journey is knowledge enrichment and knowing natural phenomena. Based on natural resources, potential of Indonesian geotourism objects are very much. Indonesia is producted of Hindia -Australia oceanic plate, Eurasian continental plate and Pasific oceanic plate interaction, so this country very much volcano, mineralisation area and natural phenomena. This country has many mining areas like gold, coal and oil. Every regency has tourism object related with natural resources like volcano, cave, water fall, sea, lake, geothermal etc. Tourism object generally attributable with legend or folklore as attraction, scarcely with natural process. Development of geotourism will added new tourism object and new attraction at old object. It is added value of geotourism than other special tourism (Ansori, 1998)

Karst is stony and barren terrain, it is Germany terminology from Slovenia language. Generally karst is terrain terminology for limestone with thin of solum soil, scarcely surface drainage but many sub surface drainages and dolines, those are product of limestone dissolve (Summerfield, 1991). Ford and Williams (1996) generally defined as topography with hydrology and terrain characteristics result of combination factor like soluble rock and good secondary porosity. It‟is happen at limestone or dolostone with acid solution of carbonate (product of rainy water and carbonate acid at soil or air space) and other acids like oxasalate and acetate (product of decomposition remaining plant). Product of limestone kasrtification has unique eksokarstic and endokarstic phenomena like sub surface drainage, stalaktite, stalagmite, pilar, flowstone, helictite, gourdam ect.

Eksokarstik phenomena inter alia :

Doline, circular and close basin with 2-100 m depth, 10 – 1000 m diameter, generally groups or disperse with special pattern. Doline shape like cup, funnel or well with gulch.

Uvala, elongated basin with ring-fence or not, undulating valley like connecting doline (UIS in PALLAWA UAJ, 1986).

Polje, is large closed ektension depression, and its floor makes a sharp break with parts of surrounding slopes.

Polje has sub surface drainage, impermeable floor, kilometers wide, ring-fence, buttom of valley covers by alluvial deposits and residual of weathering like terrarosa, pebble and granule. Flat floor across which there may be an intermittent or perennial stream. The polje may be liable to flood and become a lake.

Karst lake, depression area like doline, uvala or polje with impermeable residual of weathering like terrarosa at floor of depression, with the result that accumulation of water. It is reservoir of surface water during the year or rainy season.

Sink, disappeared surface river location with diffusion process at alluvium sediment.

Endokarstik phenomena inter alia :

Stalactite, hanging residual solution of limestone at cave roof.

Stalagmite, standing residual solution of limestone at cave floor.

Sodastraw, are very thin and long stalactites, having an elongated cylindrical shape rather than the usual more conical shape.

Helectite, are stalactites that have a central canal with twig-like or spiral projections that appear to defy gravity.

Pilar/coloumn, become or be one of stalactite and stalagmite

Flowstone, is sheet like ornament and found on cave floors and walls from residual solution of limestone. Gordeyn, is cave ornament like hanging curtain on the roof cave.

Gourdam, single or multiple embankment ornament on the floor or cave.

Indonesia has carbonate stone (limestone and dolostone), it is dispersed from Sumatra through Papua, with 154.000 km^2 wide and 39 tons quintillion reserves (Surono etc., 1999). South karst Gombong area has 559,98 hectare with potenciallity about 389.250.000 ton. This area include cockpit-karst with beautiful cave ornament, predominantly as water cave and the other as fossil cave (Samodra, 2005). At south karst Gombong area there are 171 caves (Samodra, 1999).

Methods

1. Considerable study; especially geology reference, geography, tourism, leaflet and seminar proceeding.
2. Field study; about morphology, rock structure, stratigraphy, hydrology, land use and tour object. Field observation through tour stripe, cave tracking and many important location with take photograph, rock sampling and descripsion.

Geology
The stratigraphyc unit of this area from lower to upper are Gabon Formation (Tomg), Kalipucang Formation (Tmk), Halang Formation (Tmh) and Alluvium (Fig-1). This area include Serayu southern mountain (Bememelen V, 1949). Based on geological map of Banyumas area (Asikin *et al.,* 1992), stratigraphyc unit consist :

1. Gabon formation (Tomg), consist of volcanic breccia with tuff, lapilli-tuff and other laharic material. It is intercalating with andesitic lava. Part of matric altered as trass and tuff altered as bentonite. This formation is late Oligocene – early Miocene age.
2. Andesite intrusion (Tma), early – mid Miocene that intruded Gabon formation, affected alteration and mineralisation for several area.
3. Kalipucang formation (Tmk), consist of coral limestone, clastic limestone and bitumious shale in the lower part. The relation between Kalipucang and Gabon formation is unconformity. Kalipucang formation formed as karst topography.
4. Halang formation (Tmph) consist turbidite sediment as carbonaceous sandstone, pebbly sandstone, tufaceous sandstone, marl, tufaceous marl, claystone, marly claystone and calcarenite intercalation. This formation is late of mid Miocene – early Pliocene age.
5. Quartenary Alluvium sediment (Qa), the youngest sediment in this area as loose beach sand.

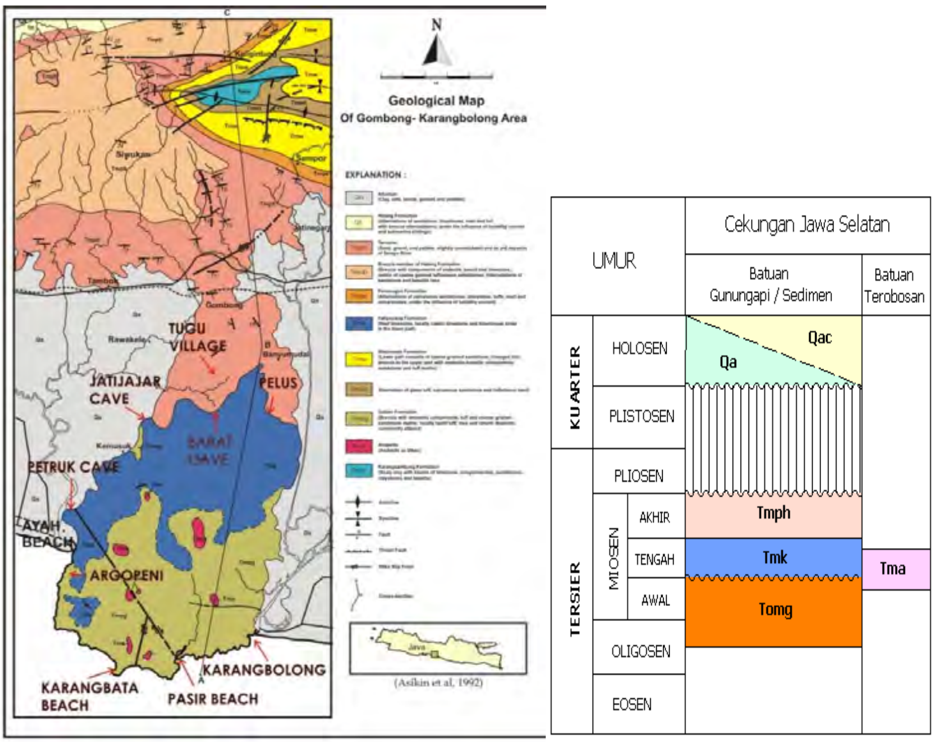

Figure 1. Geological map and stratigraphyc unit at south Gombong karst area (Asikin S, 1992)

Geotourism Object At South Gombong Karst Area

Jatijajar Cave. This cave about 23 km south of Gombong through hotmix road, about 60 minutes by car from Kebumen. Jatijajar is the main object with greatest quantity of tourist in Kebumen. At wayside to Jatijajar there is abrust morphology between steeply karst topography at southern part with moderate hilly at northern part. At karst topography, there is view of equal dome shape deforced by regular valley. Those valley controlled by joint lineament with N130 °E. Rain water entered to limestone through jointing and formed sub surface drainage and cave. The moderately hill at northern part consist of intercalating between tufaceous sandstone and claystone of older Halang formation with northpart dipping about N 240 °E/19°. Jatijajar is limestone cave from Kalipucang formation upper Halang formation.

Figure 2. Entrance and Kamandaka sculpture legend at Jatijajar cave.

Entrance cave composed of solid limestone, this tunnel is ex-guano mining about 50 m long and 10 m depth. In the front part of cave as fossil, but middle to end of tunnel as active cave with stalactite and stalagmite ornament. Total cave length about 250 m, 25 m broad and 15 m height, it is equipped with lamps and laddersteps so that confortable for mass tourism. Below entrance cave there are molusca fossils like gastropod and pelecypod at brown sandy claystone, it is indicated age of cave genetic about one million years ago. Canopy and remnant of sub surface river indicated uplifting hudred years ago, active sub surface river 5 m underneath main tunnel. Since 1975, 32 Kamandaka legend sculptures fixed to all main tunnel, this legend very poluler at Banyumas and Kebumen district. This cave detectable by Djajamenawi at 1802, when he cleaned out soil and sinked in the tunnel hole about 24 m depth.

If washing face at Kantil or Mawar springs will make ageless, and many people often take water from those springs. Flowing of Mawar spring to outer cave from little hole. In the buttom of Kantil springs found siphon connected to sub surface tunnel and we must be diving to see gourdam and waterfall.

If we entered to Jombor and Puserbumi springs must be permission management, those springs possessing supranatural qualities and many people believe it. At Jombor spring there is a white pelus fish about 1 m long, the sub surface river flow to Mawar spring. The shape of Puserbumi like upright well with 50 cm diameter, flowing outer cave. At 5,5 hectare aroud Jatijajar there are Dempok and Intan cave. Dempok cave about 90 m long, it is combining of natural and artificial cave used of limestone mining. Intan is fossil cave with stalactite, stalagmite, flowstone and pilar ornament. This cave about 100 m long, with intrance and extrance from one hole. From molusca fossils, indicated this cave about one million years ago.

Barat Cave. This cave about 10 minutes by car or motorcycle from Jatijajar to Karangpucung village, after that about 200 m walking. At entrance, 65 m long dry tunnel as ex-phosphate mining. After that, there is sub surface river with 0.5 – 1.0 m water depth and N 310 ° E trend. In this zone we can find excellent gordeyn, white centipede 2 cm long and cricket. This cave about 3305 m long with many sub surface rivers, water falls, sharp wall and other ornament, it needs 2 days tracking (Finspac, in PALLAWA UAJ, 1986). We can choose tracking route from Barat cave, Asrep cave and Redisari spring. If we entered through Barat cave, we go down 60 m tunnel to the north. There is Monosuko (free of choose) chamber at the end of main tunnel with three subtunnels, upper stream passage if we turn right, firebug bypass at middle part as Redisari springs outflow and lower stream passage if we turn left with Asrep cave extrance.

Figure 3. Helectite and gourdeyn at Barat cave

Petruk Cave. This cave about 6 km south of Jatijajar through asphalt road. Petruk cave include karst topography, product of sub surface river erosion with stalactite, stalagmite and other beautiful ornament. This ornament blossom out through 450 m long that give name like shape as female breast stone, tiger stone, crocodile stone, Maria park, bearded father stone, stamp stone and so on. In the middle part we can find ornament bell like with water shower. Mangunsrono is combination ornament of flowstone and micro gourdam with disperse water flow. Stalagmite detritus with percolation water drops as batu buaya (crocodile stone), flowstone at the buttom of horizontal layer of limestone as manusia tidur (sleeping man stone). Lukar busono (without clothing) is active flowstone with stalactite in the middle part. Batu serigala (wofl stone) is calcite deposition at broken stone. Taman gajah (elephant park) is group of stalactite about 40 cm high and white dull pointed like elephant. Bapak jenggot (bearded father stone) is stalagmite about 60 cm high with active flowstone in the middle part. Batu perangko (stamp stone) is stalactite and stalagmite with 30 – 40 cm pillars in the middle part. Taman Maria (Maria park) is groups of stalactite about 80 cm high, taman golek (puppet park) is group of stalagmite like puppet with 40 cm heigh. Batu payudara (female breast) is fat and short of initial blossom out stalactite.

Figure 4. Petruk entrance and Maria lady ornament

Petruk is horizontal cave with 450 m length and sub surface rapid flowing water. It is natural and we need lamp to investigated it. At the middle – end of tunnel there are cave bats, gray crickets and centipede. In the inner part, we can find contact between volcanic breccias of Gabon formation with coral limestone from Kalipucang formation. This cave is ideal model for knowing ornament of limestone cave, hydrological cave, animals and genetic of cave. For speleologist is funny and challenge, there is cave tracking package combine with other geotourism object so we can enjoy inner ornament and it‟s genetic. We need about one and half hour tracking tunnel from entrance to extrance cave at forest.

Karst morphology from Tugu village. At this location, we can look at difference morphology between karst topography at south-ward and undulating-hilly topography at north-ward. Those topography separated by east-west deep valley as wet rice-field and village. Spread of south karst Gombong area is 70 kilometers wide consist limestone of Kalipucang Formation, it is position upper volcanic breccias and intrusion of Gabon Formation. The top of mountain in the middle part as water devide flowing south-ward and north-ward. Karst looks like dry area, we cannot find surface water because characteristic of limestone is absorb and collect water at sub surface area. Lineament of hill in this area controlled by joint pattern, dominantly by north west – south east direction, east – west and north east – south west. Joint pattern developed as sub-surface river, tunnels cave and top hill lineament. East - west trending valley is fault zone with steeply sloping and spring water as irrigation around Jatijajar cave all the years round.

Figure 4. Karst with *cockpit topography* (backside) and hilly (front side), view south-ward from Tugu

Morphology from Argopeni. At this location, there is view of east-ward meandering Bodo river with sandbank at middle part. West part of Kalibodo is Cilacap regency, east part is Ayah flat with land use as wet land rice, dry land, farm and settlement. Lower course of Bodo river has turn and shift to the east-ward, this matter result from long shore current at Ayah beach. Highly sedimentation and long shore current that strike steeply mountain caused turn east of Bodo river. Loose and soft Alluvial sediment of Bodo river dominantly this morphology.

Figure 5. Meandering of Bodo rivet at Ayah flatness, karst topography and steeply mountain, take photograph from Argopeni village

Logending Beach. This location about 10 km south of Jatijajar and 3 km south of Petruk. East side is karst with steeply topography, west side and north side is slightly sloop as alluvial sediment and sand beach. At the south side is Majingklak hill, that is composed of volcanic breccias and resistance from erosion. No sand dune in the low land, because no much sediment input from up land. Logending beach equipped with camping ground, parking lot, horse lot, small shop and boat for rent and tracking Bodo river.


Figure 6. View of karst tophography from Logending beach and tourist boat

Karangbata Beach. This location about 10 km south of Logending through asphalt, crankle and narrow road with deep valley and panoramic beauty around it. This cape composed of andesitic breccias and intrusion of Gabon formation with Oligocene age. Around

Karangboto cape there are stones ornament, arranged like brick and people said this location Karangboto (brick stone). This phenomena producted of lava flow in arid area and contracting force when freezing over to formed columnar joint. This joint is polygonal shape with five or seven side if look at surface of stone. White sand distributed in this beach make beautiful panoramic. This sand product of erosion and transportation of limestone at north side as river sedimentation. If we look at east-side , found bold coast as a product of block faulting and beach comber at volcanic breccias.

Figure 7. Cape of Karangbata consist of volcanic breccias and lava from Gabon formation

Pasir Beach. This location at south side of karst area, consist of volcanic breccias with pebble-boulder fragment. Around this area more fertile than kasrt zone, many people developed kine and milk cow. At north side there is natural bridge phenomena, wave abrasion strike intercalating sandstone at laharic breccias. Because sandstone softer than breccias, so newly forming hole like bridge.

Figure 8. Pasir beach with fisherman activity and natural bridge ornament

Karangbolong Beach. This location about 39 km south of Kebumen through good asphalt or tourism route from Logending, Pedalen, Karangduwur, Pasir and Karangbolong about 45 minutes by car. Beyond Gombong to Karangbolong we can observe karst topography, mining activity, limestone limekiln and outcrop of Gabon Formation. At Karangbolong beach, volcanic breccias of Gabon formation cropped out, about 15 – 50 cm diameter of fragment, bad sortasion and rigid. Mountain range of Karangbolong – Karangboto is very resistant from abrasion wave, it is controlled by breccias litology. Around this beach there are many caves with swallow birds and we can look at take birds nest attraction. This tourist attraction is four times a year. The Karangbolong cave as a product of wave abrasion and fall out layer of sandstone in breccias. This cave as visual aids of take swallow nest attraction. The east side of beach as low land with sand beach sediment.

Pelus Spring. This spring is hydrological system of karst at west-side area, it is controlled by topography and impermeable rock. Spring debit about 10 litres/second all years although long dry season, it is used for irrigation and fishery. Name of this spring is pelus, because there are seven pelus fish sacred live at this spring. At south side of spring, there is mining activity of polimict breccias for building material and ornament.

Figure - 8. Mining activity and pelus fish at buttom of springs

Geotourism Object Development

All tourism object and potential object at south Gombong karst are rely on nature as main tourism attractive. Jatijajar cave, Petruk cave, Barat cave very interesting endokarstik phenomena, rocks, occurrence, hydrological and cave ecosystem. Many caves at Redisari village like Asrep and Pengantin cave closely with Jatijajar cave, it is include Tourism Zone I (UKW I) at master plan of Kebumen tourism development. Asrep and Pengantin cave are still active cave wich have interesting as geotourism object. Logending beach, Karangboto cape, Pasir and Karangbolong has good natural panoramic, sand dunes, long shore current, rock genetic, hydrologi and coast ecosystem.

Besides those objects, at north part of Kebumen regency there is Karangsambung Geological Park. This area has unique of rock variation, tectonic, structure and morphology so this area as geological site of Eurasia and Hindia Australia plate subduction at cretaceous age. There is oldest rock in java and melange complex as a track of subduction zone, geodynamic and plate evolution. Geological track of Karangsambung as basic knowledge of earth process and natural phenomena occurrence at other tourism object in Kebumen. At Karangsambung geological park can be done gemstone and rocks hunting, suiseki and gemstone processing. There is geotourism package with variation activity and attributable to other geotourism object in Kebumen. Many professional federation like IAGI, HAGI, IGCP, IATMI; kindergarten – high school student, many university student from Indonesia and foreigner has employed geotourism package. Gave attention to tourism trend, market potential and geotourism object potential, Kebumen is very potential of geotourism development. Karangsambung is very important factor to developing tourism in Kebumen, because all tourism objects in this regency rely on nature as attractive object.

For developing geotourism at south Gombong karst area must be made tourism package that attributable to Karangsambung geotourism package or made own package but marketing activity at Karangsambung geological park. Karangsambung four hour package can attributable to Jatijajar cave, Petruk cave and Logending beach for common people. Geotourism package at Tugu village, limestone mining at Redisari, Jatijajar cave, Petruk cave, Logending beach, Argopeni morphology, Karangbata beach, Pasir beach, Karangbolong beach and Pelus spring compatible with professional federation or university student. Petruk cave is very interesting for beginner speleologist, but tracking Barat cave is more challenging for advance speleologist. Geotourism include special tourism, so it needs special guide, maybe from sorounding people who has enough knowledge of earth or use tourism guide from Karangsambung geological park. In marketing sector is better if Kebumen as tourism destination not only as transit location. There is star hotel with hundreds capacity, cathering and travel bereau in Kebumen. But there is not one element like tradisional show or night music. It must be expanding to complete as tourism destination, but if firsly ordered it can be fulfilled. If this regency as destination tourism, it is appropriate as identity of Kebumen as the land of harmony in Central Java.

Conclusion

South Gombong karst area is potentially as geotourism object. The geotourism package concern with Karangsambung geological park packages. Making of package must be appropriate with tourism interest and education background. Tracking of Petruk cave is appropriate with biginner but Barat cave for advance speleologist. For professional federation and university student of earth are appropriate with morphology from Tugu village, limestone mining at Redisari, Jatijajar cave, Petruk cave, Logending beach, Argopeni morphology, Karangbata cape, Pasir beach, Karangbolong beach and Pelus springs package. For common people who will knows about earth can choose Jatijajar cave or Petruk cave and Logending beach, that is appropriate with four hour packages at Karangsambung geological park.

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CAVE TOURISM AN EMERGENT OPPORTUNITY: A CASE STUDY IN CAVES OF POKHARA SUB METROPOLITAN CITY, NEPAL

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Abstract
Caves and cavern structures are traditionally adopted for religious and cultural practices in Himalayan kingdom of Nepal. Cave tourism is one of the modern practices for local touristic approach in Nepal. Cave tourism is popular among the visitors for caving as adventure, wildlife watching as well as artistic structures of peoples‟‟ imagination. Cave tourism is one of the unavoidable parts of tourism package to Pokhara valley. The valley comprises at least 12 cavern features – 9 of them are easily accessible and eligible for show cave. Some were already popular for touristic spot while others are on the way of touristic promotion. Mahendra Cave, Chamere Cave and Gupteswore cave were three popular touristic heritages in the valley. A case study from Mahendra cave alone shows above one hundred thousand people visiting the cave annually generating ten thousand dollar income annually. In addition to employ the local guides, the income has been deployed for developing infrastructures to local school and other public set up.

Key words: cave tourism, Bat fauna, Pokhara, Bat conservation

Introduction

Tourism is one of the leading income generating industry of Nepal. The country is recognized for its unique and pristine natural and world class socio cultural diversity, which is potential for broad spectrum of international tourism. In Nepal, tourism contributes 3.61 % to national GDP and 16% of total foreign earnings to the country including 250,000 direct jobs to people (NTB, 2001). Nepal has experience of gradual growth in tourist arrival from 6000 in 1962 to 500,000 arrivals in 2000 (Ministry of Culture, Tourism and Civil aviation, 2001). Visitors have been drawn by the country‟‟s cultural heritage, religious sites, the Himalayas and the opportunities for wildlife viewing and mountain trekking. Foreign tourists, who use the airways, firstly reach to countries capital city – Katmandu. Then will orient to their destination of their interest. Mountain tourism is the predominant tourism in the country that accounts 43% (Zuric, 1992). Annapurna area ranks most visited among mountain tourism- 62% (Nyaupane, 2006). Pokhara is the transit point to the tourist who destined to Annapurna region. Geographically, the valley is located at 27º 7„„to 28º10' N & 83° 50' to 84°10' E. The area comprises 236 sq.miles ranges within 730 - 1030 m (Gurung, 1965). It is known as the gateway to the trekking round Annapurna Himalayan range

Pokhara has become a major tourist‟‟s hub of Nepal. The city offers a combination of natural and cultural diversities.. The shining background scene of Snowy Mountain on the back providing a pleasant climate, and the romantic scene. The geo- structure of the valley is adding the beauty to the valley. The Water Lake, water fall and caves are major tourist site to the valley. A small valley (236 Square miles) contains about 7 lakes and 10caves within its territory (Oli, 2003; Acharya, 2006).Caves are one of the inseparable aspects of the pokhara tourism. Mahendra cave is the first show cave opened during 1960. This represents the first show cave of Nepal, though several caves throughout the country were traditionally used as cultural practice in Hindu and Buddhist. Cultural practice in cave is another issue of anthropology. Most of the caves in Nepal are culturally bonded to the public. People visit the cave to gain merit worshiping god who inhabit in the peaceful environment of cave. People have believed the cave is the heaven to the god, such kind of practice still exists in Nepal.

Mahendra cave is became the model to aware the possible potentiality of local cave in the country. Later, several caves were locally developed for touristic practice. In Pokhara valley itself, two more caves namely – Gupteswore cave and Bat cave, were designed for show cave during 1990s. At present, about 12 cavern features were documented within the territory of the valley, 9 of them are in human access. Though 5 show caves are locally managed, only three caves are recognized through national level. The income generated from ticket is funded to the local school development.

Ecotourism is the highly discussed aspect of Nepal‟s tourism, but general perception of ecotourism is only linked with the protected areas. Though the caves are the hidden treasure of Nepalese geography, it is poorly stated in tourism sector. Hence, our primary aim is to advocate this potential source of tourism with the existing evidence from Pokhara valley. Secondary aim is to guide the local management of cave system through scientific guidelines to protect the ecosystem.

Result and Analysis

The caves of Pokhara valley, their location and their current status are mentioned in the following.

Table 1. GPS Location, co-ordinates and accessibility of various roosts in Pokhara (Acharya & Phuyal, 2006)

Site No.	Name of roosts and location	GPS Location (Lat-Long)	Characteristic of Roosts
1.	Mahendra Cave	$28^0 16'3''$ $83^0 58'36''$	Located at roadside, famous for cave tourism, simple and easy for caving, highly disturbed roost for michrochiropteran bats.
2.	Bat cave (Pokhara - 16 Batule chaur)	$28^0 15'48''$ $83^0 59'31''$	Located near roadside famous for cave tourism supports for large colony of micro-chiropteran bats. Important for bat study.
3.	Gupteswor cave (Pokhara -17 Chorepatan)	$28^o 10'56''$ $84^o 0'40''$	Located near David's fall of Pokhara regarded as largest cave to Indian subcontinent important for religious activity are speleological.
4.	Crazy Cave (Armala -6 Siplekuna)	$28^o 16'19''$ $83^o 58'52''$	Located about 2 Km. east-south of Mahendra cave. Lies at the base of Kalilek hill range across the Kalikhola at Armala VDC. Important for caving
5.	Peace cave (Hemja - 2, Kaski)	$28^o 11'22''$ $83^o 59'32''$	Located at the base of Sarangkot Hill range across the Yamdi river interesting for caving and bat study.
6.	Putli Cave Bhalam -2 Kaski,	$28^o 12'37''$ $83^0 59'33''$	Located at adjacent VDC of city. Newly explored site, important for caving and speleonology.
7.	Birendra cave Bhalam -2	$28^o 10'44''$ $83^0 59'33''$	Located in front of Putli cave lies in public land: interesting for caving and bat study.

8.	Powerstation cave Pokhara - 17; Seti dam)		Located near the water tunnel Seti Khola hydropower station 20 minute far from Birauta of Pokhara important for bat study.
9.	Sita cave Lekhnath -14 Chainpur	28°14'50" 85°0'19"	Situation at the base of Chainpur hill near settlement. Explored for first time and easy for caving

Tourist Record in Pokhara in Respect to Cave

The tourist record to the valley was documented through visitor record from regional tourism office, Pokhara. Though there is no record for cave visiting tourist with this authorized office. Since, the cave were found locally managed by the public committee, the visitor information were collected from local cave management committee. Among them, Mahendra cave is found directly managed by Bindabasini Higher Secondary School, Chamere cave (Bat cave) was also managed by the same school but was found provided to private people in lease. Another popular cave Gupteswore and Davi‟s fall is managed by the local school- Chhorepatan Higher Secondary School. Private Manager has no secured record for visitor information. Only Mahendra cave‟s visitor record has been obtained for this project.

The tourist record in Pokhara valley during 2000 – 2005 shows around 100 thousands foreigner (See figure 1)

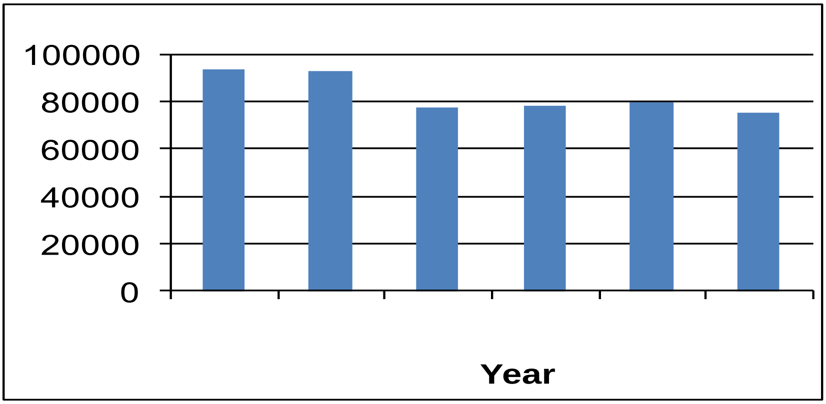
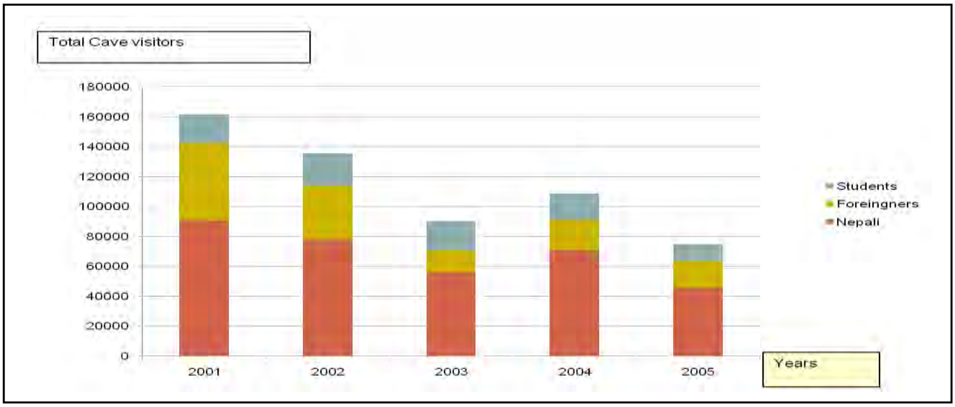


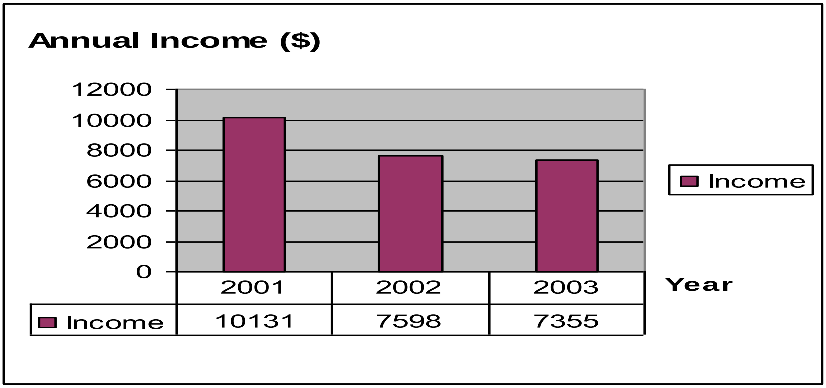
Figure1. Tourist flow in pokhara valley (Source: Nepal Tourism Board, regional sector, Pokhara

The visitor information to Mahendra cave shows three categories of visitor – Foreigner, Nepalese and student. Since the entry fee is designed to facilitate the students than other visitors. The visior record seen at the following diagram represents three categories. The result shows 160 thousand visitors in Mahendra cave annually. Majority of them are Native tourist however foreign tourist are also in significant proportion are highest in number than foreigner. However foreign visitor number is also in significant number (40% in average).



Annual Income from Mahendra Cave

The visitors have to pay as entry fee and cave guide (optional). Foreign tourist charged for 50 NRS, Nepalese non student visitor for 10 NRS and Nepalese student for 5 NRS. The total income to Mahendra cave was found approximately 10,000 dollar annually.



Discussion and Conclusion

Cave tourism is now locally established touristic source in Nepal. Which has no national policy and planning for its sustainability? Previously, most of such caves are only used for religious activities. The advancement in people‟s ideas, new and new source for touristic purpose has been searched since last decade. Caves are found as the latest source of ecotourism in Pokhara as well as Nepal. The income generated from the cave at local level is earning the good credit. The income generated through cave has found significant role in local school management. Gupteswore cave and bat cave are two more adventurous cave in the valley. Though the actual information about cave visitor is not obtained, it seems to exceed more economic input than Mahendra cave.

Though these caves are inspiring the other communities throughout the nation, to develop their local cave as show cave, the ecological aspect of such cave is missing part in cave tourism. Mahendra cave itself is facilitated with electric supply, that extremely deteriorating the cave environment. At present, there is no cave fauna. Chamere cave is roosted by thousands of bats in winter. Though, electric supply is not organized, the other human induced activities are not soundly controlled. Inspired with the cave benefit, other local communities like Armala, Hemja, and Bhalam communities were also already started to initiate the show cave, though the popularity of these site is still at infancy.

In final, the country is going to celebrate a fiesta of tourism **"VISIT NEPAL, 2011**, the new ideas of tourism source is the pre requisite. Cave tourism is now one of the inseparable issues in Pokhara tourism and also several potential caves are documented with archeological importance, which can create more jobs, more opportunity and more recreation to the visitors. Cave tourism is now looking for national identity in Nepalese ecotourism. Hence it is highly recommended to national tourism stakeholders – both governmental to organization level.

Acknowledgement

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LIVELIHOOD STRATEGY OF THE COMMUNITY IN A KARST VILLAGE, GUNUNG SEWU, INDONESIA

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Abstract
The aims of this research are: (1) to study physical characteristic of karst in Gunung Sewu, especially related to water availability and the resource management; (2) to analyze rural livelihood strategies and their response to the draught. Livelihood strategies sometimes have changed dramatically over time and according to local conditions. In a karst village of Tepus, a contrast season between dry and wet season, may stimulate community to have certain livelihood strategy. During dry season, always lack of water for irrigation as well as clean water for household. Most of agricultural lands in hilly karstic topography are non irrigated with poor soil fertility. If there is lack of rain during long dry season, the soil will dry out and fracture. Thus the land only can be cultivated with low productivity *polowijo* crops like maize, cassava and soybean. Sometimes farmers just leave the land temporarily in fallow or *bero*, because they want to restore its fertility or go to get seasonal work in construction and *srabutan* or low paid casual jobs in nearby cities. This practice also has a rational reason to avoid the economic risks of harvest failure. This is called the *paceklik* season, a difficult time to cultivate crops and even find enough water for cattle and human needs. Therefore, many farmers are compelled to lay off agricultural activities and move out of village to find seasonal works in the cities. Dynamic changes of the livelihood strategy are not only influenced by the crisis and drought, but also by the demography and lifecycle of the family, opportunities for horizontal and vertical mobility, social and economic networks, types of commodities produced and technology applied, and last but not least by the capacity and capability of the household itself. Such dynamic changes however, are not only in the hands of the households themselves, but are also influenced by solidarity relations within the community when coping with the crisis. Two types of response mechanism have been identified with respect to household behavior when facing the drought: consumptive responses and productive responses. With respect to consumption during the drought, most households had to increase their budget for daily expenditures especially to get water. Households have to have a storage water tank build in a cylindric cement. They buy water transported by truck from private water vendor. No pipe water available to the community in the karst village. In the past they have to walk 4 kilometer to get water from river inside caves. With respect to production, they have to reduce capacity. Cattle have function as saving. During dry season, many of cattle breeders have to sell some of their cattle to get money. They have to spend more in buying grass for their cattle. It also seems that all households and especially the survival households had to work harder during drought.

Keywords: Karstic village, dry season, lack of water, livelihood strategy

EDUCATION AS TOOL TO RAISE AWARENESS AND VICE VERSA, EXAMPLE OF GUNUNGKIDUL, JAVA

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Abstract

Education is essential to define own problems, to find possible solutions and to implement changes. The same applies for awareness. What needs to be first is not the question of this paper, it aims more to show how important those two goods are and how to deal with them related to citizens of karst regions. The IWRM-Indonesia project is implemented by many sub-projects and one of them is sub-project 9. In its frame an educational concept was developed which serves in this paper as base. This paper wants to give an overview of ideas for education of citizen living in karst regions, especially in Gunungkidul, Java. Another focus is the applied methodology which was used to develop an educational concept for a new waste water/ sludge treatment plant in the hospital of Wonosari.

Keywords: Educational concept, awareness, waste water, Gunungkidul

Introduction

The authors of the following paper want to introduce the difficulty of waste water as a topic of education and awareness. In general it is everywhere in the world a subject whereby the first step is always to get the audience over the discomfort what comes often in mind. The group of authors is working in an Indonesia-German project called Integrated Water Resource Management Indonesia, short IWRM-Indonesia. The IWRM-Indonesia project covers with sub-projects tasks to improve the water situation in Gunungkidul, Java. One of those sub-projects is dedicated and named “Wastewater treatment and waste management - development and implementation of adapted technologies”. Within the frame of this sub-project a survey related to education via expert interviews was carried out in June 2010. There are several forms of education and it is more or less based on three pillars – social, economical and environmental while the trend shows, that more viewpoints towards environmental and social pillars is needed, oriented to the poor and the powerless (Nomura, 2009). While wide-reaching developments in the water sector and their influence for the environment received extensive attention from media and political decision makers, another environmental problem is neglected: increasing pollution of soil and water resources due to point or diffuse sources of domestic, industrial and agricultural activities (AWDO, 2007). One of the most important tasks is to educate the public. The goal is to change the collective consciousness so that residents will realize the need to protect recharge areas and encourage governmental authorities to protect ground water in karst regions (Panno, 2006). Furthermore development and introduction of new sanitary technologies need to go along with a program to enhance public acceptance of those systems and to advocate understanding of the systematic interdependencies between water supply and waste water disposal.

Remarks for water related education in karst regions

Management of water permeates the whole society, touches different administrative units, stakeholders, social classes, urban and rural population, generations and gender (UNDP *et al.,* 2000).

Likewise with engineering developments, structures of water related problems need to be planned and managed in a way, that they are technical applicable, economical efficient, socially accepted and eco-friendly.

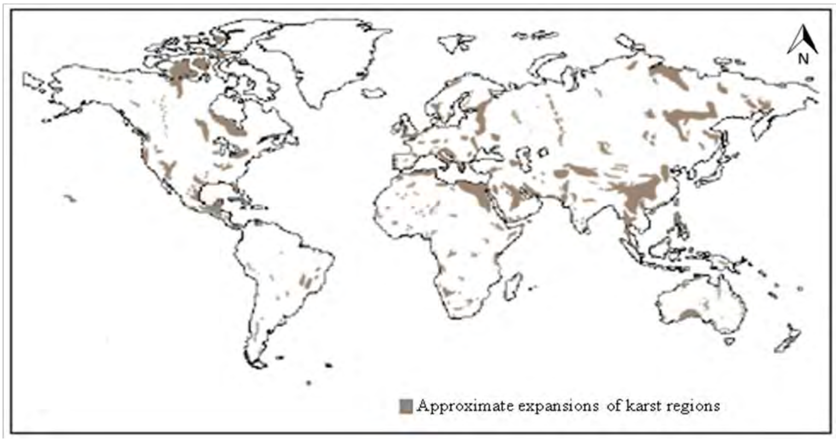

Fig. 1, Approximate location of karst areas worldwide (Guckes, 2006)

Due to the fact that 25 % of worldwide watersheds are karst, it is obvious that associated aquifers are critical resources for drinking water (Panno, 2006). Citizen of karst regions need to have an understanding of their special geological situation. Karst regions are sometimes more and sometimes less populated, but independent from this fact, awareness is needed, that ground water can be easily polluted.

In general education and awareness about water should be improved anywhere in the world. Therefore a lot of material for education and trainings is available, for different ages, for different target groups etc. The same takes effect for planning of water related projects. What is still missing in all these varieties of material is a kind of guide for education in karst regions. This article aims to contribute to this gap.

Suggested points, which need to be considered, are:

- Duration of local water cycle
- Local permeability of karst
- Sanitary zone of well protection
- Risk of ground water pollution
- Necessity for waste water treatment

A famous term which is related to the points mentioned above is Capacity Building. Nowadays it is substituted by Capacity Development or used with further differentiations like Community Capacity Building. If the aim of Capacity Development is not limited to the creation of potential, the access to information and participation in decision processes, but more understood as utilization of skills for long-term aims and results, it explains the core of Community Capacity Building. Community Capacity Building wants to reach everybody in a community. That is why it is important for education related with water issues. On one side water has to be dealt with locally and on the other side dealing with it is always connected to circumstances of a region with all matters. Furthermore has to be taken into account, that changes in one group or one subject will affect others as well. The aim of Capacity

Development in the water sector is to improve the quality in decision processes, in single disciplines as well as during the process of planning and implementation between all stakeholders to follow the aims of the project. Therefore possibilities to engage in political decision processes and developments should be created. These include access to information, participation in decision processes as well as influence on political structures (OECD, 2009).

Situation in Gunungkidul

Circumstances in the region. Sanitation systems in Gunung Kidul consist of either pit latrines or pour-flush toilets (latrines). Pit latrines are commonly found in rural areas while in urban areas, pour flush latrines take the lead (Mueller, 2009). Open defecation only happens at a low scale in the rural areas (Insani, 2009). Fecal waste in the pit latrines is simply deposited in the pit whereas for the pour-flush latrines, fecal waste is flushed off into a pit or septic tank. Although the health authority Dinas Kesehatan recommends construction of septic tanks with drainage trenches (Mueller, 2009), the fact that each household has to bear the cost leads to construction of unsealed septic tanks without drainage trenches. The liquid phase infiltrates into the ground and the septic tanks are hardly ever emptied, thus posing an evident contamination potential to groundwater in this karst region.

The current situation about waste water and its treatment is inadequate. The environmental agency KAPEDAL and Ciptakarya (DPU) are the most important institutions in Gunungkidul in the field of waste water. They implement local waste water treatment facilities, but due to financial insufficiency they only can implement them as pilot projects. Furthermore both institutions conduct awareness and educational work in whole Gunungkidul. The governmental project Sanimas involves beside Ciptakarya/ DPU and KAPEDAL also the German NGO BORDA in tight cooperation with the Indonesian NGO LPTP in Gunungkidul. Till all citizens are reached by this program it is still a long way to go. This way requires more executing institutions, because the usage of latrines or insufficient sanitary facilities is still widely spread.

Fig. 2, Open septic tank used as waste disposal in Wonosari (Oertel)

Gunungkidul region is characterized by substantial economical and technological differences between the rural and urban areas. Therefore, spatial differentiated solutions and an emphasis on decentralized as well as semi-centralized waste water and solid waste treatment are inevitable.

Most of the region is rural area and problems concerning health, economic possibilities or infrastructure facilities are reality. This situation added with water scarcity during dry season and bad (if existing) conditions of sanitary facilities are contributing to amplification for the byname of the region as “poor house of Java”. Many citizen live with less than $US 2 per day and around 14 % never visited a school.

Table 1. Educational level of population in Gunungkidul (after Bappeda Gunungkidul 2008 in Puspitasari, 2009)

Education level	%
No formal education	14,20
Elementary School	30,06
Junior High School	17,47
Senior High School	10,43
Academy level	5,80
University degree	2,30

The behavior related to waste water and solid waste is shaped by opinions and taboos linked with traditions and habits as well as with social and ecological conditions. In Islamic communities a latrine shouldn´t point in the direction of Mecca and public sanitation facilities are avoided by women (Wegelin-Schuringa, 2000). Indonesia is an Islamic oriented country; hence a sensitive handling is needed. In the project area in Gunungkidul 91 % of the population are Muslims (Puspitasari, 2009).

Talks about these topics in big rounds can lead to embarrassing feeling of the participants. Surveys on household level which were carried out in the frame of the IWRM-Indonesia project show, that is was unproblematic to gain data related to facts, e.g. how many buckets of water do you need daily or what is the size of your septic tank? To gather data related to habits about waste or waste water from others is more difficult. To reach a holistic improvement, it is important to build up trust, to be able to talk and discuss freely about waste water and solid waste.

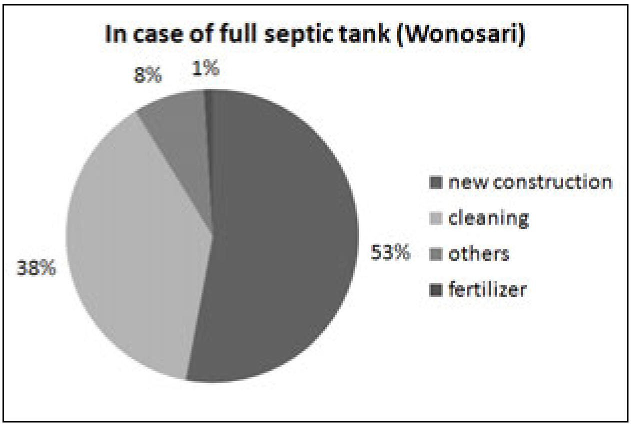

Fig. 3, Taken action if septic tank is full (Mueller, 2009)

Continuous and broadly defined educations in the field of waste water doesn´t take place in Gunungkidul. Based on the described situation it is necessary to establish waste water treatment facilities in a wide range which are operated and maintained in a proper way for solving waste water problems steadily.

So far the knowledge about water cycle or waste treatment with relevance of a karst region is very limited. Knowledge about the connection of health with water is also marginal, even when diarrhea is still under the “Top 10” of diseases in the region (Insani, 2009). One explanation might be that they are confronted with other problems which seem more important and urgent for them. Pollution of ground water can´t be seen immediately and so with easier to suppress. Therefore waste water is an issue which can be easily dealt with like “out of eyes, out of mind”.

Pollution of natural and essential resources like air, soil and water often harms the most vulnerable, because of lack of education and material resources to work against “natural injustices”. Effectively implemented Capacity Building is a major factor for changing these circumstances. Capacity Building can be implemented by using education and awareness of citizen. Commitment and participation of the society are essential to ensure that facilities will be used regularly, maintained continuously and that the financial aspects are guaranteed (Gutterer *et al.,* 2009).

Waste water and solid waste treatment are in large part a social phenomenon as a technical one. Therefore it is important to know necessary background information about cultural, social, economic and environmental circumstances before real planning takes place. This applies notably for implementation of new technologies (Wegelin-Schuringa, 2000).

Methodological Frame

General remarks. Learning means hard work and humans would prefer to do more pleasant things. That`s why informal, formal and extracurricular education always will be necessary. Methods and instruments of learning need to be questioned and adapted for particular situations. As mentioned above, motivation is the first bid, otherwise as good as the method will be, it won´t be successful.

Education and awareness can be formal and informal, but the transferred information need to be filtered, sorted, selected and intensively prepared, before they are offered to any learner. The transformation of information to knowledge and skills are the core of learning processes and the prerequisite for a successful transfer of technology. Challenging for strong partners for the implementation of a project is listening to the weaker ones, the accurate listening what the community is communicating.

Capacities develop after UNDP (2009) within three factors: enabling environment, organizations and individuals. Those three levels influence each other – the strength of one depends on the others.

For development of capacities UNDP uses a five-step approach:

1. Engagement of stakeholders
2. Assessment of capacities
3. Formulation of an answer to close the defined gaps
4. Implementation of this answer
5. Evaluation of capacity development

For the field of sanitary supply, especially for poorer population, BORDA names factors which should be considered for planning and implementation for community based sanitation (Gutterer *et al.,* 2009):

- Sanitary programs should be accompanied by health and hygiene enlightenment
- Approval of local leadership is needed to avoid obstacles by social hierarchies

- Social structures and levels, sanitary behaviors, claims of properties and restraints for changes in infrastructure should be understood and included
- Women are often decision makers in household level in reference to domestic hygiene and sanitary behaviors. Therefore they should be involved actively, already at the point of mentioning problems to define reasons, to introduce possible solutions and to be actively involved in the decision making process.

If awareness campaigns or trainings are planned it is important to figure out the “right time”. Periods like sowing, weeding, harvesting, lean seasons or festivals should be avoided. Workshops or trainings for communities should cover all ages in a balanced way and requests motivated and energetic persons. Furthermore gender balance need to be assured. Before an implementation starts, an overview about the current situation on-site is a must-have. Possible risks need to be uncovered and estimated. Instruments or methods which are usually used give information about their possibilities and limitations, e.g. which kind of presentation is usual or what is the educational behavior of the target group? Furthermore motivation plays an important role as well as the regional opinion about the topic.

Used method for educational concept in the frame of sub-project 9. The IWRM project runs already a couple of years and a lot of data is compiled. One part of sub-project 9 is a two-stage anaerobic sludge treatment. This treatment facility is located within a container and hopefully it will arrive at its final station, the governmental hospital in Wonosari by beginning 2011.The reason for the development of an educational concept is this container. As mentioned earlier, especially the implementation of new technologies need to be accompanied by Capacity Development.

The survey which was carried out was mainly based on interviews with different groups of stakeholders. Questions of concern were for example: Who will operate and maintain this treatment plant? How about their educational background? Are they supported by the administration of the hospital? How does the structure of the hospital look like? Who need to be involved in the educational concept? What are other issues in the hospital which gain more attention? What are usual education methods? Are already trainings or awareness campaigns in Gunungkidul related to waste water existing?

The interviews were used to figure out existing capacities from individual, organizations and the enabling environment. Interviewees were coming from the administration (financial and planning department) of the hospital, technicians working in the hospital (six persons) as well as governmental (3) and non-governmental organizations (6) dealing in the region with environmental education. The guidelines for the interviews were adapted for each target group and all were carried out as an open conversation, to gain as much as possible information. To start developing an educational concept those interviews were afterwards analyzed and combined with field observations and discussions with related persons were carried out.

After existing capacities were assessed and gaps of knowledge and awareness were defined, target groups for the educational concept were specified. Based on research it was show that it´s not enough to define the technicians of the hospital as only target group. The hospital has to be seen as social system and so with also medical stuff, patients and their guest, as well as the administrative level of the hospital are taking their role in capacity development. Because educational concepts always need to be tailored for existing circumstances, the developed concept will not be explained in detail here. More attention is given to outcomes which are transferable and results which need to be kept in mind while working in Gunungkidul.

For realization in the field of awareness and education clear and easy understandable materials are needed. Reading capability in rural areas with elderly population needs to be checked, because illiteracy is still common. The usage of pictures is recommended; they should have a connection to the region and offer the possibility for identification.

Fig. 4, This poster has the "right" message, but doesn´t offer identification with the region or by shown figures.

Materials which are used from governmental and non-governmental institutions for environmental education can serve as starting point and be developed further more. The question of what kind of materials can be used is quite wide, but we figured out, that CD-Rom or computer related material should be avoided, due to weak spreading of its use. Better would be to use pamphlets and small handbooks with a lot of pictorial material, because also reading is not a common activity for most citizens.

Some words for organizational matters related to capacity development. First of all it takes time, several months or years, and there is no guarantee that it works out as planned. But as better the preparation the outcomes will probably be close to the aims. To work successfully you need to win the trust of the population and this may take time you can´t plan in advance, once you got it, it is the best base to ensure motivation and continuous engagement for the topics in the community. For example the timing of awareness campaigns and trainings should not be underestimated as mentioned already above. With respect to local habits and needs you convey citizens that you take them serious.

Once environmental education is started, monitoring and evaluation (M&E) request the same attention as the planning and implementation. Only when M&E is carried out carefully successes or failures can be seen and changes are possible on time. So far M&E is not gaining the required attendance in Gunungkidul.

If they are carried out, they are done only by NGOs, which need to do it also of funding reasons. Governmental institutions often lack funding to carry out their tasks successfully, what uncovers further needs of improvements.

Small Changes with Great Effects

This part of the paper aims to give some practical ideas how awareness and education can be awaked and that simple methods already can lead to different perspectives.

- "Silent communication" with posters, stickers or wall paintings in toilets.
  - Water cycle of the region – to establish sensitivity with it
  - Waste water and its treatment – to show positive impacts of it and to show what could happen, if the situation is not changed
  - All posters should include a contact person/ responsible institution of the region for further information and assistance
- Material which is given to participants can be handed out two or more times – so they can spread the information to their neighbors, family members or friends.
- For implemented facilities: Information board easy understandable to explain the facilities behind, to pique citizens curiosity.
- Questioning citizens how much money they spend per month/ year in their household for medical treatment for water related diseases like diarrhea, this amount is cumulated with households in the village, or within the community. The aim of this questioning is the comparison of money they spend for medical treatment related to expenses a waste water treatment would request.
- Another more drastic questioning and demonstration is called "water & shit". A glass/ bottle of water is passed around between the participants and they drink the water. In advance a hair with shit is prepared and lies close to the scene. After the glass/ bottle reach again the moderator this hair is dipped in the water shortly, illustrating a fly. Who still wants to drink it? This exercise aims to wake awareness by using disgust (Kar, 2010).
- In combination a vision for the next 10-20 years could be formulated.
- The moderator or also contact person should be someone who is well respected in the community and can mediate as one of them.
- During our survey we have shown with simple material how a waste water treatment plant is working (Figure 5).

Fig. 5,
Simplification of functions in a waste water treatment plant. In the upper jar sedimentation process was simulated, middle jar for coagulation process, in the lower right corner a plastic bottle filled with local sand served as filter simulation, the "treated waste water" outflow was collected with a small jar.

Conclusion and Discussion / Remarks / Further Considerations

Solutions for water problems are not only a question of water availability, they depend on many other factors, also on those who are responsible for water management (Biswas, 2008). The competencies and capacities of institutions, social political conditions and expectations of all stakeholders during planning, development and management processes have to be considered to improve living conditions in a sustainable way. Therefore environmental education needs to consider and needs to be supported by the business level (economics), government (legal body), education facilities (e.g. schools, universities) and by the society.

Education and awareness in the water sector will always require the cooperation of several disciplines. For countries like Indonesia it is important to include several aspects and to mediate a holistic understanding. The authors of this paper are also aware that they have a “western” view on education and awareness and “non-western” viewpoints are needed to enrich the discussion and to step into action. To motivate citizens to improve their waste water and waste treatment is no simple task. The key is the understanding of influencing factors of the current situation. A further challenge for mobilization is that dealing with urine and feces is something personal and on the other side the missing of sanitary facilities is a public issue which exceeds the individual level.

Projects or education programs or further trainings should all be based on a demand-driven approach, to ensure that they are more realistic than idealistic. Citizens need to define their problems, possible solutions and wished improvements by themselves and with their words and to enable them to do so education and awareness is needed.

A big chance to empower citizen in the dealing with water related topics and to let them feel and see that they are successful will also have positive effects to other problematic issues of a region.

Acknowledgement

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USE OF INTERPRETATIVE MEDIA (POSTER AND FILM) AS EDUCATION MATERIALS FOR TOURISM DEVELOPMENT OF GOA PUTIH IN GUNUNG WALAT INTERNATIONAL EDUCATION FOREST

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Abstract
Goa Putih (White Cave) is one cave in Gunung Walat International Education Forest with high potentials in natural resources, apart from the interesting non-biological resources such as the varieties of cave formations. Unfortunately, these potentials were not well documented, untouched and lack in management. Utilization of Goa Putih by the communities would have impacts on the cave ecosystem and in the long term could destroy the cave environment. Therefore, there needs to be an effort to provide cave users with sufficient knowledge and skills. The aim of this activity was to produce education posters and film as interpretive media for the public through collection of data on cave fauna, cave conditions, socio-economic and cultural conditions of the local people. Inventory of cave fauna were conducted through interviews and field search, using Forward Method and software WCOM 32, while information on socio-economic and cultural conditions of the local communities were gathered from questionnaires and interviews. Two types of posters were produced, based on its contents, i.e., persuasive and scientific posters, while a documentary film was made for the duration of 11'23" picturing the condition of the cave and the surrounding environment, cave ecosystems and Gunung Walat International Education Forest.

Keywords: Gunung Walat International Education Forest, Goa Putih, interpretative media, education

Introduction
Goa Putih (White Cave) is a recreational cave situated within the Gunung Walat International Education Forest that has high potentials in natural resources including terrestrial and aquatic biodiversity apart from the interesting non-biological resources such as the varieties of cave formations. Goa Putih also exhibits a social function as a place for ritual meditation for the local community. Utilization of Goa Putih will no doubt have impacts on the cave ecosystem and may degrade quality of the cave ecosystem and surrounding environment. Cave is non-renewable resource due to its long formation. Therefore, there needs to be an effort to provide cave users with sufficient knowledge and skills that could minimize the impacts of their activities on the cave ecosystem. Furthermore, being an Education Forest, Gunung Walat must use all its resources to educate the local communities as well as other visitors on the importance of natural resources and their interactions with the environment.

One such effort can be carried out in the form of educational materials such as interpretive media that can be use to establish awareness, appreciation and understanding of Goa Putih. Interpretation is an educational activity which aims to explain and communicate something by using the objects original, from experience and use of illustrative media. Interpretation aims to develop awareness, appreciation and understanding of visitors who visited the area (Sharpe, 1981). Media interpretation according to Rahayuningsih (2006) is a material or medium to communicate with visitors in view of the interpretation of such photographs, posters, slides, film and video films and sheets or book concise information (brochures, booklets, leaflets, etc.). Media interpretation can be a tool to foster awareness, appreciation and understanding of visitors who come to Goa Putih. As forms of media, posters and documentary films are produced in this research to disseminate information of the resources in Goa Putih to local communityy and as education materials for tourism development. It is expected that through this, the community and visitors will participate in the preservation of Goa Putih.

The aim of this research is to develop interpretive media for Goa Putih, with the following specific objectives: (1) Inventory of Goa Putih Cave fauna and the surrounding flora; (2) Mapping of Goa Putih Cave; (3) Identification of the socio-economic and cultural conditions of the local communities: (4) Creating posters and documentary film of Goa Putih.

Methods

The research was conducted for 6 months in Goa Putih situated within Gunung Walat International Education Forest, in Cipeureu, Hegarmanah Village, Cicantayan District, Sukabumi, West Java . Materials were collected into two stages, the first was February 12th to 14th in 2010 and the second stage was in March 7th in 2010. Data processing and cave mapping were conducted beginning in March until April. Posters and documentary film were developed in April until May, then screened in Cipeureu on May 22th in 2010.

Data gathered comprised of cave fauna diversity, floral diveristy of the outer cave environment, as well as the social, economic and cultural conditions of the surrounding local communities. The methods of information gathering were as follows.

Cave fauna

Data on cave fauna were obtained through direct observation along the corridor of the cave and places like in a dome, ornaments, ceiling and underground streams. Unidentified species were captured. Large-sized species were collected manually using hand or tweezers, while small-sized species were taken by using a brush, then put into plastic bags. Bat species was captured using bat net because the ceilings of Goa Putih were low and narrow. Captured bats were placed into bags that have been provided. The identification of species were carried out by describing the special characteristics of species and match it to the *field guide*. The results of the identification were recorded.

Flora

Documention of flora around and outside of Goa Putih was conducted through interviews with the local guide. The local names were then compiled under the list of flora.

Cave condition

Cave conditions were obtained through the documentation and mapping. Documentation is an image / photo recordings of Goa Putih ornaments and internal conditions. While mapping is to map the state of cave by using *forward method*, involved 5 members who serves as leader, targets, sights, writer and descriptor. Manual method of mapping was done using the *plan section*. Furthermore, all data obtained were processed and analyzed using software WCOM 32.

Interpretative media

Data and information gathered under this aspect included history of the cave and public preferences to interpretative media. The methods used to gather data and information were: (1) Semi-structured interviews on the history of the cave and characteristics of respondents that includes personal data of respondents and their preference to posters and films. Respondents were determined using *snow ball* method, a method where the number of the sample was not determined by the interviewer but informants in the field to determine the next informant who considered significant until the information required has been completed; (2) Structured interviews with questionnaire to obtain insights of visitors knowledge about the existence of Goa Putih and their preference of the interpretative media. Respondents were taken using the *convenience sampling*, based on the willingness of visitors who were encountered in the field.

Design of Interpretative media

Data and information gathered on the preferences of respondents were used as consideration in designing posters and documentary films.

Results and Discussion

History of Goa Putih. The water from the watershed in Gunung Walat International Education Forest flowed towards the outside of the cave (south) into the cave to Cipeureu toward Cimandin then to Pelabuhan Ratu to Citarik and Cimanin. In the past, Goa Putih was known as Goa Cipeureu, taken from the name of the area where the cave is located. The word "ci" of Cipeureu meant water and "peureu" meant rust. The name was later changed to Goa Putih since many visitors who came to this cave had the intention to purify themselves. Furthermore, the cave was also known as “A Well of Seven Ladders Cave” that has a mystical value and sacred by the community.

Goa Putih was the legacy of The King of Siliwangi. In 1965, Goa Cipeureu was used by the DI (Darul Islam) as hiding place. In 1982, the cave started to be traced and explored by an Indonesian caver, R.K.T Ko. In 1983-1995, the cave became known to the local community and others, such as the people from Jakarta, Sukabumi, Surabaya, and Yogyakarta.

Biodiversity. Cave is one natural phenomena that is unique where its attractions include some outstanding value of cave ornaments and diversity of its fauna that are often use for tourists‟ attractions. Samodra (2000) remarks that cave is the place of beauty, mystery, entertainment and adventure, thus it can be developed as place for recreation and sight seeing. Flora and fauna of the cave are component of the cave ecosystem that make a food chains and food webs as various complexities. Therefore, the disruption to flora and fauna of cave, such as exploiting fish and bats, can result in disruption of ecosystem balance of cave (Sumarlin, 2007). Goa Putih Cave comprised of a diversity of fauna, with 15 species found (Table 1) and 8 species of flora found around and outside the cave (Table 2).

Table 1. List of fauna found in Goa Putih in Gunung Walat International Education Forest

No.	Name of fauna	Location
1	Dirty frog (*Bufo asper*)	Wall, transition zone
2	Spider a	Roof, wall and alley
3	Spider b	Wall, dark zone
4	Spider c	Wall
5	Cicada	Floor, wall, ceiling and the sewer cave
6	Termite	Floor, transition zone

7	Black ant	Floor in transition zone
8	Small white insect	Guano (bat dropping) in eternal dark zone
9	Small black insect	Around guano in eternal dark zone
10	Centipede	Wall, floor and alleys in dark zone and eternal dark zone
11	Fish	Flow of water in dark zone and eternal dark zone
12	Shrimp	Found in the streams in dark zone.
13	Crab	Behind a small rock, flow of water in dark zone
14	Bat	Ceiling in eternal dark zone
15	Millipede	Floor, wall in dark zone

Table 2. List of flora around Goa Putih

Local Name	Scientific Name
Akasia	*Acacia sp.*
Bambu	*Bamboo sp.*
Damar	*Agathis dammara*
Kopi	*Coffea sp.*
Kapulaga	*Amomum cardamomum*
Pisang	*Musa sp.*
Rambutan	*Nephelium lappaceum*
Singkong	*Manihot utilissima*

Goa Putih is an active cave. Topography of the cave entrance has a sloping contour with 4 entrances both horizontal and vertical. The cave also posessed a large passage called the elephant room with an area of ± 6 m². The length of Goa Putih hallway was 197,6 m, calculated from station 0 to 33. Generally, the condition of the hall was narrow, difficult with a muddy floor and watery (Fig. 1).

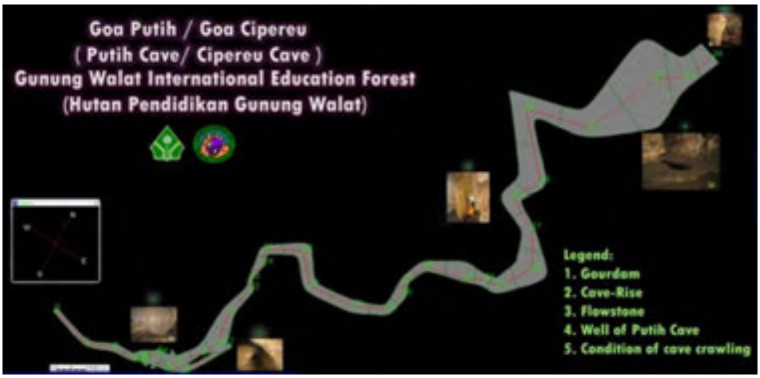

Figure 1. Overview of Goa Putih

Interpretive media. Muntasib (2003) emphasis the importance of media as element of communication, because during communication process always occurs a process of delivering information and sources of information or sending a message to the target or recipient of information through the media. Muntasib and Rachmawati (2003) say that interpretive media is a means, methods, records or equipment that can convey messages to the public.

Based on the results of the interviews and questionnaires, as many as 60% of 30 respondents (local community and visitors) stated that they have known the existence of Goa Putih since childhood. Usually they visit the cave with friends. As many as 65% of the respondents further agreed that the most attractive objects were cave ornaments. Respondents preferred to see the poster that full of pictures compared to the full article (77%) with a bright color (50%). Results of interview can be seen in Figure 2 below. As for the documentary film, respondents preferred movies with a duration between 10" to 15" (67%). These informations were further used as the basis to produce posters and documentary films about Goa Putih.

Poster was created into 2 types, a scientific poster (Fig. 3) and persuasive poster (Fig. 4) of size 41,5 cm x 59 cm. Persuasive poster was made in 2 different designs, hence there were 3 posters produced. The documentary film was made with a duration of 11"23" picturing the condition of the cave and the surrounding environment, cave ecosystems and Gunung Walat International Education Forest.

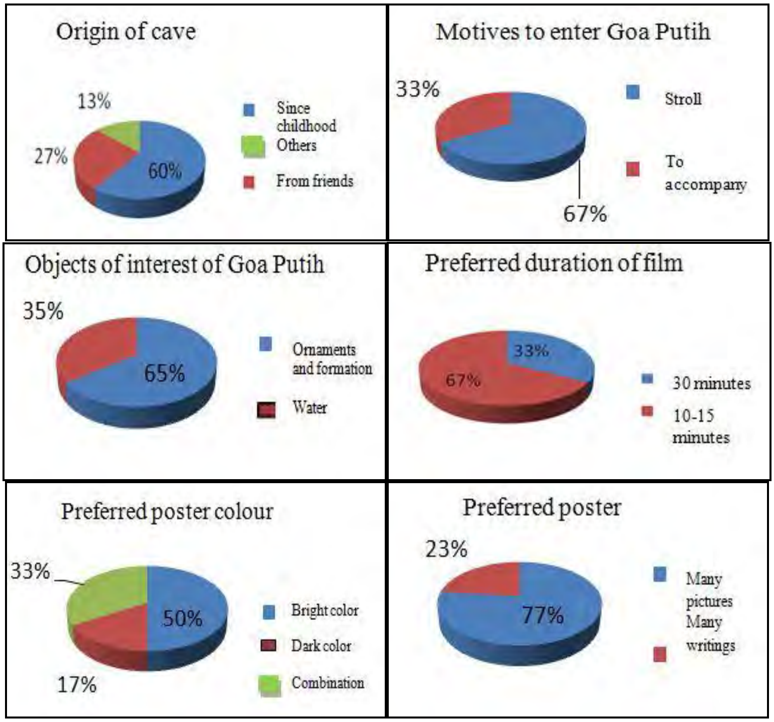

Figure 2. Preferences of local communities on interpretive media

Figure 3. Scientific Poster

Figure 4. Persuasive Posters

Prior to the film screening and distribution of the posters, only the men entered the cave and only for ritual purposes. Those who had entered the cave did not have any recognition on the diversity of cave fauna as well as the attractive cave ornaments. When the film was shown to them, they were interested to watch the film. In fact, after they watched the documented film as well as looking at the posters, they gained better knowledge of the potential of Goa Putih.

Based on the screened documentary film and distributed posters in the villages around the cave, the local people were interested to preserve Goa Putih and urged the cave to be developed into a formal tourist cave. They recognized that Goa Putih had potentials to attract others to come there, so the cave will be better-known.

Conclusion

Provision of interpretive media of the use of posters and film on Goa Putih had proved to be used as education materials. These media increased better understanding of the local communities and visitors of the potentials of Goa Putih. With the placing of the posters around the villages allowed the local community to see the potentials of Goa Putih such as the cave fauna, ornaments, underground stream and internal conditions. Existence of Goa Putih in Gunung Walat adds the value of Gunung Walat as an Education Forest.

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HEALTH AND NATURAL HAZARDS IN INDONESIAN KARST AND CAVES

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Abstract
Indonesian Cave Explorers, Karst Scientists and the medical authorities ought to know which hazards are potentially present in Indonesian caves and karst regions. Lack of publications in Indonesian Medical Journals and the press concerning these health hazards can potentially lead to epidemics in karst regions. Prophylaxis against some diseases, if available, should be carried out. Natural hazards in Indonesian karst and caves are flooding and earthquakes. No measurements were ever taken to determine the presence of radioactive Radon gas in Indonesian caves. Pulmonary Histoplasmosis was never detected among cave explorers. Malaria, Dengue, Weil"s disease sometimes inflict karst scientists and cavers. Nearly all karst springs, near villages are contaminated by Coli bacilli. Foreign Cavers and Scientists must be informed about these potential hazards.

Keywords: infectious diseases, parasites, pesticides, cave flooding, earthquakes.

Introduction

Medical Journals, worldwide, have not reported health hazards in Karst and Caves. Only very view publications are available, limited to cave radiation hazards discussed in National Cave Management Symposia in the United States (Ahlstrans, 1976; Aley, T, 1976; Beckman R.T, 1977). At the U.S.-Yugoslavian Symposium, Dubrovnik, 1976, on Karst Hydrology and Water Resources, only one paper was presented concerning Epidemics in Karst Areas of Yugoslavia, caused by spring water contaminations (Pokrajčić B, 1975).

The hazards of *Histoplasmosis* (contamination through inhalation of *Histoplasma Capsulatum* containing bat guano dust) are relatively well-known amongst cave explorers all over the world. A report of rabies, suffered by cavers, caused by inhalation of the rabies virus containing bat saliva droplets was once reported in the United States.

It is mandatory to get adequate information about health hazards, facing cave explorers and karst scientists all over the world. Many known potential diseases lurking around the corner must be identified, anticipated and competently prevented. Some illnesses, mainly caused by inherent local customs, should be recognized and coped with.

It is however a necessity to also mention *en passé* some diseases, not strictly endemic in karst areas, but prone to be hazardous to cavers and karst scientists who must wade rivers, cut a way through bushes and jungles, to reach the caves and karst regions in Indonesia.

Waterborne Diseases.

Indonesian Karst and Caves are not exempt from spring well contamination, due to the large rock and soil permeability of karst formations. Samples of “spring waters” in many karst areas of Java have been examined in laboratories. All of them is contaminated by *Coli bacilli* (Ko R.K.T, 1999). It is indeed crucial to know that springs in karst areas are recognized by locals as clean percolation water, while water tracing methods repeatedly revealed that these springs are merely resurgences of small surface streams that go underground nearby. These rivulets are used by locals to defecate in the wet or dry season and also to bathe their buffaloes and goats in the wet season.

Epidemics of *typhoid* and *para-typhoid fever*, *hepatitis A* and *gastro-enteritis*, usually preceded by heavy rains in the catchments of springs are often the rule (Ko R.K.T, 1999). The unidentified carriers of these diseases present a great danger for the population in endemic foci of intestinal infectious diseases in Indonesian karst regions.

Pesticides.

Percolation water seeping through thick layers of limestone, in the Petruk Cave, South Gombong Karst, Central Java, turned out to be unsafe for drinking, as reported by the team of Ecologists from the University of Pajajaran. Ecology Institute. They revealed In 1990, that DDT pesticide contaminated dripping water from stalactites and flowing water from rimstone dams (Ko R.K.T, 1999). Investigation revealed that local farmers on the fields, above the Petruk Cave, used DDT as pesticide, violating the Indonesian Government"s rule, that the use of DDT for agriculture is strictly banned. DDT sprays may only be utilized to eradicate Malaria causing *Anopheles Sundaicus* mosquitoes.

Weil's Disease *(Febris ictero-hemorrhagica).*

Cases of this morbid disease, obtained through ingesting food and drinks, contaminated by cave dwelling rodent"s urine, are up till now only reported by foreign cavers (Eavis A, 1989). One French caver even died, after contracting malaria and Weil"s disease concomitantly in East Kalimantan (Robert, G., 2003). Up till now, no Indonesian cavers contracted this disease, probably due to the habit to stay and prepare meals in nearby villages. Not in cave interiors or cave entrances, usually utilized as convenient campsites by foreign cave explorers. But this could also be an indication, those Indonesian cavers never venture too far away from villages to find and explore caves and karst.

Histoplasmosis.

Up till now, no Indonesian cave explorer and karst scientist have ever contracted ailments due to histoplasmosis, although some publications of histoplasma capsulatum containing bat guano are available There is however a report stating that some Indonesian village boys contracted this disease after repeatedly playing kite near dusty cassava plantations, using bat guano as fertilizer (Ko R.K.T, 1999).

Malaria.

Malaria is not restricted to karst areas, but it is still the most annoying - if not fatal - disease, threatening cave and karst expedition members, who must pass malaria ridden jungles and bushes, rivers and shores. Not all karst areas are malaria ridden. But those in Kalimantan and Papua (former Irian Jaya) are malaria invested. The malaria parasites in these regions are all resistant to *quinine* and *chloroquine*. Prophylaxis or treatment with e.g *paludrin* and *fansidar* repeatedly failed. The only effective prophylaxis and treatment is with *artemisinin* (*mefloquin*) developed from Chinese herbal medicine. Many foreign and domestic cavers are repeatedly sick with malaria. The nastiest is being periodically bedridden due to relapsing *Malaria tertiana.*

Dengue.

Dengue is caused by parasite containing mosquito (*Aedes aegypti*) bites in the morning or afternoon encountered during jungle trekking and bush walking at daylight.

Leeches.

Leeches are everywhere in the wild. Not only restricted in or near rivers and water-basins, but also in jungles and bushes. They suck blood, the victim very rarely becoming aware, that his or her skin is invested by leeches, since no pain is felt. Some species of leeches are known, the most frequently encountered is *Haemadipsa zeylandica* and *H. picta* (Whitten, T., 2000; Whitten T, 1996; Whitten, T., *et al.,* 1987) Leeches are sometimes seen on the ceilings and overhanging walls in some caves, inhabited by many bats. They feed upon the bats.

Ticks.

Bats are often invested by ticks. These ectoparasites frequently contain *plasmodia* causing malaria in mammals. Ticks are constantly scratched away by the hosts and found abundantly on cave floors. These ticks are very attracted to human skin and blood. Indonesian cavers are often bitten by these parasites, causing very itchy skin nodules lasting months without adequate treatment.

Poisonous Snakes and Pythons.

First of all, it is very important to identify which snake species are frequently found in different Indonesian islands. There are many endemic species.

Sumatra has 131 snake species, Borneo/Kalimantan has 133 species. Java has 84 species. Sulawesi has 15 species. Only about 12% - 14% are venomous. They can be classified as *Pit vipers (Trimereulus fascialus de Rooy 1917, T. wagleri. T. elobobaris)* and *Cobras (Naja sputatrix, Bungarus candidus)* (Whitten, T., 2000; Whitten T, 1996; Whitten, T., *et al.,* 1987)

Venomous snakes are found in many places where they find their prey: rats, frogs, bats and bird"s eggs. Although not restricted to karst areas and caves, snakes are sometimes found inside caves or near some cave entrances (Buniayu cave, Nyalidung karst, West Java, Luweng Jomblang, Luweng Gunung Bolong, Central Java). These snakes were sometimes flushed into a cave during flood. Some fell down into a cave through a karst window *(aven).* They become part of a cave-ecosystem or die in the cave interior. In the Gunung Bolong Cave, Gunung Sewu Karst, near the famous Jomblang and Grubug collapse sinkholes, a couple of King Cobras on the cave floor were ready to attack rapelling FINSPAC members in 1990. None were found in 2008, when Belgium cavers rappelled down this cave.

Non-venomous snakes, the longest ones being the Pythons, are sometimes encountered in karst areas. There are two species of Pythons in Indonesia. The longest one, which can be more than 9 m long, found in Sulawesi and Kalimantan is called *Python reticularis*. The smaller one is found in rocky areas: *Python molurus*. *Pythons* usually inhabit caves, dwelt by bats and swiftlets. They often nestled near small cave entrances, where bats and swiftlets pass, on their way and out of the caves. Pythons are considered dangerous to man, since they can strangle and break the bones of anyone disturbing their habitat. So be aware of Pythons near cave entrances, inhabited by numerous bats (e.g. Lawa Cave, Bali).

Poisonous Plants.

There are some plant species, found in many islands, the leaves of which can cause severe itching, even blisters on the skin, when accidentally brushed on. The most notorious are the *Rengas* leaves (*Gluta renga*), *Pulus* (*Laportea stimulan*), *Rawe* (*Mucuna prurient*), *Lateng* (*Semecarpus spp*) found in certain jungles (Nurdjito, 2010). Also the needle like structures covering Bamboo sheets,

Radon Gas Exposure.

It is unfortunate indeed that in Indonesia, exposure to radioactive Radon gas is not yet recognized a risk to health. The presence of Radon gas in Indonesian caves is never determined. Not a single Radon gas detection apparatus is available in shops. It is therefore not known, if caves with stagnant air, contain this radio-active gas, more easily causing lung cancer in the many heavy smoking Indonesian cavers. (Ahlstrans, 1976; Aley.T, 1976; Beckman R.T, 1977)

Excess Carbon Dioxide in Caves.

The ceilings of caves underneath teak forests are frequently covered by many roots hanging down the interior of caves. Carbon dioxide inside these caves is abundant, frequently causing *hyperventilation* and accompanying *dizziness*, with *disorientation,* due to *hypoxia* (Ko R.K.T*,* 1999). Caves occupied by thousands of bats, when explored at daylight, cause the same symptoms of hyperventilation due to excess of carbon dioxide and deficiency of oxygen (Ko R.K.T*,* 1999).

Kidney Stones.

One must experience camping in karst areas and boiling water in a kettle to observe the thick layer of crystalline limestone precipitating at its bottom. More than one centimeter thick if used to boil water for one week. It can thus be deducted, that large amounts of *calcium* are being consumed by people living in karst areas, drinking karst water and cooking in it. No wonder that in many karst areas in Indonesia, *nephrolithiasis (kidney stones)* is prevalent (e.g. Madura, Gunung Kidul).To cope with this problem, the greenish mineral Zeolith can be used to filter the *calcium* (Ko R.K.T*,* 1999)

Endemic Goiter.

Iodine deficiency is the main cause of endemic goiter, but other dietary substances that interfere with thyroid metabolism, called "*goitrogens*" can aggravate the effect. A well known example is *linamarin,* a *thioglycoside* found in cyanide containing cassava roots and leaves. If not adequately soaked or cooked to remove *linamarin,* it is hydrolyzed in the gut to release cyanide, which is metabolized to *thiocyanate. Thiocyanate* blocks thyroidal uptake of iodine. Soy-based flour and *tempeh* can also inhibit iodine absorption. Without added iodine, goiter and hypothyroidism can be produced in infants.

Endemic goiter is found is some Indonesian karst areas (Central Java South West of Gunung Sewu Karst at the coastal area of Wonogiri, near Sadeng village). Although the villagers consume dry fish high in Iodine, they eat a lot of cassava roots and cassava leaves which are goitrogenic substances (Ko R.K.T*,* 1999; Haque, N.R *et al.,* 2004; 13). Cassave is frequently kept for months by drying (*gaplek*) or by fermentation (*gatot*). Cyanide content in cassava is therefore highest in the dry season.

Natural Hazards.

Flooding in caves is routinely encountered during the wet season, but the scope of floods, as occurred in East Kalimantan Karst is beyond description. The French cave explorers have found huge logs clogged into some caves.

The easiest way to determine the potential of cave flooding is to look at the cave floor sediments, walls and ceilings. If the cave floor is covered by thick layers of mud, the walls depicting high "flood lines", the ceiling showing a collection of surface debris, stuck onto it, it is wise not to enter such cave in the rainy season. Already more than 15 Indonesian cavers died when exploring caves in the wet season. Five FINSPAC members had overcome a torrential flood when exploring the post-syphon part of Goa Jatijajar in 1999, by evacuation to higher parts of the cave corridor for more than 20 hours.

Earthquakes are frequently encountered in all islands, except Kalimantan, since Indonesia boasts possessing the most volcanoes in the world. But much more prevalent than volcanic earthquakes are earth movements due to the subduction of continental plates. Paroxysmal movements of these plates frequently cause tectonic quakes of different magnitudes The worst recorded magnitude is 7,8 Richter scale in Aceh, followed by deadly tsunami.

We regularly examine the interior of frequently visited caves, after strong earthquakes. Inside the Buniayu tourist cave in West Java, an area most often disturbed by quakes, and Petruk cave in Central Java, no signs of cave ceiling or cave wall breakdown were observed by us. There was only a shifting of rock piles already in place for a long time, inside the Buniayu cave. Tiny meandering passages where cavers used to squeeze and slither through them, are now totally clogged.

Even the caves in the Lok Nga karst, Aceh, are undisturbed by the disastrous earthquake in 24 December 2004. Aceh student cavers were at that particular moment mapping a cave. The cave shuddered accompanied by a tremendous rumbling. They fled panicky towards the entrance and ran out of the cave. The deadly silence after the quake did not give a clue that many friends and relatives of them at that sad moment lost their lives to the tsunami which totally destroyed large towns and small villages.

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COMMUNITY PARTICIPATION ON CONSERVING SPRINGS IN THE KARST AREA OF GUNUNGKIDUL DISTRICT, YOGYAKARTA, INDONESIA

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Abstract
Karst area of Gunungkidul District of Yogyakarta, is characterized by an area having critically water resources. This area is suffering from drought, especially during dry season. However, people may have some water from springs for domestic water supply which evenly distributed over the area. The critical area of water resources has identical to the physiographic units: Baturagung (north), Ledok Wonosari (middle), and the Thousand Mountains (south). The three units physiographic influence on the distribution of springs in the District Gunungkidul. Likewise with the community, physiographic will affect the distinctive culture to adapt to the environment, one of which is local wisdom. It's going to give a huge donation in the effort to conserve resources, particularly water springs. The objective of the research is to identify the characteristics and sustainability of springs as a function of water resources to meet the needs of community. The specific objectives defined: identify community participation in conserving the springs; and design the springs' community-based conservation. The method used in this study is the analysis of data collected by field survey and depth interviews; and formulation of the results of field interviews in relation to the facts about climate change and the characteristics of springs. The study shows that in the area has relatively a lot of springs having discharge from less than 1 l/sec to about 1000 l/sec. Water quality of the springs are relatively good, except those for the hardness. The community uses spring water for the irrigation and domestic uses. They have local wisdom to conserve spring water, especially protecting spring water from contamination. The community realized that there have some changes in climate, especially the rainfall pattern. As the springs are used for their water supply the management of the springs has been well applied in the area.

Keywords: spring, conservation, community participation, local wisdom

ARCHEOLOGY AND PALEONTOLOGY

THE GEOMORPHIC ASPECTS OF "PONJONG – RONGKOP AXIS ZONE" IN GUNUNG SEWU AREA AND ITS IMPACTS ON PREHISTORIC CULTURAL PROCESSES: A GEOARCHAEOLOGICAL STUDY

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Abstract

The "Ponjong - Rongkop Axis Zone" is a proposed term to describe an morphological anomaly of center part of GunungSewu Karst Area in the Southern Mountains of Java Island, Indonesia. The anomaly lies on its morphological orientation which forms north-south axis at the middle of GunungSewu, and flanked by two ancient intermontane basins of Wonosari and Baturetno. Some characteristics of this zone relate to geomorphic and geological aspects when the tectonic processes was uplifting Wonosari Limestone in several stages during the late Pliocene and/or early Pleistocene. The karstification processes controlled both of surface and subsurface landscape evolution subsequently and resulted multi-level cave"s mouth on the hill slopes. Prehistoric inhabitants explored this zone and more than fifty caves was occupied during the Late Pleistocene to Mid-Holocene period. Compared to other parts of GunungSewu, this zone is located farthest away from the coast (approximately 30 km) and has the highest topography with the most extensive corrosion plains. This situation raises an assumption that the zone first appeared above sea level when the uplifting processes had taken place, and has the most advanced karstification consequently.Three methods of analysis are applied, such as: (a) analysis and mapping of cave distributions, (b) terrain analysis and geomorphological mapping and (c) analysis of archaeological contexts. This cross-disciplinary approach also uses the Geographic Information System (GIS) technology as geodatabase, geoprocessing, and geovisualization tools in analyzing several layers, both terrain and archaeological variables. By analyzing correlations between the geomorphic aspects, cave site distributions and archaeological contexts, this study reveals the prehistoric cultural processes in the anomalous zone.

Keywords: Gunung Sewu, "Ponjong-Rongkop Axis Zone", morphological anomaly, geoarchaeology.

PRELIMINARY RESULTS OF A PLURI-DISCIPLINARY FRANCO-INDONESIAN PROGRAM ON THE HUMAN OCCUPATION PROCESS IN EAST-KALIMANTAN KARSTIC ENVIRONMENT

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Abstract
Karstic environments provide a large range of rock-shelters and cave-nets and have always been „goldmines" for archaeologists, since they allow a better conservation of remains. Therefore, the first investigations conducted in East Kalimantan by Franco-Indonesian teams have focused on the numerous and impressive karst ranges and outcrops. More than 150 caves and rock-shelters have been surveyed since 1992 in the East Kutai district only, including 36 ornate caves containing a very specific rock art expression.
Archaeological excavations, since 2003 in cooperation with central and local Indonesian authorities, have provided important insights into human history from the past (from 12,500 YBP) until the proto-contemporary periods, in a large triangular area (Sangkulirang-Bengalone-Merapun).
After seven years of investigations in the deserted area of GunungMarang, our project has moved 50km northwest towards the Merabu district (south of Berau Province), where large karstic outcrops and a complex rock art expression are present. In addition, Lebbo' local communities are still occupying these remote territories, with a relatively traditional way of life.
Excavations conducted in Liang Abu, since 2009, have been an exceptional opportunity to combine complementary approaches, including ethno-historical, ethno-linguistic, archaeological (ceramic, lithic, archaeozoology) and genetic investigations. This aims to explore genetic and cultural links between Lebbo" communities and their living neighbours, their putative ancestors buried or deposited in caves and rock cracks and broader issues related to the settlement processes, origin and dispersal of the Lebbo" communities linked to karstic environment.

Key words: Caves, Rock Art, Prehistory, Karst, Borneo

Introduction
A recent discovery

Since 1992, and thanks originally to the exceptional interest of one of the cavers trekking across Kalimantan provinces from West to East in 1988[i], a large amount of archaeological discoveries has been later gained. Being eventually and mostly involved into the survey of caves and rock shelters of East Kalimantan"s karstic outcrops, a Franco-Indonesian team, has since regularly let merge some parts of the deep past of that area which was still an archaeological blank. Altogether years after years more than 130 caves have been visited and checked, within which, more than 30 contain totally unexpected and determinant Rock Art paintings.

During the last decade, more precisely, the last 5 years, French and Indonesian archaeologists and cavers, have chosen to mainly survey two large karstic areas located, one North of Sangkulirang (along the Sungai Baii), the second Northwest of Sangatta (along the Sungai Marang)[2]. Since 2007 another important karstic area, some 50 km towards NW of GunungMarang (along the Sungai Lesan) has begun to be surveyed and archaeologically studied (see Fig. 1).

The first two large areas, each roughly spread over a 40 by 20 kms space each, appeared to be especially geologically well enough structured and rich concerning archaeological remains of all kinds. These large karsts,

uplifted from tectonic pressure movements after the Myocene, some 60 millions years ago, have developed a common feature consisting in three main geomorphological networks of cavities and galleries. The third one, has not been that much uplifted and being lower, comprises more or less only two main nets of cavities.

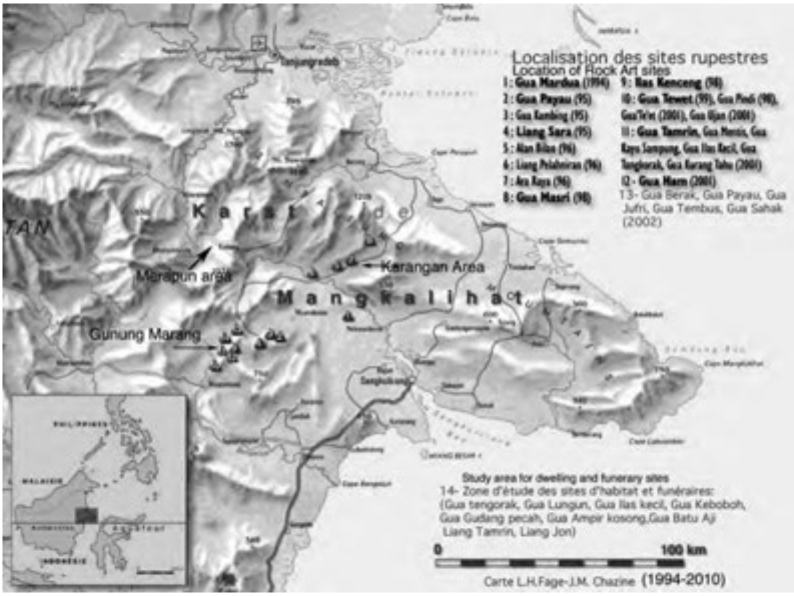


Fig. 1.A complex hierarchical cavity net use

[2]Aftermanyyearsdevoted to randomcaverssurveys in karsticoutcrops, a MOU wassignedwith the PuslitArkenas, whichprecised the cooperation frame and level, for engagingour Franco-Indonesian teams intoarchaeologicalsurveys, excavations and technicalresearches. Weoweourwarmestthanks and acknowledgment to all members of the Puslit –thenPusbang- Arkenas in Jakarta and Banjarmasin as much as PindiSetiawanfrom the ITB, withoutwhom the main bulge of ourdiscoverieswould have neverhappened. Thanks and regards to the many official or privateauthorities for theirfinancial or logistic supports: French Ministry of ForeignAffairs in Paris and SCAC in Jakarta (2001-2010); Total-Indonesia (2001-2003); Rolex Awards (2001); Société de Protection des Banques (2002-2003); National Geographic Society (2003) and all Institutions involvedwithour local aides, guides and boat drivers, who have permittedthesediscoveries.

These superposed strata, located differently in the uplifted outcrops have proved to be dwelled and used differently along the time. At a broad level of description (see Chazine, 2005, for a more precise insight), the lower one has been usually used as common or daily dwelling places since oldest periods, i.e. before 10.000 years ago, at least, before the end of Pleistocene. It contains all the classical occupation remains: food remains (bones and shells), stone tools workshops with their waste piles, charcoals and fireplaces. Ceramics are often present from surface to the upper or latest levels (surface to minus 40 to 60cm), corresponding to post-Austronesian occupation phases. Within many of the adjacent cracks or crevices, funerary ceramics associated with human bones are neighbouring with some late “Dayak” or similar cultural communities who have settled around in the vicinity and left their wooden mortuary coffin burials and displayed personal items.

An intermediate net of cavities, located between 50 to 150 m higher in the cliffs, has had various or composite uses. In a few cases, a punctual dwelling has happened, presenting smaller occupation clues than the lower level. These latter may have been used as refuge places in case of threaten from neighbouring or invading enemies. Nevertheless, the main use of these intermediate caves, cracks or dry rock shelters has been devoted towards succeeding funerary purposes.

There, a very large amount of earthen funerary urns presenting a large set of differenciated decorations had been regularly observed during 2001“ to 2007“ field sessions. During 2004' field session, while extending a new test pit in Keboboh caves complex, our colleagues Jatmiko and Udin have also unexpectedly unearthed two burials. Once unveiled from surrounding deposits, they appeared to be in a flexed position, a feature, which would correspond to a pre-Austronesian inhumation process, i.e. before 3.500 years B.P. These two burials have been completely extracted with the contribution of Dr. Harry Widianto late 2006“, but DNA and C14 determinations have not yet been successful, postponing thus any common substantial report.

The third level of cavities, practically located up to 300 m high, has not provided until now, any if almost no occupation remains but paintings. Some of these caves contain a totally specific Rock Art expression (see www.kalimanthrope.com website for detailed pictures), which induces to interpret these places as having had a very specific function. We will see later in this paper, what kind of activities the particular isolation, remoteness and emptiness of these caves and rock shelters would have had in the past.

This natural stratigraphy, which has been selectively exploited for cultural and precise goals, is one of the specificities observed in East Kalimantan's (inasmuch as Palawan's) karstic outcrops (see locations on Fig. 2). The regularity of that distribution (29 positive cases upon a total of 32) makes it a noticeable landmark, which local communities have themselvesemphasied.

Ethno-historic surveys

The short summary below presents the results of recent ethnographic surveys late 2009/2010. Basically it will relate the spatial and geographical dimensions of the MangkalihatKarstic range to the cultural background/ethnicity of these people in order to distinguish them from their Dayak and Punan neighbours (who all came from the interior of East Kalimantan, the Apo Kayan /Bulungan areas).

Therefore, the different uses of the caves/rock faces by Ulun Lebbo’ in the Lesan valley based on the 14 different locations surveyed have been more precisely sorted:

1. The openings in the upper parts of the caves were used in the past as observation sites (especially Liang Ketepu, GuaBadak/Liang Tengkorak...), as the smoke coming from the neighbouring Dayak raiding parties could be seen from above ;
2. A refuge area from the head-hunters during the same period. The Lebbo' living in scaterred swiddens locations would move temporarily to lower mouths and openings in the Karstic caves to hide themselves (they would do the same during rainy, bad weather spells, from December to February and in May);
3. Cavities were used as burial sites for monoxyle log-coffins (*lungun*) and the dead rolled in bark cloth, pandan and rattan mats (*kelasa'*), *circa* 1840s-1960s ;
4. A sample of the grave goods has been checked, it include trade items (Malay brass objects, Chinese/Dutch/English ceramics, glass beads...) and local Dayak goods (*parang* blades, *beliung* head...) besides items produced or gathered by the Lebbo' themselves (dart quiver *(telo')*, carved wooden implements, wickerwork, animal teeth...).

Practically, the former beliefs, mortuary practices and cosmological concepts of the Lebbo' interviews have provided stories, myths, legends, ritual practices...etc related to their previous hunter-gatherers background providing links with some Rock Art representations (i.e. bees nest paintings and dances).

Material Culture. Currently, the main handicraft activity is basketry/wickerwork with a large range of types (storing baskets, carrying-baskets, backbaskets, pouches, bird's cages...). Both man and women do it. Most of these is made from rattan, some from bamboo, and show an elaborate decoration, in black dyed rattan – and more rarely dyed in red - on a light color ground. Geometrical and stylized patterns are varied, also of smaller size than the similar Dayak type, and the many patterns are nicely integrated in the general ornamentation of the artifacts. It will be worth comparing these patterns to those of the decorated pottery found in the caves in the Karst area. Wood carving has been studied from a small sample of log-coffins' ornamental patterns and ritual sculptures.

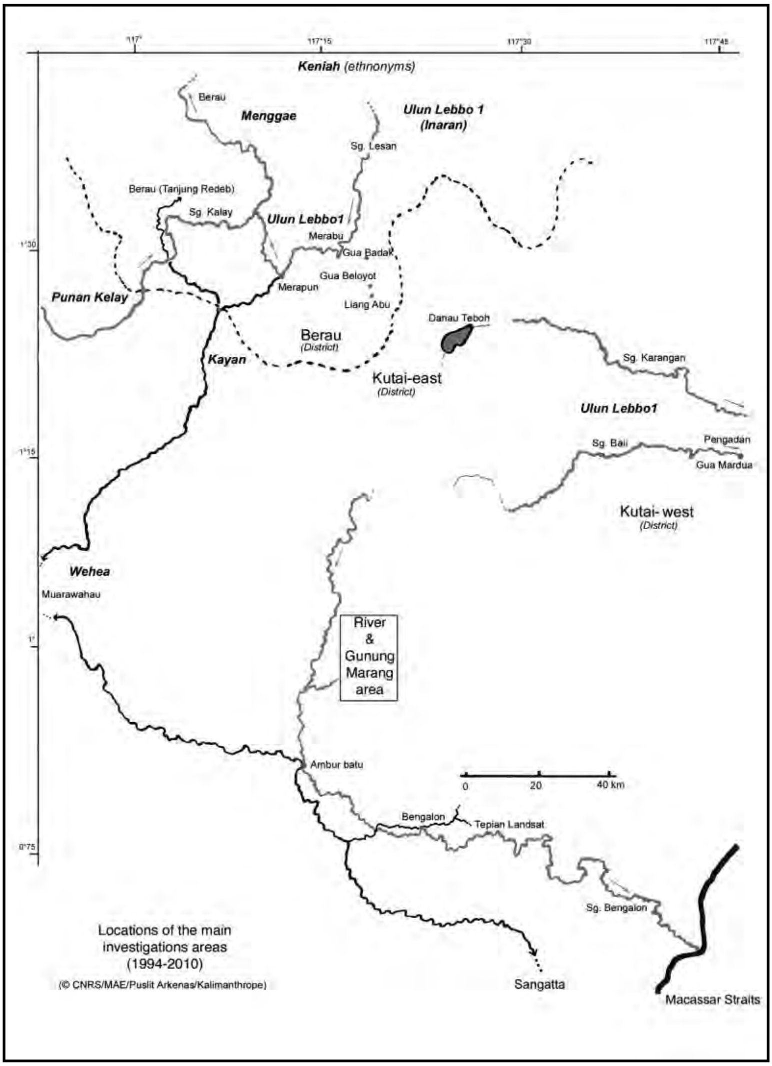
Language. Overall the everyday speech looks like a creolized form of Malayu/Dayak trade language - the so-called *basaumum* -, while the specialized lexicons and the oral literature retain more distinctive features, lexical links to the *Rejang-Sajau* grouping which span from the Western Coast to the Eastern coast of Borneo. Items recorded during the survey include a Swadesh basic world-list (SWL 200 words), phonology, verbal system and affixation, sets of simples sentences, adjectives, superlatives, conjunctions, interrogatives, kinship terminology, animals and plants names, personal names. Samples of oral literature, an invocation (*jampi*), sections of an epic (*tenar*), *tiwa'* songs have been taped but not yet transcribed. The recent changes (lexicon, phonology) from the Lesan'Basap' isolect to the current Lebbo' speech have been documented.

Settlements patterns and history. The oral history of the people in Merapun, Merabu and Mapulu shows that they have come most probably from the coastal area of Talisayan. Three main routes connecting the Eastern and Western areas of the Karstic range are known, from North to South :

- The Tabalar River route to the Tintang area and then in directions of the North (Inaran) the West (Lesan) and East (Perondongan) ;
- The Dumaring to Sangkulirang route ;
- The route from BatuPutih reaching the upper Manumbar River and down to the sea

In the past, these forest paths and river courses were used also as trade routes for the forest products (guttaperca, bird"s nests, damar...) collected by the former Basap peoples - now

UlunLebbo‟ and UlunDarat territorial groups - in the former Kutai and Berau sultanate‟s areas. The three present Lebbo‟ villages in the Lesan have split from a single, central, settlement, named BatuMelintang, about the 1920s (see Fig. 2).



Cleary during the last centuries these meek, non-violent hunter-gatherers, have been pushed and squeezed up by the speakers of Kayanic and Kenyahic languages, who have moved in large numbers from the Western Coast to the North Eastern coast of Borneo.

Besides the possibility of an invading population in the Talisayan-BatuPutih coastal strip, the occurence of piracy and forest fires may have been a factor in the scattering of a hunter-gatherer/horticulturist population into the Karstic range during the last 2000 years.

Probably the people – the first settlers in the region – have been going back and forth between the coast, the coastal highlands and the rugged interior, exploring every valleys and mountains, Karstic peaks and caves. They do have a preference for walking in the range rather than using dugouts. This knowledge was stored and passed upon from one generation to another in the different communities. They still make use of it when hunting, fishing or collecting forest products, especially honey and bird's nests. Currently the whole population of the remaining Basap/Lebbo' and UlunDarat, would be about 4,000 individuals when all territorial groups in the greater region around the Karstic mountains are considered.

Anthropo-biological background

Island Southeast Asia has become a key in the processes of migration, dispersal and contact from an early time period. In the late Pleistocene, these regions were situated within a southern dispersal corridor, enabling a rapid dispersal of modern humans across the Old World. Many millennia later, the development of long-distance seafaring technology eventually placed the region, and particularly its island components, at the centre of new maritime corridors that traversed vast swaths of the Indian and Pacific Ocean (e.g. Holocene expansion of Austronesian speaking populations), and reached regions as far as Madagascar to the west or Pacific Islands to the east. These exchanges have been intensified during the last millennia with the development of commercial strategies involving Arabia, East Africa, South India and Island Southeast Asia.

Within this context, the population history of Borneo (Kalimantan) is relatively unknown. Due to its location at a strategic crossroads (Indian Ocean/Pacific Ocean/Australasia/South Asia), a multidisciplinary approach, including archaeological, linguistic and genetic studies, appeared to be necessary to establish the spatial and temporal pattern of settlements and the relationship between the different settlement waves.This will be conducted through biological data collection:

We should begin soon to collect high quality biological samples in the form of saliva (and/or blood) from populations speaking three different Lebbo" dialects (Lesan River), and two neighbouring population groups of non Lebbo" speakers for comparisons. We plan to sample around 100 unrelated individuals per group. Samples will be collected using the most efficient kit available on the market: Oragene DNA Self-Collection kit. All samples will be collected and analyzed with informed consent protocols approved by each individual and the local community leaders. Likewise, in the second phase, populations from eastern Kalimantan will be sampled.

Linguistic/demographic data collection :

To provide an interpretative framework we will collect basic linguistic/demographic information for each biologically sampled individual, using a standard questionnaire. Information gathered will include place and date of birth, current and pre-marital community affiliation, number of children, and language(s) spoken (where spoken and in which context). Parental and grandparental affiliations will also be recorded when possible.

At a very small scale approach, contacts and explanations have begun to be provided to the local people to let them understand the interest of searching their ancestry and check it with the burial remains as much as some living samples. As far as we may appreciate their welcoming, it should be possible to verify how near –or far- from anthropological truth, their oral traditions have remained.

There too, differences between karstic environment and low land communities practices may probably reveal variations in cosmogonies and rituals associated with natural elements.

The importance of earthenware

Amongst all dwelling and occupations remains largely found in the lowest, and -less frequently- in the median levels, comprising all kinds of lithic and bone remains (to be more precisely presented later in this paper), the earthen wares are bearing a large amount of directly readable data. As it is limited to the “Austronesian techno-culture” phase, starting around 3,500 years ago, it is too early to consider it as a general objective "leading fossil" or "chronological marker". Nevertheless, at least for East-Borneo prehistory, its main characteristics may be used for discriminating styles and periods, inasmuch as local firing processes.

Since our cooperative archaeological Franco-Indonesian program has started last 2003, implying excavations conducted in selected caves and rock shelters, findings of different kinds of earthen wares ceramics both on surface and within stratigraphied dwelling places layers, have enabled us to separate common and/or funerary items.

Apart and after the very first surface findings from the Sungai Baii sites (1994 to 1996), the most complete assemblage has been gathered in the Karangan, then the Marang rivers areas (1998 to 2008).

Broadly speaking, the display of motives and shapes of pots which have yet been sorted are very similar to those which had previously been excavated or collected in Sarawak, Sabah and even Palawan island and the North-Western part of South East island Asia. Some of them being directly similar to the basis reference from "Sa Huynh-Kalanay style" long ago analysed then proposed by Pr. Solheim II (Solheim II, 1964).

They show eventually not much difference with many of those which have been studied long time ago also in Sarawak“, Brunei“ or Sabah“ sectors, by numerous and well known previous archaeologists (Harrisson, Solheim, Bellwood… etc). In East Kalimantan, styles vary from the oldest periods (around 3,500 BP) to the most recent surviving influences (Iban or so-called communities), not older than 200 to 100 BP. Decorations vary from paddle and anvil technology using different cord, square carved, mat and granulated motives, to all the possible numerous incised decorations. Some cases present also geometric excised designs or motives. Stamped features (including linear "grain rice-like" impressions) may also be combined within variable incised schemes. The incised motives comprise geometric, curvilinear and/or stencilled/stamped impressions. The use of specific tools, producing sinuous designs obtained from bivalves shells (cardium-like) which has been yet found only once in Sarawak (Solheim II &Tweedie, 1959), has been now also collected within two caves (GuaTengkorak and GuaKeboboh) along the Marang river (see location map). Macro-observations show that the prints differ one from the other, indicating at least two different shells/tools and probably makers.

A different motif implying two or three narrow parallel scratching flat points has been regularly observed in the Liang Abu and the vicinity presenting a different style of decorations. From the Liang Abu“ excavation squares ceramic was present from surface until some 30cm depth, whereas the mean value of the appearance of ceramics may reach 60cm. Unfortunately C14 datings are not yet converging enough to fix with enough precision the chronological spread of ceramic, be it borrowed or self masterised. Broad results show a predominance of open and flat lips but not many carinated bellies. From forms, shapes, variety of decorations (incised, stamped, paddle impressed, puntuated...etc) sizes and distribution, it is still almost impossible to decipher precisely the different uses of these ceramics. The fact is that they do not differ much from jars, which have been observed in funerary cavities or shelters. This would express a noticeable difference with the Marang area, where funerary sherds are not that much well fired although heavily decorated.

Lithic Technology: the "Kutai" flaking process

Until now, compared to GunungSewu for instance, no real important flaking or exclusive workshop place has been uncovered, which may probably been explained by the local extreme paucity of raw materials. As observed in Marang and Merabu"s sites, the large display of geologic components (up to 10) does not mean that it was easy to find a large amount of stuff to knap with. The rather large variety is not converging towards a large amount of raw stuff. Therefore, the lithic management economy had to be adapted to the local possibilities.

They are mostly flakes, whose statistical distributions appear to vary slightly. As first stressed by J. Espagne (see 2003" and 2004" reports), then totally confirmed in Liang Abu test pits, the frequency of Kutai flakes remains proportionally high, and lasts from buried ancient levels (above 12.000 y. B.P.) to sub-surface locations. This special flake is characterised by a diminishing flaking action from the external face of the bulb, which provides an especially strong sharp curb edge, different from the Kumbewa flaking strategy. Besides this sharp edge, it provides a point in 70% of the cases. The uses of this microlith-like flake would have been mostly intended towards rattan or vegetal matters.

Nevertheless, the main bulk of the lithic technology would confirm that the "Pleistocene knapping technology" has lasted until very recent periods (some centuries ago) although ceramic technology was spread all over Kalimantan. It shows some seemingly contradiction concerning the acceptation or borrowing of foreign technics, by prehistoric hunter-gatherers. They have clearly conserved or adopted only what was corresponding to their needs and logically culturally acceptable.

Another unexpected and puzzling discovery corresponds to some lapita-like remains including teeth decorated motif and burial features similar to the Teouma cemetery recently discovered in Vanuatu, i.e. a skeleton whose head and one forearm bone have been extracted a couple of years after first burial (Spriggs& Bradford, 2005). These surprising discoveries far inside East Kalimantan may be related to the Bellwood"s obsidian flakes findings from Sabah and connected to the very first lapita-like influences, which have possibly happened and followed (somehow like a retroverse action from R. Green & A. Noury pers. comm. 2005) the complete Lapita expression eastwards of Nusantara area (Bellwood, 1984) and Papua new-Guinea (for more precise descriptions see Chazine&Ferrie, 2008).

Bones preliminary survey from Liang Abu

Species represented at Liang Abu are mainly local wild boar (*Sus barbatus*) and Kanchil (*Tragulus sp.*). According to butchery marks, these species both have made up for the usual diet of the rock shelter"s inhabitants. More than 70% of breakage patterns were made on fresh bone. More than 30% of bones were burnt. Beside cooking activities (probably collecting bone marrow for broth), handicrafts have taken place on the premises such as tool making on bone (needles and spatula or awls). Fragments of ocre-tinted tortoise shell might have been used as containers or mortars for this material. Small pieces of crocodile skulls have probably been used for decorative purposes, such as stamping ceramic artefacts found on the site.

It is not yet possible to specify the kind of human settlement we are dealing with in Liang Abu, whether it is a shelter for temporary stops devoted to specific activities, seasonal occupation or permanent dwelling. An excavation should be undertaken in that aim.

Surface findings on the ground of near rock shelters in the Merabu area have provided a similar distribution of crushed, burnt and selected bones signifying that hunting games –at least during the recent periods- have been based upon the same mean animals. The numerous tiny dry galleries and cracks opening at the level of the ground provide a huge number of shelter-holes for many animals, rather easy to trap.

Ornate caves

Equally important by their number inasmuch as by their contents are the ornate caves which have been discovered since 13 years in that area. Being established by now that the oldest representations are older than the end of Pleistocene (10.000 years BP), they constitute a determining core of the South East Asian prehistory.

Mainly characterized by a high number of negative hand prints, it shows also different manners of using not only combinations but also overpainted hand stencils (for a large set of pictures see http://www.kalimanthrope.com). That late characteristic let it differs from all surrounding cultural expressions, and even of all worldwide examples. Its origins are not yet clearly established but analyses have proved to be dated from more than late Pleistocene (10.000 BP). Being unique in that part of the world, and presenting more links with its far neighbours from Australia, than with the closest islands (Sulawesi, Moluccas and Western New Guinea, mainly described by Kosasih, O"Connor, Delanghe&Arifin) this would induce to consider differently the settlement and cultural diffusion of Rock Art in that large area. One new hypothesis would be that long time before the end of Pleistocene (10.000 years ago) and during its move towards Australia, a group would have settled –or escaped- in that remote –and protecting because of its karstic morphology- area of East Kalimantan and locally kept that painting tradition and its usages. The fact is that there is no apparent aesthetic, neither figurative link, between the rock art painted in these caves and any ethnographic "Dayak" style figurations.

Although the presumption of a specific "Austronesian" origin has been proposed and would for many cases fit there with the local "prehistory of history", mainly in East Nusantara, by some scholars (Ballard, 1992), that explanation does not match observations for East Kalimantan.

The presence of a few general figures in some caves, presents some analogies, with some common symbolic "ideograms", in frequent use in South East Asia. For instance, the arborescent feature found in GuaTewet linking a minimum of 9 differenciated negative hand prints, may evoke possibly the universal "tree of life" scheme.

Apart that possible reference with some "Dayak" cultural expression, it would possibly also be perceptible in what seems to represent the large bees hive and the "honey tree" painted in Kerim cave. It is known from ethnography (Van Geddes, 1959; Hopes, 1997), that much respect was paid to any honey tree and a specific dance used to be performed by communities, after or against bad or difficult events or periods.

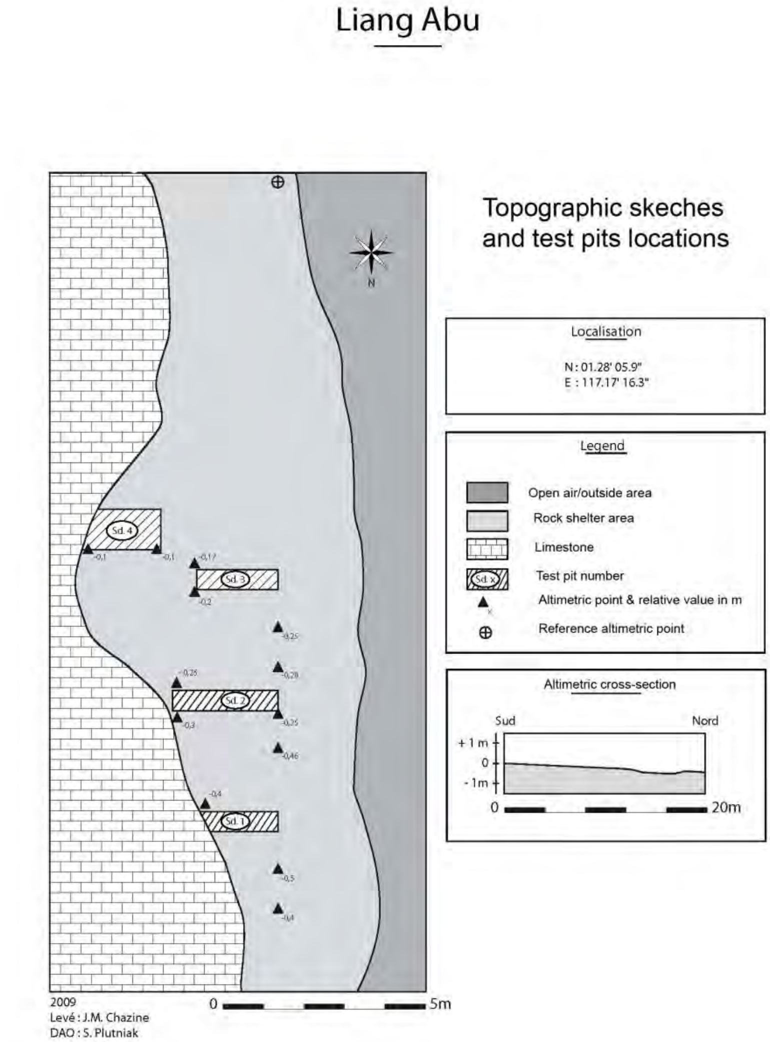
Would these representations ("tree of life/honey tree") and customs (honey tree dance) pre-exist before the arrival of Austronesians, followed themselves later by generic Dayak cultures, is still a possible hypothesis. This late one is forming the bulk of possible eventually consequences of the contacts between Pleistocene populations, long time settled in South East Asia. Samples from Niah or Tabon, show that peoples -Homo sapiens sapiens- were already living there since 30 to 50.000 years, compared to newcomers like Austronesians, some 5.000 years ago only. What kind of exchanges or inter-influences have thus and then happened, and in which directions, is still a puzzling question, breeding discussions between specialists.

The amazing number of cavities, automatically related to any karstic environment has provoked a specific adaptation from the dwellers and somehow framed beliefs and rituals slightly different from their original featuring molders.

Conclusions

As a matter of fact, birth origins of "Lapita cultural complex" inspiration is still a question debated between scholars (see the numerous Lapita and IPPA Symposia held since the past decades). It broadly varies from Eastern to Western sides of New Guinea, and our late discovery is more precisely trending towards the Western origin or clustering area. Other sites from insular SEA have also provided somehow lapita-like ceramics, although not using the very specific dentate stamped technique.

Some of the most well-known originate from Kalumpang area (Sulawesi) and Talaud islands, or even in and around Taiwan, have already been described by Bellwood (1997). The appearance of such ceramics in East Kalimantan, corresponding simply to the extension westwards of its possible influence, is just enlarging the probabilities area and does not present any contradiction with already established hypothesis.



The very remote location of these human dwellings and occupations may be directly linked to the specific karstic environment. During the settlement process, these places have probably been first explored for their numerous hidden places and then occupied for safety reasons as emergency refuges. That process would explain that not all -and even a very small number of- "Austronesian" technico-cultural items have been adopted and definitely influenced, i.e. changed the life of previous Borneo‟ forests Aborigines. The remoteness of all karstic outcrops has probably had an important influence, functioning noy only as as emergency refuge places, keeping thus their tracks in caves as much as themselves under protection but transforming them too into a somehow "living heritage" area. This has many incident consequences forcing the whole contemporary community to study and protect it as much as possible.

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GEOARCHAEOLOGICAL STUDY OF GUNUNGSEWU KARSTAS MODEL FOR ENVIRONMENTAL CONSERVATION

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Abstract

Gunungsewu karst region has recorded the development of landscape and culturalscape for very long period that contribute to the archaeological and geomorphologic theory in regional and international level. Geoarchaeological approach, integration between geomorphologic and archaeological approaches will be used to solve the actual problems of the karst region. This research covers a) geoarchaeological condition study of the karst region in order to understand the dynamic interaction between landscape and culturalscape, b). pattern of human and natural environment interaction study which have been affecting the environmental sustainability in spatial and temporal context. The goal of this research is to find a new concept on geoarchaeology of the Gunungsewu karst region, especially on the interaction of naturalscape and culturalscape. The new concept will be used as scientific basis to solve the environmental problems in the karst region. The result of the study show that the naturalscape development of the GunungSewu varies spatially. The development variations of the naturalscape are reflected on river system, marine terraces formation and karst cave development. The changing of the river course of Bengawan Solo that formerly to the south direction into Indian Ocean moved to the north are supposed due to uplift and followed by fault. The uplift and the fault also influenced the marine terraces formation; at least there are two levels of marine terraces. Karst caves are also show variation spatially; there are three level of cave according the altitude above sea level. River systems, marine terraces, karst caves usually associated with ancient human settlement. The number of the karst caves in the study area 140 and 66, 43 % are identified as human ancient settlement. Based on the spatial distribution of the ancient human settlement are correlated to the naturalscape such as river bank, marine terraces, caves and water body (springs, doline and river).

Keywords: geoarchaeology, karst region, human settlement cave.

METHOD AND TECHNOLOGY FOR SCIENCE, EXPLORATIOIN, AND MAPPING

ELECTROMAGNETIC PULSE (EMP) METHOD EXPLORATION FOR MAPPING COMPACT SITES ALONG THE UNDERGROUND RIVER

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Abstract

The karstification of a landscape may result in a variety of large or small scale features both on the surface and beneath. On exposed surfaces, small features may include flutes, funnels, clints and grikes, collectively called karren or lapiez. Medium-sized surface features may include sinkholes or *cenotes* (closed basins), vertical shafts, foibe (inverted funnel shaped sinkholes), disappearing streams, and reappearing springs. Large-scale features may include limestone pavements, poljes and blind valleys. Mature karst landscapes, where more bedrock has been removed than remains, may result in karst towers or haystack landscapes. Beneath the surface, complex underground drainage (*underground river*) systems and extensive caves and cavern systems may form. In Karst areas like the one in Gunungkidul, Yogyakarta, underground rivers are common that can be used as water source and for the operation of micro hydro power plants. To maximize the use of underground water resources further research is needed. River flow mapping can be done by conducting measurements of physical parameters from the earth surface. The focus of the research is the investigation of cave wall characteristics in the part of the underground river where the wooden pressure pipe will be placed in order to be able to find good positions for rock anchors to fix. On the one hand, we use EMP (*electromagnetic pulse*) which uses electromagnetic waves (*georadar*) to detect objects beyond the cave wall without doing excavation (non-destructive test, NDT). The objective of this research is localizing the compact sites along the underground river.

Key words: Karst, Underground River, electromagnetic pulse (EMP) method, Gunungkidul, Non Destructive Test (NDT), cave wall

Introduction

In Karst areas like the one in Gunung Kidul, Yogyakarta, underground rivers are common that can be used as water source and for the operation of microhydro power plants (Haryono, 2001). To maximize the use of underground water resources further research is needed.

River flow mapping can be done by conducting measurements of physical parameters from the earth surface. The focus and objective of the research is the investigation of cave wall characteristics in the part of the underground river where the wooden pressure pipe will be placed in order to be able to find good positions for rock anchors to fix. On the one hand, we use EMP (Ground Penetrating Radar) which uses electromagnetic waves to detect objects beyond the cave wall without doing excavation (non-destructive test).

Electromagnetic Pulse (EMP) method is a geophysical method that uses electromagnetic pulses to image the subsurface. This non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. EMP can be used in a variety of media, including rock, soil, ice, fresh water, pavements and structures. It can detect objects, changes in material, and voids and cracks.

There are a number of devices that can achieve this objective, ranging from a large low-inductance capacitor bank discharged into a single-loop antenna or a microwave generator to an explosively pumped flux compression generator. To achieve the frequency characteristics of the pulse needed for optimal coupling into the target, wave-shaping circuits and/or microwave generators are added between the pulse source and the antenna. A vacuum tube particularly suitable for microwave conversion of high energy pulses is the vircator.

EMP uses transmitting and receiving antennas. In this system, pulses are emitted simultaneously on a first frequency which may be a random frequency, and on a second frequency, close to the first and derived by mixing a third frequency derived from a crystal controlled frequency.

At the receiver, the two echo signals feed two parallel connected amplifying chains the respective outputs of which are combined to supply the above third frequency plus the difference between the frequency fluctuations, due to the Doppler effects, of the two transmitted frequency.

Geological Background

Karst is a landscape shaped by the dissolution of a layer or layers of soluble bedrock usually carbonate rock such as limestone or dolomite. Due to subterranean drainage, there may be very limited surface water, even to the absence of all rivers and lakes. Many karst regions display distinctive surface features, with sinkholes or dolines being the most common. However, distinctive karst surface features may be completely absent where the soluble rock is mantled, such as by glacial debris, or confined by superimposed non-soluble rock strata. Some karst regions include thousands of caves, even though evidence of caves that are big enough for human exploration is not a required characteristic of karst.

Karst landforms are generally the result of mildly acidic water acting on soluble bedrock such as limestone or dolostone. The carbonic acid that causes these features is formed as rain passes through the atmosphere picking up CO_2, which dissolves in the water. Once the rain reaches the ground, it may pass through soil that may provide further CO_2 to form a weak carbonic acid solution: $H_2O + CO_2 \rightarrow H_2CO_3$ (the acid). This mildly acidic water begins to dissolve the surface along any fractures or bedding planes in the limestone bedrock. Over time, these fractures enlarge as the bedrock continues to dissolve. Openings in the rock increase in size, and an underground drainage system begins to develop, allowing more water to pass through the area, accelerating the formation of underground karst features (Samodra, 2001).

The karstification of a landscape may result in a variety of large or small scale features both on the surface and beneath. On exposed surfaces, small features may include flutes, runnels, clints and grikes, collectively called karren or lapiez. Medium-sized surface features may include sinkholes or *cenotes* (closed basins), vertical shafts, foibe (inverted funnel shaped sinkholes), disappearing streams, and reappearing springs. Large-scale features may include limestone pavements, poljes and blind valleys. Mature karst landscapes, where more bedrock has been removed than remains, may result in karst towers or haystack/egg box landscapes. Beneath the surface, complex underground drainage systems and extensive caves and cavern systems may form. Erosion along limestone shores, notably in the tropics, produces a karst topography that includes a sharp *makatea* surface above the normal reach of the sea and undercuts that are mostly the result of biological activity or bio-erosion at or a little above mean sea level. Some of the most dramatic of these formations can be seen in Thailand's Phangnga Bay and Halong Bay in Vietnam.

Calcium carbonate dissolved into water may precipitate out where the water discharges some of its dissolved carbon dioxide. Rivers which emerge from springs may produce tufa terraces, consisting of layers of calcite deposited over extended periods of time. In caves, a variety of features collectively called speleothems are formed by deposition of calcium carbonate and other dissolved minerals. A karst river may disappear underground a number of times and spring up again in different places, usually under a different name (like Ljubljanica, Slovenia, the river of seven names). An example of this is the Popo Agie River in Fremont County, Wyoming. Simply named "The Sinks" and Sinks Canyon State Park, the river flows into a cave in a formation known as the Madison Limestone, and then raises again a half-mile down the canyon in a placid pool. When the river was dyed, it took two hours for the dye to reach the rising a short distance away (Wikipedia, Karst Topography).

Farming in karst areas must take into account the lack of surface water. The soils may be fertile enough, and rainfall may be adequate, but rainwater quickly moves through the crevices into the ground, sometimes leaving the surface soil parched between rains. A karst fenster is where an underground stream emerges onto the surface between layers of rock, cascades some feet, and then disappears back down, often into a sinkhole.

Water supplies from wells in a karst area may be unsafe, as the water may have run unimpeded from a sinkhole in a cattle pasture, through a cave and to the well, bypassing the normal filtering that occurs in a porous aquifer. Karst formations are cavernous and, therefore, have high rates of permeability, resulting in a reduced opportunity for contaminants to be filtered out.

Groundwater in karst areas is just as easily polluted as surface streams. Sinkholes have often been used as farmstead or community trash dumps. Overloaded or malfunctioning septic tanks in karst landscapes may dump raw sewage directly into underground channels. The karst topography itself also poses difficulties for human inhabitants. Sinkholes can develop gradually as surface openings enlarge, but quite often progressive erosion is unseen and the roof of an underground cavern suddenly collapses. Such events have swallowed homes, cattle, cars, and farm machinery.

Methodology

Hardware, Software, and Field Approach

The EMP is an integrated device for both hardware and software. The software used for the data processing is Future Series 2005. Future Series 2005 EMP is a portable device that can be used in several areas with different terrain, unlike the conventional EMP that cannot be used in extreme areas such as the one in Seropan cave. Although Future Series 2005 EMP is a portable device, it does not allow us to conduct neither comprehensive measurements nor processing comparable to EMP method which shows the pulse propagation from the surface until a certain depth. Data obtained from Future Series 2005 EMP only shows the image of medium conductivity value of all the material recorded without specifically providing the depth of each different material.

Figure 1. Measurements with a horizontal probe

The difference is that the output of the conventional georadar, unlike the one used in this project, is a reprocessed data where the processing steps can be modified to obtain better results. For the EMP we used in this project we can only improvise on the acquisition method used. There are various modes that can be used in the EMP data acquisition, and the one that is used in this research is Ground Scan. This operating mode allows recording a graphical measurement whereby the measured data will be stored into internal memory or sent directly to a connected PC. Before the measurements it has to be decided which mode shall be used (in this study an automatic mode was used, so the measurements are taken continuously). In this measuring mode a horizontal probe has to be connected. Also a certain manner and direction has to be kept in order to scan the area of interest so that the data can be recorded in a correct way. The pattern is shown in figure 1.

Underground River Spreading Map

Figure 2. shows a topographical map of the underground river Seropan which shows two waterfalls of the underground river system.

Figure 2. The research location of the Seropan underground cave. The black circles are indicates the underground river flows

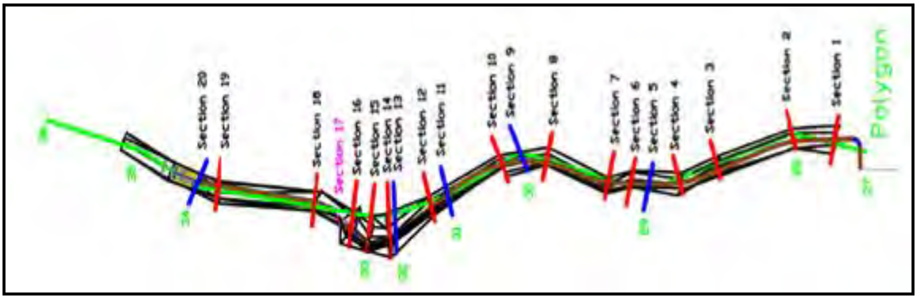

Figure 3a. The research location of the Seropan underground cave (Figure 2) and its segmentation of EMP measurements.

Figure 3b. EMP data acquisition on wall of Seropan underground river and the design of measurement step due to Figure 4.

Field Approach

The GPR method based on the articles from Hoover (2003), has an “A” value for observation methods that can be used to asses sinkholes and voids in karst area. Not only for voids that have big porous zones. Abdelhady *et al.* (2004) show that this method can also detects small cavities around karst areas. That is why this method was used in this research. Although Future Series 2005 GPR is a portable device, it does not allow us to conduct neither comprehensive measurements nor processing comparable to conventional georadar which shows the pulse propagation from the surface until a certain depth. Data obtained from Future Series 2005 GPR only shows the image of medium conductivity value of all the material recorded without specifically providing the depth of each different material. Future Series 2005 GPR is a portable device that can be used in several areas with different terrain, unlike the conventional GPR that cannot be used in extreme areas such as the one in Seropan cave

Figure 3 shows the measurement location of the EMP method and Figure 4 shows the design of EMP measurements in wall of right and left side of cave. The measurement was started from Section 1 until Section 12 where the waterfall is positioned. At the right side of the cave, the measurement was conducted from 0 – 80 meters, followed by 90 – 150 meters. In the area of the 80 – 90 meter the water is very deep, so it was too dangerous to conduct the measurement.

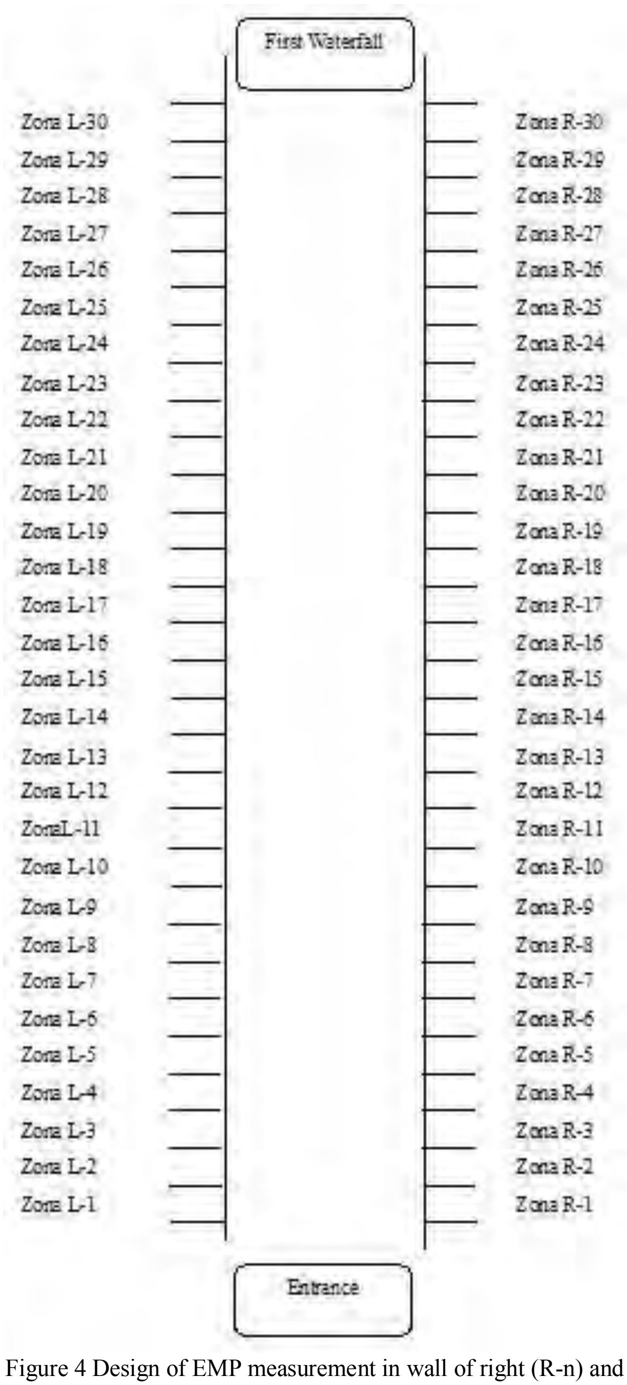

Figure 4 Design of EMP measurement in wall of right (R-n) and left (L-n) side of cave

EMP Results

These are several examples of images resulting from the EMP processing.

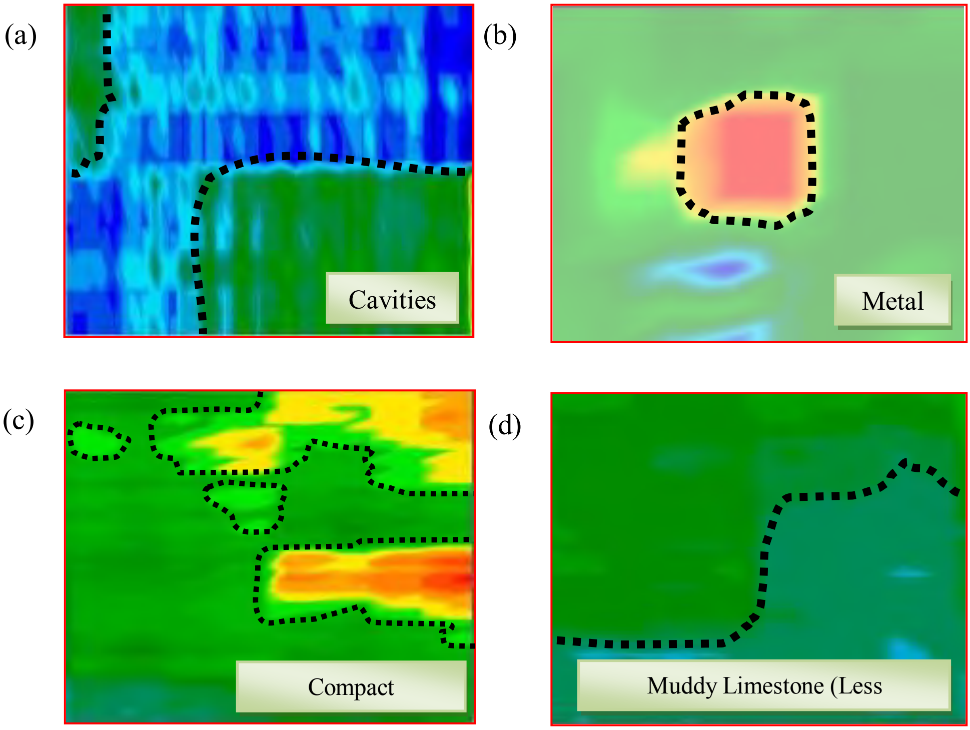

Figure 5. EMP output from several locations: (a) Porous zone, (b) Metal, (c) Compact limestone, (d) Porous limestone

EMP can detect various objects that each has its own specification, which is shown in figure 5. Figure 5a shows the result of an acquisition in a karst area which contains cavities in the area beyond the surface which is shown by the blue colour. In figure 5b the red area in the middle shows the existence of metal. What should be considered when interpreting a possible metal existence is the fact that it could also contain mineralization if the red part is surrounded by yellow and orange colours and if the objects displayed by the red colour do not represent any form (rectangular, circle, etc). An example for compact limestone is shown in figure 5c, for porous limestone in figure 5d. From the different possibilities shown in figure 5, example b can be taken as certain because the measurement was conducted on a wall where a metallic plate was put behind. The other examples are based on the interpretation from the module of the Future Series 2005 device.

Emp Data Analysis And Discussion

Data Analysis. The Data obtained from the acquisition is processed using Future Series 2005 Software, resulting in an image that represents the cave structure from the cave surface until the depth of 10 meter estimation. This image is very helpful to do data interpretation.

EMP Interpretation. EMP data interpretation is conducted to understand the characteristic of porous and compact zones, which is based on EMP Future Series 2005 output data. Zone separation of this research is conducted to separate the area containing cavities and the one that contains compact limestone and/or mud. Each zone is 5 meters in length (whether right side or the left one and also at the ceiling of some area) and 2 meters in height.

The overall result achieved during this research shows that the cave walls mainly consist of limestone and porous limestone (yellow and greenish). In the following the detailed interpretation of each side of the cave will be shown, which later will be correlated with the cave lithology. The following interpretation results shown as Zone R-1 to R-5 and Zone L-1 to L-12.

Zone R-1 (10 m to 15 m). EMP data acquisition was started on the right side of the cave wall with viewing direction downstream; the length of each zone is 5 meters while the height is 2 meters. Figure 4.1 shows the result of the first five meters on the right side of the cave wall, which shows that the area of the first scan contains compact limestone while the rest of the zone shows the domination of cavities in its lower part (blue).

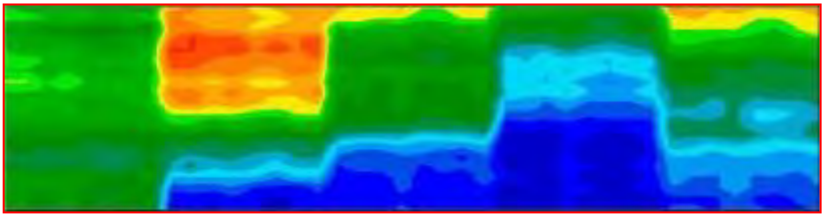

Figure 4.1 Zone R-1

Zone R-2 (15 m to 20 m). The lower part of the R-2 zone is still dominated by cavities but not as big as the R-1 zone. While the upper part, mostly contain porous limestone.

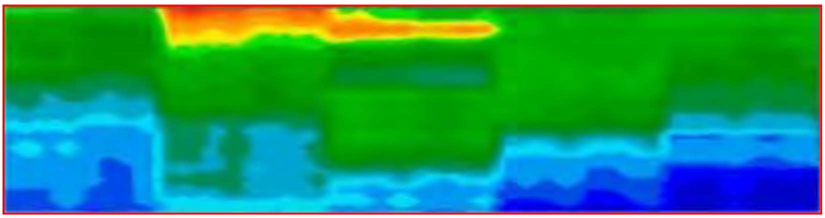

Figure 4.2 Zone R-2

Zone R-3 (20 m to 24 m). R-3 generally resembles zone R-2 which is shown by the existence of cavities in the lower part but in the upper part there are indications for a combination of porous and compact limestone.

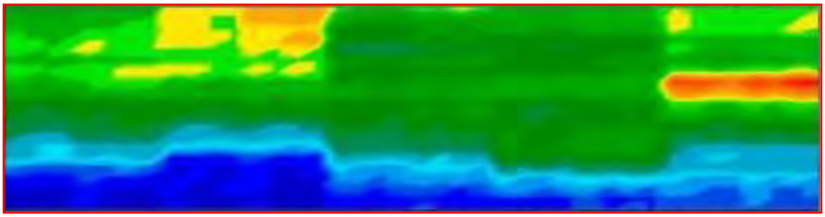

Figure 4.3 Zone R-3

Zone R-4 (24 m to 28 m). Zone R-4 is comparable to zone R-3 but on the 4th and 5th scan (27-28 meters) almost every part of it contains cavities

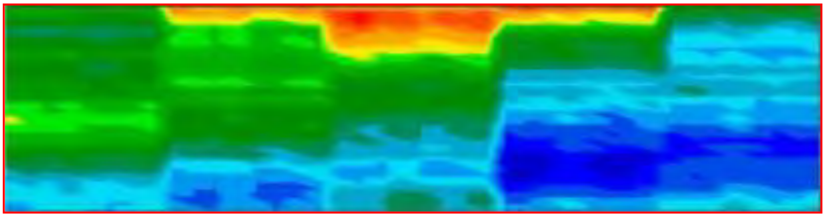

Figure 4.4 Zone R-4

Zone R-5 (28 m to 32 m). Generally this zone is the same with the last two zones but the 3rd scan (30-31 meter) shows a very compact upper part shown by the combination of yellow and reddish colour.

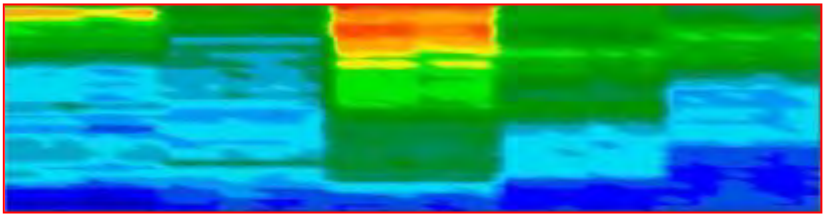

Figure 4.5 Zone R-5

Zone L-1 to L-4 (10 m to 30 m). In the following the results of left part of the cave is described. In the first part only L-3 (figure 4.14) contains cavities. The other three zones are dominated by compact limestone which is shown by yellowish and green colour (see appendix). The end of this zone is at 30 meters from the beginning.

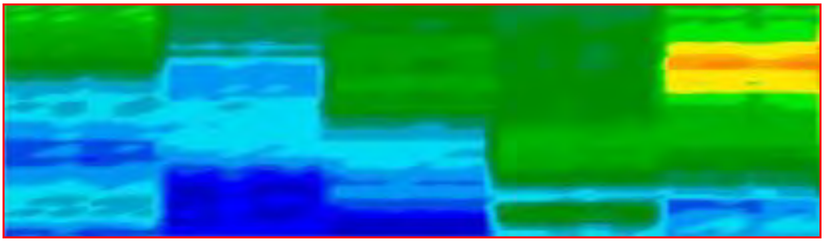

Figure 4.14 Zone L-3

Zone L-5 to L-8 (30 m to 50 m). Zones L-5 to L-7 (see appendix) have a majority of cavities except of the first three scans of zone L-5 which contain compact limestone. Zone L-8 (figure 4.15) is dominated by compact limestone and only the lower part on its last two scans contains cavities. The end of this zone is at 50 meters from the beginning.

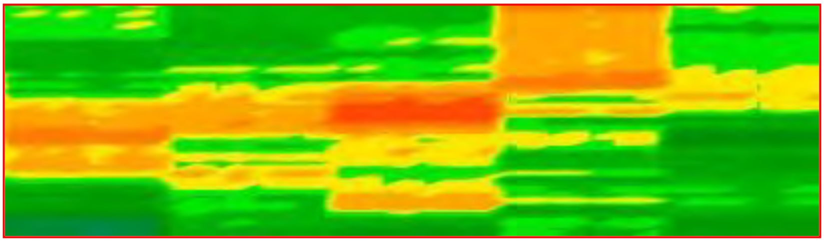

Figure 4.15 Zone L-8

Zone L-9 to L-12 (50 m to 70 m). The first three zones of this group are dominated by compact limestone, especially in zone L-10 (figure L-10) which consists nearly completely of compact limestone, while the majority of cavities occur on zone L-12 (see appendix)

Conclusions

Based on the data analysis, discussion and interpretation of the study at the Seropan underground river, it can be conclude that:

The main cave consists of 3 kinds of properties (cavities, porous limestone and compact limestone) from which each has its own specification and the cave is dominated by compact limestone and porous zones.

In the right part of the cave porous zones and compact limestone are about evenly distributed and while the left part of the cave mostly consist of compact limestone, therefore, spot picking for positioning of rock anchors is easier in this part of the cave.

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I.V.S.M.E. PROJECT: ITALIAN VIETNAMESE MULTIDISCIPLINARY SPELEOLOGICAL EXPEDITION 2010 CAVE EXPLORATION AND SCIENTIFIC RESEARCHES IN HA GIANG KARST AREA (NORTH VIETNAM)

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Abstract
The IVSME expedition, which was established and jointly undertaken by a team of scientists from Italia and Vietnam, was aim to conduct research and explore caves in karstic geological domains of the Ha Giang Province in the Northeastern Viet Nam, in order to implement the scientific knowledge on a multidisciplinary basis. The exploration of new (or scarcely explored) hypogean karstic features will allow to upgrade the hydrological and hydrochemical information on water resources related to sensitive and environmentally valuable karst areas of Viet Nam. For all the explored caves accurate topographic survey as well as multiple water sampling for isotope application in hydrogeological studies, groundwater stygofauna and rock sampling for lab petrographic analysis. Water samples for stable isotope analyses (Oxygen-18, Hydrogen-2) were collected from hypogean streams and lakes as well as from cave dripping, rivers and springs in the neighbouring area out of the karstic conduits. Stable isotope composition of $\delta^{18}O$ and $\delta^{2}H$ suggests that groundwater in the investigated area is mostly recharged from local precipitation.

Keywords: cave exploration, karst hydrogeology, isotope application

Introduction

The aim of the IVSME expedition was the research and exploration of caves in the karstic domain of Ha Giang Province, North-eastern Viet Nam, in order to implement the scientific knowledge on a multidisciplinary basis (Nguyet Vu Thi Minh, 2006). The exploration of hypogean cavities and the collection of data through the inventory of water occurrences as well as fauna and rocks, allows upgrading the hydrogeological setting of the area in order to prevent any adverse impacts on the environment and the water resources quality. The speleological exploration is focused also on improving the hydrogeological framework with the aim to establish a satisfactory water supply to the local communities and upgrade the knowledge and experience in several aspects of karst research as well as promoting the development of the first "Geopark" in Vietnam.

Investigation area

The Ha Giang Province. The working area is located in Ha Giang Province, the northernmost area of Viet Nam. Ha Giang, 300 km away from Hanoi, is located at the highest latitude in Viet Nam and is surrounded by Cao Bang, Tuyen Quang, Lao Cai, and Yen Bai. It shares the border line with China (Fig.1). Ha Giang is a mountainous area and one of the poorest province at Viet Nam, with several ethnic minorities living in the region. This karst area is called Dong Van Plateau and includes the district of Quan Ba, Yen Minh, Dong Van and Meo Vac. Dong Van Highland is situated 1.025 m above sea level. The speleological exploration was focused on improving the hydrogeological framework of Quan Ba and Dong Van districts, jointly with the Vietnamese scientists, both districts have been selected because of scarcity of experimental hydrological data..

Fig. 1, Investigation area

Geological overview

Karst of Northern Viet Nam. Karst in the northern region of Viet Nam mainly occurs on the limestone plateau and on steep ranges of carbonate rocks most of Devonian, Triassic and Cretaceous age. In the tropical regions, there are others landforms in addition to those found in temperate karst zones, as tower karst and peak cluster is specifically characteristic of tropical karst (Van, T.T *et al*, 2003). The karst landscape in Vietnam is one of the most notable and spectacular landscapes in the world. The present landform results from an ancient tectonic fault-fold zone with many unconformities between the middle Devonian and its underlying strata and between the upper Cretaceous strata and the underlying Permian and Triassic strata (Tran Thanh Hai *et al.,* 2009). The landscapes are typical of the humid tropical-subtropical cone karst, rejuvenating through successive cycles of uplift, solution, deposition and erosion, with clusters of tall narrow peaks, deep dolines and flat valleys, depressions (poljes), plains, gorges, rivers and long caverns. Large parts of the area are covered by carbonate associations (Tran Thanh Xuan, Tran Bich Nga, 2009). The movement of water down such fractures zones was not only the major cause of the formation of extensive underground caves but it also acts as primary host for groundwater concentration within the karstic unit. (Nguyen Van Lam *et al.,* 2009).

Hydrogeological aspects of karst aquifer. Most of groundwater is of atmospheric origin infiltrated in the ground directly from precipitation or indirectly from surface runoff of rivers and streams (P.Y. Jeannin, 1996). Infiltration leads to groundwater circulation in the reservoir rock from the recharge area to the drainage area of the hydrogeological unit where one or more springs occur. Karst landscapes and aquifers are extremely fragile and particularly vulnerable to contamination resulting from human activities. The great permeability of karstic rocks do to a variety of epigeal and hypogean features bears currently to groundwater pollution hazards from surface. Usually groundwater flow reacts quickly to precipitation with fast flow dynamic in karstic domains (W. Dreybroct.*et al* , 2005)**.**

Speleological and field activities: general remarks

Quan Ba. The landscape of Quan Ba are made of marl and sandstone hills with limestone formation at the top. It became a systemic work of geographical exploration of the valleys and depressions of the area. The karst belt is covered by high density vegetation and typical tropical forest while sub-horizontal cave system is dominant. The cave entrances are often opened at the bottom of the karst depressions (dolines*)*, at the base of the carbonate rock slopes. The depressions become the preferential way and collector of streams flowing into the caves during events of intense precipitation in the rainy season. Most of the explored caves are “transition” caves passing from vadose to phreatic regime in response of precipitation. The conduits are usually active during the rainy season however; a poor water stream flow was discovered at the time of our exploration as well as small to medium lakes along the hypogean conduits. The overall meters of caves surveyed are 2187 m of conduits.

Dong Van. The karst area explored is about 20 km far from the China border and the landscape is different from Quan Ba. The altitude is about 1000 m a.s.l and guarantees a dry climate as well as temperatures quite lower than in Quan Ba (J. Masschelein *et al.,* 2007). The Dong Van area is a subtropical karst landscape. It represents an excellent example of plateau karst pinnacles and knife-edged karren. Stone forests resulted from intense fissuring as well as hills from scarce fissuring and razor ridges, where the two fracture planes intersected. It is a “Residual Karst” steep-sided residual limestone hills separated by alluvial plain. The caves in Dong Van are mostly fossil, often truncated by erosion, with beautiful white speleothems. The entrances anywhere in the cones require a climbing of 60/100m. Geological processes and the atmospheric agents have contributed to the differential erosion and corrosion of the carbonate rocks giving as a result old caves formation in the middle of the peaks. Totally 1.296 m of conduits has been surveyed.

Analysis

Geochemical analysis: The use of stable isotopes, in particular the isotope ratios of oxygen and hydrogen as conservative tracer, has improved the understanding of problems related to catchment and groundwater studies. The water for stable isotope analysis was collected from cave dripping, hypogean streams, lakes and springs, mostly.

Material and methods. Stable isotope analysis does not need treatments and conservation of the samples. In each sampling site, the basic physical-chemical parameters were measured and the GPS coordinates taken. The geochemical analysis is carried out in the laboratories of the Zavod Za Zdravstveno Varstvo - Geoisotopical Unit of Institute of Public Health (Koper - Slovenja). The method carried out for the $\delta^{18}O$ uses a continuous flow isotope ratio Mass Spectrometer (IRMS) (Thermo). The method for $\delta^{2}H$ used the pyrolisis technique. Each sample is analysed twice and the arithmetic average of the machine results is introduced in a five points linear regression curve (calibration curve), obtained from the standards measured by the International Atomic Energy Agency (IAEA). One calibration for oxygen and one for hydrogen was retained satisfactory. The results are expressed in delta per mill (‰) value referring to the reference material VSMOW (Vienna Standard Mean Ocean Water). The result is the ratio of the less frequent to the abundant isotope changes in the sample (Eq.1):

$$\delta=[(Rsample - Rst)/ Rst] * 1000 \quad \text{(Eq. 1)}$$

Results and discussion. The karstic water of the investigated areas can be conferred to different structural zones that include Quan Ba and Dong Van districts. Under favourable conditions, a hydrogeological structure contains an usable resource of groundwater. The economic value depends on the yield (discharge rate) and the storage volume (water reserve). In general, due to the influence of high secondary permeability, the river and stream network is poorly developed in karst areas. The flow regime is unevenly distributed during the year with two main seasons: the flood season usually takes place from May to October while the dry season takes place from October to May (Nguyen Van Lam *et al*, 2009). Though the expedition was carried out during the dry season, it was however observed some flowing streams in the caves of Quan Ba area, as well as some springs in Dong Van. Up to day we haven‟t many isotope data referring to the springs of Quan Ba areas but fortunately we can rely on the data collected during the sampling campaign jointly performed with Prof. Van Lam, Prof. Bono and Dr. Arduino in November 2009. In Table 1 and 2 sampling sites and isotope values referred to January-February 2010 campaign are reported. It can be noticed that the most depleted value in stable isotopes is the water sample related to the Terminal Siphon located in the hypogean conduit we identified as "Capel Cave" (-9,0 δ^{18}O ‰ , -60,7 δD ‰) in Dong Van town (Pho Bang Street). People pump the water from this cave using basic methods and fittings such as plastic pipes and tanks all the year long. Other interesting isotope data refer to the Dragon Cave in San Tung locality (Dong Van District). The isotope signature of the large hypogean lake (-6.7 δ^{18}O O ‰, -43.3 δD ‰) seem to be not consistent with that of the "Tributary Stream" (-8,6 δ^{18}O ‰, -58.0 δD ‰) probably accounting for a different elevation of the respective recharge areas as well as different karst circuits other than from local precipitation. A similar hypotesis could be inferred also for the "Siphon" water isotope composition in the Capel Cave. (C.Brun *et al.,* 2010).

Table 1. Sampling in the caves for oxygen-18 and hydrogen-2 isotopes (Jan-Febr. 2010)

Code Sample inside the cave	**Name of the cave**	**Cave Code**	**Locality**	**[δ^{18}O‰] VSMOW**	**[δD‰] VSMOW**	**Notes**
C02	Cong Troi Cave	QBTS 03	QB/Tam Son	-6.8	-43.7	Hypogean stream
C04	Cong Troi Cave	QBTS 03	QB/Tam Son	-6.2	-40.6	Cave dripping
C05	Cong Troi Cave	QBTS 03	QB/Tam Son	-6.3	-40.8	Lake close to cave

						entrance
C06	Waste Cave in village	QBTS 05	Along the street	-7.3	-48.3	Hypogean stream
C07	Kho Mi	QBTS 04		-5.6	-33.8	Cave dripping close to cave entrance
C29	Fabio Scabar Cave	QB06	Tung Vai	-6.0	-37.9	Hypogean stream
C12	Ta Lung Cave	DV08	Dong Van	-5.8	-36.2	Cave dripping from left branch
C13	Ta Lung Cave	DV08	Dong Van	-7.2	-45.6	Idem
C16	Capel Cave	DV04	Dong Van town	-9.0	-60.7	Hypogean siphon
C18	Dragon Cave	DV09	Sang Tung	-6.7	-43.3	Hypogean lake
C18'	Dragon Cave	DV09	Sang Tung	-8.6	-58.0	Hypogean stream
C26	20,000 Dong Cave	DV11	Dong Van	-6.2	-38.6	Cave dripping
C27	Cave back to the waterwork	DV16	Dong Van town	-7.9	-47.3	Hypogean stream catchment

Though the available isotope data are still scarce for a comprehensive and satisfactory hydrological and hydrogeological analysis, however it appears of some scientific interest the correlation between the Global Meteoric Line (Craig, 1961) and the Local Meteoric Water Line based on groundwater and spring samples (Fig. 2,3). The diagrams (Figg. 4-11) plot the isotope data related to hypogean water samples (streams, lakes, cave dripping) and surface occurrences (springs, streams, rivers) referred to November 2009 campaign (Lam, Arduino, Bono, Brun) and January-February 2010 IVSME campaign. Karstic water is commonly distributed within the fracture systems and hypogean conduits located in the aerated zone of the aquifer, often giving rise to perched water occurrences or acting as flood channels in caves during intense rain events (Dang Duc Nhan *et al.,* 2009)

Table 2. Sampling at the surface for oxygen-18 and hydrogen-2 isotopes (Jan-Febr. 2010)

Code Sample at the surface	Sampling Site	[δ^{18}O‰] VSMOW	[δD‰] VSMOW
QB S1	Quan Ba	-7.3	-48.1
QBYM S2 - C09	Tam Son - Yen Minh road, left Song Mien river	-5.8	-35.8

YM S3 - C10	Yen Minh (Song Mien)	-8.1	-50.0
DV S4	Dong Van spring	-7.5	-49.1
DV S5 - C11	Dong Van spring	-6.8	-43.2
DV S6	Dong Van town spring	-5.8	-35.8
DV S7 – C25	Dong Van town spring	-8.2	-52.8
Tap water DV	Tap water Dong Van Hotel	-8.1	-50.8
QB S1	Quan Ba	-7.3	-48.1
DV S4	Dong Van spring	-7.5	-49.1
DV S5 - C11	Dong Van spring	-6.8	-43.2

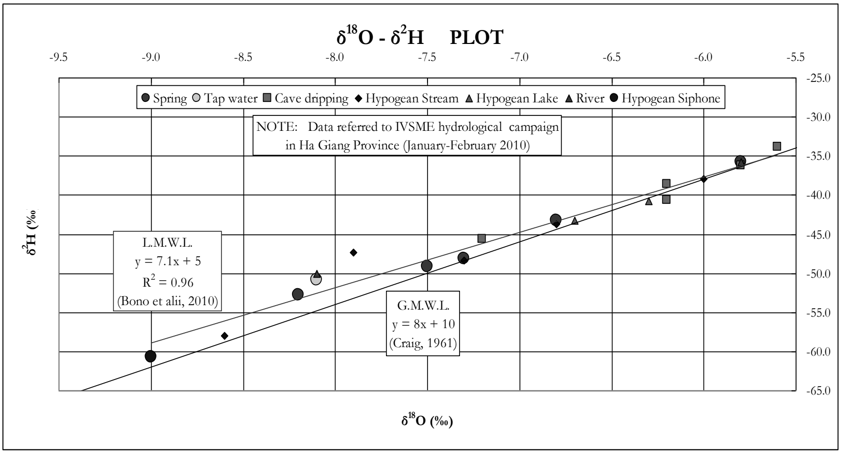


Fig. 2: Correlation between the Global Meteoric Line (Craig, 1961) and the Local Meteoric Water Line based on groundwater and spring samples IVSME hydrological campaign in Ha Giang 2010 (P.Bono, L.Rossini).

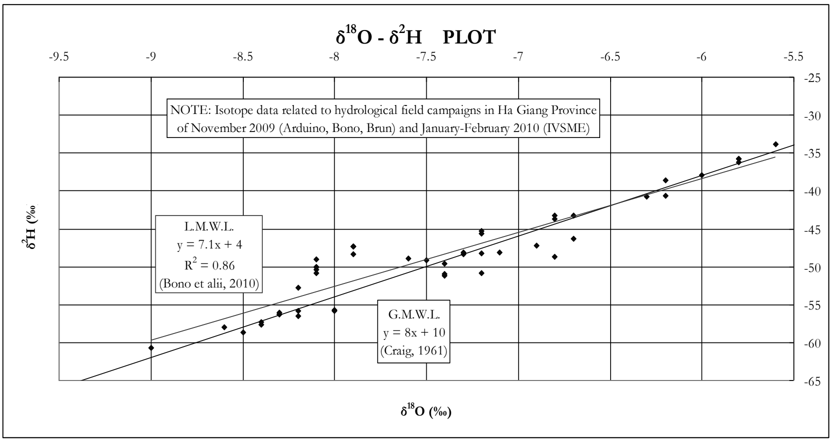
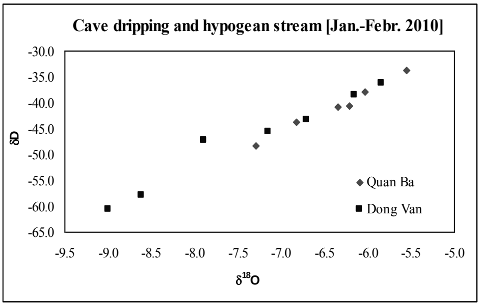


Fig. 3: Correlation between the Global Meteoric Line (Craig, 1961) and the Local Meteoric Water Line based on groundwater and spring samples November 2009 and of IVSME 2010 hydrological campaign (P.Bono, L.Rossini).

According to the hydrostructure setting, a karst system generally shows at the base a thick and large saturated zone which supplies the discharge of relevant perennial springs and rivers. Due to the development of surface and hypogean karst features as well as to climate factors, flow dynamics in carbonate aquifers involve usually strong variation in response to precipitation events. As a matter of fact rains over bare karst terrains seep easily underground recharging rapidly through a network of joints and fissures perched as well as the basal aquifer of the hydrostructure. (C.Brun *et al.,* 2010).

In the diagrams, “Caves” means: cave dripping, hypogean streams, hypogean lakes.



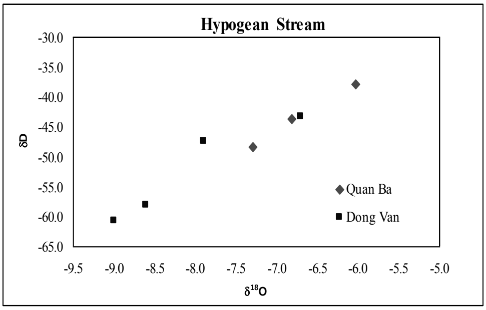
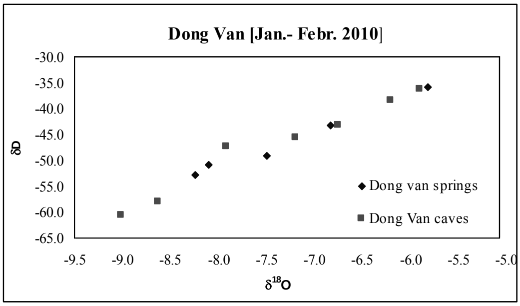


Fig. 4: δ^{18}O and δD for cave dripping and hypogean stream in Quan Ba vs Dong Van caves in Jan 2010. Fig. 5: δ^{18}O and δD for Quan Ba and Dong Van hypogean stream Jan. 2010



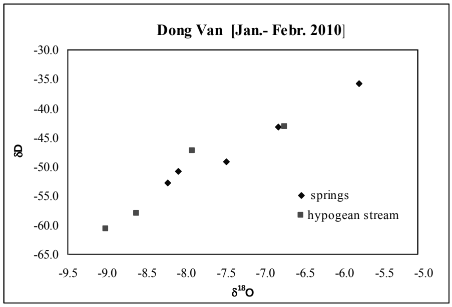
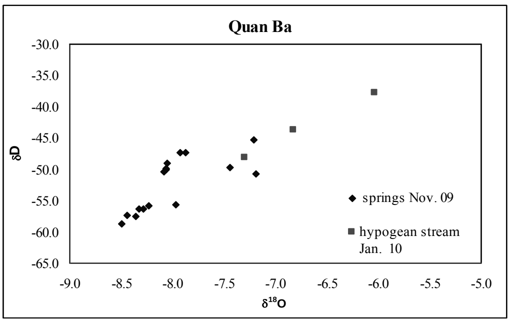


Fig. 6: δ^{18}O and δD for Dong Van springs and caves in Jan. 2010. Fig.7:δ^{18}O and δD for Dong Van springs and hypogean stream in Jan. 2010.



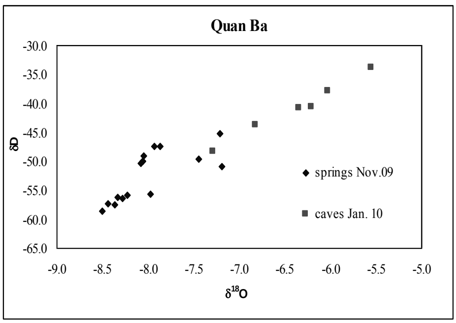
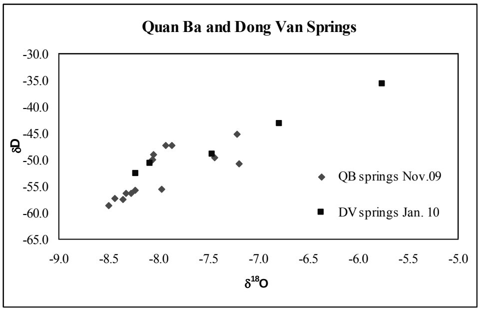


Fig. 8: δ^{18}O and δD for Quan Ba springs and hypogean stream Nov.2009 Fig. 9: δ^{18}O and δD for Quan Ba springs Nov. 2009 vs Quan Ba Caves Jan. 2010



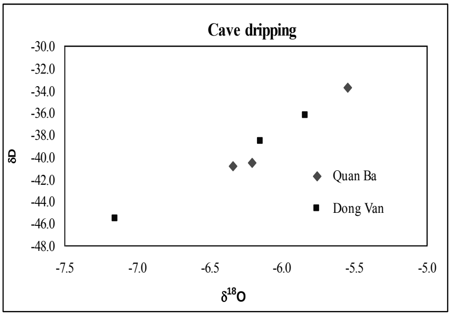


Fig. 10: $\delta^{18}O$ and δD for Quan Ba springs Nov.2009 vs Dong Van springs Jan. 2010.
Fig. 11:$\delta^{18}O$ and δD or Cave dripping in Quan Ba and Dong Van Jan. 2010

Conclusion

In Dong Van Plateau, Karst is one of the control factors of surface and groundwater resources. The protection of drinking water has become the most crucial question for human survival. Therefore it is necessary to strengthen specific environmental investigations and attain a reliable water resources assessment for a sustainable social-economic development of this area. Villages are located close to springs, rivers or caves with ferly good deposits of water, but other villages built at the top of hills and mountains have not any available water resource close to their leaving place. Discovering a cave with water occurrences inside even of limited discharge it is a very important water supply for the local people particularly during the dry season when surface water is poor or non-existent.

The waste deposits sometime dumped in the dolines is one of the major hazards that often produce contamination of the limited groundwater resources available in the investigated areas. After the Ka.W.E mission in Ha Giang Province, some priorities were preliminarily identified and proposed as issues of future joint cooperation activities:

1. Sensibilization: Sensibilize the Institutions on the vulnerability of karst aquifers in Dong Van Plateau.
2. Hydrology researches: implementing the hydrogeology knowledge of the area. Methods of investigation on vulnerability, hazard and risk mapping are of great help towards protection of karst groundwater resources.
3. Speleological Register of the caves: An "Official Speleological Register of the caves" could be one of the several steps for a good management of the karst areas.
4. Training courses for University and Institutions: seen the very impressive karst and important morphology it should be to initiate the researches and the young students at the study and at the researches in the caves by training course of topography and speleological techniques. It could be create a "Vietnamese Speleological Society".
5. Speleological School: in the framework of Geopark, we proposal the realization of a "Speleological School". This school could create the working places as "Official Speleological Guide" for the tourists.

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EVALUATION OF QUALITY AND ACCURACY OF DIGITAL ELEVATION MODELS (DEMS) AND GIS TECHNIQUES FOR KARST MAPPING AND KARSTIFICATION ANALYSIS

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Abstract

Digital elevation Models (DEMs),satellite Images and GIS techniques have been applied to detecting geomorphological units and various land forms like fluvial, glacial and Aeolian landscapes. Conversely, It‟s necessary to examine the same strategies can also be applied and Transferred to areas dominated by surface karstic landforms and Analyses of karstification. This paper examines the accuracy and quality of digital elevation models (ASTER DEMs), satellite Imagery and GIS techniques for the detection and Mapping of karst landforms mainly enclosed depressions in the Biston Mountain of western of Iran. In order to examine the applicability of DEMS for karst feature detection, digital analyses with ArcGIS 9.3(ESRI) had to perform for further data acquisition. Elevation data form ASTER DEMs were used to derive gemorphometric parameters of study area. The hydrologic surface analysis in ArcGIS permitted us to detect depressions and hollows in an elevation grid via the identify-sinks function. In order to evaluate the potentials of the digital sinkhole analysis, a raster file was generated on the basis of hypothetical flow direction patterns within the elevation Models. To verify and evaluate the quality of the digital results, karst landforms were mapped using high resolution satellite Images and sampling in a field work. Based our results, DEMs like ASTER and Its derivatives have limited precision, showing that the accuracy of the results significantly depends on the resolution of Models, especially when focusing on micro features. Standard GIS-based Applications like derivation of primary geomorphometric parameters from ASTER DEMs are not able to capture small – sized Landforms; performing hydrologic surface analysis using sink detection algorithms can provide better results.

INDONESIAN KARST AND CAVES THEIR RECENT STATUS AND FATE IN THE FUTURE

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Abstract
Karst and caves are found in many Indonesian islands. Prior to 1983, the Indonesian government, scientists and public at large did not recognize the importance and value of these nature resources. In 1983, the Federation of Indonesian Speleological Activities (FINSPAC) launched a nationwide unrelenting, continuous effort to convince the Indonesian public, scientists and bureaucrats, that karst and caves are very important to be conserved. Many environment conscious cavers, scientists, students, bureaucrats wholeheartedly joined FINSPAC"s effort to protect the Indonesian karst and caves, including the cave bat and cave swiftlet population.Unstoppable mining at some major karst areas for cement and "marble", cave destructions, unscrupulous cave swiftlet"s nest harvesting, careless cave tourism, deforestation of primary karst forests are however ongoing dilemmas, difficult to cope with.Educating local people to recognize karst and cave values seems to be the only way to protect these fast dwindling natural resources.

Keywords: dilemma in cave and karst protection.

Introduction
It becomes apparent from the geological map, made and issued by the Directorate General of Geology and Mineral Resources, Ministry of Mining and Energy, drawn on the scale 1:100.000 for the islands of Java and Madura and on a scale of 1:250.000 for the thousands of other islands, that Indonesia possesses at least 154.000 Km2 limestone and dolomite. This was officially announced by the Minister of Mining and Energy, Dr Kuntoro Mangkusubroto, in his welcome address at the National Workshop on the Karst Environment, held in Jakarta on September 29-30,1999. This vast amount indicates a fantastic wealth of 39,37 trillion tons of limestone reserves in Indonesia, estimated only 20 billion tons before.

To comprehend how large and widespread the karst areas are and how many limestone caves there are in Indonesia, it is mandatory to describe concisely, that Indonesia consists of more than 13,000 islands, stretching 6,400 km from West to East, occupying one-seventh of the earth surface. This sprawling island chain encompasses mind-stupefying extremes: 5,000 m high snowcapped mountains of Papua (Irian Jaya), most of which are karst, sweltering lowland swamps of eastern Sumatra, windy savannahs in Timor's karst, lush rainforests of East Kalimantan's very hard-to-reach interior.

Major karst areas are found in Java, Kalimantan, Sulawesi and Papua. Many smaller islands consist mostly of karstified limestone, like Madura, Nusa Barung, Nusa Penida, Sumba, Sawu, Togian, Kai, Kabaena, Muna, Buton, Biak, Most well known karst areas in Indonesia are :

1. The classical tropical conical karst Gunung Sewu, Java, made world famous by J. V. Danes (1910) (Die Karstphenomene im Goenoeng Sewoe auf Java), H. Lehman (1936) (Morphologische Studien auf Java), H. Flate and D. Pfeffer (1962) (Grűndlage der Hydrogeologischen Verhaltnisse im Gunung Sewu, Java) and Jennings (1971).
2. The cockpit karst of south Gombong. Java.
3. The tower karst of Maros-Pangkep, Sulawesi.
4. The polygonal highland karst of Papua.
5. The tower karst formation of East Kalimantan.

There is considerable variation in the age of carbonate rocks in Indonesia, the oldest of which are the dolomites in the central mountain range of Papua, *devon* (410-360 million years) and the Carstenz Pyramid, *late neogen* (95 1,7 million years). A list was published by the Geological Research and Development Center, stating the different ages of carbonate rocks in Indonesia, ranging from *mesozoicum* 18.344 km2, *tertiary*, 119.877 km2, *quarternary* 15.811 km2.

There is also considerable variation in thickness of karstified carbonate rock formations, ranging from shallow, in small islands like Nusa Barung and Nusa Penida (*merokarst*-Cvijic) till great depth extending under sea level in major karst areas of Papua, Jawa, Sulawesi and Kalimantan. (*holokarst*-Cvijic) with many off-shore springs.Only karst formations, hard to reach, uninhabited or sparsely inhabited, are covered by dense primary forests. Where karst areas are densely populated and accessible by roads, deforestation is the rule. Concomitant quarrying of limestone for road hardening, building material and industrial use is evident in many locations.

Biodiversity in limestone areas all over Indonesia and endemism of karst flora and fauna, have only recently interested very few Indonesian biologists. In stark contrast to Malaysia, where three Malayan biologists succeeded in documenting hundreds species of endemic plants and animals since 1960. Cave dwelling bat, swiftlets and collembolae are the only creatures getting sufficient interest from a few Indonesian biologists, working at the Biological Research and Development Center of the Indonesian Science Institute.

Indonesian karst is an immense treasure so widely spread, so diverse and so abundant, potentially harboring rare flora and expensive medicinal plants. It also is a habitat for endemic karst fauna (like the beautiful butterflies at Bantimurung, Maros National Park), It is indeed regrettable that only a few Indonesian scientists are interested to study the interesting Indonesian endo- and exokarst phenomena. Only three Indonesian geologists, in the late nineties, have shown interest in karst hydrology and speleology. Even presently, no Indonesian geologist has dared to venture deep into caves, in contrast with French, Belgian, British and Italian geologists who have explored many caves in Indonesia with FINSPAC's assistance.

Karst Hydrology, is not yet studied intensively in Indonesia. Geologists in charge of making the Environment Impact Analyses, still consider karst hydrology similar to surface river"s laminar flow. They still apply Laplace formula in karst hydrology. Different flow patterns of underground rivers in all major karst areas are not yet studied and mapped. No data is available on off-shore karst springs, which could easily be revealed by infrared remote sensing.

Indonesian archaeologists were fascinated by the handprints, so frequently found in many caves in East Indonesia. But they did not anticipate that the caves in the deep interior of East Kalimantan, so intensively surveyed by French speleologists since 1982, yield the most abundant cave wall paintings and handprints in the world. Karst tourism in Indonesia is limited to Bantimurung"s waterfall and cave in South East Sulawesi. No one is interested to develop karst tourism in the spectacular conical karst of Gunung Sewu and cockpit karst of South Gombong.

Only a handful of decorative caves are open to the public, all badly managed and decaying, due to overvisit and design overkill (Gong cave at Pacitan, East Jawa. Jatijajar cave, Gombong, Central Java).

The whole word knows, that Indonesia possesses several tree species which grow profusely in certain karst areas and are very expensive, due to its superb quality for building material and furniture. They are teak *(Tectona grandis),* mahogani *(Switenia mahagoni),* black wood *(Diospyros celebica* Bakh). There are also very expensive tree species, producing aromatic amber or scented wood, which are sold per gram: *Gaharu (Aquilaria malaccensis* and *A. vilaria)* and *Sandalwood (Santalum album).* It is a sad fact, that until recently, more and more trees are being felled illegally. In East and Central Java, teak are very extensively cut down illegally. Sandalwood and Gaharu trees are in danger of extinction. Black wood are cut down completely in many parts of Sulawesi. It is very difficult to cultivate different species of these endemic karst plants, since it is not sure that they grow well on other karst areas, let alone on non-karst areas. With the disappearance of endemic trees and plants, endemic fauna will become extinct also. Whole karst ecosystems will be disrupted.

Many caves were inhabited by prehistoric animals and men in the past, living in very different climates and environments. Flora and fauna at the Gunung Sewu karst was described by Jughuhn (a medical doctor and nature explorer) in his travel report through this area in 1820. His publication of Gunung Sewu"s unique geology and biology is still considered a highly valuable treatise. There is a tremendous change in vegetation since 1900. The finding of a hippopotamus jaw in a Gunung Sewu cave, depicts that this dry karst area was a large swamp in the past.

In the nineteen sixtieth, the first cement factory in Java opened at Gresik (East Java). At that time no environmental impact analyses was required. But since then, annual escalation of cement production was the rule. In the ninetieth all karst formation in Gresik have been used up, while production was already targeted at 20 million tons cement annually. So new plants were built on nearby Tuban karst, so important hydrologically. Major karst springs are up till now used up to produce cement by the wet method. Hundreds hectares of wet fertile rice fields are now left dry. However each time the investors declare that cement industries create many jobs for the unskilled karst inhabitants, who are mostly poor farmers.

To get the permits needed, the investor concocted a team of “experts”, nearly all of them mining engineers. Not any of them is a karst and cave scientist. No one dares to explore the many water caves. to map the underground river courses and calculate their water debit. They however are considered “qualified” in making the environment impact analyses, which are repeatedly questionable, inaccurate and incomplete. Nevertheless the cement factories were allowed to start producing. Within only ten years, the amount of Tuban limestone quarried, was nearly exhausted and recently a plan to mine the karst at Citeureup, in far away West Java for this factory, is being negotiated. The team of experts making the environment impact analyses and the team in charge of commenting it, once again, never consist of karst and cave scientists. No hydrological, biospeological, archaeological, palaeontological survey were performed in the past. No accurate data on the cave dwelling bats and swiftlets were ever presented. Karst ecosystems in situ were not surveyed. In short, no valid data on karst hydrology and endokarst phenomena were presented and commented, during the official evaluation of the biased environment impact analyses.

Holcim cement factory is one of very many cement factories already in operation in west, central and east Java, west and north Sumatra, south-east Sulawesi, west Timor, and other islands. Even the tiny island of Nusakambangan in the south of central Java, is being quarried intensively. South Gombong karst, the most important karst water resource in the island of Java, is geomorphologically very important, since it is the only cockpit karst in Indonesia. It was the next target in 1993 for a cement factory. FINSPAC recruited experts, consisting of scientists in related fields (speleology, soil science, geology, geography, hydrology, nature conservation, forestry, biology, ecology etc). They did their best to overhaul the bias-ridden environment impact analyses, once again made by the team of "experts" that made the biased analyses of Tuban Karst.

Very frustrating indeed that the minister of environment, at that time, unconditionally gave his permit to this cement factory to start producing, although all evidence against the biased environment impact analyses was clearly put forward. Even the using up of all karst water, supplying the town of Gombong, for the wet method cement production plant, was agreed upon by this minister and the Kebumen head of district at that time, pleading that the muddy water of nearby Sempor dam – dry in the dry season- was good enough for the people. Inhabitants at the Gombong cement quarry site were intimidated to sell their land and property for cheap. But insufficient funds was the reason why this factory never began production, although the investor had spent billions of rupiahs to purchase most of the quarry sites.

The ongoing dilemma is the lack of experts in Indonesia to perform the complicated karst environment impact analyses. There are also not enough experts who are capable to evaluate this analyses and to give their unbiased, objective scientific comments. Local governments, so euphoric in getting their autonomy due to decentralization of bureaucracy, are even less equipped, to objectively do the analyses. Prior to the birth in 1983 of the Federation of Indonesian Speleological Activities (FINSPAC), in Indonesia known as Himpunan Kegiatan Speleologi Indonesia (HIKESPI) the Indonesian government and nearly all Indonesian scientists considered karst only having economic value as a mineral resource, which can be exploited unrestrictedly.

In 1985, followed by 1996, FINPAC succeeded in organizing the First and Second National Symposium on Karst, with the full support of the Indonesian Science Institute, the Ministry of Forestry, the Ministry of Environment and the Ministry of Culture and Tourism. Each symposium was attended by more than one hundred interested scientists, bureaucrats, students and university lecturers. Several field trips and concomitant scientific meetings to the Gunung Sewu, South Gombong and Maros Pangkep karst coordinated by FINPAC's since 1993, were taken part by many scientists in related fields.

Since then scientists all over Indonesia began to appreciate the many virtues of karst, thanks also to the constant and consistent effort of Acyntia Sunyata Speleological Club, Geography and Biology Faculties University of Gajah Mada, Yogyakarta students, coordinated by an NGO (Sekretariat Bersama), University of Hasanuddin Center of Environmental Studies, many other universities and FINSPAC, to inform nationwide the importance of karst at many occasions, such as the National Karst Environment Symposia, organized twice in 1985 and 1998, by FINS PAC and sponsored by the minister of forestry.

FINSPAC has also been consulted by the minister of forestry and minister of environment several times. The multidisciplinary team of experts recruited by FINSPAC to make the Environmental Impact Analyses , has always given objective professional statements to investors who plan to quarry karstified limestone in forested areas. Many requests to quarry karst areas were denied. Only a few were given the green light, if no serious endo- and exokarst impact were anticipated.

It was therefore a milestone when Ir Kuntoro Mangkusubroto, the minister of mining and energy in 1999, did agree to organize a national workshop on mining in karst regions, thereby approving the principle of limestone resources management based on environment consideration.

The workshop was a major success, attended by experts in geology, geography, mining, hydrology, speleology, archaeology, biology, tourism, forestry, agriculture, and environment.

They all have one single target in mind, namely how to utilize and manage karst resources holistically, and interdisciplinary, in a coordinative way. The outcome of this Workshop was a Ministerial Decree on the National Classification of Karst Resources in Class 1, 2 and 3. Only Class 3 karst may be mined. Class I conserved, and absolutely prohibited to be mined. Class 2 only allowed to be mined under strict conditions.

It is unfortunate indeed, that before this Ministerial Decree could be enforced nationally, Ir Kuntoro Mangkusubroto was not reelected.

In 2000, the Minister of Environment took steps to escalate this Ministerial Decree to a Presidential Decree. A closer step towards a Karst Law. However, after nearly four years of discussions, coordinated by the Ministry of Environment, no consensus was reached to get the Presidential Decree. Karst Classification, in practice, was delegated to the District Heads, lacking even the basic knowledge of karst and cave related problems.

At Wonogiri, in 2007, the President declared the Gunung Sewu Karst and the South Gombong karst as ECOKARST. No mining activity is allowed there. A Karst museum is built south of Wonogiri, at a section of the Gunung Sewu karst. Implementation of this ECOKARST however remains a dilemma, since it is still unclear how to stop illegal limestone mining, in the Gunung Sewu and South Gombong karst areas. We urgently need international funds and international karst experts" assistance to create a data base on Indonesian Karst and Caves, in order to protect this-in many locations-fast dwindling nature resource, due to extensive, uncontrolled mining for cement and "marble".

The Case of SOUTH GOMBONG KARST

The most important fieldtrip and National Karst Workshop were performed at the south Gombong karst in 2002, by the local government of Kebumen. Participants of the Workshop were depressed to observe how fast this scenic south Gombong karst dwindles, due to unlimited blasting and illegal limestone quarrying by the local inhabitants and immigrants, to supply the 137 kilns, requiring so much wood, thereby deforesting the whole karst area, which actually produced highly priced teak. Wood is being supplied from surrounding non karst areas, some of which turned out to be illegally logged.

Unsightly open quarries and karst landscape destruction plus heavy air pollution are the result, the hamlets of Redisari and Kalisari being the most affected. Not a single day, even not a single hour is there fresh air. Smoke and dust are everywhere, even darkening the daylight environment, especially after some kilns used coal instead of wood, thereby producing a nasty scent. The locals also produce home made palm sugar, requiring again, much wood.

Former lucrative but labour intensive farming was abandoned. The locals prefer quick yielding limestone quarrying. But controversially, no one became rich. The locals only got Rp 15,000,- a day for blasting, quarrying and carrying the limestone chunks to the kilns. Kiln owners only got a profit of at most Rp 150.000 a week, since they must pay so much for firewood or coal.

Inhabitants of both hamlets still remember nostalgically the fresh air and bright days when no kilns were built. Water was abundant even in the driest season. Nowadays many spring wells are dry in the dry season and the big springs produce less water than formerly. On the other hand, flood in the plains surrounding the karst hills, especially on the eastern part during heavy rain, is the rule rather than an exception, completely inundating the main road to the village of Puring, creating a vast lake for days. Landslides have happened on the western and southeastern part of this karst area, destroying houses and killing some inhabitants.

Some hunters are still actively killing the few monkeys left in the sparse forest above the

Petruk Cave. Souvenirs and handicraft are sold by locals, benefiting from the Jatijajar Cave tourism site. A few eating stalls near the Jatijajar, Petruk and Karangbolong caves are owned by locals, but many more by immigrants. Rice planting on the fertile alluvial plain surrounding the karst hills produces good crops. Many fruit bearing trees are abundantly producing mangoes and breadfruit, which are never sold but left unharvested.

The Case of TAGOGAPU Karst Area

The same problem, encountered in a much larger scale, occurs at the Tagogapu Karst area, west of Bandung. Panoramic karst hills, are being blasted away with dynamite by the many kilns and "marble" factories, operating day and night. They all have a permit to destroy this scenic landscape. Prehistoric human skeletons, thousands of years old, found in a cave, gave the reason to declare part of the Karst region a cultural heritage site. Mining however is still unstoppable, destroying the very scenic towers.

The Case of MAROS and PANGKEP Karst Area

The destruction of the panoramic limestone towers at Maros-Pangkep karst, many of them containing caves with numerous pre-historic handprints on the walls is still going on. Many cement factories, marble industries with official permits are still quarrying and destroying these caves. FINSPAC"S effort in 1993, to declare this classical tower karst, supported by all national delegates, present at the Beijing International Conference of the Union Internationale de Speleologie, met deaf ears in Indonesia.

The Case of PATI Karst Area

PT Cement Gresik"s effort to exploit this major North Gunung Kendeng karst area met strong opposition from the local inhabitants, mostly fervent adherents of a religious system, known as Samin, but naming themselves Sedhulur Sikep. The environment impact analyses was made by the Center of Environment from the University of Diponegoro, Semarang Central Java. According to many scientists, e.g from the University of Gajah Mada and National Veteran University, Yogyakarta, backing up the ASC Speleological Club cave explorers, the environment impact analysis was completely unreliable. Only a very few karst springs and caves were reported, while in fact, more than 60 caves and scores of springwells were documented by the cave explorers. Many of them mapped.

No sufficient data on biospeleology and karst ecosystems were presented in the analyses. Karst hydrology with accompanying data on water balance, annual precipitation rates, debits of individual spring wells and cave streams, were not made. Hydrographic maps of relevant karst regions and borehole data were not presented.

The Central Java Government however agreed to determine the North Kendeng Karst plausible to be quarried for cement industries, without adequate, holistic, multidisciplinary environment analyses, depicting gross negligence towards the multiple values of karst and caves,.

The Feasible Proposed Solutions.

Karst areas in many Indonesian islands impose identical or similar dilemmas Those are short term exploitation (mining) versus long term sustained utilization (tourism, farming, forestry, agroculture). The ultimate fate of Indonesian karst environment is actually in the hands of the local inhabitants and more important, depends on the responsibility of the local governments.

However, neither side are aware of the importance of this unique and valuable nature resource. Even the central government, the parliament, the policy and decision makers, the bureaucrats, the scientists, the educators, the students and professors, members of non government organizations, are not equally aware of the global importance of karst, with emphasis on water resources and biodiversity of karst terrains. Only a very few have ever heard about the concept of karst being an dynamic energy system, with water as the driving force. "Man in karst", the most important and valuable component, upon which the ultimate fate of karst depends, is not yet highlighted in Indonesia.

The most feasible proposed solution, is thus the education of man in karst, to instill their awareness of the importance of karst. This requires nationwide, professionally prepared strategies, to be applied on several levels concomitantly, as pioneered by FINSPAC, that has in the past organized technical caving and scientific speleological courses for university students, educational lectures and fieldtrips for elementary and high school students and for scientists: scientific symposia, panel discussions, and workshops on karst and caves, attended by bureaucrats, educators and scientists as well, lobbying high standing bureaucrats and policy makers up to the level of ministers, recruiting senior government officials as active FINSPAC members or advisors, thereby creating the strong image that FINSPAC is not opposing the government, but functions as active and constructive partner, together with Universities interested in Cave and Karst conservation.

Many more "man in karst based organizations" should be created. Local inhabitants, university graduates, have been and are being recruited to identify all possible ways to solve existing karst environment problems. They are encouraged to maintain a constructive dialogue with all stakeholders and government officials. The need to improve living conditions of karst inhabitants must be discussed periodically, constructively and transparently with the local government and the local parliament members on an equal base. Local educated people are now aware of the strategic values of South Gombong karst.

Alternative solutions to utilize this important and unique karst formation in a sustainable way are scrutinized with the assistance of scientists. Lucrative fish breeding outside spring wells, mushroom cultivation in certain humid caves, and replantation or relandscaping of barren karst terrains with ground covers and shrubs at rainwater catchment areas are short term solutions. So is the use of compacted sawdust in special containers, functioning as efficient ovens for daily cooking and palm sugar production.

Cultivating edible and medicinal plants are middle term programs. So are breeding of goats, sheep, rabbits in enclosures. Duck breeding, so popular in Kebumen's neighboring districts supplying restaurants serving roast duck, satay, and curry should be introduced. Longterm programs have been pioneered by the Karst Forest Research Center of the Gajah Mada University (Wana Gama). Planting the very expensive Sandalwood trees is on the list. So is the building of swiftlets houses, producing edible nests, outrageously expensive. Cave dwelling swiftlets, occupying the southern coastal karst caves of Java are unfortunately alarmingly decreasing in numbers. This is due to robbery of the edible nests, unregulated swiftlet"s nest harvesting, and deteriorating environment.

Cave and karst tourism is also on the long term list.Management of Jatijajar and Petruk caves is bad, not in the least reflecting the international standard of tourist cave management. The urgent need to develop Petruk cave as a national sample for tourist cave management is frequently proposed by FINSPAC. All plans have no meaning if not implemented. To implement them. funds are needed. This is then the biggest dilemma in Kebumen. All sensible recommendations put down on paper on the last day of the national Workshop on South

Gombong karst still remain on paper. It is therefore mandatory that all kinds of recommendations should be backed up by available funds, enabling their implementation.

The government of Kebumen is however convinced, that developing its karst region must never be restricted to that region only. The surrounding non-karst regions should be developed concomitantly, thereby decreasing the pressure on the karst environment. Creating jobs outside the karst region should be attempted. Local inhabitants should be trained in providing facilities on a “bed and breakfast" basis, as already done by FINSPAC to teach five guesthouse owners in the hamlet near Petruk cave.

The Future of Indonesian Karst and Caves

As stated before, the fate of Indonesian karst and caves is in the hands of local inhabitants. But it is clearly nonsensical to expect them to conserve these important natural resources, as long as they do not apprehend the multi values and multi functions of karst and caves.

In 1993 the Minister of Environment, Emil Salim, decided to establish an ad hoc committee, consisting of some scientists concerned and committed to contemplate the fate of Indonesian karst and caves. This committee functioned unofficially as a think tank for the Ministers of Environment, Forestry, Tourism, and Interior on karst and caves related issues.

Subsequent Ministers of Environment alternatively ignored or appreciated this committee, the members of which working part time without fee and funds. After a dormant period until 1999, this ad hoc committee became fully active, fully sponsored by Sonny Keraf as Minister of Environment, culminating in the organization of a National Workshop on data collecting and utilization of Indonesian karst regions and caves, on August 25, 1999 in Jakarta and Cisarua.

In his directive address at this National Workshop, the Minister of Forestry and Plantation, Muslirnin Nasution pronounced his hope, that this ad hoc committee, in coordination with the Ministries of Forestry and Plantation, Tourism, Art and Culture, Interior, External Affairs and local governments all over Indonesia, will succeed in data collecting, and problem solving of karst and cave related issues.

He stressed on the uniqueness of karst and cave ecosystems and other karst, still. unknown, potentials. Thereby creating a splendid opportunity and challenge to manage karst and cave ecosystems with emphasis on conservation and active participation of local karst inhabitants. He further stressed the importance of karst terrains to retain water, so important to humankind. He recognized following weaknesses:

1) Management of karst and cave ecosystems is not yet on the priority list of the government's programs.
2) Software to protect karst and caves is still limited.
3) Data and informations on caves, possessing scientific and archaeological values, are still limited.
4) Karst and cave ecosystem studies and research are very limited.
5) Karst and cave ecosystems are not yet compulsory incorporated in geological, biological and environmental studies.
6) Professional human resources in karst areas are still limited,
7) Appreciation by the Indonesian public, of the existence of karst and caves is still insufficient.

In 2002, the Directorate General of Rural Development, Ministry of Interior, in coordination with the National Karst ad hoc Committee has organized lectures and field trips to the Gunung Sewu Karst, located in the districts of Gunung Kidul, Wonogiri and Pacitan, participated by representatives of many local governments with karst and caves under their jurisdiction. The aim was to inform and promote sustainable and integrated development of karst areas. The theme of those field trips and lectures was "Integrated National Karst Management".

It was not until March 31,2003, that the State Minister of Environment officially instituted the Working Group on Karst Regions Management, with concomitant preparation to escalate the Ministerial Decree on karst classification to a Presidential Decree. This declaration however remains dormant, since no compromise between relevant ministries was reached. The lobby of cement industries to postpone or drop any effort to protect Indonesian karst terrains and caves seems to be very strong.

It also remains to be proven, whether the official involvement of the Central Government, backed up by a Presidential Decree, can bring substantial change in attitude of karst inhabitants and local governments, facing the controversial destructive karst exploitation versus karst conservation.

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A GENERAL ASSESSMENT OF THE GREAT CAVES AND THE KARST OF SOUTHEAST ASIA

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Abstract
Southeast Asia can be sub-divided into its mainland part, which covers Burma/Myanmar, Thailand, Cambodia, Laos, Vietnam and the Malaysian peninsula with Singapore, as well as the Southeast Asian islands, which comprise the Philippines, Borneo (divided between Malaysia, Indonesia and Brunei), Indonesia, and the small state of East Timor.Karst is a widespread and important phenomenon in Southeast Asia covering about 215,000 km^2 of the mainland part of Southeast Asia and approximately 230,000 km^2 of the surface of the Southeast Asian islands. These karsts, developed in a moderate to intensive tropical climate, belong to the most varied and spectacular on Earth – some of which are World Heritage Sites in recognition of their geomorphology and biodiversity.Information on the extend cave research however is very scattered and often inaccessible. This article strives to fill the gap by providing an overview of the speleology of Southeast Asia. It is an excerpt of the recently published detailed “Atlas of the Great Caves and the Karst of Southeast Asia”.

Keywords: Southeast Asia, caves, karst

Introduction

- **General Remarks**

Southeast Asia currently has the 10th longest cave in the world (Clearwater System, Malaysia) at 175,664 m, the largest cave passage on Earth (Hang Son Doong, Vietnam) with a 4.5 km long passage of 100 m in diameter, at places even 200 x 150 m, and the largest known underground chamber (Sarawak Chamber in Lubang Nasib Bagus, Malaysia, 162,700 m^2 or 12,000,000 m^3). The importance of the karst of Southeast Asia is well recognized on a regional and worldwide scale, especially for tourism. However, no attempt has been made so far to compile and assess the complete portfolio of Southeast Asian karst and cave occurrences. This significant lack of information is caused by the fact that a lot of the data has not been published at all or has only been released in niche publications like private expedition reports produced in small numbers. This has led to the situation that speleometric data on Southeast Asia is only available to a small and relatively closed group of speleologists who know each other personally from joint field work or from speleological conventions. Thus exchange of information is efficiently hampered by data being unavailable for interested scientific circles. Consequently, the authors of this article have compiled speleological information on Southeast Asia during a two-year long exercise. Much of this data originates from the authors own long-standing speleological investigations. The great enthusiasm of amateur explorers to contribute to this data collection resulted in the release of a very detailed “Atlas of the Great Caves and the Karst of Southeast Asia” (Laumanns & Price, 2010) (see www.speleo-berlin.de), which intends to provide “Yellow Pages” on the exploration of the karst and caves of Southeast Asia as represented by verifiably published and oral sources. It is intended to update the atlas on an occasional basis. If not indicated otherwise all statements presented below were taken from this atlas.

Southeast Asia became a popular place for many speleologists for conducting research. However, although our knowledge on the karst and caves of Southeast Asia has witnessed a stunning increase since about 1970, there is still a severe lack of credible speleometric data, which makes it evidently clear that much work remains to be done on further exploration according to international standards as well as on confirming doubtful data.

This publication focuses on carbonate karst. However, extensive late Pleistocene to Holocene basaltic lava flows, which also can host significant caves, are known from Myanmar, Vietnam, the Philippines and Indonesia. Although some smaller lava tube caves became known, e.g. in south-central Vietnam and from Indonesia, these lava flows have not yet been subject of systematic speleological investigations.

- **Mainland Southeast Asia**

The mainland of Southeast Asia contains some of the more extensive karst regions in the world. Most limestone deposition has taken place in the Upper Paleozoic (with the Permian and Carboniferous being the most important). Some Jurassic, Liassic (Thailand, Laos), Ordovician (Thailand, Laos) and even Cambrian (Laos, Vietnam) limestone occurs, too.

The Indosinian orogeny, which has affected most of mainland Southeast Asia, occurred in the Middle Triassic (about 230 mya) resulting in a general uplift and a subsequent erosion episode, including karstification (Indosinian karstification). A second phase of regional uplift began in the Palaeocene about 65 mya, mainly caused by the Himalayan orogeny and the opening of the South China Sea. This uplift has led to strong erosion (e.g. some 3.2 km has been eroded from the central Khorat Plateau in northeast Thailand). This period represents the second major phase of karstification as the carbonate deposits all over mainland Southeast Asia became exposed to weathering (Cenozoic karstfication). The long-lasting uplift caused a relative deepening of the base level and has led to extensive planation surfaces, large and deep poljes, tower karst as well as fengcong karst. Due to tectonic subsidence several coastal karst areas have been inundated by the sea, e.g. the islands of the Andaman Sea, the Ang Thong Islands in the Gulf of Thailand, and Ha Long Bay in Vietnam.

- **Southeast Asian Islands**

The Southeast Asian islands have a complex tectonic setting due to interactions between the Philippines, Pacific, Indian-Australian and Eurasian plates. The area can be distinguished into an older, stable region comprising the Asian mainland, the Proto-Indosinia block and Borneo, which abuts a younger, very unstable region affected by neotectonism, abundant earthquakes and volcanism – namely on the Philippines and the Indonesian archipelago.

The most extensive limestones in Borneo are the massive Eocene to early Miocene rocks in northern Sarawak (Malaysia). Sabah (Malaysia) and Kalimantan (the Indonesian part of Borneo) have Cretaceous limestones in the NE and younger uplifted reef limestones along the NW coast.

The Philippines have many karst landscapes of very different morphology scattered over the archipelago formed on rocks ranging from Cretaceous to Tertiary in age. Karst on Quarternary raised reefs is also present. The island of Bohol (south-central Philippines) is famous for a distinctive karst known as the “chocolate hills” characterized by smooth, cone-shaped isolated hills of limestone with elongated interfluvial ridges.

In Indonesia, the Sunda and Banda volcanic arcs form the base of a discontinuous karst which consists of Mesozoic and Tertiary carbonates. The largest karst area is the one of Gunung Sewu (Java). The limestone of Sulawesi is of Tertiary age and occurs mainly in the central, southwestern and eastern part of the island.

Tectonic uplift of the large island of New Guinea attains annual rates of 2-3 mm. Its Indonesian (western) part has karst areas extending from the sea level to nearly 5,000 m at

Puntjak Jaya (Lorenz National Park) with major rivers in the central mountains cutting through the limestone. The karst morphology has a great diversity with some of the world�were"s most spectacular karren fields, giant dolines and sheer breathtaking vertical cliffs, most of which is speleologically unexplored. Just outside of the geographical boundaries of Southeast Asia, in Papua New Guinea, the cave system of Muruk-Bérénice represents the currently deepest cave of the southern hemisphere (-1,258 m).

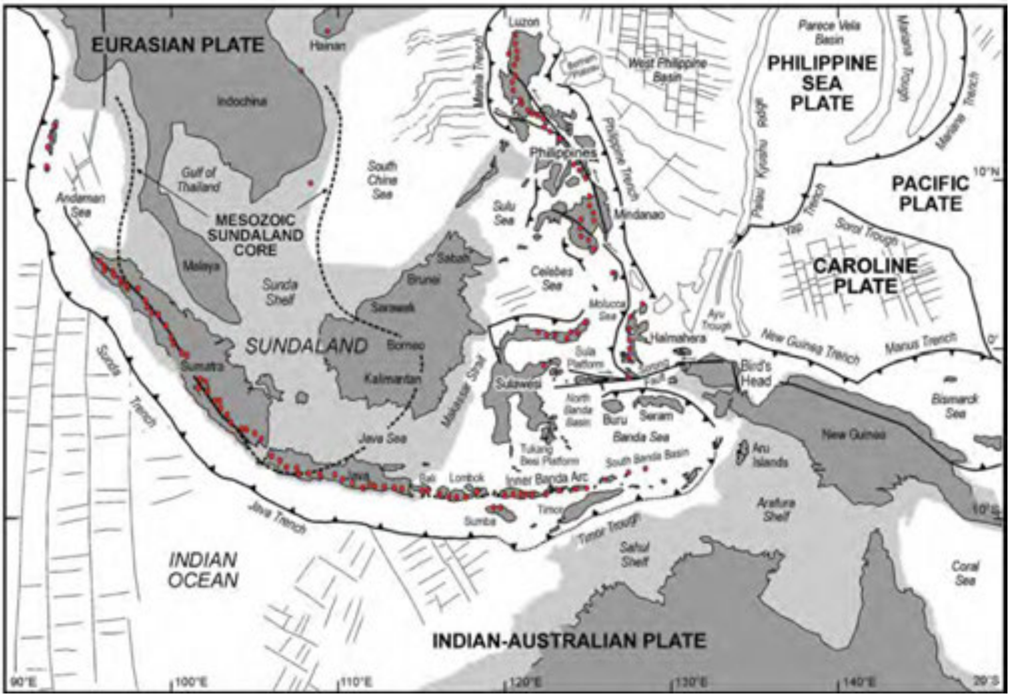

Figure1. Overview map of Southeast Asia and its geotectonic context (according to Hall 2002, completed).

- **Brunei Darussalam**

There is no known extensive karst in the small state of Brunei. One limestone cave discovered in 2008 is at Kampong Puni, in the Bangar area of Temburong District. The Bukit Peradayan Recreational Forest is reported to have limestone and caves (Bolhassan) although it could be sandstone.

Table 1: Longest caves of Southeast Asia (length in metres)

1.	Clearwater System	Malaysia (Sarawak)	175,664 m
2.	**Benarat-Moon-Cobweb System**	Malaysia (Sarawak)	50,669 m
3.	Terikan System	Malaysia (Sarawak)	32,573 m
4.	Tham Nam Non System	Laos (Khammouane)	>30,000 m
5.	Green Cathedral System	Malaysia (Sarawak)	26,382 m
6.	Saint Paul Cave (Puerto Princesa Subterr. River)	Philippines (Palawan)	~24,000 m
7.	Hang Khe Rhy	Vietnam (Phong Nha-Ke Bang)	18,902 m
8.	Tham Chom Ong System	Laos (Oudomxay)	15,827 m
9.	Hang Vom	Vietnam (Phong Nha-Ke Bang)	15,760 m
10.	Bridge-Cloud-Cobra System	Malaysia (Sarawak)	15,506 m
11.	Tham Xe Bang Fai (Tham Khoun Xe)	Laos (Khammouane)	15,180 m
12.	Tham Phra Wang Daeng	Thailand (Phitsanulok)	13,844 m
13.	Tham Thôn-Tham Houey Sam Boun	Laos (Khammouane)	13,309 m
14.	Tham Mae Lana	Thailand (Mae Hong Son)	12,600 m
15.	Tham Kong Lo (Tham Hin Boun)	Laos (Khammouane)	12,400 m
16.	Mactingol Cave	Philippines (Samar)	12,300 m
17.	Gua Salukkan Kallang	Indonesia (Sulawesi)	12,263 m
18.	Tham Phi Xua	Laos (Khammouane)	>12,000 m
19.	Lungib Can-Yawa	Philippines (Samar)	11,700 m
20.	Luweng Jaran	Indonesia (Java)	>11,249 m

Table 2: Deepest caves of Southeast Asia (depth in metres)

1.	Cong Nuoc	Vietnam (Lai Chau)	-600 m
2.	Basta Noodles	Vietnam (Ha Giang)	-528 m
3.	Snail Shell Cave	Malaysia (Sarawak)	-473 m
4.	Tham Phi Xua	Laos (Khammouane)	+465 m
5.	Bridge-Cloud-Cobra System	Malaysia (Sarawak)	-460 m
6.	**Benarat-Moon-Cobweb System**	Malaysia (Sarawak)	+/-450 m
7.	Hang Son Doong	Vietnam (Quang Binh)	+/-449 m
8.	Clearwater System	Malaysia (Sarawak)	-440 m
9.	Gua Nasib Bagus	Malaysia (Sarawak)	-423 m
10.	Ta Chinh	Vietnam (Lai Chau)	-402 m
11.	Goa Hatu Saka	Indonesia (Sumba)	-388 m
12.	Hang Ong	Vietnam (Ha Giang)	-368 m
13.	Tham Pha Pueng	Thailand (Nan)	-367 m
14.	Lomes Longmot	Indonesia (Irian Jaya)	-360 m
15.	Sibil Buk I	Indonesia (Irian Jaya)	-349 m
16.	Hang Lau	Vietnam (Quang Binh)	-354 m
17.	Xa Lung 2	Vietnam (Ha Giang)	-340 m
18.	Hang Vuc Tang	Vietnam (Quang Binh)	+/-325 m
19.	Green Cave	Malaysia (Sarawak)	+/-320 m
20.	Lomes Iono Besar	Indonesia (Irian Jaya)	-315 m

- **Cambodia**

Cambodia"s karst areas are mainly located in the south around Kampong Trach and Kampot as well as in the northwest around Battambang. A possible and most likely promising third karst area north of Stung Treng has not yet been investigated. In both areas of southern Cambodia and near Battambang, the partly dolomitic limestone of Upper Permian age appears as isolated hills and mountain massifs that overlook the flat alluvial plain. These hills have elevations of up to a few hundred metres and are called “phnom” in Cambodia.

Our knowledge of Cambodian caves is mainly based on a German expedition to Kampot/Kampong Trach in 1995/96 and a German-British project, which was carried out in 2008 in the Battambang area.

The 1995/96 project yielded 37 caves with a total of 11.6 km of passages, including the currently longest cave of Cambodia (Roung Dei Ho-Roung Thom Ken at 1,806 m) and several Hindu Shiva temples inside caves, which were unknown to science and date back to the 6th century AD. The 2008 project yielded 65 registered caves, 55 of which were visited and 42 were mapped according to international standards. A total of 4,239 metres of cave passages was surveyed in 2008.

Generally speaking, Cambodia has only small karst areas and thus a limited speleological potential. However, the known caves are comparatively well documented and published.

- **Indonesia**

The landscape of Indonesia developed in the Pleistocene during which Indonesia formed a land bridge between the Southeast Asian mainland and Australia. The islands we know today were formed by a rise of the sea level after the last glacial period. This makes the southern Indonesian islands a particularly interesting area to study archaeological remains from the time of hominid migration to Australia. This has led to the discovery of a new human-like species that lived just 18,000 years ago on Flores Island in Liang Boa rock-shelter. Skeletal remains show that the hominids, nicknamed "hobbits", were only 1 m tall, and lived on the isolated island long after *Homo sapiens* had migrated through from mainland Asia to Australia.

The southern arc of the Indonesian islands was formed by a subduction of the eastern plate of the Indian Ocean and Australian plate under the Sunda shelf, which represents the southeasternmost edge of the Eurasian plate. This subduction zone is associated with a strong Cenozic volcanism. The northeast peninsula of Sulawesi (Celebes) and the Halmahera islands also have strong volcanism caused by a collision zone of the Eurasian Plate with the Philippine Mobile Belt. With the geology of Indonesia being dominated by recent volcanic and sedimentary rocks only the Borneo block, north-central Sumatra and Timor as well as Irian Jaya, and the Buru and Seram islands, which have remained stable similar to the Indosinian block of the Southeast Asian mainland, expose older geological formations. The Sunda and Banda volcanic arcs form the base of a discontinuous karst which consists of Mesozoic and Tertiary carbonates. The stratigraphy of the western part of Indonesia is relatively young, ranging in age from Paleogene to Quarternary. Eastern Indonesia has older stratigraphy compared to the western part. The stratigraphy ranges from Triassic to Tertiary. Devonian limestones were found in Telen River, East Kalimantan, as fragments within Paleogene clastic sediments.

Early karst exploration on the Indonesian islands was done in the beginning of the last century by naturalists, mainly Dutch. The easily accessible tropical karst of Gunung Sewu (Java) has attracted many scientists since 1910, the same applies to the Maros karst in SW Sulawesi.

Many caves on Bali and Sulawesi were described by Kusch between 1979-1982. In 1979 the "Indonesian Speleo Club (Specavina)" was formed by Dr. Robby Ko, who subsequently established the "Indonesian Federation of Speleology (FINSPAC)" in 1983. The federation has made it possible for many foreign caving expeditions to visit Indonesia. Indonesian caving groups were formed at some universities (Ujung Pandang and Padang). Independently from western assistance they conducted their own speleological expeditions, e.g. to the Maros karst on Sulawesi (Acintyacunyata Speleological Club, 1989).

Expedition-style speleological exploration of Indonesia was started on Sumatra in 1977 by a Spanish team from the GESM Barcelona, when they visited western Sumatra. However, most knowledge on the karst of Indonesia was gathered by French teams, notably the "Association Pyrenéenne de Spéléologie (APS)", who started exploration in the Maros karst of Sulawesi in 1985 and returned to Indonesia almost on an annual basis until 2002 and visited many karst areas all over the archipelago, often together with Indonesian speleologists. They released excellent reports with many detailed cave surveys and in-depth biospeleological data. Furthermore, since 1982, many British, Australian, Italian, French, Belgian, Dutch and American teams also contributed to our knowledge on Indonesian karst and caves. They also co-operated with Indonesian cavers and targeted nearly all major islands with the main focus on Java (Gunung Sewu and Karangbolong) as well as Sumba, Sulawesi and Irian Jaya (since 1985), whereas the French cavers mainly focused on Sulawesi, Java (Karangbolong), Bali, Sumatra and on Kalimantan (since 1982) where the French discovered important sites with prehistoric cave paintings. More recently (since 2003), French cavers continue to work in Java (Karangbolong). A French Team also visited Irian Jaya several times between 1991-1995. Cave diving has been conducted by Australian and Belgian speleologists.

The longest caves known in Indonesia are Gua Salukkan Kallang (Sulawesi Selatan, Maros, Kappang) at 12,263 m, Luwang Jaran (Java, Gunung Sewu) at 11,249 m, Gua Tanette (Sulawesi Selatan, Maros, Kappang) at 9,692 m, and Gua Barat-Gua Purat (Java, Karangbolong) at 9,600 m. Eighty-five caves in Indonesia currently have a length exceeding 1 km. The deepest cave known is Goa Hatu Saka (Moluccas, Seram island, Saleman), which is -388 m deep. It has a spectacular large entrance pitch with a direct drop 217 m deep, followed by another 160 m deep vertical pitch. Seventy-two Indonesian caves are over 100 m deep.

Speleological documentation of Indonesian caves is comparatively good. Most of the foreign expeditions have produced comprehensive reports, especially the French APS expeditions. However, publications are numerous and scattered. Important reports are only available through specialised speleological federation libraries or the explorers themselves. Many reports are out of print.

- **Laos**

Laos mainly stretches along the east banks of the Mekong River. The topography over much of Laos is very rugged. The tectonic movements have strongly affected the limestone sequences. The main tectonic fractures run from N-S and from NE to SW. The carbonates are heavily deformed, often showing a steep or even near-to-vertical dip, and are partly recrystallised and metamorphized.

Most limestone deposition has taken place in the Upper Paleozoic (with the Permian and Carboniferous being the most important). Some Jurassic, Liassic, Devonian, Ordovician and even Cambrian limestone occurs, too. The carbonates are in most cases underlain by Carboniferous shale, schists or by older siltstones, conglomerates, rhyolithes, sandstones and claystones and are generally overlain by reddish continental formations from Trias to Cretaceous (sandstone, clay, clayey arenite) which have buried a paleokarst. In some cases the palaeokarst rejuvenated due to new exposure linked to strong Cenozoic erosion. The Permian limestone is discontinuously exposed between the Nam Ou River and the Myanmar border. Near Luang Prabang, the Permian limestone is extensively exposed and extends to Vang Vieng 100 km further south. In the Plain of Jars, in the Xien Khouang and the Ban Ban areas limestone of Permian age is exposed. In the Bolikhamsay and Khammouane provinces Permian limestone is widely exposed and forms the well-known Khammouane karst. Some Jurassic limestone layers have been identified in the area between Paklay and Luang Prabang in northern Laos. Ordovician limestone occurs in the Luang Namtha Province. The thickness of the limestone successions vary and is estimated to reach a maximum of 5,000 metres. The main karst areas identified so far occur in Central Laos (Khammouane Province), Vang Vieng, Kasi and around Phou Khoun (Vientiane Province), around Luang Prabang, Xiangkhoang, Vieng

Xai and Vieng Thong (Houaphan Province), Vieng Phouka (Luang Nam Tha Province), and in the Oudomxay Province.

Foreign cave exploration in Laos began as early as 1867 during the French colonial time. Since the retreat of the French Laos was closed to foreigners. Almost immediately after the re-opening in 1990 the country again attracted foreign speleologists due to its incredible cave potential. Primarily French as well as British and Italian expeditions investigated the limestone regions in these early years.

The French speleologist Claude Mouret, was the first to organise annual exploration campaigns since 1991, which were focused on the Khammouane karst, where most of the longest and deepest caves currently known in Laos are situated. In 2010 a total of over 170 km of cave passages were explored in the Khammouane karst. The French explored outstanding caves like Tham Nam Hin Boun (12,400 m long), Tham Nam Non, Tham Houay Sai-Tham Koun Dôn (7,000 m), and Tham Thôn-Tham Houey Sam Boun (13,309 m). Many of these caves are through caves and contain long massive underground river passages. Important cultural caves with many old Buddha figurines were also described by this team, including Tham Pafa.

The group led by Mouret split twice, creating new teams led by Charles Ghommid and François Brouquisse. The latter team has made its results from 2002-2004 accessible in a comprehensive publication including Tham Khoun Nam Pakan 2 (9,501 m long), Tham Phi Xua (>12,000 m) and Tham Lom (7,570 m). In 2010, a French-Italian-Romanian cave diving team led by Ghommid was able to link Tham Nam Non to its sinkhole cave Tham Song Dang, creating the longest cave in Laos at over 30 km.

Italian cavers also occasionally contributed to our knowledge of Laos caves. A Canadian/US-team explored Tham Xe Bang Fai (Tham Khoun Xe) during visits in 2006 and 2008. The cave was extended by the Mouret team in 2010 to 15,180 m and is currently the 3rd longest cave of Laos.

The karsts of Vang Vieng and Kasi area half-way between Vientiane and Luang Prabang in the southern part of northern Laos were first visited by British cavers before French speleologists took over in 1998 and conducted a row of successful expeditions. Forty four caves were explored up till 2003 with the longest cave currently known being Tham Hong Yé (5,916 m).

In 1999 a small Dutch group conducted a preparatory visit to the Luang Prabang Province. They returned in 2000 with a full-scale expedition, yielding many discoveries. The Dutch were followed by German explorers who founded the “Northern Lao-European Cave Project” and conducted annual expeditions to northern Laos. All their results, including the Dutch findings from 2000, were made available in three comprehensive reports. Currently, the longest cave in northern Laos and the 2nd longest in the country is the Tham Chom Ong System (Oudomxay) at 15,827 m of length, followed by Tham Na Thong (Oudomxay), 5,010m long. Eighty km of passages from 176 caves are currently known from northern Laos (excluding Vang Vieng/Kasi).

Thus only the expeditions that went to northern Laos and to Vang Vieng/Kasi have published all their results according to international standards. The same applies to the 2002-04 results of the Brouquisse team from Khammouane. Although the Khammouane teams led by Mouret continuously informed about the progress of their work in short notes including good area maps, a comprehensive publication including all their important cave surveys is still lacking. Their cave maps available in articles up to 2001 and occasional later articles are outdated. Consequently, the stand of cave documentation in Laos is currently unsatisfactory.

- **Malaysia**

Malaysia is divided into two parts, Peninsular or West Malaysia, and East Malaysia which comprises the states of Sabah and Sarawak (and the Federal Territory of Labuan) on the island of Borneo. In Malaysia as a whole, limestone hills occupy less than one percent of the land area: a figure of 0.3 % is generally quoted.

The limestones vary in age throughout the country. In the peninsula, they range from Ordovician (450 my old) through the Carboniferous and Permian to the Upper Triassic (220 my). Most occur within the Permian. Whereas in East Malaysia the rocks are much younger, from the Miocene period. Niah is only 20 my old and Mulu 10 my. In west Sarawak the limestones are of Permian, Jurassic and Cretaceous age, and mainly of Tertiary age in east Sarawak and Sabah. There are karst towers, as well as longer ranges such as the 30 km long and 5 km wide Gunung Mulu range, and also the Bau-Serian formation in west Sarawak.

There are roughly 510 limestone outcrops in Peninsular Malaysia, most of which are not very extensive. Gua Tempurung in Perak is the peninsula"s longest cave at 4.8 km, surveyed by a German and then an Australian team. The Gunung Lanno karst was the subject of an Austrian/English/German expedition in 2001 with Gua Puncak Lanno (1,584 m) being the longest cave surveyed. Although there were many occasional other expeditions, Peninsular Malaysia cannot boast of any speleological world records unlike Mulu in Sarawak. Deer Cave (4,100 m long) was considered to be the world's biggest/longest passage until April 2009 when it was announced that a larger passage in Son Doong Cave had been explored by British cavers in Vietnam. It is now debatable which is the larger. Sarawak Chamber in Lubang Nasib Bagus, a cave with a total length of 2,900 m, is the world's largest underground chamber, 162,700 m^2 or 12,000,000 m^3. Clearwater Cave at 175,665 m is the longest in Southeast Asia, and currently 10th longest in the world. Other long caves from Mulu are the Benarat-Moon-Cobweb System (50,669 m), the Terikan System (32,573 m) and the Bridge-Cloud-Cobra System (15,506 m), which is also the deepest cave of Malaysia with a difference of level of +/-473 m relative to the main cave entrance. All these caves are situated in the Gunung Mulu National Park which borders on to Brunei and were explored since 1977/78 by British expeditions. The National Park comprises the limestone massifs of Gunung Api and Gunung Benarat and the Southern Hills. The current surveyed length of caves in Mulu is 345 km. Gunung Buda National Park was gazetted in 2001. It adjoins Mulu and has around 50 caves, mostly explored by American expeditions. The main visits were in 1995 and 1997, and 2000. The total cave survey is 83.6 km. Longest cave is the Green Cathedral Cave System (26,382 m long), followed by Snail Shell Cave (11,636 m).

Caves were described from the large karst areas of Sabah but there has been no systematic speleological exploration so far. The Niah Caves in Gunung Subis are known for their archaeological importance (e.g. Niah Great Cave). The Painted Cave has famous rock paintings. The caves are part of the Niah National Park. The caves at Bau, near Kuching, in southwest Sarawak are also well known. Wind Cave and Fairy Cave are both show caves and are located in a nature reserve. The Bau-Serian limestone extends to the Kalimantan (Indonesia) border. There are many caves here, but none can rival the size of those at Mulu and Niah. Speleological exploration in Niah and Bau is still unsystematic.

Overall, speleological exploration in Malaysia has to be regarded as at the top-end of international standards with regard to the caves of the Mulu and Buda National Parks. With a few exceptions this is definitely not the case for the other karst areas in Sarawak, Sabah and on Peninsular Malaysia. Price (1998) published a bibliography of cave references, and a register of the caves of Peninsular Malaysia (Price 2001). The register is the only attempt so far to compile a complete overview of the caves of the country.

- **Myanmar**

The main limestone areas are the Shan Plateau in east Myanmar and the southern strip adjoining the Andaman coast. The Shan Plateau is a complex series of mountain chains and plateaus with an average height of 950 m. It rises abruptly from the central Myanmar plain. The limestone has a thickness of more than 2,000 m in places. It is mostly from the Carboniferous to Lower Triassic period, with some earlier Ordovician elements. In the north it is more brecciated, whereas in the south it is more compact and has cavernous development. Further east, outcrops of Permian limestones are known. The Indosinian orogeny in the Late Triassic and the Cenozoic Himalaya orogeny are responsible for a strong uplift and associated erosion causing strong incision of the rivers. Late right-lateral north-south trending normal faults affect the plateau. The Plateau is dissected by a series of deep gorges such as Gokteik, and those of the Thanlwin (Salween) River and its tributaries towards the east. The most famous cave is Pindaya Cave, which contains 8,000 statues and has been easily accessible to tourists and is published in tourist literature. Padah-Lin Cave is an important archaeological site.

Further north, there are scattered outcrops of the marbles and limestones of the Mogok Series. At Mogok itself marbles are host to the famous rubies. Open pits have exposed pinnacled rockheads on the marble karst and some of the mines have intersected cave passages, both open and sediment-filled, though no extensive cave systems have yet been found. A rich palaeontological fauna has been recorded from these caves.

In the Kayah State (south of Shan State) are many cave systems, especially around Loikaw and Demawso. In the north of Myanmar, there are outcrops of limestone of Permo-Carboniferous age in the Mytkyina District of Kachin State. The Sangkywe Cave is located here. Northwest of Yangon is the Nay Bu Taung area of limestone in the Rakhine State. There are some caves. Other small areas of limestone include the Bhamo region in Kachin State, Gangaw region of Magway State. There are Tertiary limestones in Ayeyarwady Division.

In the Hpa An (Kayin State) and Mawlamyine (Mon State) areas the strata is Upper Carboniferous and Permian, overlain by reef limestones from the Triassic period. The Moulmein Limestones are highly jointed, sometimes in several directions. The Permian Moulmein Limestone is a continuation of the limestone-dolomite sequence extending from the Shan State south through Kayah and Kayin States into Tanintharyi and is similar to the Phuket Group and the Ratburi limestone of peninsular Thailand. The upper part of this limestone has been considered Permo-Carboniferous in age. Most of the hills are isolated towers, some more than 400 m high, running NW-SE. There is also ridge karst. There is an excess of 40 major caves in 23 groups in the Mawlamyine area. Also further inland and further south, there are other caves known in the scattered blocks of limestone, but much of this area is not accessible to foreigners.

Outcrops of Permian Limestone also occur in the Tenasserim Range but little is known about these deposits which are continuous with those found in the Khwae Noi and Khwae Yai drainage basin of western Thailand.

The Andaman coastal area covers the southern part of Mon and Kayin States along with Tanintharyi Division and includes the more than 900 islands of the Mergui Archipelago. There are isolated outcrops of coarsely crystalline thick limestone. On the mainland they appear as precipitous hills, and offshore as a series of isolated islands. These islands have hongs, some are only accessible at low tide.

Many caves in Myanmar have been used by Buddhists for centuries, and are now important religious sites.

Speleological exploration in Myanmar started as early as 1826 in the areas of Hpa An and Mawlamyine. Kawgon Gu and the Farm Caves are probably the most visited caves here. Since independence in 1948 and the subsequent military rule, Myanmar did not welcome foreigners. In recent years Myanmar is opening its doors to tourists although many areas still remain off limits to foreigners, including many karst areas. As a consequence little speleological work has been done until in the years 1995-1998 when Claude Mouret and his wife mapped caves in Myanmar near Mawlamyine, Hpa An, as well as in the Shan State and other areas. None of these results were published. In 1998 a French group from Société Spéléo de l‟Ariège-Pays d‟Olmes went to the Shan State. They surveyed the longest cave currently known in Myanmar (Mondowa Guh, 1,170 m long, and Leikte Guh, 960 m), and published a valuable list of the 32 caves, which were known at that time in the country.

The Italian “La Venta” group went twice to the Shan Plateau area in 2004 and 2005. In total the Italians registered 30 caves and mapped 4.2 km of passages. The Kalaw area as well as the Pinlaung (Pinluang) area were targeted. In the Kalaw area, in 13 days they mapped about 10 caves, mostly in conglomerate rock, the longest of which was Maung Nyunt Cave (over 900 m long).

In 2009 a 3 person team from the “Northern Lao-European Cave Project” explored caves in the Hpa An and Mawlamyine areas in the southern Kayin and Mon states. They visited 14 caves and surveyed 12 of them, yielding 3.8 km in 5 days. The longest cave surveyed was Saddan Gu (800 m). This expedition prepared the contacts also used by a 2010 British expedition to the Taunggyi/Hopong area (Shan State) led by Imogen Furlong. The expedition surveyed White Water Buffalo and Tiger Cave (1,075 m long) and partly explored Htam Sam, a large cave near Hopong town.

Everything available on the speleology and the biospeleology of Myanmar was recently compiled in a comprehensive monographic publication (Laumanns, 2010). Consequently, despite some unpublished cave surveys, the access to speleological data on Myanmar can be regarded as reasonably good.

- **Philippines**

The Philippines consists of an archipelago of 7,107 islands. About 17 tectonic micro-plates form the so-called Philippine Mobile Belt of the Philippine archipelago, which is a complex and highly active collision zone where the Eurasian Plate is steeply subducting under the Philippine Mobile Belt. From the east the Philippine Plate moves westward and forms a shallower subduction under the Philippine Mobile Belt. Consequently, the archipelago is a tectonically highly active and rapidly deforming region, characterized by extensive strike-slip faulting and multiple volcanic arcs.

Relatively young karst areas, ranging from Cretaceous to Tertiary in age, with the Miocene carbonates predominant, are numerous covering about 10% of the land surface of the country, but only some karst areas on Samar, Mindanao, Cebu and Bohol exceed 100 km^2. Most of the carbonates are scattered in the central ridges orientated north-south (Mindanao and Luzon) or NE-SW (Calamian islands and Palawan).

Many foreign cavers who have broadened our knowledge of the Philippine caves co-operated with local mountaineers and outdoor clubs. The year 2001 saw the Philippine Caving

Society founded with a first caving conference in the same year. The society issues an electronic newsletter and organises occasional conventions.

Exploration of the Philippine karst started with two excursions in 1820 and 1830 when the Frenchman Paul Proust de la Gironière and Hamilton Lindsay from Great Britain visited San Mateo Cave, which is now known as Montalban Cave. Around 1970 not more than 2 km of cave passages were known from the Philippines.

Systematic speleological explorations began in 1979-1980 by French cavers in the Sagada karst (Luzon). In 1980-1993 French speleologist Claude Mouret explored caves on Luzon, Mindoro, Leyte, Samar, Bohol and Cebu islands but later focused on Luzon also accommodating Italian cavers on his expeditions. This was followed by Japanese speleologists in 1982 and 1983 (Samar and Cebu). Since then, many other expeditions targeted karst areas on the Philippine islands, e.g. British, Spanish, Dutch/Belgian, Japanese, Slovenian, and German. The most successful expeditions however were conducted by Italian and French speleologists. The Italian "La Venta" group was active on nearly all of the Philippine islands but focused on Palawan where they extended the longest cave of the Philippines, Saint Paul Cave, also called Puerto Princesa Subterranean River, to its current length of about 24,000 m. The area is a national park and contains Saint Paul Cave with its underground river that is accessible by boat for tourists. The cave is the most famous in the Philippines and was declared a national park in 1971 and inscribed on the World Heritage List of UNESCO in 1999, known as Puerto Princesa Subterranean River National Park. In the same area "La Venta" also surveyed the currently deepest cave of the Philippines, Nagbituka 1 (-270 m). The later French expeditions focused on Samar island, where they surveyed Lungib Can-Yawa (11,700 m long), the currently 3rd longest cave of the Philippines.

Generally speaking, the speleological literature on the Philippines is incomplete and difficult to access because of the language of the publications (e.g. Japanese) and the fact that some explorers have published their valuable results in obscure publications such as small club magazines or in the form of private expedition reports printed only in small numbers. Some important results were not published at all. Consequently, the Philippines belong to the Southeast Asian countries where much improvement with regard to speleological data is possible.

- **Singarore**

Singapore has no karst and is of no speleological interest.

- **Thailand**

Karst is widespread in Thailand and covers 18% of the country‟s surface. In the northeast the Mekong River marks the boundary between Laos and the Khorat Plateau while a range of sandstone hills deliniates the boundary with Cambodia. On the western edge of the Khorat Plateau there is tower karst in Loei and Nong Bua Lamphu and some fine areas of cockpit karst in Khon Kaen and Chaiyaphum. The rest of the plateau is formed from sandstone and evaporites with extensive deposits of potash and halite. Although there aren't any carbonate karst areas there is some sandstone pseudokarst. The centre of Thailand is dominated by the wide alluivial plain of the Chao Phraya river and its tributaries. At the edges of this plain tower karst and isolated limestone hills can be found in Sukhothai, Phetchabun, Uthai Thani, Nakhon Sawan, Lopburi and Saraburi. The longest known cave in Thailand is located at the edge of the plain in Phitsanulok (Tham Phra Wang Daeng, 13,844 m long).

Karst is scattered along the length of the Thai peninsula from Phetchaburi in the north to Yala on the Malaysian border. There are areas of mountain karst with allogenic drainage and some long stream caves in Surat Thani, Phang Nga, Nakhon Si Thammarat and Phatthalung. However, this region is famous for its spectacular tower karst. The karst islands in Phang Nga bay are a very popular tourist destination and other areas of tower karst and limestone islands can be found all along the coast.

The limestones in Thailand were originally mapped as being either Ordovician or Permian ("Ratburi Group"). The Ratburi Group was later split with the name Ratburi Group used for the Permian limestones found in the north, west and south and the Saraburi Group for the limestones found in central and eastern Thailand. However, recent work by paleontologists has shown that the limestones are in fact a wide variety of ages from Ordovician through to Middle Jurassic. The youngest limestones found in Thailand are of Middle-Lower Jurassic age. They are distributed down the western side of the country and have been found locally in Mae Hong Son and Kanchanaburi while in the Mae Sot and Umphang areas of Tak they are more massive and form large hills. Near Umphang some large stream caves have been found in the Jurassic limestone.

Triassic limestone is known in many areas from the peninsula to northern and eastern Thailand. In the Lampang Basin the Triassic sequence is more than 3,000 m thick and limestones make up a quarter of the total section. Triassic limestones have been identified from Phattalung, Phetchabun, Uthai Thani and in Nan.

The most widespread limestone is Permian, even after the correction of the ages of some limestone outcrops which had been erroneously assigned to the "Permian Ratburi Limestone". Upper Permian limestone is rare and has few fossils. Lower and Middle Permian limetones are rich in fossils and widely distributed. Permian limestones have been confirmed from Loei and Khon Kaen, Phetchabun, Lampang, Saraburi and Nakhon Ratchasima, Mae Hong Son and Surat

Carboniferous limestones are less widespread than the Permian limestones. They have been found in eastern Thailand, central Thailand near Noen Maprang, Phitsanulok and Chon Daen, Phetchabun, in Loei, Mae Hong Son, Chiang Mai, Kanchanaburi and the southern part of Peninsular Thailand.

Limestones from the Devonian are less important, but are widespread being found in Loei, in western Thailand from Chiang Mai to Satun, from the Mae Ping National Park, Lamphun and in the Thong Pha Phum National Park, Kanchanaburi.

The oldest limestones found in Thailand are Ordovician. These limestones are widespread in the western part of the country from Mae Hong Son down to the Malay border. The occurance of Precambrian marbles, which outcrop as a thin band 500 m wide running north from the Bhumiphol Dam in Tak, was reported.

Perhaps because Thailand was never colonised by the Western powers there were few expeditions to the country during the great era of exploration in the late 19th century. Apart from occasional visits to caves the first detailed survey of a Thai cave, Tham Chiang Dao (5,170 m long), was only carried out in 1972-1973. Between 1973 and 1978 the Austrian cavers Heinrich Kusch and Ingrid Staber toured extensively throughout the country and published reports with descriptions, some surveys and a list of 94 caves. The first expedition-like speleological project was carried out by Catalan cavers in 1978 who located 34 caves in 12 provinces and mapped Tham Kaeng Lawa (470 m) in Kanchanaburi. The 1980s could be called the “Golden Age” of cave exploration in Thailand. At the start of the decade only seven caves were known to be over 500 m long, the longest being Tham Chaing Dao, and no known caves were deeper than 100 m. By 1990 there were 22 caves over 1 km in length and 13 deeper than 100 m. This intense phase of foreign expeditions began in 1983 with a series of Australian expeditions as well as French projects carried out by the "Association Pyréenné de Spéléologie (APS)". Many American, Polish, and French groups also visited Thailand. The first British expedition was carried out in 1988 and together with Australian projects most of the long and deep caves we know today from Thailand were explored by English speaking cavers: Tham Phra Wang Daeng (13,844 m), Tham Mae Lana (12,720 m), Tham Yai Nam Nao (10,191 m), Tham Nam Lang (8,550 m), and Tham Takobi (7,346 m). The deepest cave in Thailand was only recently explored by a British team to -367 m of depth (Tham Pha Phueng, Nan Province). Near Krabi, the Vauclusian spring of Tham Sra Kaeo was dived to a depth of -240 m, representing the 2nd deepest cave of Thailand. The presence of Dean Smart in a professional position in Thailand, with his contacts in the Royal Forest Department, triggered a very productive phase of cave exploration. More recently, Martin Ellis from the UK moved to Thailand and assiduously created an incredible website (www.thailandcaves.shepton.org.uk/) on Thai caves with all available cave surveys, and also published a stunning cave catalogue in a series of publications (www.thailandcaves.shepton.org.uk/bookshop) including over 3,700 caves. Although Thailand still awaits the foundation of a national speleological organisation the country is definitely the most well-documented in Southeast Asia with regard to its cave-related data.

- **Timor Leste (East Timor)**

The oldest limestones in East Timor date to the Permian, which represents the oldest sedimentary rocks known so far from Timor, mainly consisting of shale, siltstone, sandstone and locally, limestone and marl. The Cribas Limestone has a thickness of about 500 metres. Other limestones are from the Triassic through to the Tertiary. The Post-Pliocene Baucau Limestone consists of massive white coral-reef limestone well developed around Baucau town. The unit controls the topography in the Baucau and Lautem plateaus. A continuous outcrop occurs along the north coast. In the southern foothills, the Baucau Limestone also crops out in scattered hills. The limestone occurs as coral-reef, calcarenite and a greywacke-pebbly sandstone facies.

Caves of East Timor have not been well documented, most of the work having been done by archaeologists. Research started in the 1930s, was continued in the 1960s by Glover and more recently by archaeologists from the Australian National University. Lene Hara Cave near Tutuala has yielded archaeological finds dated to 35,000 years ago. It was first excavated in 1963 by Antonio de Almeida. Lene Hara has a large entrance, and some speleothems, but no real dark zone. Jerimalai is a rock shelter on the eastern tip of the island inhabited 42,000 years ago.

- **Vietnam**

Carbonate rocks are widely distributed in Vietnam north of latitude 16^{o}. They cover almost 60,000 km^2, or approximately 20% of the Vietnamese mainland territory. Most carbonates crop out in the mountainous parts of northern Vietnam, where the deepest Vietnamese cave known is situated (Cong Nuoc). Currently, the cave is also the deepest cave of Southeast Asia (-600 m of depth). The largest continuous carbonate zone stretches over 300 km in north-west Vietnam from the Chinese border at Phong Tho (Lai Chau Province) to the coastline of Ha Trung (Thanh Hoa Province) including Son La (Tay Bac karst).

In the central part of the country the famous karst of Phong Nha-Ke Bang in the Quang Binh Province resembles the eastern part of what is called the Khammouane karst across the border in Laos. The 1,100 m thick carbonate sequence is mainly middle Carboniferous to lower Permian, consisting of massive partly dolomititc limestones. Devonian and some Visean carbonates are also present. The longest caves currently known in Vietnam occur in the Phong Nha karst. Most caves are horizontal and drain huge underground streams. The Phong Nha-Ke Bang karst was declared a national park in 2000 and became a UNESCO World Heritage Site in 2003.

The drowned Permian karst plain of Ha Long Bay at the Gulf of Tonkin (Bac Bo Gulf) is probably the most renowned Vietnamese karst area and another long-time World Heritage Site. The folded Carboniferous and Permian limestones reaches from Haiphong to the Chinese border and actually represents a drowned extension of the great Fenglin-type tower karst terrains of southern China. The most spectacular section of this karst occurs in and around Ha Long Bay where nearly 2,000 limestone islands are present. The ensemble of hundreds of rocky islands forms one of the most beautiful and famous coastlines on Earth and has very significant importance for tourism.

A small tower karst area of isolated hills formed by Permian limestone can be found in the area of Ha Tien-Hon Chong in the extreme southwest of Vietnam at the coast and the border with Cambodia (Kieng Giang province). It represents an extension of the well-explored karst known from Kampot-Kampong Trach in southern Cambodia. A remnant tower karst consisting of five limestone mountains (“Marble Mountains”) also occurs 8 km southeast of Da Nang. Another yet unexplored karst area is suspected between Da Nang and the Laos border.

Carbonates were deposited over the widest possible time span, from Archean to recent reefs. Thin-bedded, impure Precambrian and early Paleozoic limestone is less suited for karstification contrary to the very pure Permo-Carboniferous and Triassic limestone, which reach a considerable thickness of 1,000-2,000 metres. Neotectonic uplift and subsequent erosion has exposed these limestones over several thousands of metres, allowing rapid development of vertical karst features. On the other hand coastal subsidence is responsible for drowned karst plains.

Similar to Laos, early cave exploration took place during the French colonial period. After independence Vietnamese scientists continued with cave studies. Foreign speleological exploration began in 1990-1993 with two British-Vietnamese expeditions to the Phong Nha, Quang Binh and Ke Bang Massif in central Vietnam. In later years the British explorers extended their working area also to northern Vietnam (Cao Bang and other regions). The team maintains an excellent website with reports on their expeditions between 1999-2010 (www.vietnamcaves.com) and a 2007 list of the longest/deepest caves of Vietnam. The first Belgian-Vietnamese project to Son La (northern Vietnam) took place in 1993 and also extended in later years to many other karst areas in northern Vietnam. Both projects are still ongoing and the most continuous sources of speleological data from the country. Many other occasional expeditions visited Vietnam, notably Franco-Italian, French, Italian, Polish, Bulgarian, and Australian expeditions, as well a recent German-British project to Ha Tien in south Vietnam.

In 1997 a Vietnamese Caving Association, allocated to Hanoi University was founded. Also the Vietnamese Institute of Geosciences and Mineral Resources (VIGMR) in Hanoi is very active in the exploration of karst and caves.

In 2009 an enormously large 4.5 km long cave passage of 100 m in diameter (at places even 200 x 150 m) was found by the British-Vietnamese explorers in Hang Son Doong (7,678 m long), most likely exceeding the dimensions of the reportedly largest cave passage on Earth known so far from Deer Cave (Mulu, Sarawak, Malaysia). Hang Son Doong was the subject of a film project by National Geographic. The longest caves of Vietnam are: Hang Khe Rhy (Phong Nha-Ke Bang, 18,902 m long), Hang Vom (Phong Nha-Ke Bang, 15,760 m), Hang Co Ban (~8,500 m), and Hang Phong Nha (8,329 m).

Vietnam is a centrally governed country and foreign speleological expeditions are not possible without close co-operation with the authorities. This requires state-of-the-art reporting. Consequently, speleological documentation on Vietnam is well developed, although published data are often only available from private expedition reports.

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IDENTIFICATION OF POTENTIALS FOR SHALLOW KARST WATER RESOURCES BY USING REMOTELY SENSED DATA IN KERMANSHAH AREA, IRAN

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Abstract
Kermanshah is one of the karstic regions in Iran. Large numbers of karst springs have been appear in this area. Spatial distributions of these springs, implies existence of considerable permanent karst water resources in the uplands carbonate formations. Undifferentiated units of Bisetun Jurassic limestone is one of the most karstified formation in this region. The relational modeling in the Kermanshah area was applied by contribution of remotely sensed data and defining the rule bases in a GIS. Most of the areas have been mapped as potential for shallow karst water resources are coincided with this Jurassic limestone. The lands facing to sinks are quite different with the other parts of the terrain. The result of modeling shows that both sides of this range of mountain (Jurassic limestone) have been appeared as possible areas for having access to shallow karst water resources. Since some limitations, like avoiding from green vegetation have been seriously considered in the modeling, that is why some parts between these two major patches have not been appeared as indication for karst water potentials. Field evidences and terrain conditions verify the results of modeling obtained in this region. The method may be applied in similar areas as a primary exploratory method, before expending for expensive geophysical and drilling.

Keywords: shallow karst, thermal remote sensing, relational modeling, Kermanshah, Iran

Introduction

Karstified geologic formations cover more than 15% of the Earth's surface; in fact, 25% of the world's population either lives on top of karst formations or obtains needed water from them. Water demand is exceeded to more than two times in recent century in over the world. Global warming and climatic change are a great danger for having access to fresh water, particularly in dry areas.

Traditionally, water resources have been discovered by geophysical and drilling which are time consuming and cost effective. Nowadays novel technologies are assisting scientists to study living environment, especially to discover new water resources. Researchers conducted within recent two decades show that remote sensing, particularly thermal remote sensing was considered as a technology for discovering of buried caves (J. N. Rinker, 1975) and understanding properties of earth surface as well (Dale A. Quattrochi, 2004). It is a reality that methods already applied to the geological environments for water exploration had to be refined and modified. Some of them might not be applicable under the karst conditions and some are quite cost effective. Therefore new and specific investigative methods had to be developed. Finding new and more powerful investigative methods in new water resource explorations is of prime importance, generally. Availability of variety of data resources like satellite images and novel technologies like Geographic Information System (GIS) provide favorable condition to contribute in development of reasonable investigative methodology for possible Karst water resources exploration.

Background of the study

Development of remote sensing approaches was realized after first application of photography (1939). The remote sensing studies in karst terrains were concerned mainly with their potential application in the analysis of tectonic regions. Formerly, application of remote sensing was limited to stereoscopic analysis of aerial photographs for identification of location of underground karst channels (Rinker, 1973). In this respect geomorphologic features, like sinkholes and other features such as drainage network were prepared by aerial photo interpretation. These data layers then coupled by using transparency overlay in order to represent the most likely location of underground river courses and channels. Satellite images obtained by Landsat have been used for allocating the natural springs and most feasible locations for drilling boreholes (Moore *et al.,* 1977). Aside of stereoscopic analysis of aerial photographs and visual interpretation of satellite images, other digital multi spectral products of satellite images were considered to be used in study of karst related subjects.

J. N. Rinker (1975) used the infrared thermal scanner to investigate the Greenland glacier and the karst of Puerto Rico in order to identify the location of fractures and caves underground. The author drew a conclusion that this method could be used only under specific conditions.

An airborne thermal camera was used to locate springs and caves in a karst watershed by C. Warren Campbell *et al.* (1996). The detector was an imaging infrared camera with a temperature sensitivity of approximately 0.10°C. The resolution on the ground was a fraction of a meter with a total field of view of one hectare

Since the temperature of earth"s surface varies between approximately -50 and +50 degrees centigrade, the most suitable detector will be one that can register the energy of the infrared spectrum with the wavelength between 8 and 14 micrometers. For these temperatures the materials emit more energy at these wavelengths than at any others.

In the 20th century, karst research received great attention by diversity of scientists. Therefore many attempts have been made for characterization of karst systems and karst related processes. In this respect, remote sensing products were considered as data resources by many researchers. Most applications of remote sensing are focused on visual interpretation and surface temperature estimation. Surface temperature, particularly sea surface temperature mapping are the most important application of thermal remote sensing. Moreover karst related morphology, vegetation cover, lineament extraction and other thematic mapping are the known use of satellite images.

Dale A. Quattrochi (2004) has emphasized on the advantages of ETM^{+} images in separation of warm and cool zones from each other. He has also presented a few examples of rock types making use of their thermal behaviors.

Travaglia Carlo (1998) has worked on Groundwater Exploration by Satellite Remote Sensing. This study that is undertaken in the Syrian Arab Republic clearly indicates that the integration into a geographic information system of data extracted from earth observation satellites with those traditionally gathered, coupled with selected field investigations and the geological knowledge of the area under investigation, and provides a powerful tool in groundwater search.

In the basaltic terrain of southern Syria, groundwater moves along faults and fractures, mainly as a result of tectonic movements. The statistical analysis of the lineaments interpreted from Landsat TM data indicates two major directions of fracturing considered as tensional type and thus "open" for the storing and transmission of groundwater.

Large freshwater springs occurring on the seabed at a short distance from the Syrian coastline were identified and located through analysis of thermal data. As they occur on the seaward extension of lineaments mapped inland, potential drilling sites were identified and positively tested by geo-resistivity (Travaglia Carlo, Osama Ammar ,1998).

Kazemi (2002) carried out various types of assessments, including analysis of karst related features using aerial photos, satellite images, geological map and field data. He has demonstrated the importance of structural geological elements, such as lineaments and faults, in explaining the patterns of the springs.

Another attempt has been made to analyze the surface part of the karst and to highlight the karstic features and among them the conduit, and to test the performances of ground penetrating radar (GPR) in a karstic environment. This method thus appears particularly well adapted to the analysis of the near-surface (<30 m in depth) structure of a karst, especially when clayey coating or soil that absorbs and attenuates the radar is rare and discontinuous. A GPR pulse EKKO 100 (Sensors and Software) was used on the site with a 50-MHz antenna frequency. The results highlight structures characterizing the karstic environment: the epikarst, bedding planes, fractured and karstified zones, compact and massive rock and karrens, a typical karst landform. One of the sections revealed in detail the main conduit located at a depth of 20 m, and made it possible to determine its geometry. This site offers possibilities of validation of the GPR data by giving direct access to the karstic conduits and through two cored boreholes. These direct observations confirm the interpretation of all the GPR sections (Walid Al-fares *et al.,* 2002).

Based on literature, in most cases, the image-derived data have been used in a GIS modeling, in order to achieve useful information. In spite of these important sorts of activities, less attention was given to the effects of evaporation from karst water resources surface and coldness conduction on land surface, along the geomorphologic features and lineaments. This phenomena, actually reduces temperature of the affected zones, considerably. Since medium resolution remote sensing provides thermal infrared images and they are frequently available, so these images can be used for discrimination of relatively cool and warm areas as well.

Jalali *et al.,* (2009) believe that shallow karst water resources and caves may influence land surface temperatures due to cold transfer property of rocks and evaporation from buried karst. Therefore they made attempts to develop a method for recognition of karst areas based on evaluating the surface characteristics that manifest itself by low land surface temperature in the satellite images. They found out that parts of carbonate rocks that bear karst water are relatively cooler compared to areas with similar terrain conditions. They found useful information on spatial distribution of areas that have the potential to hold karst water resources and/or caves. They proposed a relational model based on Looking through a Definite Window (LTDW) that makes use of logical base rules provided good indications for potential shallow karst water resources in karst terrains. A definite window is a clear window, free of shadow, rainfall, vegetation cover and other factors that may lower land surface temperature. In this study the LTDW method was applied in Kermanshah region.

Conceptual model

Main concept is that water bodies evaporate in any conditions above absolute zero temperature. Evaporation from the open surface water clearly can be seen and measured. Evaporation from the confined water bodies like groundwater becomes limited due to overlaying materials and low energy. In spite of this reality, the story is almost different about the karst water resources. Karst reservoirs have been recharging by precipitation flowing into the karst system through joints and karst related features like sinkholes. These features also allow the karstic water to be connected to free air. In this case, water vapor can influence ground surface continuously. This phenomena cause that affected areas by evaporation from karstic water resources or heat transfer become cooler during day time in warm and hot seasons and appear warmer during night time in cold seasons. Such effects on land surface can well be distinguished when the temperature differences in karst terrain and surrounding land surface become very high. Anyhow this phenomenon is assumed to be one of the effective processes that lower land surface temperature above relatively open lineaments and geomorphologic features. This hypothesis can be explored by following discussions.

All matters with a temperature above absolute zero radiate electromagnetic energy due to molecular agitation. Anyhow a few parameters should be existed for evaporation or coldness flow to take place. These parameters are known as follow for water bodies.

1. Existence of water body underground
2. Existence of an evaporative surface
3. Availability of sufficient energy (heat)

Water vapor should be moved away in order to have continuous evaporation. Therefore existence of a transferring phase of evaporation is necessary to release water vapor to the atmosphere. This replaces saturated water vapor zone over water body with unsaturated zone and cause continuous evaporation. On the other hand, rate of evaporation in atmosphere is controlled by climatic factors. Therefore evaporation and evapotranspiration are under effect of climatic, biological, soil and water properties. Rate of evaporation from water surface and vegetation cover depends on availability of water and climatic conditions.

Primary field investigations above elongated and deep joints in a karst terrain showed that extrusive water vapor from the open joints was being condensed into water droplet and made beads of moisture. Existence of water vapor phase and persistence of soil moisture in these areas provide favorable condition for land surface temperature to be lowered, comparing to the adjacent areas.

In addition to this phenomenon that may take place in most of karst terrains having shallow depth, there is another known process that occurs in material, based on heat transfer theory. Rock mass can transfer both heat and coldness in the forms of conduction, convection and radiation. This property of rocks allows heat or coldness to flow if their sources exist.

Two main factors determine thermal characteristics of an object. These are specific heat and heat conductivity. Heat conductivity is a factor that shows how heat flows and propagates in an object. Heat conductivity of very prose lands increase with degree of saturation by water. Degree of heat conductivity of different land type varies very slightly from one land type to another. Lands consist of clayey materials and carbonate rocks have lower and higher rate of heat conductivities, respectively. Heat conductivity for clayey materials and dry sands is about 0.002 to 0.003 *cal/cm/sec* and for limestone and granite is 0.005 to 0.008 *cal/cm/sec* (Astier, 1974). Considering these rates, carbonate rocks have relatively more heat conductivity. Therefore heat or coldness flow can take place much faster in rock masses than clayey materials.

Existence of water bodies in carbonate formation provides favorable condition for coldness to flow. Near surface and land surface temperatures can also be influenced by heat/coldness transfers. Land surface temperature also is under influence of climatic changes.

Incident radiation of sun heats land surface including soils and rocks. This causes variation on land surface temperature along the seasons. Variation of land surface temperature due to this reason is valid only up to certain depth. According to temporal variation of temperature, the air temperature even can influence temperature in depths of 15 to 40 meters. Temperature of this zone is annually variable and is a function of seasonal variation of temperature. Depth of this zone is slightly more for argilic and sandy materials rather than limestone and granite (Astier, 1974). Therefore the conclusion can be drawn that any phenomena like cool shallow water bodies within in depth of less than 40 meters, may influence land surface temperature. Without any doubt the temperature underground karst features has to be quite different from the outside temperature (Parcharidis *et al.,* 1998). Moreover it can be concluded that existence of buried water bodies act as coldness source that may influence land surface by direct evaporation or any other types of coldness transfer. It has been assumed that, such areas that relatively are cooler than their surrounding should be detectable by thermal sensors, if be large enough and resolution of the sensor be adequate. Consequently these characteristics of such karst environment can be used as basis for development of a methodology for karst water identification.

Beside of the above-mentioned factors, many other parameters may affect land surface temperature. Time of thermometry, antecedent soil moisture, lithology, aspect, altitude, hydrogeological properties of rocks, rainfall, irrigation, plants cover and shadow are the most important known factors that have strong effect on lowering land surface temperature. Therefore, for having real inherent land surface temperature, influence of these factors on land surface temperature should be eliminated. For doing this, some special attempts have to be made. Since there is no such a model for ignoring effects of the mentioned factors, so each parameter should be treated individually.

Method and the materials

Thermal infrared image of ETM^+ sensor of Landsat is an image that is acquired using wavelengths of 10 to 12.5 micrometers. This image is enhanced from the spatial resolution point of view to 60 meters and provides thermal behavior of objects and phenomena. Considering these advantages and its availability and high costs of thermal surveying by aircraft, this thermal image and other required data of influencing parameters were used. The ETM^+ images, radar based DEM and its derivatives like slope and slope facing maps, NDVI and geology map of the command area at scale of 1:100000 have been used as necessary materials in this work. Moreover field observations; drainage density and distance to lineaments were used for evaluation of results obtained by the modeling.

Many parameters may affect land surface temperature. Time of thermal sensing, antecedent soil moisture, lithology, slope aspect, hydrogeological properties of rocks, rainfall, irrigation, plants cover and shadow are the most important known factors that may have considerable effects on lowering land surface temperature. Therefore, for having real inherent land surface thermal anomalies, influence of these factors on land surface temperature should be considered. For doing this, some special attempts have been made. Since there is no known model for ignoring effects of the mentioned factors, so each parameter has been treated individually. Based on this treatment, the rule bases were developed and applied in a modeling framework. Since specific cares are given to eliminate the influence of different causative factors on lowering land surface temperature, therefore the terrain having such conditions should represent the areas having possible anticipated karst water resources and caves. Therefore data integration for allocating possible sites for existence of karst water resources can be carried out using the following rules.

1. Investigation should be conducted within the carbonate rocks of the command area.
2. In order to ensure that there is no antecedent soil moisture, rainfall data for local stations of at least 10 days before image acquisition date should be reviewed.
3. None extreme higher altitude within the carbonate formations which is not appeared cool, should be considered as an upper limit for elevation factor. This is obtained by combination of DEM, geology map and thermal infrared image.
4. Mean value of thermal image, minus a portion of standard deviation may be applied as a criterion for identification of relatively cool areas. (Here, the criterion of mean minus 0.7 standard deviation is used), (Aminipouri *et al.,* 1999)
5. In order to avoid shadow effect, first cloud-free images should be chosen and shadow pixels should be identified. Therefore search should be taken place within slope facings that have almost the same inclination i.e. westward (W, NW and SW) and eastward tilting pixels, separately. For each group of slopes the mean and standard deviation values of thermal infrared image have to be calculated.
6. NDVI (Rouse *et al.,*1973) values between -0.05 and +0.05 is considered as an indicator for no vegetation cover areas or bare land. This rule ignores possible effect of vegetation cover on land surface emissivity.

Modeling was conducted by using the mentioned criteria for allocating areas that may have access to shallow karst water resources and caves. Result of such modeling is presented by Fig 1.

Results

The same rule bases that were explained in chapter four and used in the modeling with data of Azarshahr, were applied in the Kermashah area too. The result of such modeling in the Kermanshah area is presented by Fig 1. Since some limitations, like avoiding for green vegetation have been seriously considered in the modeling, that is why some parts between two major patches that have been appeared as indication for karst water potentials has gotten no such indications. While karst related landforms are evident in this area. Karst related features that have been occurred due to solution of carbonate rocks and interactions of thrusts can be seen in this area. Karst related landforms clearly visible in the central part (shown by white dashed circle) of the satellite image, presented by Fig 1. Beside the visual image interpretation, the sinks map which is automatically provided based on making use of DEM of the area indicates that sinkholes are more evident in this part of the area.

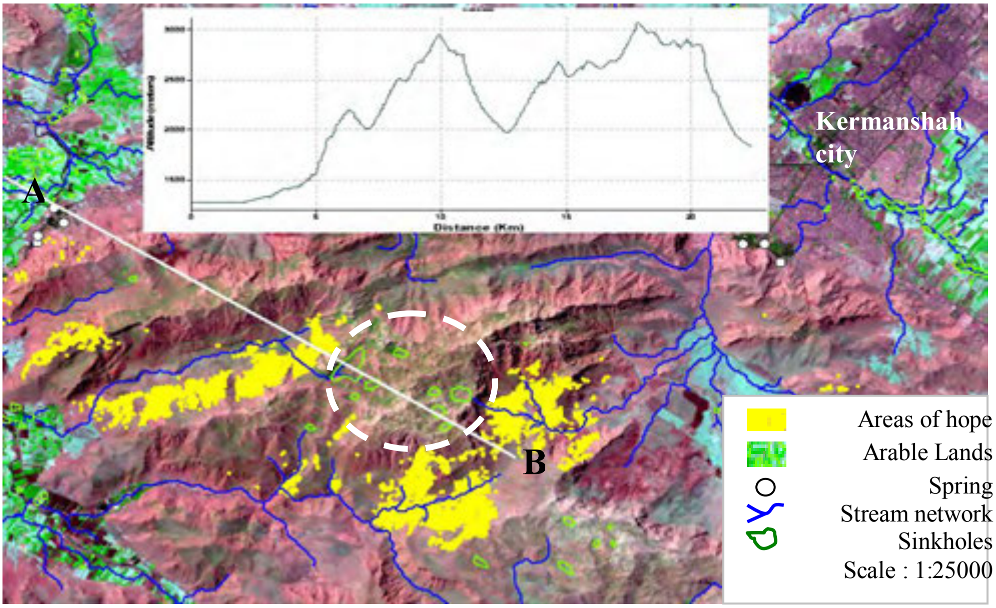

Fig 1. Spatial distributions of areas of hope (shown by yellow color) for having access to karst water resources in Kermanshah region, on Landsat color composite image (RGB 742) and a topographic cross section along the selected profile (AB)

Kermanshah is one of the karstic regions in Iran. Large numbers of karst springs have been appeared in this area. Qanbar, Taghe-Bostan and Bistoon are the most famous springs of this region. Spatial distributions of these springs, implies existence of considerable permanent karst water resources in the uplands carbonate formations. Undifferentiated units of Bisetun Jurassic limestone is one of the most karstified formation in this region. Most of the areas have been mapped as potential for karst water resources are coincided with this Jurassic limestone. Cross section of the area (as shown by Fig 1) shows how rough is the terrain and there is possibility for karst water migration to the outlet (springs) at the site of point "A". As the cross section shows the lands facing to sinks are quite different with the other parts of the terrain. Both sides of this range of mountain (Jurassic limestone) have been mapped as possible areas for having access to shallow karst water resources. Field evidences and terrain conditions support this finding in some extent, for this area.

Conclusion

It is found that elimination of the effects of shadow, vegetation cover, altitude and rainfall on land surface temperature enhances the areas that inherently and relatively are cooler. Relational modeling is a logical and knowledge base approach that facilitates ideas to be implemented in the real world. Application of the method developed by Jalali et. al., 2009 in the karstic region of Azarshahr area, also provides reasonable results on mapping sites having high probability to have access to shallow depth karst water resources and caves underground in Kermanshah region.

Land surface temperature is influenced by shallow karst water resources and caves in a certain conditions. This effect is more significant along a certain buffer of geological lineament.

Investigation showed that the output of the model is very sensitive to negative values of vegetation index (NDVI). The critical threshold of -0.05 to +0.05 for NDVI represents the bare lands but lower limit of this threshold may be stretched to -0.08 in order to include possible effect of evaporation from shallow karst water resources on soil moisture. This criterion can be applied when there is no rainfall at least 10 days before the date of image acquisition.

Although the obtained results show that relational modeling based on application of logical rules, contribution of thermal infrared image and data on terrain factors produce reliable evidences on shallow karst water resources or caves, but the results obtained by such modeling would be underestimated. Reason for this is looking through a specific window by taking into account of only the bare areas, none shadow slopes and certain range of altitude.

As the applied approach is fast and simple so that it can be applied as a prior low cost method for karst water resources and cave exploration in karst terrain of semi-arid areas.

Recommendations

In order to perform further more investigations, the following topics are recommended.

1. This research is conducted base on available data. As far as high resolution thermal infrared images are provided by some airborne remote sensing, it is strongly suggested to use such images instead of coarser spatial resolution image like TM or ETM^{+}. Without a doubt simultaneous image acquisition and land surface thermometry can provide favorable condition for obtaining more accurate and reliable results.
2. As Investigation showed, brightness temperatures and thermal image values are highly correlated. Since data on land type emissivity are rarely available and original digital numbers of thermal image have better discrimination than the brightness temperature, therefore it is recommended to use contrasts observed on thermal image produced by automatically assigned grey values to pixels (digital numbers). This is reminded that thermal infrared image itself is not sufficient for meeting the goals of such researches and contribution of affecting factors on lowering land surface temperature seriously have to be taken into account.
3. Since the output of the modeling should be verified by ground truths and verification of the results needs some high cost drillings for ensuring about existence of shallow karst water resources, therefore having financial sponsor for this type of research projects receives first priority of importance.

Acknowledgements

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A GIS AND REMOTE SENSING BASED MORPHOMETRIC ANALYSIS OF TOWER KARST AND COCKPIT KARST IN SOUTH GUIZHOU, CHINA

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Abstract
Lying mainly in Yunnan, Guizhou and Guangxi provinces, the South China Karst region extends over an area of half a million km2 and is the World‟s largest and most distinctive karst landscapes.Besides fengcong (cockpit) and fenglin (tower) karst, other variants including fengcong-depression, fengcong-polje, fengcong-valley, fengcong-gorge, fenglin-depression, and fenglin-basin have been identified by previous research. An "edge effect" has been broadly recognized, with most fenglin occuring peripheral to or interior within contiguous fengcong, but the precise spatial relationships between fengcong and fenglin have not been identified. The purpose of the study is to quantify the "edge effect" in South Guizhou and along the Guizhou-Guangxi border, and to further explore the geomorphological relationship between fenglin and fengcong karst through field survey and detailed analysis of GIS data and satellite imagery. The current study site is located in Libo County in Guizhou, which contains a large variety of impressive karst landforms. The study took advantage of a portable GPS tractor to precisely locate tower and cockpit karst landforms. At the post-processing stage, remote sensing imagery and the GPS data were combined to conduct GIS analysis. The result suggests that the edge effect is more apparent near the periphery of the Guizhou-Guangxi border, and that there are transitional forms between fenglin and fengcong.

Keywords: GIS, remote sensing, tower karst, cockpit karst, edge effect

Introduction

The karst landscape has been the focus of various geomorphhologists in the past decades. Among different study of karst, morphology study has received unprecedented attention due to its potential contribution to the process-form oriented study. The tower and cockpit karst differentiation was the most intriguing part in karst morphology exploration and also the most confusing part to some extent. As Day (1978) argued that „of all the recognized tropical karst styles, that termed cone karst has attracted by far the greatest interest, research and discussion‟. There has been much disagreement and controversies in the past regarding the differentiation of tower karst and cockpit karst. Broadly speaking, most previous studies have described the difference between tower and cockpit karst from a narrative and descriptive approach and few applied a quantitative way. With the development of GIS and remote sensing technologies, morphometric analysts were able to describe the karst in more details combined with the expertise from geography, geosciences, biography and other related disciplines. Nevertheless, the utilization of digital terrain data has not received enough attention in the study of karst geomorphology until recently. On the one hand, this was due to the price of DEM (digital elevation model) product generated from satellite imagery was relatively expensive in the past. On the other hand, the lack of related techniques to deal with such data also constrained its application. Tucker (2007) maintained that despite recent and rapid improvements in the resolution, quality and availability of digital terrain data, there have been relatively few attempts to develop morphometric indices that are diagnostic enough to reveal essential differences between landscapes. He developed a technique of using DEM to interpret morphometrics of cockpit karst in Cockpit Country, Jamaica, which exemplified a solid approach to any effort that attempts to investigate such landscape in an accurate quantitative way. In addition, Day (1978) conducted the first detailed quantitative study of cockpit karst terrain there and in 2001 he utilized GIS-based study to explore more details and suggested that development of more rigorous mathematical modeling techniques and the employment of digital elevation models and related landscape data in geographic information systems (GIS) may be expected to contribute to more productive mathematical analysis of karst landscape.

As “edge effect” has been broadly recognized with most tower karst occurring peripheral to or interior within contiguous cockpit karst near Guilin, China (Tang and Day 2000) , we also want to investigate whether development of fenglin is related to the areal extent of the fengcong that it borders, and/or to the circumference of the fengcong margin in Guizhou either.

The study region

Shown in Fig 1, the study area is around 300 square kilometers, and located in Libo County, Guizhou Province, southwest of China. It is also near the border of Guizhou-Guangxi border. Libo of Guizhou, together with Shilin in Yunnan and Wulong in Chongqing, known as South China Karst, were listed as UNESCO World Natural Heritage in 2007. (http://whc.unesco.org/en/list/1248) In this study, the area is evenly divided to two blocks for study: block one in the north containing fewer tower karst and more cockpit karst, and block two in the south containing more tower karst and fewer cockpit karst. The purpose of dividing the area into two blocks is to compare and contrast similarity and dissimilarity of tower karst features and cockpit karst features.

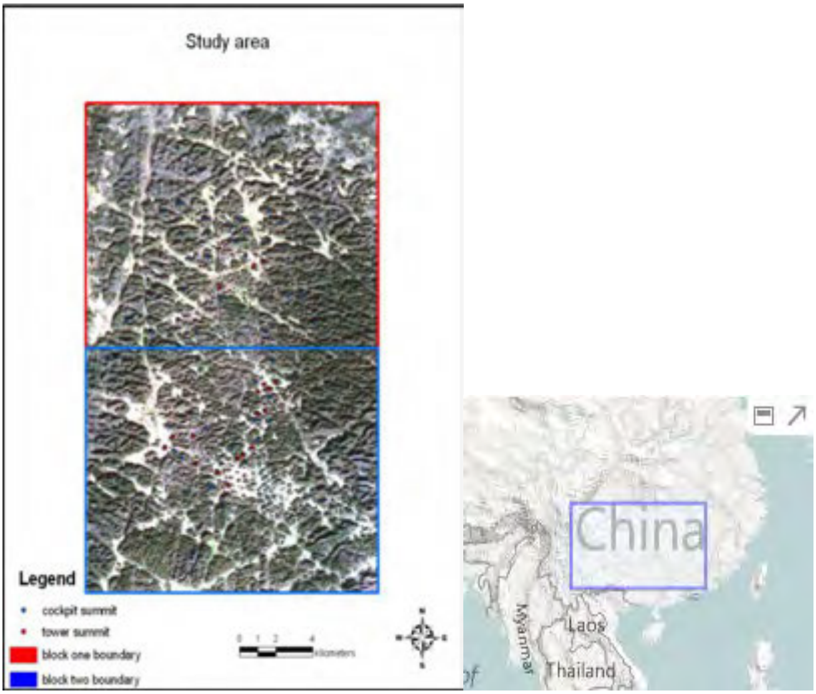

Fig. 1, Study area and its location

Given the geomorphology of the study site and available technique, and a similar approach has been conducted in Jamaica to elucidate the precise nature of the Cockpit Country and its landform (Lyew-Ayee, 2004; Lyew-Ayee *et al.,* 2007; Fleurant *et al.,* 2007, 2008, 2009) the purpose of the paper is to seek the possibility whether or not such approach can be applied to the karst in Guizhou and try to quantify edge effect in this area.

Data

DEM data used in this study comes from ASTER Global Digital Elevation Model (ASTER GDEM) with the resolution of 30 meters. The advantage of using DEM data is that it provides elevation data as well as other geological information on the continuous ground surface.

Sample points on summits of tower and cockpit karst were generated from field GPS survey and local topographic map. There are three tower karst summit points in block one and twenty nine cockpit summit points in block one, sixteen summits for both tower karst and cockpit karst in block two. The uneven number of summit points in the two blocks is due to the uneven distribution of tower karst and cockpit karst in the area.

Method and analysis

a. Semivariograph analysis

Lyew-Ayee (2007) has suggested a method of using semivariogram to investigate the nature of spatial variation. It acknowledges the assumption that points near to each other tend to be more similar than points remote from one other (Johnston *et al.,* 2001), calculating the strength of spatial autocorrelation as function of distance (Lyew-Ayee *et al.,* 2007). The analysis was conducted by using the Geostatistical Analyst in ArcGIS software. Specifically, the study used kriging to interpolate the DEM data and spherical model to generate the scatter plot.

b. Distance analysis

The Euclidean distance analysis was completed by using spatial analyst function in Arctool of ArcGIS. The study selected 550 meters as radius for the first buffer circle based on the field survey result to generate Euclidean distance map.

The nearest neighbor distance (NND) calculation is an effective method of investigating spatial distribution variance between different spatial features. The study calculates the NND both within the same features (cockpit karst and tower karst) and between different features.

c. Elevation analysis

To differentiate tower karst features and cockpit karst features, threshold of elevation and slope were estimated from empirical study and field survey data. Specifically, the study uses 1010 meters as threshold to divide the terrain into the group that over the criteria and the group below the criteria.

Result and discussion

a. Semivariograph analysis

The semivariograph analysis result is shown in fig 2 and fig3.

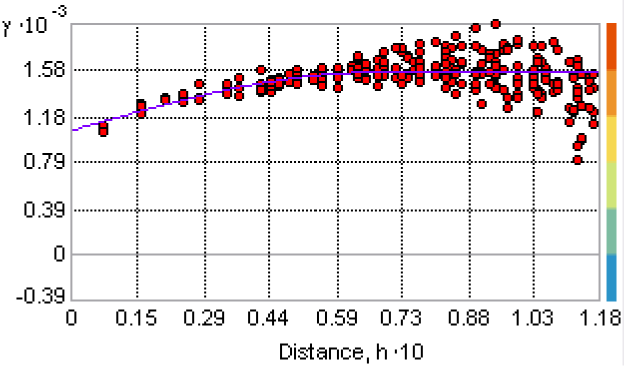

Fig 2. Semivariograph of Block one

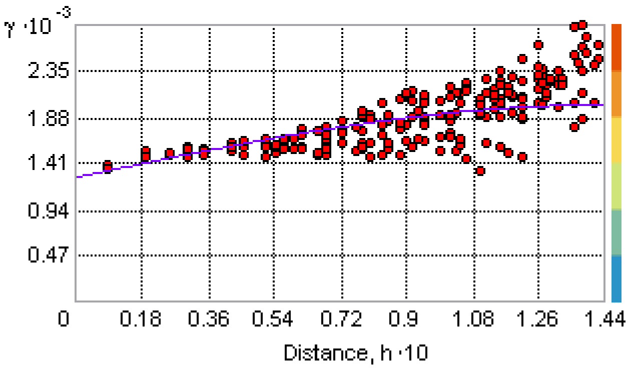

Fig 3. Semivariograph of Block two

In the similar distance range and area extension, Fig 3 demonstrates higher disparities than Fig 2, suggesting that Block two area has more geomorphologic surface variations than Block one. This reveals the fact that Block two area contains more tower karst features than Block one area, which is also coincident with the field survey result.

b. Distance analysis

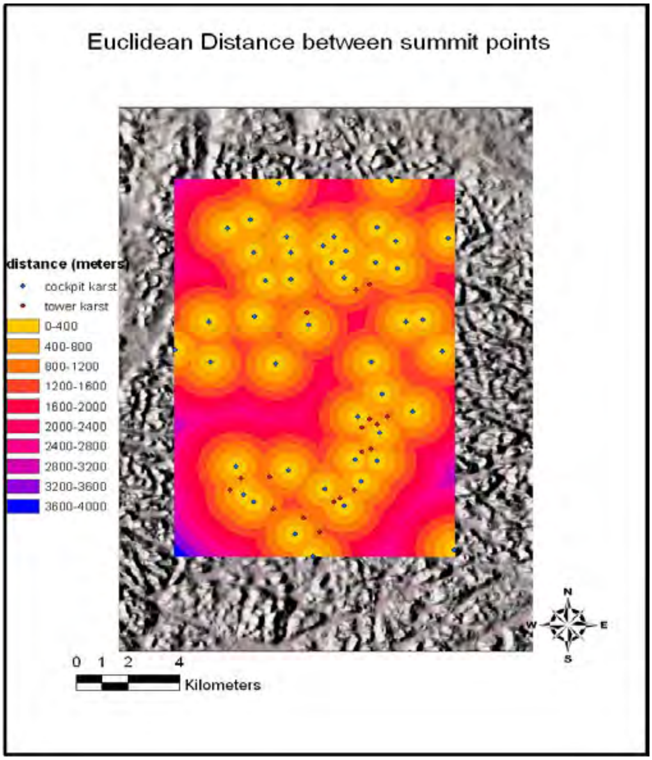

Fig 4. Euclidean distance of summit points

As Fig 4 shows, measurement from summit points of tower karst (TK) to cockpit karst (CK), the average distance between the two forms in both blocks is about 565 meters. While the distance between most summit points of cockpit karst is about 1094 meters.

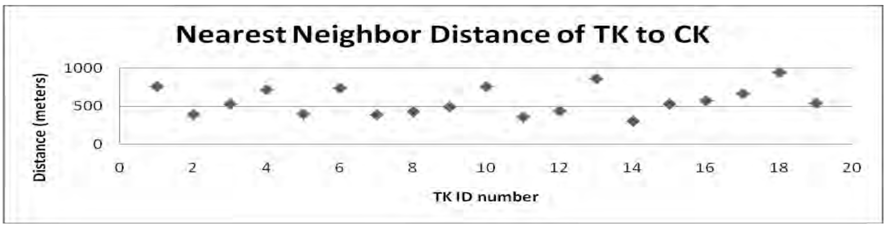

Fig 5. NND of TK to CK

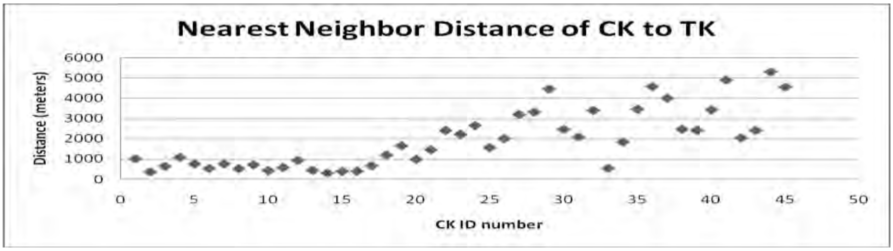

Fig 6. NND of CK to TK

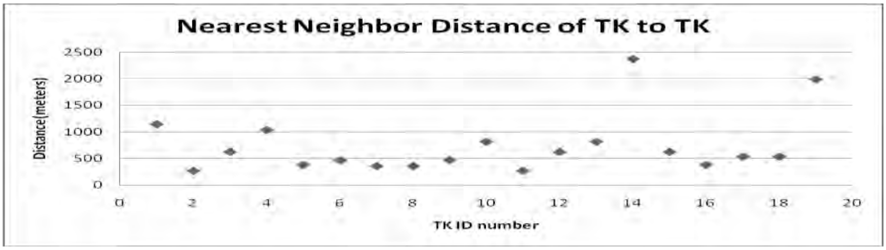

Fig 7. NND of TK to TK

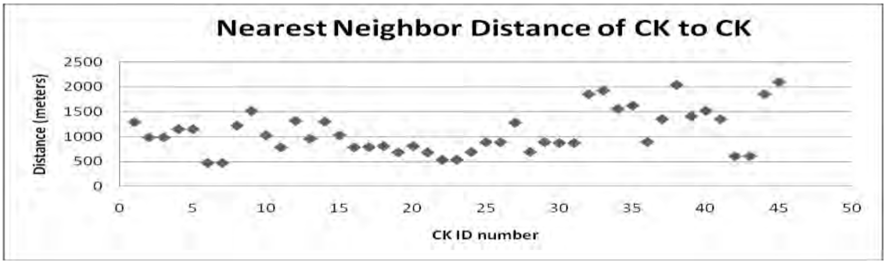

Fig 8. NND of CK to CK

In the result of Nearest Neighbor Distance (NND) analysis, Fig 7 and Fig 8 show that cockpit karst (average of 1094 meters)in the study area has larger spatial extension and areal space than tower karst (average of 736 meters). While Fig 5 and Fig 6 also demonstrate the same finding as well as the fact the tower karst is surrounded by cockpit karst area in the region given the result of NND of CK to TK is larger than NND of TK to CK.

c. Elevation analysis

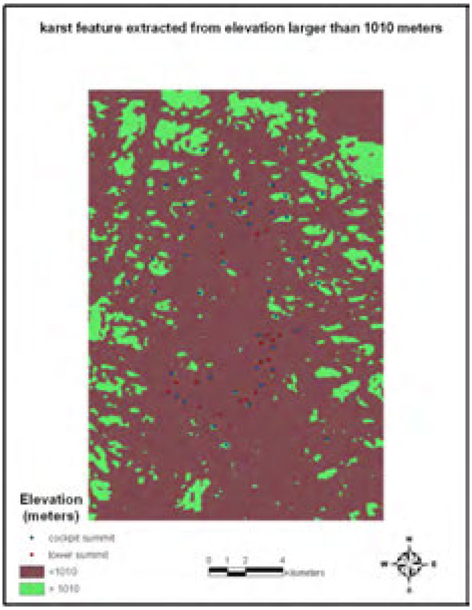

Fig 9. Elevation analysis

The result of elevation analysis by utilizing spatial analyst tools in ArcGIS suggests that cockpit karst in the area has higher elevation as opposed to tower karst features since most the cockpit features in Fig 9 has a higher overlap percentage with the features of more than 1010 meters. What the figure may not fully describe the morphology here, however, is that the presence of transitional forms (Fig 10) found in the field survey. These features have linked base lower than normal cockpit karst but definitely larger than formal tower karst.

Fig 10. Transitional form in the study area

Conclusion

The edge effect in this region is particularly strong compared to other places in Guizhou Province, China. The way of using ratio of margin length (L^m) to the size of the interior (A^i) may not work well in the study area due to the multiple fragments of study area and other limitations imposed by the local environment. Nevertheless, the nearest neighbor distance (NND) analysis is a good way to quantify the edge effect in that it may reveals the areal extension of different forms and spatial relation between the different karst features.

The results mentioned above indicate that the tower karsts are located in the interior of cockpit karsts in this region. The cockpit karst features demonstrates higher elevation than tower karst features.

For the future research, the investigation of local hydrological setting and detailed terrain and channel analysis will be necessary in an effort to understand the process and mechanism shaping the special land form in the region. And the transitional land forms pose a challenge to the research and may bring specific chances and insight to the area.

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GEOPHYSICAL RECONNAISSANCE OF KARST SINKHOLE OCCURRENCES IN JERAM, KINTA VALLEY, WEST MALAYSIA AFTER THE 2004 INDIAN OCEAN EARTHQUAKE

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Abstract
Geophysical and geospatial reconnaissance of karst features associated with sinkholes has been carried out in Jeram, Perak, West Malaysia. A rapid increase of sinkholes occurrences were reported after the disastrous 26th Dec. 2004 earthquake in Sumatera. Over 45 sinkholes of various sizes occurred in a small area of the ex-mine land. Many cavities are present in the subsurface karst that is covered by thin layers of loose sands and clay materials. These cavities are thought to be pre-existing features that had been rapidly filled with sand/clay, due to the tremor triggered from the earthquake.

Keywords: Subsurface karst, Sinkholes, Sumatran earthquake, Geophysics

Introduction
According to the report by Malaysia Department of Minerals and Geoscience, there are about 166 occurence of sinkholes in the state of Perak, West Malaysia from 31 August 1955 to 26 February 2008. A total of 70 or 42% occurs from 26 December 2006 to 26 February 2008. 45 of these sinkholes occurred in an area of about 0.186 km^3 in a time span of about two days from 28 December 2004 to 14 April 2005.

The huge increase of number of occurrence shortly after the earthquake has prompted speculation that the occurrences are related to the tremor induced by the earthquake. This study presents preliminary geophysical reconnaissance of sinkhole area in Jeram. The objective is to study the characteristics of subsurface karst in this area by geophysical method.

Study Area
The study area lies in the western West Malaysia and Jeram is located approximately at latitude 35.200°N, longitude 48.80°E (Figure 1). Kinta Valley lies between two granitic highlands, the Main Range in the east and Kledang Range in the west. Geologically, the Kinta Valley is underlined by limestone dated Devonian to Permian (Suntharalingam, 1968). Kinta Valley karst is made up of steep-sided limestone hills that protrude above vast low-lying floodplain with gentle rolling hills of metasedimentary rocks. The plain is covered by alluvium of varying thickness and underlain by rugged and uneven subsurface limestone platform. Only 30% of limestone in Kinta Valley occurs as limestone hills while the rest are subsurface karst.

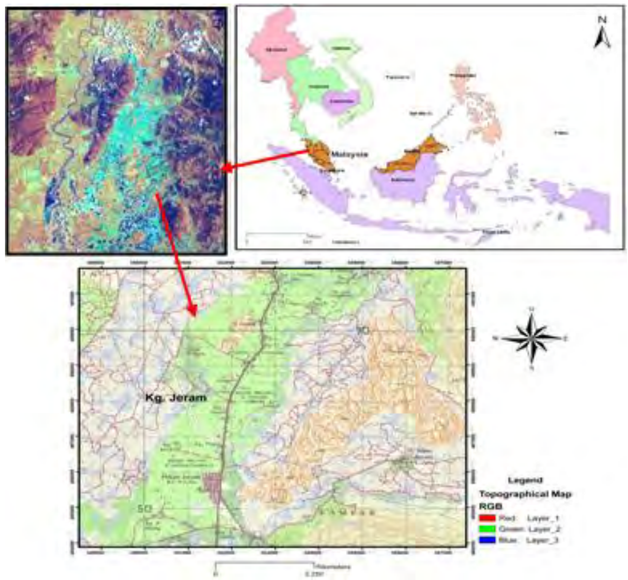

Figure 1: Location of the study area

Methodology

Spot 5 imagery is used to see the changes or the occurrences of the sinkholes before and after the earthquake (Figure 2). Field reconnaissance had been carried out to map the distribution of the sinkholes. The dimension of the sinkholes had been measured by measuring tapes, laser range finder and compass. Electrical resistivity tomography (ERT) was used to image the subsurface immediately above the sinkholes. Six electrical resistivity profiles with a line interval of 30 m over the study area were done. Three out of these six profiles were oriented in (W25^{0}S), perpendicular to the trend of sinkholes in the area. The remaining three were oriented in (N20^{0}W).

Figure 2: Satellites images showing the occurrences of sinkholes in the study area.

The use of two-dimensional resistivity profiling in karst terrain is well recognized. The tool commonly employed is the SAS1000 Resistivity Meter and ABEM Lund Automatic Electrode Selector system. The two Dimensional Resistivity Profiles were acquired by using a 41-channel array in winner configuration. The length of each profile is 200 m., with an electrode spacing of 5m. The locations of these profile lines are shown in Figure 3.

Results

On average, 190 data points were collected for each (41-electrode) in one resistivity profile, and approximately 1140 data were collected for the total six profiles in this site.
Additionally, the data were processed to generate two dimensional resistivity models of the subsurface using RES2DINV, inversion software developed by Loke and Barker, 1996. Assuming the subsurface is uniformly layered, lateral smoothing (mixing) will occur in non-layered strata.

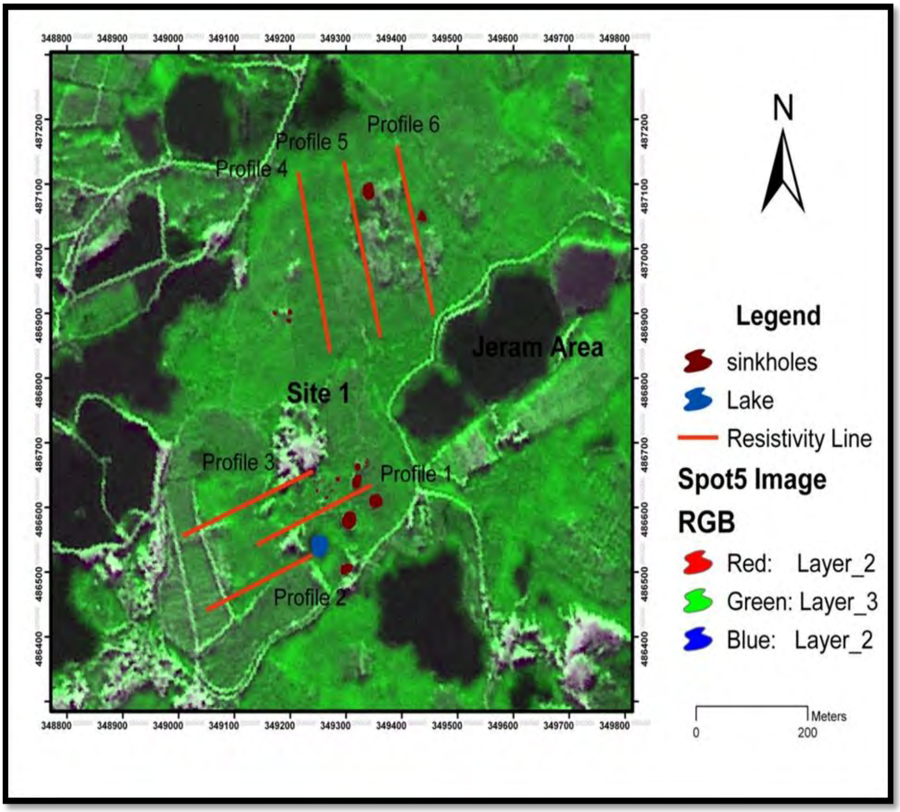

Figure 3: The location of resistivity profile lines

Based on reports of the geophysical surveys results in many karst terrains round the world (Abdel Alqadir, *et al,*. 1995), deductions on the variations in electrical resistivity values enabled geological classification of the study area into claystone, limestone and sand. The electrical resistivity values for each rock/sediment unit are tabulated in Table 1. Inverse model of electrical resistivity section for all profiles are shown in Figur 4 and Figure 5.

Table 1: The description of the range of resistivity values with the expected geological unit deposit.

No.	Range of Resistivity Values	Expected geological units deposit	Color in Inverse model of electrical resistivity section
1-	5 ohm-m. - 10 ohm-m.	Soft clay with ponded water.	Red
2-	10 ohm-m. - 20 ohm-m.	Clay with highly mineralization.	Orange
3-	20 ohm-m. - 50 ohm-m.	Clay with low mineralization.	Yellow
4-	50 ohm-m. - 70 ohm-m.	Soil, silty clay or sandy clay.	Brown
5-	70 ohm-m. - 200 ohm-m.	Clayey or silty sand.	Light green

No.	Range of Resistivity Values	Expected geological units deposit	Color in Inverse model of electrical resistivity section
6-	>100 ohm-m. - 160 ohm-m.	Sand.	Dark green
	160 ohm-m. - 200 ohm-m.	Transitional zone consist of rock fragment of limestone and sand.	Light blue
7-	>200 ohm-m. - < 400 ohm-m.	Weathered limestone, probably consisting of wet fractured and/or clay in-fill.	blue
8-	>400 ohm-m. - <3000 ohm-m.	Compact or intact limestone.	Dark blue
9-	>3000 - 4000 ohm-m.	Voids or Cavity air infill.	black

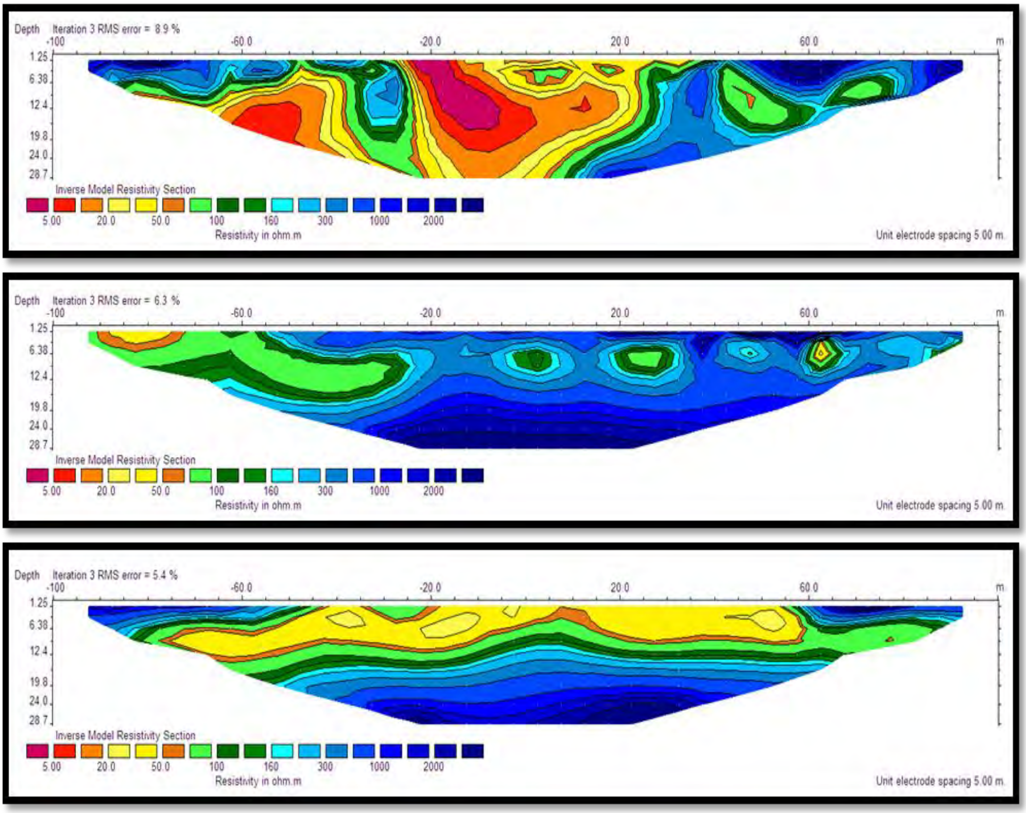

Figure 4: Inverse model of electrical resistivity section for profiles #3, #1 and #2 showing interpreted location of shallow limestone cavities and sinkhole.

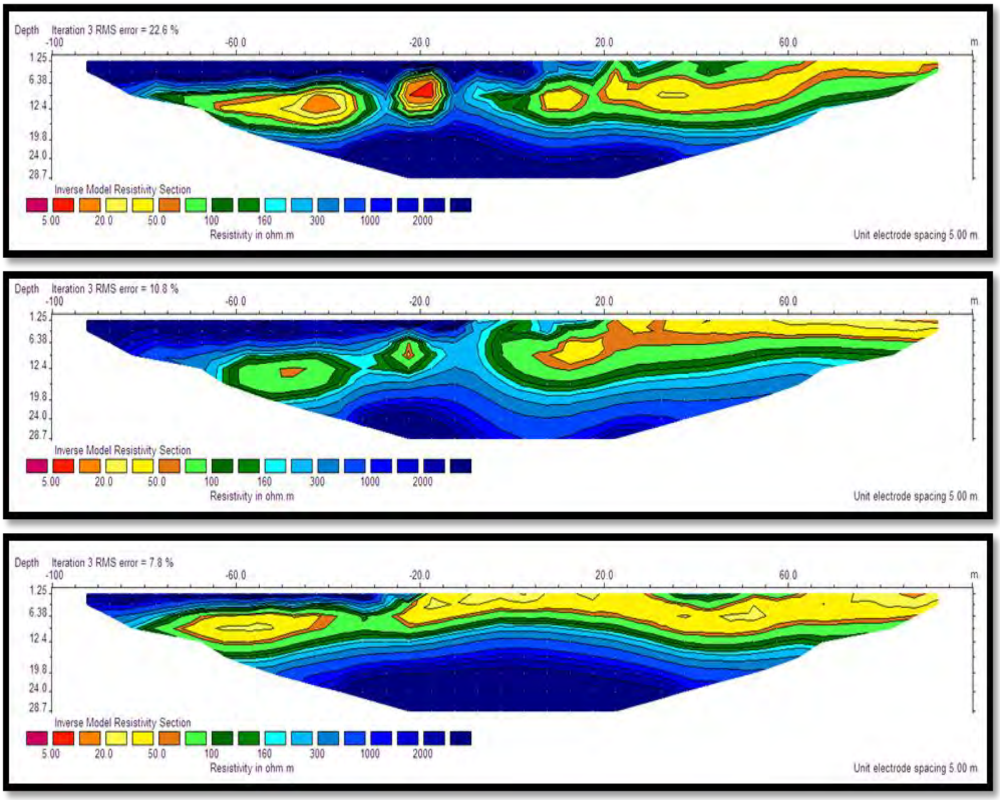

Figure 5: Inverse model of electrical resistivity section for profiles #4, #5 and #6 showing interpreted location of shallow limestone cavities and sinkhole.

Resistivity profile#3. Profile #3 shows a sinkhole with the shallowest subsurface depths less than 1.5m. and continues after the depth of 28.7m. Bedrock unit beneath and adjacent to the sinkhole at depths below 20 m., is interpreted as transitional zones of weathered limestone probably consisting of wet fractured and/or clay in-fill mineral.

Two cavities were located at the subsurface immediately to the east flank of the sinkhole. The first cavity in the left is less than 20 m wide and the height is 19 m with 1.25 to 19.8m. The middle of this cavity consists of anomaly with resistivity values of between 50 to 60 ohm-m and is interpreted as silty or sandy clay. These are surrounded by resistivity values 70 to180ohm-m and interpreted as silty sand, sand and/or deeply weathered rock fragments. The second cavity on the right is less than 15 m wide with and 6.0m high and from 6.38m to12.4m deep. It is anomalous with resistivity values of 70 -200 ohm-m, interpreted as containing clayey or silty sand, sand and deeply weathered rock fragments. These feature or cavities are interpreted as a solution widened joint or zone of deeply fractured rock.

Profile #1. The bedrock extends from electrode 2 to electrode 16 representing a semi tubular shaped anomaly representing a sinkhole. It is noted that the limestone borders around the sinkhole. Zones around the sinkhole with resistivity greater than 200 ohm-m and u to 400 ohm-m are interpreted as zone of weathered limestone, probably consisting of wet fractured and/or clay in-fill.

The base of the sinkhole was visible and the walls were both steep and weathered. Four oval-shaped cavities and one void were located along this profile, believed to be the extension of cavities from profile #3. Their size are about 5 to 17 m wide, from 4.6 to 10 m high and located at the depth from 1.25 to 13.3 m. Except for the second cavity that is filled with air and dry, the rest of the cavities are filled with clay, sandy clay, silty clay, silty sand and sand. All of the 3 sinkholes are believed to be an outlet for the transmitting of water and materials from the sinkhole collapse.

Profile #2. A tubular shaped anomaly which is representing a sinkhole can be observed here. Localized of high resistivity values of more than 200 ohm-m to 400 ohm-m is observed in the shallowest subsurface from depths of less than 1.25 m. These resistivity values and patterns are consistent with visual observations around the sinkhole and cavities, jointed limestone to a depth of at least 16 m.

At depths below 19.0 m., bedrock beneath was characterized by higher resistivity in excess of 400 ohm-m, but less than 2000 ohm-m, interpreted as intact or compact limestone bed rock.

Small voids are visible between electrodes 28-29, approximately 7.0m wide and 5.0m high and from 1.25 to 6.38m deep. This void is filled with sands and other remnant of rocks. The center is characterized mostly by resistivity of more than 3000 ohm-m representing air infill voids.

A karst depression feature extends from electrode 11 to electrode 33. This anomaly is consistent of different patterns of resistivity values in the shallow subsurface overall, from depth of 1.25m to 13m.

Intact or sold boulders of limestone with higher resistivity 400 of 1000 ohm-m are found bordering this location on both flanks of resistivity profile from electrode 5-11 and from electrode 33-40. In the shallowest subsurface from depths of 2.0m to 8.0m,

200 ohm-m to less than 400 ohm-m is interpreted as transitional zones of weathered limestone probably consisting of wet, fractured and/or clay in-fill.

Beneath the subsurface, localized intact or sold limestone bedrock, extends over the entire profile from the depth to19.8m to depth 29.0m, with higher resistivity of more than 400 ohm-m to less than 3000 ohm-m.

Profile #4. The first cavity to left flank from electrode 7 to electrode 15 was oval-shaped, approximately 40m wide and 8.62m high and from 6.38m to 15.6m deep. The base of this cavity is visible and filled with soft clay and surrounded by sandy clay, silty sand and sand. The walls of this cavity are of highly weathered limestone. The second cavity, in the middle of this profile, from electrode 16 to electrode 18, is approximately 10m wide, 11.70m high and from 2.8m to14.5m deep. It appears to have near-rounded walls, is filled with wet clay and surrounded by sandy clay, silty sand and sand. Horizontal trend anomaly in tubular shape, about 95m wide, 18m high and from 1.25 to 19.8m high is also observed.
Observation in the field shows that the surface is underlain by clay or sandy clay, in the area across the profiles. This survey shows the sinkhole and cavities in the shallowest subsurface karst extend from to depth of 7 to 19 m.

Profile #5. A continuous limestone cover is interpreted on the left flank with the depths ranging from 1.25m to 12.38m. Beneath it is a horizontal trend anomaly in tubular shape with approximate measurement of 100m wide, 18m high, from depths of 1.25m to depth 19.8m.
A prominent zone of relatively different pattern of resistivity anomaly is also observed at the depth of 6.38m beneath the cover. These oval-shaped features are interpreted as two previously identified cavities in Profile 4. They are filled with clay, sandy or silty clay and sand. The first cavity to left flank from electrode 9 to electrode 14 is oval-shaped, approximately 25m wide and 12.0m high and from 7.25m to 19.0 m deep. The second cavity, in the middle of this profile, from electrode 15 to electrode 18, approximately 15m wide and 10m high and from 2.5 to 12.4m deep in cross-section appeared to have near-rounded walls The base of these cavities are visible and filled with remnant of surficial soil or silty sand and surrounded by sand. The walls are highly weathered limestone.

Limestone bedrock of strongly widened fracture with clay infill, extend across the profiles, is observed beneath and adjacent to the sinkhole and cavities in the shallowest subsurface from depths of 6 to 24 m. Overall, it is characterized with high resistivity of more than 200 ohm-m but less than 400 ohm-m.

Continuous bedrock of solid or non weathered limestone was localized in the depth of about 24 m with overall higher resistivity of more than 1000 to 3000 ohm-m.

Profile #6. Survey under electrode 16 to electrode 40 represents a horizontal trend anomaly in tubular shape with the width of about 115m, thickness 18m and depths from 1.25 to 15.5m. It continues to left flank to electrode 2 to electrode 16, which is partly covered by the bedrock that is characterized mostly by resistivity of between 1000 to less than 3000 ohm-m. The thickness of this cover is from about 1.25 to 6.38 m. The centers of this cavity are filled with soft clay and surrounded by residual superficial soil or sandy clay.
The rest of the profile shows that areas a large sinkhole filled with clay. The shallowest subsurface karst is located from depths of19 to 24 m. Overall, it is characterized with high resistivity of more than 200 ohm-m but less than 400 ohm-m.
Continuous bedrock of solid or non weathered limestone was localized at the depth of 24 m with overall higher resistivity of more than 1000 to 3000 ohm-m.

Discussion and Conclusions

The karst corrosion plain is commonly veneered with alluvium and when uplifted, glaciated or strip mined for placer deposits, removal of the clastic veneer reveals an impressively planar rock floor that in the tropics, in particular, can sometimes be rugged in detail because of etching down joints (Ford and Williams, 1989). This can be commonly seen in Kinta Valley karst where the subsurface is exposed (Muhammad, 2003). Prolong process of dissolution under clay or sand cover may have produced the topography as what we can observe in Jeram. In the study area, very thin limestone of up to 12m thick presents as cover on the surface. The rest is in the subsurface, overlain by clay and loose sands material. Some of the thin covers may already been washed down in the large sinkholes during the collapse.

Most of the cavities found in this site appear as channels for transmission of water and material from the surface. However some of these channels are thought to be non active due to the absence of soft clay. The overlying sandstone were found in many places on the surface in the area of study, characterized mostly by high resistivity, interpreted as dry and friable sands and with limestone or rocks fragment, probably previously stripped by excavators from the pits of mine, due to ex -mining excavating operation.

The basal limestone bedrock is covered by soil or sandy clay and friable sand in some place and dissected by cavities that are believed to be produced from solution-widened joints by further dissolution.

Sinkholes and cavities found here are of tubular and cylindrical shape. These observations may indicate that these sinkholes and cavities are newly developed due to a collapse feature. This support the thought that the origin of all these cavities were of pre-existing feature as joints, and likely widened due to subsidence/collapse movement in the area that had rapidly filled with clay.

Further studies will involve the studies on the geochemistry of the water, the behaviour of water flow, comparison with other sinkhole and non-prone sinkhole areas and closer monitoring of occurrences in relation to the Sumatran earthquake in the future.

Acknowledgement

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THREE-DIMENSIONAL MAPPING OF LIANG (CAVE) TEWET, EAST KALIMANTAN

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Abstract
Liang Tewet is one of the caves in Sangkulirang-Mangkalihat Karst, East Kalimantan. The cave has the prehistoric cave paintings on the cave roof and other parts of the cave featuring hands and other images, which presumed to be older than 10,000 years old. A detailed 3D mapping was done to obtain the result of 3D model of Liang Tewet. In the model, the detailed situation of the cave and the prehistoric paintings were plotted. The measurements in the cave were made using Total Station instrument, and using Open Polygon methods. The measurements of the cave floor, walls, ornaments, roof and the localities of each cave painting were made. The raw data of the measurements were downloaded from the Total Station using LeicaGeo Office, and then processed to produce the .xls files (Microsofts Excel). The .xls files were analyzed and drawn using Liscad and AutoCAD Land Development to develop surface model of Liang Tewet in .dwg file (AutoCAD). Furthermore, the .dwg format, as a basic model, will animated using 3DStudio to create the realistic model of the cave.

Authors Index

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