National Seminar on Geospatial Solutions for Resource Conservation and Management

18-19 January, 2012, J.N.TATA Auditorium, Indian Institute of Science, Bengaluru

PROCEEDINGS

Organized by

Karnataka State Remote Sensing Applications Centre

Department of IT, BT and S&T, Government of Karnataka

Sponsored by

NABARD ISRO MoES DST ICAR MML CSIR SBM

Co-Sponsored by

esri India INTERGRAPH erdas PIXEL Aimil Ltd. GeoVISTA

ABOUT KSRSAC

Recognizing the capabilities of the cutting edge technologies like RS, GIS and GPS in addressing various issues of planning, development and management of natural resources for equitable growth and balanced development on sustainable basis, the Govt. of Karnataka established the Karnataka State Remote Sensing Applications Centre (KSRSAC) in the year 1986 and designated it as Nodal Agency for implementation of Geomatic programmes in the State.

Over the last two and half decades, KSRSAC has been rendering yeomen service to the state of Karnataka and other Central Organizations in the area of Geoinformatics and has generated voluminous geospatial data on land use / land cover, crop acreage and production estimation, soil and land resource inventory, delineation, codification, planning and evaluation of watersheds, land degradation mapping and change detection, wasteland identification, forest type mapping, forest fire risk zonation, water resources, command area development, Rajiv Gandhi Drinking Water Mission, tank information system, crime information system for maintenance of law and order, environment and disaster management, wetland and coastal zone regulation, urban infrastructure and development, slum area identification etc. The database generated at both macro and micro-levels has been made available for all the Govt. Depts. for preparing action plans at various levels for sustained development. Innovation, technical excellence and timely completion of projects are the hallmarks of KSRSAC.

KSRSAC has two Regional Centers, one located at Mysore and the other at Gulbarga to cater to the needs of geospatial data in their respective zones. The KSRSAC organizes training and awareness programmes on the utility and application of RS, GIS and GPS technologies to the planners, administrators, academicians and NGOs. It has also established Geoinformatics Cells at all the district headquarters in the State to disseminate the geospatial data and to assist the district level, zilla panchayat and village panchayat level officers in utilizing the geospatial data in planning, implementation and management of developmental projects of the district.

The dearth of well qualified professionals to generate and manage geospatial database of natural resources and other spheres using techniques of Geoinformatics is on the rise. In order to meet the growing demand for professionals with domain expertise in Geoinformatics, KSRSAC has started a two years full time M. Tech (Geoinformatics) programme in association with Visvesvaraya Technological University (VTU) and Survey of India.

KSRSAC at present is vigorously pursuing generation of geospatial database of natural resources at land parcel/ survey No. level using sub-meter level satellite data for planning at grassroots level.

National Seminar on Geospatial Solutions for Resource Conservation and Management

18-19 January, 2012, J.N.TATA Auditorium, Indian Institute of Science, Bengaluru

PROCEEDINGS

Organized by

Karnataka State Remote Sensing Applications Centre
Department of IT, BT and S&T, Government of Karnataka

Sponsored by

NABARD ISRO MoES DST ICAR MML CSIR SBM

Co-Sponsored by

esri India INTERGRAPH erdas PIXEL Aimil Ltd. GeoVISTA

Editors

Dr. D. K. Prabhuraj

Shri R. S. Reddy

Dr. T. R. Sreedhara Murthy

Dr. S. Vadivelu

Ms. Sanjana S Bakre

Ms. Prathima K

Smt. Dwija Brunda D

Ms. Priya H

List of Reviewers

The organizing committee of the National Seminar on "Geospatial Solutions for Resource Conservation and Management" (GEOSOL 2012) gratefully acknowledges the following for their critical review, constructive criticism and fruitful suggestions on the manuscripts of research papers published here as 'Proceedings'.

Dr. Najeeb K.Mohammed

Prof. Onkar Dikshit

Prof Manoj K. Arora

Prof. Abdul Razak Mohamed

Prof. G.Venkataraman

Dr. R.K.Batta

Dr. G. P. Obi Reddy

Dr. Rajeev Shrivastav

Dr.D.K.Pal

Dr. U. Baruah

Dr. L.G.K. Naidu

Dr. Sundararaj Thayalan

Dr. V. Rama Murthy

Dr. Rajendra Hegde

Dr. Sunil Maske

Dr. S.C. Ramesh Kumar

Dr. P. P. Nageswara Rao

Dr. H.M. Ramachandra

Dr. M.S. Ganesh Prasad

Dr. S.Vadivelu

Prof. T.R. Sreedhara Murthy

Sri R.S.Reddy

Organizing Committee

Chairman

Shri M. N. Vidyashankar, I.A.S
Chairman, KSRSAC and Principal Secretary,
Dept. of IT, BT and S&T, Govt. of Karnataka

Organizing Secretary

Dr. D. K. Prabhuraj
Director
KSRSAC

Convener

Dr. T. R. Sreedhara Murthy

Members

Dr.J.Krishnamurthy, Deputy Director, EoS, Dept. of Space, Govt. of India, Bangalore

Dr.Manjula, I.A.S, Commissioner, Survey Settlement and Land Records, Govt. of Karnataka

Shri Aravind Shrivastava, I.A.S, Commissioner, Dept. of Municipal Administration, Govt. of Karnataka,

Dr. Srinivas, I.A.S, Director, Dept. of Mines & Geology, Govt. of Karnataka

Shri Vinay Luthra, I.F.S, Additional Principal Chief Conservator of Forests, Govt. of Karnataka

Dr. M.Prithviraj, Director, Dept. of Science & Technology, GoI and Executive Secretary, KSCST, Govt. of Karnataka

Dr. M.Sudhakar, Advisor, Dept. of Earth Sciences, Govt. of India

Dr.S.G.Gaonkar, Deputy Director General, Geological Survey of India, Govt. of India

Dr. D.Sarkar, Director, NBSS & LUP, ICAR, Govt. of India,

Shri Rajashekar, Director, Karnataka Geospatial Data Centre, Survey of India

Dr. Udayaraj, General Manager, RRSSC, ISRO, Govt. of India

Dr. V.S.Prakash, Director, Karnataka State Natural Disaster Monitoring Centre, Govt. of Karnataka

Dr.Sarvesh, Director, Dept. of Agriculture, Govt. of Karnataka

Dr.Rajanna, Director, Watershed Development Department, Govt. of Karnataka

THE PRINTING OF THE PROCEEDINGS

WAS FULLY FINANCED BY

NATIONAL BANK FOR AGRICULTURE AND RURAL DEVELOPMENT (NABARD)

AND

INDIAN SPACE RESEARCH ORGANIZATION (ISRO)

KARNATAKA STATE REMOTE SENSING APPLICATIONS CENTRE (KSRSAC)

and

GEOSOL 2012

GRATEFULLY ACKNOWLEDGE

Sponsors

NATIONAL BANK FOR AGRICULTURE AND RURAL DEVELOPMENT (NABARD), Mumbai

INDIAN SPACE RESEARCH ORGANIZATION (ISRO), Department of Space, Government of India

MINISTRY OF EARTH SCIENCES, Government of India

DEPARTMENT OF SCIENCE & TECHNOLOGY (DST), Government of India

MYSORE MINERALS LTD., Government of Karnataka

INDIAN COUNCIL OF AGRICULTURAL RESEARCH (ICAR)

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH (CSIR)

STATE BANK OF MYSORE

Co-Sponsors

INTERGRAPH/ERDAS
Intergraph SG & I India Pvt. Ltd.

ESRI INDIA

PIXEL SOFTEK PVT. LTD.

GEOVISTA SOFTWARE SOLUTIONS PVT. LTD.

AIMIL LTD.

SCANPOINT GEOMATICS LTD.

INDIAN OVERSEAS BANK

RSI SOFTECH INDIA PVT LTD.

E-CONNECT

BANGALORE SURVEY INSTRUMENTS CO.

KRUTHI COMPUTERS SERVICES PVT. LTD.

for their financial support for the National Seminar on "Geospatial Solutions for Resource Conservation and Management" (GEOSOL 2012)

PREFACE

The Karnataka State Remote Sensing Applications Centre has organized a national seminar on "Geospatial Solutions for Resource Conservation and Management" on 18th & 19th January, 2012 at J N Tata Auditorium, IISc, Bangalore as a part of its Silver Jubilee Celebrations. The seminar was inaugurated by Dr. K.Kasturirangan, Member, Planning Commission, GoI and Chairman, Karnataka Knowledge Commission, GoK. Dr. K.Radhakrishnan, Chairman, ISRO and Secretary, Dept. of Space, GoI, delivered the key note address. Sri Ramachandra Gowda, Deputy Chairman, State Planning Board, GoK, delivered the Silver Jubilee Address. Silver Jubilee Souvenir and Abstract Volume of research papers were released by the dignitaries. The exhibition on remote sensing and GIS applications was also inaugurated by the dignitaries.

After the inaugural function, Dr. R.R.Navalgund, Director, Space Applications Centre, Ahmedabad and Dr. Mukund Rao, Expert, National GIS at Planning Commission presented "Vision Papers" on the role of geospatial data for resource conservation and management. Dr. R.B.Lal, Director, Indian Institute of Forest Management, Bhopal, Dr. P.G.Diwakar, Director, EOS, ISRO and Dr. Dipak Sarkar, Director NBSS & LUP (ICAR), Nagpur took part in the "Panel Discussion" on the innovative uses of remote sensing products and GIS in resource management.

In all, 126 voluntary research papers were received for presentation at the seminar. After review, 103 papers were accepted for oral presentation and 23 for poster presentation. Eleven Technical Sessions were organized concurrently in three different halls to orally present the 103 papers. The 11 sessions embraced all the natural resource themes like Soil Resources, Land Use/Land Cover, Watershed Management, Crop Acreage and Production Estimation, Water Resources, Environment and Disaster Management, Petroleum and Minerals, Forest Management, Ocean Resources, Urban and Country Planning and Tourism and Archaeology. The "Plenary Session" was chaired by Dr. K.R.Sridhara Murthi, GIS Expert, wherein Chairmen and Rapporteurs of all the 11 Technical Sessions presented their reports. The reports were discussed by the delegates and recommendations were drawn which were approved by the house. The "Recommendations of the National Seminar" are presented elsewhere in this publication.

Of the 126 papers accepted, 62 authors submitted full research papers for publication to be brought out as "Proceedings of the National Seminar". These 62 papers were sent for peer review to several subject matter specialists in different disciplines and finally 55 papers were accepted for publication. The organizers and the editors gratefully acknowledge the reviewers for their painstaking efforts in critically reviewing the papers and for making useful suggestions. The names of the reviewers are published elsewhere in this publication. The 55 papers cover important theme areas such as Soil and Land Resources (17 papers), Watershed Management (7 papers), Forest Resources (3 papers), Wetlands (3 papers), Water Resources and Drainage Systems (7 papers), Earth Resources (2 papers), Urban Infrastructure and Planning (6 papers), Tourism and Archaeology (4 papers) and Remote Sensing and GIS Techniques (6 papers). The publication PROCEEDINGS OF THE NATIONAL SEMINAR contains these 56 papers.

The organizers and the editors profusely thank the National Bank for Agriculture and Rural Development (NABARD) and the Indian Space Research Organization (ISRO), Dept. of Space, Govt. of India for financing the printing of the "Proceedings of the National Seminar" and many others for sponsoring the National Seminar.

Editors

Recommendations of the National Seminar on "Geospatial Solutions for Resource Conservation and Management"

The Karnataka State Remote Sensing Applications Centre (KSRSAC) organized a National Seminar on "Geospatial Solutions for Resource Conservation and Management" at J N Tata Auditorium, Indian Institute of Science, Bangalore on 18th & 19th January, 2012. The seminar was inaugurated by Dr.K.Kasturirangan, Member, Planning Commission, Govt. of India and Chairman, Karnataka Knowledge Commission, Govt. of Karnataka. About 280 scientists from all over the country attended the seminar and 72 papers were presented and discussed in 11 Technical Sessions *viz.* Agriculture – Soil Resources, Land Use / Land Cover, Watershed Management, Crop Acreage and Production Estimation, Earth Resources – Water Resources, Petroleum and Minerals, Environment and Disaster Management, Forest Resources, Tourism and Archaeology, Ocean Resource Management and Urban and Country Planning.

The Plenary Session was held at the end of the presentation of papers and the following recommendations were drawn for implementation by the concerned.

- Generation of cadastral level soil resource map using remote sensing and GIS techniques for identifying the problems and potentials and to conserve and manage them at farm level for improving productivity.
- Periodic study of soils of irrigated areas to diagnose the development of saline sodic problems and carry out ameliorative measures.
- Use of remote sensing and GIS technology for land degradation mapping to know the kind and degree of degradation.
- Use of suitable land evaluation method to identify the suitability of soils for different crops and then to design appropriate rational land use plans.
- Assessment of the economic value of generation and application of geospatial database for resource conservation and management.
- Use of pixel-wise uncertainty as quality indicator of thematic maps derived from particularly coarse resolution images containing large number of mixed pixels.

- Since, digital classification purely on the basis of statistical analysis of spectral response may not, many a times, truly represent the ground conditions, the inclusion of ancillary information from other sources such as Digital Elevation Model, Geological and Soil maps may be a more powerful way of characterizing the classes of interest.
- Use of remote sensing and GIS techniques for change detection analysis of land use/land cover at regular intervals.
- Use of high resolution satellite data, GIS techniques and participatory approach to generate geospatial database of watersheds for subsequent conservation and management for sustained crop production.
- Development of efficient web based watershed information system to assist decision makers in the various development departments.
- Forecasting Crop Acreage and Production Estimation of major crops using high resolution multi-date multi-spectral satellite data for *Kharif*, *Rabi* and Summer season crops.
- Use of remote sensing products, GPS and GIS tools in planning, development and implementation of Precision Farming technology.
- Use of new generation hyper-spectral sensors in mapping rock types and determination of fractional composition of highly weathered regolith land forms and related ground water occurrence.
- Use of ASTER DEM, a better tool for drainage network analysis of river basins for better understanding of river flow dynamics.
- Use of drainage, land use, geomorphology, geology, lineament and soils information for generating ground water potential zones maps.
- Use of remote sensing and GIS for application in petroleum industry for proper planning, design, management, operation and maintenance of pipeline system and for controlling the potential environmental impacts of mining operations.
- Extensive demarcation of lineaments and identification of geomorphic anomalies using high resolution satellite images to identify the structures developed along the younger trends (neotectonic events), since the hydrocarbons generated in the basin at one stage might have migrated and entrapped at different places due to subsequent tectonic events in Krishna, Cauvery and Tripura - Cachar basins.
- Use of high resolution satellite data (Resourcesat-1) in delineation of buried channels and their relict valleys to explore for calcrete hosted uranium mineralization in the desert of Western Rajasthan.
- Use of multi-temporal Synthetic Aperture RADAR (SAR) interferometry in mapping Glaciers and their dynamics in understanding the climate change.

- Use of satellite images, GIS and GPS in disaster management, monitoring the Himalayan Glaciers, Coral Reefs, Wetlands, Mangrove environs and concentration of pollutants.
- Study of soil and climatic conditions particularly soil depth and length of dry period for forest expansion.
- Use of GIS and remote sensing techniques to identify forest fires and forest fire risk zones, to identify high priority forest conservation zones and mega centres of endemism.
- Use of high resolution satellite images and GIS in the study of Coastal Geomorphology, distribution of *chlorophyll–a* to delineate nutrient zones for fishing in coastal waters and monitoring activities through Coastal Regulation Zone and Integrated Coastal Zone Management Plan.
- Use of geospatial tools in conservation and management of Archaeological sites and identification of potential sites for Eco-tourism.
- Use of high resolution satellite images and GIS in preparation of master plans for city development, identification of bye-pass corridors, analysis of dynamics of urban expansion, identification of sites for solid waste disposal, rehabilitation of urban and peri-urban tank systems and other infrastructural facilities.

About National Seminar

Karnataka State Remote Sensing Applications Centre (KSRSAC) has been established in 1986 under the Department of IT, BT and S & T of Government of Karnataka. It has been designated as nodal agency for carrying out Remote Sensing and GIS projects in the state. The KSRSAC has been rendering yeomen service to the state of Karnataka in the area of Geoinformatics for the last 25 years and have generated voluminous geospatial data on land use/land cover, soil and land resources etc using GIS technology. The database generated has been made available for all the Govt. Departments for planning developmental activities. On the occasion of completing 25 glorious years of fruitful service, KSRSAC is organizing a two day National Seminar on Geospatial Solutions for Resource Conservation and Management in January 2012.

Theme of the Seminar

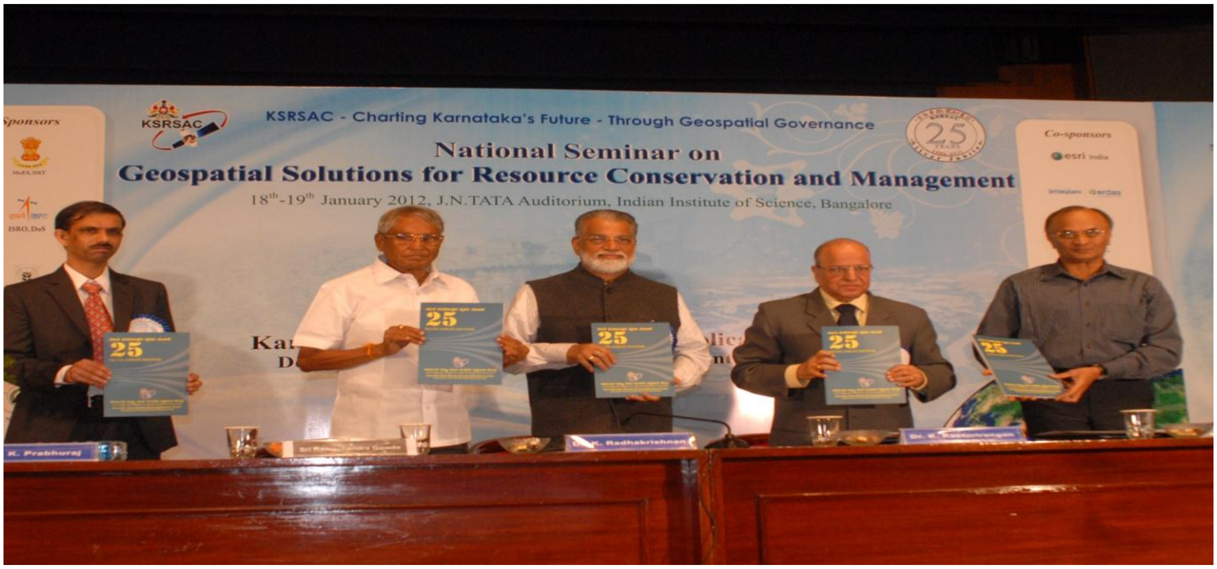
With the advent of space technology, the very concept of database generation and analysis has undergone sea change. Hence, the ways and means of earth observation and geo-information for monitoring of spatial processes has become all the more important for sustainable development of the environment. The management of these geospatial databases requires decision taking power at different tiers of administration. The proposed seminar brings all the experts of RS and GIS on a single platform to share their expertise and evolve suitable strategies for sustainable development of our precious natural resources. General theme selected for the National Seminar is **"Geospatial Solutions for Resource Conservation and Management".** The focal themes selected are

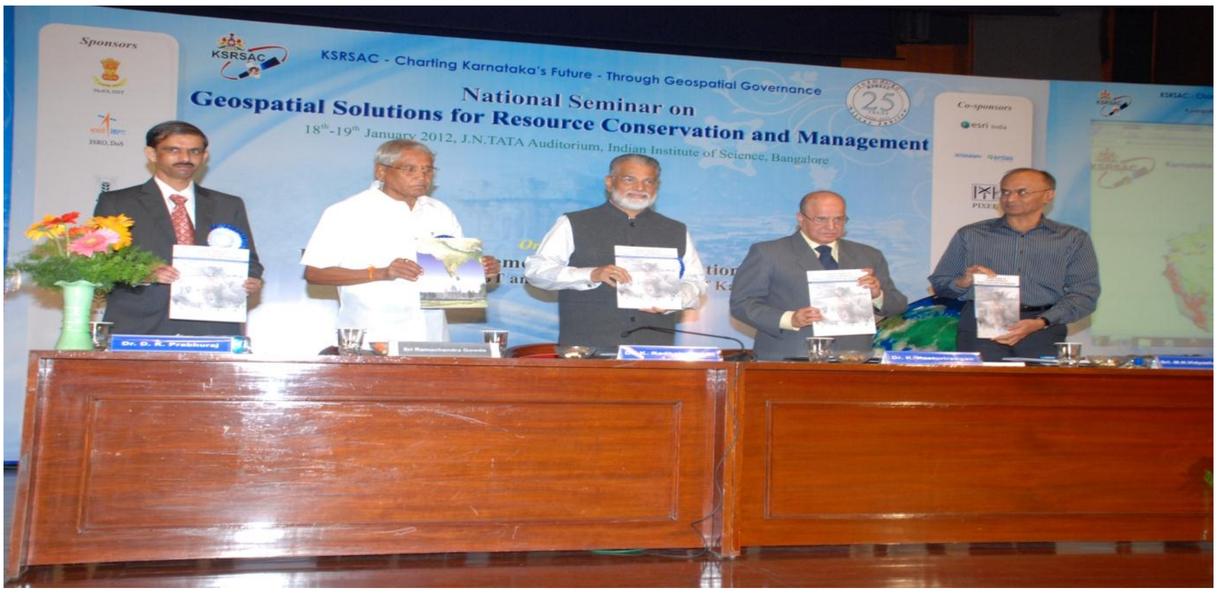
Agriculture	Soil Resource Inventory Land Evaluation and Land Use Planning Land Degradation Assessment and Mitigation Watershed Prioritization, Monitoring and Evaluation Land Use/ Land Cover Mapping Crop Acreage and Production Estimation Precision Farming Command Area Development
Forest	Forest Resource Inventory Wildlife Habitat Forest Fire & Forest Management
Earth Sciences	Geological Resource Inventory Geomorphology Water Resources Mineral Exploration including Oil and Natural Gas
Oceanography	Coastal Zone Studies Fisheries Oceanography Management of Wet lands Eco-sensitivity of Islands
Urban and Country Planning	Infrastructure Development Assessment and Management of Urban Property Slum Management Law and Order Assessment
Environment and Disaster Management	Drought and Flood Management Climate change Earthquake and Tsunami Glacial Studies Environmental Impact Assessment

Archaeology and Tourism Management

PHOTOGRAPHS OF THE NATIONAL SEMINAR

PHOTOGRAPHS OF THE NATIONAL SEMINAR





PHOTOGRAPHS OF THE NATIONAL SEMINAR

PHOTOGRAPHS OF THE NATIONAL SEMINAR

PHOTOGRAPHS OF THE NATIONAL SEMINAR

CONTENTS

Efficient Techniques for Detailed Land Resources Inventorization using Remote Sensing and Conventional Tools: A Case Study of Tirumale Sub-watershed in Magadi Taluk, Karnataka

Rajendra Hegde, Niranjana, K.V., Natarajan, A. and Naidu, L. G. K.

National Bureau of Soil Survey and Land Use Planning (ICAR), Hebbal, Bangalore
E-mail: rhegdesirsi@yahoo.com

Abstract

A pilot project to create the data base at a fast track phase was undertaken at Tirumale sub-watershed, Magadi taluk of Ramanagara district. The study was aimed at demonstrating the utility of detailed land resources database in the scientific planning, implementation and evaluation of watershed development programs by the watershed development department. Google earth image in conjunction with cadastral map (1:8000 scale) for the watershed area was used for delineating surface features like settlements, water bodies, rock outcrops, cultivable lands, plantations, streams etc. Based on the surface features, transects were selected for undertaking slope analysis and profile studies. The plot-wise detailed soil survey was completed by studying the type of soils in the field by exposing 48 soil profiles and few minipits followed by laboratory characterization. Based on the soil characteristics, 4 soil series and 20 management units were delineated. Each management unit is unique in the properties and requires specific conservation plan and management strategies to improve the plot-wise productivity. Database is presented in a GIS environment to facilitate easy reference and retrieval. Information provided in the report and maps can easily be referred by the stakeholders to identify field survey number with best land use options.

Introduction

Government of India spends every year nearly Rupees one lakh crore on various land-based rural and agricultural development programs. However, various post-project evaluation reports suggest that 50-75 per cent of farm lands are suffering from various kinds of degradation. It indicates that there is mismatch between the actual requirement and what is actually implemented in the field in the form of various land-based rural development programs. Such situations can be avoided if detailed, site specific land resources database are generated in each and every project area to identify inherent potentials and constraints and evaluate for suitability to various land uses. Inventory of land resources is the prerequisite for implementing, monitoring, reviewing and evaluating all the land development programs. This can be obtained only by conducting cadastral level detailed surveys wherein we characterize and group soils into different soil series and delineate homogenous areas based on soil-site characteristics into management units or phases. Thus, detailed surveys are essential in identifying different management units at village level which will form the basis for undertaking any developmental work later. Preparation of such a detailed land resources inventory is a very time consuming, highly skillful and costly exercise. The present pilot study was aimed at providing such a database for all the 14 villages (1650 ha) in two micro-watersheds (KSRSAC, 2005) namely Bairappapalya and Kadirenapalya in Magadi Taluk of Ramanagara district of Karnataka during February 2011.

Materials and methods

High intensity detailed soil survey at 1:8000 scale was carried out in the area lying between 77°12' 30" and 77°17'30" E longitudes and 12°55' 0"and 13°02'30" N latitudes with total geographical area of 1650 ha. Study was carried out for characterizing all the site (slope, erosion, drainage, rock fragments etc) and soil characteristics (depth, texture, colour, structure, consistence, coarse fragments, porosity, soil reaction etc) followed by grouping of similar areas based on soil-site characteristics into homogenous (management) units and showing their extent and distribution on the village cadastral map (Natarajan and Dipak Sarkar, 2009).

Base maps used

Study was carried out by using cadastral map as a base. The cadastral map shows field boundaries with their survey numbers, location of tanks, streams and other permanent features of the area. Remote sensing data products from Google earth at the same scale were used in conjunction with the cadastral maps to identify the landforms and other surface features. Google Earth Images helped in the identification and delineation of boundaries between hills, uplands and lowlands, water bodies, forest and vegetated areas, roads, habitations and other cultural features of the area. Apart from these, toposheets of the area at 1:50,000 scale were used for initial traversing, identification of geology and landform, drainage features, present land use and for the selection of transects at block level.

Field investigations

Based on the initial traversing, five representative transects were selected for study. In the selected transect, profiles were located at closely spaced intervals to take care of any change in the land features like break in slope, erosion, gravel, stones etc. In the selected sites, soil profiles were dug upto 200 cm or to the depth limited by rock or hard substratum and studied in detail for all their morphological and physical characteristics and recorded in a standard proforma. Based on soil-site characteristics, the soils were grouped into different soil series (soil series is the most homogeneous unit having similar horizons and properties and behaves similarly for a given level of management). Soil depth, texture, color, amount and nature of gravel present, nature of substratum and horizon sequence were the major identifying characteristics used for differentiating into soil series. Based on the above characteristics, four soil series were identified in the area.

75 composite soil samples were collected representing different land forms and land uses for soil fertility analysis. Soil profile samples were collected from master profiles for chemical and physical characterization. 32 farmers were interviewed on various constraints and potentials of the watershed for profitable farming, soil and water conservation and diversification of farming. Then, the area under each series was further mapped into phases and their boundaries delineated on the

cadastral map based on the variations observed in the texture of the surface soil, slope, erosion, presence of gravel, stoniness etc. A phase is a subdivision of a soil series based mostly on surface features that affect its use and management (Soil Survey Division Staff, 2000). The soil map units are shown on the map in the form of symbols. In arriving at the phases, a combination of letters, both in upper and lower case, and numerals were used. During the survey, a total of 40 profiles and about 100 spot observations in the form of mini pits, road cuts, terrace cuts and well cuts were studied. The soil map for the study area was finalized in the field itself after thorough checking of soil and site characteristics and correlation. Maps were prepared without any generalization and presented in the Report (Rajendra Hegde *et al.,* 2011). The soil map shows the individual field boundaries, their survey numbers and management units occurring in the sub-watershed (Fig.1).

Results and discussion

Landform analysis

Granite and gneiss belonging to Archaean period are the major rock types and dykes occurring in few places as intrusive in the country rock. The granite and gneiss show great variations in their texture, color, mineral assemblage and degree of weathering. These variations are reflected in the soil types identified in the area. Rocky hills and rock outcrops cover almost 30 per cent of the area. The hills and ridges are mostly covered by rock outcrops. In patches between the rock outcrops and boulders, good growth of mango, jackfruit, *ficus sps* etc are observed in the entire watershed area. The summits are always covered with rock outcrops along with cultivated plots and such areas cover around 20 per cent of the area.

The elevation of the area ranges from 818 to 897 m above MSL. Entire area consists of moderately sloping to undulating lands with a slope percentage ranging from 3-10. The direction of the slope is complex and is in all directions. Based on the general slope, the area can be broadly divided into rocky hills and ridges, summits, cultivated plots in between rocky lands, sloping uplands and valleys. A network of canals was built about 50 years back to use the water for irrigation from a village Harthi tank. For that purpose, most of the areas along the stream courses were levelled and wherever necessary bunded. Paddy was the main crop besides *ragi* for many years in these plots. But due to shortage of water during the last 15-20 years, no water is flowing in these canals and paddy is cultivated in only patches where drainage conditions do not allow any other crop to be raised. Few new tanks have been constructed and old ones strengthened by the watershed development department. All the tanks are seasonal and dependent only on rain. Most of the tanks receive their supply from their limited catchment area, which is not sufficient to fill the tanks completely every year. Due to uncontrolled erosion from marginal lands and uplands, the tanks are heavily silted and have very limited water storage capacity. Almost all the tank beds are covered by weeds.

Gently to moderately sloping lands cover around 40 per cent of the area in the watershed. These are under cultivation for a long time and bunding is commonly observed in all the villages of the watershed. These bunds were mostly built by the farmers themselves in the past and are not in good condition at many places due to their poor maintenance. However, due to the poor execution of the bunding, in about 20 percent of the area, fertile top soils are lost and such plots are left with very shallow soils or in many places the weathered parent material is exposed at the surface. Lowlands and valleys are present in about 10 per cent of the area.

Climate

The climate is semi-arid or hot tropical monsoonal type (Fig. 2). The maximum temperature during summer is 38°C and the minimum 12°C in winter. The average maximum and minimum temperatures are 33°C and 14°C respectively. The average annual rainfall is 996 mm. Most of it is received between June and September from the south-west monsoon. However, the north-east monsoon also brings in rain for a short period during November and December. The lowest rainfall of 575 mm was received in 1990 and the highest of 1913 mm during 1975. Total PET is 1499 mm. The maximum rainfall received in 24 hours duration is 96 mm in one of the years.

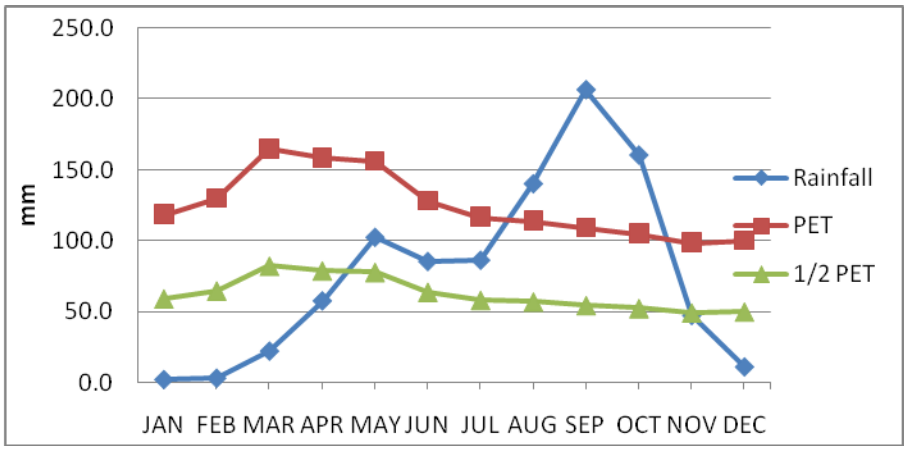


Figure 2. Water balance diagram for Tirumale sub-watershed

The growing period which indicates the availability of water for plant growth is about four to five months in a year. It starts from the beginning of July and continues upto the end of December. Due to this, short to medium duration crops like *ragi*, pigeon pea, French bean, fodder sorghum etc can be grown successfully and cultivation of any long duration crops need supplemental or assured irrigation facilities. The deep rooted castor and pigeon pea are important long duration crops cultivated in this area, normally grown as an inter crop to exploit the residual moisture present in the lower horizons of the soil. During the last decade or so, considerable area has been planted to mango and *ficus*, particularly in the marginal lands.

Socio-economic constraints

Large scale migration of young people is causing severe scarcity of labour for farm works. As per the information collected during the study, farming is no more attractive for a large majority (> 60%) of the population.

Land use

The net area sown (rainfed) is about 50 per cent in the sub-watershed. The fallow lands (about 14 %) and community lands occupy about 2.30 per cent area. Horticulture and forestry (Eucalyptus etc) occupy nearly 3 per cent area. About 30 per cent of the area are rocky hills or rock outcrops and is government owned. Large population of goats, sheep and other type of cattle are grazing extensively in the village common lands and rocky hills which is causing degradation of vegetation and soil. The natural regeneration of vegetation has become a casualty due this. The natural vegetation is sparse, comprising a few trees, shrubs and herbs. The major crops grown are *ragi*, pigeon pea, french bean, castor, mango, arecanut and coconut. Vegetables and banana plantations are present in patches where borewell irrigation facility is available.

Soils

Soils of the sub-watershed are moderately shallow to deep (50-150 cm). The colour is dark red to dark reddish brown. The texture is dominantly sandy clay. The slope is generally 1-10 per cent. These soils are developed from granites and gneisses. The major differentiating characteristics of four soil series identified in the watershed are depth, color, texture and horizon sequence (Table1). Taking into consideration the soil and site characteristics, 20 management units are identified (Table 2 & Fig.1).

Table 1 Series identification characteristics of Tirumale sub-watershed

Series	Depth (cm)	Color (moist)	Texture	Gravel (%)	Horizon sequence	Classification
Hebbalpalya (Hpl)	50-75	2.5YR3/4, 3/6 5YR4/4, 4/6, 5/6 7.5YR 4/4	sc-scl	10-20	Ap-Bt-Cr	Fine Typic Haplustalfs
Byadarahalli (Brh)	50-75	2.5YR 3/4, 3/6	sc-scl	10-25	Ap-Bt-Cr	Fine Rhodic Paleustalfs
Belagumba (Bgb)	75-100	2.5YR 3/4, 3/6	sc	0-20	Ap-Bt-Cr	Fine Rhodic Paleustalfs
Kallentepalya (Klp)	100-150	2.5YR 3/4, 3/6	c, sc	0-25	Ap-Bt-Cr	Fine Rhodic Paleustalfs

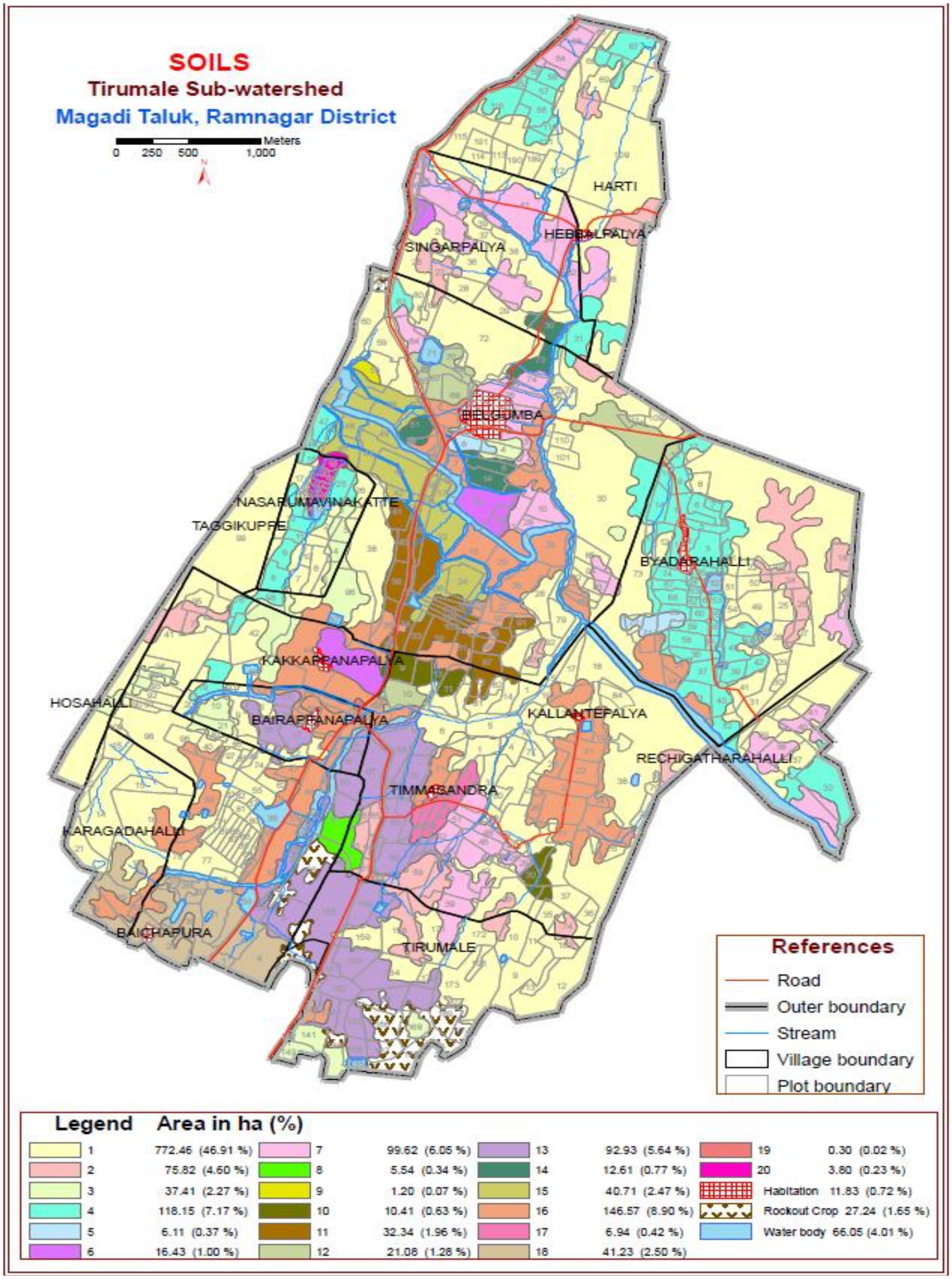


Figure 1 Soils of Tirumale sub-watershed

Table 2 Soil legend –Tirumale sub watershed

Map unit	Description	Area (ha)	Area (%)
1	Mostly of rock outcrops with patches of shallow gravelly loam soil on highly denuded hills/ ridges with the spread of boulders and sparse scrub vegetation.	772.46	46.91
2	Shallow, gravelly sandy loam surface and gravelly red clay sub soils with 15 to 20 per cent gravel on side / foot slopes with moderate erosion.	75.82	4.60
3	Deep, loamy sand surface and red clay sub-soils on gently sloping summits and uplands, gravelly in few horizons, moderately eroded.	37.41	2.27
4	Moderately deep, loamy sand surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on very gently to gently sloping summits and uplands, moderately eroded.	118.15	7.17
5	Moderately shallow, loamy sand surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on very gently to gently sloping summits and uplands, moderately eroded.	6.11	0.37
6	Moderately shallow, loamy sand surface and red clay sub surface soils on very gently to gently sloping summits and uplands, moderately eroded.	16.43	1.00
7	Moderately deep, loamy sand surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on very gently to gently sloping uplands, moderately eroded.	99.62	6.05
8	Moderately shallow, loamy sand surface and red clay sub soils on gently sloping uplands, moderately eroded.	5.54	0.34
9	Moderately shallow, sandy loam surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on gently sloping uplands, moderately eroded	1.20	0.07
10	Moderately shallow, sandy loam surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on very gently to gently sloping uplands, moderately eroded.	10.41	0.63
11	Moderately deep, loamy sand surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on gently sloping uplands, moderately eroded.	32.34	1.96
12	Moderately shallow, loamy sand surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on gently sloping uplands, severely eroded.	21.08	1.28
13	Deep, sandy loam surface and red clay sub-soils on gently sloping uplands, gravelly in few horizons, moderately eroded.	92.93	5.64

14	Moderately deep, sandy loam surface and gravelly red clay sub-soils with 15 to 20 per cent gravel on very gently sloping uplands, moderately eroded	12.61	0.77
15	Moderately shallow, sandy clay loam surface and red clay sub-soils on gently sloping uplands, moderately eroded.	40.71	2.47
16	Deep, loamy sand surface and red clay sub-soils on very gently sloping uplands, gravelly in few horizons, moderately eroded.	146.57	8.90
17	Deep, loamy sand surface and red clay sub-soils on gently sloping uplands, gravelly in few horizons, moderately eroded.	6.94	0.42
18	Deep, sandy loam surface and red clay sub-soils on moderately sloping uplands, gravelly in few horizons, moderately eroded.	41.23	2.50
19	Deep, cracking clay surface and sub-soils on nearly level lowlands with slight erosion.	0.30	0.02
20	Deep, clay surface and sub soils on nearly level lowlands with slight erosion.	3.80	0.23
40	Habitation	11.83	0.72
41	Rock outcrops	27.24	1.65
42	Water bodies	66.05	4.01
TOTAL		1646.78	100.00

The data collected from the detailed land resources survey of the sub-watershed provides comprehensive information on land resources of the area. The effective utilization of the database depends on the extraction of relevant and required data by the concerned users to meet their specific needs. To help various land users and planners to make use of the database effectively, various user friendly interpretations were carried out for the study area.

Identification of prime farm lands

Prime farmland is one which has the best combination of physical and chemical characteristics for producing food, fodder, fibre, oilseeds, plantation and other crops (Plate 1). Prime farmland has the required soil quality, growing season, and moisture supply to produce high yields in a sustainable way when treated and managed according to the acceptable farming methods (eg water management). In general, prime farmlands have an adequate and dependable water supply from precipitation or irrigation, a favorable temperature and length of growing period, acceptable acidity, not prone to erosion or saturated with water for a long period of time and either do not flood frequently or are protected from flooding. In the watershed area, the lands falling within the capability class II can be easily categorized as prime farm lands as they contribute significantly to the food and economic security of the area. In the present study, nearly 15 per cent lands are prime farm lands and the remaining 85 per cent land is available for other uses including industry and recreation etc.

Land Capability

The soil phases mapped in the watershed were grouped into three land capability classes. Class III lands occupy about 25 per cent of the area. In the uplands, the class III lands have soil depth and erosion as major limitation. Moderately good agricultural lands (Class II) with the limitations of erosion and other soil related issues occupied 17.5 per cent area and occur mostly in the valleys all along the streams.

Slope

Moderately sloping lands (D) (5-10%) occupy the major part of the watershed area (54%). The cultivable area available is minimum under this class as rock outcrops and denuded hills and hill slopes are the major land forms noticed under this class. The very gently sloping lands (1-3%) occupied the next largest area (23%). These lands are occurring mostly along the streams. Another major slope class noticed is gently sloping lands (3-5%) occurring in 16 per cent area and are found near streams.

Soil depth

Within the cultivated fields, deep soils (100-150 cm) occurred in major part (20% area) particularly along the streams and gently sloping lands. Moderately deep (75-100 cm) soils occur in about 16 per cent area which formed the next major group. Such soils are noticed mostly in the gently sloping uplands. Shallow and very shallow lands are noticed in about 10 per cent area either very near to water canal/streams or hill tops. Near the streams, these soils are noticed due to severe cutting and filling for levelling and making bunds to facilitate paddy cultivation.

Surface soil texture

Loamy sand and sandy loam are the dominant surface soil textural classes found in the watershed. Together, they occupy 43 per cent of the area. These soils are found mostly on gently sloping uplands and low lands. Sandy clay loam and clay occupy minor area mostly along the streams.

Soil erosion

Moderate erosion is the dominant erosion class observed in nearly 39 per cent of the area in the watershed. It is noticed in all types of land forms. Sheet erosion is a serious problem in the very gently to gently sloping uplands. Rill erosion is observed in some areas. Neglect of rills has led to the development of gullies, mostly seen in the lower part of the uplands. Soil erosion that has taken place due to unscientific cutting and filling of soils is one of the major constraints for crop production in the area. It affects soil management in a significant way and is used to divide the series into different phases.

Available water capacity

Deep soils all along the streams in the valleys showed medium available water capacity and such lands occupied nearly 20 per of the watershed area. Lands with lower available water capacity were noticed in uplands and gently sloping lands. They occupied nearly 27 per cent area in the study area.

Land suitability

Land or soil-site suitability evaluation was carried out for all the major crops like *ragi*, redgram, castor, arecanut, coconut, banana, mango etc (Naidu *et al*. 2006). A map of land suitability for mango is presented here (Figure 3).

Soil fertility

Fertility evaluation was carried out for all the major nutrients and few important micronutrients for the surface soil samples. In the entire study area, available nitrogen status is low. Available phosphorus content is high in 37 per cent area and in 57 per cent it is medium. In 52 per cent of the area, available potassium is low and in 41 per cent it is medium. Available iron, manganese, copper and zinc are available in sufficient quantities in all the cultivated fields except for zinc which is low in few fields in Hebbalapalya and Harthi villages. The surface soils of the entire study area are low in boron (Fig.4). Available sulphur is deficient in 38 per cent of the study area and in 20 per cent it is more than the essential level. In 36 per cent area, its availability is optimum.

Plate1. Well Terraced prime farm land in the watershed

Problems and Potentials

Major constraints

1. Considerable area is covered with rock outcrops and marginal lands are widespread. Marginal lands are facing degradation problems due to erosion and overgrazing. These lands are not bunded systematically as they are surrounded by rocks in most places. Overgrazing, particularly by sheep and goats in these areas is rampant which is not allowing natural regeneration of vegetation thus exposing the soils for further degradation. In the long run, this becomes the cause for poor performance of these animals in terms of growth and disease resistance. This has got cyclic adverse effect on the income of the farmers and they need to be made aware of the problem. Regeneration of forestry and horticultural crops becomes very difficult unless stall feeding is adopted for these animals.

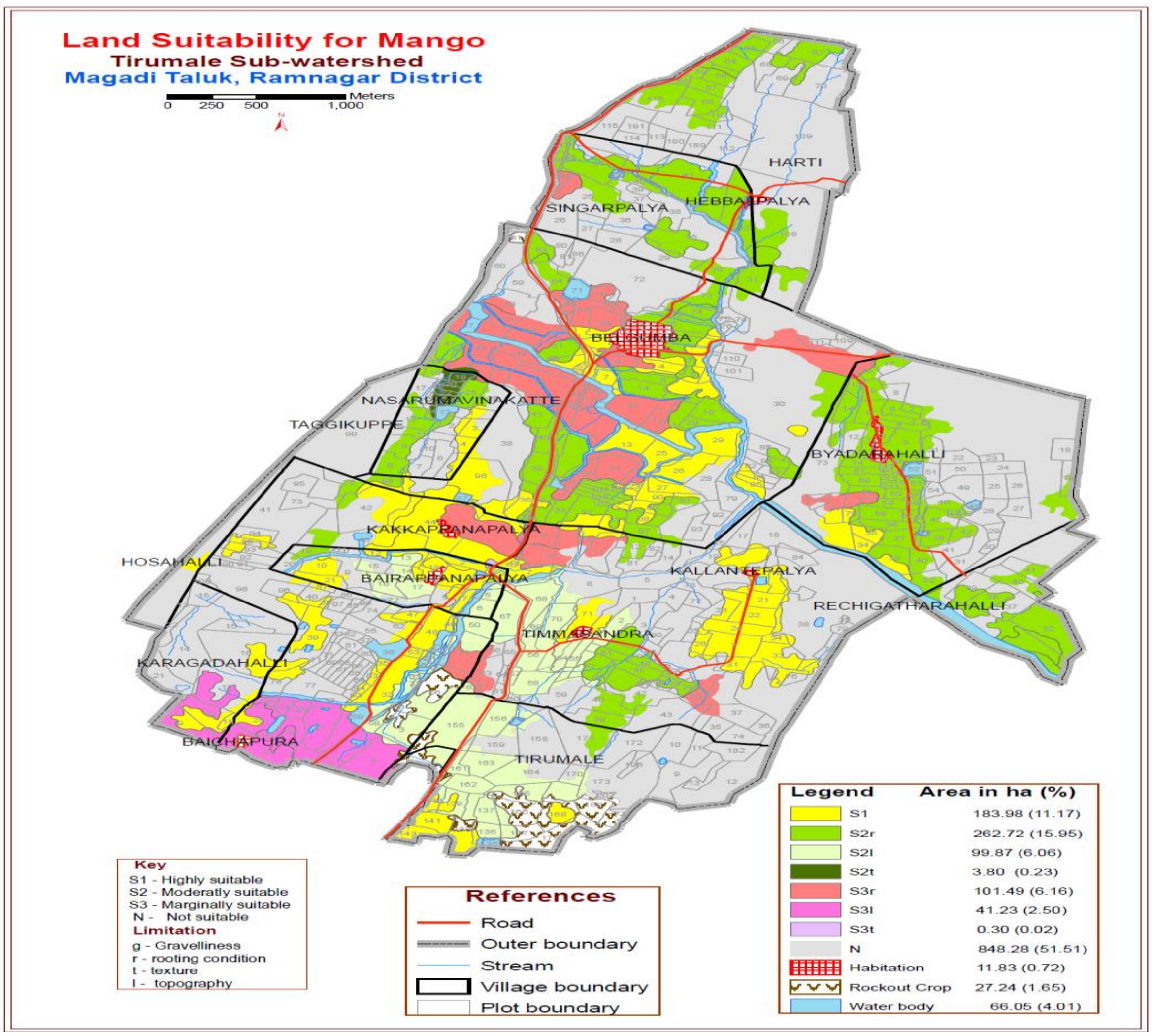


Figure 3 Land suitability for Mango

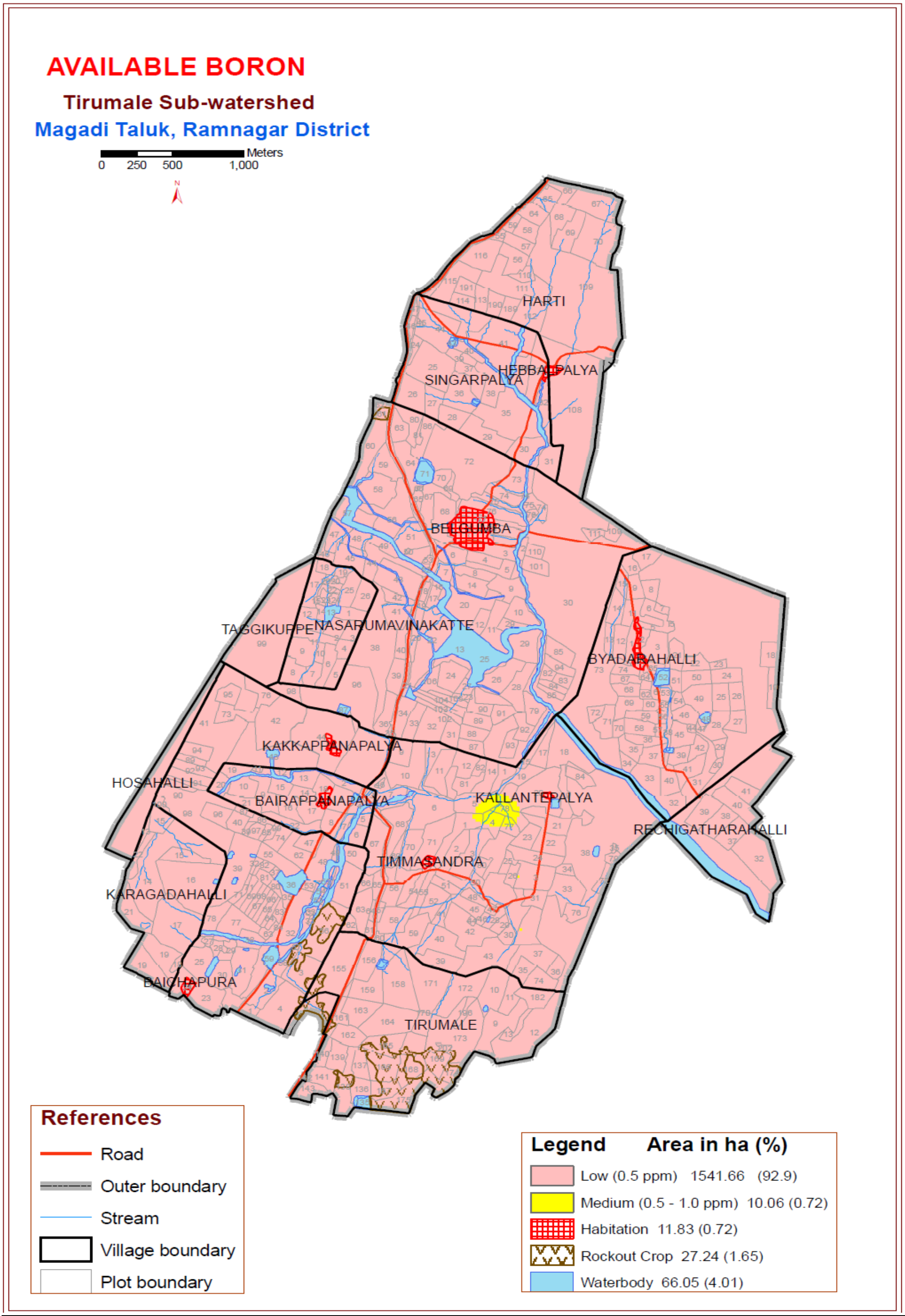


Figure 4 Available Boron content in the sub-watershed

2. Area receives an average rainfall of about 996 mm. Hence, in most of the areas one rainfed crop mixed with two or more crops are raised. Lowest rainfall recorded was 575 mm during 1990. During the years of deficit rainfall, farmers experience economic stress unless they have diversified enterprises to tide over the situation. Ground water level is going down below 200 meters and efforts/awareness for rain water harvesting and ground water recharging are not at all noticed. Farmers express that "water is the main limiting factor" in achieving higher productivity/diversification of enterprises. They tell that if water is made available, then they can create another green revolution". However, there is complete lack of awareness about the economic use of water as well as harvesting of rainwater. Digging of deep borewells is very rampant and awareness in adoption of water efficient irrigation technologies and tools like micro-irrigation are not at all adopted in the study area. Large number of borewells has failed.

3. While bunding the cultivated areas, large quantity of top soils are lost and in some areas weathered parent material is exposed which is very poor in fertility and quality.

4. Labour scarcity has become a serious limiting factor in adopting essential package of practices in the region. Due to shortage of labour, farmers are employing heavy machinery like JCB for opening the pits to plant perennial crops like arecanut, banana etc. While doing so, the weathered parent material is exposed and young saplings are virtually planted in weathered parent material which is very poor in fertility. Thus, the young saplings suffer during initial growth period leading to overall poor performance of the crops.

5. Goat and sheep rearing is a most common enterprise in the region which provides a good source of income. But they are allowed to graze in the village common lands and these lands are facing the threat of severe degradation of soil and vegetation due to overgrazing. Natural regeneration of vegetation has become a casualty.

6. Green energy technology "Bio-gas" is totally missing, even though adequate cattle population is there in all the villages.

Potentials and opportunities

1. Most of the cultivated fields are already bunded. There is a need for strengthening the structures wherever they are found weak and damaged to minimize the soil erosion. In this area dominated by red soil with lighter surface soil texture, infiltration rate of rainwater is rapid and run-off losses are minimum. If the conservation structures in the hillocks and summits are foolproof, there will be only a minimum run-off. Under such circumstances, the need for bigger soil and water conservation structures like check dams becomes minimum. Safety of such structures shall also be better as there will be minimum runoff.

2. Rainfed cropping system consisting of *ragi*, pigeon pea, castor and field bean is very ideal for maintaining soil-health and utilizing nutrients from different depths of the soil profile. In most areas, the top soil layer consists of lighter soil texture (sandy loam and sandy clay loam) which allows easy infiltration of water into the soil profile. The sub-surface layers are of heavy texture which hold good quantity of soil moisture thus allowing good performance of rainfed crops.

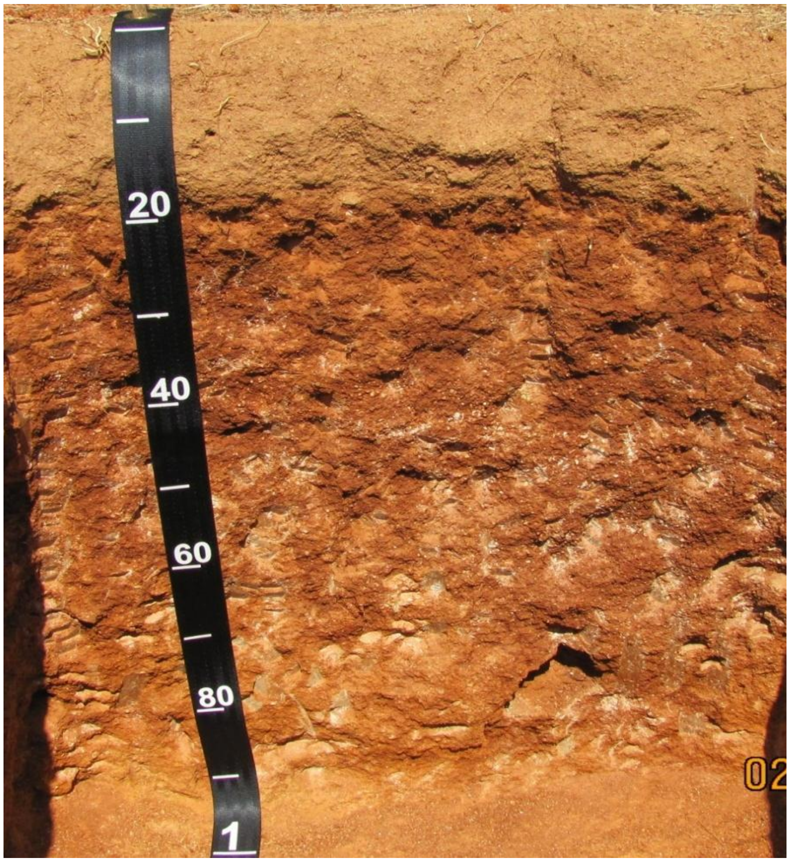


Plate 2 Soil Profile features of Bydrahalli series: lighter surface soil and heavy sub soil

3. Deep soils occur even below rocky surfaces in certain places allowing the good performance of tree crops like mango, jack fruit etc.

4. The soils of the watershed are free from soil alkalinity, acidity, drainage or erosion problems. Hence there is absolutely no need for costly ameliorative measures.

5. The average rainfall of the region is 996 mm. However, there are years when a rainfall higher than normal is received. During 1975, a very high rainfall of 1913 mm was received. During 2010 also more than 1500 mm rain was received. On an average during a period of 10 years, more than average rainfall is normally received in 5 years. During other years also there are heavy rain spells/unseasonal heavy downpours leading to runoff of water. If rainwater harvesting is practiced, then it becomes very easy to harvest and recharge the ground water.

Plate 3 Deep soils occur in between the rock outcrops: good scope for perennial horticulture crops

6. Nearness to Bangalore and suitable climate provides good scope for cultivation of high value fruit and vegetable crops.

7. Goat and sheep rearing is a most common enterprise and provides a good source of income. However, stall feeding needs to be promoted to prevent the degradation of soil and vegetation in village common lands.

8. Higher generation and higher consumption of energy is most essential for the economic progress. There is good scope for generation of low cost green energy “Bio-gas” in these villages. Studies have conclusively proved that “Bio-gas slurry” is most useful in generating good quality compost and thus useful in enhancing the soil fertility.

9. Farmers were approaching the soil survey personnel requesting them to collect the soil samples from their plots for fertility analysis. It gives a ray of hope for reviving the interest in better farming among the farmers.

Conclusions

The study conclusively proves that the detailed land resources database is most useful and essential in preparing a comprehensive development plan for any watershed. This can be effectively used for implementing the site specific land based development plans based on a scientific foundation. Such a database provides the basis for monitoring, reviewing and post project evaluation. The programs can be modified in the future as per the requirement of the site for which readymade date base is available. Thus, the resources can be conserved and improved with the help of detailed land resource database and save the public funds during the project implementation.

References

Karnataka State Remote Sensing Applications Centre (2005). Watershed Atlas of Karnataka Report. KSRSAC, Bangalore-34, p 137.

Natarajan, A. and Dipak Sarkar (2009). Field guide for soil survey, NBSS&LUP (ICAR), Nagpur-10, p 73.

Naidu, L.G.K., Ramamurthy, V., Challa, O., Rajendra Hegde and Krishnan, P.(2006). Manual soil-site suitability criteria for major crops, NBSS & LUP Publ. 129, p 118.

Rajendra Hegde, K.V. Niranjana, A. Natarajan, L.G.K. Naidu and Dipak Sarkar (2011). Land Resource Inventory for Tirumale Watershed, Magadi taluk, Ramanagara district, Karnataka for integrated development. NBSS&LUP Tech. Bull. p 113.

Soil Survey Division Staff (2000). Soil Survey Manual. United States Department of Agriculture Hand book No. 18, p 437.

Soil and Land Resource Information System – A Case study of Chikkakanya Village, Mysore Taluk and District

Prabhuraj, D.K., Jyothi, B.L., Harindranath, C.S., Shivaprasad, C.R. and Guruswamy, K.T.

Karnataka State Remote Sensing Applications Centre, Bangalore
E-mail: cs.hari.cs@gmail.com

Abstract

Land resource information at the village level has become essential under the present scenario of the farmers' agitation for not parting with the fertile agricultural land which is the back bone of food security. Soil is part of the land which is a non-renewable natural resource. Soil and land resource inventory using the Quick Bird satellite image and Geographical Information System at parcel level on 1:4000 scale has been generated for Chikkakanya village, Mysore district. The soils were mapped as phases of soil series. Six soil series were identified in the village. A total of 13 soil phases (management units) were mapped. The soils in any one map unit differ from place to place in their land and soil characteristics that affect management. The soil map has been used for identifying the suitability of land areas for specific agricultural / horticultural or other uses.

Chikkakanya village has about 81 per cent of the area (TGA) under deep soils which are suitable for growing long and short duration crops as well as perennial crops. About 10 per cent area has shallow soils. The village has four surface soil textural classes. About 64 per cent of the area has non-gravelly soils and 36 per cent gravelly soils. About 41 per cent of the area has very high available water capacity (25-30 cm/m), 16 per cent has moderately high AWC (15-20 cm/m), 10 per cent has moderately low AWC (5-10 cm/m) and one per cent of the area has high AWC (20-25 cm/m). Major area of the village has very gently sloping (1-3%) lands. 86 per cent area of the village has moderate erosion (e2) which require proper soil and water conservation measures. About 57 per cent of the area has soils that are mildly alkaline (pH 7.4-7.8), 23 per cent slightly acid (pH 6.1-6.5) and about 19 per cent neutral in reaction (pH 6.6-7.3). About 42 per cent of the area has high organic carbon content (> 0.75%), 35 per cent medium in organic carbon (0.5-0.75%) and 22 per cent has low organic carbon content (<0.5%).

All the lands in the village are suitable for agriculture and all are suitable for irrigation. About seven per cent of the area in the village has soils that are highly suitable (class S1) for growing *ragi*, with 86% moderately suitable (class S2) with moderate hazards of erosion, gravel and effective rooting depth and 10 per cent marginally suitable for growing *ragi* which have severe erosion hazard. The information generated can be used in land use policy decisions as this has scientific basis.

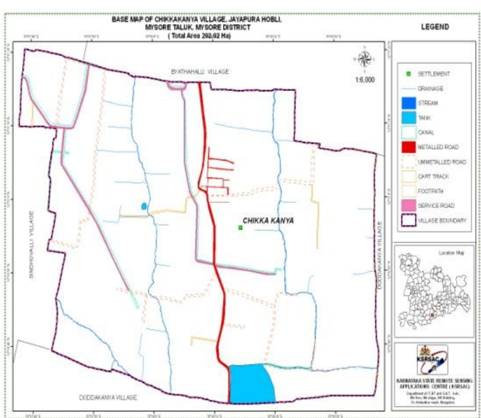
Introduction

For any agricultural planning and development, an inventory of natural resources is a pre-requisite. The land resources in Karnataka state are under severe strain due to various forms of degradation and competing demands of various land users. The challenge before us is not only to increase the productivity per unit area to meet the growing needs of the bourgeoning population, but also to reduce, if not to prevent the degradation of the basic natural resources like land, water and vegetation in the state. We are well aware that most of the problems exist at the field level which can be tackled only by formulating and adopting rational, site-specific and viable land-use options suitable for each and every parcel of land at village or watershed level. Any other macro-level planning will not have the desired effect in solving the problems faced by our farmers. To address the issues at farm or field level, we need a detailed site-specific data base covering each and every plot or parcel and survey number occurring in each village. From the site-specific data base, viable and sustainable land-use options suitable for each and every parcel of land can be formulated. Detailed natural resource information at larger scales (1:4000 to 1:15000) can only provide such basic information for optimal utilization of natural resources.

With this objective in view, a village (Chikkakanya village) in Jayapura hobli, Mysore taluk and district in the state of Karnataka has been selected to demonstrate the utility of data base generated at parcel level under Land Resources Information System (LRIS) project for Mysore district (KSRSAC, 2010).

Study area

Chikkakanya village (Fig. 1) is located in Jayapura hobli, Mysore district and is bounded by Byathahalli village in north, Sinduvalli village in west, Doddakanya village in south and east. It is situated between 12^{o} 10’ 33” to 12^{o} 11’ 21” N latitudes and 76^{o} 37’ 39” to 76^{o} 39’ 36” E longitudes. It has a geographical area of 202.02 ha. The climate is semiarid tropical.



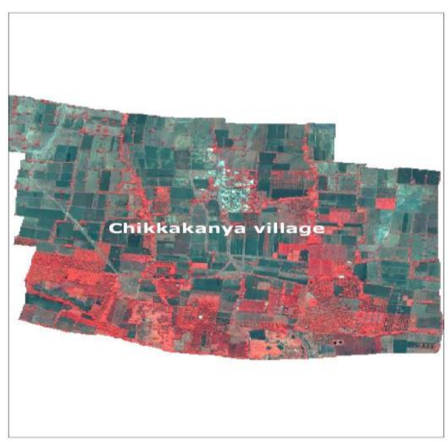


Figure 1 Base map Figure 2 Quick bird image

Methodology

Soil is a three-dimensional body that has depth, length and breadth, and as such cannot be seen or recognized on the surface. For proper characterization of soils, soil profiles (pits) are studied in detail for morphological, physical and chemical properties. The close relationship between physiography and soils has been well established based on the principle that the soils are the product of the same natural processes and factors that are responsible for the development of landforms. The methodology adopted for mapping soils in brief is as follows. On-screen Quick Bird satellite (61 cm resolution) image (Fig. 2) interpretation for physiography, checking and correction of the physiography map during ground truth, selection of soil profile sites based on physiography, study of soil profiles, collection of soil samples, identification of soil series and soil phases (management units), developing physiography soil relationship,laboratory analysis for physical and chemical properties, mapping the geographic distribution of phases of soil series. Refinement of image interpretation based on ground truth has been used for validation and for preparation of final soil map showing the phases of soil series as mapping units. The digital software used is Arc map.

Results and Discussion

Soils

The soils were mapped as phases of soil series. Six soil series were identified in the village. A total of 13 soil phases of soil series were mapped. The soil map can be used for identifying the suitability of land areas for specific agricultural / horticultural or other uses. The soils in any one map unit differ from place to place in their land and soil characteristics that affect management. The soil map is given in Figure 3.

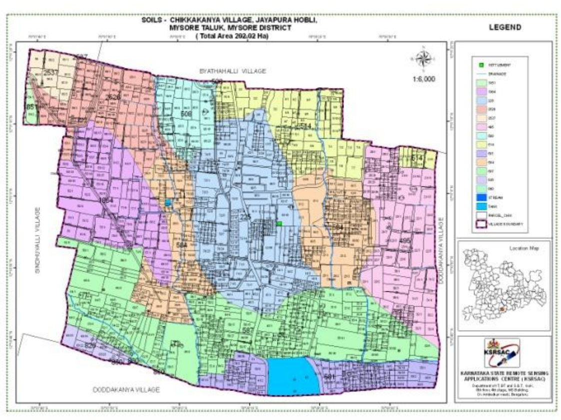


Figure 3 Soil map of Chikkakanaya village

Soil survey interpretations

The information on a soil map must be explained in a way that has meaning to the user. These explanations are called interpretations. Soil maps can be interpreted by the individual kinds of soil on the map and the grouping of soils that behave similarly to a given level of management and treatment (Klingebel and Montgomerry, 1966).

Land capability

Land-capability classification is an interpretative grouping of soils to show the capability of different soils to produce field crops or to be put to other alternative uses such as pasture, forestry, as habitat for wildlife, recreation etc on a sustained basis. It is based on inherent soil characteristics, external land features and other environmental factors that limit the use of the land (IARI 1970). Three Classes, five subclasses and five units have been identified (Table 1). Their distribution and extent are given in Fig.4. All the lands in the village are suitable for agriculture. About 65 per cent of the areas are having good cultivable lands (IIe and IIs) with hazards of erosion and soil fertility; they occur in northern, northeastern and southwestern parts of the village. About 25 per cent of the area has moderately good cultivable lands (IIIe and IIIs) with hazards of erosion and fertility; they occur in the central and northwestern parts of the village. About 10 per cent of the area has fairly good cultivable lands (IVe) with erosion hazard and occur in the western and northwestern parts of the village.

Land Irrigability

Land irrigability classification is primarily concerned with predicting the behaviour of soils under the greatly altered water regime brought about by introduction of irrigation. The soil mapping units of Chikkakanya village have been interpreted for land irrigability grouping. The land irrigability map is given in Figure 5. All the lands in the village are suitable for irrigation, of which about 52 per cent area has good irrigable land (2s) with soil hazards, gravel and texture; they occur in almost all parts of the village. About 48 per cent of the area has moderately good irrigable land (3s and 3st) with soil and topography hazards; they occur in the northern, eastern, central and western parts of the village.

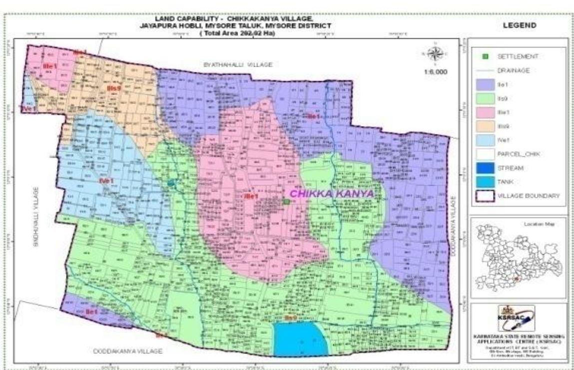


Figure 4 Land capability map of Chikkakanya Village

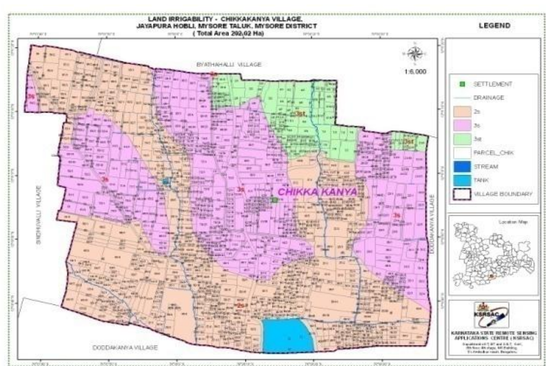


Figure 5 Land irrigability map of Chikkakanya village

Table 1 Soil legend-Chikkakanya village

Map unit/phase symbol	Soil series and phase description	Area (ha)
1851 MDHfB2g0ST0S0N0W0	Madihalli soils are shallow red loam on very gently sloping uplands (sandy clay loam surface, moderately eroded)	0.84
1864 MDHjB2g0ST0S0N0W0	Madihalli soils are shallow red loam on very gently sloping uplands (sandy clay surface, moderately eroded)	19.45
225 BLHfB2g1ST0S0N0W0	Ballaryhatti soils are moderately deep red gravelly clay on very gently sloping uplands (sandy clay loam surface, slightly gravelly, moderately eroded)	32.71
2526 SDVfB1g0ST0S0N0W0	Sindhuvalli soils are moderately deep red clay on very gently sloping uplands (sandy clay loam surface, slightly eroded)	15.03
2537 SDVjB2g0ST0S0N0W0	Sindhuvalli soils are moderately deep red clay on very gently sloping uplands (sandy clay surface, moderately eroded)	3.53
495 CKJbB2g1ST0S0N0W0	Chikkajataka soils are deep red gravelly clay on very gently sloping uplands (loamy sand surface, slightly gravelly, moderately eroded)	20.63
508 CKJcB2g0ST0S0N0W0	Chikkajataka soils are deep red gravelly clay on very gently sloping uplands (sandy loam surface, moderately eroded)	7.70
514 CKJcC2g2ST0S0N0W0	Chikkajataka soils are deep red gravelly clay on gently sloping uplands (sandy loam surface, moderately gravelly, moderately eroded)	16.40
581 CKYcA1g0ST0S0N0W0	Chikkakanya soils are deep alluvial clay on nearly level lowlands (sandy loam surface, slightly eroded)	13.37
584 CKYfB2g0ST0S0N0W0	Chikkakanya soils are deep alluvial clay on very gently sloping lowlands (sandy clay loam surface, moderately eroded)	26.06
587 CKYjB2g0ST0S0N0W0	Chikkakanya soils are deep alluvial clay on very gently sloping lowlands (sandy clay surface, moderately eroded)	44.16
826 GDKcB2g1ST0S0N0W0	Gowdanakoppalu soils are moderately deep red clay on very gently sloping uplands (sandy loam surface, slightly gravelly, moderately eroded)	2.24
860 GDKjB2g1ST0S0N0W0	Gowdanakoppalu soils are moderately deep red clay on very gently sloping uplands (sandy clay surface, slightly gravelly, moderately eroded)	0.05

Soil available water capacity

Available-water capacity (AWC) of soils is mainly dependent on soil texture, type of clay minerals, soil depth and content of coarse fragments. The AWC of soils of Chikkakanya village estimated from soil texture, depth, gravel and stone content and mineralogy (Sehgal, 1990) will help in determining the length of crop-growing period which helps in preparing rational land-use plans. The soils of Chikkakanya village were grouped into five AWC classes. The extent of area under each AWC class is given in Figure. 6. About 41 per cent of the area has very high available water capacity (25-30 cm/m) where long duration annual and perennial crops can be grown successfully; they are distributed in southern, west-central and east-central parts of the village.

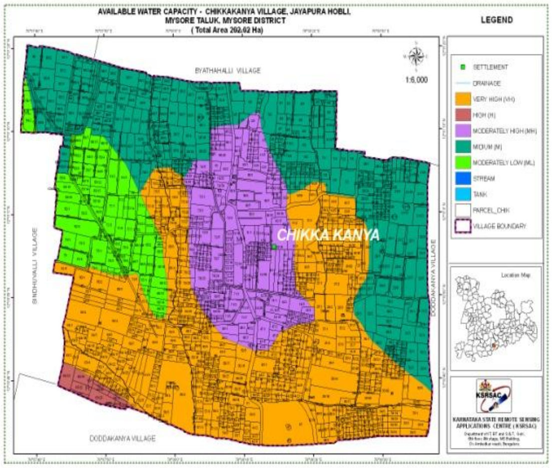


Figure 6 Available water capacity

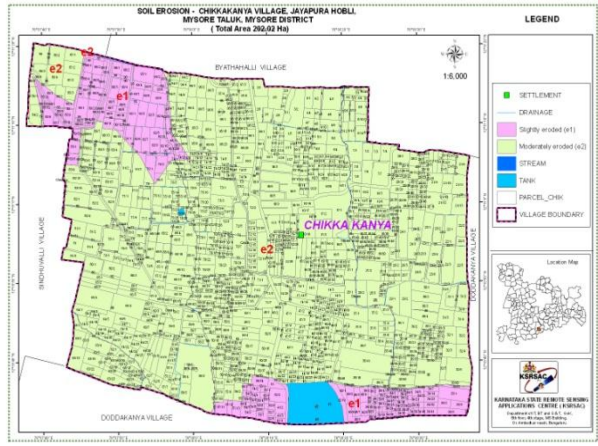


Figure 7 Soil erosion

About one per cent of the area has high AWC (20-25 cm/m) where long duration annual and perennial crops can be grown; they are distributed in southwestern portion. About 16 per cent has moderately high AWC (15-20 cm/m) where long duration annual crops can be grown; they occur in the central portion. An area of 31 per cent has medium AWC (10-15 cm/m) where short duration crops can be grown; they are distributed in the northern and eastern parts. About 10 per cent of the area has moderately low AWC (5-10 cm/m) where only short duration crops can be grown if rainfall is normal; they occur in western and north western parts of the village.

Soil erosion

Soil erosion refers to the wearing away of the earth's surface by the forces of water, wind and ice. It is aggravated by human intervention through indiscriminate felling of trees, overgrazing and cultivation on steep slopes and degraded lands. Based on the intensity of erosion observed visually in the soil profiles examined during field survey and mapping, and also the amount of soil removed (loss of A or B horizons), the soils of Chikkakanya village were classified under two erosion classes which are given in Figure 7. Major area of the village has moderate erosion (e2) that require proper soil and water conservation measures. About 14 per cent area has slight erosion (e1) and requires minimum soil and water conservation measures.

Soil fertility status

Surface soil samples from each survey number of the village were analyzed for macro nutrients (Figure 8) like available phosphorus (P_2O_5), available potash (K_2O) and micronutrients like Iron (Fe), Copper (Cu), Zinc (Zn) and Manganese (Mn). Maps were prepared using GIS software.

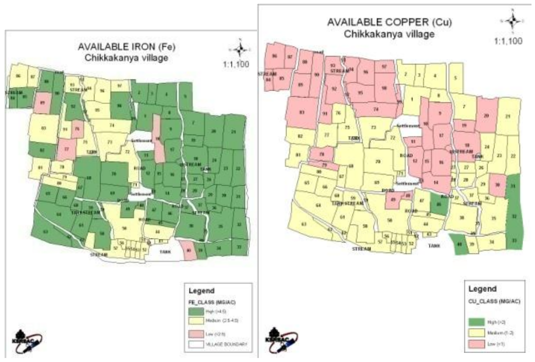


Figure 8 Fertility status (Micronutrients)

Based on the soil fertility data, recommendations to improve fertility status were given to the farmers for specific crops.

Conclusions

The above information about soils and their interpretations will be of help to the user departments like Agriculture, Horticulture, Watershed, Forest and Planning for including this for their developmental activities.

References

I.A.R.I. (1970). Soil Survey Manual, All India Soil and Land Use Survey Organization, I.A.R.I., New Delhi.

KSRSAC (2010). Land Resource Information System (LRIS), Mysore district, Karnataka. Project Report, Karnataka State Remote Sensing Application Centre, Bangalore.

Klingebel, A.A. and Montgomerry ,P.H.(1966). Land capability classification, Agri.HandBook 210, Soil Conservation Service,USDA,Washington, DC.

Sehgal, J.L. (1990). Soil Resource Mapping of Different States of India, Why and How? NBSS Publ.23, National Bureau of Soil Survey and Land Use Planning, Nagpur.

Soil Resource Information System for Karnataka State

Prabhuraj, D.K, Rajashekar, A.S., Jyothi, B.L., Shivaprasad, C.R., Harindranath, C.S. and Guruswamy K.T.

Karnataka State Remote Sensing Applications Centre, Bangalore
E-mail: cs.hari.cs@gmail.com

Abstract

Soil resource mapping of Karnataka State was carried out under the State Natural Resource Information System (SNRIS), a National project which is an integrated decision support system for planning and development at state / district level. IRS-1C LISS III False Colour Composites (FCC) on 1:50,000 scale were used for preparing soil maps. Visual interpretation techniques were adopted for image interpretation to delineate physiography. Physiography and soil relationships were established in the field and the soil map generated.

The soils were mapped at series level and associations of soil series formed the soil mapping units. A total of 757 soil series were identified and mapped as 1215 soil map units as association of soil series and 5 miscellaneous areas. The main soil types of Karnataka are red, laterite, black, alluvial, brown forest and coastal soils. The red soils cover nearly 37.3%, laterite soils about 6.6%, black soils around 27.77%, alluvial soils nearly 15.74% and brown forest soils cover 6% and coastal soils occupy approximately 3.9% of the total geographical area (TGA) of the State. The soils of Karnataka have been interpreted for land capability, land irrigability and hydrologic soil groups for various uses by identifying the limitations and potentials of soils. About 80 per cent of the area is suitable for agriculture and about 12 per cent is suitable for forestry and grass lands. About 65 per cent of the soils are suitable for irrigation and about 16 per cent is not suitable for irrigation. Database has been generated for the soil map of the State.

Introduction

The natural resources particularly soils have undergone significant changes in the last 100 years because of anthropogenic activities, Industrial revolution and two world wars. The technological development during this period and increase in population has lead to an increase in demand for natural resources and consequently to indiscriminate utilization of resources and environmental degradation such as deforestation, desertification, soil erosion, water logging, flood, drought etc. At present, therefore, the main issue is to maintain a balance between development and conservation of resources. This is best achieved when there is proper inventory of resources from time to time followed by suitable management practices for sustainable development. For inventory, planning and sustainable development of natural resources spatial and non-spatial data are required. With the availability of space technology, wherein systematic, synoptic, rapid and repetitive coverage over large areas is possible from its vantage point in space, it is possible to generate and update the Natural Resources Information System (NRIS) in a spatial format. Natural Resource Information System (ISRO, 2000) is a nation-wide network of spatial information system nodes interlinked with each other under a centre-state-district hierarchy. The spatial GIS based database is an integrated decision support system for planning and development at state / district level. Soil is an important constituent of the NRIS. The type and formation of soil depends on the influence of parent rock, climate, vegetation, physiography over a period of time and various soil forming processes. Soil resource mapping of Karnataka State was carried out under the State Natural Resource Information System (SNRIS) a National project which is an integrated decision support system for planning the use of soils.

Study area

The Karnataka State lies between latitudes 11° 31' 00" and 18° 45' 35" N and longitudes 74° 12' 00" and 78° 41' 00" E with an area of 19.2 million hectares. The state has 30 districts and 176 taluks. The major physiographic divisions of Karnataka State are the Deccan plateau, the hill ranges and the coastal plain and further sub divided into four regions *viz.*, a) South Deccan Plateau, b) Western Ghats, c) Eastern Ghats and d) West Coastal Plains. The important geological formations of the State are Archaean group, Proterozoic, Mesozoic and Cainozoic rocks. The Archaean or Peninsular Gneiss are the oldest formations and the rocks are gneisses, granites and charnockites. The Dharwar schist belt of the Proterozoic comprises ferruginous quartzite, pyroxenite, gabbro, serpentinite, phyllite, chlorite schist, limestone, dolomite, manganese and iron ores and metabasalt. Kaladgi and Bhima formations consist of sandstone, shale, limestone and dolomite. Deccan traps of Mesozoic have basalt. Laterites are Cainozoic. Recent alluvial deposits are found in river and stream valleys, and in coastal areas. In the South Deccan Plateau parent material has played a major role in the soil formation.

The state has very moist climate on the West-Coast, sub humid climate in the Malnad regions and warm (semiarid) climate in the plateau region. Summer (March to May), South-West monsoon (June to September), North-East monsoon (October to December) and winter (January - February) are the four seasons of the state. The spatial variation in the occurrence of rainfall in the state is highly variable from the western region (malnad and coastal plain) to the maidan region.

Land use in Karnataka is governed by topography, climate, soils and food habits of the people. About 54 per cent of the area of state is under cultivation of which 13 per cent area is irrigated. About 16 per cent area is under forests. The remaining 30 per cent is either left barren or unculturable/culturable waste.

Methodology

Soil resource mapping of Karnataka was carried out following a three tier approach *i.e.* Image interpretation for physiographic delineation, field survey and laboratory investigation and digital Cartography using Geographical Information System. Geocoded IRS-1C LISS III False Colour Composites (FCC) on 1:50,000 scale acquired during September - October 2000, November - December 2000 and March - April 2001 (317 scenes) were used in conjunction with Survey of India topographic maps of 1:50,000 scale as base maps. Image elements such as colour, tone, texture and pattern were employed in visual interpretation of the imagery to delineate, major physiographic regions like the 1. Karnataka plateau, 2. Ghats and 3. Coast. These regions were further subdivided based on image characteristics. Several transects were selected in such a way that they covered most of the physiographic units. At least three soil profiles were studied in each unit, following the guidelines given in Soil Survey Manual (IARI, 1971) and depth classes were adopted from field manual (Sehgal *et al.* 1987). Field reviews were conducted to confirm the soil physiography relationship, to check soil classification and soil correlation in the field. The soils were mapped at series level and associations of soil series formed the soil mapping units. A total of 757 soil series has been finalized after correlation using the series diagnostic characteristics. There were 1215 soil map units as association of soil series and 5 miscellaneous areas. Each soil map unit includes about 15 per cent of other soils as inclusions or impurities. Soil samples for each soil series, represented by typifying pedon were collected for laboratory characterization. The soils were analyzed for particle-size, organic carbon, pH, electrical conductivity, calcium carbonate, exchangeable bases, and cation exchange capacity (Sharma *et al*. 1987). Per cent base saturation and exchangeable sodium percentage were calculated. Under the Natural Resources Information System (NRIS) Node Design and Standards, the Soil Look Up Table (SOIL.LUT) has been prepared. This includes the 18 digit coding starting from two digits each for Order, Sub order, Great group, Sub group, Family texture, Family mineralogy, Family temperature regime and four digits for the series. The soil classification adopted as per the 8th Edition of the Soil taxonomy, USDA (1998). The codes are also adopted as per the new system. Further the Soil Data (SOIL.DAT) has been prepared with few modifications.

Results and discussion

The soil series were placed under the traditional soil groups such as red, laterite, black, alluvial, brown and coastal soils.

Red Soils

The red soils are shallow to deep, well drained to excessively drained and gravelly or non-gravelly and are characterized by the accumulation of clay. The surface texture ranges from loamy sand to sandy clay loam and sub soil texture from sandy clay loam to sandy clay and clay.

The red soils cover nearly 37.3% of the total geographical area of the State and are distributed in all the districts except Bidar.

Laterite Soils

Laterite Soil covers an area of about 6.6% of the total geographical area of the State. Lateritic soils of Bangalore, Kolar are sheet laterites on gneisses. Bidar and Gulbarga are associated with plateau basalt. These laterites are presently under disintegration. The Laterite Soils of Malnad in Belgaum, Hassan, Chikmagalur, Uttara Kannada, Udupi, Dakshina Kannada and Kodagu districts have developed under humid climate. They occur at the foothills of Western Ghats on Gneisses, Schists and Phyllites.

Black Soils

Black Soils occupy around 27.8% of total geographical area of the State. They occur on plateau summits, slopes and valleys developed from basalt in northern Karnataka. They are also known as swell-shrink soils as they swell and shrink due to alternate wetting and drying processes. The infiltration rate and hydraulic conductivity of black soils are very low. Based on soil depth, soils are grouped as shallow, medium and deep black soils.

Alluvial Soils

Alluvial Soils are present in the Western Ghats and Deccan plateau area which are transported from higher elevated areas by water and deposited in valleys and low lands. These soils occupy nearly 15.7% of the total geographical area of the State. Majority of the area is under irrigation in the plateau region and is under rain-fed cultivation in Malnad and Western Ghats. The alluvial soils are generally very deep, moderately well drained to imperfectly drained and well drained. They have textures of loam to clay loam, clay and cracking clay and stratified with coarse and fine textures.

Brown Forest Soils

Brown Forest Soils occur mainly in the Western Ghats under forests, in humid and sub-humid climates. They cover 6% of the total geographical area and have developed on granites, gneisses and schists. They are deep to moderately deep, well drained to excessively drained and have sandy clay to clay, sandy loam surface soils and clay to sandy clay sub soil.

Coastal Soils

Coastal soil occurs in the West Coast of Karnataka between the Western Ghats and Arabian Sea. They occupy approximately 3.9% of the total geographical area of the State. They are of two types *viz.*, a) coastal laterite soils and b) coastal alluvial soils.

The soils of Karnataka have been interpreted for land capability, land irrigability and hydrologic soil groups for various uses by understanding the limitations of soil.

For brevity sake Bellary taluk, Bellary district is extracted from the main state map. The same has been presented as soil map with legend (fig 1) along with interpretative maps like land capability (fig. 2).

Conclusions

Soil survey interpretations form a very important part of the soil survey and mapping programme, since they help to generate several thematic maps for different user agencies. The soil resource maps provide basic information on physiography, soil, their geographic distribution, characteristics, classification, problems and potentials. These data are useful to farmers, extension workers, planners, administrators and decision makers at district or taluk level. Land users and land-use planners need, in addition to basic soil data, information on the capacity of the soils for sustained agricultural production which calls for evaluation of soils data for generating various interpretative maps such as those of land capability and land irrigability, soil depth, soil reaction, soil organic carbon and soil available water capacity. Such interpretations have been used for developing optimum land-use plan for Karnataka State.

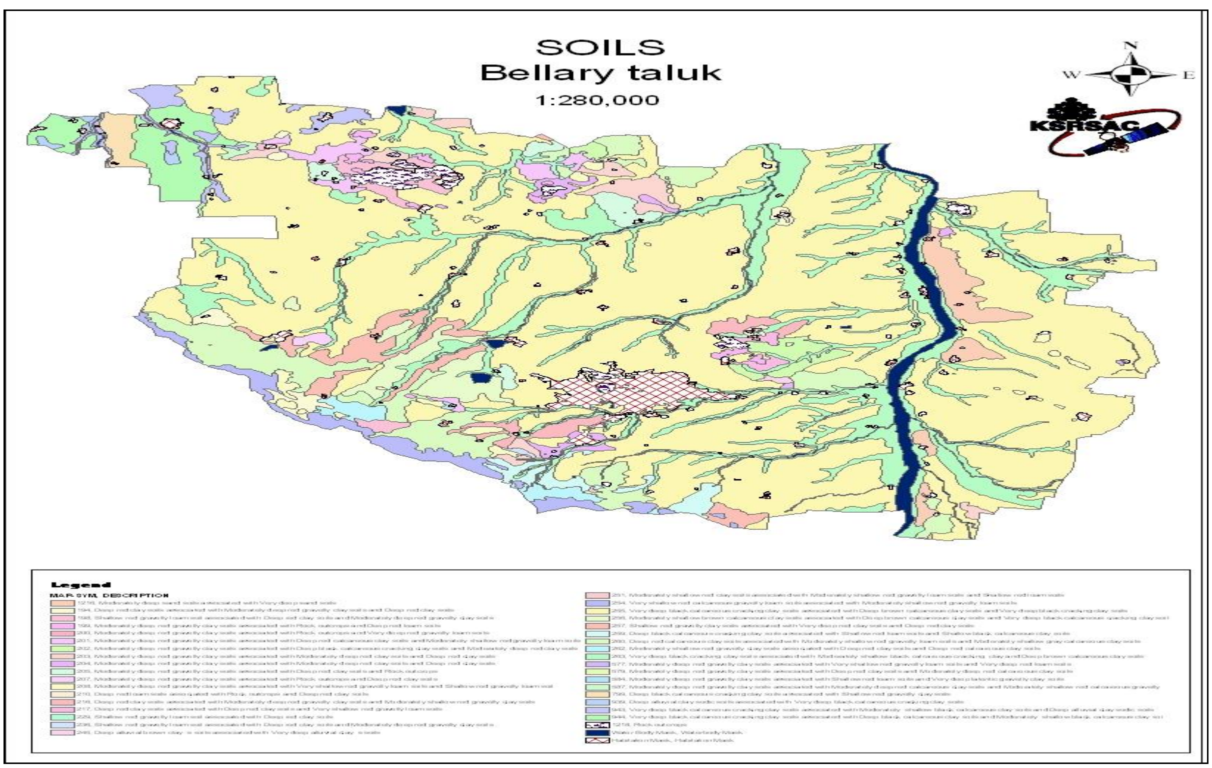


Figure 1 Soils – Bellary taluk

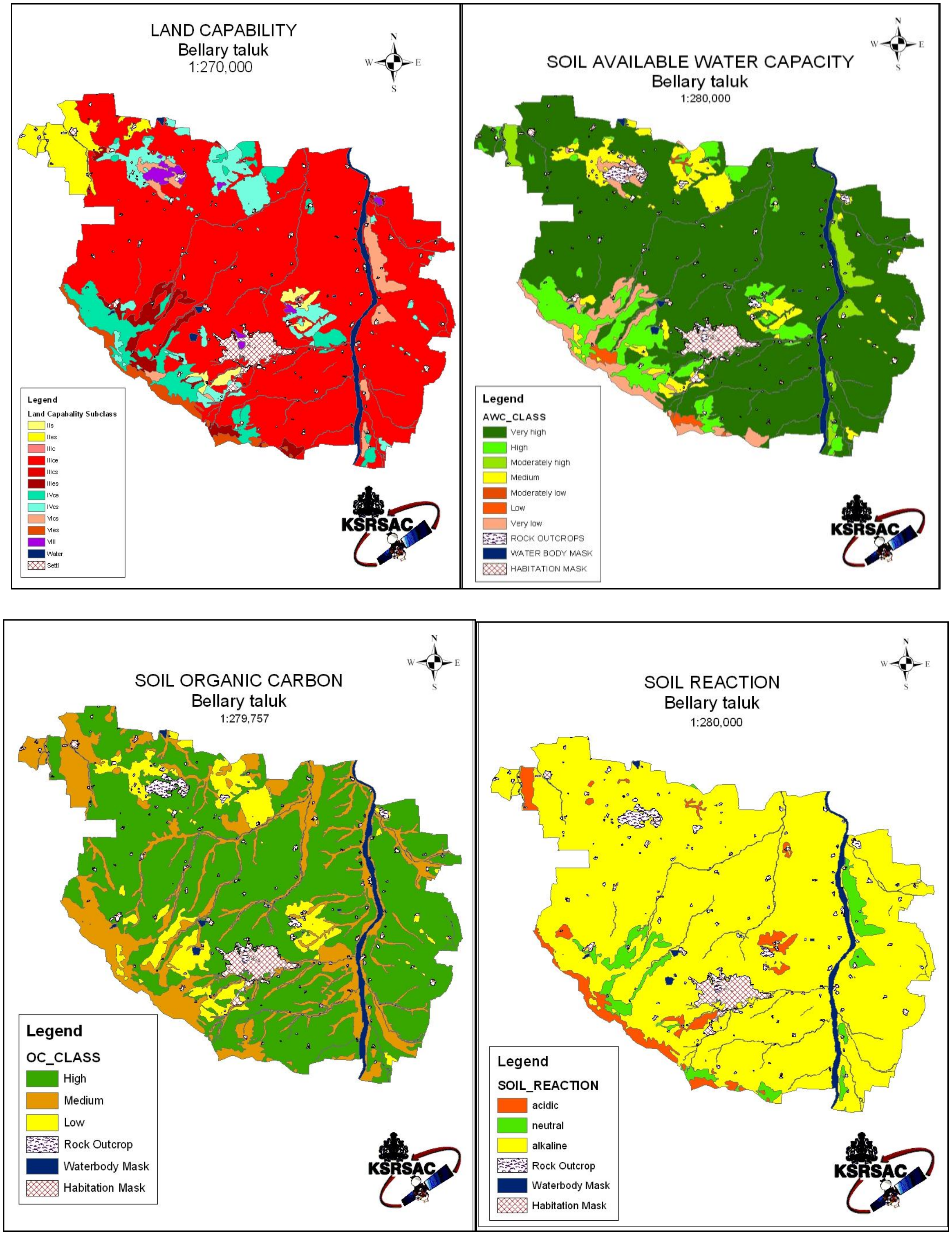
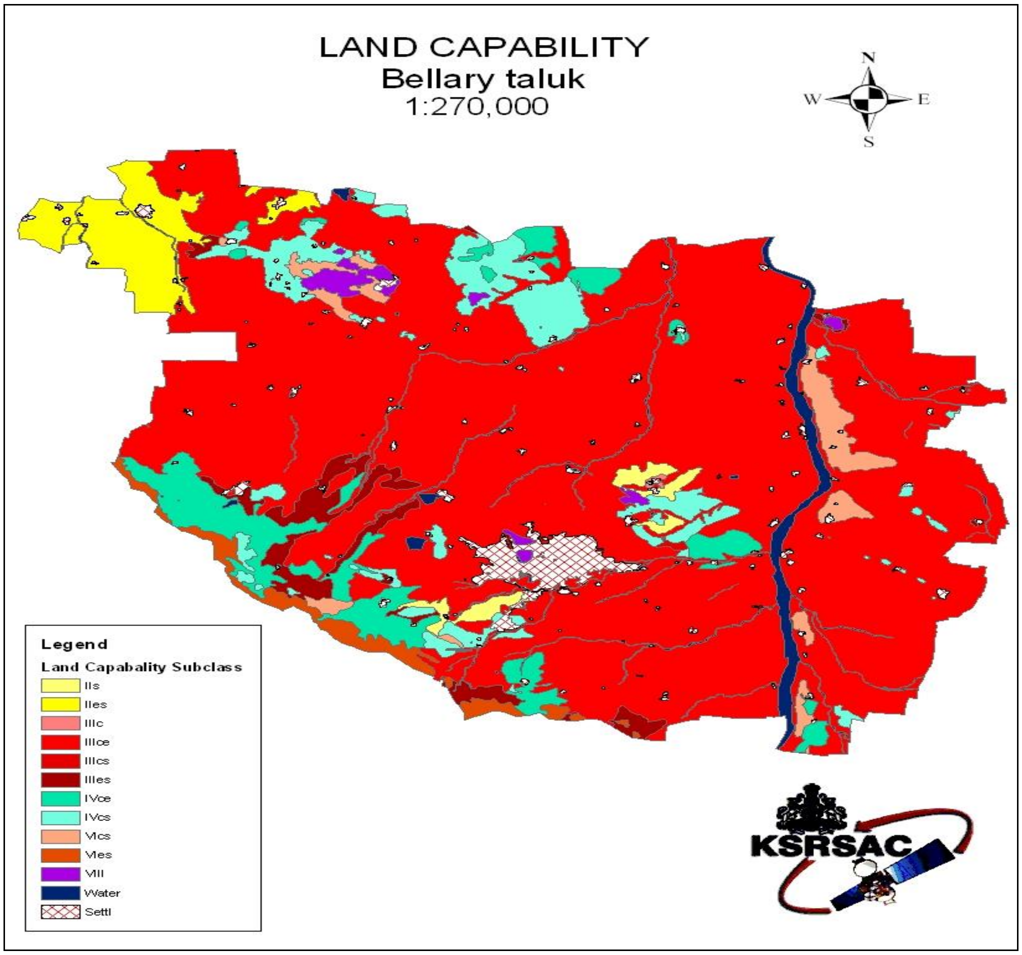


Figure 2 Interpreted maps, Bellary taluk



References

I.A.R.I. (1971). Soil Survey Manual, All India Soil and Land Use Survey Organization, I.A.R.I., New Delhi.

ISRO, (2000). Natural Resource Information System, NRIS standards, Space Application Centre, Ahmedabad.

Sarma.V.A.K, Krishnan.P and Budhihal.S.L., (1987). Laboratory Manual. Tech. Bull. 14 NBSS Publ. Nagpu, India.

Sehgal, J.L.,Saxena, R.K., & Vadivelu, S. (1987). Field Manual, National Bureau of Soil Survey and Land Use Planning, Nagpur.

Soil and Terrain Information System for Resource Planning of the Indo-Gangetic Plains, India

P. Chandran[1], C. Mandal[1], T. Bhattacharyya[1], D. Sarkar[1], D.K. Pal[1], S.K. Ray[1], Jagdish Prasad[1], P. Tiwary[1], R. Srivastava[1], M. Lokhande[1], K. Wadhai[1], V. Dongre[1] and J.A. Dijkshoorn[2], N.H. Batjes[2] and P.S. Brindaban[2]

[1]National Bureau of Soil Survey and Land Use Planning (ICAR), Amravati Road, Nagpur 440 033, Maharashtra, India
[2]International Soil Resource and International Centre (ISRIC), Wageningen, The Netherlands
E-mail: pchandran1960@yahoo.co.in

Abstract

Soil information system of IGP has been developed in Global Soil and Terrain Digital database (SOTER) in a GIS framework. It deals with two types of information, *viz*. geographic and attribute database. The soil and terrain information are geometric components which include topology of SOTER-Unit and its attribute data indicates the non-spatial SOTER-Unit characteristics stored in Relational Database Management System (RDBMS) files. The geographic information for SOTER-IGP was carved out from 1:1 m soil map of India. About 400 georeferenced soil series information was used to develop a robust attribute database. The SOTER unit is progressively made by developing information on terrain (physiography and lithology), terrain component and soil component. Morphological, physical and chemical properties of horizons of each profile are stored in the database and are linked with the map to develop different theme map. Apart from soil database climatic, land use and other ancillary data are also stored. The system permits updation of database. The SOTER database is expected to expand knowledge in the field of soil carbon, soil degradation, land evaluation, soil quality monitoring, soil input data for different models and environmental studies. It is also expected to meet the demand of spatially referenced soil information system for use by policy makers, researchers, modellers and farmers.

Introduction

Land use is governed by the process of Society – Nature interaction and in land use planning different component such as soil, water, climate, biota and environment play significant role in the survival of life particularly of human in nature. Soil is considered as one of the important components of land use planning as it is both a source as well as sink for energy. A wide range of information on soils is available in scattered and unorganized format but the modern day information system of any natural resources requires its location in terms of time and space and exact referencing or geo-referencing of important spots has become very necessary. Therefore, soil information with exact co-ordinates can be used for developing such systems. A geographic information system (GIS) has been an important tool for geo-referencing soil information system (GeoSIS).

The Indo-Gangetic Plains (IGP) produces nearly 50 per cent of the total food grains of the country. Recently there are reports of decline in fertility and productivity of the soils due to changes in some soil properties. Though the information on soils is huge but is scattered and therefore requires to be archived in a standard format to provide georeferenced information in spatial and digital domain for researchers, policy makers and other managers and users of natural resources.

The NBSS&LUP (ICAR) has prepared soil resource maps at different scales at country, state and district level. The available soil map information is not utilised to its optimum due to lack of digitized soil information system compatible with the users. Therefore, it is necessary to collate all the available geo-referenced information in systematic order through SIS, which can be retrieved, monitored, modified and used for different purposes. In the project on “Geo-referenced soil information system for land use planning and monitoring soil and land quality for agriculture” NAIP (Comp-4), under progress at NBSS &LUP, the development of soil information system is included as one of the major activities.

Methodology for Development of SIS in SOTER

Global and National Soils and Terrain Digital Database (SOTER) framework developed at ISRIC (The Netherlands) in collaboration with other international organisations is used to create and maintain the digitized map units and their attributes which can provide necessary data for improved mapping and monitoring of changes in soil and terrain resources. The approach resembles physiographic and land system mapping and the collated information is stored in the SOTER framework which is linked to GIS permitting a wide range of application (Batjes and Dijkshoorn, 1999; Falloon *et al*. 1998). The database also allows periodic updating and removing obsolete and/or irrelevant data. The database can also be used as a baseline information for a variety of users of natural resources.

In SOTER, two types of information are present *viz*. geographic and attribute database. Soil and terrain information are geographic components indicating the topology of SOTER unit and attribute data indicates spatial unit characteristics stored in a set of RDBMS files. In SOTER, areas of land with a distinctive often repetitive pattern of landform, lithology, slope, parent material and soils were identified as SOTER unit and this has an unique combination of terrain and soil characteristics. A SOTER unit is made by developing information on terrain, terrain component and soil component. The database can also store climatic data, source of databases, land use and other auxillary data which are useful for many users of land. Basic data required for the construction of SOTER unit are topographic, geomorphological, geological and soil map on

1:1 m scale as layers. According to SOTER, a soil map accompanied by sufficient analytical data for soil characterization can be used for mapping (van Engelen and Wan, 1995).

Development of SOTER IGP

Database of IGP

The IGP is situated between Gurudaspur (Punjab) in the west to Jalpaiguri (West Bengal) in the east and is extending to Morigaon (Tripura) in the north-east and covers an area of 52.1 m ha (Mandal *et al*. 2010). Earlier, the NBSS&LUP has developed a soil map of India on 1:1 m scale (NBSS&LUP, 2002) with distinct map units taking into consideration pattern of landforms, lithology, surface form and parent material and soils were identified. The map units are soil associations at great group level (Soil Survey Staff, 1999) with description of dominant textural class, drainage class and soil characteristics. Soil map of IGP were carved out from the 1:1 m map and is used as a geographic database (Fig. 1) for developing SOTER-IGP (Mandal *et al*. 2010). This soil map was digitized using Arc View 9.3 version with the following layer boundaries (district, state and international), drainage, agro-ecoregion and subregion and soils. The IGP is subdivided into 8 agro-ecoregions and 17 agro-eco-subregions depending upon major physiography, climate and length of growing period (Velayutham *et al*., 1999; Bhattacharyya *et al*., 2004).

<Fig. 1>

In SOTER-IGP, physiography and lithology are the criteria used to differentiate terrain. The IGP has a nearly level physiography and the parent material is alluvium brought down by the river Ganga and its tributaries. Therefore, each soil map unit is considered as separate terrain. Thus, each map unit of IGP is given a number which is the terrain number of SOTER-IGP.

SOTER-IGP has 716 map units showing associations comprising dominant and subdominant soil series. Since SOTER is a global database, the dominant soils occurring in the terrain is considered as major soils of the terrain and wherever possible some subdominant soils are also included. A total of 416 soil series are identified for SOTER-IGP (Ray et al. 2011; Chandran *et al*., 2005) for linking with the map. The number of soil series identified in each state for consideration of SOTER-IGP and its source is given in Table 1.

<Table 1>

The series information has been collected from different sources mostly from the information generated during the soil resource mapping programme and published by NBSS&LUP. However, some information from other reliable sources was also included. Therefore, authenticity and reliability of the information is assured. The information has been checked and corrections/deletions were done wherever necessary. Information on some of the laboratory parameters like bulk density and saturated hydraulic conductivity were not available in most of the soil survey reports. Therefore, pedotransfer function (PTF) was developed for generating this information (Tiwary *et al*., 2011) and validated for IGP region.

Development of SOTER-IGP database development

Under the SOTER system of labeling, SOTER units are given unique identification code (IN_1993: country code-Map unit No.). In the subsequent tables of terrain and soil components, the identification code is completed with sub codes for terrain and soil components. The attribute tables for terrain and terrain component are derived from site characteristics and other general landform features of each map unit. In SOTER database, soil component information is stored in three tables namely soil component table, profile table and horizon table. The soil component table holds the proportion of each soil component within a SOTER unit and terrain component has information of the terrain and the representative profile id. This table was prepared as per SOTER structure and the fields of database on soil classification, surface characteristics and soil depth.

<Table 2>

The profile table of the SOTER holds attribute data for the profile as a whole which includes exact location, laboratory detail and the horizon table and coded as per SOTER procedure manual (van Engelen and Wan, 1975). All the collated 416 geo-referenced soil series profile information were given profile id by coding.

<Table 3>

IN UP 26_206, IN represents country code, UP represents state code, 26 represents the profile number of that particular state and 206 represents the profile number of the whole IGP dataset. Horizon table of each profile holds data of each individual horizon. Since the datasets were compiled from different sources, the availability of all data required for this table is seldom possible. Therefore, in SOTER a minimum set of mandatory soil attributes are set for realistic interpretation and other data are considered as optional. An example of one profile and its horizon characteristic is represented in table 4.

<Table 4>

During the development of database, reference profile for each SOTER unit in the generic data base is selected from available series and the information were completed. The SOTER structure has a link with each table in the database using primary keys (Fig. 2). The primary keys helps in linking the tables of the attribute database with each other and help in entering the data of common field of each attribute table. In SOTER database, SUID (SOTER id) is the primary key and it is used to link with the maps. The linking was done on the basis of SUID and Terrain.

<Fig. 2>

Development of Theme Maps

Using the base map of the IGP and SOTER database, a number of thematic maps were generated. The soil reaction map of IGP indicates that about 15% of the area is acidic particularly in the lower IGP where rainfall is high (Fig. 3). These soils may need liming for growing crops sensitive to acidity or can be utilized for crops which can tolerate acidity. However, efforts should be made to arrest further acidification of these soils by better soil and crop management. The map shows 31% of the soils as neutral to slightly alkaline particularly in the middle part of the IGP. However, major part of the IGP (53%) is moderately to strongly alkaline. These soils are occurring in the upper part of the IGP wherein semi-arid climate and intensive agriculture are followed. These areas need special attention for reclamation programme.

<Fig. 3>

Soil bulk density

The bulk density (BD) of soils regulates hydraulic properties and root penetration depending on the texture, organic matter content and cultural practices (Bhattacharyya *et al.*, 2007). In rice and potato growing regions of West Bengal, an increase in bulk density in the subsurface soils just below the plough layer has been observed which has adversely affected the potato yield. This has been attributed to high mechanization under intensive agriculture. Therefore, the theme map for BD of surface soils (0-30 cm) of the IGP assumes a great importance. The study indicates that about 30% of the area in the IGP had favourable BD in the range up to 1.4. However, in 70% area, BD is more than 1.6 Mg m^{-3} which may increase further to form hard pans and to make the soils nonporous if the present management system of mechanized farming and use of water with high salt content is continued.

Soil Organic Carbon

Soil organic carbon status of the surface soils of the IGP indicates about 99% soils have organic carbon of less than 1% (Fig.4) which is considered as threshold value of sufficient level of organic carbon in the soils of tropical India (Velayutham *et al.* 2000). Therefore, IGP soils need immediate management intervention in 88% areas, wherein organic carbon is less than 0.5%. The climatic aridity in the major part of the IGP along with intensive agriculture with low organic input may be the reason for their low organic carbon. However, it was reported that there is an increasing trend of SOC stock in the IGP after an initial decline (Bhattacharyya *et al*. 2004, 2007). Pal *et al*. (2000) reported that soils of the arid and semi-arid climate occupying more than one-third area of the IGP are poor in organic carbon content and are thus prone to be calcareous and sodic. Proper rehabilitation programme can make these sodic soils resilient and thus improve soil quality through carbon sequestration (Gupta and Rao, 1994; Bhattacharyya *et al*. 2004; Pal *et al*. 2006).

Conclusions

The SOTER database is being compiled from soil information collated from different sources mostly from district soil survey (1:50,000 scale) and resource inventory on 1:250,000 scale. Thus, the scale of survey and intensity of observation varied considerably. There are also differences in field and laboratory techniques in the 1980's and 1990's and the techniques used today. Some of the mandated properties required for SOTER were not generally measured and reported during the routine soil survey. Therefore, PTF were used to fill up the gap. The database once developed can be updated with the recent and relevant data. It is expected that this database in a structured framework can be utilized by many users in their future scientific and planning purposes and thus remains as national and international reference database.

Acknowledgements

The present work is a part of the research sponsored by NAIP (ICAR) under the project entitled "Georeferenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture" (Component-4) and the fund received from NAIP is thankfully acknowledged. The authors also acknowledge the assistance received from National Director, NAIP and National Coordinator, NAIP Component-4.

References

Anonymous (2009). "Benchmark Soil Series of India, National Register" NBSS&LUP, Amravati Road Nagpur, India (Unpublished).

Batjes, N.H. and Dijkshoorn, I.A. (1999). Carbon and nitrogen blocks in the soils of the Amazon region. Geoderma 89:273-286.

Bhargava, G.P., Pal, D.K., Kapoor, B.S. and Goswami, S.C., (1981). Characteristics and genesis of some sodic soils in the Indo-Gangetic Plains of Haryana and Uttar Pradesh. Journal of Indian Society of Soil Science, Vol. 29(1):61-70.

Bhattacharyya, T., Chandran, P**.,** Ray, S.K., Pal, D.K**.,** Venugopalan, M.V., Mandal, C., Wani, S.P., Manna, M.C. and Ramesh, V.(2007). Carbon sequestration in red and black soils. II. Influence of physical and chemical properties. *Agropedology* 17:16-25.

Bhattacharyya, T., Pal, D.K., Chandran, P**.,** Mandal, C., Ray, S.K., Gupta, R.K. and Gajbhiye, K.S. (2004). *Managing Soil Carbon Stock in the Indo-Gangetic Plains, India,* Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi-110 012, India. pp 44.

Bhattacharyya, T., Ray, S.K., Sahoo, A.K., Durge, S.L., Chandran, P.; Sarkar, D. and Pal, D.K. (2006) Pan formation in soils under paddy –potato/ Mustard-paddy systems in Indo-Gangetic

Plain, West Bengal Rice-Wheat Consortium for the Indo-Gangetic Plains (www. rwc.cgair.org/Pub_Info.asp?ID=165.

Bhattacharyya, T. *et al.* (2007b). Modelled soil organic carbon stocks and changes in the Indo-Gangetic Plains from 1980 and 2030. Agriculture, Ecosystem and Environment 122, 84-94.

Chandran, P., Bhattacharya, T., Ray, S.K., Durge, S.L., Mandal, C., Sarkar, D., Sahoo, A.K., Singh, S.P., Jagat Ram, Ram Gopal, Pal, D.K., Gajbhiye, K.S., Aurangabadkar, B., Mendhekar, P. and Singh, B. (2005). **"***SOTER (Soil and Terrain Digital Databases) IGP, India"***.** Special publication for "Assessment of Soil Organic Carbon Stock and Change at National Scale.". NBSS & LUP, India, p.101.

Falloon, P.D., Smith, P., Smith, J.V., Szabo, J., Coleman, K. and Marshall, S. (1998). Regional estimates of C sequestration potential : linking the Rothamsted C model to GIS databases. Biology and Fertility of Soils. 27:236-241.

Gupta, R.K. and Rao, D.L.N. (1994). Potential of watersheds for sequestering carbon by representation. *Current Science* 66:373-380.

Jagat Ram, Ram Gopal, Obi Reddy, G.P. and Sarkar Dipak (2009). "Soil Resource Mapping for Land Use Planning of Moradabad District (U. P.)" NBSS Publ. National Bureau of Soil Survey and Land Use Planning, Nagpur, India, 159p (unpublished).

Lal S, Deshpande, S.B. and Sehgal, J. (Eds.) (1994). Soil series of India. Soils Bulletin 40, National Bureau of Soil Survey and Land Use Planning, Nagpur, India.684p.

Mahapatra, S.K., Sharma, J.P. and Sarkar Dipak (2010). Soil resource mapping of Mathura district of Uttar Pradesh for perspective land use planning. NBSS Publ. NBSS&LUP, Nagpur, India, 156pp (unpublished).

Mandal, *et. al.* (2011). Soil map of Indo-Gangetic plains(IGP), India (unpublished).

Martin, D., Sharma, J.P., Singh, S.P. and Sarkar, Dipak (2009) **"**Soil Resource Mapping of Shahjahanpur district of Uttar Pradesh for perspective land use planning**"** NBSS Publ. National Bureau of Soil Survey and Land Use Planning, Nagpur, India (unpublished).

Murthy, R.S., Hirekerur, L.R., Deshpande, S.B., VenKata Rao, B.V. and Shankaranarayana, H.S. (1982). Benchmark soils of India- morphology, characteristics and classification for resource management, National Bureau of soil survey and land use planning, Nagpur, India, p.374.

Nayak, D.C., Sarkar Dipak and Velayutham, M. (2001). Soil series of West Bengal. NBSS Publ. No. 89, NBSS&LUP, Nagpur, 260p.

Pal, D.K., Bhattacharyya, T., Ray, S.K., Chandran, P., Srivastava, P., Durge, S.L. and Bhuse, S.R. (2001). Significance of soil modifiers (Ca-zeolites and gypsum) in naturally degraded Vertisols of Peninsular India in identifying the sodic soils. *Geoderma* 136:210-228.

Pal, D.K., Sohan Lal, Bhattacharyya, T., Chandran, P., Ray, S.K., Satyavathi, P.L.A., Raja, P., Maurya, U.K., Durge, S.L. and Kamble, G.K. (2010). “Pedogenic thresholds in Benchmark soils under rice-wheat cropping system in a climosequence of the Indo-Gangetic Alluvial Plains” Final Project Report, Division of Soil Resource Studies, NBSS&LUP, Nagpur, p.193 (unpublished).

Ray, S.K., Chandran, P., Bhattacharyya, T., Durge, S.L., Mandal, C. Sarkar, D., Sahoo, A.K., Singh, S. P., Jagat Ram, Ram Gopal, Pal, D.K., Gajbhiye, K.S., Milne, E. Singh, B. and Aurangabadkar, B. (2005). “Benchmark Soil Series of the Indo-Gangetic Plains (IGP), India”. Special publication for “Assessment of Soil Organic Carbon Stocks and Change at National Scale.” NBSS&LUP, India. p.184.

Ray, S.K., Bhattacharyya, T., Sarkar, D., Mandal, C., Sidhu, G.S., Sahoo, A.K., Nair, K.M., Singh, R.S., Dutta, D., Chandran, P., Pal, D.K., Tiwary, P., Mandal, D.K., Prasad, J., Venugopalan, M.V., Srivastava, A.K., Rayachaudhury, M., Velmourougane, K., Srivastava, R., Sen, T.K., Chatterji, S., Obireddy, G.P., Patil, N.G., Mahapatra, S.K., Das, K., Singh, A.K., Srinivas S., Reza, S. K., Balbuddhe, D. V., Mrunmayee Lokhande, Wadhai, K. N., Vishakha Dongare, Mohanty, B., Majumdar, S., Ganjanna, K.V., Garhwar, R.S., Meena, K.K., Hazarika, D., Sahu, A., Mahapatra, S., Ashutosh Kumar, Nimje, A. N., Deshmukh, R. R., Deshmukh, A. D., Thakre, S. W., Dasgupta, D., Telpande, B. A., Likhar, C. K and Sheikh, S. (2011). **“**Georeferenced Soil Information System for Land Use Planning and Monitoring soil and land quality for Agriculture” Baseline Data for the Indo-Gangetic Plains and the Black Soil Region**,** Vol- I IGP, Division of Soil Resource Studies, NBSS&LUP, Nagpur, p563.

Ray, S.K., Chandran, P., Bhattacharya, T., Durge, S.L., Mandal, C., Sarkar, D., Sahoo, A.K., Singh, S.P., Jagat Ram, Ram Gopal, Pal, D.K., Gajbhiye, K.S., Singh, B. and Aurangabadkar, B. (2004). Benchmark Soil Series of the Indo-Gangetic Plains (IGP), India”. Special publication for “Assessment of Soil Organic Carbon Stock and Change at National Scale”. NBSS & LUP, India p186.

Sahoo, A.K., Sarkar Dipak and Gajbhiye, K.S. (2002). “Soil series of Bihar” NBSS Publ. No. 98, NBSS&LUP (ICAR), Nagpur, 289p.

Sarkar, D., Velayutham, M. and Bhattacharyya, T. (1999). Soils of Madhubani district for optimizing land use. NBSS Publ. 76, NBSS&LUP (ICAR), Nagpur, 177p.

Sarkar Dipak, Nayak, D.C., Maurya, U.K. and Gajbhiye, K.S. (2008). Mineralogy of Benchmark Soils of West Bengal. NBSS Publ. No. 139, NBSS&LUP (ICAR), Nagpur, 171p.

Sehgal, J.L. and Sharma, P.K. (1982). Benchmark soils of Punjab, Soils bulletin 5, Department of Soils, Punjab Agricultural University, Ludhiana, 211p.

Singh, S.K. and Agrawal, H.P. (1995). Morphology and taxonomy of prominent soils developed in alluvial pedogenic complex of Gomti-Sai interfluve, Dist. Jaunpur, U. P., Journal of Scientific Research, Banaras Hindu University, Varanasi, Vol 45, p.49-61.

Soil Survey Staff (1999). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd edition. Agril. Handbook No. 436, SCS-USDA, US Govt. Printing Office, Washington DC, 869p.

Staff, NBSS&LUP (2002). Soils of India, NBSS Publ. No 94, National Bureau of Soil Survey & Land Use Planning, Nagpur, India, pp130+11 sheet maps.

Tiwary *et. al.* (2011). Development of pedotransfer functions for estimating soil physical properties for BSR and IGP. (In process)

Van Engelen, V.W.P. and Wan, T.T. (Eds.) (1995). Global and National Terrain digital Database (SOTER) Procedure Manual (revised edition) International Soil Reference and Information Centre, Wageningen, The Netherlands.

Velayutham, M., Mandal, D.K., Mandal, C. and Sehgal, J.L. (1999). Agro-ecological subregion of India for development and planning, NBSS Publ. No. 235, National Bureau of Soil Survey and Land Use Planning, Nagpur, India, 450p.

Verma, T.P., Singh, S.P., Martin, D., Dhankar, R.P., Sharma, J.P. and Sarkar Dipak (2009). "Soil Resource Mapping of Mainpuri District of Uttar Pradesh for Perspective Land Use Planning" NBSS Publ. National Bureau of Soil Survey and Land Use Planning, Nagpur, India.((unpublished).

Verma, T.P., Singh, S.P., Ram Gopal, Dhankar, R.P., Jagat Ram and Sarkar Dipak (2005). "Soil Resource for Land Use Planning Etawah District (U.P.)" NBSS Publ. 124, National Bureau of Soil Survey and Land Use Planning, Nagpur, India.

Walia, C.S., Sharma, J.P. and Sarkar Dipak (2009). Soil resource mapping of Firozabad district of Uttar Pradesh for perspective land use planning. NBSS Publ. NBSS&LUP, Nagpur, India, 107 pp (unpublished).

Table 1 Source of soil database for development of SOTER-IGP

Sl. No	States	No. of Soil Series	AESRs covered	Source
1	Punjab	49	9.1, 4.1, 2.3	Sehgal and Sharma, (1952); Lal et al. (1994), Ray *et al.* (2005).
2	Haryana	8	4.1, 9.1, 2.3	Lal et al. (1994), Ray *et al.* (2005).
3	Uttarakhand	1	14.5	Pal *et al.* (2010)
4	Delhi	3	4.1	Lal *et al.* (1994), Ray *et al.* (2005).
5	Uttar Pradesh	169	9.1, 4.1, 4.3, 4.4, 9.2, 13.1, 13.2	Martin *et.al.* (2009), Murthy *et al.* (1982), Verma *et al.* (2005), Jagat Ram *et al.* (2005), Singh *et al.* (1995), Ray *et al.* (2005), Bhargava *et al.* (1981), Mahapatra *et al.* (2010), Jagat Ram *et al.* (2009), Verma *et al.* (2009), Walia *et al.* (2009).
6	Bihar	83	13.1, 9.2	Lal *et al.* (1994), Sahoo *et al.* (2002), Ray *et al.* (2005).
7	West Bengal	100	12.3, 15.1, 18.5, 16.2, 15.3	Lal *et al.* (1994), Murthy *et al.* (1982), Nayak *et al.* (2001), Ray *et al.* (2005).
8	Tripura	2	17.2, 15.3	Ray *et al.* (2011).
	Total	416	17	

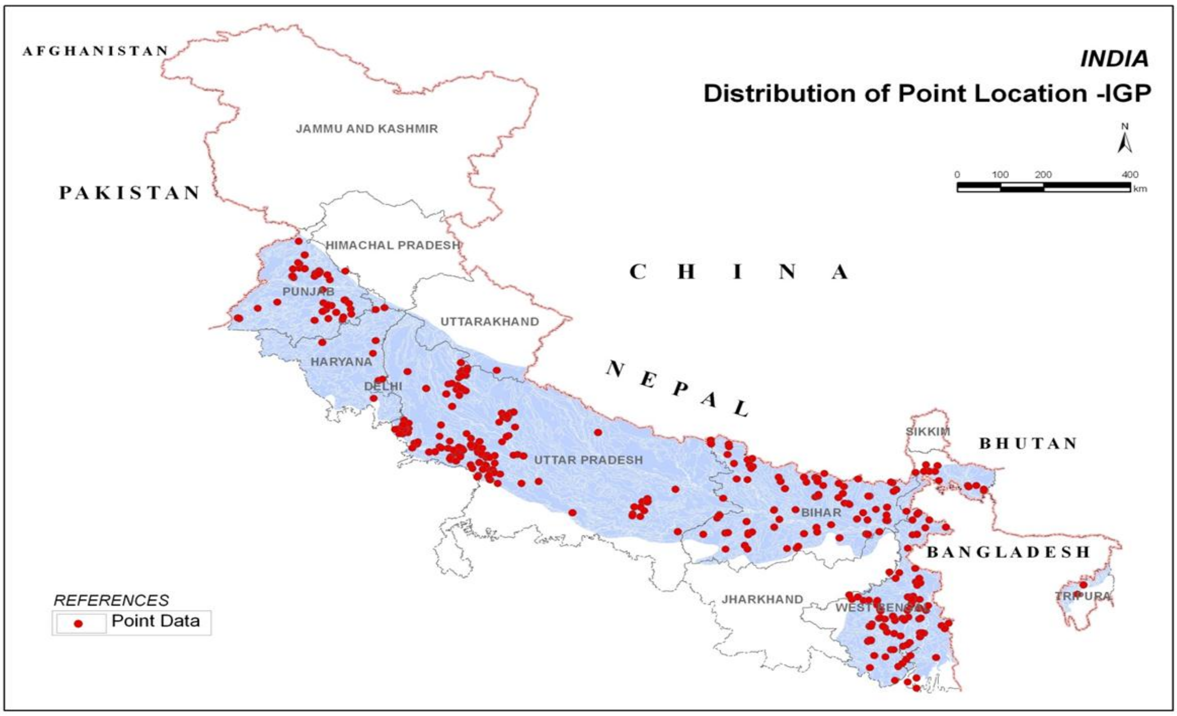


Fig.1. Georeferenced location of soils of IGP

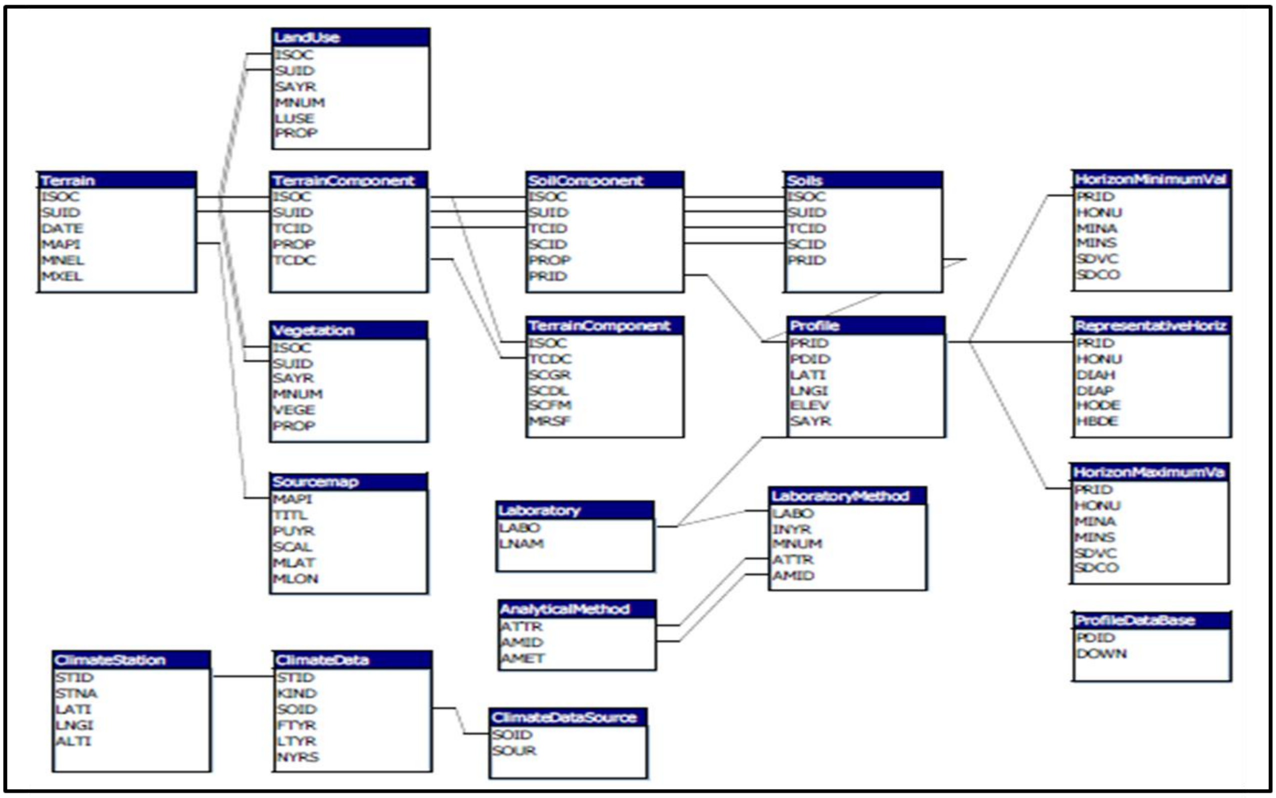


Fig 2. SOTER –framework relationships

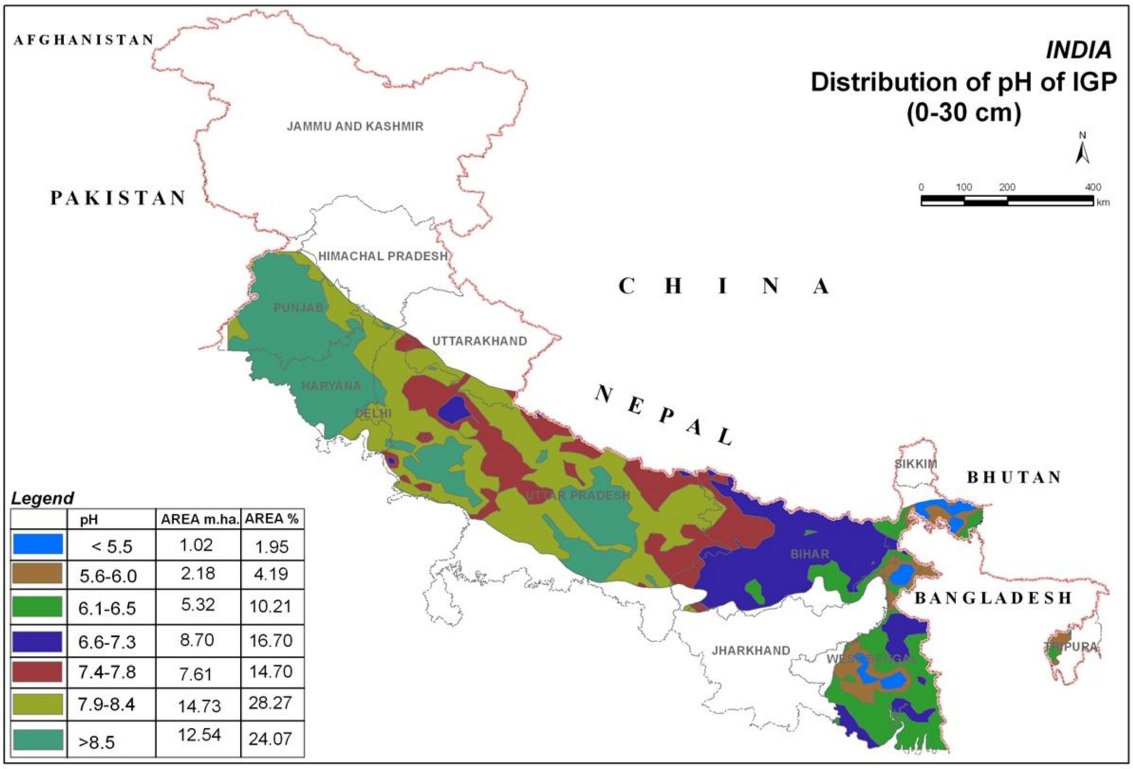


Fig.3. Soil reaction (pH) of IGP soils

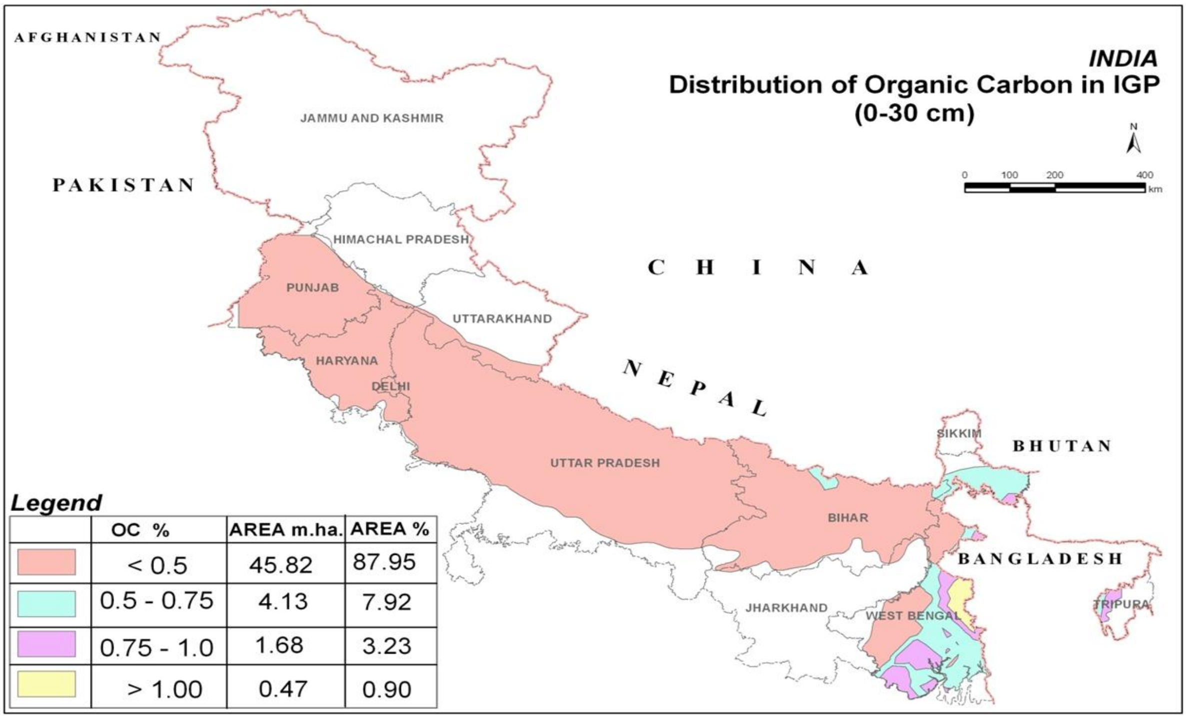


Fig.4 Organic carbon status of soils of IGP

Revision of Black Soil Map of India for Sustainable Crop Production

C. Mandal, D.K. Mandal, Jagdish Prasad, Dipak Sarkar, P. Chandran, P. Tiwary, N.G. Patil, G.P. Obi Reddy, M.A. Lokhande, K.N. Wadhai, V.T. Dongare, G.S. Sidhu, A.K. Sahoo, K.M. Nair, R.S. Singh, D.K. Pal, S.K. Ray and T. Bhattacharyya

National Bureau of Soil Survey and Land Use Planning (ICAR), Amravati Road, Nagpur 440 033, Maharashtra, India
E-mail: champa_mandal@yahoo.co.in

Abstract

Indian black soils are commonly known as Black Cotton Soils or "Regur" and classified to Vertisols and Vertic intergrades of other orders. These soils swell on wetting and shrink on drying and become extremely difficult to work and manage. Traditionally, these soils were believed to be confined to the Peninsular region, but research endeavours at the National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur have reported their presence in other parts of the country as well. Understanding the importance of these soils for sustainable crop production, it is essential to assess the spatial distribution of these soils for efficient planning and management. Lack of terrain information on earlier published scale (1:4.7 M) necessitated refinement based on new information developed through a National Agricultural Innovation Project (NAIP) (GeoSIS) of the Indian Council of Agricultural Research, New Delhi. The revisions involved the delineation of physiographic boundary based on ASTER database of 30 m resolution, georeferencing the 414 pedon database information and cartographic and categoric generalization of 1:250,000 scale Soil Resource Mapping (SRM) information to 1:1 m scale. This was done by superimposing the above component maps and using pedotransfer functions (PTF) and synthetic profile information for filling the gaps to generate a refined map on 1:1 m scale.

Shrink-swell soils in India were reported to cover 70.3 M ha. The present revision from available datasets resulted in an increase in area to about 117 M ha. The geo-referencing of 407 points indicates that the BSR has extended and found to exist outside the basaltic Peninsular region including states like Bihar, West Bengal, Punjab, Assam, Jammu & Kashmir and Kerala. The knowledge of the revised black soil information system (BSIS) in spatial domain would be useful to carry out research with respect to sustainable crop production for effective land use planning.

Introduction

Black soils comprise mainly of Vertisols and their geographically associated soils (Vertic intergrades of Inceptisols, Entisols and Alfisols). These are widely distributed across the globe and occupy about 335 M ha (FAO, 1991) of land area of the world (Blokhuis, 1981). They lie between 45° N and 45° S and are abundant in India, Sudan, Australia, Argentina, Kenya and South western USA and Canada. These soils are locally recognized in various names, popular among those are: *regur* (India), *adobe* (USA, Philippines), *badobes* (Sudan), *gilgai* (Australia), *tirs* (Morocco, N. Africa) and margalite (Indonesia).

In India, these soils occur mainly in the Peninsular region. As per earlier estimate from reconnaissance soil survey, these soils occupy about 70 M ha constituting 21.4 per cent of the total geographical area of the country (Murthy *et al.* 1982). Latest estimate of the extent of Vertisols and their intergrades indicate that area under these soils is 51.3 M ha of which area under Vertisols is 26.62 M ha and area under Vertic Intergrades of Entisols (Vertic) is 0.20 M ha, Inceptisols (Vertic) is 23.76 M ha and Alfisols (Vertic) is 0.72 M ha (Bhattacharyya *et al*. 2009) . These soils are deep to shallow, dark coloured dominated by specific clay mineralogy with unique profile structure (Sehgal and Bhattacharjee, 1988). Among the black soils, the deep black soils (Vertisols) are generally calcareous, dark in colour with low chroma, high in clay content, low in organic carbon, high CEC and high in shrink-swell potentials due to the presence of large amount of smectitic clay in the fine earth. Under the Global Environmental Facility project - Soil Organic Carbon Stocks and Changes (GEFSOC) project in 2004, some Vertisols were identified in Chunchura area of Hooghly district of West Bengal (Ray *et.al.* 2006). In general, Vertisols occupy lower topographic positions (toe slopes) and sometimes they also occur on comparatively higher positions with stable slopes in association with shallow black soils. The climatic setting of these soils ranges from arid to semi-arid to sub-humid to humid, characterised by hot and dry summer and mild winter intervened by short period of summer monsoonal rainfall.

The shrink-swell characteristics make them very difficult to manage for cultural operation unless they are tilled at appropriate moisture. The results of the frontline demonstrations of the All India Coordinated Project of ICAR showed a large gap in crop yield does exist between the farmer's yield and the achievable yield. This indicates that despite the fact Vertisols make up a relatively homogenous major soil group in India, this gap can be due to different pedogenetic processes occurring in Vertisols under different climatic environments (Pal *et al.* 2011). This suggests that the soil chemistry of Vertisols that is regulated by the climatic environments needs to be understood before adapting any management protocol, developed under a different set of climatic environments (Kadu *et al*. 2003). Under rain-fed conditions, yield of deep rooted crops in cracking clay soils (Vertisols) mostly depend on the amount of rain water that enter the soil profile and the extent to which this water is released during the crop growth. However, the release of soil water during the crop growth is a function not only of the nature and content of clay minerals but also of the nature of exchangeable cations. Therefore, antecedent soil moisture after the cessation of rain would be most realistic soil water scenario to calculate the length of growing period by FAO method. Vertisols of Nagpur, Amravati and Akola districts of Maharashtra of central India occur in the adjacent AESR 10.2 and 6.3 (Sehgal *et al.* 1998) and indicates a climatic transition from subhumid dry to subhumid moist with moisture availability period (LGP) varying from 180 (Nagpur) to 150 days (Akola). Both the LGP are suitable for deep rooted crops (cotton) but the yield of cotton (seed + lint) of Nagpur is much higher than that of Akola district. The reason for the difference in yield was investigated by Pal *et al*. (2009) and it was observed that progressive aridity in western part of Akola and Amravati favours the formation of sodic soils with accumulation of calcium carbonate leading to impairment of saturated hydraulic conductivity (sHC). The reduced sHC is the reason for the low storage of soil water that impairs the yield (Kadu *et al*. 2003). Vertisols of Gujarat (Sokhada and Semla Bench mark soils) under semiarid conditions with less than 150 days growing period are not suitable for cotton but gives very high yield of cotton of 1.8 to 2.0 tons/ha. Presence of calcium zeolite as a natural soil modifier wards off the adverse effect of sodium on the soil exchange sites and induces better sHC that favours the movement of rain water in the downstairs of the profile and also the storage of soil water in the subsoil regions. Because of better soil water release Vertisols are productive. Therefore, there is a need to assess the shrink-swell soils with and without natural soil modifiers, the mapping of their spatial distribution (Pal *et al*. 2009). These soils, if left unattended without any vegetative cover, would be degraded and lost through erosion due to the formation of gullies. The productivity potential of these soils can be viewed in perspective as boon or bane in relation to agro-management. Therefore, there is a need for mapping of their areal extent and classifying these soils for profitable crop production through improved soil management technology and thus the present project was undertaken.

Vertisols and their Distribution

Vertisols and Vertic intergrades are generally known as black soils or '*Regu*r' in India. These are mainly developed over alluvium of the weathering Deccan trap basalts. Vertisols are shrink-swell soils which require huge amount of smectitic clay for their formations (Bhattacharyya *et al*. 1997, Pal and Deshpande, 1987). The source of smectitic clay mineral is available in the alluvium of Deccan trap Basalt or parent material rich in the bases (Pal and Deshpande, 1987). Landey *et al.* (1982) observed some Vertisols developed on granitic genesis/ lime or soda lime feldspar. These soils are generally developed on slope less than 8 per cent (Dudal and Bramao 1965). The development of Vertisols on different parent material is shown in Table 1. In toposequences, the Entisols occur in upper topography, structurally they are weak sub-angular blocky and Inceptisols in mid topography with moderate to strong sub-angular blocky structure with shiny pressure faces in deeper horizons. The Vertisols occupying lower element of topography have normally very thick horizons with strong structure, slickensides close enough to intersect, wedge shaped aggregates (25 cm or more thick within 100 cm) and associated with 30 or more than 30 per cent clay and cracks close and open (0.5 cm) periodically up to 30 cm deep. The thickness of slickensides (*i e* 25 cm within 100 cm.) in soils and their taxonomy has been debated (Jagadish Prasad *et al.* 1998, Jagadish Prasad, 2007) *vis a vis* management.

Table 1 – Development of Vertisols on different parent material

Reference	Particulars of parent material	Inferences
Dudal and Bramao (1965)	Basalt, shales, limestone, volcanic rocks, tuffs, basic metamorphic rocks, alluvium (fluvial and marine), colluvium basic in nature	Common parent materials develop black soils
Bal (1935); Wadia (1945); Basu and Sirur (1938)	Basalt (Deccan trap)	Dominant parent materials
Hosking (1935); Simonson (1954)	Limestone, shales, calcareous clay	Responsible for the formation of Vertisols
Ramaiah and Raghavendrachar (1936)	Materials rich in soda lime feldspar	Responsible for the formation of Vertisols and associated soils, while potash feldspar gives rise to red soils under similar climate and land form
Tamhane and Sen (1954)	Dharwar schists basalt and diorites	Responsible for the formation of black soils
Parthasarathy (1959)	Calcic gneiss	Gives rise to black soils, while orthoclase feldspar and hornblende give rise to red soils
Kalbande Swamynathan (1976)	Hornblende granulite, calcic gneiss, granitised schist and chorite schist	Responsible for the formation of Vertisols and associated soils
Bhattacharjee, Landey and Kalbande (1979) (Unpublished)	Marine alluvium and coastal alluvium	Responsible for the development of Vertisols and associated soils
Ray *et al.* (2006)	Old Deltaic alluvium Presence of smectitic alluvium	Responsible for development of Vertisols associated soils.
Kolhe *et al.* (2011), (Unpublished)	Red bole	Responsible for the formation of Vertisols.

Soil distribution

Wadia *et al.* (1935) compiled soil map of India based on geological formation where *Regur* soils were mentioned as black soils. Raychaudhury *et al.* (1963) reported that the black soils occupy an area of 810,000 km^2 constituting nearly half of Deccan peninsula and lie between 15º - 26º N latitude. Pascoe (1964) observed the *Regur* everywhere in the plains of Deccan traps except near the coast. Dudal and Bramao (1965) reported that the black soils occur in 60 M ha covering the central and the south central Deccan plateau in the states of Maharashtra, Andhra Pradesh and Madhya Pradesh. Murthy *et al.* (1982) reported that the Vertisols and associated soils of Peninsular India extended between 8º45' - 26º00' N latitude and 68º 00' - 83 º 45' E longitudes covering an area of 72.9 M ha and spread over in Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orissa, Bihar and Uttar Pradesh. Pofali *et al.* (1999) revised the area of the Vertisols based on collation of 1:2 million scale soil survey data largely extrapolated and reported the area of 70.3 M ha. All these earlier estimates are based on reconnaissance level soil survey data extrapolated based on broad physiography and selective transect studies.

NBSS&LUP undertook the Soil Resource Mapping (SRM) project of different states on 1: 250,000 scale in 1986 (Sehgal, 1990) and published soil family association maps of different states of India. This study provides the scope for further revision of areal extent of black soils of India.

Methodology

The black soil region map of India was generated using the existing information on 1:1 million scale at sub-group association level which was originally based on 1:250,000 scale map at state level. These were reduced and using the categorical and cartographic generalisation, the map on 1:1m scale was prepared at the country level. Further, the entire information of the soil was brought under the GIS environment and the map was digitized and each soil polygon was attached with attribute table showing the dominant and sub-dominant soils with their taxonomic classification, their depth, texture, slope, erosion, salinity, sodicity and gravelines (if any). The map thus generated was attached with different soil information available from different sources (as point data). Information of each point was geo-referenced with respect to the location. The AESR map of NBSS&LUP (Sehgal *et al.*, 1996) was super-imposed to know the distribution of black soils in different agro-climatic zones. In the gap areas where sufficient data is not available, pedo transfer function (PTF) and ASTER data (30 m resolution) were used to fill the gaps in the black soil region (BSR). The 414 soil profile data of BSR region collected from different sources (mostly published reports), were put systematically in the excel format showing their areas in different agro-ecological zones of the states of the country. The locations of soil observation (point data) were super-imposed and geo-referenced to update the BSR map. The state-wise and agro-ecological sub-region wise (AESR) distribution of black soils was also completed. The salient physical and chemical properties of the dominant Vertisols of different AESRs are discussed below for making agro technology transfer meaningful.

Results and Discussion

The earlier BSR map of NBSS and LUP showed that the area under black soils was 70 M ha constituting approximately 21.4 per cent of the total geographical area of the country (NBSS Staff, 1988). Black soils are dominantly observed in the states of Maharashtra (34.3%), Madhya Pradesh (30.2 %), Gujarat (7.0 %), Andhra Pradesh (13.4), Karnataka

(8.0%), Tamil Nadu (4.0%), Rajasthan (1.5%) and Uttar Pradesh (1.6%). The soils mainly were classified as Chromusterts and Hapluslerts as the dominant members. The associated shrink-swell soils are Pellusterts (now Hapluslerts), Ustropets, Ustochrepts (Haplustepts), Ustorthents, Ustifluvents occuring mainly in the Deccan trap region. The map was published in 1:4.7 m scale using soil information collected from various sources. Where soil survey information was not available, the existing knowledge on soil-physiographic relationship was used to extrapolate the soils information. It has fifty soil units at great group association. The revised map (Fig. 1) contains soil information at subgroup level with 284 soil mapping units. The map also depicts the distribution of Vertisols and Vertic intergrades (Inceptisols and Entisols). The total area under black soils in India has been estimated to be 76.4 M ha, of which Vertisols alone occupy 27.4 M ha (35.8 % of total black soils) area and Vertic intergrades of Inceptisols contributing 39.7 M ha (51.9 %) and Entisols (Vertic) occupy 4.4 M ha (5.8 %) (Table 2). Vertisols mainly belong to the great group Haplusterts as a dominant member and the associated soils are classified as Haplustepts, Ustorthents, Ustifluvents, Rhodustalfs, Endoaquepts, Epiaquepts, Fluvaquents, Haplustalfs and Sulfaquepts.

Table 2 Distribution of different soil orders in BSR of India

Order (Subgroups)	Black Soils Area	
	M ha	% of total area under BSR
Vertisols	27.4	35.8
Inceptisols (Vertic)	39.7	51.9
Entisols (Vertic)	4.4	5.8
Others	4.9	6.5

The state-wise areal distribution of black soils (Table 3) indicated that out of the total area under black soils, the highest percentage is in Maharashtra (27%) followed by Madhya Pradesh (21.3 %), Gujarat (11.5%), Karnataka (9.2 %), Andhra Pradesh (7.1 %) and Chhattisgarh (5.6 %). Black soils occur also in Bihar (3.1 %) and West Bengal (3.0%) in parts of the lower Gangetic plains. A small area under BSR in the Brahmaputra Valley of Assam, coastal plains of Kerala (at dipping point of the Western Ghats) and Jammu and Kashmir have also been identified. The BSR map also shows the distribution of soils in the form of polygons with dominant (60 %) and sub-dominant (40 %) soil associations. On the basis of relative occupancy of black soils in each polygon, about 41.28 M ha are Vertisols. The database of black soil region has the soil map and attributes data of soil depth, texture, erosion, slope, salinity, sodicity and flooding. In addition, the point data information collected from various sources have been linked and geo-referenced with the maps indicating horizonwise information with respect to morphological, chemical and physical properties.

Table 3 State-wise distribution of black soils in India

Sl. No.	Name of State	Earlier estimate*		Revised area**	
		m ha	%	m ha	%
1.	Maharashtra	10.81	20.9	20.63	27
2.	Madhya Pradesh	16.75	32.3	16.27 (Including Chhattisgarh)	21.3
3.	Gujarat	5.31	10.2	8.79	11.5
4.	Karnataka	4.46	8.6	7.03	9.2
5.	Andhra Pradesh	4.73	9.1	5.42	7.1
6.	Chhattisgarh	-	-	4.28	5.6
7.	Orissa	2.02	3.9	1.91	2.5
8.	Rajasthan	1.68	3.2	1.91	2.5
9.	Tamil Nadu	2.33	4.5	1.53	2
10.	Uttar Pradesh	1.63	3.1	2.37	3.1
11.	Bihar	1.12	2.2	0.08	0.1
12.	Punjab	0.02	0	2.29	3
13.	West Bengal	0.91	1.8	0.23	0.3
14.	Jammu and Kashmir	0	0	0.08	0.1
15.	Assam	-	-	0	0
16.	Kerala	-	-	0.08	0.1
17.	Haryana	0.01	0	3.59	4.7
18	Pudducherry	0.01	0	-	-
19	Andaman and Nicobar	0.01	0	-	-
		51.81	100	76.4	100

* Based on 1996 survey and reported by Bhattacharyya *et al*., (2009)
** Based on present study.

Soil - Climatic Environment

Black soils occur in the arid (<600 mm), semi-arid (600 – 1000 mm), sub-humid (1000-1500 mm) and humid (>1500 mm) climates (Velayutham *et al*. 1999). The map (Fig. 2) shows the largest area of black soils is in the semi-arid climate *i e* 36.38 M ha followed by 32.73 M ha in sub-humid climate, 5.98 M ha in humid climate and very small area in arid climate (1.30 M ha). The monsoonic climate of India giving rise to alternate aridity and humidity has a major role in the formation of black soils. The climate of the BSR range from hot arid climate in parts of Karnataka and Andhra Pradesh with less than 600 mm rainfall to semi-arid parts of Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu states with rainfall of 600-1000 mm, the sub-humid parts with rainfall of 1000-1500 mm of eastern India including Madhya Pradesh, Chhattisgarh, Maharashtra and Orissa. The humid areas with rainfall more than 1500 mm are in the states of Bihar, West Bengal, Assam and Kerala. The climate is generally hot and dry in summer and mild in winter. The main feature about the climate is the seasonality of rainfall allowing alternate wetting and drying of the solum and leading to many unique physical properties of black soils. The mean annual temperature ranges between 24° to 27°C. The mean summer and mean winter temperature ranges from 30° to 33°C and 15° to 22°C respectively. The annual rainfall ranges from 500 to > 1500 mm of which 80 to 90 per cent is received during monsoon period and the rainfall satisfy 42 to 77 per cent of mean annual potential evapo-transpiration (PET). The soil moisture control section (SMCS) remains dry either completely or in parts for 4 to 8 months in a year and represent Ustic moisture regime.

AESR-wise distribution

Agroecological sub-region (AESR)-wise black soil distribution is shown in figures 3 and 4 indicate that there are total 18 AERs and 42 AESRs where black soils occur. Maximum areas of black soils are in the AER 5 and 6 of semi-arid ecosystem contributing 30.5 per cent. The benchmark soil series so far identified in this region are 166. The representative soil series ‘Semla’ is very dark greyish brown, deep to very deep, moderately well drained, moderately eroded, clay and developed in basaltic alluvium. These soils are dark grayish brown to brown (10 YR 2/2) with pH 7.8 on the surface and 8.0 in sub-surface and occur on 1-3% slope at an elevation of 150 m above MSL. These represent the drier parts of semi-arid and are classified as fine Aridic Hapluslerts. The land use is groundnut, cotton, fodder sorghum, chickpea and wheat.

Similarly, the soil series Asra is in village Asra Bhatkuli, Amravati district of Maharashtra (AER 6) on lower Maharashtra Deccan plateau (1-3 % slope) at an elevation of 287 m above MSL. These are moderately well drained soils and developed in basaltic alluvium. The soils are deep to very deep, very dark brown to very grayish brown (10 YR 2.5/2) with pH 7.8 in surface and 8.5 in sub-surface. These soils are classified as very fine, smectitic, hyperthermic Sodic Haplusterts. The land use is cotton/ green gram/ pigeon pea intercropping.

The AER 10, 11 and 12 sub-humid eco-systems contribute to 31.7 per cent of BSR covering mainly the states of Maharashtra, Madhya Pradesh and Chhattisgarh representing Malwa plateau of central Highland and Chhattisgarh/ Mahanadi Basin and Chota Nagpur plateau. The numbers of point data representing these AER are 178. The Sub-humid drier part of the BSR is represented by Linga series located at Fruit Research Station, Wandli, Katol, Nagpur (Maharashtra) on lower Maharashtra Deccan plateau (1-3% slope) at an elevation of 420 m above MSL. These are dark brown to very dark grayish brown (10 YR 3/2 M), deep to very deep, developed in basaltic alluvium, and have pH 7.9-8.0 and are classified as very fine, smectitic, hyperthermic Typic Haplusterts. These soils are moderately well to well drained and are under citrus cultivation.

The sub–humid moist part of the BSR is represented by Kheri series located in village Kheri, Jabalpur, Madhya Pradesh part of Deccan plateau – Satpura ranges. They have developed in basaltic alluvium with 1-3 % slopes and are moderately well drained, deep to very deep, greyish to very dark greyish brown (10 YR 3/2 M). The pH varies from 7.5 to 8.0. The soils are classified as very fine, smectitic, hyperthermic family of Typic Haplusterts. They are cultivated to soybean -wheat/ paddy- wheat/ fallow/ wheat.

AER 15 and 19 represent humid ecosystem contributing 2.8 per cent of BSR in parts of Assam – Bengal plains, Western Ghats and West Coastal plains. They cover the states of West Bengal, Kerala and Maharashtra. The total number of point data representing the ecosystem is 6. These soils are represented by Karuvapara series which are fine, mixed, hyperthermic, Vertic Epiaquepts located in Muthalamada panchyat, Chittoor taluka, Palakkad district of Kerala state. Physiographically, they represent the Western Ghats – Coastal plains. The soils of Karuvapara are very deep and occur on nearly level and very gently sloping low lands (1-3 % slope). They are moderately well drained, dark brown (10 YR 3/3) to dark greyish brown (10 YR 4/2) with pH 7.9 in the surface to 8.2 in the sub-surface, and are fine, mixed, hyperthermic, Vertic Epiaquepts. Black soils of the humid Bengal plains is represented by Hangram series (fine, mixed, hyperthermic family of Vertic Endoaquepts) in village Shyamsundarpur, Barddhaman district, West Bengal. Hangram soils are formed in alluvium (old floodplain) of the Damodar River in West Bengal. They occur on nearly level to level land at an elevation of 20 to 30 m above MSL. They are dark grayish brown (2.5 Y 5/2 M), imperfectly drained, deep clayey olive brown (2.5 Y 4/4 M) to strongly to slightly acid with pH 5.5 (surface) to 6.5 in sub-surface, with very slow permeability. These soils are intensively cultivated to rice in *kharif* and wheat under irrigation. These soils are subject to flooding and water stagnation during rainy season. The different soil series distributed in different AESRs are given in Table 4.

Table 4 The identified soil series distributed in different AESRs, their areal extent and states covered.

AESR	Soil Series	Area (m. ha.)	%	States Covered
2.1	0	0.01666	0.02	Rajasthan
2.2	0	0.015112	0.02	Gujarat
2.3	0	0.258965	0.34	Gujarat, Rajasthan, Haryana, Punjab
2.4	5	1.859003	2.43	Gujarat
3	23	1.554022	2.03	Karnataka, Andhra Pradesh
4.1	1	0.287557	0.38	Uttar Pradesh, Rajasthan, Haryana, Punjab, Delhi
4.2	7	1.089915	1.43	Rajasthan, Gujarat
4.3	1	0.857738	1.12	Uttar Pradesh
4.4	11	2.730177	3.57	Madhya Pradesh, Uttar Pradesh,
5.1	11	1.704804	2.23	Gujarat
5.2	38	8.497774	11.12	Madhya Pradesh, Gujarat, Rajasthan,
5.3	1	0.134783	0.18	Gujarat
6.1	22	3.810504	4.99	Maharashtra, Karnataka,
6.2	31	7.21315	9.44	Maharashtra, Andhra Pradesh, Karnataka
6.3	47	4.659995	6.10	Maharashtra

6.4	16	1.936435	2.53	Maharashtra, Karnataka
7.1	14	1.34781	1.76	Andhra Pradesh
7.2	11	2.463552	3.22	Andhra Pradesh
8.1	4	0.683083	0.89	Tamil Nadu
8.2	0	0.366726	0.48	Karnataka
8.3	2	1.611264	2.11	Tamil Nadu, Andhra Pradesh
9.1	1	0.052063	0.07	Uttar Pradesh, Punjab
9.2	2	0.983513	1.29	Uttar Pradesh, Bihar
10.1	26	7.35755	9.63	Madhya Pradesh
10.2	70	2.669803	3.49	Maharashtra, Madhya Pradesh
10.3	11	2.859897	3.74	Madhya Pradesh
10.4	27	4.440588	5.81	Madhya Pradesh, Maharashtra
11	11	4.218358	5.52	Chhattisgarh, Bihar, Uttar Pradesh
12.1	33	4.519524	5.92	Orissa, Chhattisgarh, Maharashtra
12.2	1	0.44647	0.58	Orissa, Andhra Pradesh
12.3	0	0.08629	0.11	West Bengal, Bihar
13.1	2	0.726358	0.95	Bihar, Uttar Pradesh
14.1	0	0.035361	0.05	Himachal Pradesh
15.1	0	1.396996	1.83	West Bengal
15.2	0	0.015672	0.02	Assam
18.1	0	0.124624	0.16	Tamil Nadu
18.3 & 18.2	1	1.288752	1.69	Andhra Pradesh, Tamil Nadu
18.4	2	0.937187	1.23	Orissa, Andhra Pradesh
18.5	0	0.41262	0.54	West Bengal
19.1	4	0.68018	0.89	Maharashtra, Gujarat
19.2	0	0.046021	0.06	Karnataka, Maharashtra, Kerala
19.3	2	0.003145	0.00	Kerala, Maharashtra
	438	76.4	100.00	

Conclusions

Black soils, especially the Vertisols occur in a wide range of climatic environments of India and show a considerable variability in their agricultural land use and productivity despite the fact that they make up a relatively homogeneous soil group. Therefore, for Vertisols there is no single farming system that can be universally applicable on a worldwide basis. There still exists a wide potential for pedological research required to resolve some of their enigmatic edaphological issues as agricultural productivity is firmly rooted in their physical, chemical and biological properties. In view of the above, a dire need was felt to assess the areal extent of BSR using modern tools and hugely extended new database generated on BSR since 1996. In the present endeavour, reassessment of the extent of Vertisols of BSR region indicated that Vertisols occupy 76.4 m ha spreading in 17 states and 42 agroeco sub-regions. These soils have been grouped state-wise and agro-climatic-wise under GeoSIS NAIP project to assist in the development of appropriate agrotechnologies for each AESR. The revised map on black soils would help in planning management of these soils to enhance crop productivity.

References

Bal, D.V. (1935). Some aspects of the black cotton soils of the central provinces. Trans. 3rd Int. Congr. Soil Sci. 3: 154-158.

Basu, J. K. and Sirur S. S. (1938) Soils of Dccan Canals. Indian J. Agric. Sci. 8 : 637-697.

Bhattacharjee, J.C., Landey, R. J. and Kalbande, A. R. (1979) (Unpublished) .

Bhattacharyya, T., Pal, D.K. and Deshpande, S.B. (1997) On Kaolinitic and mixed mineralogy classes of Shrink-swell oils. Anst. J. Soil. Res. 35: 1245-52.

Blokhuis, W.A., (1981). Problem soils: their reclamation and management – vertisols. In Land Reclamation and water – management: Int. Inst. Land Reclam. Improve., ILRI, Publ. 27, 44-48.

Dudal, R. and Bramao, D.L. (1965). Dark clay soils of tropical and sub-tropical regions. FAO. Agric.Dev.Pap- No.83, Rome, Italy.

FAO, (1991). Land use Planning Applications; World Soil Resource Report; 68, 260 . Rome (Italy).

Hosking, J. S., (1935). A Comparative Study of the black earth of Australia and the Regurs of India. Trans. Royal SOC. S. Aust. 59.

Jagadish Prasad (2007). Soil taxonomy rationale of rice and non-rice growing shrink-swell soils of Nagpur district, India. Soil survey Horizons 48 (1): 6-8.

Jagadish Prasad and Rajeev Srivastava (2010): Occurrence of red Vertisols in Central India. Soil Survey Horizons 51: 25-25.

Jagadish Prasad, Rajeev Srivastava and Chandran, P. (1990): Problems in classification of some black cotton soils in India. Soil Survey Horizons 39 (1): 23-26.

Kadu, P.R., Vaidya, P.H., Balpande, S.S., Satyavathi, P.L.A. and Pal, D.K. (2003). Use of hydraulic conductivity to evaluate the suitability of Vertisols for deep rooted crops in semi-arid parts of Central India. Soil Use & Management 19:208-216.

Kalbande, A.R. and Swamynathan, R. (1976). Characterisation of potassium in black soils developed on different parent materials in Tungabhadra catchment. J. Indian Soc. Soil Sci. 24: 290-294.

Landey, R.J., Hirekerur, L.R. and Krishnamurthy, P. (1982). Morphology, genesis and classification of black soils. Review of Soils Research in India, Part II, 12th Intl. cong. soil sci., New Delhi, India, 8-16 Feb. 1982, pp. 484-497.

Murthy, R.S., Bhattacharjee, J.C. Landey, R.J. and Pofali, R.M. (1982). Distribution, characteristics and classification of vertisols. Vertisols and rice soils of the tropics. Symp. Papers II, 12th Intl. cong. soil sci., New Delhi, India, 8-16 Feb. 1982, pp. 3-22.

NBSS Staff (1988). Vertisols and associated soils-map. National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur.

Pal, D. K. and Deshpande, S.B. (1987) Characteristics and genesis of minerals in some benchmark Vertisols of India. Pedologie 37:259-275.

Pal, D.K., Bhattacharyya, T. and Wani, S.P. 2011. Formation and management of cracking clay soils (Vertisols) to enhance crop productivity: Indian Experience. In World soil resources, ed. R. Lal and B.A. Stewart, Francis and Taylor, pp.317-343.

Pal, D.K., Mandal, D.K., Bhattacharyya, T., Mandal, C. and Sarkar Dipak (2009). Revisiting the agroecological zones for crop production. Indian journal of Genetics 69 *(4)* (Spl. Issue): 315-318.

Parthasarthy, K. (1959). Thesis, Indian Agric. Res. Int. New Delhi.

Pascoe, E.H. (1964). A Manual of Geology of India and Burma, vol. III, GSI. Govt. of India press, Calcutta.

Pofali, R. M., Vadivelu, S. and Deshpande, S.B. (1999). Environment of Swell-Shrink soils (Vertisols and Associated Soils). Swell-Shrink soils (Vertisols) of India – Resource Appraisal and Management. Published by Kalayani publishers, New Delhi. pp. 5-19.

Ramaiah, P.V. and Raghavendrachar, C. (1936). The origin of Black Soils in Madras Presidency, Proc. Soc. Boil. Chemists (India), 1: 9-10.

Ray Chaudhuri, S.P., Roy, B. B., Gupta, S. P. and Dewan M.L. (1963). Black Soils of India, Mong. 3:1-47. National Institute of Sciences of India.

Ray, S. K., Bhattacharyya, T., Chandran, P., Sahoo, A. K., Sarkar, D., Durge, S. L., Raja, P., Maurya, U. K. and Pal, D. K. (2006). On the formation of craking clay soils (Vertisols) in West Bengal. Clay Research Vol. 25 No.2: 141-152.

Sehgal, J. (1990). Soil resource mapping of different states of India – Why and How? NBSS publ. 23, 2nd reprint, Nagpur (India), 49p.

Sehgal, J.L. and Bhattacharjee, J.C. (1988). Type vertisols of India and Iraq their characterization and classification. Pedologie, XXXVII-I, pp. 67-95.

Sehgal, J.L. and Sohan Lal. (1988): Benchmark swell-shrink soils of India – morphology, characteristics and classification, published by NBSS and LUP, Nagpur. pp 166.

Simonson, R.W. (1954). Morphology and Classification of Regur Soils of India. J. Soil Sci. 5: 275-288.

Tamhane, R.V. and Sen, A. (1954). Bull. Nat. Sci. India, 3: 177.

Velayutham, M. Mandal, D.K., Mandal Champa and Sehgal, J. (1999). Agro-Ecological sub-regions of India for planning and development, Publ. 35, NBSSLUP, Nagpur, 372p.

Wadia, D. N., Krishnan, M.S. and Mukherjee, P. N. (1935) Rec. Geology Survey of India, 68:363.

Wadia, D.N. (1945). Soils of India. J. Intl. Indust. Res. 3:359-367.

Interpolation of Village Level Datasets through Krigging in different Agro-eco Subregions

T. Bhattacharyya, S. Kundu[1], D. K. Benbi[2], B. Mandal[3], U. Mandal[4], A. Subba Rao[1], D. Sarkar, S. K. Ray, P. Chandran, D. K. Pal, C. Mandal, B. A. Telpande, P. Tiwary, M. A. Lokhande, A.S. Deshmukh and Sonali Varma

National Bureau of Soil Survey & Land Use Planning, Nagpur – 440 033
[1]Indian Institute of Soil Science, Bhopal,
[2]Punjab Agricultural University, Ludhiana,
[3]Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal,
[4]Central Research Institute for Dryland Agriculture, Andhra Pradesh

Abstract

For sustainable agriculture and monitoring soil quality, it is important to have information on spatial variance of soil properties. However, variance of soil properties is not controlled by the global spatial variability but also by field variance due to different crop or management practices applied by the farmers. Moreover, measurement of soil properties for field-by-field is time-consuming and expensive. Hence, use of interpolation technique has significant importance for preparing a prediction map from the limited number of point data.

In the present study, ordinary krigging interpolation technique was used, which is based on the assumption that the parameter being interpolated can be treated as a regionalized variable, for converting polygon information of point data to generate the prediction maps of various soil properties. To assess the quality and resilience of soil in diverse agro-ecological subregions (AESRs), four AESRs (15.1, 10.1, 7.2 and 4.1) were selected. These AESRs represent districts of Bankura and Hooghly from West Bengal (AESR 15.1), Warangal and Nalgonda from Andhra Pradesh (AESR 7.2), Vidisha and Sehore from Madhya Pradesh (AESR 10.1) and Roopnagar and Ludhiana from Punjab (AESR 4.1) respectively.

Total 160 nos. of villages were selected for collecting soil samples to determine the soil quality parameters for developing soil quality indices (SQI) in four agro-eco subregions. These maps showing ranges of different soil parameters are ultimately culminated into useful soil quality parameters. Nearly 96 prediction maps were generated. In AESR 15.1 very labile pool of soil organic carbon (SOC), in AESR 10.1 soil organic carbon (SOC) and soil microbial carbon, in AESR 4.1 total carbon and humin carbon and in AESR 7.2 Walkley-Black Carbon were found as the important soil quality parameters. These parameters are assessed for resilience of soils out of various information in the four selected agro eco-sub-regions. For brevity two AESRs (10.1 and 7.2) representing districts of Warangal and Nalgonda from Andhra Pradesh (AESR 10.1) and Sehore from Madhya Pradesh (AESR 4.1) are discussed in this article.

Introduction

Kriging is a method of interpolation named after a South African mining engineer named D. G. Krige who developed the technique in an attempt to more accurately predict ore reserves. Over the past several decades kriging has become a fundamental tool in the field of geostatistics. Kriging is based on the assumption that the parameter being interpolated can be treated as a regionalized variable. A regionalized variable is intermediate between a truly random variable and a completely deterministic variable in that it varies in a continuous manner from one location to the next and therefore points that are near each other have a certain degree of spatial correlation, but points that are widely separated are statistically independent (Davis, 1986). Kriging is a set of linear regression routines which minimize estimation variance from a predefined covariance model. The krigiging routines implemented in Groundwater Modeling System GMS are based on the Geostatistical Software Library (GSLIB) routines published by Deutsch and Journel (1992). Since krigging is a rather complex interpolation technique and includes numerous options, a complete description of krigging is beyond the scope of this article. The user may refer to the GSLIB textbook (Deutsch and Journel, 1992) for more information (Royle et. al. 1981, Davis 1986, Lam 1983, Heine 1986, Olea 1974, Journel and Huijbregts 1978).

The present paper aims to assess the quality and resilience of soil in diverse agro-ecological subregions (AESRs). Two AESRs (10.1 and 7.2) representing districts of Warangal and Nalgonda from Andhra Pradesh (AESR 10.1) and Sehore from Madhya Pradesh (AESR 4.1) and a few selected soil quality parameters are discussed in this article.

Material and Methods

Study area

The project encompasses four states (Punjab, Madhya Pradesh, Andhra Pradesh and West Bengal) representing four AESRs covering two districts each from a state. However, for brevity, we have focused on two states covering three districts as our study area.

The area was selected from the states of eastern, southern, central and western part of the country as shown in table 1

Geographical Information System (GIS)

Various thematic maps of the selected districts showing the village boundaries (Anonymous, 2010) representing different Agro-Ecological Sub-Regions (Velayuthum et al, 1999) were generated using Arc GIS (version 9.3.1) (ESRI, 2010) which involved the following steps:

a. collecting district maps showing village boundaries,
b. searching the exact village location using latitude-longitude values for each spot of soil sample collection,

c. georeferencing and digitization of the village boundaries,
d. linking selected soil quality parameters data attachment,
e. generation of thematic maps,
f. the final maps for different soil quality parameters were generated. The text and the legend attributes were added to the maps using literature and / or experience and
g. final preparation of map layout.

Results and Discussion

Total 160 nos. of villages were selected for collecting soil samples to determine the soil quality parameters for developing soil quality indices (SQI) in four agro-ecological sub regions. These maps showing ranges of different soil parameters are ultimately culminated into useful soil quality parameters. Nearly 96 prediction maps were generated. In AESR 15.1 very labile pool of soil organic carbon (SOC), in AESR 10.1 SOC and soil microbial carbon, in AESR 4.1 total carbon and humin carbon and in AESR 7.2 Walkley-Black Carbon were found as the important soil quality parameters. These parameters are assessed for resilience of soils from various other information in the four selected agro eco-sub-regions.

Agro-ecological Sub-Region 7.2

This AESR is represented by Warangal and Nalgonda districts. The 7.2 agro-eco subregion constitutes south central Deccan plateau encompassing Telangana plateau. The area covers 9.2 m ha and accounts for 55% of the area of agro-ecoregion 7 and 2.8 percent of total geographical area of the country. The entire 7.2 AESR is distributed within the state of Andhra Pradesh. The districts of this state which falls within this AESR are Karimnagar, Warangal, Rangareddy, Mahabubnagar, Nalgonda, Khammam, Medak and Hyderabad.

The agroclimate of the subregion is characterized by hot, semi-arid moist with dry summers, and mild winters. The mean annual temperature varies from 25 to 29^oC. The mean summer (April-May-June) temperature varies from 32 to 34^oC rising to a maximum of 39^oC in May while the mean winter (December –January-February) temperature varies from 20 to 24^oC. The mean annual rainfall varies from 700-1000 mm covering 42 to 45% of the mean annual potential evapotranspiration (PET) ranging between 1600-1800 mm. The district-wise average annual rainfall during 2000-2005 and their normal annual rainfall are presented in Figure 2. While Khammam recorded highest rainfall during 2000-2005 with more than 1000 mm annually in this subregion followed by Warangal, Karimnagar, Hyderabad, Rangareddy, Medak, Nalgonda and the district Mahbubnagar recorded lowest rainfall with annual rainfall less than 600 mm. The southwest monsoon in the area breaks around second-fourth week of June with 90% probability extends till the first week of October covering 85% of the mean annual rainfall. The first peak of bi-modal rainfall occurs in early part of July when precipitation exceeds PET followed by the lull period during the later part of July and early part of August which is usually interrupted by inter dry spell periods at different frequencies.

Therefore, mid season agriculture drought is quite frequent in this Telangana zone. General probability of moderate agricultural drought in this region is about 15%. The second peak occurs in September recharging the soil adequately to meet initial moisture requirements of the post rainy reason (*rabi*) crops in the area. The area has an ustic soil moisture regime. The moisture availability period begins from last part of June and extends till end of November ranging between 120-150 days in a year. The mean annual soil temperature (MAST) in the area being higher than 22^{o}C and the difference between mean summer soil temperature (MSST) and mean winter soil temperature (MWST) being less than 6^{o}C the area qualifies for an isohyperthermic temperature regime.

Warangal District

Warangal district is located in the northern area in the state of Andhra Pradesh, India. The district has an area of 12,846 sq. km and a population of 3,522,644 of which 19.20% was urban as of 2011. The district is bounded by Karimnagar district to the north, Khammam district to the east and southeast, Nalgonda district to the southwest, and Medak district to the west. Warangal is well known for its granite quarries and as a market for rice, chilies, cotton, and tobacco. The Warangal district headquarter is Warangal city which is situated at 17˚ 57’00”N and 79˚30’00”E. The district has a population density of 274 inhabitants/km^2. This district is famous for the production of cotton red chilly watermelon, musk melon and gherkins are grown in the district.

There are total 976 villages in this district. Total carbon and humin carbon were found to be important soil quality parameters. Besides these parameters available K, available N, available P, Copper, cation exchnge capacity, electrical conductivity, dehydrogenase (DHA), organic carbon, exchangeable sodium percentage, pH and zinc were used to generate different thematic maps (Fig.1).

Nalgonda District

Nalgonda / Nallagonda district is a district in Andhra Pradesh. The Nalgonga district headquarter is Nalgonda city which is situated 17°03′00”N 79°16′00”E at Nalgonda district occupies an area of approximately 14,200 square kilometers. The rivers Krishna, Musi River, Aleru, Peddavagu, Dindi and Paleru flow through the Nalgonda district. Major crops include paddy, pulses, mousambi/lime (fruit), millets and oil seeds. Minerals in the district include limestone, black and colour ranites.

There are total 1144 villages in this district. Thematic maps (Fig.2) were generated for different sol properties like available potassium (Av. K), available nitrogen (Av. N), available phosphorus (Av. P), dehydrogenase (DHA), exchangeable sodium percentage (ESP), organic carbon (OC) and soil acidity (pH).

Agro-ecological Sub-Region 10.1

This AESR is represented by Sehore district. The agro-eco sub region constitutes a part of the central highlands and Bundelkhand region. The sub region occupies an area of 8.1 m ha representing 36.3% of the Agro eco region 10 and 2.5% of the total geographical area of the country.

The agro-climate of the sub region in characterized by the hot dry sub humid with dry summers and mild winters. The mean annual temperature varies from 24-25°C. The mean summer (April, May, and June) temperature ranges from 31 - 32°C raising to a maximum of 40°C in the hottest month of May. The mean winter (December, January and February) temperature ranges from 18-19°C dropping to a minimum of 9-11°C in the coldest month of January. The sub region receives a mean annual rainfall of 1000-1500 mm which covers more than 72% of the mean annual PET demand ranging from 1400-1600. The water balance diagram of Bhopal shows that the south west monsoon sets in first /second week of June and recharging the SMCS it extends first half of October covering 94% of mean annual rainfall. In the unimodel rainfall of the sub region the peak period rainfall intensity occurs in the month of July, August and September when P< PET and covers 84% of the total monsoon rainfall and corresponding to humid resulting in water surplus of 300-400 mm. The rainfall ceases in October whereas moisture availability continues up to November. As such the LGP of the region varies from 150-180 days starting from middle of June till the 3rd week of November. Sometimes the rainfall is delayed till the last week of June or first week of July and rainfall is continued in October too. The winter crop gets enough moisture couples with rainfall received in January people harvest good crop on residual moisture. The moisture index varies from -3 to -22 suggesting the prevalence of dry sub humid condition in the area. The soil moisture regime is ustic. The MAST greater than 22°C and the difference between MSST and MWST exceeding 6°C suggest the hyperthermic soil temperature regime in the area.

Sehore District

Sehore district is a district of Madhya Pradesh state in central India and is located at 23°12′N 77°05′E. Its height ranges from 1500 ft. to 2000 ft from the sea level. Sehore is surrounded by six districts *viz*. Bhopal, Raisen, Hoshangabad, Dewas, Shajapur and Rajgarh. It extends between the parallels of latitude 22'31 to 23'40 N and between the meridians of longitude 76'22 and 78'08 E. It has an average elevation of 502 meters. The location of Sehore is in the foothills of the Vindhyachal mountains.

The total number of villages in this district is 1042. The different properties used to generate maps (Fig.3) were alkaline phosphatase, bulk density (BD), available potassium (Av. K), available nitrogen (Av. N), available phosphorus, soil organic carbon (SOC), soil acidity (pH), calcium carbonate ($CaCO_3$%), total nitrogen (Total N).

Discussion

Organic carbon has been considered as single most important soil quality parameter to judge the health of soil (Bhattacharyya et.al. (2000, 2009). It is in view of this, the datasets for soil organic carbon (SOC) for Nalgonda and Warangal districts (Andhra Pradesh) and Sehore district (Madhya Pradesh) were analyzed to find out the distribution of SOC in these three districts. It is found that in-spite of difference in frequency of observation (Table 2), nearly 66%, 47% and 67% areas have 0.5-0.75 percent of SOC indicating medium level of organic carbon. Interestingly, in Sehore and Warangal districts, 20 and 34 percent areas did not have any sample points. AESR 10.1 represented by Sehore district experiences higher (1000-1500 MAR) rainfall than AESR 7.2 represented by Nalgonda and Warangal districts (700-1000 MAR). We have earlier found a strong correlation between MAR and SOC in various parts of the country (Bhattacharyya *et al*., 2000). This may be the reason why nearly 15-18% area of the districts of the dry AESR of 7.2 contains low SOC than the AESR 10.1 showing only 4% areas under SOC to justify relation between organic carbon and climate.

Conclusion

- Interpolation of village level datasets in two strikingly different AESRs was found as an easy and interacting way to find out a relative proportion of soil quality parameters in the form of organic carbon.
- Interpolation technique such as Krigging may be utilized to find the status of soil health as shown in this article.

References

Anonymous (2010) http://maps.google.co.in

Bhattacharyya, T., Pal, D. K., Velayutham, M., Chandran, P. and Mandal C. (2000) Total Carbon stock in Indian soils: Issues, priorities and management. In Special Publication of the International Seminar on Land Resource Management for Food, Employment and Environmental Security (ICLRM), New Delhi, 8-13 November, 2000 pp 1-46.

Bhattacharyya, T., Pal, D. K., Chandran, P. Ray, S. K., Mandal C. and Telpande B. (2008) Soil carbon storage capacity as a tool to prioritise areas for carbon sequestration. *Current Science* **95,** 482-494.

Davis, J.C. (1986). Statistics and Data Analysis in Geology, 2nd ed. John Wiley and Sons, New York

Deutsch, C. V and A. G. Journel, (1992) *GSLIB: Geostatistical Software Library and User's Guide*. Oxford University Press, Oxford, 340 p.

ESRI (2010) www.esri./software/arcgis/index.html

Heine, G. W. (1986) A controlled study of some two-dimensional interpolation methods. COGS Computer 2, no. 2; 60-72.

Journel, A.G. and C.J. Huijbregts (1978) Mining Geostatistics, Academic Press London.

Lam,N. S. (1983) SpatialInterpolation Methods: a Review. American Cartogrpaher. 10. 129-49.

Olea, R. (ed) (1974) Geostatistical Glossary and Multilingual Dictionary. Oxford University Press New York.

Royle, A. G., Clausen, F. L., and Frederiksen, P. (1981) Practical Universal Kriging and Automatic Contouring. Geoprocessing, Vol. 1, pp. 377-394.

Velayutham, M., Mandal, D.K., Mandal, Champa and Sehgal, J. (1999). Agro-ecological subregions of India for planning and development. NBSS Publication 35, 372p. NBSS&LUP, Nagpur, India.

Table: 1 Study area for assessment of quality and resilience of soils in diverse agro-ecosystems

State (districts)	Climate		Soils	Crops	No. of villages
	MAT (^{0}C)	MAR (mm)			
AESR 7.2: North Telangana Plateau, hot moist semi-arid ESR with deep loamy and clayey mixed Red and Black Soils, medium to very high AWC and LGP 120-150 days					
Andhra Pradesh (Warangal and Nalgonda)	25-29	700-1000	Vertisols	Rice-Sorghum	976 (Warangal) 1144 (Nalgonda)
AESR 10.1: Malwa Plateau, Vindhyan Scarpland and Narmada Valley, hot dry, sub humid ESR with medium and deep clayey Black Soils (shallow loamy Black soils as inclusions), high AWC and LGP 150-180 days					
Madhya Pradesh (Sehore)	24-25	1000-1500	Vertisols and associated shallow shrink-swell soils	Wheat-Wheat	1042 (Sehore)

[1]ESR: Eco sub region; [2]AWC: Available water capacity; [3]LGP: Length of growing period

Table: 2 Distribution of Soil Organic Carbon showing various ranges

State	Districts (AESR : MAR, mm)	Frequency of Distribution (per ha)	Organic carbon Range (%)	Area (m ha)	%
Andhra Pradesh	Nalgonda (7.2: 700-1000)	0.001	<0.5 (L)*	0.19	15
			0.5-0.75 (M)*	0.85	67
			>0.75 (H)*	0.24	19
	Warangal (7.2: 700-1000)	0.012	<0.5	0.22	18
			0.5-0.75	0.58	47
			>0.75	0.01	1
			NA	0.42	34
Madhya Pradesh	Sehore (10.1: 1000-1500)	1.637	<0.5	0.02	4
			0.5-0.75	0.40	67
			>0.75	0.05	9
			NA	0.12	20

*H: High; M: Medium; L: Low

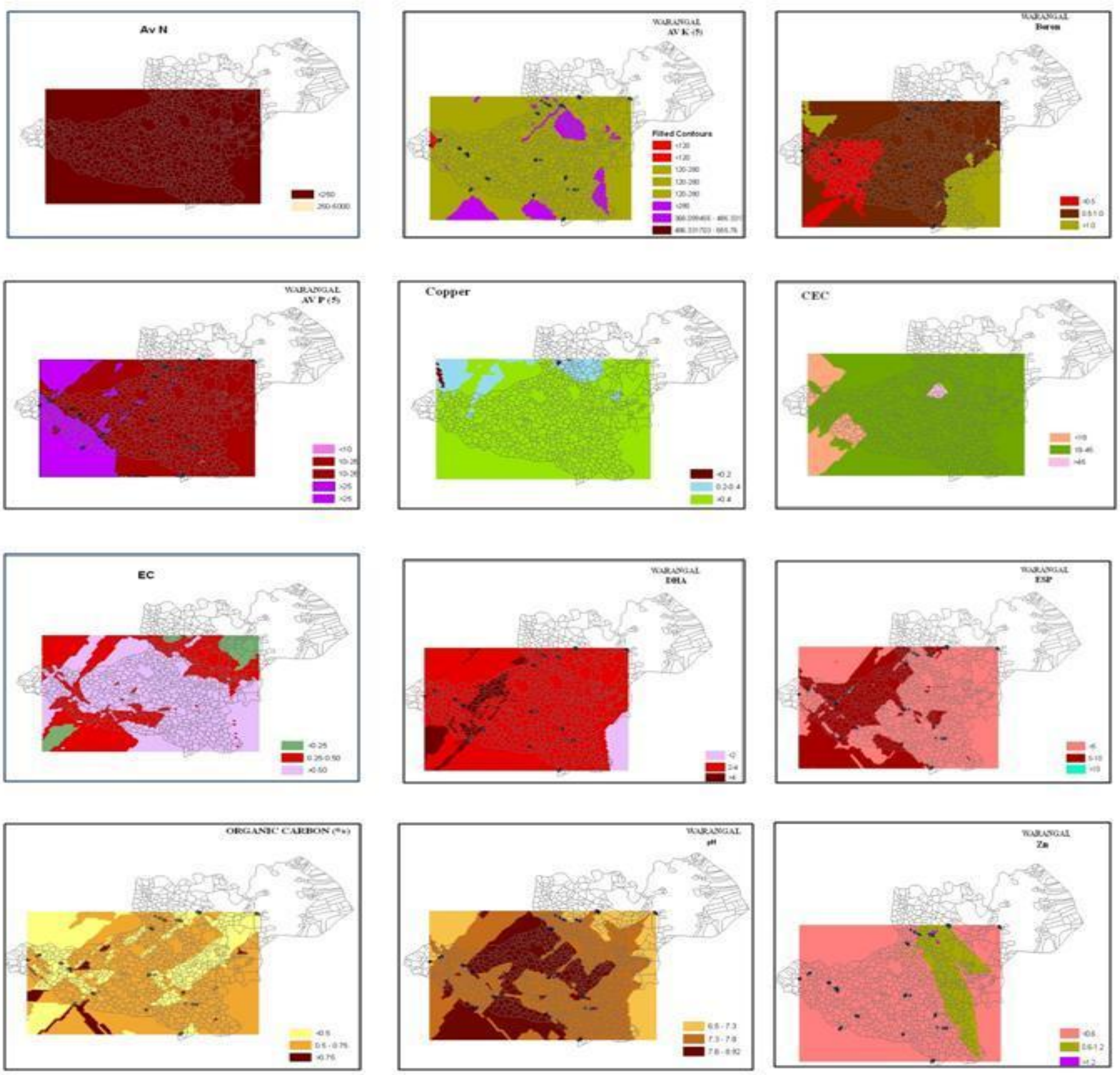


Fig.1 Thematic maps of Warangal district, Andhra Pradesh showing (a) available nitrogen (Av.N), (b) available potassium (Av.K), (c) Boron, (d) available phosphorous (Av.P), (e) copper, (f) cation exchange capacity (CEC) (g) EC, (h) dehydrogenase (DHA), (i) ESP, (j) organic carbon (OC%), (k) pH, (i) Zinc.

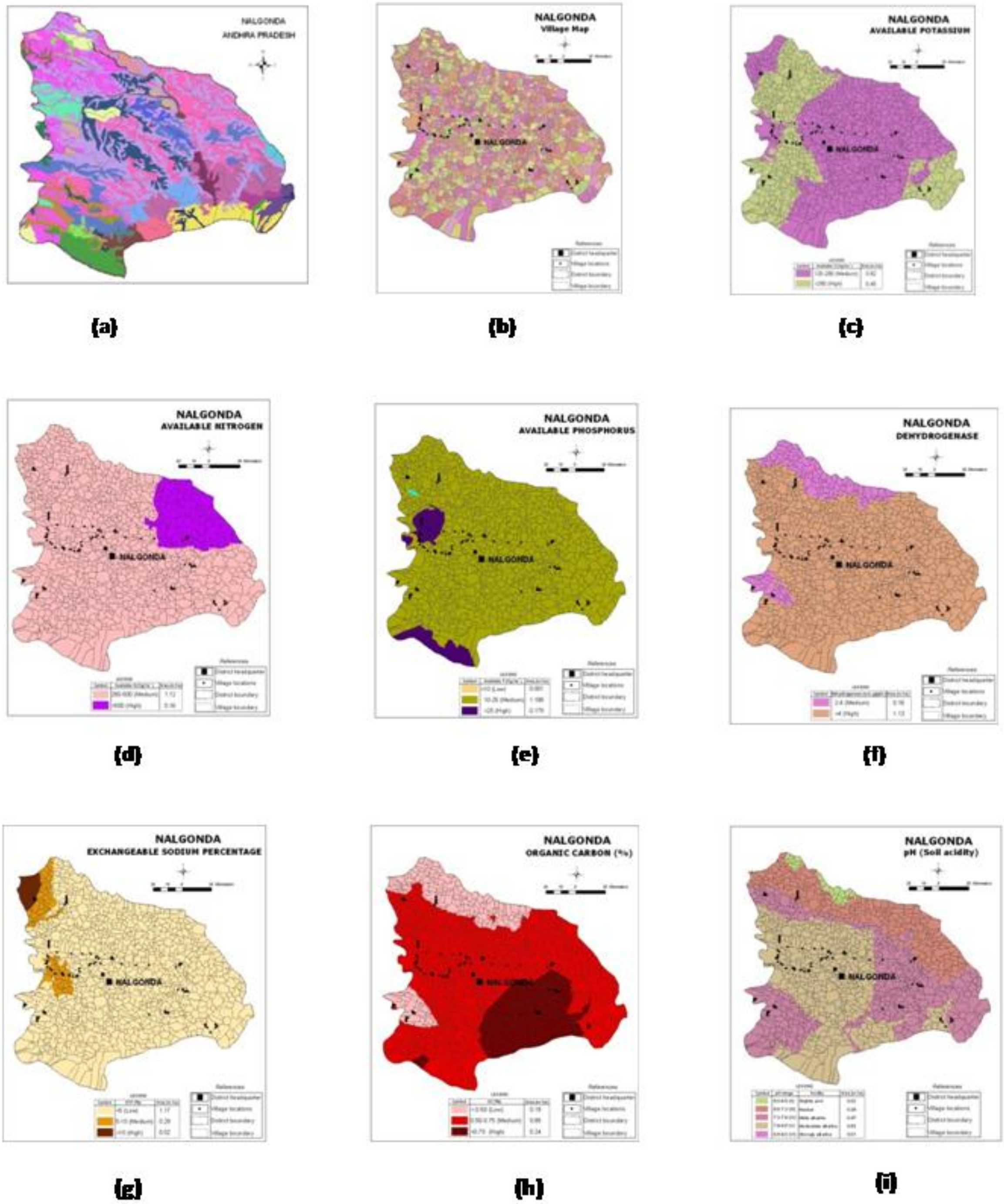


Fig.2 Thematic maps of Nalgonda district, Andhra Pradesh (a) Soils (b) Village boundary. The maps (c) to (i) have been generated following the krigging technique from the 160 no. of point data of soil sample collection. The properties shown in figures (c) to (i) *viz.* available potassium (Av.K), available nitrogen (Av.N), available phosphorus (Av.P), dehydrogenase (DHA), exchangeable sodium percentage (ESP), organic carbon (OC) and soil acidity (pH) are the major characteristics of soils to assess soil quality for its resilience.

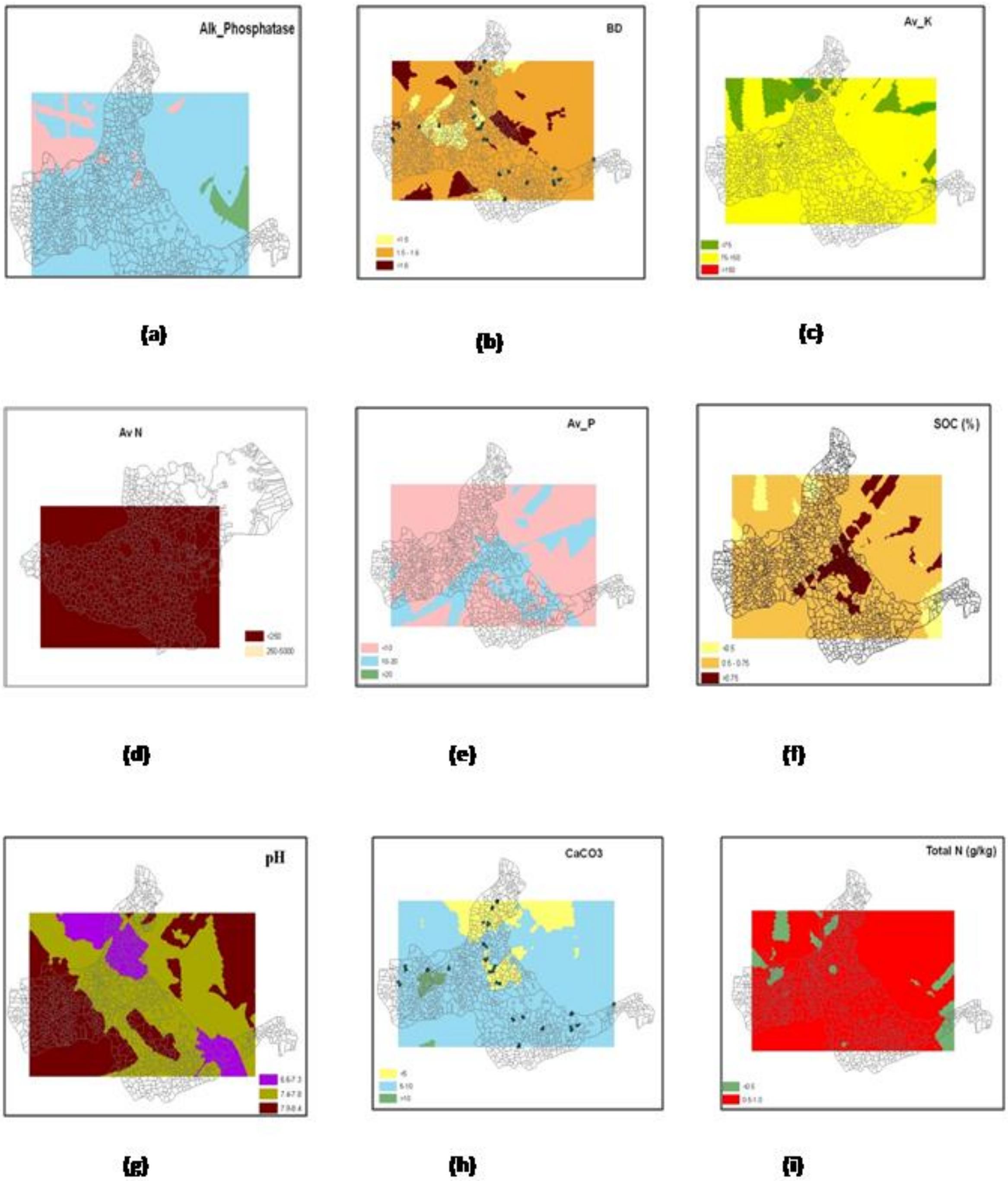


Fig.3 Thematic maps of Sehore district, Madhya Pradesh. The maps have been generated following the kriging technique from the 140 no. of point data of soil sample collection. The properties shown in figures are (a) alkaline_phosphatase, (b) bulk density (BD), (c) available potassium (Av.K), (d) available nitrogen (Av.N), (e) available phosphorous, (f) soil organic carbon (SOC%), (g) soil acidity pH, (h) calcium carbonate ($CaCO_3$%), (i) total nitrogen (Total N).

Assessment of the Economic Value of Soil Resources Information

S.C. Ramesh Kumar[1], L.G. K. Naidu[1], K.V. Niranjana[1] and Dipak Sarkar[2]

[1]National Bureau of Soil Survey and Land Use Planning, Bangalore 560024
[2] National Bureau of Soil Survey and Land Use Planning, Nagpur 440033
E-mail: scrameshkumar@gmail.com

Abstract

Soil surveys are basically aimed at providing comprehensive information about soils. The usefulness of soil survey information depends on the timely supply, details of soil information and its cost effectiveness in application. Providing precise information in shortest possible time with minimum cost is a challenge for a soil surveyor. The advancement in the methodology in soil mapping from conventional to improved methods will be helpful in saving time and cost in conducting the soil survey programme. In this paper, an attempt was made to estimate the cost of soil survey using conventional and improved methods at a micro-watershed scale and the likely economic benefits for the farmers in the use of soil information in soil fertility management.

Garakahalli micro-watershed, the case study area, is located in Channapatna taluk of Bangalore rural district, Karnataka. Detailed soil survey was carried out using cadastral maps of 1:8000 scale. Fourteen soil series and 85 phases of soil series were delineated and a soil map prepared through conventional method. For the same area, IRS 1C PAN+LISS III imagery on 1:12,500 scale was visually interpreted and 5 physiographic units were identified based on elevation and slope and further divided into 10 photomorphic units based on image characteristics. The detailed field investigations were carried out and 12 series were identified and mapped into 30 phases of soil series. The overall cost of detailed soil survey by conventional and improved methods worked out to be Rs 337/ ha and Rs 264/ha respectively. The cost analysis indicates improved method of soil survey can save about Rs 73 per ha (22 %) over conventional method.

The economic benefit that accrued to the farmers of Garakahalli watershed by adoption of proper nutrient management based on soil fertility status as compared to the existing farmer's practices was analysed. The per hectare investment required for site specific nutrient management in Garakahalli micro-watershed worked out to be Rs. 561. The per hectare additional income due to soil management is Rs 1600. The annual net return over investment in soil survey programme is Rs 1039 with a Benefit Cost Ratio of 2.85. This reveals that improved method of soil mapping will help in reduction in cost and time and the investment in soil mapping and fertility assessment is economically viable.

Introduction

Soil survey and mapping is commonly a laborious and costly exercise in subjective judgment. The efforts and cost are justified if soil map allows us to make precise statements about soil properties which influence land development (Beckett, *et al*. 1967). Burrough and Beckett (1971) reported that the grid survey seems likely to give better value for money than series mapped by free survey at map scale greater than 1:50000 and use of aerial photographs reduced the cost of survey (Veenenbos, 1957 and Buringh, 1960). An attempt is made in this paper to make cost benefit analysis of soil survey by both the conventional methodology and by using remote sensing techniques. The economic benefits of using soil survey information in fertility management are also worked out.

Cost - benefit analysis of soil survey

Soil surveys have a wide range of uses that result in benefits which could repay costs in the first year (Klingebiel 1966). The Benefit Cost Ratio (BCR) is 64:1 for soil surveys in low intensity (predominantly range and woodland); an average BCR of 61:1 for soil surveys in medium intensity (mixed agriculture, about half cropland); and an average BCR of 123:1 for soil surveys of high intensity (fringes of rapidly growing metropolitan areas). Estimates of benefits were based on case histories and records of soil survey users. The methodologies by which these benefit estimates were arrived at included costs avoided by using soil survey information for selecting appropriate home sites or routes for motorways, thus avoiding the risk of flooding, subsidence and associated repair costs, as well as straightforward cost savings in construction, higher yields or avoidance of low yields on salt affected irrigated lands, and optimization of revegetation strategies with savings accruing to various range and woodland management practices (eg. those carried out by the National Parks authorities). Dent and Young (1981) used a simplified example to illustrate methodologically that the economic benefits of a soil survey can be calculated by comparing the profitability of different cropping systems on each of mapping unit.

In an open and competitive market, a good measure of the quality of a soil survey would be the economic benefits generated by the use of the information. These benefits would depend upon changes in the production system resulting from the use of the information, which in turn would depend on the accuracy and precision of the information. The utility/usefulness of soil survey information depends on the timely supply, details of soil information and its cost effectiveness in application. Providing precise information in shortest possible time with minimum cost is a challenge for a soil surveyor. The advancement in the methodology in soil mapping from traditional soil mapping techniques to improved methods is very helpful in saving time and cost in the soil survey programme.

A Case Study of Garakahalli Micro-Watershed

In this study, an attempt was made to estimate the cost of soil survey using conventional and improved method in Garakahalli micro watershed located in Bangalore rural district of Karnataka State. The objective is to estimate different cost components involved in two soil survey methods and likely economic benefits for the farmers in the use of soil information in soil fertility management.

Detailed soil survey using conventional methodology

Garakahalli micro watershed is located in Garakahalli village, Channapatna taluk of Bangalore rural district, Karnataka. The area of the water-shed is 527 ha. The detailed soil survey of Garkahalli micro-watershed was carried out using cadastral maps of 1:8000 scale. Preliminary traverse of the watershed was taken up to aquaint with field boundaries, field survey numbers and physiography. During the traverse variation in geology, drainage pattern, slope characteristics, land use, land forms and physiographic units were identified and initial legend was prepared. Based on the variability observed on the surface, transects were selected across the slope covering all the physiographic units. In the selected transect, profiles were located at close intervals to take care of any change in the land features like break in slope, erosion, gravel, stones etc. In the selected sites, profiles were opened up to 180 cm or to the depth limited by rock or hard substratum and studied in detail for all their morphological and physical characteristics. The soil and site characteristics were recorded for all profile sites on a standard proforma at per the guidelines given in USDA Soil Survey Manual (Soil survey Staff, 1993).

Based on soil-site characteristics, the soils were grouped into different soil series. Soil depth, texture, colour, gravel content, calcareousness, nature of substratum and horizon sequence were the major identifying characteristics for differentiating soil series in the watershed area. Based on the above characteristics, 14 soil series were identified and 85 phases of soil series (management units) were mapped and a soil map prepared at 1: 8000 scale (Ramesh Kumar *et al.* 2002).

Detailed soil survey using improved methodology

False colour composite of IRS 1C PAN+LISS III imagery on 1:12,500 scale was visually interpreted. The physiography map delineated during conventional survey was used in conjunction with the imagery. Based on image interpretation elements like tone, texture, pattern, shape, size, association and drainage pattern, land use/land cover details were used for delineating landforms and their further subdivisions. The Garkahalli watershed consists of granite and granite gneiss landform. This landform was divided into 5 physiographic units based on elevation and slope. They were further divided into 10 photomorphic units based on image characteristics. A soil map was prepared through visual interpretation of satellite imagery at 1: 12,500 scale.

Before starting the field survey, listed all the phsyiographic units occurring in the watershed area and its geographic distribution and frequency of occurrence. Checked thoroughly the accuracy of image interpretation for physiography specially for geology and slope classes while traversing for transect studies. Corrections were incorporated wherever necessary. This facilitated in deciding the number of transects to be studied and also in the proper distribution of transects in the watershed. The profiles in each transect were studied intensively at close intervals for accounting the soil variability that could be expected in each unit. On completion of each transect, the soil profile data was arrayed unit wise and a preliminary legend was developed by translating each image interpretation-cum-physiographic unit in terms of soils. About 12 series were identified and mapped with 30 phases of soil series. The phases were mapped by traversing all over the area.

Cost of soil survey

The cost of information increases with its precision and specificity in soil resource programme. The details of cost involved in conventional and improved methods are given in Table 1. The major items in soil survey are salaries for field staff (one party leader, field assistant, supporting staff and driver) which accounts for Rs 72253 (41%) and Rs 43352 (31%) in conventional and improved methods respectively (Table 1). Daily allowances for field staff during field work accounts for 8.4 and 6.5 per cent to total cost of survey. Cost of satellite data, field materials like base map, field kit etc works out to 0.3 and 14 per cent in conventional and improved methods. Transport cost (POL) for field visit and sample collection accounts for 3.4 and 2.9 per cent of total cost in conventional and improved method. Labour cost for profile digging and soil sample collection accounts for 10.6 and 5.4 per cent of total cost in conventional and improved methods respectively. Laboratory analysis of profile soil samples includes sample preparation, chemicals and glassware cost which accounts for 10 per cent each in both conventional and improved methods.

Table 1 Cost of soil survey in Garakahalli micro watershed (527 ha)

Items	Conventional Method (Rs)	% to total	Improved Method(Rs)	% to total
Salaries for field staff	72253	40.7	43352	31.2
Daily Allowances	15000	8.4	9000	6.5
Cost of Satellite data, SOI top sheets and filed material etc.	500	0.3	19000	13.7
Transport cost	6000	3.4	4000	2.9
Cost of Labour for field survey	18750	10.6	7500	5.4
Laboratory analysis	17500	9.9	15000	10.8
GIS map making and printing	8000	4.5	8000	5.8
Report preparation and printing	10000	5.6	10000	7.2
Total Cost	148003	83.3	115852	83.3
Over head charges (including administration, electricity, rent on building etc.) @ 20 % of total	29601	16.7	23170	16.7
GRAND TOTAL (Rs)	177604	100.0	139022	100.0
Per hectare cost of soil survey		337		264

Using Geographic Information System (GIS) for map making involves digitization of base map and data inputting and map generation accounts for 5 per cent in both the methods. Report preparation and printing of soil maps worked out to about 5 per cent of total cost in both the methods and the cost of overhead charges worked out to 17 per cent of total cost of soil survey. The overall cost of detailed soil survey in conventional method is Rs 337/ ha and Rs 264/ha in improved method. The cost analysis indicates improved method of soil survey can save about Rs 73 per ha (22 %) over conventional method of soil mapping. Likewise, modern method of reconnaissance soil survey using remote sensing techniques may save about 50 per cent of time and cost over that of conventional soil survey using Survey of India topographical maps.

Benefits from soil survey information

It is very difficult to assess the benefits from a soil survey programme. The economic benefits of soil survey information depend on the period of utility of soil map. Beckett (1981) in his paper on cost benefit relationship of soil survey reported that the useful life of soil survey is about 25 years. One of the valuable features of soil information is that, once generated, it can be used repeatedly and across a range of applications – soil information can therefore create significant options for future use, but only if such information is appropriate to the needs is retained, and remains easily accessible to future users. The idea to 'collect once, use twice (or more)' makes sense in economic terms, and the more often a piece of information can indeed be utilized, the higher is its cost-effectiveness.

The soil survey report consists of different thematic informations like soil depth, texture, slope, erosion, gravelliness, soil pH, available soil macronutrients (Nitrogen, Phosphorus, Potassium) and micronutrients (Iron, Zinc, copper and Manganese), land capability classification, land irrigability classification , fertility capability classification and information on soil suitability (potential area) for different crops.

Utility of soil maps

The utility of soil maps is assessed in terms of land capability for agriculture and suitability for locally grown crops. This analysis shows the suitable area available in the watershed for allocation of various crops to be grown and to maximize net income from land. The utility of soil maps in interpreting for land qualities and land use planning are as follows.

Assessment of soil quality and productivity

Soil forms the basis for crop production activity and is the most precious resource. The contribution of soil quality for crop productivity (B:C ratio) was assessed by analyzing the soil mapping unit wise benefit cost ratios for five major crops viz., finger millet, groundnut, mulberry coconut, banana and horse gram are presented in the Table 2. The distinct variation in benefit cost ratio with respect to soil mapping units is recorded. The Benefit cost ratio is 3.4 to 3.9 for banana, 1.84 to 4.5 for mulberry, 1.68 to 2.96 for coconut and < 2 for groundnut, finger millet and horse gram. The soil mapping unit Khb1 covering 19.26 ha has a benefit cost ratio of 4.5 for mulberry, 3.92 for banana, 1.73 for horse gram and 1.41 for groundnut. The economically suitable soil units for crops are ranked based on benefits cost ratio as follows.

Table 2 Soil mapping unit wise benefit cost ratio for different crops in Garakahalli

Soilmapping units	Land use types (B:C Ratio)						Area (ha)
	Finger millet	Ground nut	Mulberry	Coconut	Banana	Horse gram	
CbB1	1.87	1.31	3.43	1.57	3.82	1.49	16.44
CcB1	1.81	1.50	3.37	1.99		1.49	17.49
DgibB1	1.65		2.78	1.97			1.52
EgihB1-R	1.61	1.79		1.82			5.33
FbB1	1.94	1.36	3.85			3.85	9.69
FcB1	1.63	1.10					15.44
GcB1	1.66	1.22	2.79	2.14	3.83		8.76
HbB1		1.25	2.89	2.09			6.00
HcB1	1.41	1.14	2.63	1.92			2.41
Hg1iC1		1.21	2.09	2.11		1.70	3.71
Hg2iC1	1.49			1.68			2.31
HmC1st3	1.42					1.27	2.16
IcB1	1.52					1.26	3.29
ImB2	2.12					1.65	2.08
JhB1	1.27			2.64			7.08
KbB1	2.04	1.41	4.5	2.52	3.92	1.73	19.26
KbC2	1.26	1.22					5.97
KcB1	1.59	1.59	3.54	2.24	3.69	1.50	22.77
KcC1	3.74			2.76			4.57
Kg1hB1	1.49		1.90	2.32			2.54
Kg1hC2st4-R	1.52	1.24					4.50
KhB1	1.69	1.60	4.5	2.06	3.48	1.66	43.77
KmB1	1.50	1.77	3.08	2.05	3.41		16.59
Lg1bC2st3	1.36		1.84	2.20			5.28
MhB1	1.51	1.54	2.73	2.22			10.41
NhB1	1.31	1.44	4.76	2.21	3.93		4.68
NcB1	1.92	1.64	2.71	1.97	3.53	1.63	10.82
NhB1	1.95			2.96			3.89
NiB1	1.89	1.51	4.04	2.17	3.65	1.70	10.68

Crop	Profitable map units (Benefit Cost ratio)
Finger millet	KcC1 (3.74) > ImB2(2.12) > KbB1(2.04)
Groundnut	Eg1hB1-R (1.79) > NcB1(1.64), KhB1 (1.66)
Horse gram	FbB1 (3.85) > NiB1(1.7)>KhB1(1.66)
Mulberry	NbB1(4.76) > KbB1(4.5) >NiB1(4.04)
Banana	NbB1(3.93) >KbB1(3.92)>GcB1(3.83)

The benefit cost ratio indicates the most profitable crops. They are mulberry (B:C ratio of 4.5), banana (B:C ratio of 3.5) and coconut (B:C ratio of 2.5). Similar kind of analysis on effect of soil variability on gross returns of cling peach varieties were reported by Bie *et al* (1973). This kind of analysis helps in selection of soils for improving productivity and profitability of a given land.

Land use planning

A general objective in land-use planning concerning agricultural production is to allocate the land in such a way that net benefits are maximized and the various costs are minimized. In order to do this, the bio-physical and socio-economic data were integrated using GIS to study the productivity performance of different land use types in the Garakahalli watershed. The normative land use plans were worked out using Multiple Goal Linear Programme (MGLP). Multiple goals can involve such consideration as maximization of net income, minimization of cost, minimization of bullock, men and women labour, maximization of farm yard manure use, minimization of nitrogen, phosphorus and potassium use. The land management indicators show that the minimum area required for meeting food requirements of local population is 200 ha under finger millet which is a staple food crop (Table 3).

Table 3 Normative land-use plans for Garakahalli watershed (area in ha)

Crop	Series B	Series C	Series D	Series E	Series F	Series G	Series H	Series I	Series J	Series K	Series L	Series M	Series N	Total
Model I — maximization of net income														
F. millet	7.35	50.61		21.87			51.47	29.95	10.66	19.99	8.10			200.00
Mulberry										123.49			21.62	145.11
Banana					38.00	27.03								65.03
Coconut			8.61									11.38	8.45	28.44
Total use	7.35	50.61	8.61	21.87	38.00	27.03	51.47	29.95	10.66	143.48	8.10	11.38	30.07	438.58
Model II — minimization of cost														
F. millet	7.35	50.61	0.00		38.00	27.03	38.96	29.95			8.10			200.00
Mulberry			8.61				2.13					11.38		22.12
Coconut													28.44	28.44
Total use	7.35	50.61	8.61		38.00	27.03	41.09	29.95			8.10	11.38	28.44	250.56
Model III — minimization of bullock labour														
F. millet					38.00			29.95		123.95	8.10			200.00
Mulberry		14.92	7.20											22.12
Coconut		0.00	1.41			27.03								28.44
Total use		14.92	8.61		38.00	27.03		29.95		123.95	8.10			250.56
Model IV — minimization of men labour														
F. millet	7.35	26.53			38.00		37.96	29.95	10.66		8.10	11.38	30.07	200.00
Mulberry			8.61				13.51							22.12
Coconut		1.41				27.03								28.44
Total use	7.35	27.94	8.61		38.00	27.03	51.47	29.95	10.66		8.10	11.38	30.07	250.56
Model V — minimization of women labour														
F. millet	7.35	50.61		21.87	0.00	27.03			10.66	41.03	0.00	11.38	30.07	200.00
Mulberry					22.12									22.12
Coconut							28.44							28.44
Total use	7.35	50.61		21.87	0.00	27.03	28.44		10.66	41.03	0.00	11.38	30.07	250.56
Model VI — maximization of FYM														
F. millet	7.35	50.61	8.61	21.87	33.95	0.00	51.47	29.95	10.66	143.48	0.00	0.00	30.07	388.02
Mulberry						2.64					8.10.	11.38		22.12
Coconut					4.05	24.39								28.44

Total use	7.35	50.61	8.61	21.87	38.00	27.03	51.47	29.95	10.66	143.48	8.10	11.38	30.07	438.58
Model VII — minimization of nitrogen use														
F. millet	7.35	50.61	8.61	21.87	15.88	27.03	51.47	17.18						200.00
Mulberry					22.12									22.12
Coconut									10.66	6.40		11.38		28.44
Total use	7.35	50.61	8.61	21.87	38.00	27.03	51.47	17.18	10.66	6.40	8.10	11.38		250.56
Model VIII — minimization of phosphorus use														
F. millet	7.35	50.61	8.61	21.87	38.00	27.03	40.73				5.80			200.00
Mulberry							10.74					11.38		22.12
Coconut									10.66	17.78				28.44
Total use	7.35	50.61	8.61	21.87	38.00	27.03	51.47		10.66	143.48	5.80	11.38		376.26
Model VIII — minimization of potash use														
F. millet	7.35	50.61	8.61		37.75	27.03		29.95	10.66		8.10	11.38	8.56	200.00
Mulberry				21.87	0.25									22.12
Coconut							28.44							28.44
Total use	7.35	50.61	8.61	21.87	38.00	27.03	28.44	29.95	10.66	143.48	8.10	11.38	8.56	394.04

The suitability analysis shows that there is a possibility of increase in area of 7.4 ha in series B, 50.61 ha in series C, 21.87 ha in series E and 51.47 ha in series H. The area under mulberry remain unaltered as 22.12 ha except under maximization of net income (145.1 ha). The estimated cost and net income for each alternate land use plan are documented and reported (Ramesh Kumar *et al*. 2002).

Minimizing nutrient misapplication

Declining soil fertility is one of the important factors that directly affect the productivity. Among others, fertilizers are one of the costly inputs and continue to exert significant contribution to production of additional food grains. Farmers are presently applying fertilizers according to the cost and availability of fertilizers during crop season without any due consideration to inherent soil fertility. The extension agencies are recommending the fertilizers based on package of practices that are based on soil test results for a region. Under these circumstances, soil variability within a field/watershed should be taken as a basis for fertilizer recommendation. In this paper, an attempt has been made to demonstrate the possible economic benefits for the farmers by proper nutrient management based on soil fertility status compared with the existing situation. The fertility variability in Garakahalli micro-watershed is presented in Table 4. Large extent of area is under low nitrogen and phosphorus status.

Table 4 Fertility status of Garakahalli micro watershed (Area in ha)

Items	Low	Medium	High
Nitrogen	492	35	0
Phosphorus	239	233	55
Potash	148	295	83

Finger millet is the major crop grown in Garakahalli micro-watershed. The present level of fertilizer use by farmers is taken for calculating fertilizer requirement without soil test. In the total watershed (527 ha), farmers are presently applying 65922 kg of NPK fertilizers and are producing 6851 quintals of finger millet (Table 5). When the fertilizer requirement for finger millet cultivation is made by considering the soil fertility status (with soil test) the total (NPK) fertilizer requirement will be 69006 kg which can yield 7905 quintals.

Table 5 Fertilizer use pattern with and without soil information in finger millet cultivation

Soil fertility management	Fertilizers use pattern					Yield (Qt) /income(Rs) level
	Items	Nitrogen	Phosphorus	Potash	Total (NPK)	
WITH OUT SOIL TEST	Quantity (kg)	37770	27578	574	65922	6851
Blanket level of fertilizer use	Value(Rs)	395075	441247	12637	848959	5480800
WITH SOIL TEST Site specific application	Quantity (kg)	32506	22917	13584	69006	7905
	Value(Rs)	340008	366668	298841	1005517	6324000
Difference in fertilizer (excess/deficit) use	Quantity (kg)	-5265	-4661	13009	3084	1054
	Value(Rs)	-55067	-74579	286203	156558	843200

The change in fertilizer use (difference between soil test and without soil test) shows that there is scope for reducing nitrogen (-5265 kg) and phosphorus (-4661 kg) and additional requirement of potash (+ 13009 kg) for the watershed. The additional cost for implementing the site specific fertilizer recommendation is Rs 156558 for the watershed. With the introduction of site specific fertilizer management, the finger millet production can be increased by 1045 quintals with an additional economic benefit of Rs 843200 for the watershed.

The economic viability of soil survey information is presented in Table 6. The per hectare cost of soil survey (improved method) is Rs 264 and the per hectare additional cost for site specific fertility management (cost of fertilizers) is Rs 297. The per hectare investment required for site specific nutrient management in the micro-watershed works out to be Rs 561. The per hectare additional income due to soil management is Rs 1600. The annual net return over investment in soil survey programme is Rs 1039 with a Benefit cost ratio of 2.85.

Table 6 Economic viability of soil survey information

Particulars	Total watershed (Rs)	Rs/ ha
A) Cost of soil survey using improved method	139022	264
B) Cost of soil fertility management	156558	297
C) Total investment required (A+B)	295580	561
D) Additional in income due to soil fertility management	843200	1600
E) Annual returns over investment in soil survey and nutrient management (D-C)	547620	1039
F)Benefit Cost ratio (D/C)	2.85	2.85

Conclusions

The economics of conventional and improved methods of soil survey has showed that improved method of soil survey can minimize the cost upto 22 per cent. The soil survey information is useful in studying the soil quality and productivity relationship and to allocate crops based on net returns per rupee investment and minimizing fertilizer misapplications. The investment in soil survey and fertility management is economically viable.

Acknowledgement

The authors are thankful to Sri. R.S. Reddy, Ex Principal Scientist, Regional Centre Bangalore for his suggestions in preparing this paper.

References

Abichandini, C.T.(1980). Use of aerial photographs in soil survey of arid zone of western Rajasthan, Ann. Arid Zone Res. 4: 172-184.

AIS & LUS.(1970). Soil Survey Manual. All India Soil and Land Use Survey, I.A.R.I., New Delhi. 121 p.

Beckett, P.H.T., Burrough, P.A. and Webster, R.(1967). The cost of soil survey in relation to the classification criteria employed. Journal of the India Society of Soil Science. 15:187-192.

Beckett, P.H.T., and Burrough, P.A.(1971). The relation between cost and utilitility in soil survey IV: Comparision of utilities of soil maps produced by different survey procedures. Journal of soil Science society of America. 22: 466-480.

Beckett, P.H.T and Webster, R.(1971). Soil variability –a review. Soil fertility. 34,1-15.

Beckett, P.H.T.(1981). The cost–benefit relationships of soil surveys. In the proceedings of workshops on Soil Resource Inventory and Development Planning held at Cornell University, Technical Monograph No 1, Soil Management Support services, USDA, Washington, DC.

Bie, S. and Beckett, P.H.T.(1971). Quality control in soil survey procedures. Journal of soil Science society of America. 22: 453-465.

Bie, S. W. and Ulph, A.(1972). Economic value of soil survey information. Journal of Agricultural Economics. 23. 285-297.

Bie, S.W., Ulph, A. and Beckett, P.H.T.(1973). Calculating the economic benefits from soil survey, Journal of Soil Science. 24 . 429-435.

Burrough and Beckett, P.H.T.(1971). The relation between cost and utility of Soil Survey Journal of Soil Science. 22:359-394.

Buringh, P.(1960). The application of areal photographs in soil surveys. in "Manual of Photographic Interpretation", American Society of Photogrammetry, Washington, DC.633-666.

Dent, D. and Young A.(1981). Soil Survey and land evaluation. George Allen & Unwin, London.

Dwivedi, R.S. (1985). Soil resource survey of silent valley and it's environs using Land Sat MSS data J. Ind. Soc. P.I. & R.S. 13.(2).

Karale, R.L., Venugopal, K.R. and Hilwig, F.W.(1970). Report on Reconnaissance Soil Survey in the Ganges Alluvial Plain, Meerut District, U.P., Internal Report, I.P.I., Dehra Dun.

Klingebiel, A.A., 1966. Cost and returns of soil survey. Soil conservation 32:3-6.

Kolarkar, A.S. and Abichandini, C.T.(1967). Soil survey of Jalor development block- using aerial photo-interpretation technique, Ann. Arid Zone Res. 6: 220-227.

Kudrat, M., B. Prabhakaran, T.R.S.V.S. Sastry, A.K. Tiwari, K.P. Sharma & M.L. anchanda. (1977). Quantative estimation of soil loss through remote sensing: A case study of part of Chotanagpur Plateau, India. pp. 37-44. *In:* C.V.J. Varma & A.R.G. Rao (eds.) Management of Sediments: Philosophy, Aims and Techniques. Central Board of Irrigation and Power, New Delhi.

Mirajkar, M.A. and T.R. Srinivasan (1975). Landsat Photo interpretation for preparation of small scale maps through a multistage approach. *Photonirvachak* 3**:** 87.

NBSS&LUP (2005). Standardization of methodology for large scale soil mapping using satellite data, Division of Remote Sensing Application, NBSS Report No. 907 NBSS&LUP, Nagpur.

NRSA(1976). An Application of Satellite Remote Sensing Techniques for Integrated Pilot Survey of Natural Resources in Parts of Punjab and Haryana – An Abstract Report, National Remote Sensing Agency, Secunderabad, India.

NRSA(1978). Satellite Remote Sensing Survey of Natural Resources of Andhra Pradesh. Project report, National Remote Sensing Agency, Secunderabad, India.

NRSA(1979). Satellite Remote Sensing Survey of Natural Resources of Haryana. Project Report, National Remote Sensing Agency, Secunderabad, India.

NRSA(1981). Satellite Remote Sensing Survey for Soil and Land Use in Part of Uttar Pradesh. Project Report, National Remote Sensing Agency, Hyderabad, India.

Ramesh Kumar, S.C., Krishnan, P,.Velayutham, M. and Gajbhiye, K.S.(2002). Economic Land Evaluation for Sustainable Land Management of Watersheds in Different Agro-Climatic Zones of Karnataka. Volume - I Summary report and Vol-II Database, NBSS&LUP Technical Report no.582, National Bureau of Soil Survey and Land Use Planning, Nagpur.

Reddy, R.S. Shivaprasad, C.R., Reddy,P.S.A., Sehgal,J.L., Ranganath,B.K. and Adiga,.S.(1991). Workshop on IRS satellite mission and its applications, Bangalore, October, 28, 1991.

Sehgal, J.L., Saxena,R.K. and Vadivelu, S (1989). Soil resource mapping of different states in India, Filed manual, NBSSULP, Technical Bulletin No 13. 73p.

Sehgal, J.L.(1990). Soil Resource Mapping of Different States of India. Why and How? Soil Bull. 23**.** National Bureau of Soil survey and land Use Planning, Nagpur, India. 73 p.

Singh, A.N. (1980). Comparison of reconnaissance soil maps prepared by conventional method and Landsat imagery interpretation. Photonirvachak, J. Indian Soc.Photo-Int. and remote sensing, 8 (1): 1-8.

Singh, A.N. and Dwivedi, R. S. (1986). The utility of Landsat imagery as an integral part of database for small scale soil mapping. Int. J. Rem.Sens.7, 1099-1108.

Soil Survey Staff (1999). Soil Taxonomy. Agriculture Handbook 436. 2nd edition. U.S. Department of Agriculture, Washington DC. 869 p.

Srinivasan,T.R.(1976). Taxonomy of saline, alkali and saline and alkali soils. J. Ind. Soc. Soil Sci. 24, 12.

Stephens, C.G. (1953). Soil survey for land development, FAO Agric. Studies. 20

Veenenbos, J.S. (1957). Methods and costs of soil and land classification survey when using areal photographs. Afri. Soils 4. 122-135.

Venkataratnam, L. and K.R. Rao (1977). Computer aided classification and mapping soils and soil limitations using landsat multispectral data. pp. 101-104. In: Proceedings of Symposium on Remote Sensing for Hydrology, Agriculture and Mineral Resources. Space Applications Centre, Ahmedabad, India.

Venkataratnam, L.(1980). Use of remotely sensed data for soil mapping. Photonirvachak 8: 19-26.

Western, S. (1978). Survey quality and survey value. In Soil survey contracts and quality control. Monographs on Soil survey. Clarendon Press, Oxford, UK.

Suitability Evaluation of Major Soils of the Indo-Gangetic Plains for Wheat

Jagdish Prasad, P. Tiwary, Dipak Sarkar, G.S. Sidhu, R.S. Singh, A.K. Sahoo, S.K. Mahapatra, C. Mandal, S.K. Ray, P. Chandran, D.K. Pal and T. Bhattacharyya

National Bureau of Soil Survey and Land Use Planning (ICAR), Amravati Road, Nagpur 440 033, Maharashtra, India
E-mail: jprasad57@gmail.com

Abstract

The Indo-Gangetic Plains with an area of 52 m ha cover most of the northern states with rice-wheat as the dominant cropping system. These two crops have been providing major share of the national pool of the foodgrains since the Green Revolution. It is reported that the Green Revolution era is no more sustainable due to various soil related problems. The situation is further aggravated by climate change. This situation warrants for scientific evaluation of soils and their productivity so that possible intervention can be adopted particularly in wheat grown soils under mechanized farming.

We have evaluated soils (*viz.* Masitawali, Hirapur, Jagjitpur, Sakit, Zarifa Viran, Haldi, Mohanpur and Fatehpur) for their suitability to wheat crop. The landscape and soil suitability evaluation was carried out following the standard method. The computation of climatic limitation (temperature), landscape and soils indicated that except Jagjitpur (suitable), other soils are moderately suitable (Sakit, Haldi, Mohanpur, Fatehpur) or permanently not suitable due to the combined influence of exchangeable sodium and organic carbon in soils. Since effect of irrigation makes moisture-related soil factor redundant for crop growth the atmospheric temperature during the growing season seems to be important. The lowering of suitability class based on selected soil parameters is not justified on these soils which produce more than 4 tons of grain as these properties are dynamic. We took Fatehpur soils as reference for evaluation. These soils produced wheat yield of 4.5 t ha^{-1}. Accordingly soil parameters and crop yield were normalized to derive absolute deviation. The correlation between yield and soil parameters was also carried out. An excellent correlation (r=0.99) between the bulk density (BD) of soil and wheat yield indicated that BD should be considered as an important soil parameter influencing the yield.

Introduction

Land evaluation is culturally based on the understanding of soil, and consequently on its characteristics, quality and geographical distribution. The methodologies of land evaluation have an almost infinite series of variations, depending on the cultural and practical context in which they are carried out. The land evaluation (so called suitability evaluation) directly explains predictions for potential land use (Van Diepen et al., 1991). However Dent and Young (1981) stressed that land evaluation fundamentally aims to anticipate the consequences of change. In general, it provides a rational basis for taking land-use decisions based on analysis of relation between land use and land, giving an overall estimate of required inputs and projected outputs.

Many Indian researchers worked out soil-site suitability for different crops based on biophysical factors. Frequently used limitation methods without considering the realised yield or actual productivity of the crop wherein the relative importance of a soil property on crop production is often expressed by a weight factor. In most of the cases the computed suitability class does not match the productivity of crop at a reference site. In this paper we tried to improvise upon the method of Soil Property Crop Performance (Tang and Ranst, 1998) to evaluate the suitability of some major soils of the Indo-Gangetic Plains stretching from west to eastern part of the country for wheat crop. This information is very crucial in determining the weighting factors of the land properties on crop production in the overall land evaluation process.

Materials and Methods

Eight Benchmark soils namely Masitawali, Hirapur, Jagjitpur, Sakit, Zarifa Viran, Haldi, Mohanpur and Fatehpur have been included in present study. The general information on these soils was taken from NBSS & LUP reports.

The soils were evaluated for their suitability using two quantitative land evaluation methods described by Sys *et al*. (1991) and Tan and Ranst (1998). For the Sys method, the soil characteristics are expressed on weighted mean basis. The soil-site characteristics were expressed in terms of degree of limitation (0, 1, 2, 3, 4) as per standard definition (FAO, 1976). The method of Tan and Ranst (1998), is based on the principle of similarity between crop yield and soil property distribution and its quantification using the following steps:

- Normalization of the yield and the soil properties of series
- Calculation of the absolute distance values and their ranges (maximum and minimum)
- Computation of the correlation between yield and soil property series

Results and Discussion

The site characteristics (Table 1) and relevant physical and chemical properties are given in table 2. The constraints of parameters and suitability for wheat have been shown in table 3. The weighted mean of parameters is given in table 4. The clay content of soils vary from 3.8- 45.8 per cent gradually increased with depth except Sakit, Jagjitpur and Fatehpur soils (Table 2). The silt content ranged from 8.5 to 71.8 per cent and its distribution with depth was uniform in most of the soils whereas Haldi and Fatehpur soils showed opposite trend. The depth distribution of clay indicates that P4, P6 and P7 show the enrichment in clay content in their lower horizons (Table 2). The increasing trend of fine clay with depth may be due to translocation of fine material from surface horizons and to the subsurface layers (Pal *et al.*, 1994). Bulk density (BD) of soils ranged from 1.4 to 1.8. BD values more than 1.4 Mg m^{-3} may pose problem for root penetration (FAO, 1995).

The saturated hydraulic conductivity of soils varied from 0.02 to 30.3 $mmhr^{-1}$. In P1, P4 and P6, the sHC decreased with depth whereas, P5 and P8 showed gradual increase and P2, P3 and P7 show irregular trend with depth (Table 2). The higher values in surface horizons are due to their porous nature as a result of regular tillage operations and relatively less clay content. The decrease in sHC with depth in P1, P4 and P6 is due to increase in ESP in the same order.

Soil pH (1:2 soil water suspension) ranged between 7.1 to 9.8 i.e. neutral to very strongly alkaline (Table 2), and increased with depth in all the soils. The increase in the pH values appears to be related to increase in ESP. Calcium carbonate ranged from 0.5 to 16.7 per cent (Table 2) with an increase in trend with depth in all the soils. The precipitation of Ca^{2+} as $CaCO_3$ is due to decrease in PCO_2 and due to the increase in the ESP (Pal *et al.*, 2000a). Organic carbon content in these soils ranged from 0.2 to 1.17 per cent which is low to moderate and in general decreased with depth (Table 2).

ECP varied from 2 to 78 per cent and showed irregular distribution with depth. The EMP ranged from 5 to 49 per cent and decreased with depth except P3, P4, P7 and P8. The ESP varied from 1 to 78 per cent (Table 2) and increased with depth in P1, P2, P4. The ESP was almost similar in P6, P7 and P8. The enhancement of ESP and EMP is related to the relative decrease of Ca ions in soil solution due to the precipitation of Ca ions as $CaCO_3$ (Pal *et al.*, 2000).

In land evaluation (Sys *et al.*, 1991) except temperature other climatic parameters have been omitted because wheat is grown with additional irrigation. Further computation of landscape and soil properties indicated that except Jagjitpur (suitable), other soils are moderately suitable (Sakit, Haldi, Mohanpur, Fatehpur) or permanently not suitable owing to limitation of either organic carbon or exchangeable sodium percentage. This is also reflected in the productivity ($43qha^{-1}$) of wheat at Zarifa Viran site. It indicates that the method is analogous to the “law of minimum” postulated in 1840 by Liebig, who stated that “yield is proportional to the amount of the most limiting nutrients, whichever nutrient it may”. Here organic carbon and/or ESP are not static properties but dynamic one and which can be corrected.

With reference to soil of Fatehpur series and productivity realised on these soils we have normalised the yield and soil properties of other seven soils. Thereafter, we have calculated the absolute distance values, maximum and minimum values of absolute distance, correlation and correlation coefficients (Table 5, 6, 7, 8, 9 (a) and 9 (b)) to identify the most important soil parameter/parameters influencing the yield. Initially we took silt, clay, BD, sHC, pH, $CaCO_3$, OC, ECP, EMP and ESP for correlation with respect to observed wheat yield. As silt and clay parameters are static parameters, we omitted these from further correlation study. The results (Table 9b) indicated that combined effect of BD, sHC, pH, $CaCO_3$, OC, ECP, EMP and ESP with same agro-managements practised at Fatehpur site, 94% of the yield can be realised at Masitawali and Jagjitpur soil series, 90% at Zarifa Viran, 87% at Hirapur, 94% at Sakit and Haldi and 93% at Mohanpur site. In general, BD had higher correlation at all the sites whereas pH and $CaCO_3$ had higher correlation at sakit and Haldi sites, organic carbon in Zarifa Viran soils. A high correlation (0.99) with observed yield was observed for exchangeable calcium percentage at Masitawali, Jagjitpur and Zarifa Viran sites and for exchangeable magnesium percentage at Sakit soil. Mohanpur site had high correlation with exchangeable sodium percentage and yield.

It is concluded that Soil Property Performance Approach is more robust suitability evaluation method for wheat as it gives rational weightage to every factors through normalization rather than averaging procedure or weighted mean method. The results further indicated that by similar agro-management (as followed at Fatehpur site) we can realise more than 87% yield on different sites. Our results show that bulk density is a crucial factor in deciding the productivity of wheat.

References

Dent, D. and Young, A. 1981. *Soil survey and land evaluation*. London, Allen and Unwin. 278 pp.

FAO. 1976. *A framework for land evaluation*. FAO Soils Bulletin No. 32. Rome, FAO. 72 pp. Also published as Publication 22. Wageningen, the Netherlands, ILRI. 87 pp.

FAO. 1995. *Forest Resources Assessment 1990 - Tropical forest plantation resources*. FAO Forestry Paper No. 128. Rome.

Pal, D.K., G.S. Dasog, S. Vadivelu, R.L. Ahuja and T. Bhattacharyya, 2000. Secondary calcium carbonate in soils of arid and semi-arid regions of India. In : Lal, R., Kimble, J.M., Eswaran, H., Stewart, B.A. (eds), Global Climate Change and Pedogenic Carbonates. Lewis Publishers.

Pal, D.K., Kalbande, A.R., Deshpande, S.B. and Sehgal, J.L. 1994. Evidence of clay illuviation in sodic soils of the Indo-gangetic plain since the Holocene. Soil Science, 158: 456-473.

Sys, C., Van Ranst, E. and Debaveye, J. 1991. Land evaluation. Part 2: Methods in land evaluation. Agricultural publications 7, 2. General Administration of Development Cooperation of Belgium, Brussels. 247 p.

Tang, H.J. and Van Ranst, E. 1998. Soil Property Crop Performance Approach to Land Evaluation.

Van Diepen, C.A., Van Keulen, H., Wolf, J., and Berkhout, J.A.A. (1991).Land evaluation : from intuition to quantification. In : Advances in Soil Science, Steward, B.A. (Ed.), Springer, Newyork, 15: 139-204.

Assessment of Land Use / Land Cover Dynamics in Chandrapur District of Maharashtra using Remote Sensing for Planning Sustainable Agricultural Development

Sundararaj Thayalan[1], Arun Chaturvedi[2] and Dipak Sarkar[2]

[1]*National Bureau of Soil Survey and Land Use Planning (ICAR), Regional Centre, Bangalore*
[2]*National Bureau of Soil Survey and Land Use Planning (ICAR), Headquarters, Nagpur*
E-mail: thayalan.sundar@gmail.com

Abstract

Land use/land cover dynamics is a key to many diverse applications such as environment, forestry, hydrology, agriculture and ecology. Various natural resource management, planning and monitoring programs depend on accurate information about the land use / cover in a region. Keeping this in view, an attempt was made to study the land use / land cover dynamics and its effect on agricultural development in Chandrapur district of Maharashtra state using RS and GIS techniques. Satellite data from 1986-87 to 2009-10 has been selected to assess the pattern of land use dynamics over the last two decades. Multi-date satellite data of kharif, rabi and summer are studied conjunctively to derive the land use status for the particular agriculture season. Major crops grown are jowar, paddy, cotton and other short duration pulses. Area under cropland found continuously increasing over all the study cycles.

Four predominant types of wasteland i.e. land with scrub; land without scrub, stony / barren rocky area and industrial / mining waste are delineated in the district. Total wasteland proportion shows overall reducing trend from the year 1986-87 to 2009-10. This shows the growth of mining and industrialization in the district which is coal rich and famous for electricity generation in the state.

Dense forests with crown density more than 40% are observed in Bhadravati and Chandrapur talukas on either sides of the river Andheri and also in Gondpipri and Sindewahi talukas. The area under these categories is continuously decreasing from 27.3 % in 1986-87 to 22.4% in 2002-03, further to 21.1% in 2005-06 and finally to 18.6 % in 2009-10.Open forest area has been increasing consistently from 1986-87 to 2009-10.

With rapid urbanization and industrialization, more employment opportunities are generated, leading to sprawl in dwelling units, thereby increasing the built up areas and formation of new housing sites. Settlement area has increased from 0.73 % in 1986-87 to 1.63% in 2009-10. Chandrapur, being a drought affected district, massive soil and water conservation programmes are adopted. A large number of water bodies have been constructed dotting the entire district. Area occupied by these water bodies have increased. A large database has been created for land use / land cover dynamics, which will be of immense help in planning sustainable agricultural development. Remote Sensing is found to be a useful

technique for thematic map preparation and GIS in establishing links amongst all the inter-related resource parameters.

Introduction

Land Use / Land Cover patterns are a reflection of the man – environment relationship at a given period of time. The dynamics of Land Use / Land Cover manifests the changes in these relationships. Since, the geomorphic units are the ideal, spatial, eco-system mapping units; they have a direct bearing on the evolution of land use. With this in mind an attempt has been made to study the Land Use / Land Cover dynamics in Chandrapur district of Maharashtra State between 1986 and 2010.

Chandrapur district is abundantly endowed with rich flora and fauna, water resources and mineral wealth. India's largest thermal power plant, many coal mines, cement and paper factories, huge lime stone deposits, bauxite, iron and chromite mines are the sources of wealth of the district. Tadoba-Andhari Tiger Project is a major tourist attraction. Different tribal people are the original inhabitants of this district for millennia.

Kaufmann and Seto (2001) described a new change detection method to determine the date of land-cover change in a sequential series of Landsat TM images of the Pearl River Delta, China. The method is a three-step change detection procedure that uses time series and panel econometric techniques. Land use land cover is the major research activity in any of the NASA's space science program, since this information at different scales is of utmost importance to many facets of the society (Shah, 2003). Obi Reddy *et al*.(2008) analysed spatio-temporal patterns of major land use systems of Vidarbha region over a period of 25 years using remote sensing and GIS techniques. Mendoza *et al*., (2011) analysed land cover change processes over a 28-year time period in Central Mexico, by means of integration of existing databases of land cover and land use (1975 and 2000), and updating through visual interpretation of Landsat MSS and ETM satellite images and orthophotos (1986, 1996 and 2003). In all these studies, multitemporal analyses included mapping, evaluation of transition matrices, computation of rates of land use change for the main change processes during each period, and cluster analysis.

Materials and Methods

Satellite data of three seasons was used to delineate the Land Cover/Land Use of the district for the period 1986, 2002-03, 2005-06 and 2009-10(Table 1).

Table 1 Satellite Data Used for the Study

l.no.	Satellite	Sensor	Path	Row	Season
1	Landsat 7	TM	100	58	December 1986
2	IRS 1D	LISS-III	100	58	December 2002
3	IRS 1D	LISS-III	100	59	December 2002
4	IRS 1D	LISS-III	100	58	January 2003
5	IRS 1D	LISS-III	100	59	January 2003
6	IRS 1D	LISS-III	100	58	March 2003
7	IRS 1D	LISS-III	100	59	March 2003
8	IRS-P6	LISS-III	100	58	November 2005
9	IRS-P6	LISS-III	100	59	November 2005
10	IRS-P6	LISS-III	100	58	February 2006
11	IRS-P6	LISS-III	100	59	February 2006
12	IRS-P6	LISS-III	100	58	April 2006
13	IRS-P6	LISS-III	100	59	April 2006
14	IRS-P6	LISS-III	100	58	October 2009
15	IRS-P6	LISS-III	100	59	October 2009
16	IRS-P6	LISS-III	100	58	February 2010
17	IRS-P6	LISS-III	100	59	February 2010
18	IRS-P6	LISS-III	100	58	April 2010
19	IRS-P6	LISS-III	100	59	April 2010

The digital image processing of the IRS 1D / P6 LISS III Multidate data of 2002-03, 2005-06 and 2009-10 and visual interpretation of 1986 TM data were undertaken following the NRSA/ANDERSON'S Classification (ANDERSON 1977, NRSA, 1989) for Land use/Land cover.

Vectorization, editing, cleaning and mosaiking of the visually interpreted sheets and generation of Land Use / Land Cover Statistics were done. Similarly, the digital output of the classified land use/land cover maps of the IRS 1C / P6 LISS III data was completed. Land Use / Land Cover Dynamics were assessed using the above maps and quality field checks carried out in selected window areas. Hot Spots / Critical areas were identified by the integration of the geomorphic units and Land Use / Land Cover categories in the GIS environment.

Location and Extent

Chandrapur district is one of the eleven districts of the Vidarbha region of Maharashtra State (Fig.1). It is bounded on south by Adilabad district of Andhra Pradesh State, east by Garhchiroli district, on north by Gondia, Bhandara, Nagpur and Wardha districts on west by Yavatmal district. Wardha River forms the western boundary, whereas Wainganga River forms the eastern boundary of the district.

The district lies between 19°30’ and 20°45’ N latitudes and 78°46 ’ and 80°00’ E longitudes, covering an area of about 11443 sq km. The district headquarters is located at Chandrapur Town. For administrative convenience, the district is divided in 15 talukas.

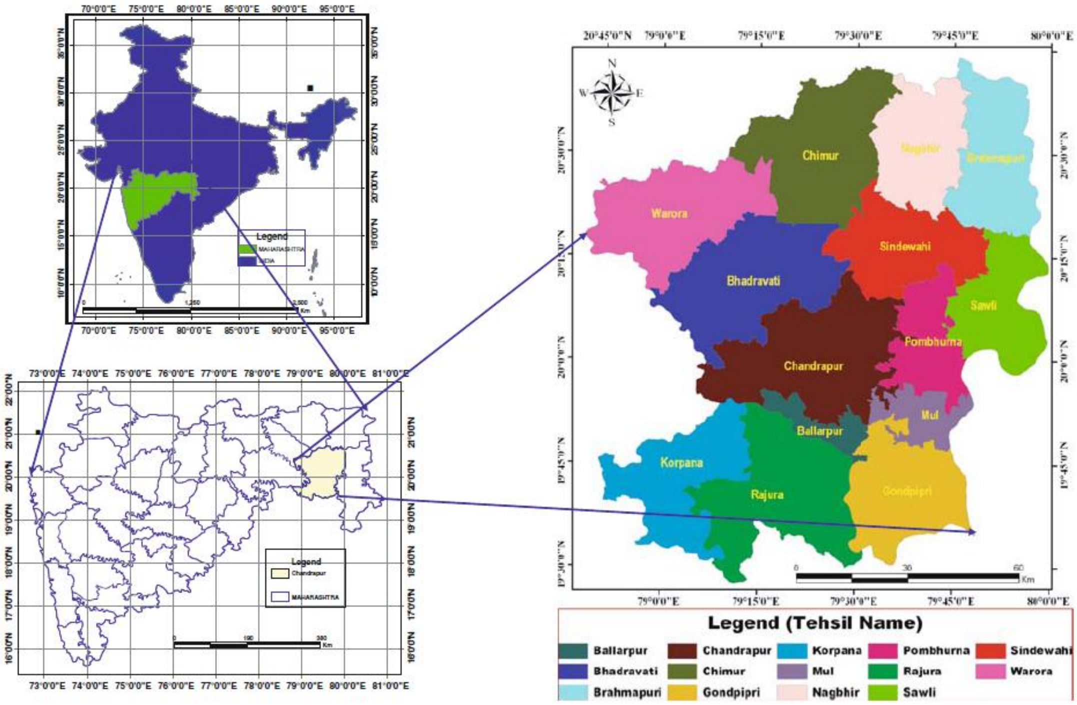


Figure 1 Location of Chandrapur District (Source: Satapathy et al., 2009)

Relief and Drainage

The district has been divided into twelve geomorphic units based on lithology, structure, the crenulations of contours and drainage morphometry. The elevation of various plateaus in Chandrapur district ranges between 350 and 550 m from MSL, high level in southwestern and low level in southeastern region. The ridges, hills, highly and moderately dissected plateau over the Deccan traps are grouped into geomorphological units of structural origin. The subdued hills and footslopes are grouped into geomorphological units of denudational origin, whereas, the younger and older alluvium forms the units of fluvial origin. Physiographically, the district is situated within the Wainganga and Wardha river basins, which are the tributaries of Godavari River, respectively flowing on the eastern and western boundaries of the district. Wardha, Penganga and wainganga are the important rivers in Chandrapur district. The dominant drainage pattern found in the area is dendritic.

Geology

Geologically, Chandrapur district forms a part of Gondwana sedimentary basin. The Gondwana sedimentation took place in Wardha valley where the sediments have overlain the Archean rocks. Lithologically the district presents a variety of statigraphic units' right from Archean to recent alluvium and laterites.

Climate

The Climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e., June to September. The temperature rises rapidly after February till May, which is the hottest month of the year. The mean daily maximum temperature during May is 42.8°C and the mean daily minimum temperature during December is 12.2°C. The mean annual precipitation is 1263 mm of which nearly 90 per cent is received during the monsoon period of June to September. The annual precipitation covers only about 65 per cent of the potential evapotranspiration (PET) demand of about 1929 mm. The length of growing period is around 150 days and it starts from the 1st week of May and it extends up to the end of August.

Natural Vegetation

The vegetation of the district is characterized as Southern Tropical Dry Deciduous Forest where teak is the dominant species. Other associated species are Aain, Bamboo, Bijja, Dhada, Haldu, Semal, Tendu etc. depending on the physiographic position. Jamun, Mango, Arjun are found in moist areas. The slopes of the hills and plateaus have poor and low density vegetation. The plains on the contrary have luxuriant forest cover. The district had about 3651 sq km of forest cover in 1998-99, which accounted for 33.44 per cent of the TGA of the district.

Land Use

The total agricultural area concentrated in the valleys of the rivers Wardha, Penganga and Wainganga is 4870 sq km accounting for 46.05 per cent of the total TGA of the district. Paddy, Cotton, Jowar and Soybean are the major crops grown in the district. About 34.33 per cent of the area is under forest cover. The total population is 22,15,000 (2001) and the Scheduled Caste and Scheduled Tribe population is 16.78 and 19.70 per cent, respectively. There are 7 urban centres and 13 major rural centres. About 6.26 per cent of the population lives in the slums and 13.36 per cent of the population is below poverty line. Total work force in the 4 existing industrial estates is just 2071, but there are major industries such as coal mines, thermal power station, cement factories, paper mill etc., which are situated outside the industrial area, where the work force is about 30,000. Seasonal migration is temporary phenomenon lasting for about 2 to 3 months. The workers mostly migrate to Chandrapur district from Madhya Pradesh, Andhra Pradesh, Orissa and Bihar.

Mining

The district is gifted with deposits of various minerals like coal, iron, limestone, clay, copper, chromium, etc. Thermal power plant, many coal mines, cement and paper factories, huge lime stone deposits, iron, and chromite mines are the sources of wealth for the district. Natural deposits of the high-grade iron ore in Sindewahi taluka are estimated to be 2,200,000 tonnes; limestone in Rajura and Korpana talukas (547,000,000 tn). Coal in Chandrapur taluka alone is estimated to be 1,227,000,000 tonnes. Availability of huge coal deposits has led to increased coal mining activity and the power plant. Availability of limestone has prompted cement industries particularly in Rajura Tehsil. Paper mills are established because of availability of wood/bamboo located on banks of river or nallas. Decadal growth rate of the district is about 25%. Chandrapur taluka has experienced 47% growth rate and is closely followed by the Rajura taluka. This growth is mainly due to the abundance of the minerals and industries developed in the district.

Results

Land Use / Land Cover Dynamics

For the present investigation satellite data since 1986-87 to 2009-10 has been selected comprises of four land use land cover mapping cycles. This has given a insight to assess the pattern of land use dynamics over last two decades. Multi-date satellite data of kharif, rabi and summer are studied conjunctively to derive the land use status for the particular agriculture season. Three season satellite data has been used for all the years, except for 1986-87, due to constraint of cloud free data availability. Spatial distribution of different land use / land cover categories are depicted in figure (2 and 3) and are summarized in table 2 along with their percentage with respect to TGA of the district**.**

Table 2: Area under Different Land Use / Land Cover Categories

LULC CATEGORIES		1986-87*		2002-03		2005-06		2009-10	
		Area (ha)	**% TGA**	**Area (ha)**	**% TGA**	**Area (ha)**	**% TGA**	**Area (ha)**	**% TGA**
Agriculture	Kharif	391833	34.24	416761	37.29	403227	35.24	384032	33.56
	Rabi	0	0.00	56919	4.97	69228	6.05	80897	7.07
	Summer	0	0.00	2395	0.21	2979	0.26	3097	0.27
	Double Crop	0	0.00	69736	6.09	82977	7.25	87065	7.61
	Fallow	155794	13.61	5974	0.52	13507	1.18	13468	1.18
Wasteland	Land with Scrub	98024	8.57	63429	5.54	67780	5.92	66901	5.85
	Land without scrub	14972	1.31	14824	1.30	13908	1.22	13591	1.19

	Stony waste	909	0.08	1444	0.13	1545	0.14	1431	0.13
	Mining/ Industrial waste	2741	0.24	12138	1.06	14526	1.27	16402	1.43
Forest (Notified / Un-notified)	Dense forest (Notified)	312586	27.32	256310	22.40	241614	21.11	212950	18.61
	Open Forest (Notified)	23153	2.02	26726	2.34	24256	2.12	36819	3.22
	Scrub forest (Notified)	11586	1.01	64289	5.62	81455	7.12	97556	8.53
	Dense forest (Un-Notified)	60984	5.33	59439	5.19	24519	2.14	24356	2.13
	Open Forest (Un-Notified)	33773	2.95	43330	3.79	42430	3.71	42110	3.68
Water bodies	Waterbodies (River/Tank/Reservoir)	29623	2.59	38921	2.53	44631	3.90	45021	3.93
Settlement	Settlement	8321	0.73	11665	1.02	15717	1.37	18604	1.63
		1144300	**100**	**1144300**	**100**	**1144300**	**100**	**1144300**	**100**

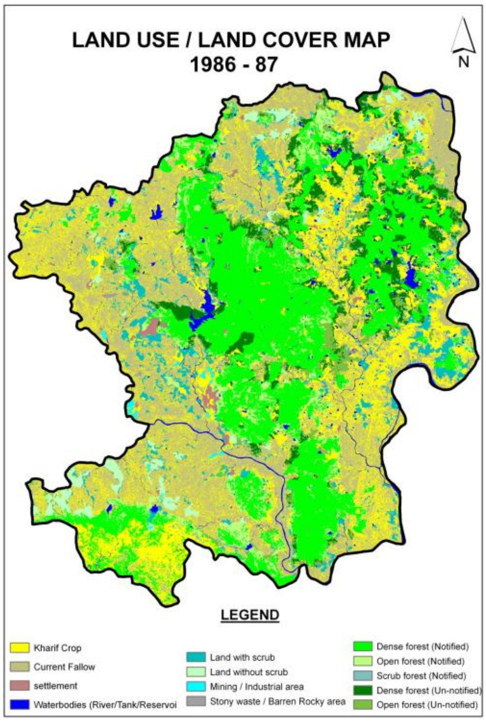


Figure 2

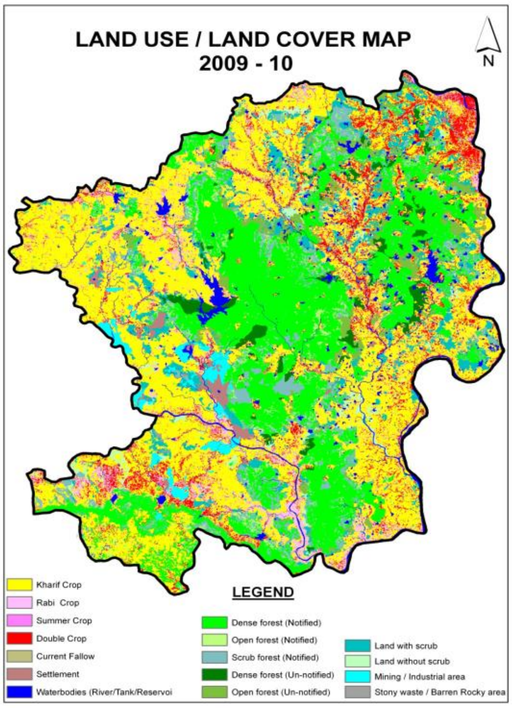


Figure 3

Agriculture

Rainfed farming is the major practice spread over 48 to 50 % of the geographic area of the district, from 1986-87 to 2009-10. Agriculture is spread along the entire western and most of the eastern boundary of the district in the river valleys. The crop lands are also observed on the gently sloping plateau regions or flat uplands.

Kharif crops are dominated along the banks of the rivers Penganga and Wardha, while *rabi* crops are frequented all along Wainganga River. K*harif* area during the year 1986-87, was 34.24 % of the district. It increased in 2002-03 to 37.29 % but decreased to 35.24 % in 2005-06 and further to 33.56 % in the year 2009-10. Cropping in both the season is not very common in this district, due to lack of irrigation facilities and choice of crops. However, some patches of double cropping have been delineated in Rajura, Chandrapur and Mul tahsils. *Rabi* crops are predominant in Gondpipri, Bhadravati and Chimur tahsils. *Rabi* area is continuously increasing over the years. It was 4.97%, 6.05% and 7.07 % for the years 2002-03, 2005-06 and 2009-10, respectively. Fallow lands (current fallow) are observed on the satellite image especially on the rainfed uplands and also plateau plains during both the seasons (*Kharif & Rabi*). Fallow lands can be broadly attributed to lack of irrigation or lack of adequate soil moisture to raise the crops or due to litigation among the cultivators. Double crop area has also been increased from 6.09 to 7.61 % from the year 2002-03 to 2009-10. Overall agriculture is dominated by Jowar, Paddy, Cotton crops and other short duration pulses. Area under cropland found continuously increasing over all the study cycles. It was about 547627 ha (47.86%) in the year 1986-87, about 561785 ha (49.09%) in 2002-03, about 571918 ha (49.98%) during 2005-06 and become 568559 ha (49.69%) in 2009-10. This reflects the stabilization in the expanse of the cropland, as majority of the district is occupied by forestland.

Wasteland

Four predominant types of wasteland i.e. land with scrub, land without scrub, stony / barren rocky area and industrial / mining waste are delineated. Large patches of scrub land are observed in Bhadravati, Chimur and Nagbhid tahsils with smaller patches scattered mostly adjoining the open forest. The land with or without scrub is observed almost all over the study area on the undulating uplands. These lands are mostly covered with thin soil cover with exposed rock outcrop, at places.

Total wasteland proportion shows overall reducing trend from the year 1986-87 to 2009-10, i.e. from 10.19 % to 8.59 %, respectively. Land with scrub is the major category in wastelands. Mine / industrial area form an important and commercially driven class of wastelands. About 2741 ha (0.24%) of mining area was mapped in the year 1986-87, which is increased to about 12138 ha (1.06%) in 2002-03, further rose to 14526 ha (1.27%) in the year 2005-06 and finally to 16402 ha (1.43%) in 2009-10. Fly ash of thermal power stations, transportation of coal by road and/or aerial route is the major environmental concern in the area.

Forest

Central, south central, south-west and north-eastern corners of the district has large patches of forest. Chandrapur, Bhadravati and Sindewahi tahsils have majority of area under forest. Deciduous type of forest constitutes about 90 % of the forest types present in the district.

Dense forests with crown density more than 40% observed in Bhadravat, Sindewahi and Chandrapur tahsils is continuously decreasing from 27.32 % in 1986-87 to 22.40% in 2002-03, further to 21.11% in 2005-06 and finally to 18.61 % in 2009-10. This decreasing trend of dense forest cautions the environmentalist for strategic planning.

Forest categories with crown density between 10% to 40% are classed as open forest, which is scattered all over the district with conspicuous patches near the Naleshwar and Asolamendha tank in Sindewahi and Gorazari tank in Nagbhid tahsil. Open forest area has been increased consistently from 1986-87 to 2009-10(Table 2). The increasing trend of open forest is not a good sign from forest management point of view. Open forest and scrub forest are increasing at the cost of dense forest, which needs to be addressed in the forest management plan. Developmental activities encompassing forest plantation needs to be undertaken in and around mine and industrial areas. Forest fires are the frequent threats to this forest wealth which are quite often in the area.

Settlement

Settlement categories comprising of residential areas (rural and urban), transportation facilities are mapped in the study area for four land use cycles from 1986-87, 2002-03, 2005-06 and 2009-10. Major part of the district is rural in nature. Dwelling units from urban areas, slum, recreation and transportation services (road, rail etc.) are also mapped. Among the urban conglomerates, the areas dominated by vegetation and its association with residential / institutional areas within urban built-up areas have been delineated under this category.

With rapid urbanization and industrialization, more employment opportunities are generated, leading to sprawl in dwelling units, thereby increasing the built up areas and formation of new housing sites. Settlement area has increased from 0.73 % in 1986-87 to 1.63% in 2009-10.

Waterbodies

Chandrapur, being a drought affected district massive soil and water conservation programmes are adopted and funded by the state and cetre scheme. A large number of tanks have been constructed dotting entire district. Minor tanks, reservoir, river, canal, local farm ponds are included under these categories. Area occupied by these waterbodies have also increased with developmental activities and enhanced usage. It has grown from 29,623 ha in 1986-87 to 45,021 ha in 2010-11.

Conclusions

The study brings out the decline in dense forest areas and cultivation being increased in the forest lands. The process of cultivation starts near the water bodies and expands in the level lands surrounding them. In the long run this affects the storage capacity of these water bodies leading to a situation of abiotic stress.

A large database has been created for land use / land cover dynamics, which will be of immense help in planning sustainable agricultural development. Remote Sensing is found to be a very useful technique for thematic map preparation and the GIS in establishing links amongst all the inter-related resource parameters.

References

Anderson, J. R., (1977). Land use and land cover changes. A framework for monitoring. Journal of Research by the Geological Survey, *5*, 143-153.

Anil, Z.C. and Katyar, S. K. (2010). Impact Analysis of Open Cast Coal Mines on Land Use/ Land Cover using Remote Sensing and GIS Technique: A case study. International Journal of Engineering Science and Technology Vol. 2 (12) 7171-7176.

Katpatal, Y.B. and. Patil, S.A (2010). Spatial analysis on impacts of mining activities leading to flood disaster in the Erai watershed, India. Journal of Flood Risk Management. Volume 3, Issue 1, pages 80–87.

Kaufmann, R. K, Seto, K.C. (2001). Change detection, accuracy, and bias in a sequential analysis of Landsat imagery in the Pearl River Delta, China: econometric techniques. Agriculture, Ecosystems and Environment 85: (2001) 95–105.

Kayhko, N., Fagerholm, N., Asseidb, B. S. and Mzee, A. J. (2011). Dynamic land use and land cover changes and their effect on forest resources in a coastal village of Matemwe, Zanzibar, Tanzania. Land Use Policy 28 26–37.

Lu D., Mausel P., Brondizios E.,Moran E. (2004). Change detection techniques. International Journal of Remote Sensing, 25, pp. 2365-2407.

Mendoza, M. E., Granados E. L, Geneletti D., Pérez-Salicrup, D. R., and Salinas, V. (2011). Analysing land cover and land use change processes at watershed level: A multitemporal study in the Lake Cuitzeo Watershed, Mexico (1975-2003). Applied Geography 31 (2011) 237-250.

NBSS & LUP (1993). Soils of Chandrapur district, Maharashtra. Soil Survey Report No*:* 525 NBSS Publ., NBSS & LUP, Nagpur. pp. 61.

National Remote Sensing Agency (1989). Manual of nationwide land use/land cover mapping using visual interpretation techniques, Part-1. Hyderabad, pp: 1-58.

Obi Reddy, G.P., Maji, A.K., Nagaraju, M.S.S., Thayalan, S. and Ramamurthy, V. (2008). Ecological evaluation of land resources and land use systems for sustainable development at watershed level in different agro-ecological zones of Vidarbha region, Maharashtra using remote sensing and GIS techniques, NBSS Publ., NBSS&LUP, Nagpur. pp. 270.

Patil S. S., Nagaraju, M.S.S and Srivastava, R (2010). Characterization and evaluation of land resources of basaltic terrain for watershed management using remote sensing and GIS. Indian Journal of Soil Conservation, Volume: 38, Issue: 1.

Satapathy D. R., Salve P. R., and Katpatal, Y. B (2009). Spatial distribution of metals in ground/surface waters in the Chandrapur district (Central India) and their plausible sources. Environ Geol (2009) 56:1323–1352.

Shah, C. A. (2003). Advanced Land Cover Mapping and Change Detection Techniques. NY Star Centre for Environmental Quality Systems, March 25, 2003.

Singh A. (1989). Digital change detection techniques using remotely sensed data. International Journal of Remote Sensing, 10, pp. 989-1003.

Thakre, C. S. (1995). Soil and Agroclimatic based land use planning for increased and sustained agricultural production – A case study of Erai Watershed, Chandrapur district. M.Sc thesis submitted to Dr.P.D.K.V, Akola, 131p.

Carbon Sequestration through Improved Agronomic Practices

G.K. Girijesh[1], A.S. Kumara Swamy[1], K.S. Rajashekarappa[2] and D.K Prabhuraj[3]

[1]*College of Agriculture, Shimoga*
[2]*Dept. of Agricultural Engineering, GKVK, Bangalore*
[3]*Karnataka State Remote Sensing Applications Centre, Bangalore*
E-mail: gk.girijesh@gmail.com

Abstract

The climate change is happening much faster now than anticipated earlier. Global warming will threaten our farms/forests and other habitats. Carbon dioxide is one of the principal heats trapping gases and cause for green house effect. It is responsible for 50% of global warming. Green plants fix carbon in the form of complex organic molecules. So, more sequestration of carbon through vegetation into soil is need of the hour.

Carbon sequestration is the ways and means of sequential build up of organic carbon in soils. The amount of carbon that is present in the form of organic carbon in the world soils is about three times that of the atmosphere and about four times that of the biotic pool. Most part of the organic residues added to the soil is decomposed and nearly 60-80% of it escapes into atmosphere in the form of CO_2 and part of it converted into humus. Humus is not only responsible for improvement of soil fertility and productivity but also serve as a great sink for carbon in the soils. However, there is a limitation on the extent of conversion of organic residues into humus and it is a great challenge to achieve it.

Intensive agriculture, forests denudation, energy intensive crop production, reckless burning, methane production by anaerobic decomposition of organic farm wastes and soil erosion etc are important causes for global warming. Appropriate site specific agronomic interventions, it is possible to sequester more carbon into soil. Low external input farming, energy efficient mechanization, development and restoration of degraded lands, avoiding anaerobic decomposition of organic matter, aerobic rice cultivation and alternate land use system are some of the means to enhance carbon sequestration.

Introduction

Carbon dioxide is one of the principal heat trapping gasses of biological origin and cause for greenhouse effect and result in global warming consequently. The climate change is happening much faster than anticipated earlier, and if the present trend is allowed to continue unabated, global warming will threaten our farms and forests, beaches, wet lands and coastal habitats. It is responsible for 50 per cent of global warming. Carbon dioxide in the atmosphere is a part of the carbon cycle in nature. Green plants fix carbon in the form of complex organic molecules which form the source of energy for animals and micro-organisms. So, more sequestration of carbon into soil is need of the hour. Carbon sequestration is the ways and means of sequential build-up of organic carbon in soils. Soil is the major sink for atmospheric carbon dioxide. The present level of soil organic carbon is around 0.5 per cent in the state of Karnataka. There is a need to raise this by another 0.3 to 0.5 per cent which is an uphill task in the tropical situations. Even if we increase soil organic carbon by additional 0.1 per cent through sound agronomic practices, it works out to 22.4 t ha^{-1}. On a large scale, for net cultivated area of 101.73 lakh ha in Karnataka, it is estimated to be 223 lakh tones. So, all our efforts should be focused towards more and more carbon sequestration into the soil.

The United States Protection Agency defined carbon sequestration as the uptake and storage of carbon by trees and plants. Soil organic carbon plays a very important role in the global carbon cycle. The amount of carbon that is present in the form of organic matter in the world soils is about three times that of the atmospheric pool and about four times that of the biotic pool. Carbon dioxide, methane and nitrous oxide are the principal heat trapping gases of biological origin, while the CFCs and part of Co_2 are the other major ones resultant of human- industrial and transport activity. These heat trapping gases cause green house effect and result in global warming consequently.

Methane is generated as a result of anaerobic decomposition of organic matter that may take place in paddy fields, in water bodies and by the animals due to incomplete digestion and respiration. Most part of the organic atmosphere in the form of CO_2 and part of it converted into humus. It is responsible for improvement of soil fertility and productivity. Humus, thus play a great role not only in enhancing the agricultural productivity of lands but also in serving as a great sink for carbon in the soils, thereby reducing the level of CO_2 and its effect on global warming. However, there is a limitation on the extent of conservation of organic residues into humus and it is a great challenge to achieve a higher degree of conversion. Conversion of organic residues into stable humus through agronomic management practices is important. This paper deals with the ways and means of enhancing the conversion of organic residues into stable humus through agronomic management practices.

Intensive agriculture, denudation of forests, energy intensive crop production practices, reckless burning and turning, methane production by anaerobic decomposition of organic farm wastes and soil erosion etc are the important causes for global warming. Agricultural practices have a major impact on production and release of these green house gases and on the global warming. Intensive agriculture cropping and monoculture has lead to the destruction of soil structure, fertility, accelerated erosion and release of carbon from soil to the atmosphere. Due to intensive agriculture with best soil management practices about 35-45 kg ha^{-1} of soil organic carbon is lost every year under red soils of Bangalore region. Further, energy intensive crop production practices which consume many times more energy from the fossil fuel sources than the energy produced on the farm. Denudation of natural vegetation and forests for cultivation of crops since several centuries is unabated (Global deforestation is 15 x 10^6 ha annually releasing 16 x 10^{15} Pg C annually to atmosphere. Reckless burning and turning of soil that favours plant growth but results in large scale release of methane gas into atmosphere due to decomposition of organic matter under anaerobic conditions.

Agronomic practices to enhance soil carbon sequestration and to minimize the green house gases

There are two principal strategies of mitigating the greenhouse gases effect i) reduction in emission of greenhouse gases and ii) sequestration of atmospheric C in biomass and soil. Through appropriate site specific agronomic interventions, it is possible to sequester more carbon into the soil. Low external input farming, energy efficient mechanization, development and restoration of degraded lands, avoiding anaerobic decomposition of organic matter, aerobic rice cultivation, adoption of recommended agronomic practices, alternate land use systems are of the means to enhance carbon sequestration.

Minimization of external energy use in agriculture

Faulty priorities aiming at short term benefits have ended up in energy intensive modern agricultural practices which consume much higher energy of fossil fuels than the energy produced ultimately in the production system. This system, widely followed now throughout the world, has resulted in release of more CO_2 to the atmosphere than that is fixed in the biological activity of the agricultural sector. Therefore, a great opportunity exists to develop low external energy use crop production systems like minimum tillage, zero tillage, use of animal power, organic farming, natural farming and lower use of fertilizers and plant protection chemicals which consume large quantity of energy for their manufacture.

Minimization of agricultural land area expansion

Indiscriminate deforestation for expansion of agricultural lands is increasing the CO_2 release due to burning of natural vegetation and also due to less fixation of carbon dioxide in agricultural lands compared to natural vegetation. Instead of expanding agricultural lands, we must aim at increasing the productivity on the existing land, for which a great potential exists. Research must be intensified on achieving high productivity with the use of low external energy in the system.

Increasing the energy efficiency of agricultural machines and irrigation systems

Huge quantity of energy used in agricultural sector can be saved through improvisation of existing farm machines, pump sets, processing plants etc. Alternate sources of energy like wind energy, solar energy and biomass energy could be adopted in place of conventional machines that use fossil fuel energy. Energy efficiency of irrigation systems could be increased by adopting low energy using drip irrigation system.

Proper recycling of agricultural wastes

The biomass that is generated in agricultural and forest ecosystems should not be burnt, as that results in release of all the carbon content to the atmosphere in the form of carbon dioxide. The biomass must be properly decomposed in controlled aerobic conditions to prepare good quality compost and then added directly to deeper layers of the soil to increase carbon sequestration in the soil.

Soil and water management practices for 'C' sequestration

Soil management and agronomic practices affect the soil biochemical, physical and microbiological processes. Land cultivation brings enormous changes in soil organic carbon. Deep and intensive tillage practices in the long run are responsible for oxidizing soil organic matter by disrupting the macro aggregates of soil and incorporating large amount of air into the deeper layers of the soil. No tillage or reduced tillage or zero tillage cultivation conserves organic matter, preserve the microbial population and increase the microbial activity in the surface layer.

Four aspects of water management in relation to soil organic matter content are i) *in situ* conservation, ii) enrichment of carbon, iii) water harvesting and supplemental irrigation and iv) drainage. These practices reduce the loss of organic carbon in soils by control of soil and water erosion by practicing suitable conservation measures. Run off of rain water leading to soil erosion should be strictly prevented. Even with the slightest erosion, it is mostly the organic debris that is on the surface of the soil that is carried away. This organic debris, which otherwise would have entered into the soil and become a part of soil organic matter is carried along with the rain waters to water bodies where it putrefies and produces methane.

Avoid anaerobic decomposition of organic matter

Anaerobic decomposition of organic matter in open spaces results in production of methane gas which is 30 to 50 times more potential than carbon dioxide in causing global warming. Efforts must be made to capture and use all the methane produced in anaerobic decomposition as in the case of bio-gas plants. Use of biogas collected form the digesters serves as an alternate source of energy and hence avoids burning of fossil fuel to that extent. In this context, the present design of bio-digester without an arrangement to capture the methane gas should be discouraged.

Encourage aerobic rice cultivation in place of puddled paddy lands

Under puddle conditions, to which a large quantity of organic matter is added as a source of nutrients, there is a lot of methane generation due to anaerobic decomposition. Aerobic rice cultivation minimizes the methane production. Low water consumption in this system can also reduce the energy required for pumping of huge quantity of water. Under puddle conditions, drainage must be provided at least once in 20 to 25 days in order to reduce methane generation.

Cropping systems/farming systems/alternate cropping systems for more carbon sequestration

Adoption of cropping systems that are able to produce more recyclable biomass can help in better build up of soil organic carbon. Cropping systems that produce nitrogen rich organic matter, as in the case of leguminous crop residues can help to enhance the level of soil organic carbon, because of fairly constant C:N ratio in the soil. Similarly, cropping systems like cover cropping, strip cropping, wind breaks, etc. that prevent soil erosion can also help in build-up of soil organic carbon. Permanent plant cover, growing crops that produce huge biomass, legumes and forages in rotation (legumes leave lot of surface residue) and sod crops which help in build-up of organic carbon in soil ecosystem and inturrn help conserving bio-diversity. The highest carbon enrichment of soil was reported with silvi-pastoral than agri-horticultural system, agri-silvicultural and agri-horticultural system.

Further, addition of green manure crop /green leaf manure preferably a legume in a sequence or addition of farm yard manure/compost and crop sequencing with legumes should be a part of the strategy to maintain organic carbon to permissible higher level. Residue management may save energy, recycle nutrients, enhance soil quality, improve soil structure, sequester carbon and mitiage green house grasses.

Efficient conversion of raw organic matter into humus

Conversion of higher proportion of raw organic matter into compost and humus can account for higher extent of carbon sequestration. This can be achieved by addition of well composted organic matter to the soil, instead of raw organic matter, by using higher quantity of leguminous crop residues along with low nitrogen residues or little quantities of fertilizer nitrogen while preparing the compost and by adding lignaceous materials, clay, small quantities of wood ash along with other raw materials while preparing the compost.

Efficient management of nitrogen to minimize release of reactive nitrogen gases

Reactive nitrogen gases, N_2O and NO are released into atmosphere during the process of de-nitrification under anaerobic conditions. This occurs both in dry land and wetlands. All care must be taken to provide good drainage in dry lands. Similarly, nitrogen must be applied deep into subsoil in case of puddle paddy fields to avoid de nitrification losses. Native as well as applied nitrogen must be efficiently managed to minimize the losses as it can increase the carbon sequestration into the soil because of fairly constant C:N ratio in the soil. Thus, agronomic practices can increase the soil organic carbon which improves in the soil productivity, fertility and sustainability of the ecosystem. Taking marginal lands out of production through Afforestation, Land application of bio-solids, adopting agro-forestry measures, establishing conservation buffers in wetlands and installing engineering structures

Restoration of degraded soils and ecosystems

Vegetation acts as a carbon sink because plants covert carbon dioxide into soil organic material. When the natural biosphere reservoir is damaged, there is a greater release of CO_2 and potentially an impairment of sinks function. Wood produced in forestry, agro-forestry or plantation crop production sequesters significant quantity of carbon. Vegetation acts as a carbon sinks because the plant converts carbon dioxide into solid organic material.

As a subcomponent of the World Bank supported Rs 360 crore Mid-Himalayan Watershed Development Project, the creation of carbon sinks through afforestation is likely to accrue a net gain of Rs 20 crore to the communities over the next 20 years. Fiscal incentive has triggered a renewed interest in protecting the aforestated lands says Kushi Ram in Baddi Village in Kangra district that is ‘green currency’ from plantation. The World Bank which is a trustee of the Bio-Carbon Fund is a public/private initiative administered by the World Bank that aims to deliver cost-effective emission reductions, while promoting biodiversity conservation and poverty alleviation. It has been argued that not only will the project generate environmental benefits through carbon sequestration but will improve revenue-generating capacity of small farmers as well. The carbon revenue will go to the village community, providing them the necessary incentive to protect watershed and forests. In reality, the carbon sequestered both in tree biomass above and the soil below is immensely complicated. However, a ton of carbon dioxide converted into biomass under new plantations is counted as one credit. The carbon credits form such projects is sold as Certified Emissions Reductions (CER). The land owners need to ensure that the tree density is no less than 1,100 plants per ha and no felling of trees from the land under the project shall be permitted. Farmers are expectedly awaiting the validity of the project by the UN Framework Convention on Climate Change.

Conclusions

The soil carbon pool composed of soil organic carbon and soil inorganic carbon plays an important role in the global C cycle. In addition, the soil C pool is also an important factor that affects soil productivity and its environment moderating capacity (air and water quality including atmospheric concentration of traces of gases). The depletion of the SOC pool upon conversion from natural to agricultural ecosystem is accentuated by soil degradation, especially that caused by soil erosion and nutrient depletion. Accelerated soil erosion causes preferential removal of surface soil and has low density; it is easily removed and carried away by runoff water or by blowing wind. Soil organic carbon content is a function of soil management practices that can alter SOC content in soil. Adoption of agronomic practices which can enhance the production of both above and below ground biomass and increase the SOC content through atmospheric carbon sequestration is the need of the hour under the given situation of global warming.

Climate Change Vulnerability Study Using GIS for Developing Farmers Adaptation Strategy

L.Vignesh Rajkumar, K.Shimola and M.Krishnaveni

Centre for Water Resources, Anna University, Chennai
E-mail: rkumarsigns@gmail.com

Abstract

Climate change is expected to have serious environmental, economic, and social impacts in India particularly on rural farmers whose livelihood depend largely on rainfall. Understanding the factors that cause changes in climate is essential to increase adaptive capacity and to develop strategies to cope with future disasters. Climate change impacts water availability, productivity of crops and various other factors as well.

Vaippar basin is chosen as study area which is subjected to uneven rainfall distribution, moderate drought and reduction in crop productivity. This leads to an overall decline in agricultural activities and migration of people from agriculture to industries like fireworks, cement factories and in brick manufacturing. This project is taken up not only to study the climate change and its vulnerabilities but also to suggest suitable adaptations for farmers. A proper adaptation strategy could help them to increase their crop productivity and thereby increase their income from agriculture. The problems are identified directly by conducting questionnaire surveys to the farmers of different catchment areas.

Various data related to rainfall, temperature, surface and ground water were collected from various line departments and vulnerability mapping was carried out using GIS. The vulnerability factors included in mapping are soil type, land cover, crops grown, population, water sources, farming systems and livestock data. The GIS provides reliable and accurate information which will enable prioritizing issues and channeling attention to the most appropriate areas. After the study, suitable adaptations are given for various farmers involved in various agricultural activities. Each block in the basin is provided with separate adaptation practices to improve their livelihood and socio-economic status.

Introduction

Climate change has been attracting global attention at an ever–increasing rate over the last two decades, starting with the appearance of First Assessment Report of Intergovernmental Panel on Climate Change (IPCC) in 1990. Climate change, in as much as it affects the common man is indeed hydrologic change. Climate change has brought spatial and temporal variation in the climatic parameters particularly in precipitation resulting in flooding and drought within a region. Climate change poses significant risks to the water resources for the Asian countries. The annual mean surface air temperature is projected to rise by 1.7°C and 2.0°C in 2030s over the Indian sub-continent.

India is one of the most important countries in the world with regard to the climate change. With a large and growing population, India's emissions of greenhouse gases are increasing. At the same time, potential climate impacts in India are severe; they include sea level rise, changes in the monsoon, increased severe storms and flooding and drought. Recently, climate variability in the form of floods and cyclones has resulted in destruction of crops, property and infrastructure as well as in negative impacts on human health and well-being. All of these impacts have a setback on general socio-economic development and continuing dependence upon agriculture for food and livelihood makes the Indian people particularly vulnerable to climate variability and change. A GIS based mapping could form a basic dataset to know the climate change vulnerability of the basin. This mapping and interviews with the farmers would enable us to form new possible and the most suited adaptation strategies to be implemented in order to get an increasing trend in agricultural practices carried out by the basin farmers.

Objectives

To identify the vulnerability indicators through preliminary analysis of climate variables, to generate climate change vulnerability map of the basin using GIS and to develop adaptation strategies based on questionnaire and vulnerability map.

Study Area

The Vaippar basin lies between latitudes 8°57´N and 9°48´N and longitudes 77°16´E and 77°22´E covering a total catchment area of 5423 km^2. The basin is located in southern part of Tamil Nadu (Fig:1) which is bounded on the west by Western Ghats, on the east by the Gulf of Mannar (Bay of Bengal), on the north by Vaigai and Gundar basins and on the south by Tambaraparani basin. The study area is covered by the Survey of India toposheet Nos. 58G, 58K and 58L on 1: 250,000 scale. The River Vaippar originates from the Echamalai Mottai, Neduntheri Mottai and Kiladiparai hill ranges of Western Ghats with an elevation of 1651m above MSL near Sivagiri in Tirunelveli district and flows generally in the easterly and south-easterly direction for a length of 146 km and finally joins the Gulf of Mannar. The catchment area consists of hilly regions falling in the Kodaliparai Mottai, Vasudevanallur reserve forest, Periya Sudangi Malai etc. These mountain ranges fall in the rain shadow regions of the Western Ghats and hence receive only a meagre rainfall. The catchment area of Vaippar basin lies entirely within state of Tamil Nadu.

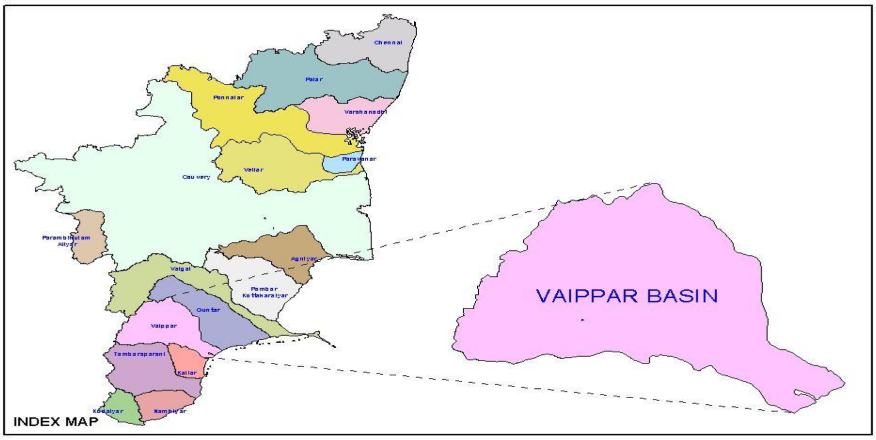


Fig 1 Index Map of Vaippar Basin

Climate

The Vaippar basin has a tropical climate. It has a hot summer and mild winter. Agro-climatically, the area falls under the group of semi-arid region. The climate in the basin is influenced by the monsoonic winds as in other parts of Tamil Nadu. The monsoonic season is mainly responsible for most of the rains over the basin with the north-east monsoon accounting for the maximum amount of rainfall. Most of the agricultural activities are centered around this season between September and December. The south-west monsoons during the months of June to September also produce a reasonable amount of rainfall which is quite useful for the rainfed agriculture. Unfortunately, the basin falls on the rain shadow area of the Western Ghats as far as south-west monsoon is concerned. The winter (January to February) and summer (March to May) season's rainfall may not be significant in producing any useful runoff but certainly helpful in maintaining the soil moisture in the basin. The temperature variation is from 20°C to 30°C in winter and 30°C to 40°C in summer. The mean monthly humidity varies between 55% and 73%. Generally, the humidity is quite high during the monsoon season compared to the non- monsoon season. The average monthly wind velocity varies between 3.5 kmph and 7.25 kmph. The wind velocity is high during the months of June, July and August mainly influenced by the south-west monsoon winds.

Data Used and Methodology

The Methodology adopted in the present study is given in Fig 2. Data regarding the climate variables have been collected from various line departments; these are the observed values of the basin from the meteorological stations and the rainfall stations. A simple trend analysis was carried out with the obtained data to prove climate change in the basin.

Air temperature is a weather variable that is also used to describe climate. It is easily measured, directly observable and geographically consistent. Thus, it can be used to construct the statistical properties of climate and infer climatic conditions by computing average conditions, variance and trends. Precipitation is also an important property of weather and climate. It is highly variable spatially because of the influence of local features such as topography, elevation, aspect and exposure. Not only is total (accumulated) precipitation over a time important, but also the rate at which it falls, the form (rain or snow) and its spatial distribution.

Climate trends provide a picture of how much change has occurred in the past, for example over a period of 30-60 years. Climate trends are derived from statistical analysis of historical climatic data or from analysis of paleoclimate records (before direct measurements).A historical climate trend based on past weather observations describe the climate that occurred over a certain period. To determine whether climate trends reflect climate variability or climate change, the statistical significance of trends over time periods of several decades must be considered and comparisons of trends between stations and between adjacent regions need to be made. A linear trend cannot be extrapolated into the future because the climate system is non-linear**.**

Vulnerability Indicators

Vulnerability indicators are identified based on the preliminary analysis carried out with the climate variables and also suggestions from the experts related to climate change. The selected factors are explained in relation to climate change and vulnerability. The vulnerability indicators are to be mapped as individual layers using Arc GIS. After mapping the vulnerability indicators as separate layers, an overlay analysis is performed in order to bring out vulnerability map of the basin.

Land use

Deforestation, urban sprawl, agriculture, and other human influences have substantially altered and fragmented our landscape. Such disturbance of the land can change the global atmospheric concentration of carbon dioxide, the principal heat-trapping gas which affects local, regional and global climate by changing the energy balance on Earth's surface. Both climate and land use changes are simultaneous processes. Land use changes due to change in climatic conditions, conversely climate is getting affected due to the land use change and increased usage of excessive fertilizers. Climate change shows adverse impacts on land use; the slow and continuous change in the climate of the basin has severe impact on land use. The marked changes are like changes in the rainfall pattern, changes in the monsoon, increased temperatures, colder nights and warmer days. These are some of the climatic extremes recorded or observed in the basin.

From the previous studies about climate change and its relation to land use it is found that land use suffers adverse impacts because of the changing climate which results in the negative influence on climate. The change in the pattern of rainfall or a decline in monsoon affects the crop productivity. The excessive usage of fertilizers leads to the increased emission of carbon and other toxic gases. Thus, land use is considered to have a drastic change due to climate change; it is considered as a good indicator to climate change.

METHODOLOGY

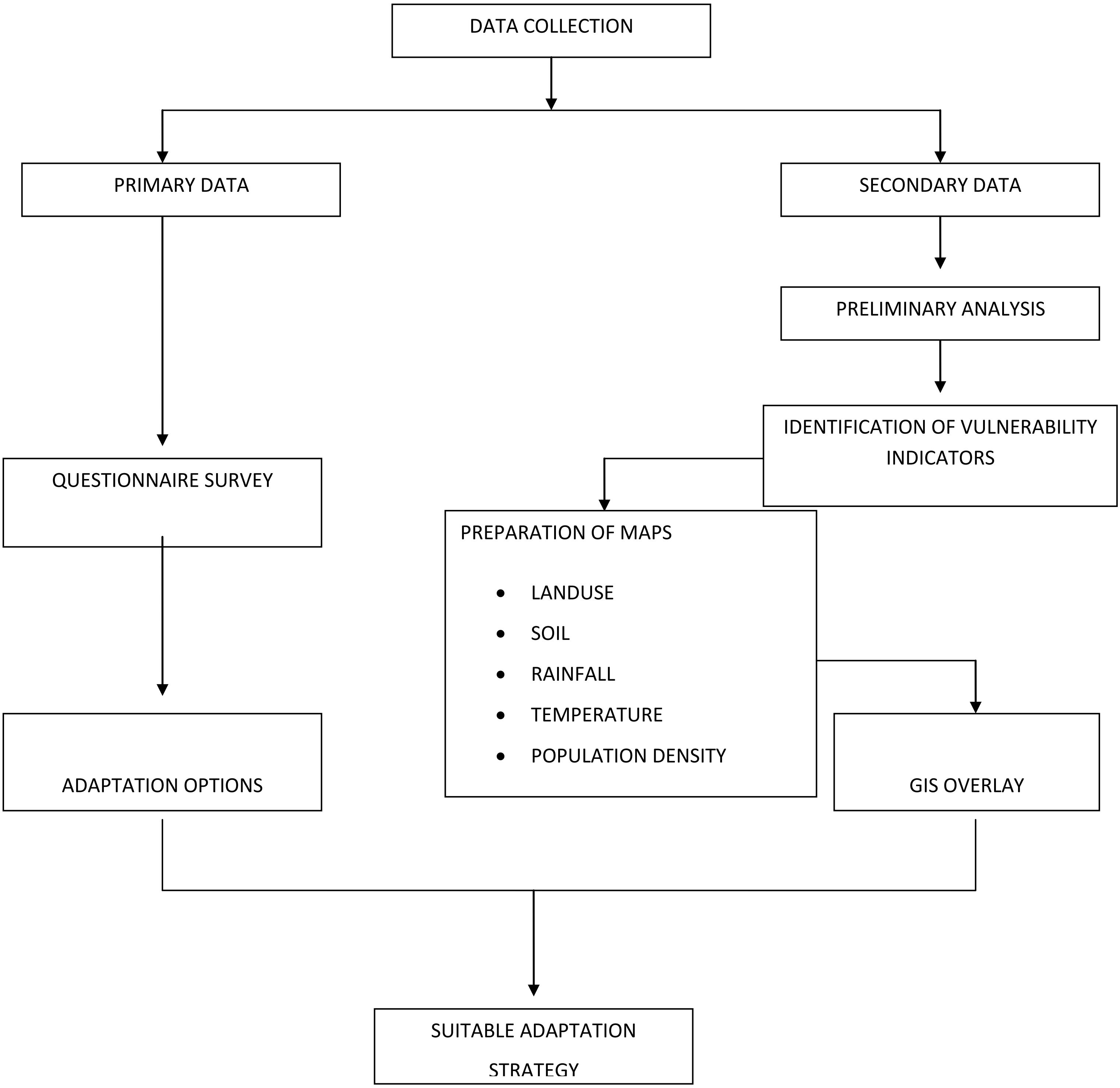


Figure 2. Flow diagram showing the methodology followed

Soils

Although, the earth's climate has been slowly evolving over millions of years, rapid changes have occurred in recent times due to the activities of humans. Climate change is now recognized as something which is affecting all our lives. Soil is a part of the natural world that is both affected by and contributing to global warming. Soil is one of the largest sources of carbon in the world. The change in temperature and rainfall patterns is also damaging the physical structure of soils. The organic matter in particular is being affected, its balance being crucial to the nutrient balance on the soil, its stability, the amount of water it can hold and the population of soil organisms. Additionally, the changes are likely to leave some soils more vulnerable to damage by erosion.

As a converse process, the soil also contributes to climate change. Carbon in the soil is broken down naturally and released into the atmosphere as carbon dioxide gas. However, as the air temperature increases, this process occurs more quickly which means too much gas is produced adding to the atmospheric trap and consequently to global warming. Soil can also produce other harmful 'greenhouse' gases such as methane and nitrous oxide. Waterlogged and flooded soils in particular are responsible for producing methane. The changes in soil structure or the changes in the soil pattern could be a direct indicator of climate change. Thus, it is considered as a major indicator to climate change and is mapped as a layer for vulnerability mapping.

Rainfall and temperature:

Rainfall is one of the major factors included in mapping vulnerability of the basin since the basin is experiencing various shifts in the rainfall pattern. Vaippar basin receives more rainfall in summer compared to winter. The summer rainfall in Vaippar basin varies from 40mm to 200mm. More than 50% area receives rainfall above 130 mm. This makes a significant effect during the summer period. Rainfall in a place has significant impact on climate change of the place. Similarly, climate change is caused due to insufficiency in the amount of precipitation. Air temperature is an important weather variable which is used in mapping vulnerability. It has been used to construct the statistical properties of climate and infer climatic conditions by computing average conditions, variance, and trends. Temperatures are changing in the lower atmosphere - from the Earth's surface all the way through the stratosphere (9-14 miles above the Earth's surface). Most climate change scenarios project that greenhouse gas concentrations will increase with a continued increase in average global temperatures. How much and how quickly the Earth's temperature will increase remains unknown given the uncertainty of future greenhouse gas, aerosol emissions and the Earth's response to changing conditions.

Population

There is an increased possibility of high emission as the population increases. The main factors which have caused the rise in CO_2 emissions are twofold: (a) growth in population and (b) growth in energy use per person. As population being a major threat to climate change and its vulnerability, this is considered as one of the major indicator of climate change. The population data is collected and analyzed block-wise and a population layer is prepared based on which vulnerability is assessed using ArcGIS.

GIS Overlay

Overlay is an analysis performed using ArcGIS. Overlay analysis helps us to create the vulnerability profile for the selected basin. All the indicators chosen for vulnerability mapping are created as separate layers. These layers are analyzed and individual weights are given to each layer. The weights are assigned to each layer by literature study and expert guidance. The weightages are given based on the percentage at which each indicator is prone to risk. If rainfall is most vulnerable, then it is given the maximum weight and the next vulnerable layer is given the second maximum weight. Similarly, each layer is weighted individually out of hundred percentage and the values are fixed. After assuming the weights for each layer, ranks are given for different classes in each layer. This ranking is within each separate layer. The area which is the most affected or the area more prone to risk is given the highest ranking and the next class prone to risk is given the next rank. Similarly, all the layers are ranked for different classes in it. Now the weighted overlay analysis is performed with all these layers assigned with different ranks and weights. As a result of this overlay analysis our objective of generating vulnerability map is achieved.

Adaptation Strategy

Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Adaptation to climate change refers to adjustment in ecological, social or economic systems in response to actual or expected climate stimuli and their effects or impacts, addressed to the solution of relative problems, as well as to the benefits from the undertaken measures. The necessity to design the adaptation strategy is based upon the vulnerability assessment and is conditioned by the demand in sustainable development of the national economy and its better adaptation to climate changes and extreme weather events. National action programmes and plans including those dealing with environmental safety, desertification, flood management, protection of the ozone layer, ecological public education and others indicate a high priority in realization of measures concerning unfavourable climate change consequences.

National obligations on implementation of the UNFCCC are to design and implement adaptation measures, to improve and develop systematic observation network, to support education and enhance public awareness. The strategy covers the sectors of national economy vulnerable to climate changes as well as the issues related to public health and natural resources.

Results and discussion

The results obtained from mapping the vulnerability indicators using ArcGIS are briefly discussed below.

Rainfall map

The rainfall pattern in various parts of the basin is identified from the rainfall map (Fig.3) generated by ArcGIS. The rainfall being the major indicator determining the vulnerability, it is mapped to overlay with the other indicators. The rainfall layer suggests the variable patterns in the basin. Rainfall is given the maximum weightage. The regions receiving maximum rainfall is given the highest rank and least ranking for the region with minimum rainfall. Vaippar basin receives more rainfall in summer compared to winter. The summer rainfall in Vaippar basin varies from 40mm to 200mm. More than 50% area receives rainfall above 130 mm. This makes a significant effect during the summer period. Rainfall in a place has significant impact on climate change of the place. The rainfall at head reach is higher than the rainfall in the middle and tail ends. The map clearly represents the variation from head to tail end and conversely the vulnerability also increases from head to tail. The tail end of the basin is more vulnerable to climate change when rainfall is considered a major parameter indicating vulnerability.

Temperature map

Temperature in the basin is generally high and there are variations of temperature in different regions of the basin (Fig.4). The variations are mapped using ArcGIS. The rain shadow region where the basin originates experience a colder temperature compared to the later part of the basin. The temperature as recorded by the weather station has increasing trend from the past several decades. When the temperature is taken as maximum and minimum, the analysis reveals that the maximum temperature is increasing and the minimum temperature is decreasing. The middle reach of the basin gradually increases and reaches the maximum at the tail of the basin. Most part of the basin after the rain shadow region experiences warmer temperature. Agro practices carried out in these parts of the basin has declined in the recent decades due to the increased temperature and decreased rainfall pattern. The map clearly shows that temperature is the important factor in determining the vulnerability of the basin. This could be overlaid with the other indicators to determine the vulnerable places of the basin from vulnerability map.

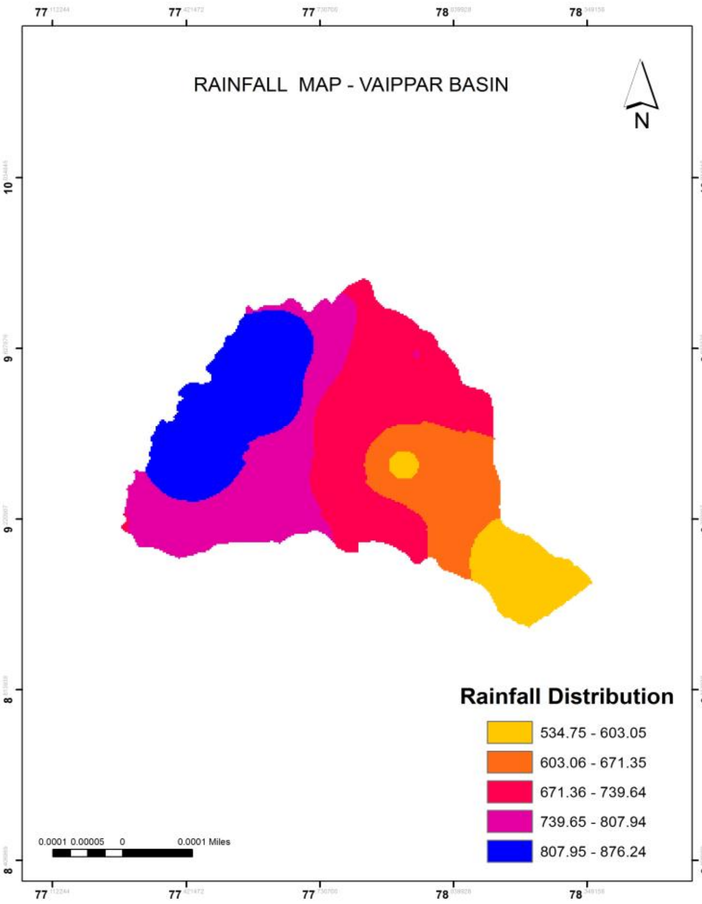


Figure 3. Rainfall

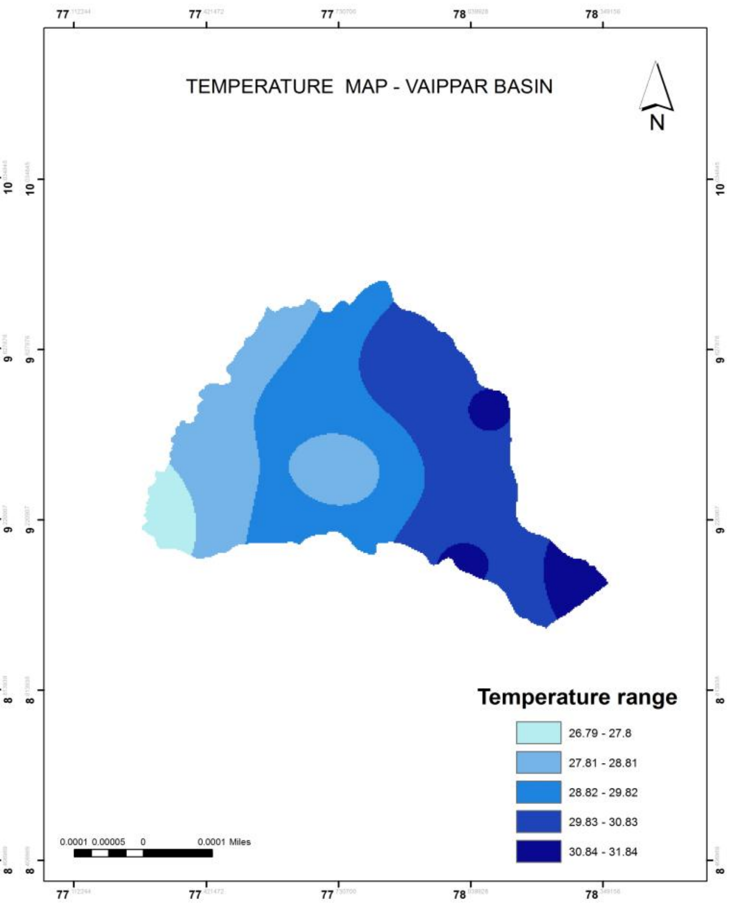


Figure 4. Temperature

Landuse map

There are seven different land uses (Fig.5) at different parts of the basin based on the differences in temperature and rainfall. The map is generated with data about various land use patterns obtained from the basin. From the map, it is clear that major portion of the basin is covered with barren lands. These barren lands are free from cultivation and the soils are not fertile and as such not suitable for agriculture. Hilly regions are found in the Western Ghats separating Tamil Nadu from Kerala. This region is the fertile part of the basin where intense irrigation is practiced in some places. The irrigated areas are found near the foot of the mountains and near the river course. The regions adjacent to the intensely irrigated areas are sparsely irrigated regions which suffer from water stress. Other than the irrigated regions and tanks and hills in the head reach, all the other regions suffer from drought. The tail-end where the Vaippar River drains into the sea suffer from drought and are more vulnerable to climate change.

Population density map

The population in the basin is mapped block-wise (Fig.6). The population density is high in the industrial regions and sparsely populated in the other drought prone areas. The hilly and the coastal regions are very sparsely populated. The irrigated regions are moderately populated with some settlement zones. Sivakasi and Virdhunagar being the industrial blocks are very thickly populated. The intensively irrigated blocks like Sriviliputhoor and Rajapalayam are also densely populated.

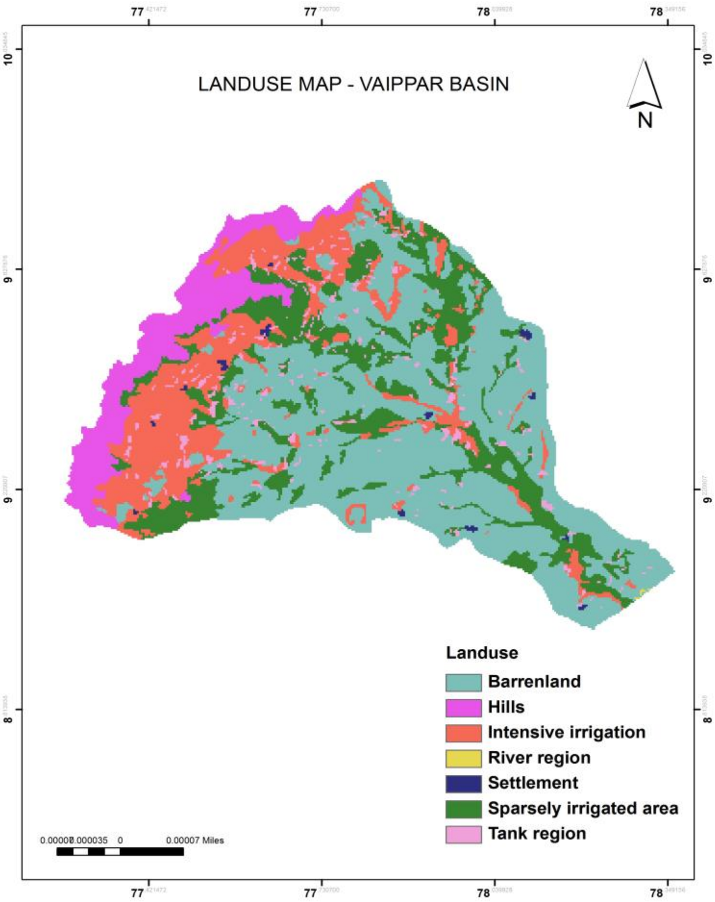


Figure 5. Land Use

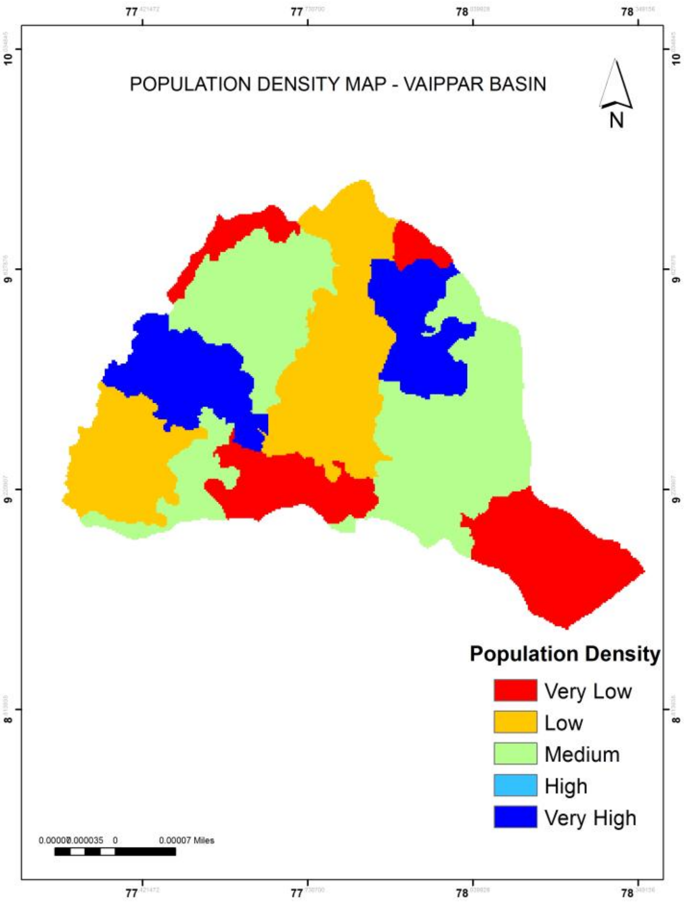


Figure 6. Population density

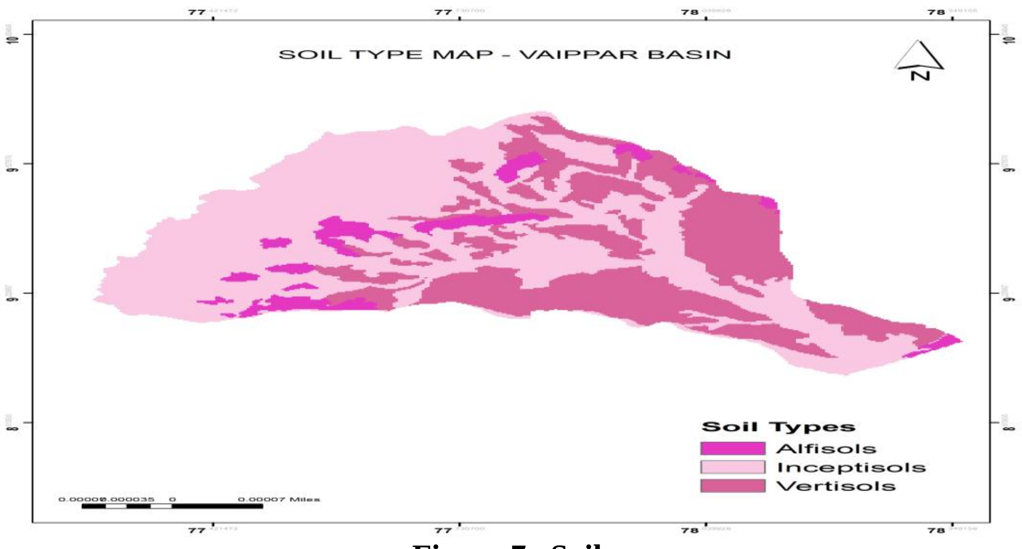


Figure 7. Soils

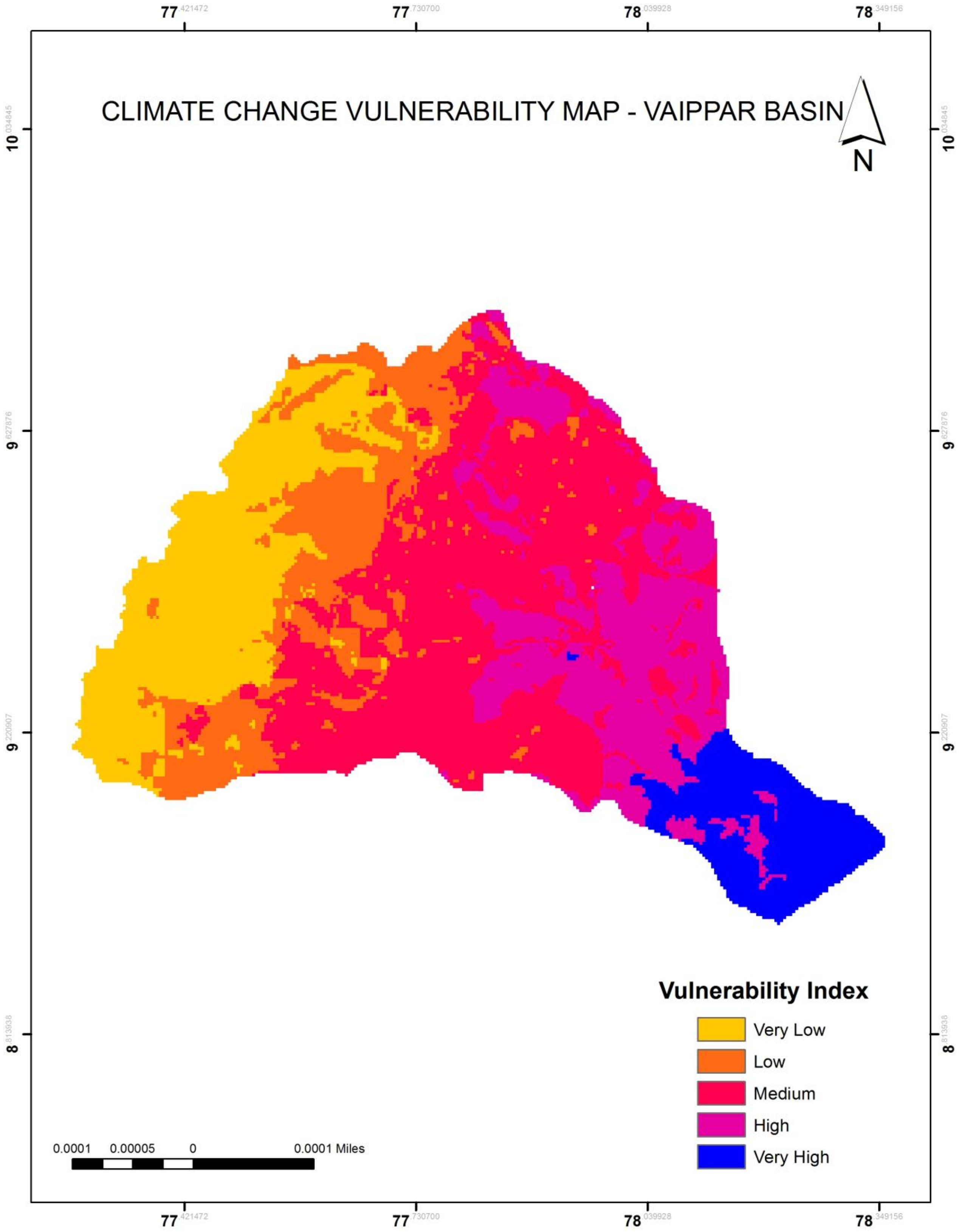
Soil map

There are three major soil types in the basin (Fig.7). The majority of the basin is covered by Inceptisols which are found near the hills and along the river courses. Vertisols are found in major amount next to Inceptisols. Irrigation is practiced in these soils. It is found on either side of the river regions and also in some parts near the foot of the hills. Alfisols are found in the regions experiencing high rainfall and minimum temperature. It is found in minor extent in regions where the water drains from the mountains to originate as river. The Alfisols are not much vulnerable to climate since it has high soil moisture content. The Inceptisols are the most vulnerable soil type of the basin.

Vulnerability map

The vulnerability profile is achieved after the generation of all the individual layers for the vulnerability indicators and overlaying them. Each vulnerability layer is given separate weights and the vulnerability map is generated (Fig.8). The vulnerability map consists of various regions of the basin at various degrees of vulnerability. The map suggests the head reach of the basin is much fertile and gets reduced as it moves onto the tail reach. The rain shadow region and regions followed by it are less susceptible to vulnerability as it receives more rainfall and proper agro practices are carried out. The middle reach has industries and barren lands. As there are many industries in this region, it is densely populated. Other than this, the climate is getting worse because of rapid industrialization. The rainfall is in the declining trend in the entire region and the temperature is on the increasing trend. Thus, the basin when it is considered as a whole is classified as a region of moderate drought. The vulnerability profile clearly indicates the stage by stage development of vulnerability from the head reach to the tail reach. Regions at the tail suffer very high vulnerability and prone to risk.

The vulnerability map would be helpful in carrying out the mitigation and the adaptation measures to overcome drought situations. The areas which require immediate adaptive measures could be identified and actions can be taken as per the requisites. Vulnerability map of Vaippar basin indicates that majority of the regions are affected by drought and at risk of high vulnerability.


CLIMATE CHANGE VULNERABILITY MAP - VAIPPAR BASIN
N
Vulnerability Index
Very Low
Low
Medium
High
Very High
0.0001 0.00005 0 0.0001 Miles
77 421472
77 730700
78 039928
78 349156
10 034845
9 627876
9 220907
8 813938

Conclusions

Vaippar river basin is highly affected due to the changes in climate. More than half the area is vulnerable due to the demographic, climatic, agricultural and other occupational hazards. The climate variables such as long term rainfall average, annual rainfall and long term average maximum temperature are important in affecting the area under paddy. In case of paddy, the climate variables (rainfall and temperature) are influencing the productivity of paddy, where as in case of rainfed crops, the proportion of irrigated area has maximum effect in increasing the productivity. Since climate change is gradual and the impact is marginal over the years, it is important to examine the appropriate interventions. Using the results of the basin, adaptation practices being practiced in the extreme situations should be documented, as certain crops such as horse gram, black gram, red gram and gingelly are grown in the drought prone regions. This is an indication, that the traditional cropping systems suitable for the areas should be re-introduced at least as a crop rotation measure.

Also, interventions should be grouped under the short term and long term categories. The short term interventions normally range from the adoption of crop varieties to water management practices to suit the climate changes, suitable irrigation methods and soil moisture conservation measures etc. The long–term interventions normally refer to the governmental programs that will help address the climate change impacts. The preliminary analysis of temperature data in the Vaippar basin showed a linear trend of increasing pattern resulting in warming up of the basin. Rainfall is characterized by large annual variability with a significant decrease in the amount of rainfall. Agriculture in this basin is heavily dependent on climatic conditions. The overlay analysis carried out with the vulnerability indicators results with the identification of the vulnerable areas of the basin. Other than this, a survey was conducted with the farmer's about their perception and adaptation. The farmer's perceptions about climate are in same path with the climate data analysis. The study reveals that most of the farmers are aware of decreasing rainfall trend with increased temperature and the impacts of the changes on their environment. But they don't have sufficient knowledge to connect this with the climate change. There is no awareness and knowledge among the farmers to understand the climate change scenarios. They follow few adaptation measures like crop diversification, changing the planting dates and short duration crops. Some more adaptation practices like water harvesting, soil conservation practices, agro-forestry and crop insurance to farms can also be implemented in the basin.

The policy makers can start from the highly vulnerable areas and then move to less vulnerable areas thus minimizing the impact of climate change. It is also important that climate awareness and capacity building should be an integral part of the development programs at all levels.

Land Evaluation using Remote Sensing and Geographical Information System

Prabhuraj, D.K., Jyothi, B.L., Shivaprasad, C.R., Harindranath, C.S. and Guruswamy, K.T.

Karnataka State Remote Sensing Applications Centre, Bangalore
Email: cs.hari.cs@gmail.com

Abstract

Land evaluation using a scientific procedure is essential to assess the potential and constraints of a given land parcel for agricultural purposes. Hence, analysis of crop suitability under various systems that could be grown in a given area is essential. Remote sensing (RS) data is used for estimating biophysical parameters and indices besides cropping systems analysis, and land-use and land-cover estimations during different seasons. However, RS data alone cannot suggest crop suitability for an area unless the data is integrated with the site-specific soil and climate data. RS data can be used to delineate various physiographic units besides deriving ancillary information about site characteristics, *viz.* slope, slope direction and aspect of the study area. However, detailed information of soil profile properties is essential for initiating crop suitability evaluation. Hence, soil survey data are indispensable for generating a soil map of the given region which helps in deriving crop suitability and cropping system analysis. RS data coupled with soil survey information can be integrated in the geographical information system (GIS) to assess crop suitability for various soil and biophysical conditions. The present study was undertaken to demonstrate the usefulness of RS and GIS technologies coupled with soil data to assess crop suitability in order to implement sustainable cropping systems in Hunsur taluk, Mysore district.

The parametric approach of Sys (1985) which is a modified version of the FAO Framework for Land Evaluation (1976) was used for evaluating the land suitability of map units for various crops. The FAO Framework recognized two orders, namely, order S—suitable for agriculture and order N—not suitable for agriculture. The soil-site suitability assessment of the soil map units in Hunsur taluk was done for rice, tobacco and mango crop, which are the major crops grown in the area. Out of the total irrigated area assessed for rice suitability, about 35.3% area in the taluk was rated as highly suitable (S1), 55.3% area as moderately suitable (S2) and 9.4 % as marginally suitable (S3) for paddy production. Out of the total tobacco grown area assessed for suitability for tobacco, about 6.1% area has been classed as highly suitable (S1), 71.9% area moderately suitable (S2), 17.8% area marginally suitable (S3) and 4.4% area not suitable (N). Out of the total area assessed for suitability for mango, about 8.5% area has been classified as highly suitable (S1) in the taluk, 31.5% area moderately suitable (S2), 54.8% area marginally suitable (S3) and 5.9 % area not suitable (N).

Introduction

Land evaluation assesses the potential and constraints of a given land for crop growth. Soil forms the base for growth of natural vegetation, agricultural crops, horticultural plantations and fodder. Soil productivity depends on its characteristics, use and management and climatic and environmental settings. Soil map and soil database are generated using remote sensing (RS) and GIS techniques. The soil-site characteristics are integrated in the Geographical Information System (GIS) to assess crop suitability with climatic data and crop requirements. The present study was undertaken to demonstrate usefulness of RS and GIS techniques to assess crop suitability in Hunsur taluk, Mysore district to implement sustainable cropping systems.

Study area

The Hunsur taluk is in the western part of Mysore district between 12^{o} 07' 35" and 12^{o} 25'38" North latitudes and 76^{o}06'02" and 76^{o} 31' 06" East longitudes covering an area of 897 sq km. The area forms part of South Deccan plateau. The elevation ranges from 882 m to 740m. The relief is normal. The area belongs to the Archaean Precambrian gneiss and schist with intrusions of basic dykes. The Plateau area is drained by Laxamanathirtha and its tributaries. The climate is semi-arid tropical. The mean annual rainfall is 826mm of which 68 per cent is received during the Southwest Monsoon (June to October) .The annual rainfall ranges from 800 mm to 900 mm in the western parts of area. The rainfall is about 162 mm in October which is highest for the taluk. Potential evapotranspiration (PET) is about 1531mm and is high during March (166 mm/month) and is lowest during November (106 mm/month). The major crops are *ragi, rice* and *tobacco*. Mango is also predominant.

Database and methodology

Geocoded Quick Bird (61 cm resolution) False Colour Composites (FCC) on 1:4000 scale was interpreted on screen for physiography at village cadastral level and mosaicked to hobli/taluk level for the present study. The Physiogrpahy map formed the base for field survey and mapping of soils (LRIS, 2010). Soil mapping comprised study of soil profiles, grouping of soils to soil series, establishing physiogrpahy-soil relationship and finalizing soil map with phases of soil series.

Table 1 Soil-Site Characteristics of Dominant Soil Series– Hunsur Taluk

Series	Soil Drainage	Texture	pH	CEC emol(+)kg^{-1}	OC(%)	Soil depth(cm)	Gravel %	Salinity ECe dS/m	Sodicity (ESP)
ALLIANPURA	WD	cl, sc, scl	8.0	24-40	0.64	100-150	10	0.31	1.59
ANGARAHALLI	WD	gscl, gsc	6	24-40	0.28	75 - 100	50 - 80	0.06	2.32
BANNIHATTI	WD	sc	7	16-24	0.51	100 - 150	NIL	0.05	3.03
BENAKANAHALLI	WD	gsc, sc	6.0	16-24	0.6	75-100	10-20	0.06	4.46
BESAGARAHALLI	MWD	scl, sc	6.0	24-40	1.18	100-150	-	0.78	1.06
BIKKANAHALLI	WD	sc	7.0	24-40	0.16	75-100	-	0.41	2.02

CHIKKAJATAKA	WD	c,sc,gc,gsc	6	16-24	0.27	100 - 150	30-60	0.08	3.44
CHIKKONAHALLI	WD	gsl	6	16-24	0.6	25-50	35-55	0.16	0.17
GALAGA	WD	gscl	7	10-16	0.16	50-75	60	0.03	4.22
GOLLENAHALLI	WD	scl	5	10-16	0.5	100-150	15	0.5	4
GORAVALE	WD	scl, ls	8	24-40	0.58	100-150	-	0.51	0.07
GOVNAL	WD	gsc,gscl	6.0	16-24	0.51	50-75	35	0.19	1.96
GUDDADAHULIKATTI	WD	gcl, gsc	5.0	10-16	0.96	75-100	50-80	0.4	3.36
HAGARE	WD	scl, gscl	5	<10	0.65	100-150	30	0.5	0.32
HIRIYANGAL	WD	gsc, gc	7	16-24	0.54	100-150	25-40	0.07	3.06
HOSPURA	WD	gsc	7	16-24	0.45	75 - 100	45	0	0
HUTAGALLI	WD	gc, gsc	7	16-24	0.39	50-75	15	0	3.33
INDIRANAGAR	WD	gsc	7.0	16-24	0.57	25-50	20-80	1.11	0.99
KABINI	WD	scl	7	16-24	0.48	100-150	-	0.31	1.12
KALLUR	WD	gcl	5	10-16	1.22	75-100	10-50	0.06	4.44
KAVALGUNDI	WD	gsc, c	5.0	10-16	0.55	50-75	10-40	0.13	1.4
KOPPALI	WD	gscl	6	10-16	0.26	50 -75	35	0.03	3.13
MUDDAPURA	WD	gscl, gcl	7	24-40	0.68	50 - 75	30-40	0.43	6.69
MUKKAL	WD	gscl, scl	7	10-16	0.29	75-100	25	0.06	2.21
NAVALI	WD	c, sc	6	10-16	0.4	100-150	-	0.2	0
SAVATAGI	WD	gscl	7.0	16-24	0.79	50-75	50-60	0.4	1.88
SHIVASANDRA	WD	gscl, gsc	6	10-16	0.7	100-150	50-60	0	3.67
SHRINGARATHOTA	WD	gscl, gsc	7	16-24	0.25	50 - 75	50	0	0
SIGULAHALLI	WD	scl, c	9	24-40	0.28	100-150	-	0.09	6.52
UGRANAHALLI	WD	gscl	6	10-16	0.49	50-75	40-50	1.2	4.45
UNNALA	WD	gsc	6.0	10-16	0.35	25-50	50-60	0	0
BUDIKOTE	MWD	c	6	16-24	0.62	100-150	-	0	6.32
NELSOGE	MWD	c, sc	8	24-40	0.57	75-100	5 - 10	0.38	1.26
SANKIHALLI	WD	sl	7.0	10-16	0.42	10-25	-	0.07	5.69

The soil and site characteristics (table 1) of each soil map unit relevant for growing the above crops were evaluated (Sys 1978) in terms of their limitations. The suitability classification for each crop was made by matching the land and soil qualities against crop requirements. The suitability classes and subclasses were determined based on the number and kind of limitations. The FAO Framework recognizes two orders, namely, order S suitable for agriculture and order N not suitable for agriculture. Order S has three classes, S1—Highly Suitable, S2—Moderately Suitable and S3—Marginally Suitable. Order N has two classes, N1-Currently Not Suitable and N2-Permanently Not Suitable for agriculture. The suitability subclass reflects the kinds of limitation and guide land improvements required. The subclasses are indicated by suffixing lower case letters (**c** for climate, **e** for erosion hazard, **f** for flood hazard, **g** for gravelliness, **k** for workability, **l** for topography, **m** for moisture availability, **n** for nutrient availability, **p** for crusting, **r** for rooting condition, **t** for texture, **w** for drainage, **z** for excess salt or calcareousness) to the suitability class.

Results and discussions

A total of 57 soil series have been identified and mapped. The soil map has 574 soil map units as phases of soil series. Rock outcrops were mapped as miscellaneous lands. Each soil map unit includes up to about 15 per cent of other soils as inclusions or impurities. Out of 57 soil series, 34 soil series occur dominantly; their characteristics are given in Table1. Broadly, the soils of the area are grouped into four traditional soil classes (Fig.1). They are red soils which are deep, moderately deep and shallow on uplands and alluvial soils in valleys.

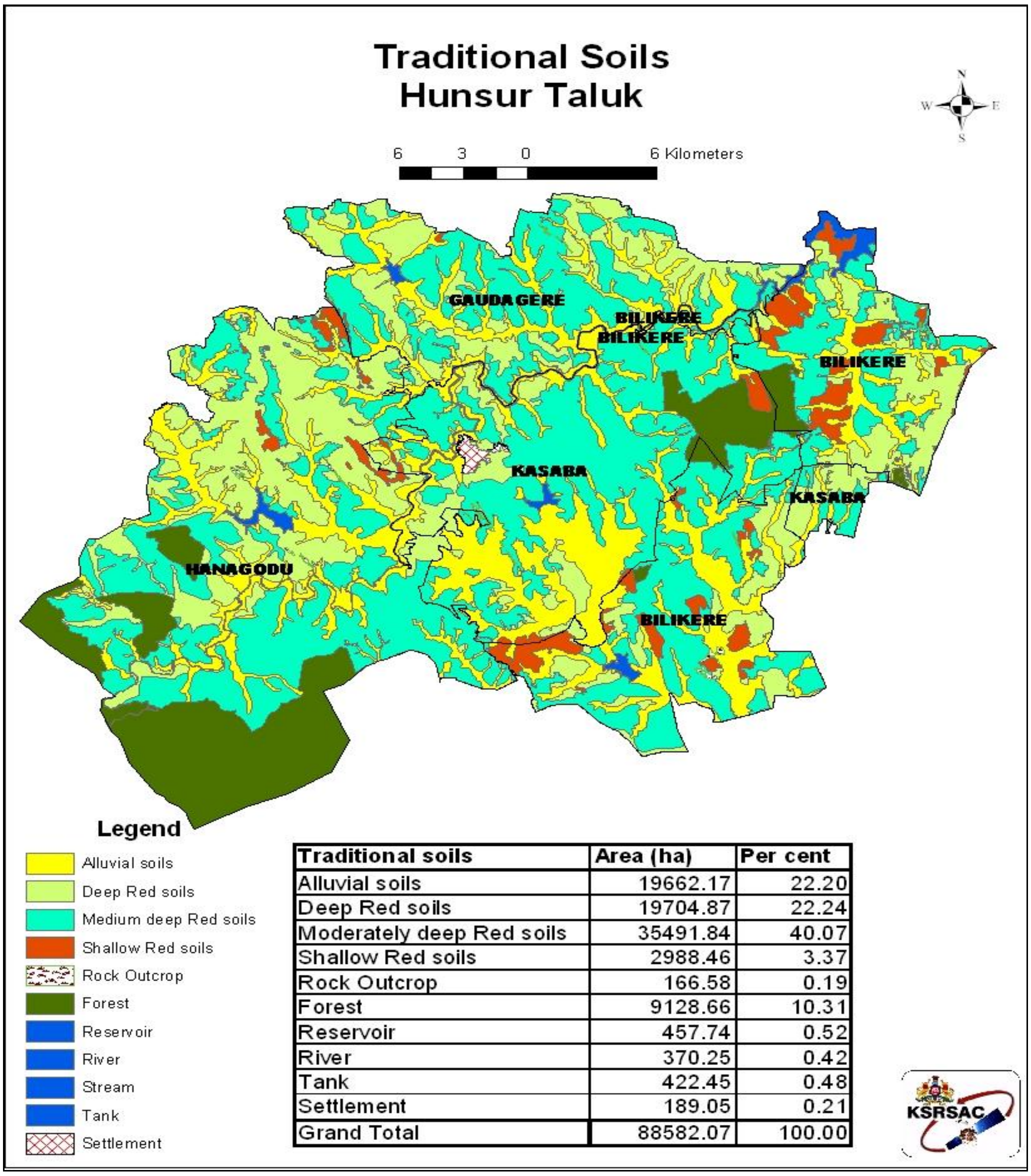
The soils of Hunsur taluk was evaluated for ragi, rice, tobacco and mango, the major crops grown in the taluk. For brevity sake, *ragi* (*Finger millet*) is discussed in this paper. *Ragi* is grown under rainfed as well as irrigated conditions. According to the criteria (Table 2) for optimum yield of *ragi*, well distributed rainfall of about 750 to 900 mm is required with length of growing period of more than 110 days. The area receives a rainfall of 800 to 900 mm. The crop requires well drained (WD) conditions, moderately deep to deep (> 75 cm) soils with loamy surface soil and clay to sandy clay subsoil and coarse fragment (gravel) content should be less than 15 per cent. About 60 per cent area in the taluk has moderately deep, well drained, loamy to clayey soils. About 54 per cent area has more than 35 per cent gravel in the subsoil which limits the water holding capacity of the soils. The data revealed, about 15 per cent area is highly suitable (S1), 53 per cent moderately suitable (S2) (Table 3) with limitations of soil erosion, gravelliness, rooting depth and soil texture (Fig 2).These limitations can be improved with soil and water conservation measures to obtain higher yield. About 18 per cent of the area is marginally suitable (S3) with severe limitations of soil depth and high gravel content. Plant growth requirements in these soils can be improved with application of high organic matter and practicing mulching.

Table 2. Soil-site suitability criteria for Ragi

	Land use requirement		Rating			
	Soil–site characteristics		Highly suitable	Moderately suitable	Marginally suitable	Not suitable
			S1	S2	S3	N
Climatic regime	Mean temp. in growing season (°C)		28–34	25-27 35-38	39-40 20-24	>40 <20
	Rainfall in growing season (mm)		750-900	600-750	450-600	<450
Land quality						
Moisture availability	LGP (days)		>110	90-110	60-90	<60
Oxygen availability to roots	Soil drainage		WD	MWD,	ID,SED	PD, ED
Nutrient availability	Texture	Surface	sl, scl	ls, sc	s, sic c	-
		Subsoil	l,cl,sc	sic,c, scl	ls, s, c>60%	-
	pH (1:2.5)		5.5–7.5	7.6–8.5 4.5-5.4	8.6–9.5 4.0-4.4	<4.0

Rooting conditions	Effective soil depth (cm)		>75	50-75	25–50	<25
	Gravel (vol %)	surface	<10	10–15	15-35	>35
		subsoil	<15	15–35	35-60	>60
Soil toxicity	Salinity (ECe) satn (dS m^{-1})		<1.0	1.0-2.0	2.0-4.0	>4.0
	Sodicity (ESP)		<10	10–15	15–25	>25
Erosion hazard	Slope (%)		<3	3–5	5–10	>10

Source: NBSS&LUP (2006)



Traditional soils	Area (ha)	Per cent
Alluvial soils	19662.17	22.20
Deep Red soils	19704.87	22.24
Moderately deep Red soils	35491.84	40.07
Shallow Red soils	2988.46	3.37
Rock Outcrop	166.58	0.19
Forest	9128.66	10.31
Reservoir	457.74	0.52
River	370.25	0.42
Tank	422.45	0.48
Settlement	189.05	0.21
Grand Total	88582.07	100.00

Fig. 1 Soils – Study area

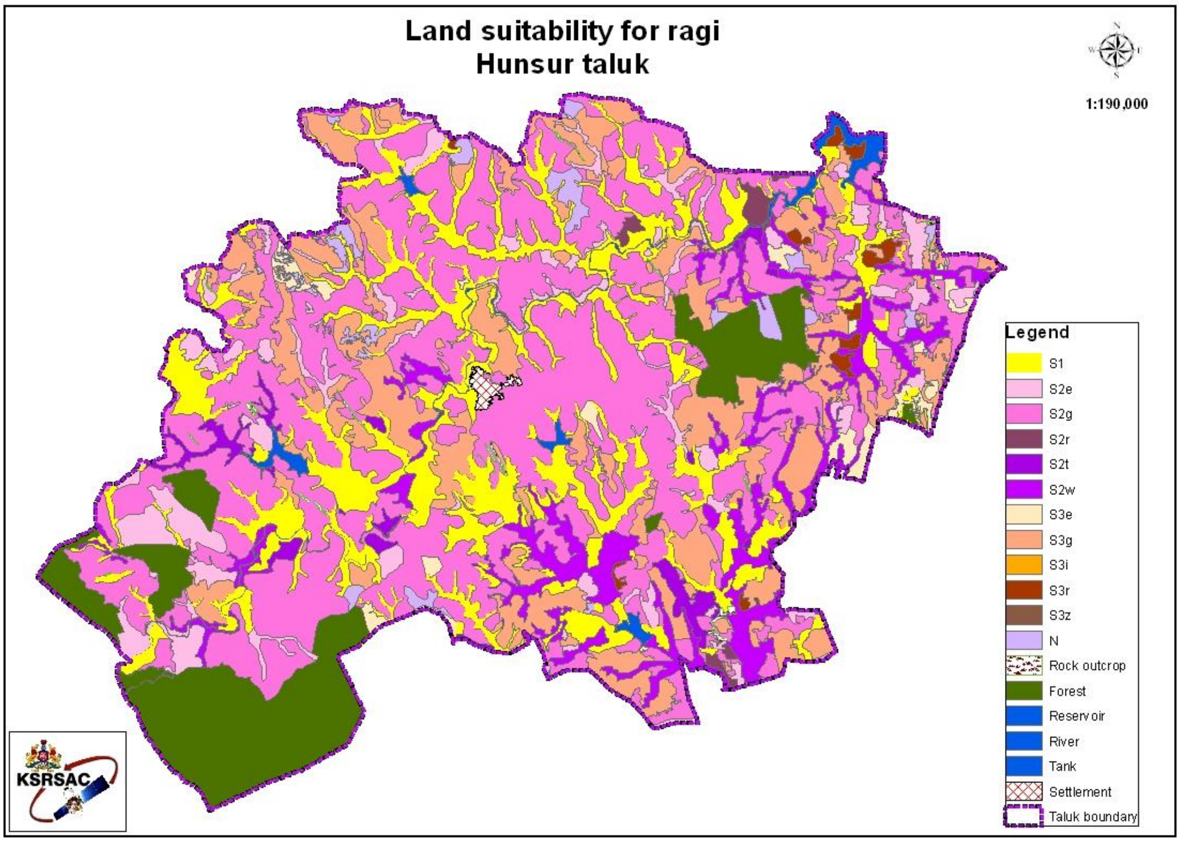


Fig 2 Land suitability for ragi – study area

Table 3. Land suitability for Ragi – Hunsur taluk

Ragi suitability	Area (ha)	Per cent
S1	13218.34	14.92
S2e	5638.57	6.37
S2g	33493.62	37.81
S2r	416.12	0.47
S2t	1276.05	1.44
S2w	6128.98	6.92
S3e	1345.68	1.52
S3g	14332.28	16.18
S3i	5.33	0.01
S3r	545.33	0.62
s3z	2.18	0.00
N	1442.70	1.63
Rock Outcrop	168.76	0.19
Forest	9128.66	10.31
Reservoir	457.74	0.52
River	370.25	0.42
Tank	422.45	0.48
Settlement	189.05	0.21

Conclusions

The land resource units of Hunsur taluk of Mysore district generated using large scale Quick bird satellite data and geographical information system were assessed for their suitability for growing *ragi*, rice, tobacco and mango, the major crops. The study brings out the limitations of the land and soil which reduces the yield of the crop. Proper recommendations can be made to overcome these limitations and suggest package of practices to increase crop yield on a sustainable basis.

References

FAO. (1976). A Framework of Land Evaluation, Soils Bulletin 32: 71, FAO, Rome.

KSRSAC (2010). Land Resource Information System (LRIS), Mysore, Karnataka Project Report, Karnataka State Remote Sensing Applications Centre, Bangalore.

Naidu, L.G.K *et al.* (2006). Manual – Soil site suitability criteria for major crops, NBSS & LUP, Pub. 129, NBSS & LUP, Nagpur.

Sys, C. (1978). Evaluation of Land Limitations in the Humid Tropics, Pedologie, Ghent, # 28, 307-335.

The Role of Remote Sensing and GIS in Land Degradation Detection, Assessment and Mitigation: A Case Study of Namkum Block, Ranchi, Jharkhand

Rahul Kumar Singh, Jayashree Shahdeo and Amrita Dibya Minj

Jharkhand Space Applications Centre, Ranchi
Email: rahul.iirs@gmail.com

Abstract

In this paper an attempt has been made to highlight the potential of Remote Sensing and Geographic information System in detection, assessment, mapping, mitigation and generating essential quantitative information on the land degradation in the Namkum block of Ranchi district, Jharkhand. The main problem to be investigated in the present study is to identify the land degradation categories, the extent of land under each category and the expanse of land not brought under cultivation. Such land which has not been brought under cultivation nowadays categorized as wasteland. The study aims at investigating the categories of such wastelands and the possibilities of expanding agriculture on those lands. The methodology used in this study can be used in the decision making process of the selection of areas that need mitigation measures to be adopted which will reduce or even reverse their degrading potential.

Introduction

Land degradation has been a major global issue during the 20th century and will remain high on international agenda in the 21st century. The importance of land degradation among global issues is enhanced because of its adverse impact on agronomic productivity, the environment, and its effect on food security and the quality of life. Land degradation is commonly defined as a human or climatically induced process having negative consequences to the functioning of the land and related ecosystem. The Global Land Assessment of Degradation (GLASOD) estimates that nearly 2 billion hectares worldwide (22 percent of all cropland, pasture, forest, and woodland) have been degraded since mid-century. Some 3.5 percent of the 2 billion hectares are estimated to have been degraded so severely that the degradation is reversible only through costly engineering measures. Africa and Latin America appear to have the highest proportion of agricultural land, and Asia has the highest proportion of degraded forestland.

According to National Commission on Agriculture (1976), about 175 million hectares of land constituting 53.3 percent of the total geographical area of 329 M ha is subject to various kinds of degradation. Soil Degradation map of India was prepared using GLASOD methodology (Oldeman, 1998), showes that an area of about 187 million hectare representing almost 57 per cent of the total geographical area of the country has been affected by various land degradation problems. The largest category of land is affected by water erosion, which accounts for 80 percent of degraded land that results in loss of topsoil. Among the remaining categories, salinization, water logging, and loss of top soil from wind erosion, are the most pervasive problems.

Study Area

Namkum block of Ranchi district (Fig 1 & 2) comprises Chotanagpur Plateau, which forms a part of Deccan bio-geographic province. The spatial extent of Namkum block is $23^0$10’17’’ to $23^0$23’19’’N and $85^0$13’34’’ to $85^0$34’04’’E. With the total geographical area of 469.77sq.km, it is a hilly undulating plateau characterized by tropical forests and tribal settlements. This block is having 114397 total population (2001) out of which 103886 rural population and 10511 urban population.

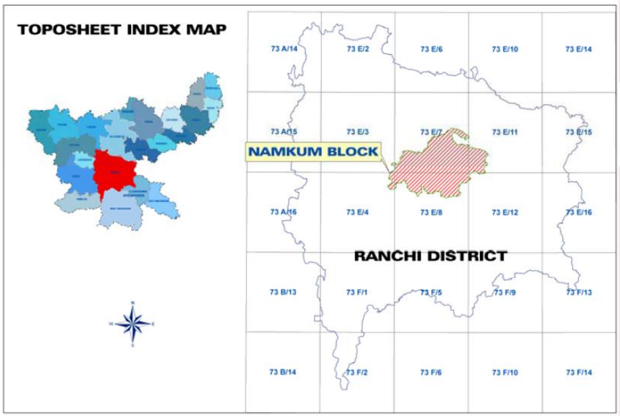


Figure 1: Location map of the Study area

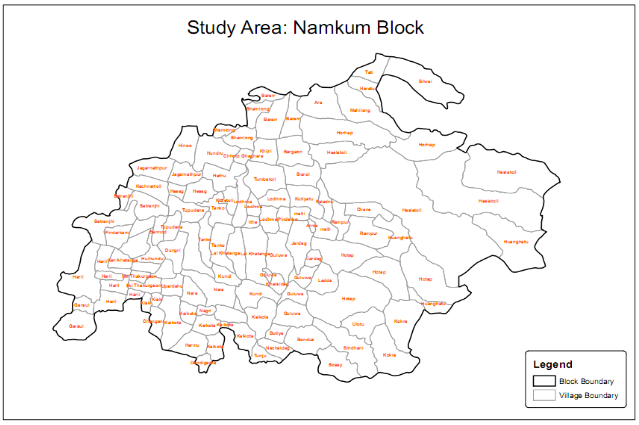


Figure 2: Village Boundary Map of Study Area

Objectives

The Objectives of the present study is: Classification of land as per present pattern of land use, to identify landscape units according to their potential risk to land degradation process, to investigate the cause of land degradation and its impact on the environment, to suggest methodological framework that provides a tool for the appraisal of the impact of changes in land degradation and assessment of degraded and waste lands.

Data Used and Methodology

For the present study LISS III Multispectral data of satellite(spatial resolution-23.5m) has been used. Survey of India toposheet on 1:50000 scale of the study area has been used for reference and georefrencing of LISS III data.

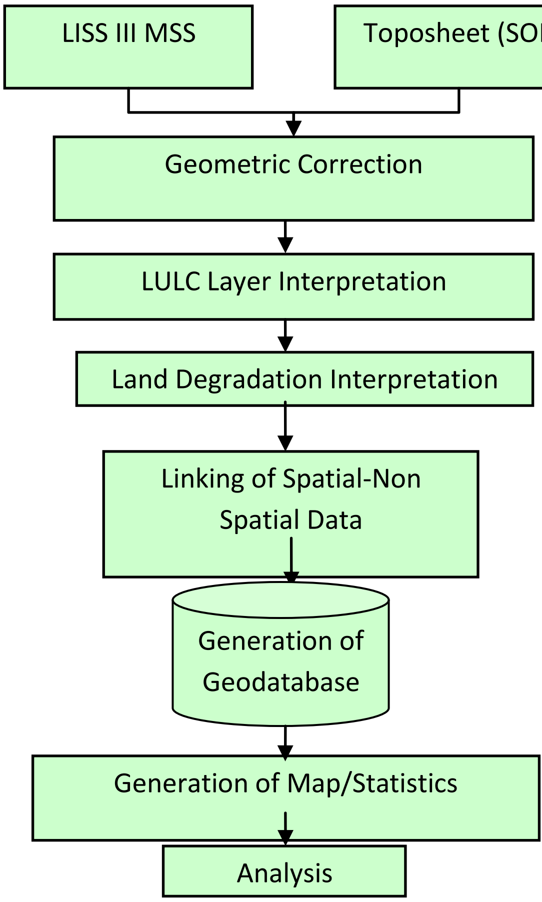


Figure 3: Flowchart of Methodology

Accurate LULC mapping over large areas has become necessary in order to monitor LULC changes and has received a considerable boost from the advent of multispectral satellite data. Such data have become operationally available since the early 1970s and have paved the way for LULC and vegetation cover studies due to their suitable spectral, spatial and temporal resolution, thus providing scientists with a useful tool to study LULC changes and their relationship with land degradation processes. For the present study land use/land cover layer has been interpreted using LISS III multispectral data having 23.5m spatial resolution. The methodology adopted is presented in Figure 3.

Figure 4: Visual Interpretation of LULC layer

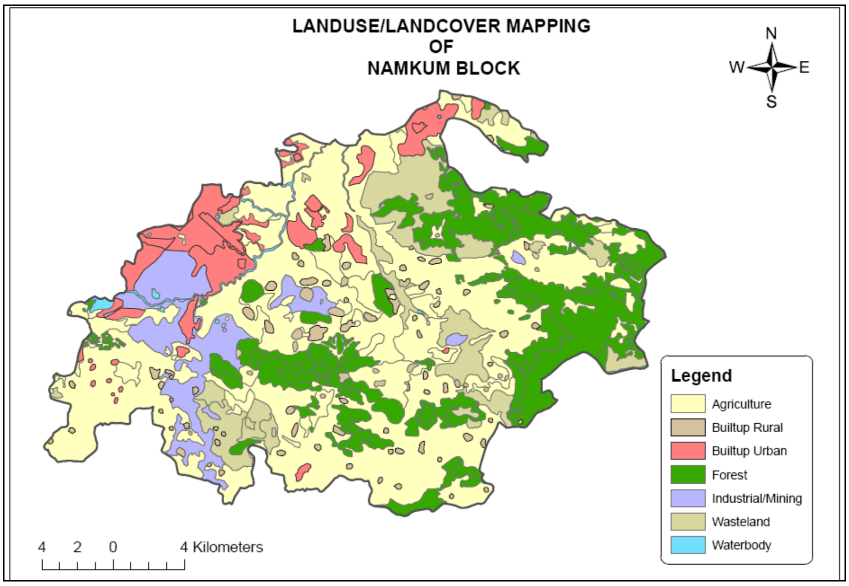


Figure 5: Map showing LULC class

Results and Discussion

Soil erosion since long has caused damage to soil cover. As such the study aims at recognizing the factors responsible for the wastelands or lands degraded from the viewpoint of agricultural utilization. Vegetative cover have also been reduced to such an extent that the intensity of soil erosion has increased. It is also a problem to be investigated that how much the problem of forest degradation has caused the degradation of agricultural lands. Not only Namkum block but Jharkhand as a whole is suffering from very limited extent of agricultural lands. So the main aim of the present study is to find out the factual data of such waste and degraded land for the extension of agricultural land. For this purpose land degradation classes has been visually interpreted using LISS III multispectral data.

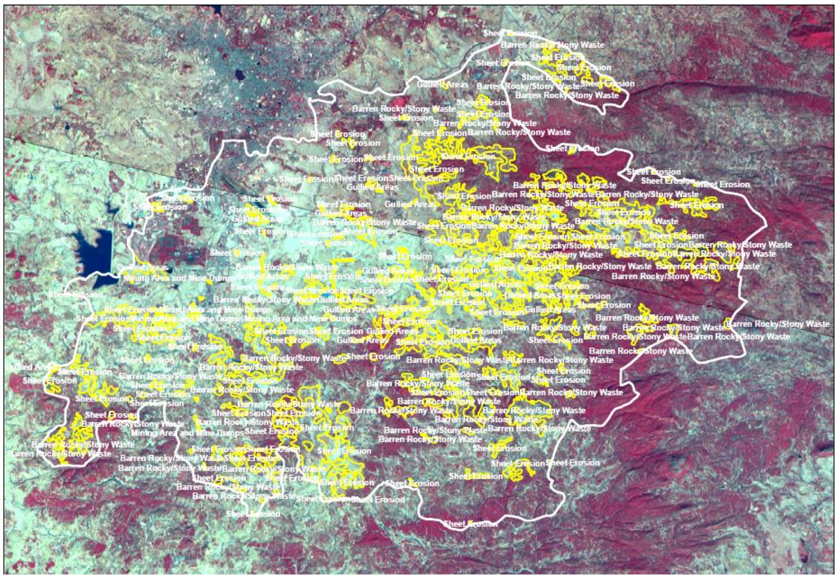


Figure 6: Visual Interpretation of Land Degradation layer

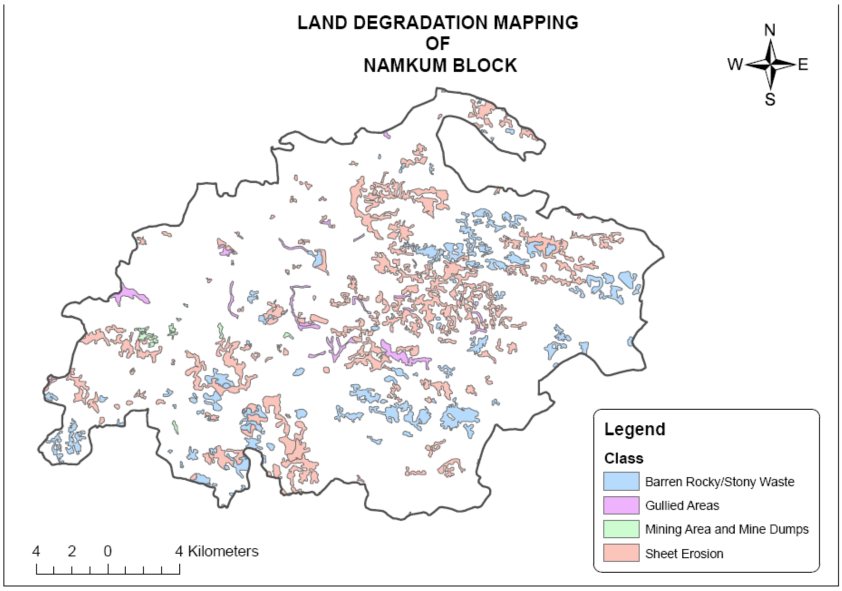


Figure 7: Map showing Land Degradation class

The analysis of the land use and land cover of the Namkum Block (Fig's 4 & 5,Table 1) reveals that 15.56% area is occupied by different categories of wastelands. The major area of the study area is covered by Forest i.e. 40.37%. Namkum Block is famous for its industrial and mining activity and many important industries of Ranchi City are located in this region.

Class	Area (In Hectare)	Area (In %)
Forest	14334.71	40.37
Builtup Urban	6333.73	17.83
Wasteland	5525.92	15.56
Industrial/Mining	3496.07	09.84

Waterbody	2984.70	08.40
Agriculture	1537.95	04.33
Builtup Rural	1293.99	03.64

Table 1: Land use class of Namkum Block

The analysis of the land degradation of the Namkum Block (Fig's 6 & 7,Table 2) reveals that sheet erosion is the main problem which covers 64.57% area of the total degraded land in Namkum Block. Barren Rocky/Stony Waste is also widespread in Namkum Block and covers 27.93% area of the total degraded land.

Class	Area (In Hectare)	Area (In %)
Sheet Erosion	5835.14	64.57
Barren Rocky/Stony Waste	2524.53	27.93
Gully Erosion	574.65	06.35
Mining Area/Dump	102.34	01.13

Table 2: Land Degradation class of Namkum Block

Conclusions

In the study an attempt has been made to demonstrate the possibility of combining remotely-sensed data with ancillary data, in order to identify the land degradation prone areas and to study the potential relationship between LULC changes and land degradation in the Namkum Block, Ranchi District. Though conventional soil surveys provide information on land degradation; they are slow, time consuming and expansive. Among the new technologies emerged for studding natural resources, space born remote sensing technology proved to be powerful because of synoptic view of terrain features, repetitive coverage of same area at regular time intervals , collection of data in visible through near infra red , thermal to micro wave regions and amenability of data to computers for quick analysis. This methodology can be used in the decision making process of the selection of areas that need mitigation measures to be adopted which will reduce or even reverse their degrading potential. The study will provide knowledge about the categories of degraded and waste lands and potential for its agricultural utilization.

Precision Farming in Karnataka – A New Initiative Towards Strengthening Farming Community

Patil, M.B., Shanwad, U.K., Veeresh, H., Rajesh, N.L., Pandit Rathod and Mastan Reddy, B.G.

University of Agricultural Sciences, Raichur-584 102, Karnataka
E-mail: patilmb_65@yahoo.com

Abstract

Strengthening agriculture is crucial to meet the myriad challenges of rural poverty, food security, unemployment and sustainability of natural resources. In this context, an initiation has been made in Karnataka State under RKVY funded project on "Precision Farming" towards strengthening the research institutions / scientists, farmers, extension groups to address the issues pertaining to the adoption of precision farming techniques through farmer-centric plans and strategies emphasizing more on educating farmers and line departments. It is being implemented in the farmers' fields of Raichur, Koppal and Gulbarga districts covering Cotton, Rice and Pigeon Pea crops respectively. To begin with, efforts are made towards delineation of management zones through grid sampling (Sub-field level approach) based on the variability that exists in soil with respect to fertility, EC, and Organic matter content. Further, GIS maps (at 1:1 scale) were generated for each parameter which would help to correlate with the yield maps to develop a robust action plan at grid level for precise farming management. The project is envisaged to develop spectral signatures of the crops through surface and remote sensing techniques to understand the variability in crop health under the influence of biotic and a-biotic stresses. Based on these, a systematic strategy will be developed and adopted towards precise application of various farm inputs and farm management practices. Apart from the conventional field survey and laboratory analysis, state-of-the-art intelligent guidance tools like Differential Global Positioning System, Electro-Magnetic Probe, Green Seeker and Weather Trackers are being used to arrive at comprehensive solutions. The project is aimed to develop a professional approach to ensure the knowledge empowerment of farming and scientific community of the State with an overall objective of improving the livelihood of the farmers.

Introduction

Precision Agriculture / Farming besides other aspects enables the reduction of use of fertilizers/chemicals in crop production while decreasing farming risks and contributes to specific field-crop-plant applications, makes production processes more designable and increases profitability. Further, it describes an agricultural management system using information and communication technologies (ICT) such as Global Navigation Satellite Systems (GNSS), Geographic Information System (GIS), Remote Sensing and data management systems for optimal and variable rate based use of nutrients, water, seed, pesticides and energy in heterogeneous field situations.

One approach to apply precision agriculture to optimize crop production and environmental quality is identifying management zones. Management zones (MZ) are defined as sub-regions of a field that has a relatively homogeneous combination of yield-limiting factors, for which a single rate of a specific crop input is appropriate to attain maximum efficiency of farm inputs. Besides, representing areas of equal production potential, within-field management zones have many other uses. Several studies have indicated that homogenous management zones could be used as an alternative to grid soil sampling and to develop nutrient maps for variable rate fertilizer application. While methods for delineating management zones vary widely in the information used, usually they are based on soil and yield information possibly over several years. Many researchers used the soil and/or relief information *viz.*, soil Electrical Conductivity (EC), fertility, texture, topography *etc* to define management zones. But EC based management zones were found more reliable (Khosla and Alley,1999). The combination of different layers of information can be performed using different algorithms. The most common is the use of cluster analysis. This can be used to identify areas that have similar landscape attributes, soil properties and plant parameters, to quantify patterns of variability and to reduce the empirical nature of defined management zones. Fuzzy clustering of combined yield monitor data to divide a field into potential management zones is considered as a powerful tool. Stafford *et al*. (1998) used fuzzy clustering of combine yield monitor data to divide a field into potential MZs. Many have found approximately 54% of the yield variation was explained by the identified management zones using cluster analysis due to apparent EC, elevation and slope. In this context, an initiation has been made in Karnataka State at the University of Agricultural Sciences, Raichur under RKVY funded project on "Precision Farming" towards strengthening the research institutions / scientists, farmers, extension groups to address the issues pertaining to adopt precision farming techniques through farmer-centric plans and strategies emphasising more on educating farmers and line departments.

Materials and Methods

This project was initiated during *Kharif*-2011 at UAS, Raichur on-farm at 8 experimental plots and also in the farmers' fields of Raichur, Koppal and Gulbarga districts covering Cotton, Rice and Pigeon Pea crops respectively. The details of area and crops with co-ordinate points are given below (Table 1);

Table 1 Details of experimental plots at on-farm (UAS, Raichur) and at farmers fields

Sl. no.	Crop	Area (acres)	Village/Taluka/ District	Latitude/Longitude	Remarks
1.	Cotton	115	Marichethal, Raichur, Raichur	16.09289949/77.30100457	Famers' fields
2.	Pigeon Pea	150	Ingalagi, Chowdapur, Chimmanageri, Afzalpur, Gulbarga	17.22092512/76.58069512	Famers' fields
3.	Paddy	125	Jangamara Kalgudi Gangavathi, Koppal	15.47567655/76.55459727	Famers' fields

4.	Cotton	5.00	Main Agricultural Research Station, Raichur	16.19641982/77.31729513	On Research Farm
5.	Cotton	5.00	College of Agriculture, Bheemarayangudi, Shahapur, Yadgiri	16.73682469968076/ 76.79718017578125	On Research Farm
6.	Pigeon Pea	5.00	Agricultural Research Station, Gulbarga	17.36145680/76.81536013	On Research Farm
7.	Pigeon Pea	5.00	Main Agricultural Research Station, Raichur	16.19644505/77.31926002	On Research Farm
8.	Paddy	5.00	Agricultural Research Station, Gangavathi	15.45437722/76.53224173	On Research Farm
9.	Paddy	2.50	Main Agricultural Research Station, Raichur	16.19229608/77.31271695	On Research Farm

The surface soil samples (0-20 cm depth) were collected on grid basis *i.e.*, 10X10m at research farms (Fig.1) and 50X50m at farmers' fields to assess the spatial variability in the soil fertility status. The exact sample location was recorded using DGPS. Processed soil samples were analyzed for various parameters such as pH, electrical conductivity (EC), soil organic carbon (OC), N, available N, available P_2O_5 and available K_2O.

Variable rate of input application was made based on soil test crop recommendation (STCR) approach (Fig's. 2 and 3). This emphasizes the application of fertilizer nutrients to each crop as per targeted yield and also considering the soil analysis results. The equations developed by AICRP on STCR which are unique for each crop, soil type and climatic condition were used. Therefore, each grid area received variable rate of NPK application depending on the initial soil nutrient status, thus minimized the probability of grid areas with high soil test values receiving higher doses of nutrient inputs and vice versa which is a common impediment under blanket application of fertilizer inputs.

STCR equation as recommended by AICRP for Hyderabad – Karnataka Region for Pigeon pea is

$$FN=5.61T-0.54SN$$
$$FP_2O_5=5.72T-4.73SP$$
$$FK_2O=6.33T-0.17SK$$

With a Targeted Yield of 18 q/ha of Pigeon pea

Figure 1 10 X 10 m Grid (Plot 136)

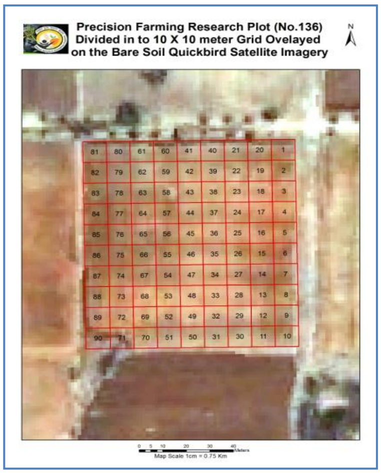


Figure 2 VR Application of Urea

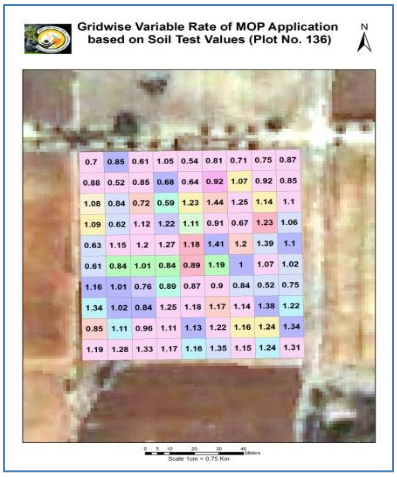


Figure 3 VR Application of MOP

Results and Discussion

It is planned that the first two years will be kept for recording the various observations to map the spatial variability. This will help deriving the management zones more accurately. Initially plants were properly labelled for recording systematic observations of their growth and phenology. So far, the spatial variability has been found in many aspects during the plant growth, the details of which are presented in the Fig. 4 and Fig. 5 for plot for number 136, which shows the spatial variability in total plant population and germination percentage of pigeon pea respectively. Further correlation studies will be made with respect to the soil data and fertilizer applied (based on the STCR approach) and the yield data. The integration of all the layers under GIS environment for various season data of the crop and at the same area, would result in delineating appropriate management zones. [Since the determination of homogeneous areas within a field is difficult to achieve due to the complex combination of factors which may influence yield (Jose and Cesar 2008), it is advisable to have enough observation to delineate management zones].

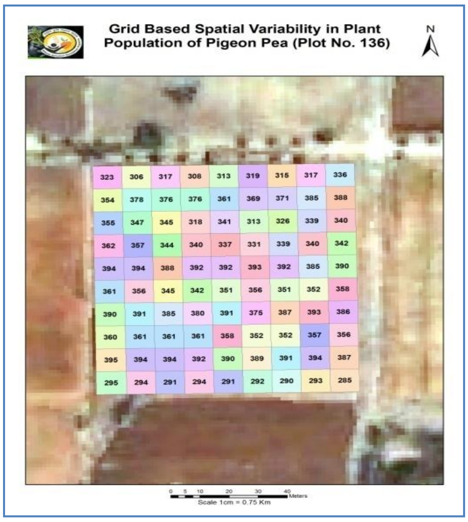


Figure 4 Spatial Variability of Plant Population in Pigeon Pea (Plot No. 136)

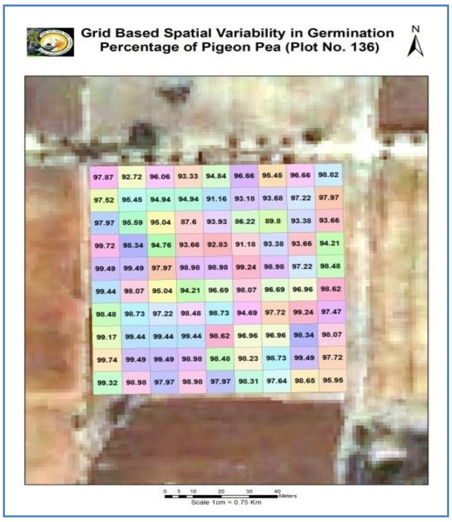


Figure 5 Spatiaariability in Germination % of Pigeon Pea (Plot No. 136)

Conclusions

Future strategy for adoption of Precision Agriculture (PA) in India should consider the problem of land fragmentation, lack of highly sophisticated technical centres for PA, specific software for PA, poor economic condition of general Indian farmer etc. 'Integrating farmer knowledge, precision agriculture tools and crop simulation modelling to evaluate management options for poor-performing patches in cropping fields can be an excellent option for country like India. This century is the century of biotechnology and Information technology revolution. Precision Agriculture will be an offspring of these two technologies with a rich heritage of relatively old, satellite based technologies of last century. PA has created scope of transforming the traditional agriculture and suite of techniques and technologies will make PA not only suitable for developed countries but also for developing countries, if applied properly, and can work as a tool to destroy the distance between developed world and the rest.

References

José Paulo Molin and Cesar Nunes de Castro, (2008). Establishing Management Zones using Soil Electrical Conductivity and other Soil Properties by the Fuzzy Clustering Technique. Sci. Agric. 65(6): 567-573.

Khosla , R. and Alley ,M.M. (1999). Soil-specific management on mid-atlantic coastal plain soils. Better Crops with Plant Food. : 83(3):6–7.

Stafford, J.V., Lark, R.M. and Bolam, H.C. (1998). Using yield maps to regionalize fields into potential management units. In: Robert, P.C. (Ed.), Proceedings of the Fourth International Conference on Precision Agriculture. ASA, CSSA, SSSA, Madison, WI, 1998. pp. 225–237.

Land Degradation Mapping using Multi-Temporal Satellite Data

Prabhuraj, D.K., Jyothi, B.L.,Chaitra, R., Shilpa, R. and Guruswamy, K.T.

Karnataka State Remote Sensing Applications Centre, Bangalore
E-mail: prabhuraj_1464@yahoo.com

Abstract

Land is the most valuable natural resource for human and animal needs. Land degradation implies temporary or permanent recession of its productivity due to deterioration of physical, chemical and biological aspects. The land degradation problem has reached an alarming proportion due to various factors and is a continuing problem presently. Hence mapping of land degradation was taken in 22 districts of Karnataka using multi-temporal satellite data for the year 2005-06 on 1:50,000 scale. The methodology involved the on-screen visual interpretation of land degradation types, degree of the problem and extent of area. IRS–LISS IV satellite data of *Kharif, Rabi* and *Zaid* seasons were used. This was supported by ground truth studies, sample collection and laboratory analysis. The data base has been generated for the districts individually and merged for the State level.

Water erosion, particularly sheet erosion (Wsh1) is prevalent in all the districts covering more than 80 percent of the area followed by rill erosion (Wri2) covering 10 per cent of the area and Barren rocky/stony waste covering about 3 per cent. The other types of degradation covers less than one per cent of the area. The salt affected soils covering about 936.7 sq km (2.2 % of LD units) were updated from the State Salt affected soils on 1:250,000 scale and Salt affected soils from the 85 command areas in Karnataka on 1:50,000 scale.

Introduction

Land degradation, in general, implies temporary or permanent recession from a higher to a lower status of productivity through deterioration of physical, chemical and biological aspects. Land degradation has both environmental and economic consequences and has reached alarming propositions due to various factors like over exploitation and mismanagement of natural resources and basic socio economic factors like land shortage, inappropriate land use, severe economic pressures on farmer, poverty and population growth. Hence, a nation-wide mapping of land degradation project was taken up by National Remote Sensing Centre, Hyderabad. Land degradation mapping of Karnataka State was carried out by Karnataka State Remote Sensing Applications Centre and University of Agricultural Sciences, Dharwad (five districts).

Study Area

The Karnataka State lies between latitudes 11° 31' 00" and 18° 45' 35" N and longitudes 74° 12' 00" and 78° 41' 00" E with an area of 19.2 million hectares. The state has 30 districts and 176 taluks.

Methodology

Land degradation mapping was carried out as per National Remote Sensing Centre (NRSC) manual (2007). For delineation and mapping of land degradation classes multi temporal geo-rectified resourcesat-1 LISS-III data of three seasons *kharif, rabi and zaid* seasons of 2005-2006, Survey of India (SOI) toposheets and other legacy data on salt effected soils and wastelands were used. ArcMap 9.2 was used to digitize the land degradation data. An overview of the methodology is given in fig1.Visual interpretation keys for land degradation symbol and descriptions to map units were referred (table1). The description of each of the land degradation class is also given.

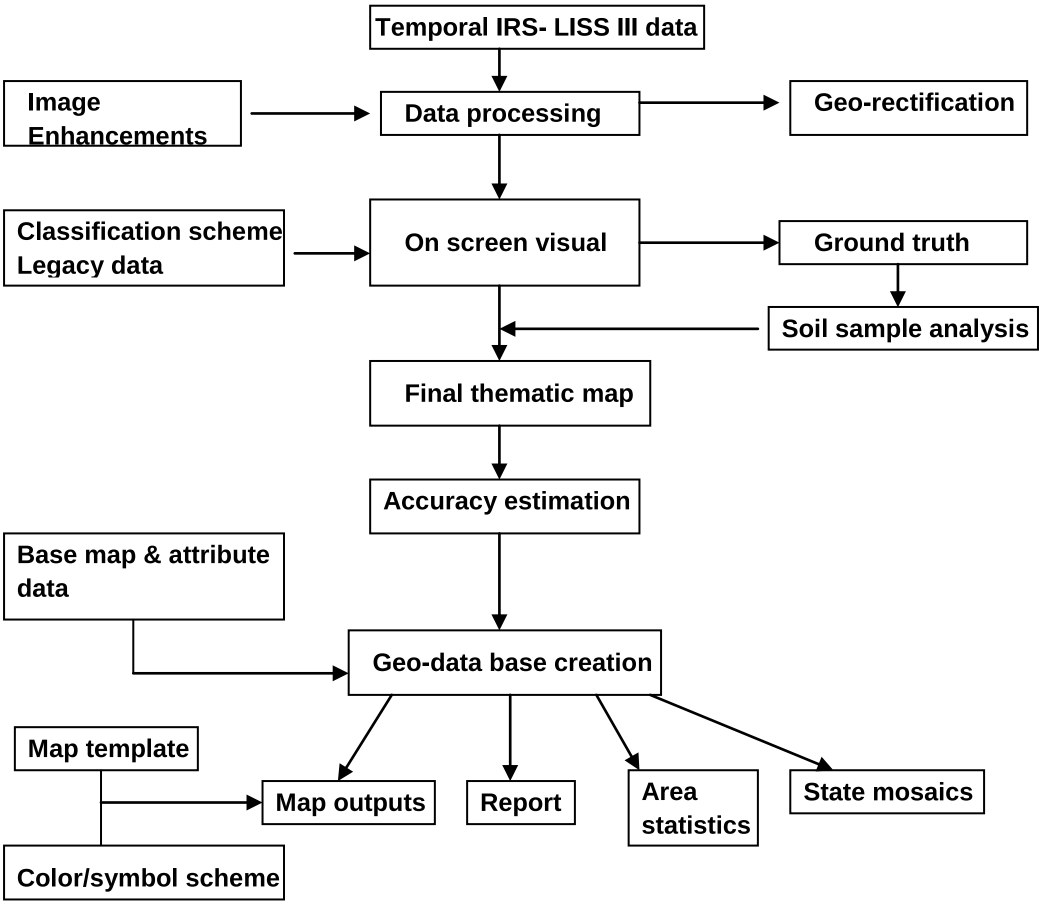


Figure 1 Methodology

Table 1.Symbol and description of land degradation mapping units

Sl No	Symbol	Description
1.	**Wsh1**	Sheet erosion – a decrease in depth of the top soil layer (A horizon) due to more or less uniform removal of soil material by run-off water - Slight
2.	**Wri2**	Rills – an irregular displacement of soil material causing clearly visible scars in the terrain - Moderate
3	**Wgu3**	Gullies – net work of rills - Severe
4	**Wrs4**	Ravines – shallow – Very severe
5	**Wrm5**	Ravines – moderately deep to deep – Extreme
6	**Esh1**	Sheet erosion – uniform displacement of top soil due to wind action - Slight
7	**Eds1**	Stabilized dunes –stabilized sand dunes with good cover of sod forming plants (<60% cover) -Slight
8	**Edp2**	Partially-stabilized dunes – sand dunes subjected to severe-deformation with moderate cover of sod forming plants (30-60%) - Moderate
9	**Edu3**	Un-stabilized dunes – sand dunes subjected to severe deformation. They are generally devoid of any vegetation - Severe
10	**Lsp1**	Surface ponding – Slight. Water logging with 4-6 months of ponding affecting one crop (excluding paddy)
11	**Lsp2**	Surface ponding – Moderate. Permanent water logging with more than 6 months affecting more than one crop (excluding paddy)
12	**Lsw**	Sub-surface water logging. The area with water table close to surface affecting the crop growth and performance. Areas with water table <2m are considered
13	**Ssa1**	Saline - Slight
14	**Ssa2**	Saline - Moderate
15	**Ssa3**	Saline - Severe
16	**Sso1**	Sodic - Slight
17	**Sso2**	Sodic - Moderate
18	**Sso3**	Sodic - Severe
19	**Sss1**	Saline Sodic - Slight
20	**Sss2**	Saline Sodic - Moderate
21	**Sss3**	Saline Sodic - Severe
22	**Aac2**	Acidity – Moderate pH 4.5-5.5 (1:1 soil-KCl) excluding. Forest areas and paddy areas
23	**Aac3**	Acidity – Severe pH <4.5 (1:1 soil-KCl) exclu. Forest areas and paddy areas
24	**Gfh**	Frost heaving. Areas with ice in sub-surface horizons leading to expansion of soil, forming undulations on the surface. This restricts the growth of plants
25	**Gfs**	Frost shattering. Areas with shattered material because of freezing and thawing in periglacial environments
26	**Hie**	Industrial-effluent affected areas. Areas affected with effluents discharged from industries (area under industry per se excluded)
27	**Hmd**	Mining. Surface/open cast mines including mine dumps
28	**Hbk**	Brick kiln areas
29	**Tmm**	Mass movement/mass wastage. Areas with land slides
30	**Tbs**	Barren rocky/Stony waste. Rock outcrops/sheet rock exposures devoid of vegetation
31	**Tms**	Miscellaneous – Riverine sands/sea ingress areas etc. Includes mainly sands other than desert sands
32	**Nml**	Normal land

Result and Discussion

Land degradation map of Karnataka state of 1:50,000 was prepared (fig.2) with geo-database. Out of 31 degradation classes 21 degradation classes (table 2) were identified and mapped in Karnataka. Water erosion is the dominant degradation class covering about 24.6%, out of which sheet erosion (wsh1) accounts to 21.1% which occur in red, lateritic and black soil region. Rill erosion (wri2) is about 3.5% which is dominantly occurring in black soil region and steep slope areas with less vegetative cover. In preliminary interpretation sheet erosion was exaggerated. After ground check it was found that the sheet erosion was not found in flat areas and therefore earlier map was modified. Saline (ssa) and sodic (sss) classes cover about 0.5%. The salt affected soils cover large area in Chitradurga, Bellary, Koppal, Raichur, Davangere and Gulbarga districts particularly in irrigated command areas. Total degraded area in Karnataka is 26.1% of total area.

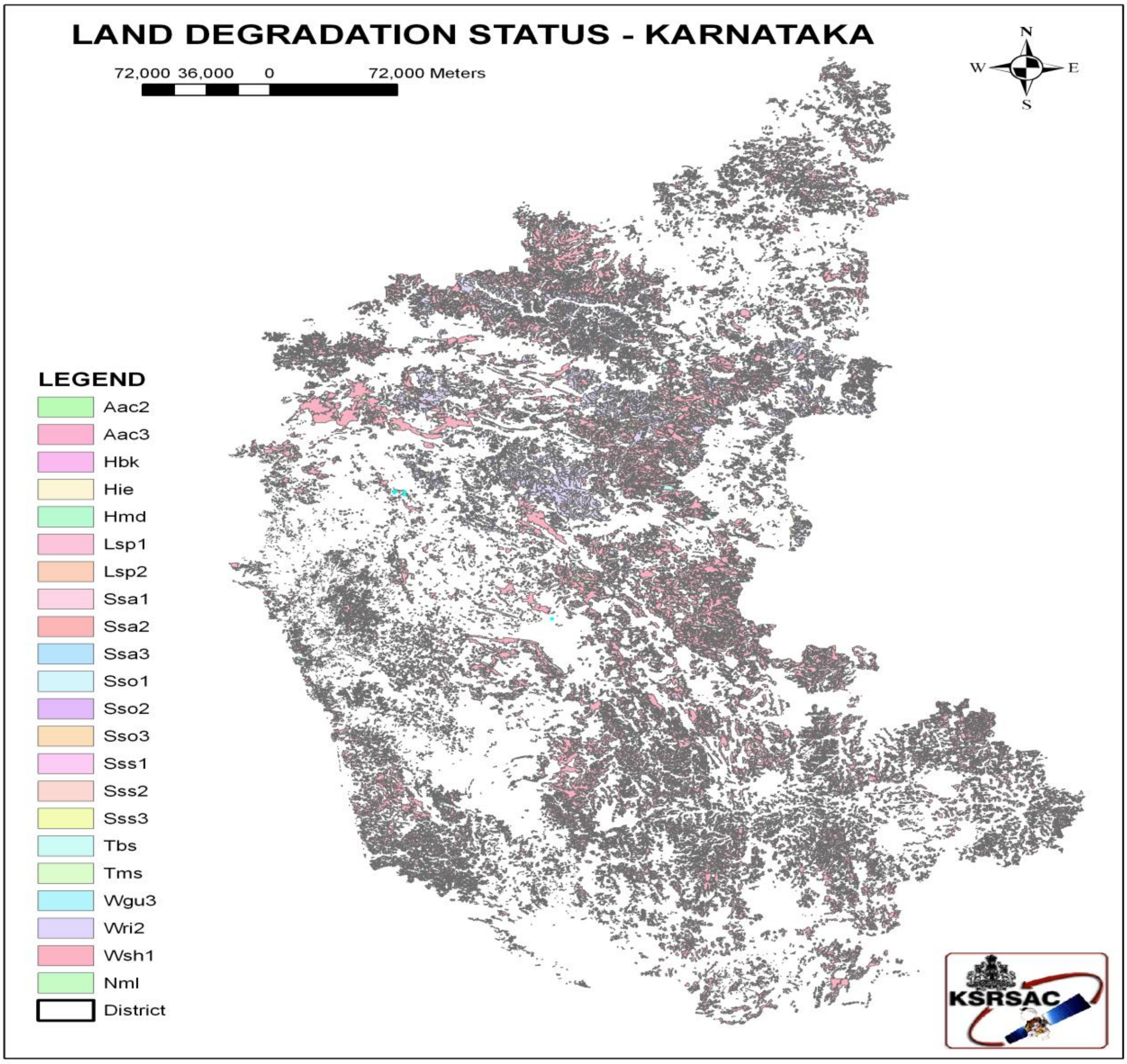


Figure 2.Land degradation status

Table 2.1 Land degradation status-Karnataka

Sl.no	LDCODE	DESCRIPTION	AREA(ha)	PERCENT
1	Wsh1	Sheet erosion	4041790.77	21.074
2	Wri2	Rill erosion	672675.14	3.507
3	Wgu3	Gullies	12058.45	0.063
4	Lsp1	Surface ponding - Slight	428.83	0.002
5	Lsp2	Surface ponding - Moderate	1247.07	0.007
6	Ssa1	Saline - Slight	23169.24	0.121
7	Ssa2	Saline - Moderate	2942.19	0.015
8	Ssa3	Saline - Severe	3791.55	0.020
9	Sso1	Sodic - Slight	15996.01	0.083
10	Sso2	Sodic - Moderate	7288.99	0.038
11	Sso3	Sodic -Severe	230.33	0.001
12	Sss1	Saline Sodic - Slight	20025.48	0.104
13	Sss2	Saline Sodic - Moderate	14521.04	0.076
14	Sss3	Saline Sodic - Severe	7594.93	0.040
15	Aac2	Acidity - Moderate	4875.66	0.025
16	Aac3	Acidity - Severe	553.77	0.003
17	Hie	Industrial effluent affected areas	2970.70	0.015
18	Hmd	Mining	36956.84	0.193
19	Hbk	Brick kiln areas	36.19	0.0001
20	Tbs	Barren rocky/Stony waste	131445.81	0.685
21	Tms	Reverine sands	2906.75	0.015
22	Nml	Normal land	14175919.26	73.912
Grand Total			**19179425**	**100.000**

Conclusions

Database of degraded lands was generated for the entire State of Karnataka for the year 2005-2006. A land degradation information system was established for easy query and retrieval of data so that reclamation measures can be planned.

References

NRSC (2007). Nation-wide mapping of land degradation using multi-temporal Satellite data, National Remote Sensing Agency, DoS, GoI, Hyderabad.

Crop Acreage and Production Estimation of Sorghum using AWiFS Satellite Image for Gulbarga District

Anupama Reddy, M.B. and K. Ashoka Reddy

Karnataka State Remote Sensing Applications Centre, Bangalore
Email: anupamaredi@gmail.com

Abstract

The objective of the study is Crop Acreage and Production Estimation (CAPE) of sorghum for Gulbarga district, Karnataka, using IRS P6- AWiFS satellite data. The end result of the study was to get the statistical analysis and estimation of the crop production. The final statistical result is produced using maximum likelihood algorithm. Using of multi-date data CAPE, accuracy was as good as that of estimates of Department of Agriculture (DOA) was obtained. The Crop Acreage and Production Estimation for Gulbarga district is 274329 ha and 252382 tons respectively, with Relative Deviation (RD) of -4.88%. This study demonstrated the use of remotely sensed (RS) data for generating Estimates of Crop Acreage and Production Estimation but also on land use/land cover classes.

Introduction

Geospatial technologies play an important role in crop identification, acreage and production estimation, disease and stress detection, soil and water resources characterization and also by providing required inputs for the following: generation of land and water resources developmental plans, bringing 479ha additional land into cultivation through mapping and reclaiming wastelands, increasing the irrigation potential through ground-water prospects mapping, crop-yield and crop-weather models, integrated pest management, command area management, watershed management, agro meteorological services, precision farming, etc. Remote sensing applications to agriculture have grown to a stage where such inputs are being used for number of policy level decisions related to food security, poverty alleviation and sustainable development in the country. Decision on buffer stock of food grains could be based on pre-harvest crop acreage and production estimation while the ground water prospects maps serve as the major source of information in ensuring drinking water and other needs in rain fed and less favored areas. Nation-wide wasteland, land use/land cover and soil mapping has helped in expanding and intensification of agricultural activities and also in identifying the land capability classes and crop suitability indices.

The experience gained on implementation of CAPE project and also to meet the requirements of timeliness, accuracy and coverage of crops, an integrated concept of Forecasting Agricultural output using Space, Agrometeorology and Land based observation (FASAL) has been evolved. A National Crop Forecasting Centre is being established by the Department of Agriculture and Co-operation, Govt. of India to execute the project. As remote sensing, weather and field observation provide complementary & supplementary information for making crop forecasts, FASAL proposes an approach which integrates inputs from these three types of observations on to make forecasts of desired coverage, accuracy and timeliness. The concept of FASAL, thus strengthens the current capabilities of early crop season estimation using econometric and weather-based techniques, mid-season assessments supplemented with multi-temporal coarse resolution remotely sensed data based analysis and in the later half of crop growth period, remote sensing providing acreage estimates and yield forecasts.

CAPE/FASAL is providing pre-harvest crop information on an operational basis for major food crops namely, paddy, wheat and jowar, oilseeds crop like soyabean, groundnut, commercial crops like cotton and sugarcane. In the past few years, investigations have been carried out on sourghum crop acreage and production forecasting using IRS AWiFS data. This research paper describes the overall methodology and the standard steps for operationalising of sorghum crop production estimation. The objective of the study is to provide multiple pre-harvest production and estimates of sorghum crop at district level using multi-date AWiFS data.

Area of study

The study area is of Karnataka State, India. This district is situated in northern Karnataka between 76°.04' and 77°.42 east longitude, and 17°.12' and 17°.46' north latitude, covering an area of 10,951 km². This district is bounded on the west by Bijapur district and Solapur district of Maharashtra state, on the north by Bidar district and Osmanabad district of Maharashtra state, on the south by Yadgir district, and on the east by Rangareddy district of Andhra Pradesh state. Gulbarga is a rainfed district of north Karnataka with sorghum (jowar) dominated cropping system. There are 10 talukas in Gulbarga district. Tur, Sorghum (Jowar) and Gram dominate the cropping pattern of these talukas. According to the 2001 census, the population of Gulbarga district was about 26 lakhs and the density of population was 159 persons per square kilometer. The number of cultivators in the district is about 3 lakhs. The fig. 1 shows the study area of Gulbarga District.

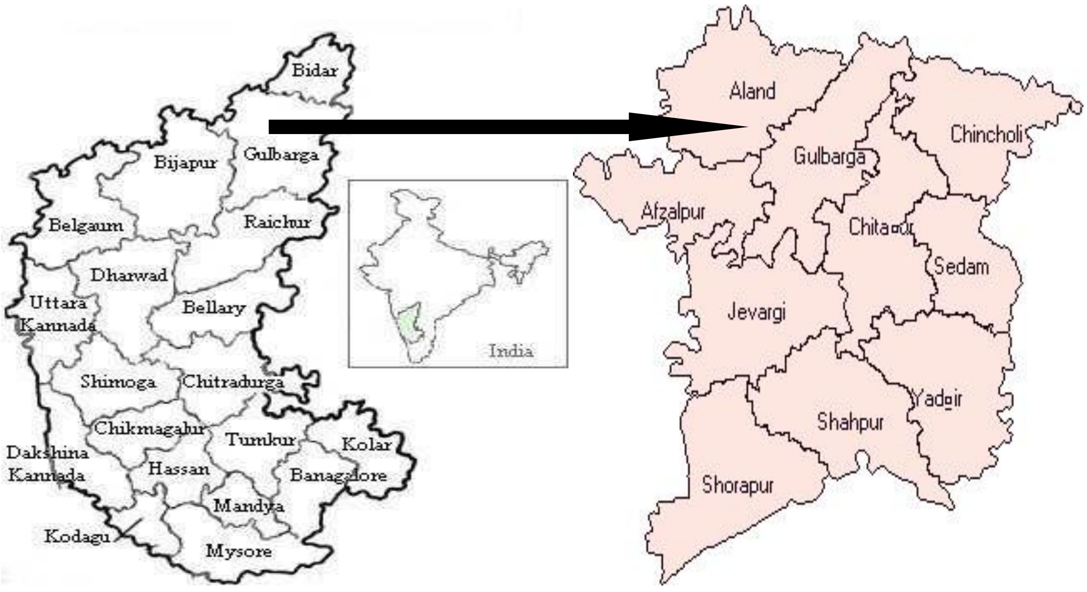


Fig. 1: Study Area of Gulbarga District

Data used and Methodology

In this study, three types of data were used. They are crop related data, economics related for yield modeling and RS data for acreage estimation, cropping pattern and crop growth monitering. Using multi-date Advance Wide Field Sensor (AWiFS) data from Indian Remote Sensing Satellite (IRS P6). AWiFS Sensor has four spectral bands: Green, Red, NIR and MIR with 56m spatial resolution and 10bit radiometry. This sensor gives better revisit cycle to monitor crop phenology and radiometric resolution to discriminate the crop types grown in the district. The methodology adopted is given in Fig.2.

The methodology for acreage estimation is primarily based on the use of digital image analysis techniques and statistical enumeration.

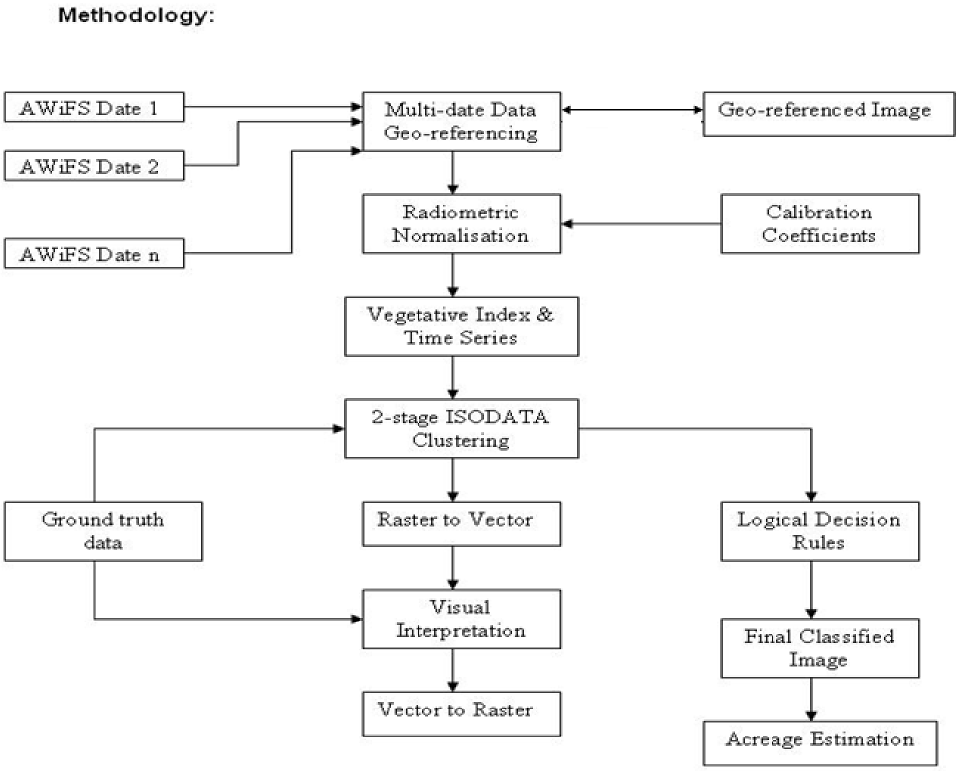


Fig. 2: Flow chart of the methodology for acreage estimation

Results and Discussions

Digital analysis for Rabi jowar acreage and production estimation in Gulbarga district of Karnataka for the year 2010-11 was carried out using multi-date IRS P6- AWiFS data. The results indicated, the first forecast of sorghum crop acreage estimation was under taken during Nov. 2010, where the crop was one month old. The Relative Deviation is -46.21% , because of the low vegetation index (Table 1).

Table 1: First forecast of sorghum crop acreage estimation (Nov. 2010).

Sl No.	District	Estimation by R S Data(2010-11) (ha)	Estimation by DOA (2010-11) (ha)	RD%
1	Gulbarga	155118	288425	-46.21

The second forecast of sorghum crop has been under taken in the month of Jan. 2011, where the crop was more than 100 days old. The details of acreage estimation with RS is 2,74,329 ha, where as DOA, the average estimation is 2,88,425 ha with a RD -4.88%. Based on the area estimation, the production estimation for Gulbarga comes to 2,52,382 tons, as shown in the Table 2.

Table 2 : **Second forecast of sorghum crop acerage & production estimation (Jan. 2011)**

Sl No.	District	Estimation by RS Data(2010-11) (ha)	Estimation by DOA (2010-11) (ha)	Yield in kg/ha	Productio-n (tons) (RS)	RD%
1	Gulbarga	274329	288425	920	252382	-4.88

Traditional needs mainly focus on area estimates for large administrative units (region, country). Other specific needs have emerged for information in spatial units that do not coincide with administrative regions, for example: area hit by a natural disaster: drought, kill-frost, windstorm, flood, etc. Mapping where events have hit is a major product by itself and complements traditional statistics, Crop presence information in cells of a grid is an important input for yield modelling or environmental assessment. For example the success of an analysis to assess floods depends on the availability of pre-event and post-event cloud free RS data, identification of crops before the event etc. For the crop area that could not be detected before the event, the impact will be more difficult to assess. For traditional farm surveys this type of target may be a major problem, but for approaches based on area frame sampling and remote sensing, the methodology is relatively easy to adapt. If quick results are required, few or no current ground data can be obtained and the criteria stated above should be applied accordingly.

Cultivated and harvested area can be substantially different in some regions of the world, in particular in arid countries. For the estimation of production, harvested area is usually the most important information if yields are estimated with regard to harvested area. Making the difference between both concepts is a delicate problem both for ground surveys and for remote sensing approaches. The issue needs to be analyzed on a case-by-case basis keeping in mind that production is generally the main target.

Micro Watershed Level Land Use Planning for Sustainable Natural Resource Conservation

S. Edison and Nizamudeen, A.

Kerala State Land Use Board, Thiruvananthapuram, Kerala
E-mail: landuseboard@yahoo.com

Abstract

Watershed is a topographically delineated area derived by a stream or a hydrologic unit, used as a physical – biological unit within an agro-ecological environment for planning and management of natural resources. The watershed approach will ensure scientific land evaluation at micro level. The planning unit must be micro watersheds for sustainable natural resource conservation, development and management. The resource data generation is at cadastral level, *ie.* 5K. High resolution satellite data can be used intelligently to generate various natural resource layers, integrate socioeconomic database and merge in GIS platform for meaningful planning. KSLUB has evolved a methodology to prepare vision documents of LSGIs in a systematic manner and prepared watershed master plans at 5K for 50 LSGIs in various districts representing coastal, lowland, midland and highland physiographical regions. The present study was an attempt at using high resolution satellite data, GIS techniques and participatory approach to understand the current situation of the natural resources and to propose an integrated land and water resource development plan for the next 20 years including infrastructure development, agriculture, water harvesting and soil conservation measures.

Geo-scientific analysis of the terrain and assessment of natural resources such as soil, geology, drainage etc was done using high resolution satellite images. The recommendations suggested include extension of paddy area, intercopping, waste land development, conservation of fresh water lakes, stream bank protection, soil and water conservation, mitigation of flood, waterlogging and drought, crop intensification, renovation of water sources, construction of check dams, infrastructure development etc. The entire application is web based and can be accessed through any standard web browser with user-friendly navigational approach. Thus, watershed master plans at 5K can be effectively evolved by utilizing the innovative technologies of remote sensing and GIS and by harnessing the locally available wisdom through participatory approach.

Introduction

Land use planning is a process for determining suitable future actions through the application of scientific, intelligent, fore-thought and co-ordinations. Land use planning is to be attempted based on scientific and systematic evaluation of land resources *viz.*, climate (macro and micro), soil, water, vegetation, biotic life, human population, economic and social considerations. This will facilitate alternative land use options enabling every piece of land to be put to its best possible use that will meet the needs of the people on sustainable basis and ensure environmental and economic stability.

Watershed is a topographically delineated area that is derived by a stream or a hydrologic unit that has been described and used as a physical – biological unit within an agro-ecological environment for planning and management of natural resources. The watershed approach will ensure scientific land evaluation at micro-level through land capability and land suitability classification for sustainability of the ecosystem and development, keeping the farmer and his plot in the centre stage. Development of the watershed needs better understanding about the various natural resources, their relations with each other and their relations with livelihood of the stakeholders.

In Kerala, area under paddy got shrunk from 12 lakh ha to 2.6 lakh ha in four decades. Diversion of good rice fields for non-agricultural uses not only made the food security in danger but also caused depletion of water resources and drainage congestion leading to unhealthy environment. Indiscriminate felling of forest and converting them to agricultural settlements, industry and other non-agricultural activities led to drinking water scarcity, severe drought during summer, landslides and floods during monsoon, soil erosion and land degradation. Population increase alone is not the reason but the major causes are resources depletion, deforestation and mismanagement of land resources. Ground water is getting depleted, quality of water in the rivers and streams and ground water is getting polluted and agricultural productivity is dwindling due to the decline in inherent soil-health. Hence, land use planning at micro-watershed level helps to conserve the land resources.

Land Use Planning at What level?

Before embarking on a Land Use Planning project, ascertain the target group for which the planning is to be done, find out expectations and decide the level of planning. Sometimes, objectives are set by social or political priorities, often leading to unwise land use causing serious damage to environment and depletion of basic resources like water and good agricultural land.

For preparing and implementing Land Use Plan, Level of Planning is a key factor. There must be a clear understanding about the decision on the level of planning required. It may be at National, District or Panchayat level. At National level, national priorities and allocation of resources are considered for general use. These are often complex due to policy decisions, required legislation, financial measures, etc. Land Use Planning at National Level is based on the baseline data on soil environment and other natural resources at the scale of 1:250,000/1:1 million. District Development planning is based on reconnaissance level of data generation at 1:50,000 scale. Panchayat / Village level must be the first level of planning and perhaps the most needed level for actual implementation of programmes for the farmer or the land user. Soil and soil environment data, climate, water, vegetation, biotic life and socio-economic condition of people are to be taken into account at this level. The planning unit must be the micro-watersheds for land use planning and for sustainable natural resource conservation, development and management.

The resource data generation at this level of planning must be the cadastral level, *ie*. 1:5000 scale. High resolution satellite data can be used intelligently to generate various natural resource layers and merge the database in the GIS platform for meaningful planning. Experienced knowledge of the local farmer about the area should also be utilized together with information from technical staff, R&D scientists of Agriculture University, ICAR R&D Centres and officials of Directorate of Agriculture, Forest Department etc. The land use plan must be resource based including socio-economic factors of people living within the project in order to make it economically viable and sustainable. The plan must identify the problems and potentials of the area based on the resources available at individual plot. State and District level support is very much needed for the success of the local land use plans.

Vision Document for each Grama Panchayat

Panchayat level resource data base and proper interpretation of these data will crystalise into firm recommendations for better land utilization. The easy understandability of the information upto the level of Panchayat functionaries and farmers are essential requirement while drawing recommendations. These must be supported by vital infrastructure build up, development of agro-based industry, marketing etc as per "value chain analysis" for specific location.

Kerala State Land Use Board (KSLUB) has evolved a methodology to prepare vision documents of LSGIs in a systematic and phased manner. Resource maps of 979 LSGIs out of 1057 have been prepared in the first phase on 1:5000 scale. Thematic layers such as land use, water resources, assets, administrative boundaries, transport network, drains are the integral part of these resource maps. In the second phase, utilizing these resource maps, preparation of watershed action plans of LSGIs was attempted to. Here, participatory approach of evolving watershed master plans was the strategy by actively involving the Panchayat functionaries, local level resource persons, farmers etc. In addition to the above thematic layers, additional layers of information such as soil, geomorphology, slope, land capability etc were generated using high resolution satellite images and integrated them in a GIS platform to develop meaningful watershed master plans.

KSLUB has prepared watershed master plans on 1:5000 scale for 50 LSGIs in various districts *viz*. Thiruvananthapuram, Kollam, Pathanamthitta, Alapuzha, Kozhikkode and Palakkad. These LSGIs represent coastal, lowland, midland and highland physiographical regions. KSLUB has identified various developmental and environmental problems and suggested appropriate remedial measures for sustainable land use.

Watershed master plan - Kalliyoor Grama Panchayat – A case study

The present study was an attempt of using high resolution satellite data, GIS techniques and participatory approach to understand the current situation of the natural resources and to propose an integrated land and water resource development plan for the next 20 years including infrastructure development, agriculture, water harvesting and soil conservation measures for each micro-watershed in Kalliyoor Grama Panchayat of Thiruvananthapuram District, Kerala.

The project envisages in the use of satellite remote sensing technology for the generation of reliable information on the natural resources, conversion of these databases into digital form for future analysis and utilization, to identify the problems and potentials of the area and to prepare location specific land and water resources development plans by integrating these databases with socio-economic data and contemporary technology in the GIS environment. Geo-scientific studies of the terrain and assessment of natural resources such as soil, geology, drainage etc was done using high resolution satellite images. The socio-economic appraisal of the stakeholders is carried out through household survey. GIS based model of the terrain with all relevant spatial data related to natural resources, infrastructure and administrative boundaries attached with relevant attribute data enabling the planners, stakeholders and funding agencies to develop each micro-watershed was also developed. The study also developed cadastral level resource information system to evolve at location specific, cadastral boundary level action plan considering land and water resource for optimal utilization.

The methodology consisted of following five stages, *viz.* (i) generation of resource/ thematic maps, (ii) collection of socio-economic and secondary data, (iii) integration of basic data and inter institutional / user's interaction, (iv) finalisation of maps and reports and (v) generation of location specific action plans.

Satellite images on 1:12,500 scale were visually interpreted for generation of different thematic maps. Base maps were prepared using cadastral maps from Department of Survey and Land Records pertaining to the project area. The major soils occurring in the area were studied in detail using satellite data and ground truth and a soil map of the panchayat on series level was prepared on 1:12,500 scale. The land use/land cover map was generated by adopting the classification system upto level IV. The major land use/land cover classes were grouped into built up land, agricultural land, forests, waste land, wetlands and water bodies at level 1 and further into level II, level III and level IV.

Cadastral maps were digitized and integrated with the above thematic maps. The land records database has been developed and interfaced with these maps in such a way that it is possible to access data relating to a piece of land from the thematic maps. This kind of integration between various type of data helps in planning as it is possible to view all relevant information on a single platform. The nature, extent and distribution of natural resources were evaluated. The potentials and limitations of resources, ecologically fragile areas etc were assessed for suggesting technological solutions. The thematic maps and resource evaluation report was presented before the Panchayat level expert committee comprising of ward members, farmers, implementing officers of various line departments for formulation, finalization and prioritization of action plans with people's participation.

Micro-watershed based Action plan

The entire Kalliyoor Grama Panchayat area having an area of 1732 ha is divided into four micro-watersheds and the action plans for each of the micro-watershed is generated separately. The action plan of micro-watersheds has been derived by giving thrust to the activities that can be undertaken by local bodies under the various development programmes. Different category of recommendations suggested for one micro-watershed *viz.* Vellayani (2K29b1) micro-watershed includes extension of paddy area, inter-cropping, wasteland development, conservation of fresh water lake, stream bank protection, soil and water conservation, mitigation of flood and water-logging, crop intensification, renovation of water sources, mitigation of drought, infrastructure development, improvement of transport network, construction of check dams etc.

Web based GIS Information System

State-of-the-art web technology tools and systems conforming to Services Oriented Architecture were used in implementing the Information System. The Web GIS application is developed using Open Source Tools and Standards that result in a robust, scalable and flexible Web GIS application. The entire application is web based and can be accessed through any standard web browser with user-friendly navigational approach. M/s. IIITM-K, Government of Kerala initiative was entrusted with the development of Web GIS, deployment of the system and training the necessary staff to manage the system at district nodes.

Conclusions

Realistic Land Use Planning is imperative for the sustainability of Kerala and other states in the country. Scientific approach to Land Use by seriously following the basic principles of watershed planning at grass-root level is vital for mitigating the adverse effect of climate change and biodiversity. Scientific Land Use Planning from grass-root level is the lifeline of success in our endeavour to ensure sustainability to the ecosystem without adversely affecting our developmental, industrial and economic activities. Watershed master plans on 1:5000 scale can be effectively generated by utilizing the innovative technologies of remote sensing and GIS and by harnessing the locally available wisdom through participatory approach.

Acknowledgements

The work is a part of the Plan Project implemented by the Kerala State Land Use Board, Government of Kerala, in collaboration with Local Self Government Institutions. The authors place deep gratitude to Land Use Commissioner, Kerala for valuable guidance, meticulous supervision and constant encouragement throughout the study.

Watershed Prioritization of Inaccessible Micro-Watersheds of Dal Lake Catchment (J&K) using Geographical Information System

Adil Mushtaq and A.Q.Dar

Department of Civil Engineering, National Institute of Technology, Srinagar, Kashmir (India)
E-mail: adilaquarian@gmail.com

Abstract

Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management. Morphometric analysis has been commonly applied to prioritization of watersheds. The quantitative analysis of drainage system is an important aspect of characterization of watersheds. Using watershed as a basic unit in morphometric analysis is the most logical choice because all hydrologic and geomorphic processes occur within the watershed. The present study makes an attempt to prioritize sixteen inaccessible micro-watersheds of Dal Lake catchment of Srinagar district, Jammu and Kashmir, based on morphometric analysis, using Geographical Information System. These have been classified into three priority categories as high, medium and low for conservation and management. Four micro-watersheds viz., Z1b3, Z2b5, Z2a2 and Z1b8 qualify for high priority and are likely to be subjected to maximum soil erosion and susceptible to natural hazards. Micro-watersheds Z2a3, Z2a5, Z2a6, Z2a7, Z1b1, Z1b4, Z1b6 and Z1b7 have been categorized as medium priority and Z2a1, Z2a4, Z2a8 and Z1b2 as low priority category. Watersheds categorized as high priority have been proposed for conservation treatments.

Introduction

Proper planning at smaller hydrologic units like milli and micro watershed level is a prerequisite for development of the drainage channels. Therefore it is recognized that a watershed based approach to restoration is necessary for healthy and productive watersheds. It also recognizes that it is not possible to restore all degraded areas at the same time even with the most aggressive proposed management. The rational approach is to undertake an inventory of the land and water resources available and then use a systematic planning method to make best use of resources. An attempt to assess the erosion hazard and prioritization of watersheds for treatment would aid for better planning. Morphometric analysis is a significant tool for prioritization of micro-watersheds even without considering the soil map (Biswas et al., 1999). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002). Morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed. The prioritization process identifies the highest priority watershed(s) or erosion susceptibility zone to initiate treatment. Watershed prioritization is the ranking of different micro-watersheds of the catchment according to the order in which they may be undertaken for drainageline treatment and soil conservation measures. Once the micro-watersheds are prioritized, quantitative assessment of morphometric parameters of micro-watersheds serve as basic information for adopting suitable soil and water conservation measures.

In the present study an attempt has been made to quantify various morphometric parameters of inaccessible micro-watersheds of Dal lake catchment and prioritize erosion susceptibility zones mapping based on ranks obtained from morphometric parameters to initiate management. The present study utilizes the Geographic Information System (GIS) analytic techniques to evaluate morphometric parameters. The morphometric parameters considered for analysis are area of watershed, perimeter, length of basin, stream length, bifurcation ratio, drainage density, drainage texture, stream frequency, compactness coefficient, form factor, circularity ratio, elongation ratio, length of overland flow etc. Watershed boundary map, drainage network map and contour map are utilized for computation of morphometric parameters. A watershed management programme has been proposed for one of the high priority micro-watershed.

Study Area

The study area is situated between 34°02´ - 34°13´ N latitude and 74°50´ - 75°09´ E longitude. The catchment has an area of approx. 328.785 km², nearly half of which comprises the Dachigam National Park. The Dal lake catchment is a fan shaped and broadens in the westward direction. The western portion of the catchment is a flatter area, whereas the northern and eastern sides rise high. The Dal lake catchment exhibits a varied topography with altitudinal range of 1580-4360 m. The climate is sub-humid temperate with an average annual rainfall of about 951.5 mm. The maximum temperature rises up to 37°C in June, whereas minimum temperature can be as low as -14°C in January. The catchment is surrounded by Sindh basin in the north and Jhelum basin in the south. Marsar is a glacial oligotrophic alpine lake and is major feeding source to the famous Dal Lake. The location map of the study area is depicted in Fig.1.

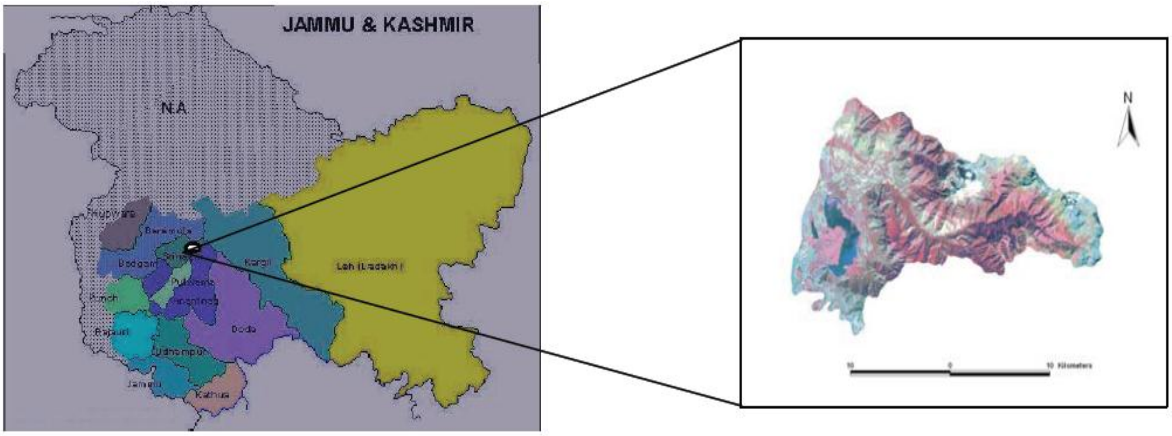


Fig. 1 Location map of the Dal lake catchment

As per methodology for codification of watersheds, in vogue in the Department of Soil Conservation (Jammu and Kashmir), Dal lake catchment has been assigned three digit code as (1EZ).The code indicates Dal lake catchment falls in the Water Resource Region 1 (Indus Drainage), Jhelum basin (E) and catchment Dal (Z). It has further been divided into sub-catchments, watersheds and micro-watersheds as shown in Table1. The codification map of the Dal lake catchment is given in Fig.2.

Table 1. Codification of watersheds for Dal Lake Catchment

Basin	Catchment	Sub-Catchment	Watersheds	Micro-Watersheds
Jehlum (1E)	Dal catchment (1EZ)	Nambal(1EZ$_{1)}$, Dara(1EZ$_{2)}$	Z1a,Z1b,Z2a,Z2b	Z1a$_{1\ \text{to}}$ Z1a$_9$
				Z1b$_{1\ \text{to}}$ Z1b$_8$
				Z2a$_{1\ \text{to}}$ Z2a$_8$
				Z2b$_{1\ \text{to}}$ Z2b$_{13}$

Source: (Department of soil conservation J&K/1982)

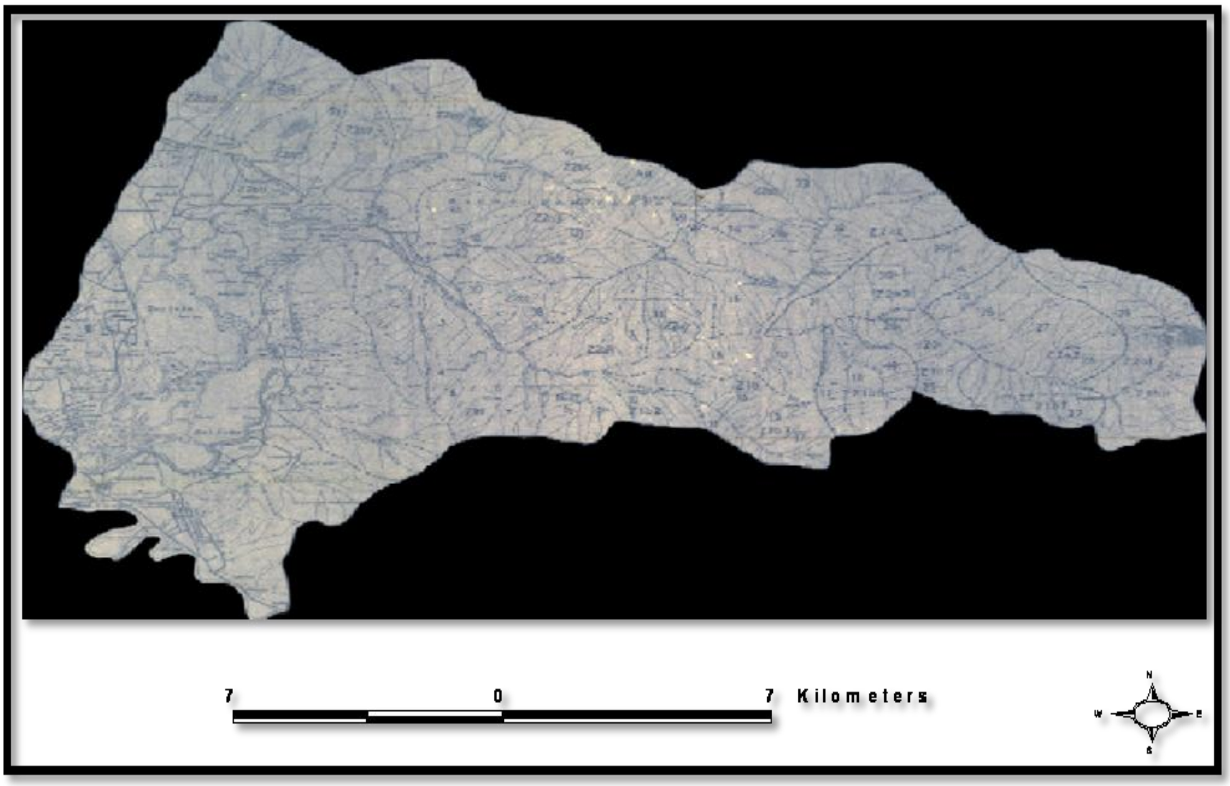


Fig. 2: Micro-Watershed map of Dal Catchment, (Source: Department of Soil Conservation/ 1982 Srinagar, J&K).

Database and Methodology

The study was carried out on micro-watershed level utilizing survey of india SOI toposheets. All the steams were digitized from Survey of India Toposheets, 1961 on a scale of 1:50,000. Codification map provided by Department of Soil Conservation, Jammu and Kashmir has been taken as a reference for delineation of catchment and micro-watersheds boundary. Strahler (1964) system of stream analysis is probably the simplest, most used system and the same has been adopted for this study. The study was carried out in GIS environment utilizing Arcview 3.2a for digitization and computational purposes and also for output generation. Map creation, Scanning, Georeferencing, Spatial data and Topology Creation are the steps involved in the morphometric analysis of micro-watersheds. The various morphometric parameters such as area, perimeter, length of basin, stream length, stream number, bifurcation ratio, drainage density, stream frequency, drainage texture, length of basin, form factor, circulatory ratio, elongation ratio, length of overland flow were computed using standard methodology and formulae are given in Table 2.

Table 2: Formulae for computation of morphometric parameters

Morphometric parameter	Formula	Reference
Stream order	Hierarchial rank	Strahler (1964)
Stream length (Lu)	Length of stream	Horton (1945)
Mean stream length (Lsm)	Lsm =Lu/Nu where, Lsm = mean stream length Lu = Total stream length of order ‘u’ Nu = Total no. of stream segments of order ‘u’	Strahler (1964)
Stream length ratio (RL)	RL = Lu / Lu-1 where, RL = stream length ratio Lu = Total stream length of order ‘u’ Lu-1 = Total stream length of its next lower order	Horton (1945)
Bifurcation ratio (Rb)	Rb = Nu / Nu + 1 Rb = Bifurcation ratio Nu = Total no. of stream segments of order ‘u’ Nu + 1 = no. of stream segments of the next higher order	Schumn (1956)
Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
Drainage density (Dd)	Dd = Lu /A where, Dd = Drainage density Lu = Total stream length of all orders A = Area of basin (km^2)	Horton (1932)
Stream frequency (Fs)	Fs = Nu / A where Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of basin (km^2)	Horton (1932)
Drainage texture (Rt)	Rt = Nu / p where, Rt = Drainage texture Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)

Form factor (R_f)	$R_f = A/Lb^2$ A = Area of basin (km^2) Lb^2 = Square of basin length	Horton (1932)
Circulatory ratio (Rc)	$Rc = 4*pi*A /P^2$ where, Rc = circulatory ratio pi = 'Pi' value i.e 3.14 A = Area of basin (km^2) P^2 = Square of the perimeter (km)	Miller (1953)
Elongation ratio (R_e)	$R_e = 2 \sqrt{(A / Pi)}/ Lb$ where, Re = Elongation Ratio A = Area of basin (km^2) Lb = Basin length Pi = 'Pi' value i.e 3.14	Schumn (1956)
Length of overland flow (Lg)	Lg = 1/Dd*2 where, Lg = Length of overland flow Dd = Drainage Density	Horton (1945)

Linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility. Higher the meter value, higher is the erodibility. For prioritization of micro-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility (Nooka Ratnam *et al.*, 2005). Lower the value, more is the erodibility. Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Hence, the ranking of the micro-watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters. After the ranking has been done based on every single parameter, the ranking values for all the linear and shape parameters of each micro-watershed were added up for each of the micro-watersheds to arrive at compound value (Cp). Based on average value of these parameters, the micro-watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on. The micro-watershed which got the highest Cp value was assigned last priority constituting an index of high, medium and low priority.

Results and Discussion

The various morphometric parameters are given in Table 3. These are broadly divided into linear and shape factors.

The Linear Parameters include Drainage Density (Dd), Stream Frequency (Fs), Mean Bifurcation Ratio (Rb), Drainage Texture (Rt), Length of overland flow (Lg). The drainage density in the Dal lake catchment exhibits a wide range in its values from 1.79 (lowest) in Z2a1 to 3.46 (highest) in Z2a7. The high value of drainage density (Dd) 3.46 indicates that the region is composed of impermeable sub-surface materials, sparse vegetation and high mountainous relief. In Dal lake catchment the lowest stream frequency (Fs) is in Z2a8 (2.07), followed by Z1b2 (2.49) and Z1b1 (2.92). The highest stream frequency is found in Z1b3 (4.74). High stream frequency (Fs) is indicative of high relief and low infiltration capacity of the bedrock pointing towards the increase in stream population with respect to increase in drainage density. The watersheds having large area under dense forest have low drainage frequency and the area having more agricultural land have high drainage frequency. High value of drainage frequency produces more runoff in comparison to others. The mean bifurcation ratio (Rb) of the Dal lake catchment is (5.073). The lowest mean bifurcation ratio (Rb) is found in Z2a7 (2.87) whereas highest Rb of 7 is in Z2a8. Low Rb value indicates less structural disturbance and the drainage patterns have not been distorted whereas high Rb value indicates high structural complexity and low permeability of terrain. The lowest Drainage Texture (Rt) of 1.31 is in Z1b2, while as the highest is in Z2a2 (2.69). The drainage Texture of the micro-watersheds in Dal lake Catchment ranges from very course to course. The mean Length of overland flow (Lg) of Dal lake Catchment is 0.94. It is highest in Z2a1 (1.12), while as lowest is found in Z2a7 (0.58). Higher value of Lg is indicative of low relief and where as low value of Lg is an indicative of high relief.

The shape parameters include Form Factor (Rf), Shape Factor (Bs), Circulatory Ratio (Rc), Elongation Ratio (Re) and Compactness Coefficient (Cc). Dal lake catchment has a mean Form Factor (Rf) of 0.26. Form Factor is highest in Z2a7 (0.47), and lowest in Z2a2 (0.41), indicating that the catchment is elongated in shape and exhibits flatter peak flow for longer duration. Shape Factor (Bs) is lowest in Z2a7 (2.13), while as it is highest in Z2a2 (2.45). Dal lake catchment has a mean Shape Factor (Bs) of (3.78). Z2a4 has the lowest Circulatory Ratio (Rc) of 0.32, and it is highest in Z1b3 (0.69) indicating that all the micro-watersheds represent an elongated shape. Z2a7 and Z1b6 have the highest Elongation Ratio (Re) of 0.77 and the lowest of 0.72 is observed in Z2a2. Dal lake catchment has an mean Elongation Ratio of 0.54 which indicates high relief and steep ground slope. Compactness Coefficient (Cc) is highest in Z2a4 (1.76) and lowest in Z2a2 (1.20). The mean Compactness Coefficient in Dal lake catchment is 1.55.

Watershed Prioritisation

The final priority of micro-watersheds based on compound value has been given in Table 4. The micro-watersheds have been broadly classified into three priority categories according to their compound value (Cp) - High (11.4-14.2), Medium (14.3-16.3) and Low (>16.4). The final prioritized map of the study area is shown in Figure. 3.

Table 3: Micro-watershed wise morphometric parameters in Dal lake catchment

Morphometric paramters										
	Linear parameters					Shape parameters				
Micro-watershed code	Mean bifurication ratio (R_b)	Drainage Texture (R_t)	Length of overland flow (L_g)	Drainage Density (D_d)	Stream Frequency (F_s)	Form Factor (R_f)	Elongation Ratio (R_e)	Circulatory Ratio (R_c)	Compactness Coefficient (C_c)	Shape Factor (B_s)
Z2a1	5.12	1.74	1.12	1.79	3.21	0.43	0.74	0.40	1.59	2.33
Z2a2	5.91	2.69	0.76	2.64	3.14	0.41	0.72	0.69	1.20	2.45
Z2a3	5.35	2.07	0.82	2.44	3.12	0.42	0.73	0.51	1.40	2.38
Z2a4	4.50	1.47	0.90	2.22	3.38	0.44	0.75	0.32	1.76	2.26
Z2a5	5.62	2.06	0.74	2.69	3.33	0.42	0.73	0.47	1.45	2.36
Z2a6	5.66	1.96	0.78	2.56	3.18	0.43	0.74	0.52	1.38	2.33
Z2a7	2.87	2.15	0.58	3.46	4.31	0.47	0.77	0.64	1.25	2.13
Z2a8	7.00	1.28	0.85	2.36	2.07	0.44	0.75	0.62	1.27	2.27
Z1b1	5.16	2.12	0.80	2.49	2.92	0.42	0.73	0.59	1.31	2.39
Z1b2	4.50	1.31	0.83	2.42	2.49	0.45	0.75	0.51	1.40	2.24
Z1b3	3.45	2.61	0.66	3.01	4.74	0.43	0.74	0.39	1.59	2.34
Z1b4	4.58	1.68	0.83	2.41	3.87	0.45	0.76	0.35	1.68	2.23
Z1b5	6.00	2.64	0.71	2.82	4.08	0.44	0.75	0.69	1.20	2.27
Z1b6	4.00	1.93	0.74	2.69	4.62	0.46	0.77	0.40	1.57	2.17
Z1b7	4.50	2.08	0.81	2.47	3.81	0.46	0.76	0.65	1.24	2.18
Z1b8	3.50	2.33	0.79	2.55	4.45	0.44	0.75	0.48	1.44	2.25

Table 4: Prioritization of micro-watersheds based on morphometric parameters

Morphometric Parameter												
	Linear parameters					Shape Parameters						
Micro-watershed code	Rb	F_s	R_t	L_g	D_d	R_c	R_e	R_f	C_c	Bs	Cp	Priority Category
Z2a1	9	15	23	30	26	5	9	26	9	11	16.3	Medium
Z2a2	3	28	27	18	21	12	24	19	30	5	18.7	Low
Z2a3	7	11	12	31	7	30	19	5	3	23	14.8	Medium
Z2a4	15	6	18	26	32	23	5	9	13	13	16	Medium
Z2a5	5	16	3	23	3	21	16	22	8	25	14.2	High
Z2a6	4	14	7	21	18	31	25	13	28	21	18.2	Low
Z2a7	25	27	8	14	22	20	21	23	17	8	18.5	Low
Z2a8	1	22	13	11	8	16	7	15	5	20	11.8	High
Z1b1	8	13	24	22	14	22	19	4	18	12	15.6	Medium
Z1b2	15	5	25	27	15	17	18	20	26	16	18.4	Low
Z1b3	22	9	22	29	27	24	4	13	25	27	20.2	Low
Z1b4	14	1	17	12	13	25	12	17	12	1	12.4	High
Z1b5	2	21	4	17	4	14	3	25	29	17	13.6	High
Z1b6	19	12	6	4	10	11	10	13	1	28	11.4	High
Z1b7	15	2	29	6	24	3	7	6	24	26	14.2	High
Z1b8	21	10	11	20	9	2	23	21	27	4	14.8	Medium

The micro-watersheds which fall in high priority category are Z1b6, Z1b4, Z2a8, Z1b7, Z1b5 and Z2a5. These micro-watersheds generally consist of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio. These micro-watersheds need immediate attention to take up soil conservation measures. There are five micro-watersheds falling in medium priority. These include Z2a3, Z1b8, Z1b1, Z2a4 and Z2a1. These micro-watersheds consist of moderate slopes, moderate values of drainage density, stream frequency, Drainage Texture and moderate to high form factor, circulatory ratio and elongation ratio. These micro-watersheds needs attention immediately after high priority micro-watersheds. Low priorty category has been attained by Z2a6, Z2a7, Z1b2, Z1b3 and Z2a2. These watersheds consist of lower slopes, very low drainage density, stream frequency, texture ratio, high form factor, circulatory ratio and elongation ratio. They may need agronomical measures to protect the sheet and rill erosion.

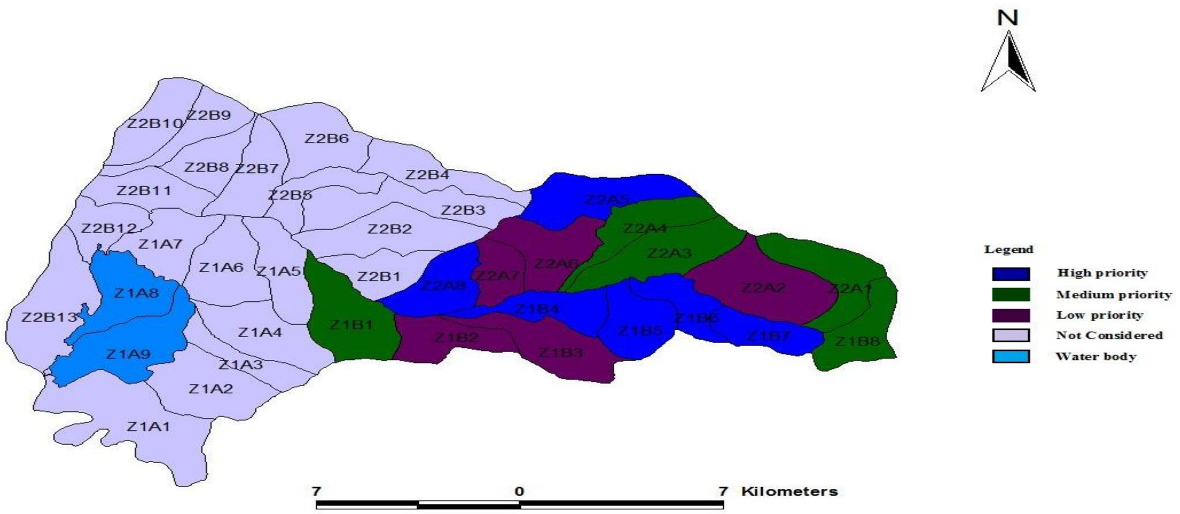


Fig. 3 Priority of micro-watersheds for taking soil and water conservation activities

Watershed Management

Watershed development programmes primarily aim to reduce soil erosion by way of appropriate structures like check dams, gabion, loose boulders, afforestation on waste lands, etc. In such programmes micro-watersheds which are prone to rapid erosion, assumes the highest priority.Considering massive investments in watershed development programme, it is important to plan the activities of these watersheds on priority basis for achieving fruitful results which also facilitate addressing the problem areas to arrive at suitable solutions. Accordingly sixteen inaccessible micro-watersheds under study have been categorized into three categories, *ie* the micro-watersheds which require high priority, the micro-watersheds which require medium priority and the micro-watersheds which require low priority.

Watershed management in high priority micro-watersheds

For undertaking soil conservation measures in the Dal lake catchment area various indirect or preventive measures like direct or remedial measures like engineering measures have been discussed in the following paragraphs. Even as suggestions have been made regarding certain specific treatment measures to be undertaken in a particular micro-watershed, these measures, however, may require further micro-planning during the implementation stage. It is always better to undertake preventive measures than to mitigate the factors that ultimately lead to soil erosion. Such preventive measures will indirectly help to conserve soil in the long run, keeping in view the importance of integrating eco-restoration strategy with socio economic needs of the local community wherein both ecology and economics are developed. The preventive measures that are suggested for the study area have been discussed below.

Watershed management of micro-watershed Z1b5:

For taking up watershed management of inaccessible micro-watersheds of Dal lake catchment one of the high prioriy micro-watershed Z1b5 (Table 5) was taken for soil conservation measure. Intense rains resulting in high degree of erosion on steep slopes, and Insufficient and sparse vegetation cover.

Table 5: Micro-watershed Z1b5

Location:	
Latitude	34º 03' to 34º 04'
Longitude	74º 77' to 74º 79'
Watershed Area	7.60 km^2
Perimeter	11.73 km

The significant land treatments suggested as indicated in Fig.4. are as follows

Afforestation / Vegetative cover

The forest in the micro-watershed under study has been observed to occupy higher slopes and highly erodible soils. The soil gets easily transported down the slope. The micro-watershed has a considerable degraded forest area and accordingly afforestation programme has been suggested in such area which will help to intercept rainfall and prevent the soil erosion due to improved binding of soil with the roots as well as by reducing splash erosion.

Silvipasture- Silvipasture has also been proposed on the degraded forest areas. The presence of silvipasture dissipates the impact force of rain drops on the soil surface and protects the soil from splash erosion by modifying the volume, drop size and impact velocity of rainfall.

Pasture development- Development of the pasture land has also been suggested in Bhaks, which are used by the Bakerwals, Nomads etc in the forests for growing of live stock.

Crate Wire Structures- The micro-watershed under study being hilly often produce, flash floods which erode the lands located along the banks of drainage lines. Such bank erosion problem is accentuated in the lower reaches of the micro-watershed. The micro-watershed being sensitive to the problem needs protection by crate wire structures as indicated in the annexed drainage map. Further it is suggested that willow tree should be planted on both sides of crates to provide additional support to banks.

Check Dams- A series of Rubble Dry Stone Masonray Check dams (RDSM) are recommended to be created on the drainage lines to prevent stream bed erosion .Further protection by lines of Mawa Check dams (Willow) above and below the degraded drainage lines may be provided. This will help in sediment control and more and more vegetation would establish on the deposited slit and will start arresting slit.

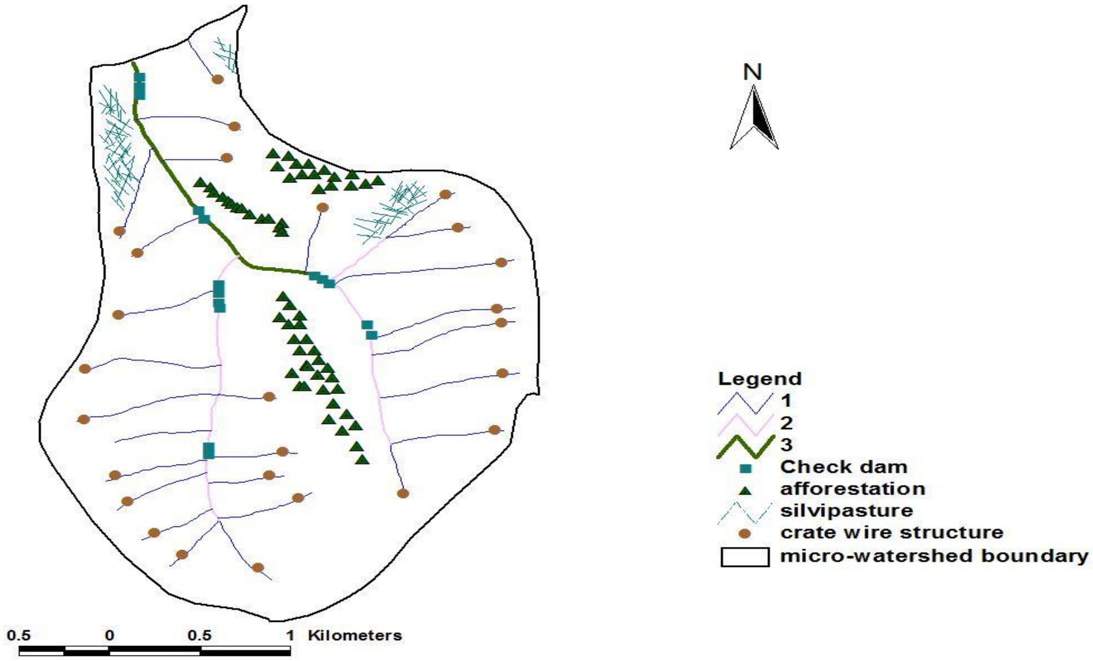


Fig.4.Treatment map of micro-watershed Z1b5

Conclusions

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programs. The present study demonstrates the usefulness of GIS for morphometric analysis and prioritization of inaccessible mountaneous watersheds of Dal lake catchment. The morphometric characteristics of different micro-watersheds show their relative influence on hydrologic response of the micro-watershed.

Morphometric analysis can help in decision making process for water resources management. Results of prioritization of micro-watersheds show that micro-watersheds Z1b6, Z1b4, Z2a8, Z1b7, Z1b5 and Z2a5 fall under high priority and are more susceptible to soil erosion. These micro-watersheds generally consist of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio. High priority indicates the greater degree of erosion in the particular micro-watersheds and it becomes potential case for undertaking soil conservation measures. Immediate attention towards soil conservation measures is required in these watersheds to preserve the land from further erosion and to alleviate natural hazards.

References

Agarwal, C.S. (1998). Study of drainage pattern through aerial data in Naugarh area of Varanasi
district, U.P. J. Indian Soc. Rem. Sens., 24(4): 169-175.

Biswas S, Sudhakar S and Desai VR (1999). Prioritization of sub-watersheds based on Morphometric Analysis of Drainage Basin, District Midnapore, West Bengal. J. Indian Soc. Remote Sensing 27(3):155–166.

Horton, R.E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull. 56:275– 370.

Kango, G.H. and Bashir, Qadri. (1982). Codification of watesheds in Jammu & Kashmir. Vol.1 Jhelum Basin. Technical Bulletin, SP&R-1. Directorate of Soil Conservation, Srinagar.

Miller, V.C. (1953). " A quantitative geomorphic study of drainage basin characteristics in the Clinch mountain area, Virginia and Tennessee, Deptt. Of Geology, Columbia University, Contract N6 ONR 271-30, TechinicalReport3, pp. 1-30.

Nooka Ratnam, K., Srivastava, Y.K., Venkateswara Rao, V., Amminedu, E. and Murthy, K.S.R. (2005). Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis - Remote sensing and GIS perspective. J. Indian Soc. Rem. Sens., 33(1): 25-38.

Obi Reddy, G.P., Maji, A.K. and Gajbhiye, K.S. (2002). GIS for morphometric analysis of drainage basins. GIS lndia, 11(4): 9-14.

Schumm, S.A. (1956). "The evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersy, Bull. Geol. Soc. Amer,Vol. 67, pp 597-646.

Strahler, A.N. (1957). "Quantitative analysis of watershed geomorphology." Trans.Am. Geophys. Union. 38: 913-920.

Strahler, A.N. (1964). Quantitative geomorphology of basins and channel networks. Hand book
Of Applied Hydrology (Ed. Ven Te Chow), Mcgraw Hill book company, New York, section 4II.

Watershed Prioritization for Soil Conservation using RS and GIS

H.B.Balakrishna and D.Shivaprasad

Dept. of Civil Engineering, Bangalore Institute of Technology,
V.V.Puram, Bangalore
E-mail: balubit@gmail.com

Abstract

Prioritization is a process of identifying areas of main concern based on single or many parameters. It is the selection of one or few watersheds out of many watersheds by using predefined set of criteria. The present study emphasizes prioritization based on the soil erosion in the catchment. The study area chosen for the present study was Thippagondana Halli (T. G. Halli) catchment of Arkavathy river basin comprising Bangalore urban, Bangalore rural and Kolar district. The study area geographically lies between 770 14' and 770 41' E longitude and 120 57' and 130 24' N latitude. The catchment comprises an area of 1448.64 Sq. km. The catchment was delineated into 8 watershed based on topography and drainage pattern. The thematic maps like land use/ land cover, slope, soil maps required for the estimation of soil erosion was prepared using satellite data and Geographic Information system (GIS) software. The Universal Soil Loss Equation (USLE) was used to estimate the soil erosion in all the subwatersheds of the catchment. It predicts, essentially the soil loss from sheet and rill erosion under specified conditions. It enables to determine the land management, erosion rate relationship for a wide range of rainfall, soil, slope, crop and management conditions. The watershed 2 is experiencing high erosion and considered as highly critical, and watershed 5 experiences least erosion. The most affected watershed is preferred for soil conservation on top priority to reduce soil erosion and enhance the cultivable area of catchment.

Introduction

The T.G Halli catchment covers Bangalore urban, Bangalore rural and Kolar districts of Karnataka state. Fig. 1 shows the location map of the T.G Halli catchment. The aim of the present study is to estimate the soil loss in the catchment. The necessary maps were prepared using remote sensing data and analyzed using GIS software. To compute soil loss the theory and methodology as suggested by Wischmeier and Smith (1978) known as USLE (Universal Soil Loss Equation) to predict the long-term average soil losses from a specified land in a specified cropping and management system was used. It predicts, essentially the losses from sheet and rill erosion under specified conditions. It enables to determine the land management, erosion rate relationship for a wide range of rainfall, soil, slope, crop and management conditions. The USLE is as follows;

$$A = RKLSCP \qquad (1)$$

where,

A = computed soil loss (t/ha/year), R = Rainfall Erositivity (it is the sum of erosion index (EI) units during the period under consideration). The erosion index is a measure of the erosive force of specific rain event, *K* = soil erodibility factor and is the soil loss per erosion index unit for a specified soil as measured on a unit plot (it compares the actual erosion to the erosion from a clean, tilled, fallowed, uniform slope 9% and length of 22.13 m), *L* = slope length factor (it is the ratio of soil loss from the field slope length to that from a 22.13 m length on the same soil type and gradient), *S* = slope steepness factor (it is the ratio of soil loss from the field slope gradient to that from 9 percent on the same soil type and gradient), *C* = cover and management factor (it is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow), *P* = erosion-control practice factor (it is the ratio of soil loss with a support practice like contouring, strip-cropping or terracing to that with straight row farming up-and-down the slope).

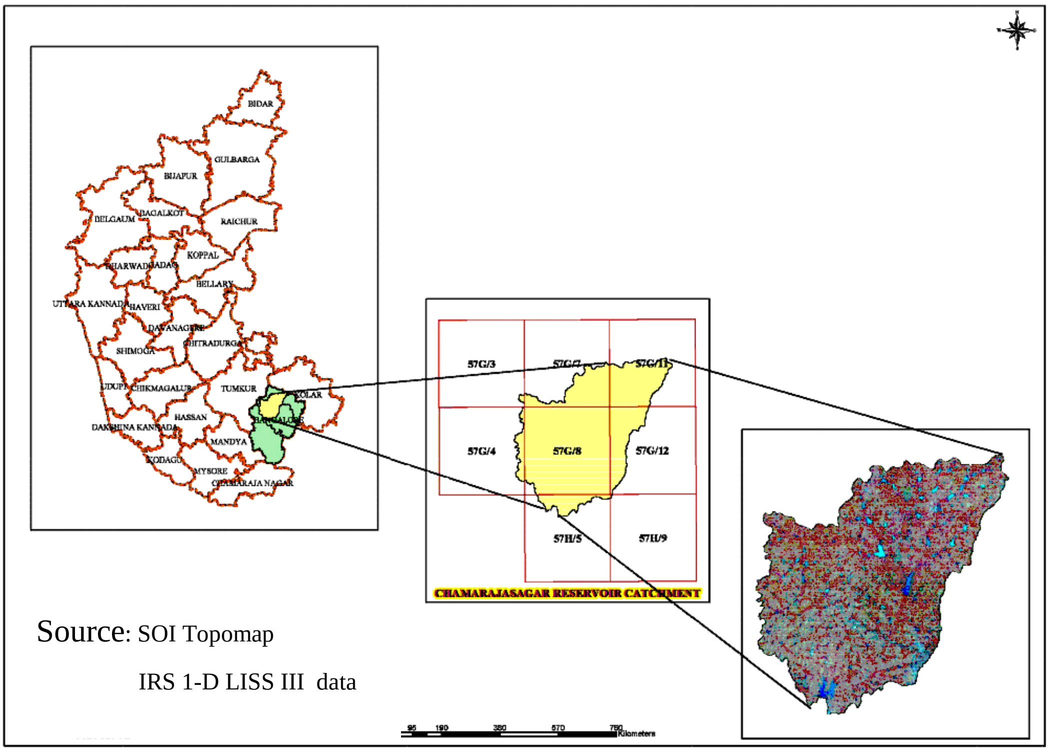


Fig. 1 Location map of the study area

Rainfall Factor *(R)*

The soil erosivity factor is quantified by the term '*R*' in the USLE equation and is expressed as one hundredth of the product of the kinetic energy of the storm (KE) and the 30 minute, rainfall intensity (EI_{30}) is the most reliable single estimated of rainfall erosion potential and termed it as EI_{30} values and referred as the rainfall erosion index. For a given storm the rainfall and runoff erosivity index (EI) is determined by multiplying the kinetic energy of the storm to the maximum 30-minute intensity for that storm. The EI values for all the storms occurring in a given year for location are added to obtain an annual erosivity index. However for the present study the rainfall factor (R) has been taken from published isopleath Map of India (Raghunath B. *et. al*., 1982).

Soil Erodibility Factor (K)

The soil erodibility factor *(K)* relates the rate at which different soils erode under the conditions of equal slope, rainfall. The soil erodibility factor *(K)* calculated from the following regression (Wischmeier and Smith, 1978)

$$100K = 2.1 \times 10^{-1} (N1.N2)^{1.14} (12 - OM) + 3.25(S - 2) + 2.5(P - 3) \qquad 2$$

where

K = soil erodibility factor, $N1$, $N2$= particle size parameter (% silt + % very fined sand), OM = percent organic matter content, S = soil structure code (very fine granular 1; fine granular 2; medium or coarse granular 3; blocky, platy, or massive 4), P = profile permeability class (rapid: 1; moderate to rapid: 2; moderate: 3; slow to moderate: 4; slow: 5; very slow: 6)

In order to use the Wischmeier and Smith equation, it is necessary that the grain size of the soil in the catchment area are determined down to sand, fine sand and silt. The soil (Fig. 2) in the catchment consists of coarse (medium angular), blocky platy or massive type of soil structure for the calculation of *K* factor. The soil properties of the watershed are shown in Table 1. The soil erodibility factor *K* for different watersheds in the catchment is shown in Table 2.

The percentage of sand, silt of the different soil series in the watershed was taken from NBSS and LUP(1998). Weighted average K factor calculated for all the soil texture. Similarly K factor was estimated for 8 watersheds in the catchment and is shown in Table 2.

Table 1 Major soil properties of the study area

Texture	Sand %	Silt %	Clay %	Organic Matter %	K
Clay	37.33	8.50	51.50	0.54	0.29
Clay Loam	42.20	22.60	35.20	0.61	0.46
Dyke Ridges	0.00	0.00	0.00	0.00	0.00
Gravelly Clay	54.00	6.00	40.00	1.00	0.38
Gravelly Loam	76.51	14.87	10.25	0.60	0.68
Gravelly Sandy Loam	83.29	4.19	12.16	0.39	0.63
Habitation Mask	0.00	0.00	0.00	0.00	0.00
Loamy Sand	85.70	4.40	9.90	0.23	0.65
Rock out crops	0.00	0.00	0.00	0.00	0.00

Sandy Clay	52.93	4.50	41.50	0.54	0.34
Sandy Clay Loam	50.60	14.00	35.40	0.60	0.41
Sandy Loam	75.81	3.75	19.00	0.60	0.52
Water Body Mask	0.00	0.00	0.00	0.00	0.00

(Source: NBSS and LUP 1998, KSRSAC, 2006)

Table 2 *K*-factor for watersheds

Watershed No	1	2	3	4	5	6	7	8
Area of watershed (Sq.km)	137.82	138.46	137.82	182.79	163.89	212.14	278.76	187.78
K-factor	0.41	0.41	0.38	0.40	0.38	0.49	0.41	0.41

Slope Length Factor (L)

The slope length and gradient are represented in the USLE as *L* and *S*. However, they are often evaluated as a single topographic factor as LS. Slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where runoff enters a defined channel (Ravikumar *et al.*, 2007). Slope length factor was computed as

$$L = \left(\frac{l}{22}\right)^m \qquad 3$$

where ,
L = slope length factor, l = slope length in m, m = dimensionless exponent = 0.5 for slopes > 4 %; 0.4 for 4% slope; 0.3 for slopes < 3%

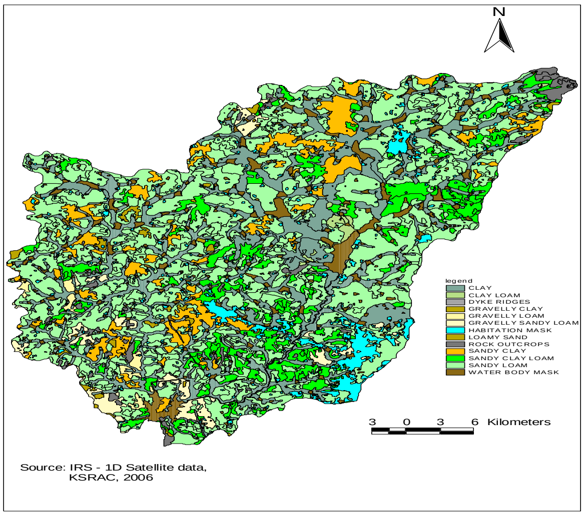


Fig. 2 Soil map of the study area

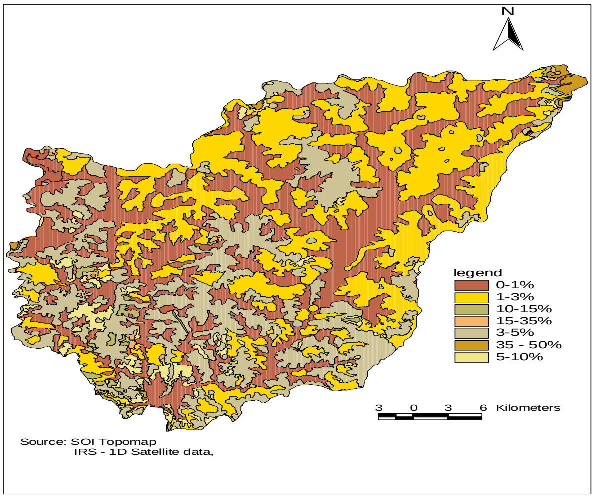


Fig. 3 Slope map of the study area

Slope Steepness Factor *(S)*

Slope gradient is the field or segment slope usually expressed as percentage (Wischmeier and Smith, 1978). Table 4 shows the LS values calculated for all watersheds. Fig. 3 shows the slope map of the catchment.

Crop Management Factor *(C)*

This term '*C*' represents the combined effect of cover crop sequence, productivity level, length of growing season, tillage practices, residue management and the expected time distribution of erosive rainstorm with respect to planting and harvesting date. Crop management factor is most complex and there are many methods for managing the growing crops.

Table 4 Topographical factors *'LS'* for T G Halli catchment

WaterShed No.	Area of watershed (Km^2)	Length (m) (x)	Difference in elevation (m) (y)	Slope (%) $\theta=\tan^{-1}(y/x)$	*LS* factor
1	137.82	25000	60	0.138	0.39
2	138.46	13000	40	0.176	0.52
3	137.82	14000	40	0.164	0.46
4	182.79	26000	40	0.088	0.21
5	163.89	17000	20	0.067	0.15
6	212.14	15000	40	0.153	0.41
7	278.76	17000	30	0.101	0.23
8	187.78	12000	30	0.143	0.35

The major crops in the study area include ragi, paddy, Jowar, vegetables and mixed plantations. However, the C factor is taken from the literature Dhruva Narayana (1996) suggested C factor for different crops as paddy = 0.28; ragi = 0.60; jowar = 0.62; pulses = 0.6 and so on and the average value 0.525 was taken for the study.

Conservation Practice Factor *(P)*

Conservation practice factor is the ratio of soil loss with a specific supporting practice to the corresponding loss with up and down cultivation. The most important support practices are contour cultivation, strip cropping, terrace system and waterways for the disposal of excess rainfall. The values are selected based on the recommendations of Wischmeier and Smith (1978). Since the study area comprised of unprotected lands, conservation factor P was taken as unity. The weighted soil loss for the study area was estimated to be 17.85 t/ha/year, which is a moderate loss (ISRO-NNRMS-TR-103- 2002). The soil loss for all the watersheds is shown in the Table 5. Fig. 4 shows the erosion map of the catchment.

Table 5 Soil Loss estimated for T G Halli catchment

Watershed	1	2	3	4	5	6	7	8
Area of Watershed Sq. km	137.82	138.46	137.82	182.79	163.89	212.14	278.76	187.78
K-factor	0.41	0.41	0.38	0.4	0.38	0.49	0.41	0.41
LS-factor	0.39	0.52	0.46	0.21	0.15	0.41	0.23	0.35
Erosion t/(ha/year)	20.88	28.19	23	10.82	7.47	26.53	12.18	18.72

Results and Conclusions

The soil loss for T G Halli catchment was estimated using USLE which comprised of 6 major factors i.e, *RKLSCP*. Rainfall erosivity factor, R is taken directly as 250 from the published Isopleth map of India (Raghunath, B *et al*., 1982).The rainfall erodibility factor(K) was evaluated by using Wischmeier and Smith equation and the value obtained was found to be 0.41, the slope length and slope steepness was calculated using the Wischmeier and Smith equation for (LS) and the value obtained was found to be 0.60, the crop management factor *(C)* is taken as the average values for various crops grown in watershed and the average value obtained was 0.525, and the watershed consisted only bunds around the agricultural lands and no conservation were followed, so the cropping management factor P was taken as 1. The weighted soil erosion for the T G Halli catchment was estimated to be 17.85 T/ha/year which is a severe loss. Based on the results of the model watershed 2 was experiencing high erosion and considered as highly critical and watershed 5 least erosion. The most affected watershed is preferred for soil conservation on top priority to reduce soil erosion and enhance the cultivable area of catchment.

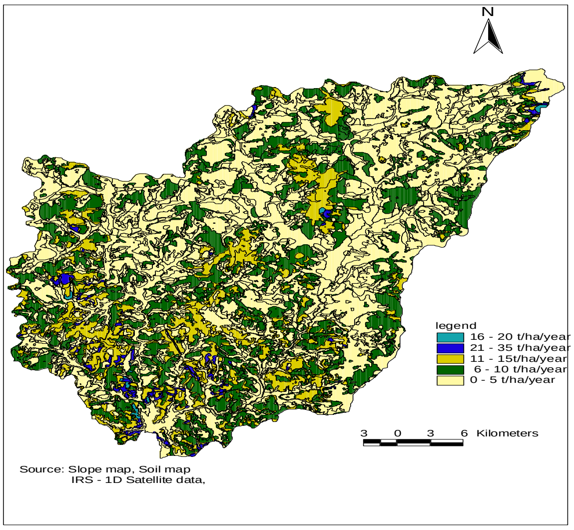


Fig. 4 Soil erosion map of the study area

References

Dhruva Narayana, (1996) Design of earth dams for water harvesting and erosion control in Shiwaliks, Journal of Institute of Engineers.

ISRO-NNRMS-TR-103-2002: Regional Remote Sensing Service Centres (2002), Indian Space Research Organisation, Bangalore; watershed characterisation, prioritisation, development, planning and monitoring-Remote sensing approach.

National Bureau of Soil Survey and Land Use Planning, (1998) Soils of Karnataka for optimising landuse- Executive Summary in cooperation with Government of Karnataka, pp 33-35.

Ravikumar A.S., Balakrishna H.B., Anand B.K. (2007) Runoff and Soil Loss Estimation Using RS and GIS for Watershed Development, National conference on Watershed Management and Impact of Environmental Changes on Water Resources (WMEC – 2007), Department of Civil Engineering, JNTU college of Engineering, Hyderabad–560 085, AP, India.

Wischmeier, W.H. and Smith, D.D., (1978) Predicting rainfall erosion losses- A Guide to Conservation Planning, USDA Agricultural Service Handbook No. 537, Washington, D.C., U.S.A.

Watershed Prioritization Using Morphometric Analysis in Kuttiyadi River Basin: A Geospatial Approach

Girish Gopinath[1], Manasa, M[2]., Swetha, T.V., Ashitha, M.K.[3] and Ajith, G.Nair[3]

[1]*Remote Sensing Cell, Centre for Water Resources Development and Management, Calicut, Kerala - 673 571*
[2]*Department of Geology, Govt. College, Kasaragod, Kerala*
[3]*Department of Geology, Govt. College, Kottayam, Kerala*
E-mail: gg@cwrdm.org

Abstract

An evaluation of drainage network of Kuttiyadi river basin (676 km^2) with a humid tropical setting is carried out using Geospatial techniques. The Digital Elevation Model or DEM is prepared from the Shuttle Radar Topography Mission (SRTM) data which shows the elevation from the Mean Sea Level. Contour map of the study area was derived from DEM, with the aid of ArcGIS. The streams of the basin generally conform to Horton's laws. The drainage basin is fed by six Sub watersheds. Linear parameters like drainage density, stream frequency and texture indicate a moderate relief, infiltration capacity, run off and peak flood discharge for the watershed. The various linear and spatial morphometric parameters have been ranked based on their susceptibility to run off and erosion. Sub watershed II is found to be a hot spot, being most vulnerable to effects of inundation and erodability underscoring the need for immediate planning and management strategies. Sub watersheds V and VI were distinguished by their marginal runoff, relief and textural values and very elongated nature hinting at varying structural control in the different parts of the basin.

Introduction

Watershed management, which in essence is the application of land resource management systems and is considered by many to be the most appropriate approach to ensure preservation, conservation and sustainability of all land-based resources, and improving the living conditions of people in the uplands and lowlands (Moujahed *et al*., 2003) .Watershed management is increasingly being recognized as the ideal approach for integrated natural resources management in rain-fed areas. Management of watershed encompasses various activities from watershed delineation to monitoring. Holistic integrated planning, involving Remote Sensing and GIS has been found to be effective in planning for regional development based on watershed approach. The prioritization of sub-watersheds using morphometric analysis for watershed development activities is gaining importance in recent years. The humid tropics like Kerala State in India, is getting squeezed by increasing population and associated water needs in domestic, industrial and agricultural sectors exerting tremendous pressure on the watersheds. The state receives three times the global average precipitation and bestowed with 44 rain-fed rivers, making the demarcation of watershed difficult. More than 80% of the water in the river wastefully flows in to the Arabian Sea, because of topography and experiencing serious seasonal water shortage as a combined result of improper management, land and water degradation and increased population.

Morphometric analysis is a significant tool for prioritization of sub-watersheds even without considering soil map (Biswas *et al*., 1999) and many works have been reported on Morphometric analysis using GIS. Remote sensing and GIS have been found useful tools in identification and categorization of watersheds on the basis of natural resources and their limitations (Khan *et al*., 2001). Drainage density and stream frequency are the most useful criterion for the morphometric classification of drainage basins which certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin (Imran Malik *et al*., 2011).The morphometric parameters evaluated using GIS help to understand various terrain parameters such as nature of the bedrock, infiltration capacity, runoff, etc. Similar studies in conjunction with high resolution satellite data help in better understanding the landforms and their processes and drainage pattern demarcations for basin area planning and management (Nageswara Rao *et al*., 2010 , Nookaratanam *et al*., 2005) carried out study on check dam positioning by prioritization of micro-watersheds using sediment yield index (SYI) model and morphometric analysis using GIS. Akram *et al*., (2011) have studied the watershed prioritization using morphometric and landuse/ land cover parameters.

The present study area, Kuttiyadi river basin is drained for a variety of agricultural fields. The plantations like cashew, rubber and coconut are commonly seen in the area under investigation and preponderance of population living here depends on the income from agricultural activity. The Kuttiyadi river basin is blessed with two reservoirs, Peruvannamuzhi and Kakkayam, Peruvannamuzhi reservoir is famous for hydroelectric project and also serves water for the famous Japan Govt. Aided Drinking Water Project, to serve water to the population in the secluded villages in Kozhikode district, long tunnels are running from the upstream; thereby diminish the stability of top soil and rapid augment in soil erosion. Therefore catchment area of the Kuttiyadi river basin is more susceptible to get eroded and can cause reservoir siltation. The whole basin is divided into six sub-watersheds by considering its drainage system for morphometric analysis. In the present study, an attempt has been made to prioritize the sub-watersheds of the Kuttiyadi River basin of the Northern Kerala through morphometric analysis using GIS and SRTM data.

Environmental Settings

Kuttiyadi River Basin falls in the Kozhikode district, Northern Kerala which lies between latitudes 11^0 30'N and11^0 44'N and longitudes 75^0 34 'E and 75^0 58'E is an important water source of Kannur and Kozhikode districts of Kerala (Fig.1). It is a west flowing river, rising from the Narikota Ranges on the western slopes of the Wayanad Hills, a part of Western Ghats, at an elevation of 1220m above mean sea level (amsl) and drains into the Arabian Sea at Kottakal. The river is 74km long and along with its tributaries it drains an area of 676 km^2 in Kozhikode district of Kerala. The perimeter of the basin is 136 km. The major tributaries are Onipuzha, Thottilpalampuzha, Kadiyangadupuzha, Mannathilpuzha and

Madappalipuzha. The Kuttiyadi basin enjoys typical tropical humid climate. The annual mean rainfall along highland is 4522 mm whereas lowland receives 3070 mm. About 60% of the rainfall is received during SW monsoon and 30% during the NE monsoon. The maximum and minimum temperature of the basin is 34^0C and 20^0 C.

Geology and Geomorphology

Geologically, the Kuttiyadi River Basin has three distinct formations; Crystalline rocks of Archean age, Laterite capping over the crystallines and sedimentary rocks, and Recent and sub- recent sediments in low-lying areas. Crystalline rocks chiefly consist of charnockite and gneisses (Fig.2). The gneisses consist of garnetiferous biotite gneiss and biotite hornblende gneiss (Premachandran, 2007). Granite gneiss and charnockite have low permeability and high bearing capacity. The laterite layers are thick, porous and slightly permeable, so the layers can function as aquifers. The major distinct geomorphic units in the area are denudational plateaus, denudational hills and valleys, denudational slopes, flood plain and valley flat (GSI, 2002) Geohydrology of the area varies. The narrow coastal belt, with alluvial deposit, is a potential aquifer with depth of ground water ranging from 0.3-3m with yield of around 50 lps is suitable for filter point wells. The midland region has a thick laterite cover with depth to water from 5 -20 mbgl, yield upto 30 lps is suitable for open wells. Open dug wells meet the domestic needs of water. In Foot hills and High hills of the east, with thin soil cover, yield of ground water is poor, but fracture planes are potential zones (CGWB, 1983).

Materials and Methods

The base map for morphometric analysis of the Kuttiyadi river basin is Survey of India topographical maps on a 1:50,000 scale. The hard copy topographic map was scanned and exported in ERDAS IMAGINE 9.1 where it was georefernced. After georeferencing onscreen digitization process was carried out using ARC GIS 9.2 to extract stream network .The designation of the stream order is the first step in morphometric analysis of a drainage basin, which is based on the hierarchy ranking of streams proposed by Strahler (1964).

Kuttiyadi river basin is divided into six sub-watersheds, (Fig.1) digitized from topographic map, were designated as SW 1 to SW 6. Computation of basin parameters required for morphometric analysis, ordering, lengths, area etc. were estimated using GIS technique, which were later used to calculate other parameters like drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow, form factor, circularity ratio, elongation ratio and basin shape for each sub-watersheds. These parameters were evaluated with the help of established mathematical equations (Table 1). Prioritization of sub-watersheds was carried out by assigning weight factors to all the computed morphometric parameter. The Digital Elevation Model (DEM) (Fig.3) derived from the SRTM data reveals that the eastern region of the area under investigation is highly undulating and higher elevation of 1900 m above mean sea level is associated with denudational hills and valleys and denudational plateaus in the eastern region.

Results and Discussion

The morphometric analysis is performed for Kuttiyadi river basin covering an area of 676 km^2. The Linear, areal and relief parameters of the basin is discussed here.

Linear Parameters

The linear aspects include the Stream Order, Total Stream Length, Stream Length Ratio and Bifurcation ratio.

The Kuttiyadi river basin is a 6^{th} order basin with six sub-watersheds. Out of six sub-watersheds, one watershed (SW-VI) is of 6^{th} order and the rest five sub-watersheds is of 5^{th} order. Highest number of segments is found in SW IV (881 and stream) lowest number in SW II (191 stream), it is observed that there is a decrease in stream frequency as the stream order increases. Thus the law of lower the order higher the number of streams is implied throughout the catchment. The higher number of streams in sub-watersheds IV, I, III indicates that the topography is likely to get eroded. From the Table.2 it is observed that the first order streams have the maximum frequency and the frequency decreases as the order increases.

The channel length of each order is measured with the help of Arc GIS 9.2. Stream length reveals the surface run off characteristics of a stream. Relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer length of streams is generally indicator of gentle gradient. Generally, the total length of stream segments is maximum in first order streams and decreases as the as the stream order increases. The variation in slope, topography and rock type influence stream length. The total stream length is minimum (93.84 km) in the SW-II and maximum (462.94 km) in the SW-IV (Table 2). The total stream length of Kuttiyadi River is 1302.02 km.

The mean stream length is a characteristic property related to the drainage network components and its associated basin surfaces (Strahler 1964). Average length of stream channel segment is greater than that of the next lower order, but less than that of the next higher order. The calculated values of Lsm are presented in the Table 2. Lsm ranges between 0.49 to 23.04 in SW-III and SW IV respectively. The Lsm has a significant association with the surface flow discharge and erosional stage of the basin, low Lsm shows high surface flow and erosion.

Length ratio (RL) is defined as the ratio of mean length of an order to that of the lower order. It was noticed that RL between successive stream orders varies due to differences in slope and topographic conditions, and has an important relationship with the surface flow discharge and erosional stage of the basin (Sreedevi *et al*., 2005). The values of RL vary from 0.23 to 1.86 for the sub-basins IV and V respectively.

Bifurcation ratio is related to branching pattern of a drainage network and is the ratio of number of stream segments of one order to the number of streams in next higher order (Schumm 1956). Bifurcation ratio characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern (Strahler 1964), but exceeds 10 where pronounced structural control encourages the development of elongate narrow drainage basins (Chorley, *et. al*., 1984). Bifurcation ratio also gives an indication about the shape of the basin. An elongated basin is likely to have a high Rb value; where as a circular basin will have low Rb value. If Rb is low, the flow of energy is high, not giving adequate time for infiltration and ground water recharge, as well as high probability of flooding and vice versa.

This present study revealed that, the mean Rb varies from 3.55 to 7.55 in SW-II and SW-VI respectively (Table 2). The Rb value 7.55, indicate the influence of structural control on the development of drainage network. The higher Rb for sub-basin is the result of large variation in the frequencies between successive orders and indicates the maturity in topography (Sreedevi et al., 2009).

Areal Parameters

Area of a basin (A) and perimeter (P) are the important parameters in quantitative morphology. Basin area is hydrologically important because, it directly affects the size of the storm hydrograph and the magnitude of peak run off. It is interesting that, the maximum flood discharge per unit area is inversely related to size (Chorley, *et. al*., 1957). The areal aspects of the drainage basin are Drainage Density (D), Stream Frequency (Fs), Drainage Texture (T), Elongation Ratio (Re), Circularity Ratio (Rc), Form factor (Ff), Shape factor (Bs), Length of Overland Flow (Lo). The values of these parameters are presented in Table 3.

The measurement of Drainage Density (Dd) is a useful numerical measure of landscape dissection and runoff potential (Chorley, 1969). Drainage density is the total length of streams of all orders per drainage area, expressed in terms of miles/ $miles^2$ or km/ km^2. Drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin (Horton, 1932). Dd is known to vary with climate, vegetation, soil and rock properties, relief and landscape evolution processes. A low drainage is more likely to occur in regions of highly resistant or highly permeable subsoil material under dense vegetative cover and low relief; whereas high drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief (Nag,1998). Drainage density must reflect the amount of run-off that a basin generates. A high value for Dd will imply rapid and efficient run-off during rain-storms (Small, 1989). Slope gradient and relative relief are the main morphological factors controlling drainage density. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964) Drainage density of the six sub-watersheds varies between 0.66 to 3.23 for SW-VI and SW-II respectively (Table 3). It suggested that sub-watersheds with low Dd are highly permeable with sub soil and thick vegetation cover. Generally lower values of Dd tend to occur on granite, gneiss and schist region. The chief rock type of the area is Hornblende-biotite gneiss (Fig.2). Out of six sub-watersheds, SW-II with high density is showing fine drainage texture, so infiltration capacity is less and most prone to erosion.

Stream Frequency or channel frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932). It is an index of the various stages of landscape evolution. The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability. Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of same stream frequency and differing in drainage density. High values of stream frequency indicate more surface run off and steep ground surface (Horton, 1945). The stream frequency is highest in SW-II (6.58), SW-III (6.44) and SW-IV (5.99) indicating high surface runoff and thereby soil erosion.

Drainage texture (T) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). Drainage texture includes drainage density and stream frequency. According to Horton (1945), infiltration capacity is the single important factor which influences the drainage texture. According to Smith (1950), five different drainage textures have been classified based on the drainage density. The drainage texture less than 2 indicates very coarse texture, 2 to 4 is related to coarse texture, 4 to 6 is moderate texture, 6 to 8 is fine and greater than 8 is very fine drainage texture. The value obtained for six watersheds reveals very coarse to very fine drainage texture (Table 3) of water. The fine drainage texture SW-II (21.25), SW-III (19.83), SW-IV (18.8), SW-I (11.6) watersheds indicate less infiltration capacity.

The Form factor (Ff) may be defined as the ratio of basin area to square of the basin length. The value of Form factor would always be greater than 0.78 for a perfectly circular basin and smaller the value of Form factor, the basin will be more elongated. Flood flows of such elongated basins are easier to manage than of the circular basin. Calculated value of Form factor shows that the sub-watersheds are more or less elongated in shape. The form factor is highest for SW-II (0.32) and for the rest five sub-watersheds it ranges between 0.24 and 0.28, indicating elongated sub-watersheds.

Circularity Ratio (Rc) is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953). The Circularity Ratio (Rc) is influenced by the length and frequency of streams, geological structures, land use / land cover, climate, relief and slope of the basin (Srinivasa, *et. al*., 2004). The low, medium and high values give an indication about youth, mature and old stages of the life cycle of the tributary basins respectively. If the Rc value is 1.0 the basin is to be a perfect circle in shape and discharge quantity would be high. If the described Rc ranges from 0.44 to 0.5, watersheds are elongated with highly permeable geologic materials. The Rc values of sub-watersheds ranges between 0.44 to 0.55 indicating all sub-watersheds are elongated. From the DEM derived from the SRTM data shows that the topography in SW-I, II, III and IV are highly undulating, more susceptible for erosion.

Basin Shape (Bs) provides an extent of the irregularity in the shape of the basin and is defined as ratio of square of basin length to the area of the basin (Horton, 1932). Though, the Basin shape is not usually used directly in hydrologic design methods, the parameters that reflect basin shape are used occasionally and have a conceptual basis. Watersheds have an infinite variety of shapes, and the shape supposedly reflects the way that runoff will bunch up at the outlet. A circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than that of the circular watershed. The basin shape of sub-watersheds ranges from 3.09 to 4.19. These values indicate that sub-watersheds are elongated.

Elongation Ratio (Re) is the ratio between the diameter of a circle of the same area as the basin (A) and the maximum basin length (L) (Schumm, 1956). Higher values of Re indicates active denudational processes with high infiltration capacity and low run-off of basin susceptible to high headward erosion along tectonic lineaments (Gangalakunta, *et. al*., 2004). A circular basin having more Elongation ratio is very significant index in the analysis of basin shape, which helps to give an idea about the hydrological character of a drainage basin. Values of elongation ratio between 0 and 0.6 indicate rotundity and low degree of integration within a basin and values between 0.6 and 1.0 assumes pear-shaped characteristics of a well integrated drainage basin (Strahler, 1964). The Elongation ratio for SW-II and SW-V is 0.64 and 0.62 indicating the elongated shape (Table 3). Further, it is noticed that SW-II is having high drainage density than that of SW-V. It shows less infiltration capacity of the basin and more prone for erosion.

Constant of Channel (C) Maintenance is the area required to maintain one linear kilometer of stream channel; hence it is the inverse of drainage density (Schumm, 1956). It depends on the rock types, permeability, climatic regime, vegetation cover and relief as well as duration of erosion. Generally, higher the C values of a basin, higher the permeability of the rocks of that basin and vice-versa (Shubha, 2009; Vijay, *et. al*., 2003). The value of C is less for the sub-watersheds II (0.31), IV (0.31), III (0.32), I (0.36) (Table 3). Low C values indicate that these sub basins have high drainage density thereby low permeability with steep to very steep slopes.

Length of Overland Flow (Lo) is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. It is one of the most important independent variables, affecting both the hydrological and physiographical development of the drainage basin (Horton, 1945). The length of overland flow approximately equals to half of reciprocal of drainage density. The value of Lo ranges between 0.15 to 0.75 in SW-II and SW-VI, sub-watersheds with high Dd value showing less of overland flow.

Prioritization of Sub-watersheds on the Basis of Morphometric Analysis

The response of a watershed to different hydrological processes and its behavior depends upon various physiographic, hydrogeological and geomorphological parameters. Though these are watershed specific and there by unique, the prioritization of a watershed provides an idea about its behavior. Considering the massive investment in the watershed development programs, it is important to plan the activities on priority basis for achieving fruitful results, which also facilitate addressing the problematic areas to arrive at suitable solutions. In the present study for prioritization of sub-watersheds, the rating has been assigned based on every single parameter. For the slope ranking was given on the basis of all parameters. The rating value for all the six sub- watersheds were averaged so as to find out a Compound value (Cp). This compound value of the sub-watersheds was used to prioritize on the basis of their severity to soil erosion. Hence the sub-watershed with lowest Cp value was given first priority and next lower value has been given second priority and so on. The sub-watersheds were categorized as very high (1.36), high (2.9), medium (3), low (3.18) and very low priority (5.27) on the basis of final compound value and slope (Table $). Out of six sub-watersheds, SW-II fall in very high priority, SW-III fall in high priority, SW-I and SW-IV fall in medium priority, SW-V fall in low and SW-VI fall in very low priority category (Table 4 & Figure 5). The prioritization of sub-watersheds shows that SW-II is more susceptible to soil erosion. Therefore immediate attention towards soil conservation measures is required in this sub-watershed to prevent further erosion.

Conclusions

The present study reveals the effectiveness of Remote Sensing and GIS techniques for morphometric analysis of sub-watersheds of Kuttiyadi River Basin, Kozhikode. The Kuttiyadi Basin is identified as a sixth order basin with dominantly dendritic pattern. The linear and spatial aspects of sub-watersheds reveal their moderate nature of relief, run-off, peak discharge and differentially elongated shapes. They also indicate the limited influence of structural disturbances of the terrain on drainage characters. The various morphometric parameters of each Sub watershed were ranked based on their susceptibility to run-off and erosion. SW-II is found to be most vulnerable to high peak flows and erosion. This calls for setting up of immediate and viable remedial strategies for soil conservation and flood management. The present study further demonstrates the utility of Remote Sensing and GIS techniques in prioritization of watersheds, which may be helpful for taking the high priority implementation of soil and water conservation measures.

References

Akram Javed, Mohd Yousuf Khanday And Subah Rais (2011). Watershed Prioritization Using Morphometric and Landuse/ Landcover Parameters: A Remote Sensing and GIS approach. Jour. Geol. Soc. of India, Vol 78, pp. 63-75.

Biswas, S., Sudhakar, S. And Desai, V.R. (1999). Prioritization of Sub-watershed based on Morphometric Analysis of Drainage Basin: A Remote Sensing and GIS Approach. Jour. Of Indian Soc. of Remote Sensing, Vol 27(3), pp. 155-166.

Chorley, R.J., Donald Malm, E.G. And Pogorzelski, H.A. (1957). A New Standard for Estimating Drainage Shape. American Journal of Science, Vol.255, pp 138-141.

Chorley, R.J., Stanley, A., Schumm, Sugden David.E. (1984). Geomorphology. Methuen & Co. Ltd., pp 316 – 319.

Geological Survey of India, 2002. Geomorphological map of India.

Gangalakunta, P., Reddy, O.G.P., Amal, K., Maji, A.K. and Gajbhiye, S. (2004). Morphometry and its influence on landform characteristics in a basaltic terrain,Central India - A Remote Sensing and GIS approach. Internat. Jour. Applied Earth Observation and Geoinformatics, Vol 6, pp. 1-16.

Horton, R.E. (1932). Drainage basin characteristics. Trans. Amer. Geophys. Union, Vol 13, pp. 350 – 361.

Horton, R.E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Geol. Soc. Amer. Bull., Vol 56, pp. 275-370.

CGWB, 1983. Hydrological atlas of Kerala.

Imran Malik (2011). Watershed based drainage morphometric analysis of Lidder catchment in Kashmir valley using Geographical Information System. J. Recent Research in Science and Technology, Vol 3, pp 118-126.

Khan, M. A., Gupta V. P & P. C. Moharana (2001). Watershed Prioritization Using Remote Sensing and Geographical Information System: A Case Study from Guhiya, India, J. Arid Environments Vol 49, pp 465–475.

Miller, V.C. (1953). A Quantitative geomorphic study of drainage basin characteristics on the Clinch Mountain area, Virginia and Tennessee, Proj., Tech Rep 3, Columbia University, Department of Geology, ONR, New York. pp 389- 402.

Moujahed, Achouri, Larry,Tennyson, Kumar,Upadhyay and Roger,White (2003). Preparing for the Next Generation of Watershed Management Programmes and Projects, Asia, Watershed Management & Sustainable Mountain Development Working Paper 5, Kathmandu, Nepal, 177p.

Nag, S.K. (1998). Morphometric analysis using Remote Sensing techniques in the Chaka sub-basin-Purulia district, West Bengal. Jour. Indian Society of Remote Sensing, Vol 26, pp 69-76.

Nageswara Rao.K (2010). Morphometric analysis of Gostani river basin in Andhra Pradesh state, india using spatial information technology. International journal of geomatics and geosciences, Vol 1, pp 179-187.

Nookaratnam, K., Srivastava, Y.K., Venkateswara Rao, V., Amminendu, E. And Murthy, K.S.R. (2005). Check Dam Positioning by Prioritization of Micro watersheds using SYI Model and Morphometric Analysis – Remote Sensing and GIS Perspective. Journal of the Indian Society of Remote Sensing, Vol 33, pp 25 – 38.

Premachandran, P. N. (2007). Bench Mark Soils of Kerala. Soil Survey Organization Agriculture (S.C. Unit) Department, pp 481.

Schumm, S.A. (1956). Evaluation of drainage system and slopes in badlands at Perth Amboy. New Jersey. Bull. Geo. Soc. Amer. Vol 17, pp. 595-646.

Shubha, Rao. (2009). A Numerical scheme for Groundwater Development Watershed Basin of Basement Terrain: A case study from India. Hydrogeology Journal, Vol 17, pp. 379- 396.

Small, R.J. (1978). The Study of Landforms. 2nd edition. Cambridge University Press, p. 219.

Small, R. J. (1989). Geomorphology and Hydrology. Longman Group UK Ltd. p. 48.

Smith, K.G. (1950). Standards for Grading Texture of Erosional Topography. Amer. Jour. of Science, Vol 248, pp. 655 - 668.

Sreedevi, P.D., Subrahmanyam, K. And Shakkel, A. (2005), The Significance Of Morphometric Analysis for obtaining Groundwater Potential Zones in a Structurally Controlled Terrain. Environmental Geology, Vol 47, pp 412–420.

Sreedevi, P.D., Owais.S., Khan, H.H. And Ahmad, S. (2009). Morphometric Analysis of a watershed of South India Using SRTM Data and GIS. Jour. Geol. Soc. of India, Vol 73, pp. 543-552.

Srinivasa, V.S., Govindaiah, S. And Honnegowda, H. (2004). Morphometric Analysis of sub-watersheds in the Pavagada area of Tumkur district, South India, using Remote Sensing and GIS techniques. Jour. Indian Soc. of Remote Sensing, Vol 32 , pp. 351 –361.

Strahler, A.N. (1957). Dynamic Basics of Geomorphology. Bull. Geol. Soc. Amer.Vol 6, pp. 923-928.

Strahler, A.N. (1964). Quantitative Geomorphology of Drainage Basins and Channel Networks. *In*: V.T. Chow (Ed.), Handbook of Applied Hydrology. McGraw - Hill, New York, pp. 439-476.

Vijay Pakmode, Himanshu Kulkarni and Deolankar, S.B. (2003). Hydrological Drainage Analysis in watershed programme planning: A Case study from the Deccan Basalt, India. Hydrogeology Journal, Vol 11, pp. 595-604.

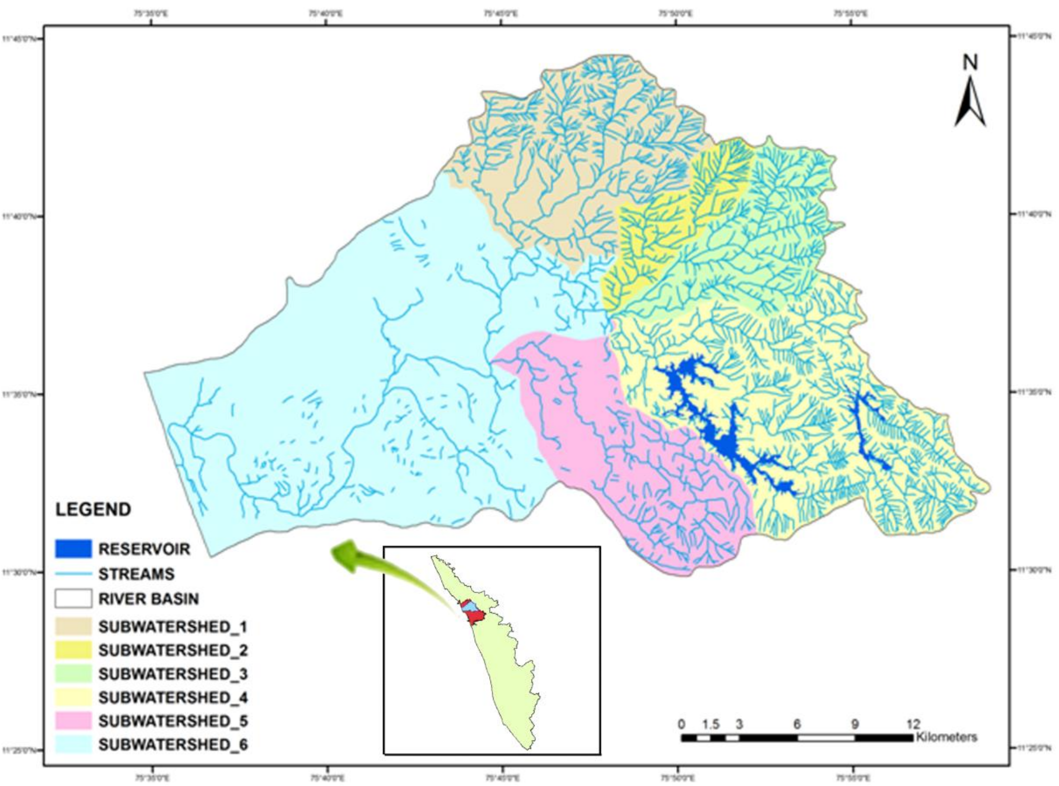


Fig. 1 Study area with sub-watersheds

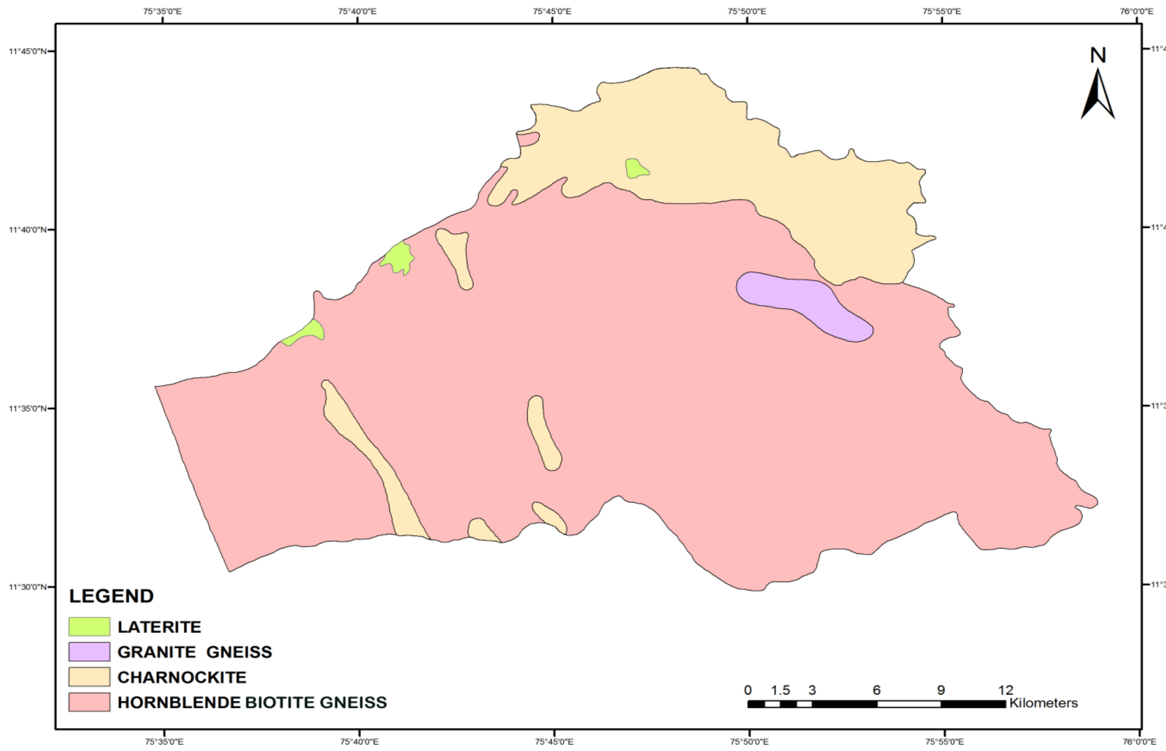


Fig. 2 Geology map of study area

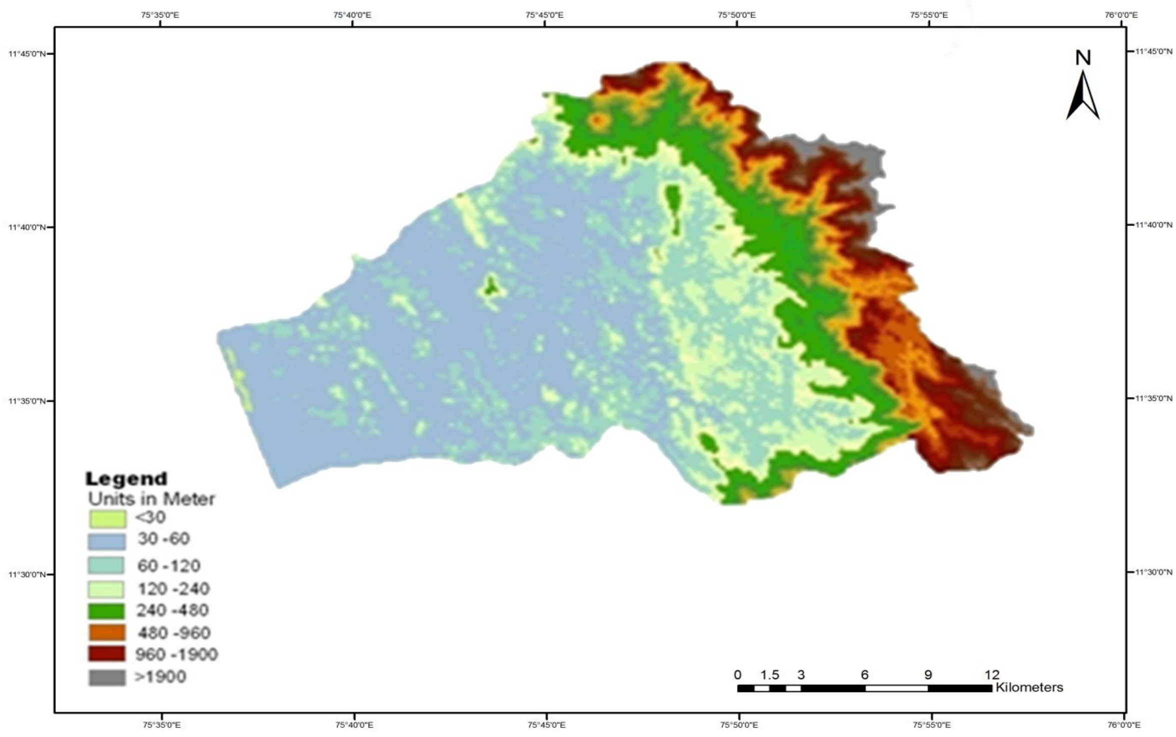


Fig. 3 DEM derived from SRTM

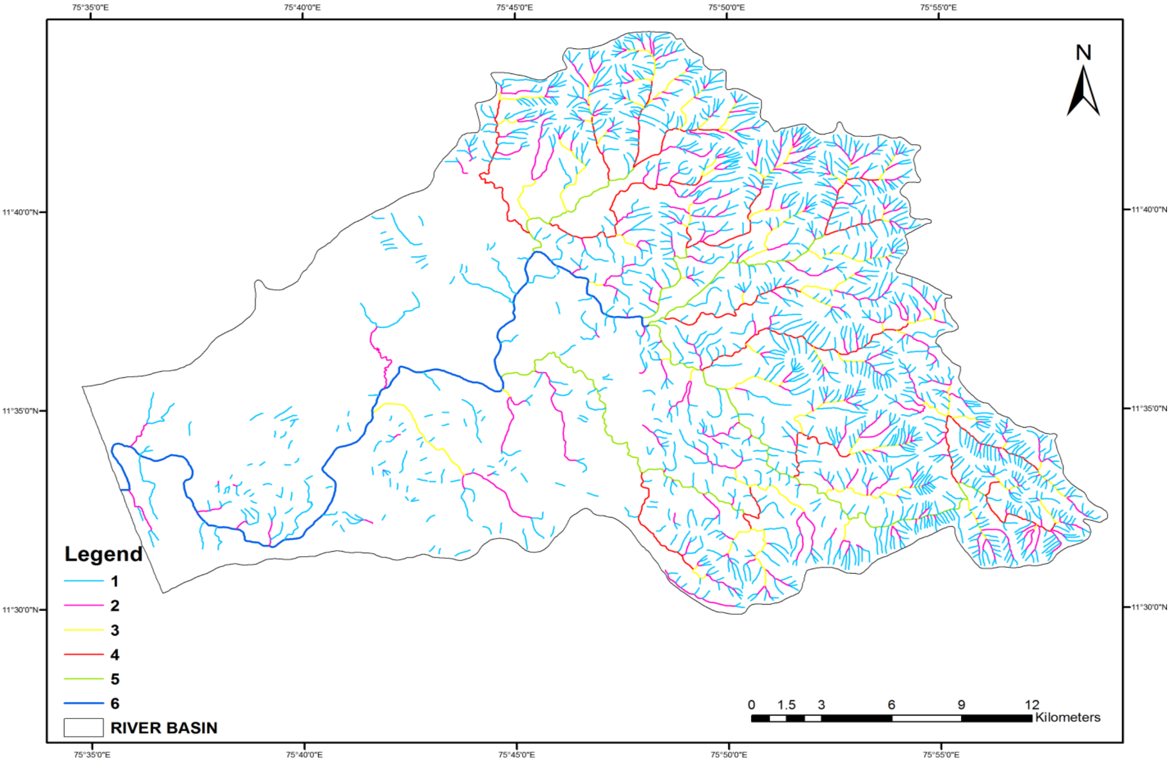


Fig. 4 Drainage map with Stream order

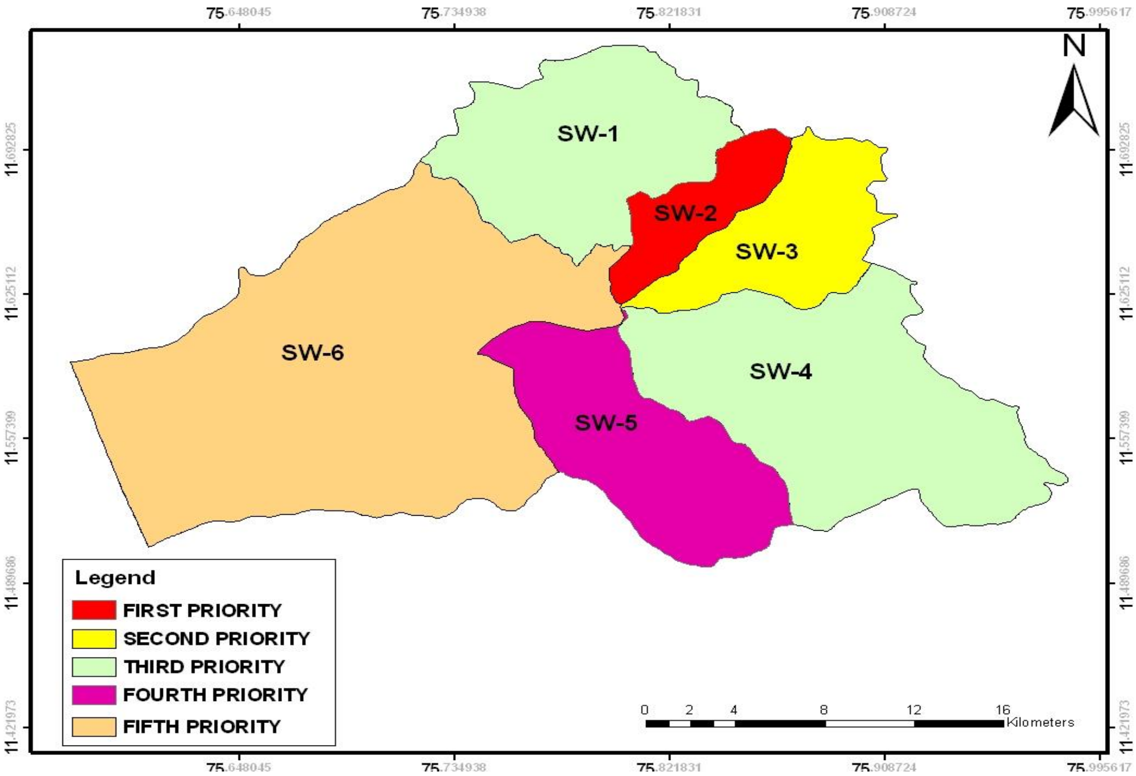


Fig. 5: Sub-watersheds with Priority

Table 1: Formulae adopted for the calculation of morphometric parameters

Sl. No.	Morphometric parameters	Formula	Reference
LINEAR ATTRIBUTES			
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (Lu)	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	***Lsm = Lu / Nu***, where, Lu = Total stream length of order u Nu =Total no. of segments of order u	Horton (1945)
4	Stream length ratio (RL)	***RL=Lu / Lu-1***, where, Lu=Total stream length of order u Lu-1=Total stream length of next higher order	Horton (1945)
5	Bifurcation ratio (Rb)	***Rb = Nu / Nu+1***, where, Nu= Total number of stream segments of order u Nu+1= Number of segments of next higher order	Schumm (1956)
6	Mean Bifurcation ratio (Rbm)	**Rbm** = Average of bifurcation ratios of all orders	Strahler (1957)
7	Basin length (Lb)	$Lb = 1.4A^{0.568}$, where, A= Area of the basin	Nookaratnam (2005)
AREAL ATTRIBUTES			
8	Elongation ratio (Re)	$Re = 1.128\sqrt{A} / Lb$, where, A=Area of the basin L=Basin length	Schumm (1956)
9	Drainage density (D) (Kms/km^2)	***D = Lu / A***, where Lu=Total stream length of all orders A = Area of the basin	Horton (1932)
10	Stream frequency (Fs)	***Fs = Nu / A***, where, Nu=Total no. of streams of all orders. A = Area of the basin	Horton (1932)
11	Drainage texture (T)	***T = D * Fs***, where, D = Drainage Density Fs = Stream frequency	Horton (1945)
12	Form factor (Ff)	$Ff = A / Lb^2$, where, A = Area of the basin Lb^2 = Square of the basin length	Horton (1932)
13	Circularity ratio (Rc)	$Rc = 4\pi A / P^2$, where, $\pi = 3.14$, A= Area of the basin P=Perimeter	Miller (1953)
14	Basin shape (Bs)	***Bs =Lb/A,*** where L= Basin length A=Area of the basin	Horton (1932)
15	Length of overland flow (L_0)	$L_0 = 1 / 2D$, where D = Drainage Density	Horton (1945)

Sub-watersheds		SW-I	SW-II	SW-III	SW-IV	SW-V	SW-VI	Kuttiyadi basin
Total stream length of order u in km	1	157.19	55.22	101.49	303.01	73.99	103.98	794.88
	2	44.52	20.76	24.39	71.8	28.12	23.72	213.31
	3	28.58	6.16	17.03	35.04	11.06	7.14	105.01
	4	21.7	6.80	14.02	30.05	9.15	-	81.72
	5	8.03	4.9	9.6	23.04	17.08	-	62.64
	6	-	-	-	-	-	43.43	43.43
	∑Lu	**260.03**	**93.84**	**166.52**	**462.94**	**139.41**	**178.28**	**1301.02**
Mean stream length in km (Lu/Nu)	1	0.55	0.52	0.49	0.55	0.58	0.6	0.55
	2	0.61	0.77	0.54	0.64	1.04	1.08	0.69
	3	1.43	1.02	1.55	1.21	1.84	2.38	1.4
	4	4.34	3.4	4.67	6.01	3.05	-	5.05
	5	8.03	4.9	9.6	23.04	17.07	-	12.52
	6	-	-	-	-		43.43	43.43
Stream length ratio (RL)	2/1	0.28	0.38	0.24	0.23	0.38	0.23	0.29
	3/2	0.64	0.29	0.69	0.48	0.39	0.16	0.44
	4/3	1.08	1.11	0.82	0.86	0.08	-	0.79
	5/4	0.26	0.72	0.68	0.76	1.86	-	0.86
	6/5	-	-	-	-	-	-	0.69
Number of streams (Nu) of different stream order (u)	1	286	106	208	545	128	172	1445
	2	73	27	45	112	27	22	306
	3	20	6	11	29	6	3	75
	4	5	2	3	5	3	-	18
	5	1	1	1	1	1	-	5
	6	-	-	-	-	-	1	1
	∑Nu	**389**	**191**	**348**	**881**	**217**	**231**	**1850**
Bifurcation ratio (Rb)	1/2	3.91	3.92	4.62	4.86	4.7	7.81	4.72
	2/3	3.65	4.5	4.09	3.86	4.5	7.33	4.08
	3/4	4	3	3.66	5.8	2	-	4.16
	4/5	5	2	3	5	3	-	3.6
	5/6	-	-	-	-	-	-	5
	mean	**4.14**	**3.55**	**3.84**	**4.88**	**3.55**	**7.55**	**4.32**

Table 2 : Linear Parameters of Kuttiyadi River Basin

Table 3 : Areal Parameters of Kuttiyadi River Basin

Parameters	**SW-I**	**SW-II**	**SW-III**	**SW-IV**	**SW-V**	**SW-VI**	**Kuttiyadi Basin**
Area (A) km^2	93	29	54	147	84	268	676
Perimeter (P) km	46	28	39	62	45	84	136
Basin length (Lb)	18.37	9.47	14.16	23.83	17.34	33.52	56.69
Drainage Density (D)	2.79	3.23	3.08	3.14	1.65	0.66	2.43
StreamFrequency (Fs)	4.18	6.58	6.44	5.99	2.58	0.86	4.43
Drainage Texture (T)	11.66	21.25	19.83	18.8	4.26	0.57	12.73
Form Factor (Ff)	0.28	0.32	0.27	0.26	0.28	0.24	0.28
Circularity Ratio (Rc)	0.55	0.46	0.44	0.48	0.52	0.47	0.48
Elongation Ratio (Re)	0.59	0.64	0.58	057	0.62	0.55	0.59
Basin Shape (Bs)	3.62	3.09	3.71	3.86	3.57	4.19	3.67
Length of Overland Flow (Lo)	0.18	0.15	0.16	0.159	0.303	0.75	0.20
Constant of Channel Maintenance(C)	0.36	0.31	0.32	0.31	0.6	1.51	0.57

Table 4: Ranks and Priorities of sub-watersheds in Kuttiyadi River Basin

Sub - watersheds	**SW-I**	**SW-II**	**SW-III**	**SW-IV**	**SW-V**	**SW-VI**
Form factor (Ff)	0.28 [2]	0.32 [1]	0.27 [3]	0.26 [4]	0.28 [2]	0.24 [5]
Elongation Ratio (Re)	0.59 [3]	0.64 [1]	0.58 [4]	0.57 [5]	0.62 [2]	0.55 [6]
Circularity Ratio (Rc)	0.55 [1]	0.46 [5]	0.44 [6]	0.48 [3]	0.52 [2]	0.47 [4]
Shape factor (Bs)	3.62 [3]	3.09 [1]	3.71 [4]	3.86 [5]	3.57 [2]	4.19 [6]
Constant of Channel Maintenance (C)	0.36 [3]	0.31 [1]	0.32 [2]	0.31 [1]	0.6 [4]	1.51 [5]
Bifurcation Ratio(Rb)	4.14 [3]	3.55 [1]	3.84 [2]	4.88 [4]	3.55 [1]	7.57 [5]
Drainage Density (D)	2.79 [4]	3.24 [1]	3.08 [3]	3.14 [2]	1.65 [5]	0.66 [6]
Drainage Texture (T)	11.66 [4]	21.25 [1]	19.83 [2]	18.8 [3]	4.26 [5]	0.57 [6]
Stream Frequency (Fs)	4.18 [4]	6.58 [1]	6.44 [2]	5.99 [3]	2.58 [5]	0.86 [6]
Length of Overland flow (Lo)	0.18 [4]	0.15 [1]	0.16 [3]	0.159 [2]	0.303 [5]	0.75 [6]
Slope	[2]	[1]	[1]	[2]	[2]	[3]
Compound Value	**3**	**1.36**	**2.9**	**3**	**3.18**	**5.27**
Priority	**Medium**	**Very high**	**High**	**Medium**	**Low**	**Very low**

Erosion Prone Spatial Analysis for Kattehole Sub-Watershed, Tarikere Taluk Chikmagalur District - A Remote Sensing and GIS Approach

Chandrashekarppa, K.N, Ahmed, S.A, Govindaraju, Shruthi Monohar and Devarajaiah

Dept. Applied Geology, Kuvempu University, Shankaraghatta, Shimoga
E-mail: kn_chandrashekar@rediffmail.com

Abstract

According to FAO (1994), there are six types of land degradation: water erosion, wind erosion, soil fertility decline, water logging, and lowering of the water Table. Soil erosion not only reduces soil depth, but also reduces the capacities of soil such as water holding and decrease plant nutrient. Furthermore it can cause offsite effects including pollution of water. Remote sensing (RS) and Geographical Information System (GIS) has proved to be an efficient tool for Land-degradation analysis. In this study, the various thematic maps like, land use/land cover, slope, relief dissection index, drainage density and frequency are prepared using IRS LISS III data of 2008 along with SOI topo-maps 48 O/14 and 48O/13. About 10% of the basin area is highly prone to erosion because the area being hilly terrain, and the drainage density, frequency, relative relief, dissection index and slope are very high. About 32.17% of the total area has moderate erosion prone and rest of the area are less prone to the erosion as this is a plain terrain and the values of drainage density, frequency, relative relief, dissection index and slope is low.

Introduction

Soil erosion is one of the sever land degradation problems in many part of the world. Kattehole **s**ub watershed is facing severe problems of soil erosion due to deforestation for long times. The mountain areas covered by dense forests has been changed to crop land on the slopes together with removal of vegetation cover that has caused negative effect on soil properties and the structure. Improper land use practices in agriculture are triggering soil erosion process in water shed. The main objective of the present study is to assess erosion proneness in the Kattehole Sub-watershed.

Study area

The Kattehole sub-watershed (fig.1) is located between lat. 13°44'5.02"N-13°43'40.14"N and long. 75°48'39.96"E-75°56'54.13"E. of Tarikere Tq. Chickmagalur Dist. of Karnataka state and covers an area of 228.7 km^2.

Physiography and Climate Geology:

Based on the Murphy system of landform classification, the landform of Kattehole sub-watershed may be symbolized as GMH (mountains in Gondwanas shield with humid land areas) and GPH (Plain area in Gondwana shield region with humid areas). The basin is surrounded by hillocks in the northern and southern part whereas central part of the basin is characterized by flat to undulatory topography. The sub-watershed enjoys a tropical wet dry climate. The climate is semiarid and enjoys all the three seasons viz, pre monsoon (Feb–may), monsoon (June-Sept) and post monsoon (Oct-Jan). The monthly mean temp ranges from 89-38 ^{0}c. The relative humidity varies between 50-84% and highest during the month of August and September, and lowest during the month of February and January. The precipitation and distribution of rainfall is highly erratic. The annual average rainfall is 670mm, in about 55 rainy days.

Material and methods

Watershed boundaries and drainage map were delineated using IRS LISSIII satellite data in conjunction with (SOI) toposheets No. 48O/13 and 48 O/14 in the scale of 1:50,000. The spatial (thematic) maps of drainage density, drainage frequency, relative relief and slope have been prepared in the Arc Map environment. Further IRS LISS III data has been used to prepare land use and land cover, and DEM.

The basin has been demarcated on Topo-maps of 1:50,000 and divided in to grids of 4 km^2, each for drainage frequency (streams number/area, Horton 1945), drainage density (total length of streams/ area, Horton 1945), relative relief (difference between maximum and minimum height (Glock, 1933), dissection index (relative relief/ maximum height (Nir Dove, 1957) and for calculation and construction of isopleths map. The topomaps has been used to draw contour map, and for the preparation of slope map using Wentworth's formula. Isopleths of maps were prepared to understand regional variation of the morphometric variable.

Results and Discussions

The drainage frequency (fig.6) of the basin has been classified in to low (0-4), medium (4-8) and high (8-11) categories. The major part of the basin dominates with low drainage frequency (156.31km^2), followed by medium frequency (63.94 km^2), high frequency (8.45 km^2). The low frequency increases from central part to peripheral part of the basin (Table 1).

Table 1: Drainage Frequency

Stream No. Range	Area in km^2	Category
0-4	156.31	Low
4-8	63.94	Medium
8-11	8.45	High

The Drainage density (fig.5) varies from 0 to 9, The major part of the basin covered by low drainage density 143.28 km^2, 81.29 km^2 followed by and high density 4.21 km^2 of the basin (Table 2).

Table 2 Drainage Density

Stream length range in km	Areakm^2	Category
0-3	143.28	Low
3-6	81.29	Medium
6-9	4.21	High

Relief properties are useful in analyzing the landforms. Topomaps have been used to construct spatial maps of relative relief, dissection index and average slope. The basin (fig.11) elevation increases from central (260m) to peripheral (1040m) part of the basin. The relative relief is the difference in height in an unit area with respect to its base level. This parameter helps to ascertain the amplitude of available relief (Glock, 1932).

Table 3: Relative Relief Ratio

Range (meter)	Area (Sq.km)	Category
0-40	201.92	Low
40-80	24.41	Moderate
80-120	2.37	High

The areas of low relative relief (Fig.7) are in the central (low land) part (201.92 km^2) of the basin (table 3). The undulatory terrain (middle) is characterized by moderate relative relief (24.41 km^2) and the peripheral part of the basin (hilly) exhibits maximum relative relief (2.37 km^2). The ratio between the absolute relief and relative relief provides a good index called dissection index, which represents the vertical balance of erosion in the area. The low dissection value (table 4) occupies an area of 144.43 km^2. The moderately dissected and less dissected area (16.19 km^2) occupies 67.98 km^2 and 16.19 km^2 respectively.

Table 4: Dissection Index

D.I Range	Area (Sq.km)	Category
0.00-0.10	144.53	Low
0.10-0.15	67.98	Moderate
0.15-0.20	16.19	High

The slope, defined as loss or gain in altitude per unit horizontal distance in a direction, may be calculated by various methods. The slope (average slope) map is prepared for the basin by using Wentworth's formula. By using the slop values, isopleths are drawn with an interval of 5^o (Fig. 9). The central part of the basin is characterized by low slope values (table 5) and covers an area of about 166.39 km. The undulatory part of the basin is characterized by moderate slope and occupies an area of 59.68 km^2 whereas the reaming hilly terrain is covered by high slope.

Table 5: Slope

Range (Degree)	Area km^2	Category
0-8	166.39	Low
8-16	59.68	Moderate
16-22	2.63	High

Though erosion is a natural process in sculpturing the landmass, the human interference has resulted in the deterioration of soil surface. The enhanced rate of erosion is one of the most serious environmental problems. Flooding of rivers, silting of estuaries and landslides are some of the environmental problems associated with the erosion. Though the field evidences provide information to understand erosion dynamics and to suggest remedial measures, lack of infrastructure like gauging stations at appropriate places to major channels and tributaries, and base maps like vegetative index map are not available for the study area to understand the erosion dynamics. However, it is possible to identity erosion prone areas based on geomorphological aspects of a basin.

An attempt is made here to evaluate the erosion proneness (EP) of the Kattehole basin by using density distribution of source and junction points of all streams (number/unit area) and average slope map (Chattopadhyay et al., 1985) of the basin. The total number of source points and junction points was recorded for each grid (5 km^2) and the erosion proneness for each grid was determined by using slope grades and density of source and junction points (table 6).

Table 6: Scheme of Erosion proneness Index (after Chattopadhyay et al., 1985)

Grades of Slopes	Density of source and Junction points (Numbers/km^2)			
	<6	6-11	12-17	>17
>25	H	VH	VH	VH
20-25	H	H	VH	VH
15-20	M	M	M	M
10-15	L	L	L	L
05-10	VL	VL	L	L
<5.0	VL	VL	VL	VL

VH – Very high erosion proneness; **H – High erosion proneness**
M – Medium erosion proneness; **L – Low erosion proneness**
VL – Very low erosion proneness

The erosion prone analysis map (fig 10) shows that major part (56.9%) of the basin (table 7) is less susceptible for erosion , 10.9% of the basin is prone for erosion and the reaming 32.1% of the is less to medium for erosion.

Table 7: Erosion proneness Index map

EPI	Area in.km^2	Area in %
Low	130.16	56.91
Medium	73.58	32.17
High	24.96	10.91
Total	228.7	100

Conclusions

Erosion Proneness map is prepared by integrating geomorphologic and other variables using GIS technology. The study area is then again classified into three landform zones (fig 13),

Landform Zone I Plain terrain

Table 8: Landform for Zone I

Drainage Density	Drainage Frequency	Relative Relief	Dissection Index	Slope	Erosion Proneness	Area	Area in %
0-3	0-4	0-40	0.00-0.10	0-8	Low	130.16	56.91

Zone I comprises of plain land in the middle of the basin characterized by low drainage frequency (1 to 4) and drainage density (1 to 3 km per unit area). The relative relief values are in the range of 0 to 40 and this zone is having a low dissection index in the range of (0.00-0.10). The average slope varies from 0 to 8 degree. However, the slope of this tract is normally less (0-8^0). The dominant drainage pattern is dendritic (table 8). The erosion proneness of this zone is low to very low and covered by mainly agricultural land.

Landform Zone II Undulatory terrain

Table 9: Landform for Zone II

Drainage Density	Drainage Frequency	Relative Relief	Dissection Index	Slope	Erosion Proneness	Area	Area In %
3-6	4-8	40-80	0.10-0.15	8-16	Moderate	73.58	32.17

Zone II exhibit rolling topography that lies between low land and hilly (Table 9) areas and differs significantly from zone I and zone III. The terrain is moderately dissected. The relative relief varies between 40 to 80 m. The drainage frequency varies from 4 to 8. The lower half of this zone is having lesser frequency than that of the upper half. The density varies from 3 to 6 Km/unit areas. The average slope varies from 0 to 16^0 and this zone is characterized by moderate erosion proneness with shifting cultivation.

Landform Zone III Hilly terrain

Table 10: Landform for Zone III

Drainage Density	Drainage Frequency	Relative Relief	Dissection Index	Slope Degree	Erosion Proneness	Area Km^2	Area In %
6-9	8-11	80-120	0.15-0.20	16-22	High	24.96	10.95

Zone III is characterized by very high values (table 10) of drainage density, and frequency (6-9 and 8-11), relative relief ranging from 80 to 120, high value of dissection index (0.15-0.20) and slope values from 16 to 22.In the hilly terrain the erosion proneness is high to very high which comprises shrubs and herbs.

Acknowledgement

Authors are thankful to co-coordinator SAP for providing financial assistance.

References

Chattopadhyay, S., Chattopadhyay M and Shankutala C (1985). Identification of erosion prone areas and their relation with landslides, Proc. Workshop on Landslides in Western Ghats, Kerala State Committee on Science, Technology and Environment, Trivandrum, pp.4.4-4.10

Fourier.F. (1972) Aspects of Soil conservation in the different climatic and pedologic Regions of Europe, Council of Europe. pp. 1-194

Glock.W,S. (1932) Available relief as a factor of control in the profile of a landform. Jour.Geol., V.40. pp. 74-83

Horton.R.E (1945) Erosional development of Streams and their Drainage Basins. Bull. Geol. Soc. Amer. V. 56. No. 1, pp.275-370.

Nir Dov, (1957) The ratio of relative relief and absolute altitudes of Mt.Carmel. Geographical Review V. 47. pp. 565.

Smith, G.H., (1935), Relative Relief of Chio. Geograohical Review, V.25, pp.272

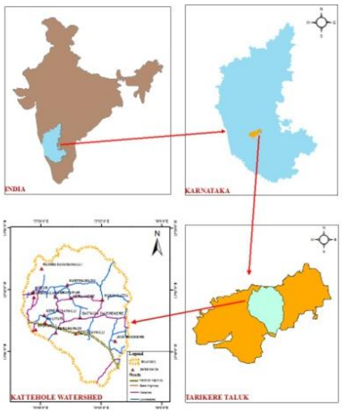


Fig: 1

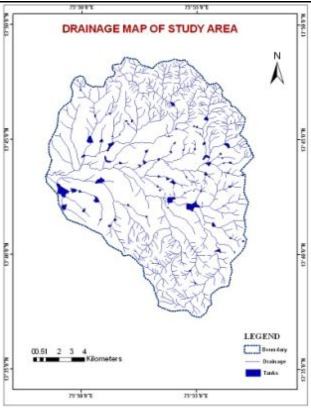


Fig: 2

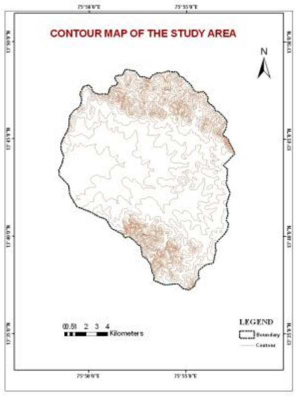


Fig: 3

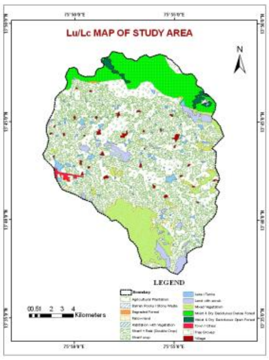


Fig: 4

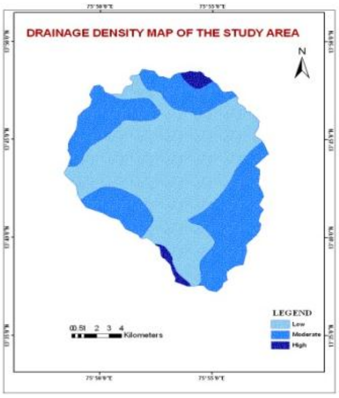


Fig.5

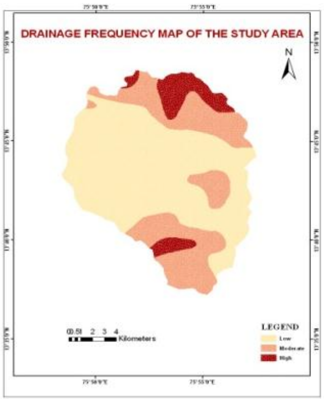


Fig.6

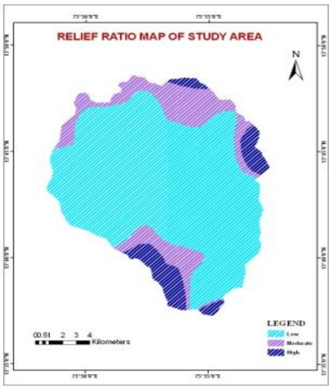


Fig: 7

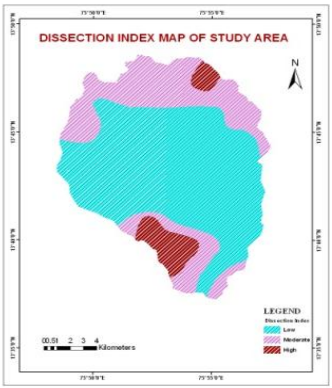


Fig: 8

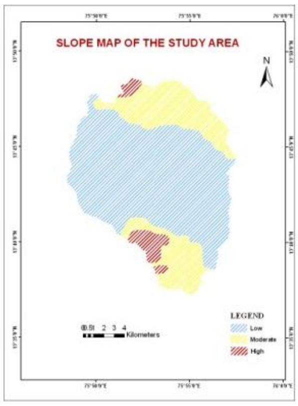


Fig: 9

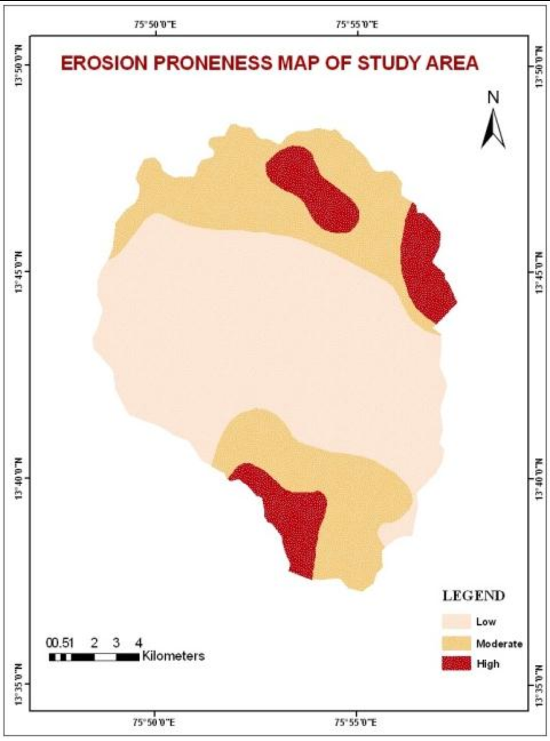


Fig: 10

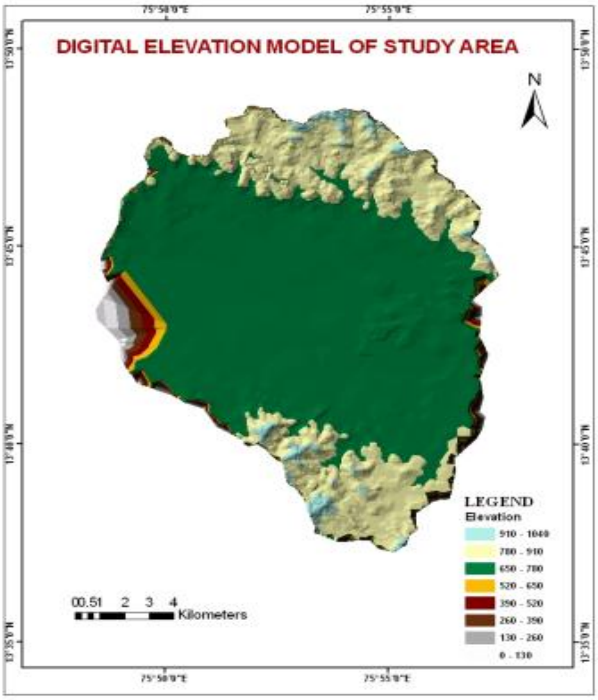


Fig: 11

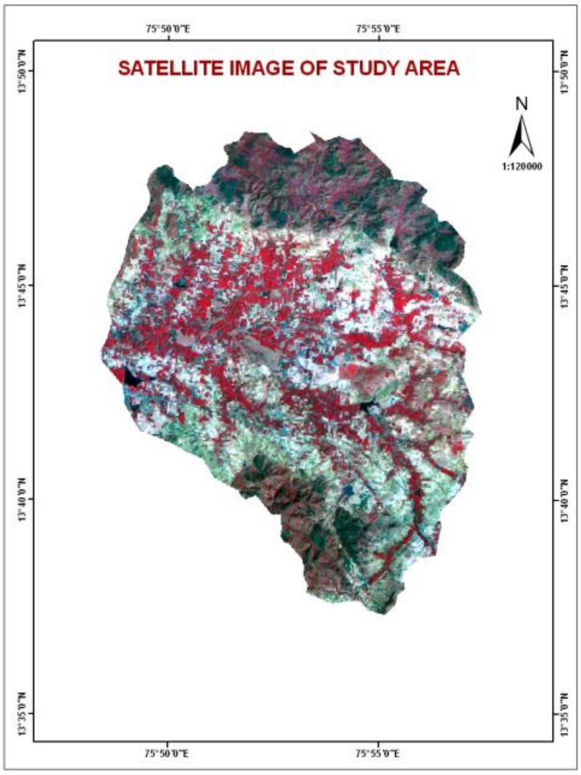


Fig: 12

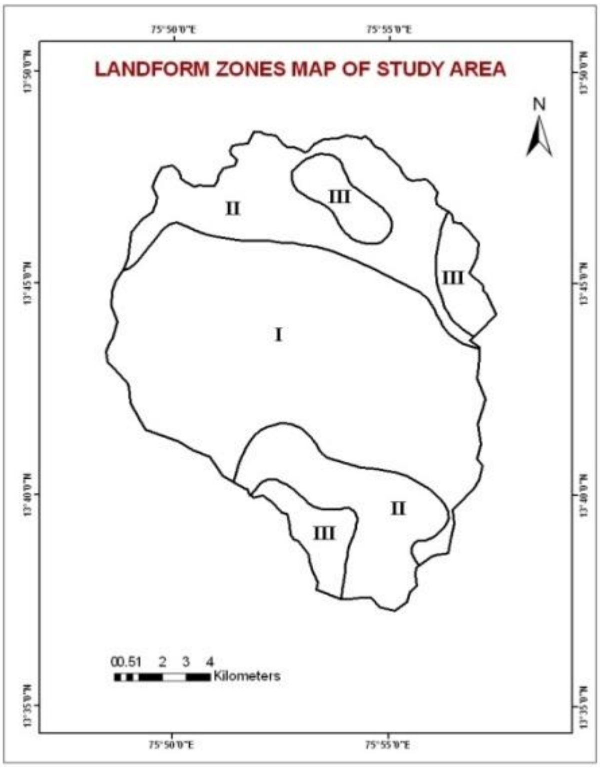


Fig: 13

Estimating Water Balance and Crop Water Productivity of Osman Sagar Catchment Area of Musi River Basin using Remote Sensing and Secondary Datasets

Sharvari Shridharan

TERI University, New Delhi
E-mail: sharvarishridharan@gmail.com

Abstract

Water scarcity is the major crop production constraint in the arid and semi-arid tropics. Limited water availability critically hampers agriculture by affecting food production, limiting progress and development and resulting in expansion of rural poverty. The challenge is to enhance food production with available water resources. It has been well proved that watershed management is one of the most suitable techniques for increasing crop yield and water productivity in agriculture. Watershed development, by implementing various soil and water conservation practices makes more water available within the boundary of the landscape. This study analyzes impact of soil and water conservation measures on evapotranspiration. Further, crop water productivity is also analyzed. Time series remote sensing data of 1 km x 1 km resolution was downloaded from MODIS site at 8 days interval between year 2007 and 2008. The number of water harvesting structures built during project development and their storage details were collected from village level census data of Andhra Pradesh, India. Area cultivated under different crops, total crop production and yield were collected from Bureau of Economics and Statistics, Andhra Pradesh for each mandal (a political unit comprising several villages) of Osman Sagar Catchment area for year 2007. Positive relation is found among degree of soil and water conservation measures and actual ET. ET in fully developed watersheds was found higher by 25-50 mm compared to no intervention areas on annual time interval. This additional amount of ET is expected to increase crop yield in rainfed areas which is important for small and marginal farmers. On the other hand, such increase in ET at upstream may reduce inflow at Osman Sagar by 20-40 per cent compared to no interventions stage. However, it is beyond the scope of this study to analyze other trade-offs such as soil loss and various ecosystem services, but it is important to understand the system as a whole and is recommended for future studies. Water productivity of sorghum and cotton crops is found to be 0.43 Kg m^{-3} and 0.10 Kg m^{-3} respectively, in rainfed areas.

Introduction

Water scarcity is a serious problem especially in arid and semi arid regions. The semi-arid tropics (SAT) include mainly sub-Saharan Africa and Asia covering an estimated area of 20 million km^2. The SAT environment is characterized by high atmospheric water demand, a high mean annual temperature (>18°C), and a low, variable annual rainfall (400 to 1100 mm) (Vandenbeldt, 1992). Low and erratic rainfall is the main cause for water scarcity in SAT.

In India, the SAT covers an area of 1.2 million square km, including about 37.2 % of the country's total geographic area. It is home to 37% of India's population, a population containing high poverty and low literacy (Rao, et al, 2005). As the population grows, the number of persons below the poverty line is also increasing. The growing population of the country puts immense pressure on agriculture. As a consequence, overexploitation of water resources with excess drawing of ground water has been leading to swift drying up of water sources. It is important to quantify water resources for better management and proper planning. Water resources are defined in two forms, viz. Green Water and Blue Water resources (Rockstrom, 2011). That water which is available in liquid form and can directly be used for human consumption (such as drinking) is Blue Water. Water in groundwater aquifers, river and reservoirs constitute Blue Water. Water which is available in vadoze zone in the form of soil moisture is known as Green Water. Rainfall that falls on the earth is partitioned into evapotranspiration and soil moisture change, both contributing to green water. A part of the rainfall converts into runoff and reaches the ground water aquifer (blue water).

Evapotranspiration (ET) is the combined effect of evaporation and transpiration. Evaporation is the non productive loss of water from soil, water bodies, pavements and wet vegetation. Transpiration is the productive use of water from plants; it is a very important process by which it allows plants to cool down in warm temperatures and provides for intake of carbon dioxide necessary for photosynthesis and production of biomass and yield. The water balance equation is expressed as: Rainfall = Evapotranspiration (Green Water) + Runoff (Blue Water) + Groundwater recharge (Blue Water) + Soil moisture change (Green Water).

Specific objectives of present study are Defining water balance component of Osman Sagar Catchment area, Developing relationship among measured ET and various level soil and water conservations at Catchment scale and Estimating water productivity of major crops in OS Catchment area

Study area

The Osman Sagar Catchment (Fig.1) lying at the western most part of the Musi sub-basin covers an area of 750 square km. Most of the Catchment is relatively flat with an elevation of 544 - 688 m above sea level (Garg *et al*., forthcoming). The climate of the Catchment is monsoonal with hot summers (38 - 44 ^{o}C in May) and cool winters (5 -12 ^{o}C in December), and an average annual rainfall of 750 mm; of that, 80-85 % falls between June to October (Garg *et al*., forthcoming). The geology of the Catchment is mainly dominated by hard rocks of Archaen granite and gneiss. Cultivable land constitutes nearly 60% of the area in the Catchment, nearly 20% is classified as wasteland and around 20% is urban, while forests cover only 4% of the land.

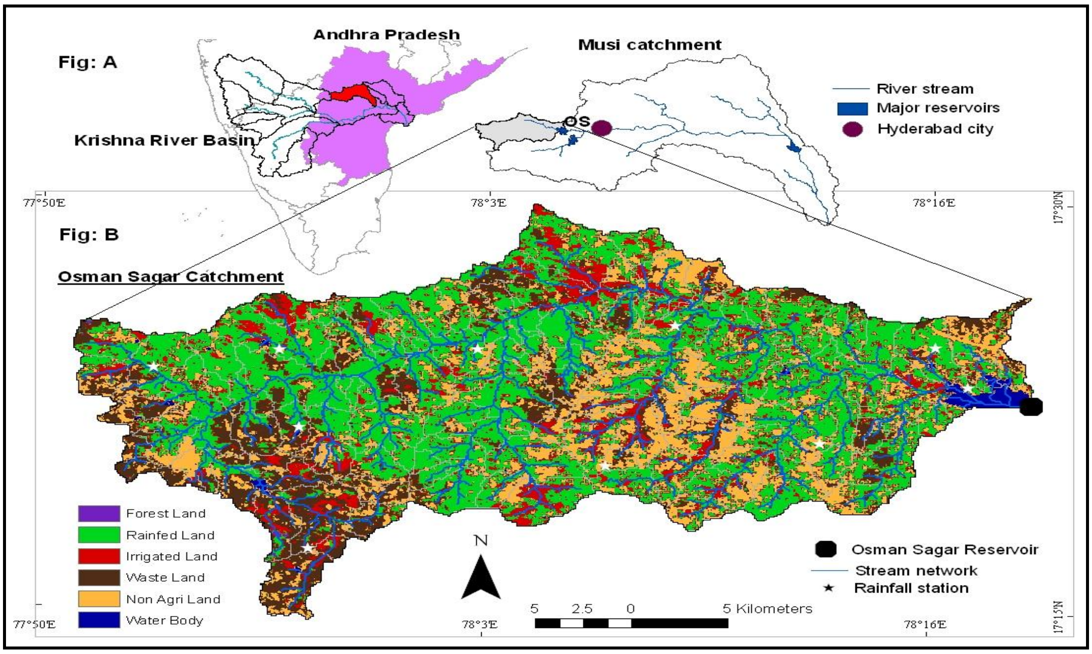


Figure : a) Location of Osman Sagar Catchment area in Musi sub-basin of the Krishna River; b) land use pattern of the Osman Sagar Catchment (Source: Garg *et al*., forthcoming)

Data and Methodology

Public domain remote sensing ET files were downloaded on 8 day time interval for entire Musi sub-basin for year 2007 and 2008. This data was already been processed by University of Montana's Numerical Terradynamic Simulation Group and pixel wise ET was made readily available (http://www.ntsg.umt.edu/project/mod16. Access date: 15th may, 2011). The spatial resolution was 1 km x 1 km. Village wise ET was extracted using GIS tools and was estimated for Kharif (June-Oct), Rabi (Nov-Feb) and for yearly time period.

Mandal level data of different cropping patterns, crop cultivation area, production and yield, and details of various water harvesting structures built during various scheme of national program (e.g., DPAP, Hariyali etc.) in Osman Sagar Catchment villages were collected from Directorate of Economics and Statistics, Government of Andhra Pradesh, India. These data were used for analyzing water productivity. Moreover, inflow at Osman Sagar on monthly time interval is obtained from Garg *et al*.,(2011). forthcoming, in the present study for year 2007. Analysis is made for various kinds of water interventions in different villages (m^3/ha) and ET flow (Kharif, Rabi and annual time frame) to understand response of watershed interventions on the major hydrological component, ET.

Crop Water productivity (WP) is the amount of grain yield obtained per unit of water used (Tuong and Bouman, 2003). In this study, technical WP was calculated using remote sensing based evapotranspiration and yield values of selected crops over the entire basin area. The water which is used by the crop can only be determined by transpiration. Mandal wise crop WP for Sorghum and Cotton crops are estimated in present analysis. Crop WP is calculated as per given below:

$$WP_{ET}\,(Kgm^{-3}) = \frac{CropGrainYield\ /\ BiomassYield}{Evapotranspiration}$$

Results and Discussion

Agricultural water interventions and ET

Present analysis shows that there is direct relation between degree of water interventions and ET magnitude. **Figure 2A** and **Figure 2B** shows that ET increases with increasing degree of water interventions on village and Catchment scale, respectively.

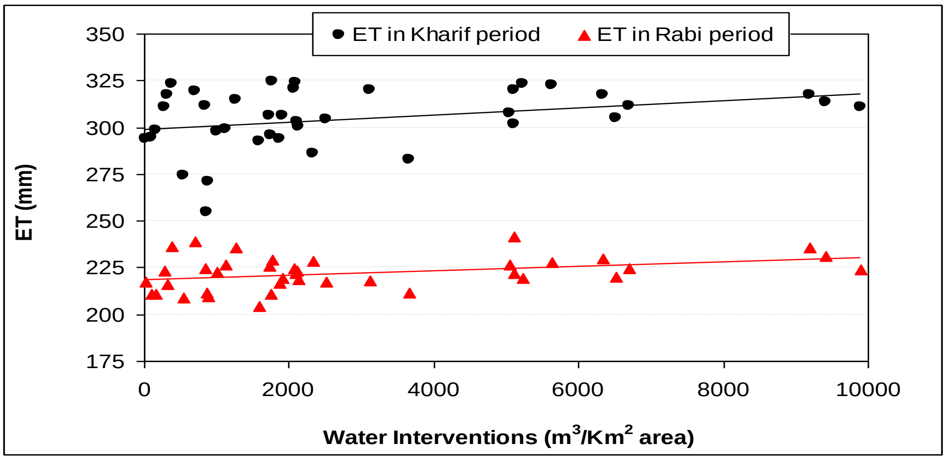


Figure 2A: Impact of watershed interventions on seasonal ET during Kharif and Rabi; data are shown at village level in Osman Sagar Catchment area during year 2007-08.

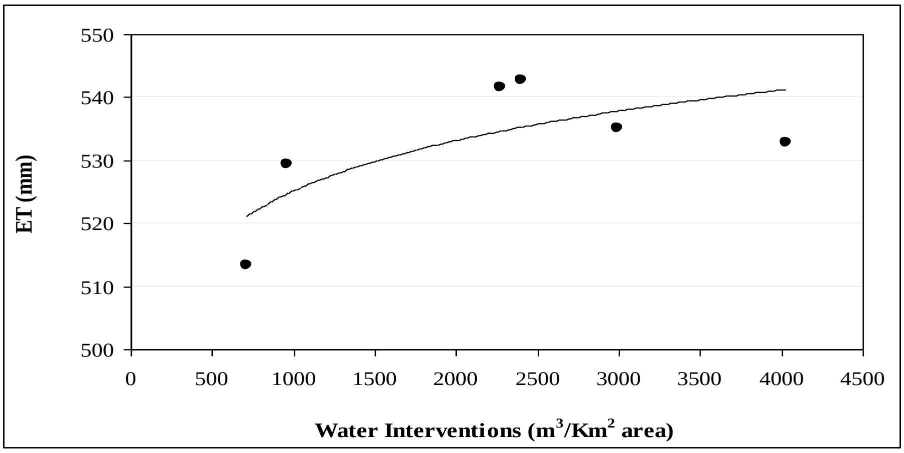


Figure 2B: Impact of watershed interventions on annual ET; data are shown at mandal level in Osman Sagar Catchment area during year 2007-08.

Water balance of Osman Sagar Catchment

In the water balance equation given earlier, the components of rainfall and runoff are available from meteorology department and reservoir statistics. ET is estimated using remote sensing data (Table 1).

Table: Annual water balance of Osman Sagar Catchment area in year 2006-07 and 2007-08

Water balance	Year 2006-07	Year 2007-08
Rainfall (mm)	741	820
ET (mm)	578 (78%)	527 (64%)
Inflow at OS (mm)	43 (6%)	84 (10%)
GW recharge + Change in soil moisture storages (mm)	120 (16%)	209 (26%)

Crop Yield and Water Productivity

Kharif and Rabi yield for selected crops were analyzed. Crop water productivity for the sorghum in Kharif and cotton in Rabi was estimated and mapped for Osman Sagar catchment area (**Figure 3A** and **Figure 3B**). Average water productivity in OS catchment area for sorghum and cotton is found to be 0.45 Kg m^{-3} and 0.10 Kg m^{-3} in year 2007-08, respectively.

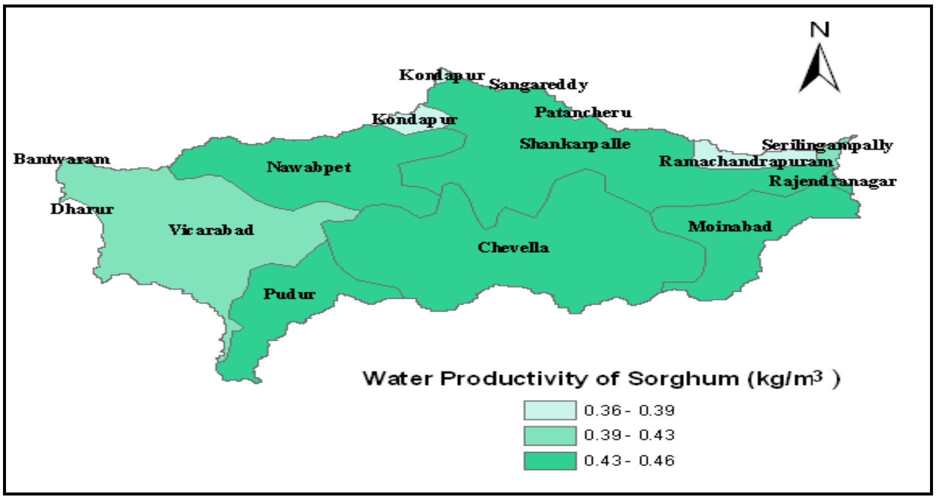


Figure 3A: Water Productivity of Sorghum crop in Osman Sagar Catchment area during Jun 07 to Oct 07

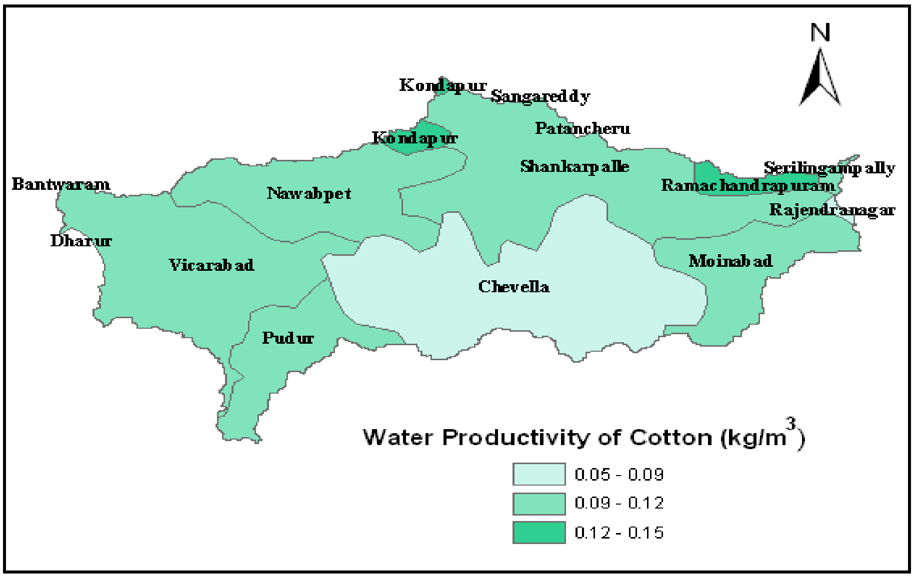


Figure 3B: Water Productivity of Cotton crop in Osman Sagar Catchment area during Jun 07 to Dec 07

Conclusions

The key findings of the study are the Osman Sagar Catchment receives 80% rainfall during the months of June to October. Average annual rainfall in Osman Sagar Catchment is 780 mm. About 64-78% of it is lost as ET, 5-10% flows as surface runoff and rest is stored in form of soil moisture and groundwater reserves. Agricultural water interventions like check dams and other storages structures increase ET. Increasing trend of ET is found with higher degree of water interventions among different villages of Osman Sagar Catchment area. Increasing ET with water interventions indicates enhanced crop yield which is important for small and marginal farmers. Shifting rainfall amount more in terms of ET also may decrease downstream water availability by 20-40% depending on rainfall received. Moreover, other trade-offs such as soil loss and ecosystem services are also important to analyze (not looked into present study) for sustainable point of view from micro to meso scale. Yield and water productivity of Sorghum is found to be 1.36 ton/ha and 0.43 kg m^{-3}. Yield and water productivity of the Cotton is found to be 0.43 ton/ha and 0.10 kg m^{-3}. Yield and WP estimated in Osman Sagar catchment are relatively found poor compare to its potential. Water alone cannot enhance the crop production to its potential level, integrated water resources management (IWRM) approach (*e.g.*, supplemental irrigation; selection of suitable crop variety, nutrient and pest management etc.) is required to be adopted for enhancing crop yield and WP in Osman Sagar catchment area.

References

Garg KK, Karlberg L, Wani SP, Barron J and Rockström J, (2011). Assessing impact of agricultural water interventions at the Kothapally watershed, Southern India, *Hydrological Processes*, DOI: 10.1002/hyp.8138.

Government of Andhra Pradesh, 2007-2008. Handbook of Statistics Ranga Reddy District 2007-2008. Published by Chief Planning officer Ranga Reddy District, Hyderabad, India.

Rao KPC, Bantilan MCS, Singh K, Subrahmanyam S, Deshingkar P, Rao P Parthasarathy and Shiferaw B., 2005. Overcoming Poverty in Rural India: Focus on Rainfed Semi-Arid Tropics. Patancheru 502 324 Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 96 pp. ISBN 92-9066-474-6. Order code BOE 035.

Rockström J , Garg KK, Wani SP, Barron J, Karlberg L, and (forthcoming), 2011. Up-scaling potential impacts on water flows from agricultural water interventions: opportunities and trade-offs in the Osman Sagar Catchment, Musi sub basin, India (Submitted to Water resources Management).

Tuong TP and Bouman BAM (2003) Rice production in water-scarce environments. Proceedings of the Water Productivity Workshop, 12-14 November 2001, IWMI, Sri Lanka.

Vandenbeldt, R.J., (1992), Agroforestry in the semi-arid tropics, FAO Corporate Document Repository, Unasylva - No. 168 - Arid zone forestry, An international journal of forestry and forest industries - Vol. 43 - 1992/1.

Land Slide Hazard Study using Remote Sensing and GIS in Kattary Watershed, Nilgiris, Tamil Nadu, India

S.P.Kasiviswanathan[1], U.Sathya[2] and T.Subramani[1]

[1]*Department of Geology, Anna University, Chennai, Tamil Nadu*
[2]*Centre for Environmental Studies, Anna University, Chennai, Tamil Nadu*
E-mail: geosubramani@annauniv.edu & geosubramani@yahoo.com

Abstract

Landslide is a common problem in the Nilgiri region, Tamilnadu, India causing mass movement leading to heavy land degradation, decline in the quality and quantity of water resources and disruption of communication system and road network. Denuded slopes especially with an angle higher than the angle of internal friction are more vulnerable to erosion. During the past three decades the frequency of landslides has increased in Nilgiri hills particularly due to extensive urbanization. The present study was carried out in Kattery watershed where a major landslide occurred on 9th November 2009.

Thematic maps of drainage, slope, geology, soil, land use/land cover, geomorphology and lineament prepared from the satellite imageries. were integrated using GIS and the landslide hazard zonation map was prepared by assigning proper weights and ranks. The north eastern and south western parts of the watershed are more vulnerable to landslides whereas the south eastern part is less vulnerable. Revegetation of affected areas is the final insurance against erosion but such highly degraded lands are difficult to accept the vegetation growth due to their unstable nature and poor fertility status.

Introduction

Landslide is defined as the movement of a mass of rock debris, or earth down the slopes (Cruden, 1991). The term 'Landslide' encompasses events such as ground movement, rock falls, and failures of slopes, topples, slides, spreads, and flows such as debris flows, mudflows or mudslides (Varnes, 1978 & 1984). In the hilly terrain of India including the Himalayas, landslides have been a major and widely spread natural disaster that often strike life and property and occupy a position of major concern. Landslides that are triggered by seismicity are insignificant in the Western Ghats. These cause geomorphic makeovers of the earth's surface resulting in significant damage to life and property. Remote sensing and GIS techniques are widely used in various natural resources management and disaster and mitigation studies.

Study area

The study area is Kattery Watershed, which is located in Nilgiri District, Ooty, Tamilnadu (Fig.1). The study area falls between latitudes 76º41'0''E and 76º45'0''E and longitudes 11º19'0''N and 11º24'0''N. Structurally, the Kattery watershed comprises

Archean metamorphic rocks made up of charnockite. The terrain is terraced for potato cultivation and tea plantation. The watershed has a maximum elevation of 2400m above MSL and is characterized with steep slope, lateritic soils and fairly good drainage network. The annual rainfall is about 1000 mm. The climate of Nilgiris district is temperate and salubrious throughout the year. The day temperature in the district ranges from 22.1°C in summer to 5.1°C in winter. The night temperature touches 0°C in some times. The summer begins early in March, the highest temperature being reached in April and May. Weather cools down progressively from about the middle of June and by January; the mean daily maximum temperature drops to 5.1°C.

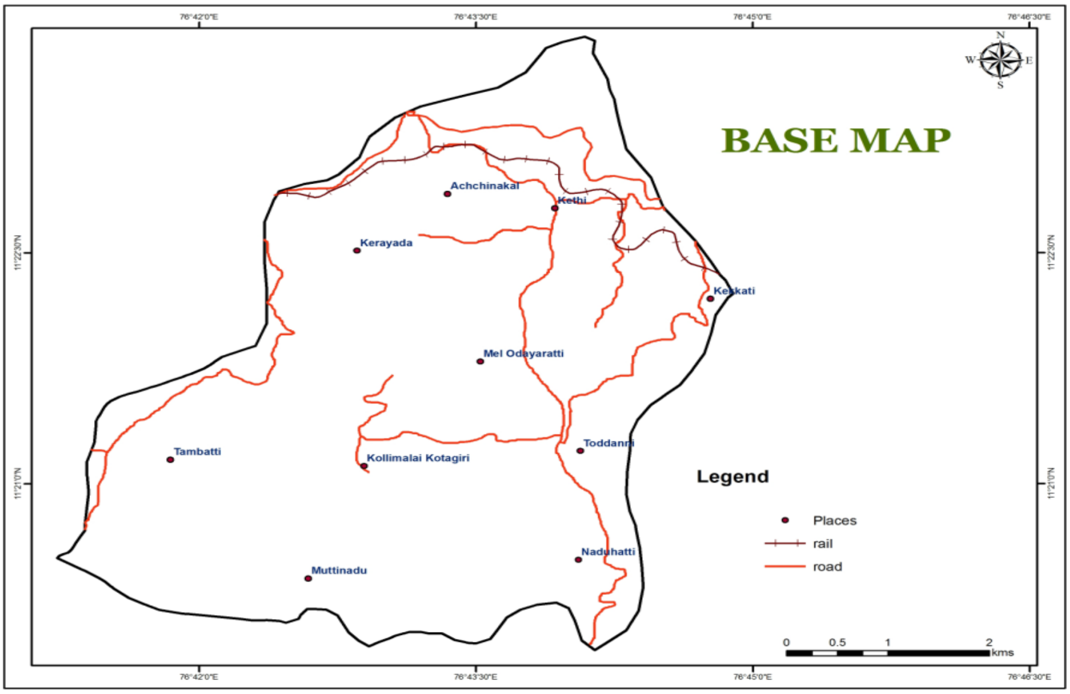


Figure. 1 Kattery Watershed

Methodology

Several thematic maps have been prepared to understand various parameters like drainage, slope, geology, geomorphology etc in order to create a detailed database of the watershed. Toposheet of the study area and various satellite images were collected for preparation of various thematic maps such as base map, geology, geomorphology, soil, drainage, drainage buffer map, drainage density, lineament, land use, landslide scar and slope map. All the thematic maps were integrated using GIS and finally the landslide hazard zonation map of the watershed has been prepared after giving proper weightage and rank.

Results and Discussion

The study area consists of clayey and loamy soils. Only a small area in the north western part consists of loamy soil and the remaining whole area is covered with clayey soil (Figure. 2)

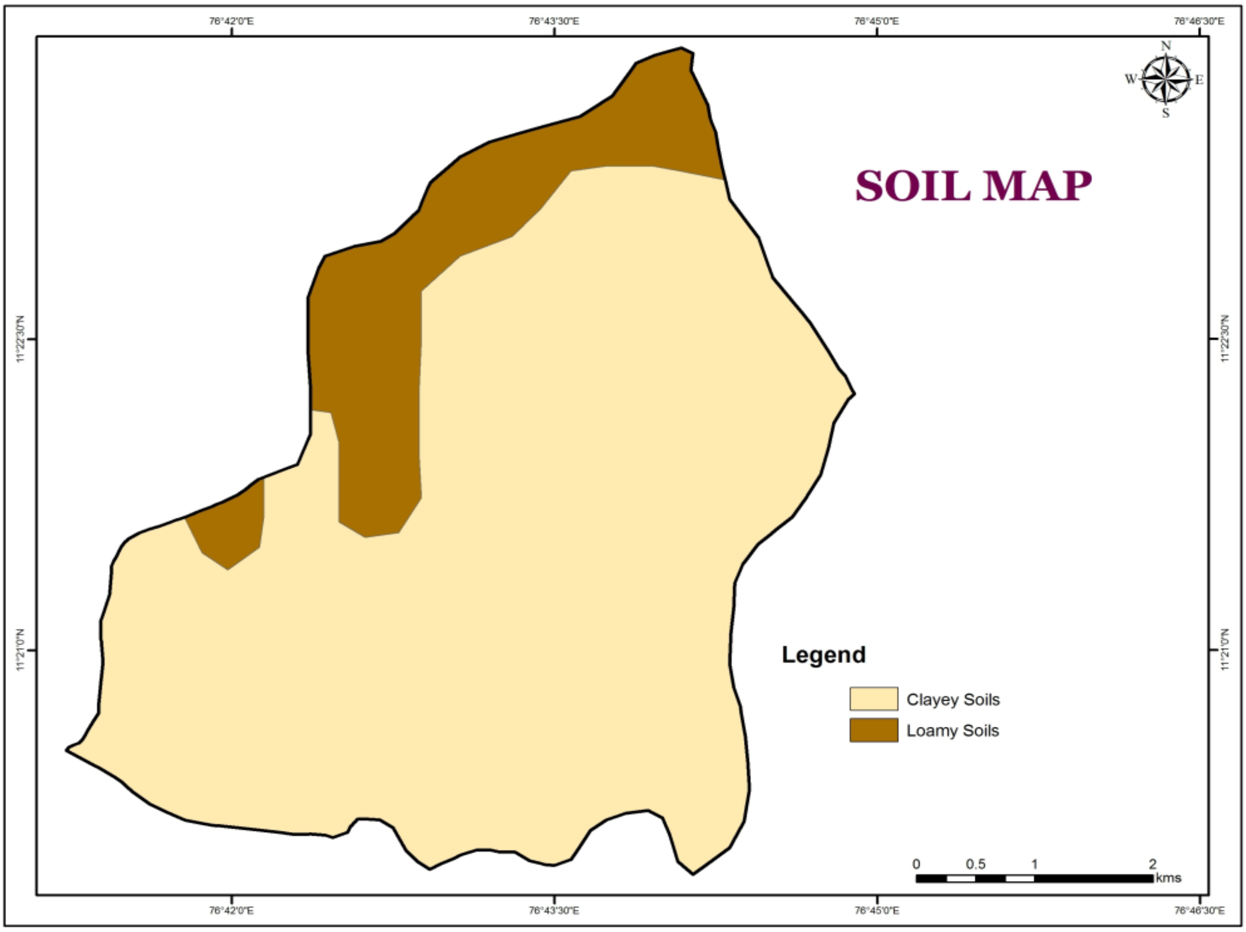


Figure. 2 Soil map

Drainage map (Fig.3) shows that the first order streams are high in the north western part of the study area. It is understood that it is an elevated area and the erosion rate is more. There are two water bodies in the southeast part of the study area. Due to high erosion rate, siltation rate is more in these water bodies. Hence, the silt monitoring station is also located in this region. Majority of landslides occur close to the stream within a distance of 100 m and some of the landslide occurs in 100 m to 150 m distance. Beyond 150 m the occurrence of landslide is rare. Hence, drainage buffer can be taken as basis for landslide hazard zonation. This is because the erosion rate will be high near the streams. The drainage density is an important factor as rain water percolates in areas with low drainage density. Moreover, the erosion action by streams also plays a role in increasing the slope instability. If the drainage density is high the water percolation will be less and erosion rate will be more. Further, high drainage density is encountered in steeper slopes. In the study area the drainage density is high in north western part and moderate to low in south eastern part which is shown in (Figure. 3).

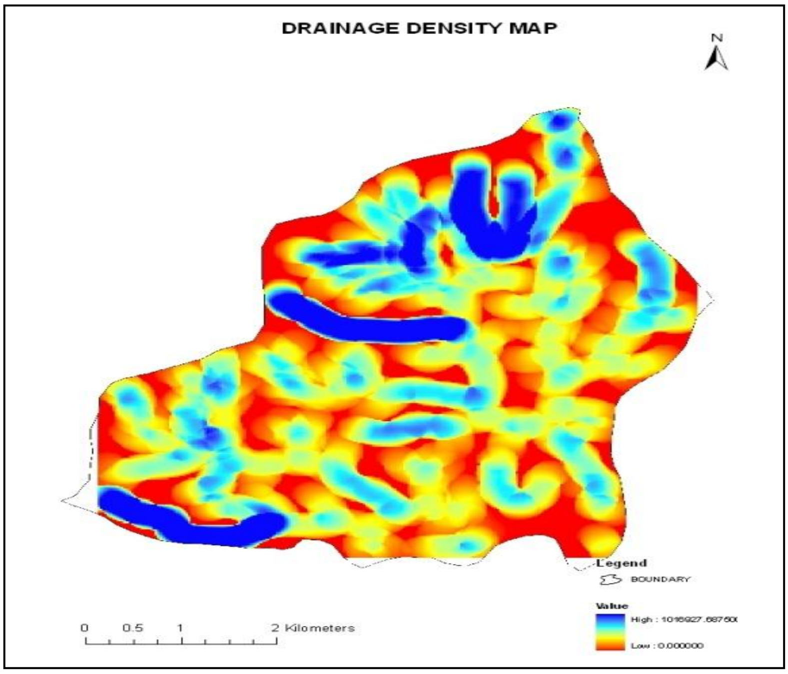


Figure 3 Drainage density map

Dissected upland covers 70 % of the study area. The north eastern part is a dissected plateau (Figure. 4) covering about 10% of the study area. About 10% of the area in the south-eastern and north-western parts consists of fractured valley fill. The remaining 10% is valley fill and barren plateau, confined to the southern part of the study area. It is clear that the geomorphology is a major controlling factor and thus the northern part is more vulnerable than the southern part for landslides.

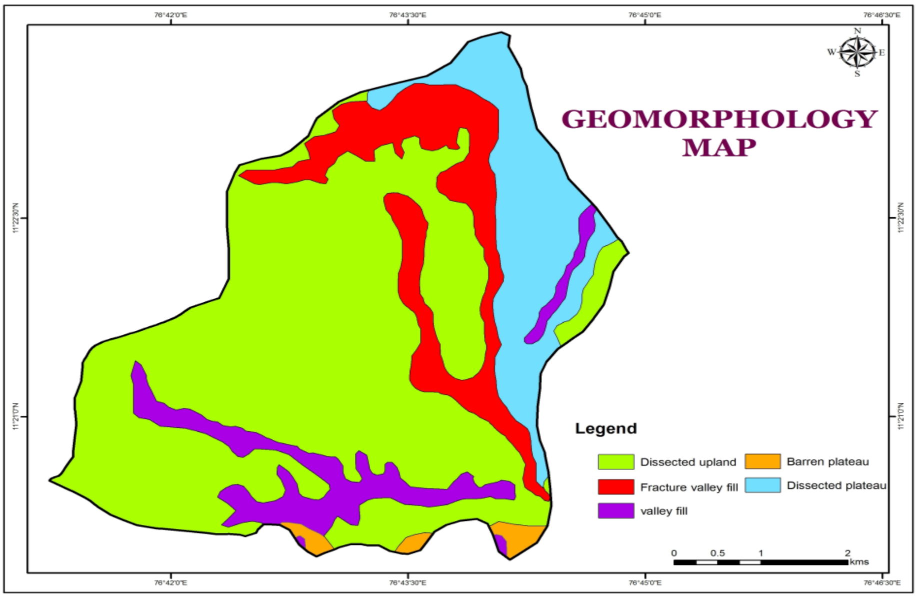


Figure. 4 Geomorphology map

The land use/land cover exerts a control over landslides and is considered next to slope in importance, as human activities and consequent deforestation has altered the stability of slopes. While urban activities result in the modification of slope due to leveling of the terrain forming steep cut, modification for agriculture enables the percolation of water particularly in areas wherein vegetables are grown. The land use factor has been classified as forest plantation, plantations, croplands, built up and water bodies. The highest ratio is noticed in vegetable crops as the field is prepared for cultivation loosening the soil for aeration. Further, periodical tilling is carried out to remove the weeds and to aerate the land. The ground is hence, devoid of vegetation growth except for the cultivated crops. This enables percolation of water during rains and the pore pressure of clay bearing soil increases. The susceptibility for landslides increases manifold where tubers like potato, turnip, carrot, and beetroot are cultivated. Settlements and tea gardens rank next in the susceptibility followed by forest plantations. Contrary to expectations, forests also record landslides. When the tea planters converted large tracts of forests into tea estates, they have left only the steep slopes as forests which have difficulty for accessibility. Thus forests exist only in the steep slopes. The study area (Figure. 5) consists mostly of plantations and crop lands. Forest lands are also there in the northern part of the area. Built up land is very less in the study area.

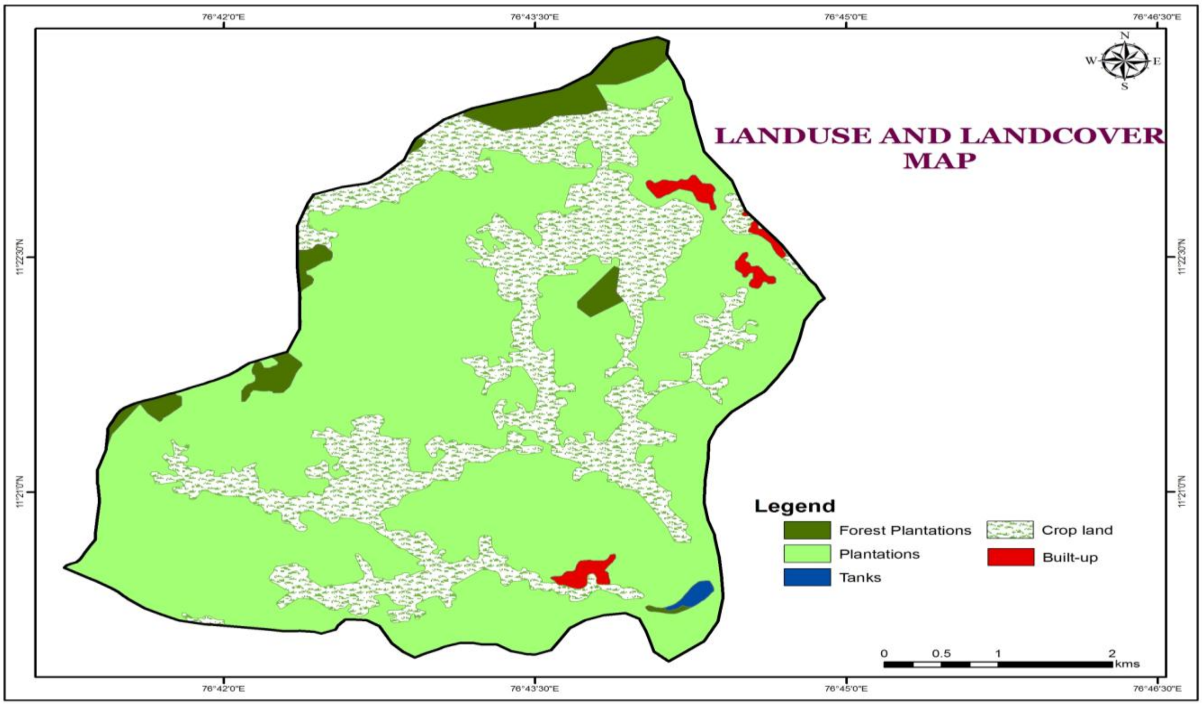


Figure 5 Land use/ land cover map

Lineament map shows that the area consists of weak planes (Figure. 6). If there are more lineament intersections the possibility of occurrence of landslides are more. In the study area the lineament density is high in the north western part.

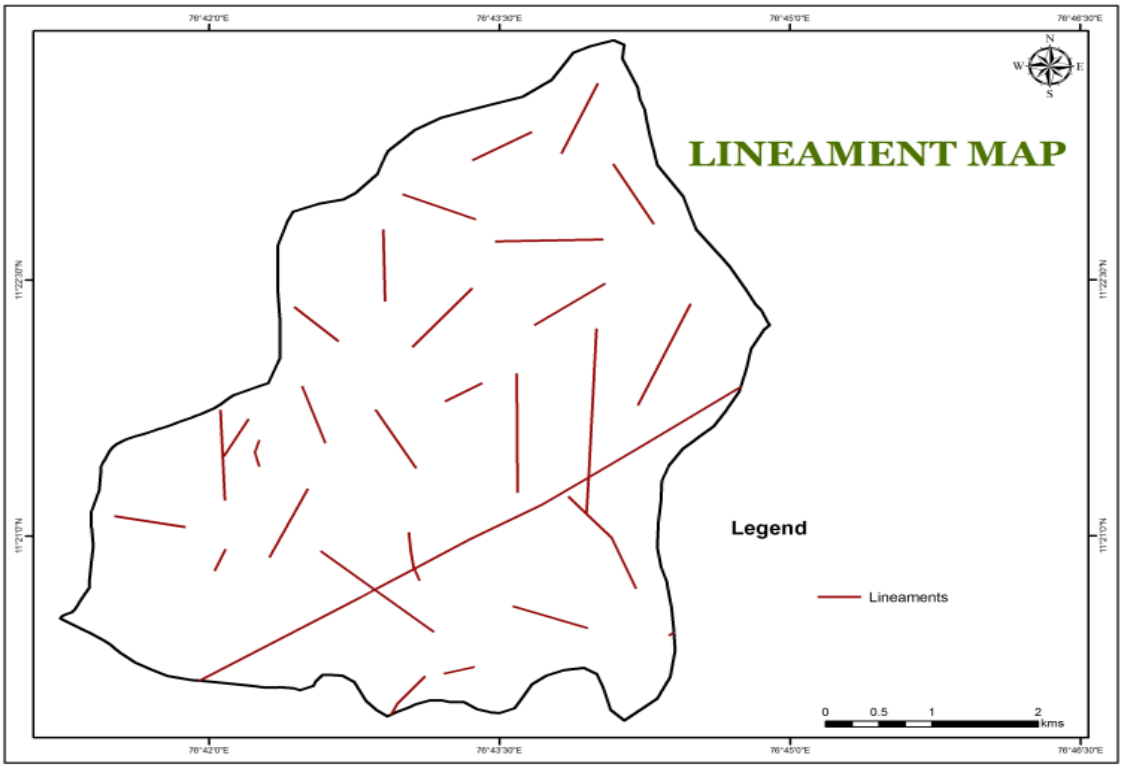


Figure 6 Lineament map

Landslide Hazard Zonation

By integrating all the above thematic maps a landslide hazard zonation map of the area (Figure. 7) is prepared using ArcGIS after giving proper weightage and ranks for all the components. Weightage and rank allotted for various themes and components are given in table. 1.

Table 1 Rank and weightage for landslide hazard zonation mapping

CRITERIA	CLASS	RANK	WEIGHT/ PERCENTAGE
Geomorphology	Dissected upland	1	20
	Dissected plateau	2	
	Fracture valley fill	3	
	Valley fill	4	
	Barren plateau	5	
Landuse	Crop land	1	
	Plantation	2	

	Built-up	3	15
	Forest Plantation	4	
	Tank	5	
Soil group	Clayey soil	1	10
	Loamy soil	2	
Slope	Very high	1	20
	Medium	2	
	Low	3	
Lineament	Present	1	20
	Not present	2	
Drainage	First order	1	15
	Second order	2	
	Third order	3	

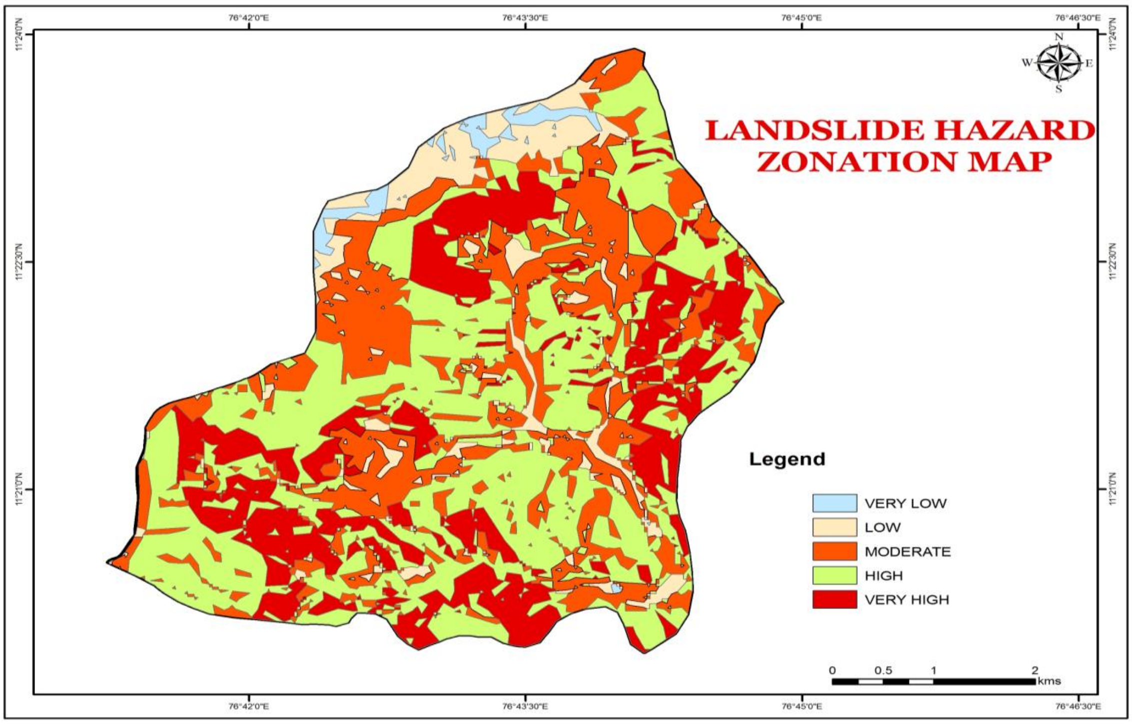


Figure 7 Landslide hazard zonation map

Conclusions

The landslide hazard zonation map shows that the north eastern and south western part of Kattery watershed is more vulnerable to landslides, whereas the south eastern part is less vulnerable. There are much possibilities of occurrence of landslide in the area where the landslide occurred during the year 2009 (near Achanekal)

References

Cruden, D.M., 1991. A Simple Definition of a Landslide. Bulletin of the International Association of Engineering Geology, No. 43, pp. 27-29

Varnes D. J.: 1978 Slope movement types and processes. In: Schuster R. L. & Krizek R. J. Ed., Landslides, analysis and control. Transportation Research Board Sp. Rep. No. 176, Nat. Acad. oi Sciences, pp. 11-33

Varnes, D. J.: 1984, Landslide Hazard Zonation: a review of principles and practice, Commission on landslides of the IAEG, UNESCO, Natural Hazards No. 3, 61 pp.

Geographical Modeling for the Conservation and Management of Rattan Resources in Western Ghats

Sreekumar, V.B., Suganthasakthivel, R. and C. Renuka

Forest Ecology & Biodiversity Conservation Division,Kerala Forest Research Institute, Peechi, Thrissur
Email: sreekumar@kfri.res.in

Abstract

Rattans are spiny climbing palms occurring in the Old World tropics and Subtropics and used as a major NTFP after timber. The Western Ghats is a unique treasure trove home to 21 species of rattans under one genus, *Calamus* distributed from the sea level to 2000 m elevation. Ecological Niche Modelling, a method which explores the potential distribution of a species was used to map the distribution potential and resource availability of rattans in Western Ghats. A total of 146 unique occurrence records were available from the field surveys covering four states in South India viz., Kerala, Tamil Nadu, Karnataka and Goa. The Maximum Entropy Modelling (Maxent) was used to predict the potential distribution of the rattan species. Of the 21 species available from the Western Ghats and West Coast region, only 15 species has unique occurrence points totalling above two which can be used in the modelling. Of the 15 species modeled 12 species have suitability areas significantly low for the Palghat gap region. The absence of suitable areas in the gap region indicates presence of a geographical barrier for the dispersal of the rattan species in the Western Ghats. The niche is concentrated especially south of the Palghat gap and the less number of dry months, high precipitation, and absence of two peaks in the rainfall marks the characteristic features of this region which favours the environmental requirements of the rattans to flourish.

Introduction

Rattans are a group of mostly trailing or climbing, spiny palms with characteristic scaly fruits. With about 600 species under 13 genera, they are mainly distributed in Palaeotropics with maximum species diversity in SE Asia. An economically important group, it provides livelihood for millions of tribal and rural people and raw material for industries in various parts of the world. In India, rattans are represented by four genera *Calamus, Daemonorops, Korthalsia,* and *Plectocomia* with 60 species occuring in three major centres, southern Peninsular India, North and North-eastern India and Andaman and Nicobar islands. The Western Ghats, the main peninsular hill range which runs parallel to the Arabian Sea, extends to a length of nearly 1600 km in southern India. The Western slope of the Ghats receives very heavy rainfall ranging from 2000-6000 mm per year, the eastern foothill slopes are almost a rain shadow area. The greatest biological wealth of the Western Ghats is due to the vast geographical area extending over many degrees of latitude, varied topography, climatic zones and the geographical position. The Western Ghats is represented with one genus *Calamus* with 21 species remarked by great diversity and forms one of the few ideal hotspots of rattans. Species of *Calamus* are distributed from the sea level to 2000 m elevation, most of them showing altitudinal preferences. The conspicuous niches of rattans are mainly forests of lower and upper hill valleys, mountain plains and deep ravines along the water sources. With the exception of *C. metzianus*, a rattan of the plains, all other species are montane. Most of the species are distributed below 1000 m and only four species – *C. brandisii, C. gamblei, C. pseudotenuis* and *C. lacciferus* are seen above this altitudinal level. In Western Ghats, some species like *C. thwaitesii*, *C. gamblei* and *C. hookerianus* and *C. metzianus* are widespread occurring from the southern part of Agasthymala to Goa. In contrast, certain species seem to be very narrow endemics: for example *C. neelagiricus* is found only in Silent valley National park and *C. wightii* is known only from Nilgiri Biosphere Reserve. Depending on the species, they show wide distribution patterns in evergreen, semi-evergreen and moist deciduous forests. More number of species is seen towards the southern part of the Western Ghats whereas from the northern part (Maharashtra and Goa) only two species have been reported so far. With the rampant destruction of forests and habitats, the wild stock of rattans in Western Ghats, at present is highly depleted. Since most of the species in Western Ghats are critically endangered with restricted distribution in few patches, information on the pattern of distribution and environmental amplitude controlling the species distribution can be effectively utilized for future conservation and management. In this context, the best way to map the distribution of rattans is by using the recently developed Ecological Niche Modelling, methods which explores the potential distribution of a particular species (Franklin, 2009). Since the available information on the distribution of rattans in the Western Ghats and West Coastal moist habitats is less and scanty, conventional methods are costly and time consuming. The Ecological Niche Models reconstructs the potential habitat of a particular species by combining the known occurrence records and GIS data that explains the environmental space in a particular region. Accurate maps were produced by this method which is very much useful and cost effective in understanding the geographical spread of rare and threatened species.

Materials and Methods

A total of 146 unique occurrence records were available from the field surveys conducted by the Kerala Forest Research Institute covering four states in South India viz., Kerala, Tamil Nadu, Karnataka and Goa. The localities recorded during the field surveys were geo-referenced in GIS to make presence localities. The background environmental data is given in the form of seven bioclimatic variables available from the Worldclim dataset version 1.4 (Hijmans *et al*. 2005) viz., annual mean temperature, mean diurnal range (Mean of monthly (max temp - min temp)), max temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest month and precipitation of driest month. In addition, three topographic variables of elevation, aspect and slope of the terrain were also included. The elevation data was extracted from the Shuttle Radar Topography Mission (SRTM) 30 Plus data (http://topex.ucsd.edu/WWW_html/srtm30_plus.html). The resolution of all raster coverages were standardized to the unit of 2.5 minutes. All the layers are masked to the natural boundaries of Western Ghats and West Coastal region of South India.

The Maximum Entropy Modelling (Maxent) was used to predict the potential distribution of the rattan species. Maxent is a presence only environmental niche modelling method that makes predictions from incomplete information (Phillips *et al.*, 2006). It is shown to produce good results when compared to other general purpose modelling algorithms (Elith *et al.*, 2006) and works extremely well with small number of occurrence records. The recent Maxent version 3.3.3e (http://www.cs.princeton.edu/~schapire/maxent/) was used to develop the models. In the program, 500 iterations were ran with a convergence threshold of 0.00001 and a maximum of 10,000 background points and algorithm parameters were set to auto features (Phillips and Dudik, 2008). Only the random test percentage in the settings was turned to 10-25% when the occurrence localities were available above 10. All other parameters were set at default settings. Maxent produces outputs in the form of cumulative rasters with real numbers ranging between 0 and 100 representing the probability of occurrence. The model quality is tested with the receiver operating characteristic (ROC) analysis which is available in the form of area under curve values (AUC). Maxent computes response curves of each variable though jackknife procedure that computes the percentage of variable importance that influences the probability of occurrence of a species in its environmental space.

Results and Discussion

Of the 21 species available from the Western Ghats and West Coast region (Figure 1), including *C. rheedeii* which was not yet rediscovered after the type collection. Of the remaining 20 species, only 15 species has unique occurrence points totalling above two which can be used in the modelling (Table. 1). The predictions of all the 15 species of rattans are significant that is revealed by the higher AUC scores (0.880-0.993). The result maps were given in a colour ramp of light red to dark red which means the less suitable areas to high potential/suitable areas. The variable contributions of all the 15 species were given in Table 2. The results are summarized as follows:

Calamus brandisii: An endemic rattan, all the available records are present in the southern Western Ghats south of Palghat gap. The maxent also predicts the more possible areas with suitability in the southern Western Ghats and south of the Malabar Coast in Kerala. The precipitation of the driest month accounts for more than 68% of the variable contribution followed by the mean diurnal range and maximum temperature of the warmest month (Figure 2).

Calamus delessertianus: An endemic rattan has been reported from only seven localities in the southern and central Western Ghats of Kerala and Karnataka. The prediction shows a broader range in the southern Western Ghats and medium level suitable habitats in Central Western Ghats. The Palghat gap is predicted negative. The precipitation of the driest month, maximum temperature of the warmest month, annual mean temperature and aspect influences the occurrence of this rattan more (Figure 3).

Calamus dransfieldii: Solitary, high climbing, endemic rattan; reported distribution restricted to only three locations in the northern part of the southern Western Ghats i.e. north of Palghat gap and the predicted distribution also follows the same trend. Again the Palghat gap is predicted negative for this species also (Figure 3).

Calamus gambliei: This is a clustering rattan, which extends its distribution from Agasthyamala to Coorg in southern Western Ghats. The Palghat gap and the Arienkavu pass are predicted negative. Major suitable areas are found in the evergreen areas of Waynad, Nilgiri hills, Nelliampathy and Anamalai hills, Periyar Plateau and the Agasthyamalai hills. The factors influencing the distribution of this species are mean annual temperature, mean diurnal range and minimum temperature of the coldest month (Figure 3).

Calamus hookerianus: Clustering rattan; actual distribution is concentrated mainly in Southern part of the Palghat gap and only a few locations were reported from the north. The predicted distribution is mostly found in the region south of Palghat gap where the mid and lowlands have high suitability areas. The precipitations of the driest and wettest month were the factors that influenced the potential distribution of this species (Figure 3).

Calamus karnatakensis: Endemic rattan; known from four localities in the states of Karnataka and Kerala. The potential distribution is found in the southern Western Ghats region excluding Palghat gap. The most influencing variables for this species are the maximum temperature of warmest month and minimum temperature of coldest month.

Calamus lacciferus: The distribution of this species is from the central Western Ghats and the predicted distribution also shows the same trend. Only restricted regions in the Nilgiri and Anamalai hills are predicted suitable for this species. The main variables contributing to its potential distribution are the precipitation of wettest month and annual mean temperature.

Calamus lakshmanae: Only three occurrence points were available for this species in the whole Western Ghats (two from Karnataka and one from Kerala). The predicted distribution shows that the maximum potential of this species is seen along the crest line of the Western Ghats in its range.

Calamus metzianus: Clustering rattan; distribution predominantly in the coastal lowlands of Karnataka and Kerala. It occurs in lowland forests, river margins, disturbed marshy areas of the Malabar Coast and is also associated with the Sacred groves of Kerala. The predicted suitability is mainly seen in the coastal lowlands and midlands of Kerala and Karnataka i.e., coastal region of Malabar and Karnataka. Its occurrence is highly influenced by mean diurnal range and annual mean temperature.

Calamus prasinus: Distribution limited to the northern most part of the Southern Western Ghats and in central Western Ghats. The predicted distribution is mainly seen in the central Western Ghats and Karnataka coastal regions and somewhere sparsely along the crest line of the northern Western Ghats. In the south only Nilgiri and Anamalai hills have some restricted areas predicted suitable for this species. Palghat gap is negatively predicted. The most influencing variables are slope, annual precipitation, annual mean temperature and the precipitation of wettest month (Figure 4).

Calamus pseudotenuis: Comparatively widely distributed in the southern Western Ghats and occurs sparsely in the central Western Ghats. The predicted potential distribution is high in the southern Western Ghats region south of Palghat gap and feebly occurring along the crestline in the rest of the Western Ghats region. The main factors influencing the potential distribution of this species are the precipitation of the driest month, slope, annual precipitation and annual mean temperature (Figure 4).

Calamus thwaitesii: Clustering, widespread species which has occurrence points throughout the Western Ghats. The predicted distribution is high in the southern Western Ghats and sparsely seen along the crest line of the central and northern Western Ghats. This is the only species which has its potential habitat fairly good in the Palghat gap. The factors influencing this trend are precipitation of the driest month, elevation, slope and aspect (Figure 4).

Calamus travancoricus: Restricted to the Southern Western Ghats south of Palghat gap. The potential prediction also shows high values in the region except for some high elevation areas in the Nilgiri hills. The Palghat gap is predicted low for this species. Precipitation of driest month is the main variable which contributes over 90 % of the total variable contributions (Figure 4).

Calamus vattayila: This species is widely distributed in Southern Western Ghats and have some more occurrence records in the southern part of the central Western Ghats. The prediction is more in the southern Western Ghats south of Palghat gap, and the lowland and midland regions of Kerala.

Calamus wightii: Rare, endemic rattan; known distribution of this species is mainly in the northern part of the southern Western Ghats, north of Palghat gap. The predicted distribution shows fairly good suitability in this region and the hill region south of Palghat gap. Annual mean temperature and elevation are the two main variables that accounts for the influence of most of the contribution.

The other five species have occurrence points below three which is not suitable to be applied to the ecological niche modeling. The rattan species *C. shendurnii*, *C. renukae, C. stoloniferus* and *C. neelagiricus* are known from only one type locality. Similarly *C. nagabettai* is known only from two localities - Kukke Subrahmanya of Karnataka and Achenkovil forests of Kerala.

Conclusions

Of the 15 species modeled 12 species have suitability areas significantly low for the Palghat gap region. The three species that have fair suitability for this gap region are *C. metzianus*, *C. thwaitesii* and *C. travancoricus*. For other species, the absence of suitable areas in the gap region indicates presence of a geographical barrier for the dispersal of the rattan species in the Western Ghats. In all the predictions the southern Western Ghats provide suitable areas for most of the species. The niche is concentrated especially south of the Palghat gap where the bioclimatic conditions in the respective regions are relatively less variable. The less number of dry months, high precipitation, and absence of two peaks in the rainfall marks the characteristic features of this region which favours the environmental requirements of the rattans to flourish. In the present outlook using GIS modelling methods, the Western Ghat region south of Palakkad gap emerges as a high priority conservation zone for rattan species. Most of the areas in this region have higher suitability and potential for the rare and threatened rattan species. Anamalai and Agathymalai hill systems are considered as the mega centres of endemism within the Western Ghats. Due to lack of enough staff in the forest department, there are limitations to prevent the illicit harvesting of economically important species. Even from National parks and Sanctuaries, good quantities of rattans continue to be harvested. Uprooting the entire plant, extraction of immature stem also pose a main threat to decline rattan population in wild. The population of narrow endemics need to identified and should be declared as local reserves.

References

Elith J., Graham, C. H., Anderson, R. P., Dudı´k, M., Ferrier, S., Guisan, A., Hijmans, R. J., Huettmann, F., Leathwick, J. R., Lehmann, A., Li, J., Lohmann, L. G., Loiselle, B. A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J. McC., Peterson, A. T., Phillips, S. J., Richardson, K. S., Scachetti-Pereira, R., Schapire, R. E., Sobero´n, J., Williams, S., Wisz, M. S. and Zimmermann, N. E. (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29: 129-151.

Franklin, J. (2009). Mapping species distributions. Cambridge University Press, Cambridge.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A., (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology. 25: 1965-1978.

Phillips, S.J. and Dudik, M. (2008). Modelling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography, 31: 161-175.

Phillips, S.J., Anderson, R.P. and Schapire, R.E. (2006). Maximum entropy modelling of species geographic distributions. Ecological Modelling, 190: 231-259.

Figure 1 Distribution of Rattans in Western Ghats region

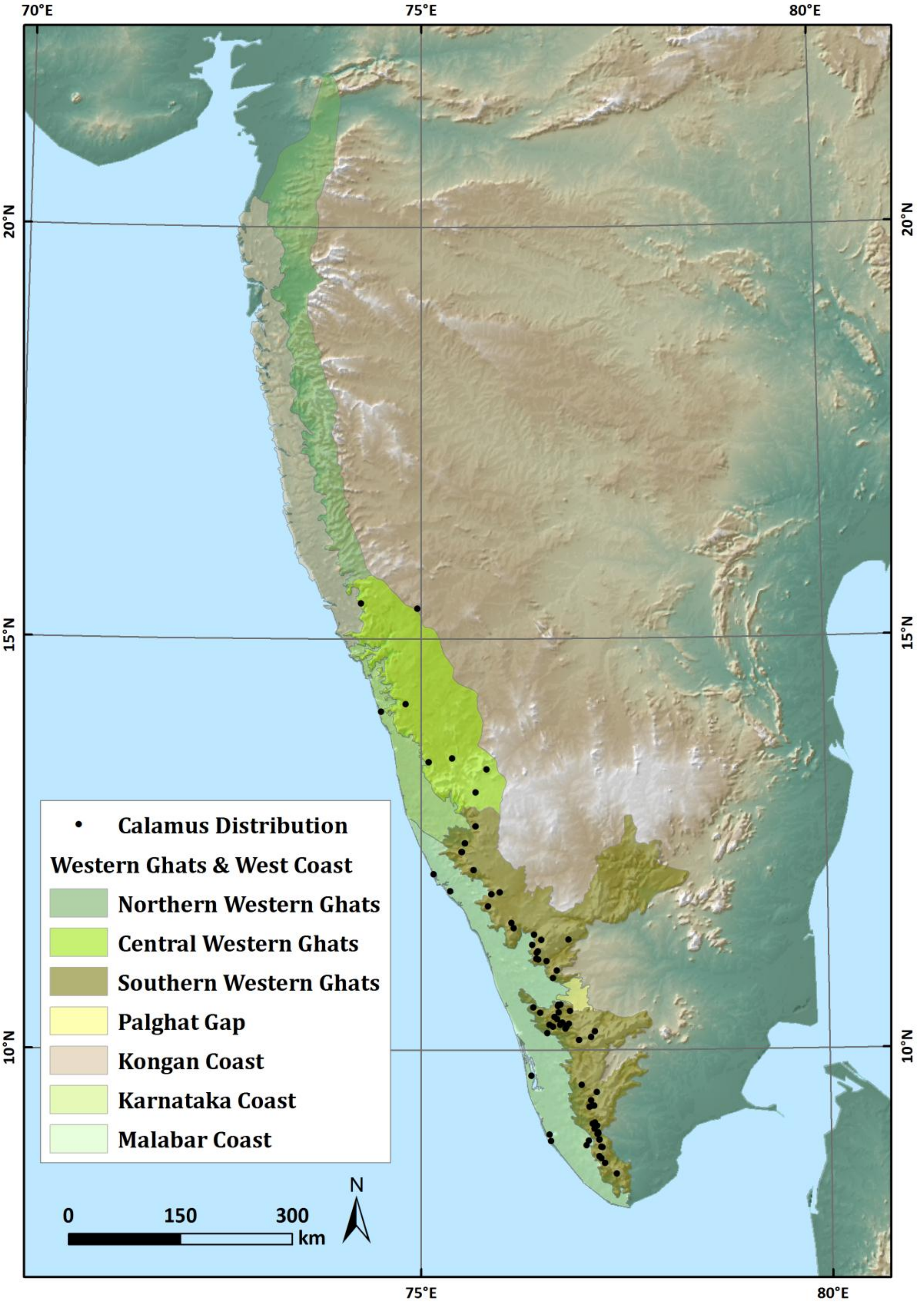


Figure 2 Potential distribution prediction of *C. brandisii* by Maxent

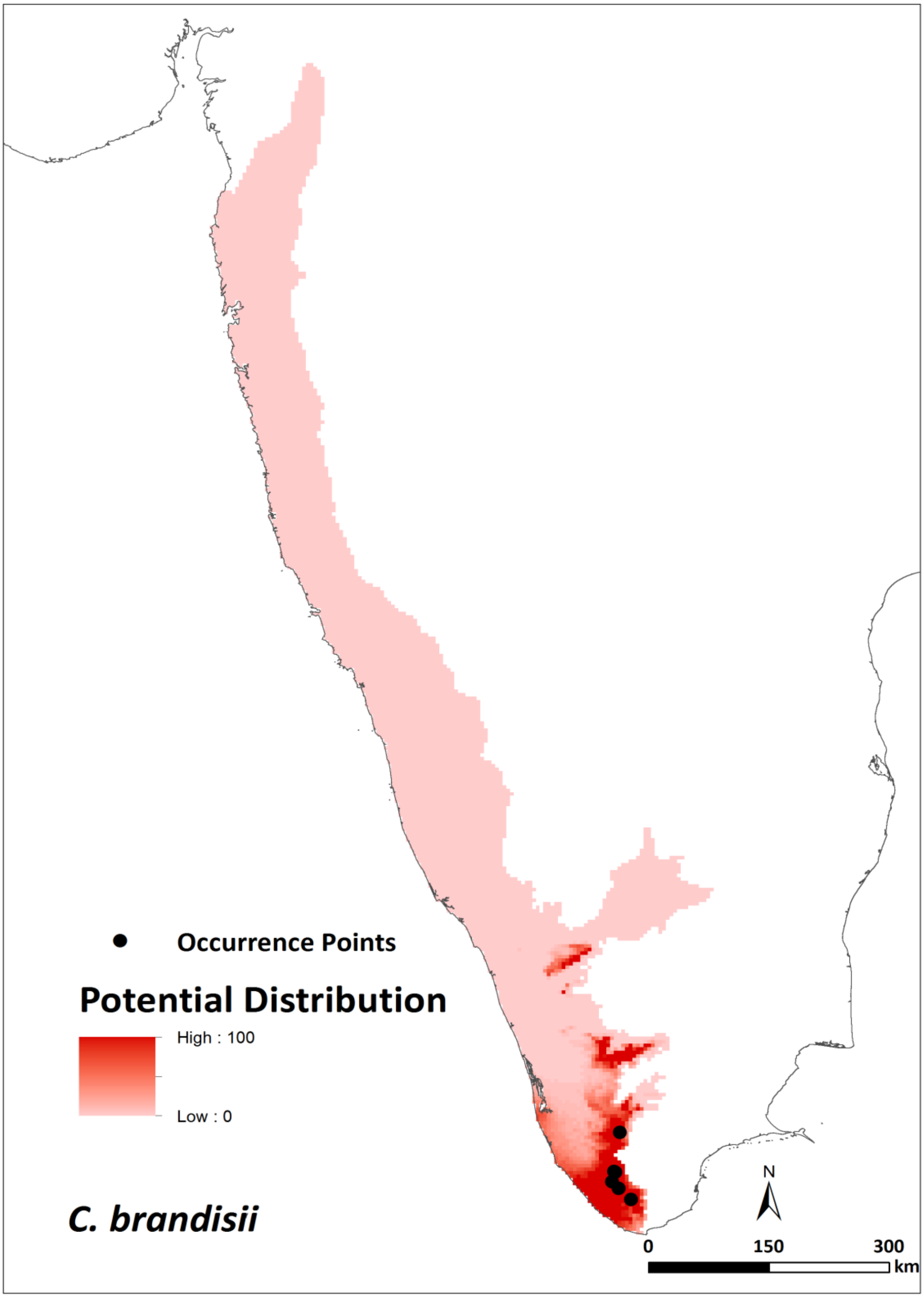


Figure 3 potential distributions of rattans

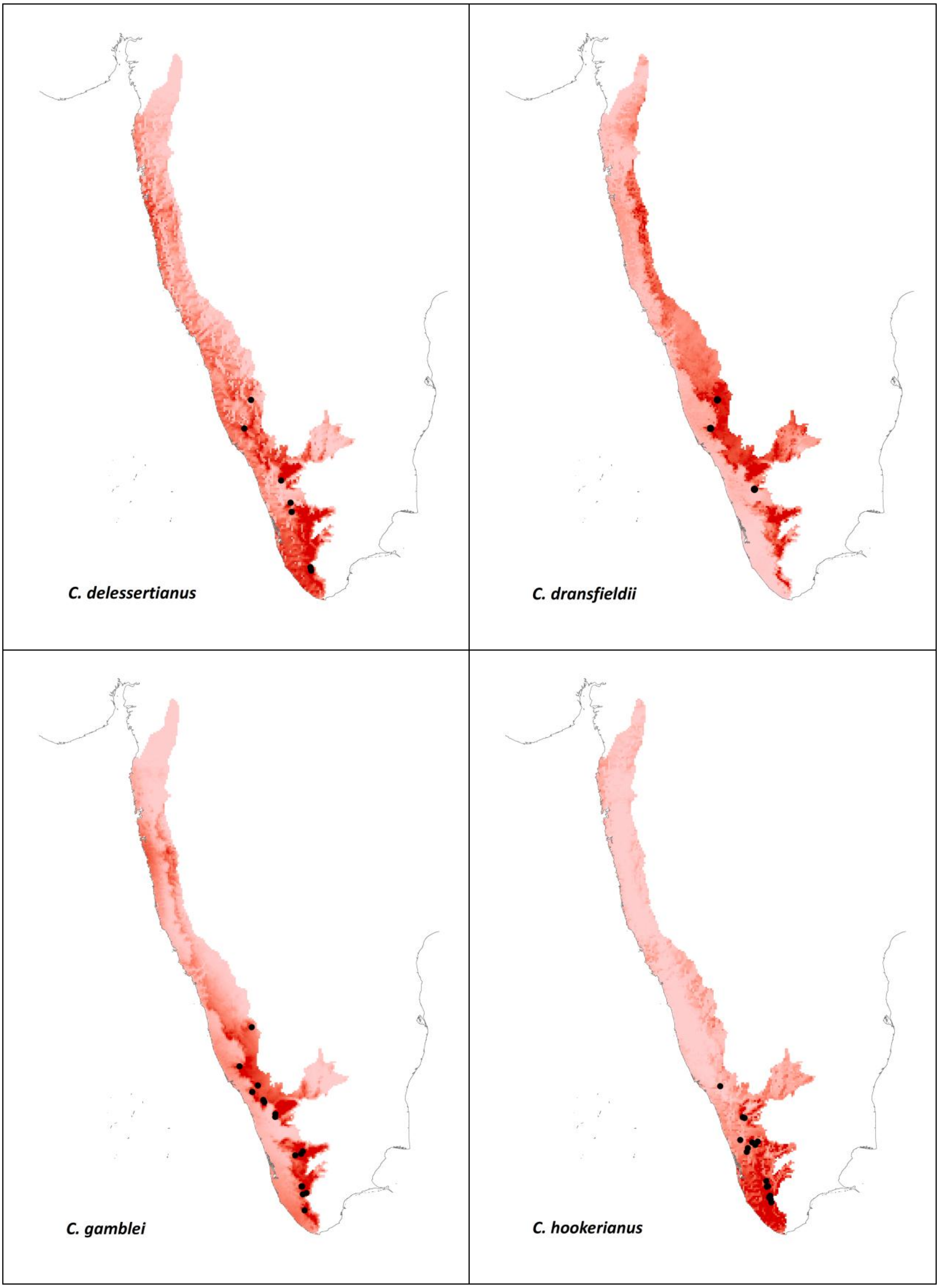


Figure 4 potential distributions of rattans

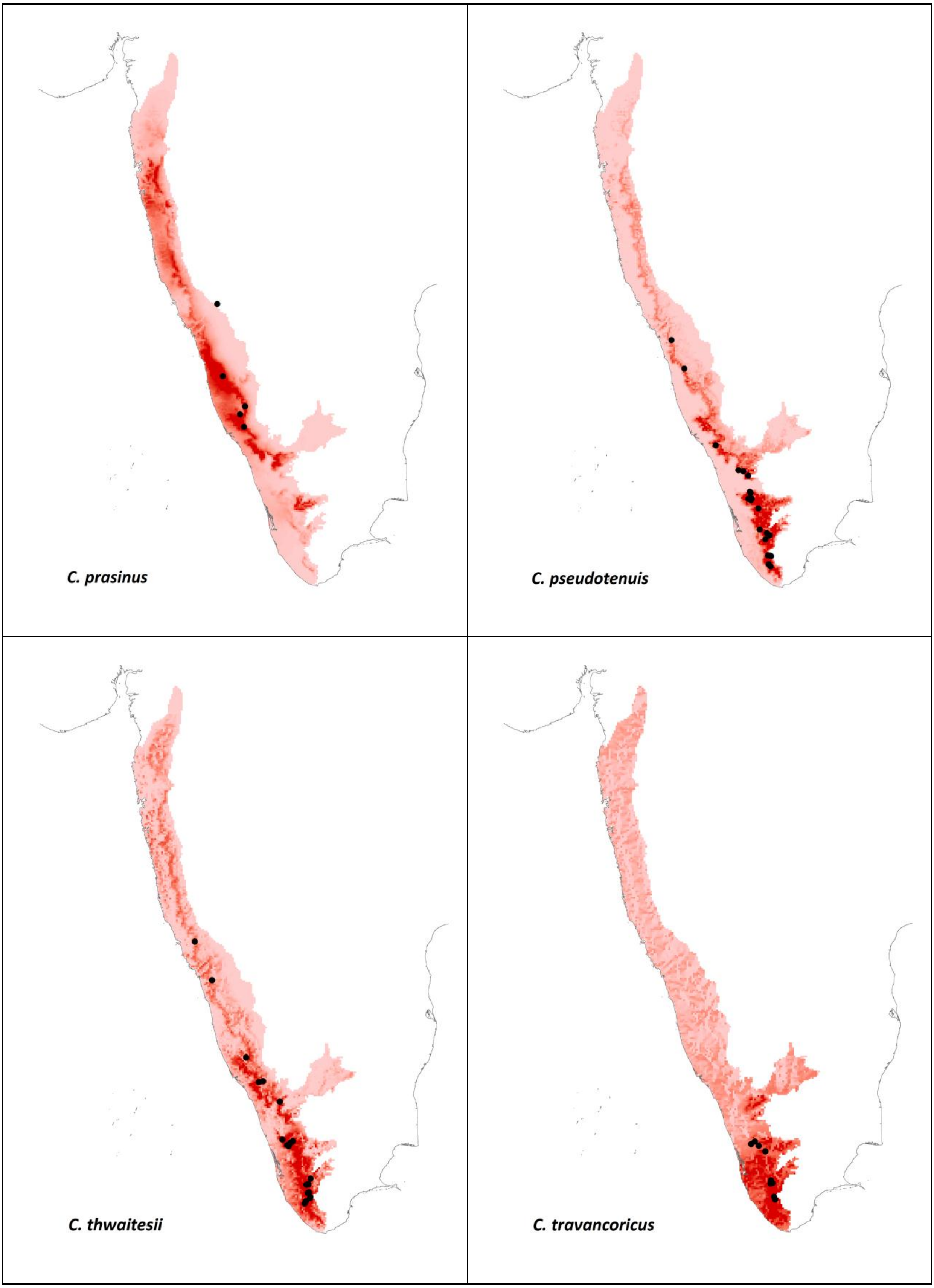


Table 1 Occurrence records and model significance

Sl.No	Species	No. of occurrence Records	AUC Score
1	*Calamus brandisii*	6	0.993
2	*C. delessertianus*	7	0.910
3	*C. dransfieldii*	3	0.935
4	*C. gamblei*	17	0.937
5	*C. hookerianus*	16	0.927
6	*C. karnatakensis*	4	0.907
7	*C. lacciferus*	4	0.936
8	*C. lakshmanae*	3	0.952
9	*C. metzianus*	7	0.880
10	*C. prasinus*	6	0.970
11	*C. pseudotenuis*	21	0.968
12	*C. thwaitesii*	23	0.945
13	*C. travancoricus*	10	0.926
14	*C. vattayila*	13	0.881
15	*C. wightii*	6	0.960

Use of Soil and Climatic Information for Delineation of Potential Areas for Forest Development in Karnataka using GIS and Remote Sensing Tools

L.G.K. Naidu[1], S.C. Ramesh Kumar[1], S.Srinivas[1] and Dipak Sarkar[2]

[1]*National Bureau of Soil Survey and Land Use Planning, Regional Centre, Bangalore*
[2]*National Bureau of Soil Survey and Land Use Planning, Headquarters, Nagpur*
E-mail: scrameshkumar@gmail.com

Abstract

Karnataka state is implementing different forest developmental programs for increasing area under forest cover in the state. Recently it has announced *Krishi Aranya Protsaha Yojane* (Farm Forestry Incentive Scheme) and financing the farmers to grow Pongamia, Bamboo, Neem and Teak plantations over large area. Before launching of any farm forestry program it is essential to assess the suitability of areas for expansion of farm forestry in Karnataka.

The soil map (1:25,000) of Karnataka state, length of dry period assessed for 175 taluks and the land use/land cover maps (prepared by KSRSAC) formed the basis for delineating the potential area for forest expansion. Soil site characteristics, length of dry period and forest types were integrated in the GIS environment to identify relationship between the forest types with soil and climatic conditions. The soil/climatic parameters responsible for development of good/poor forest types were correlated to identify further potential areas for forest expansion.

Introduction

Soil, water, forest and agro-climate are the prime natural resources. Soil is the upper most layer of the earth crust which form medium for plant growth and production of several kinds of goods, agriculture, horticulture and forestry. Forests are important for conservation of biodiversity, water generation and prevention of global warming. They act as environmental buffer. Forest conservation at present is an important issue all over the world. The pressure on these vital resources is increasing due to rapidly growing population, urbanization and industrialization. Information on soil site characteristics such as soil depth, presence of gravel/hard pans, texture, length of dry period and slope for the existing forest sites is lacking. Such information will help in planning, development and management of sustainable forestry. Remote sensing application is widely applied in mapping of forest types, their distribution, fire hazards, forest monitoring, stock mapping, and preparation of work plan and forest inventory. Growth and development of seedlings in a forest ecosystem is influenced by soil and prevailing climatic factors. Important soil properties that affect seedling growth are texture, bulk density, soil depth, organic matter and nutrient contents (Kramer and Kozlowski, 1979). In this paper an attempt was made to characterize soil and climatic constraints and identifying the potential areas in Karnataka using Remote Sensing and GIS techniques.

Materials and Methods

The soil mapping at 1:250,000 scale, involved satellite image interpretation using False Colour Composites (FCC) of Landsat images (1:250,000 scale) for delineating physiographic map units to study soils and establishing soil-physiographic relationship, characterization and classification of soils (Shivaprasad *et al*.1996). The length of crop growing period (LGP) as defined by Higgins and Kassam (1981) was assessed for 175 taluks of the state using long term (1980-2004) rainfall data (DMC-2002), potential evapo-transpiration (PET) and soil available water capacity. LGP is the duration in days or months when precipitation exceeds 0.5 PET and ends with utilization of stored moisture till it reaches 0.25 PET. The LGP for all taluk locations were worked out and soil information was digitised using SPANS GIS and prepared LGP map (Naidu, *et al.*, 2006) using interpolation techniques. The length of dry period for each taluk location was arrived by considering the period between ending and starting of the crop growing season.

The land use/land cover map (KSRSAC, 2006) prepared by KSRSAC using IRS1C/1D LISS III + PAN merged data (2000-2001) formed base map for delineating the forest sites. Soil site characteristics and length of dry period for all forest sites were extracted by integrating three layers of maps viz. Soil, length of dry period and forest types in the GIS environment. Using GIS overlay technique the soil/climate parameters responsible for maintenance good/poor forest types were correlated to identify the potential areas for forest expansion based on soil depth and length of dry period.

Results and Discussion

The extent and distribution of different forest types in the state along with soil details are presented below:

Soils: The soil resource mapping of the state revealed that red soils occupy largest extent (38%) followed by black soils (28%), alluvial soils (16%) lateritic soils (6%), forest brown soils (6%) and coastal sandy soils (4%) to total geographical area. (Shiva Prasad *et al* 1996). However the Distribution and extent of different soils types vary from region to region. Black soils followed by red and alluvial and Lateritic soils are extensive in northern districts whereas in southern districts red soils occupy large area followed by alluvial, black and lateritic soils. In Malnad region, lateritic soils are predominant followed red and alluvial (valley) soils.In coastal region, coastal laterite, alluvial and sandy soils in that order are distributed.

Climate: The climate of the state vary from arid to semiarid tropical in Plateau region subhumid to humid tropical in Western Ghats and coastal. Major part of the plateau region (Bidar, Gulberga, Bijapur, Tumkur, Bangalore, Kolar, Mandya, Mysore, Hassan, Davangere districts) is characterized by hot moist semi arid climate. Rainfall varies from 600 to 1000mm with dry period ranging from 6-8 months. Arid climate prevails in parts of Belgaum, Bagalkote, Koppal, Bellary, Chitradurga, Tumkur and Chamarajnagar districts. The annual rainfall varies from 430 to 580 mm. The dry periods prevails 8 to 9 months period. Western ghats region (U. Kannada. part of Shimoga, Chikmangalur, D. Kannada and Kodagu districts) is characterized by hot moist, subhumid to humid climate with rainfall ranging from 1500 to 3800mm. The dry period prevails for less than 3 months to 6 months. West coast plain experience (Part of U. Kannada., Udupi and Dakshina Kannada) hot humid climate with annual rainfall between 3000 to 4700 mm. The dry period ranges from 4 to 5 months.

Extent and distribution of forests

Karnataka State has 19 M ha of total geographical area (TGA) spread over 32 districts. Forest occupies about 2.7 M ha accounting for 14. 2 per cent of TGA of the state. Uttara Kannada district has highest forest area (7.71 lakh ha) followed by Chamarajanagar (2.68 lakh ha) and Shimoga (2.2 lakh ha). Dakshina Kannada, Belgaum, Mysore and Chickamagalur districts have forest area ranging from 1.0 to 1.5 lakh ha. Bijapur district has the lowest forest cover (1433 ha) followed by Bangalore urban (5133 ha) and Koppal district (5477 ha). The remaining 17 districts have forest area in the range of 0.1 to 0.8 lakh ha.

Distribution of forest types in relation to soil and climate

Ever-green /Semi-ever green forest: The ever-green/semi-evergreen forests (Table 1) are mainly concentrated in Western Ghats area spreading as a continuous strip across Belgaum, Uttara Kannada, Haveri, Shimoga, Chickamagalur, Udupi, Dakshina Kannada and Kodagu districts. Higher rainfall of 1070-3812 mm with a shorter dry period of 3-5 months from December to Feb/April is responsible for development of thin forests. Soils of the area are dominantly deep (100-150 cm) to very deep (>150cm), well-drained, lateritic clay (Kanhaplic Haplustalfs/Ustoxic Dystropepts/Kandic Paleustalfs/Rhodic Paleustalfs) medium to strongly acid, occurring on these low to high hill ranges. Thick ever-green/semi ever-green and moist deciduous forests occur in areas with rainfall of 1000 to 3000 mm (Lal, 1989).

Table 1 Distribution of Ever-green /Semi-ever green forest in Karnataka

District	*Taluk*	*Rainfall (mm)*	*Dry period (Months)*	*Soil depth (cm)*	*Texture of the control section*	*Gravels (%)*	*Land form*
Ever-green /Semi-ever green forest							
Uttara Kannada	Sirsi	2400	5-6	100-150	Clay	>35	Dissected Hills
Uttara Kannada	Yellapur	2450	5-6	100-150	Clay	>35	Laterite Plateaus
Uttara Kannada	Supa	2488	5-6	100-150	Clay	>35	High hills
Uttara Kannada	Kumta	3434	5-6	100-150	Clay	-	Low hills
Uttara Kannada	Honnavar	3661	5-6	100-150	Clay	-	Low hills

Uttara Kannada	Siddapur	2959	5-6	100-150	Clay		Dissected Hills
Uttara Kannada	Bhatkal	4115	5-6	50-75	Clay	-	Foot hills
Uttara Kannada	Mundgod	1209	5-6	100-150	Clay	>35	Undulating uplands
Uttara Kannada	Ankola	3537	5-6	100-150	Clay	-	Low hills
Uttara Kannada	Karwar	3220	5-6	100-150	Clay	>35	High hill ranges
Shimoga	Sorab	1469	5-6	100-150	Clay	>35	Plateau
Shimoga	Sagar	2018	5-6	>150	Clay	>35	High hill ranges
Shimoga	Hosanagar	2800	5-6	100-150	Clay	>35	Low hill ranges
Shimoga	Tirtahalli	2718	5-6	>150	Clay	>35	Low hill ranges
Belgaum	Khanapur	1854	5-6	>150	Clay	>35	Low hills
Chickmagalur	Mudigere	2231	3	100-150	Clay	-	Ridges
Chickmagalur	Sringeri	3812	4-5	100-150	Clay	-	Low hills
Kodagu	Somvarpet	2106	3	100-150	Clay	-	Low hills
Kodagu	Virajpet	2453	3	100-150	Clay	-	Plateau
Kodagu	Madikeri	3101	3	100-150	Clay	>35	High hills

Moist-dry deciduous forest: The moist/dry deciduous forest (Table 2) occur in Khanapur, Haliyal, Kalghatgi, Dharwad, Haveri, Shiggaon, Hangal, Mundgod, Shimoga, Shikaripur, Bhadravathi, Channagiri, Tarikare, Chikmagalur, N.R. Pura, Somawarpet, Periyapatna, Hunsur, H.D. Kote, Gundlupet, Kollegal, Kanakapura, Ramnagaram, Magadi Chincholi, Chitapur and Yadgir taluks. The rainfall in this belt varies from 760-1293 mm with a dry period of 6-7 months from mid November/December to mid June/July. The soils under these forests are

dominantly moderately deep (75-100 cm) to very deep (>150cm), gravelly and non-gravelly, clay (Kandic Paleustalfs/Rhodic Paleustalfs/Haplohumults/ Haplustults/Kanhaplustalfs) on gently/rolling/undulating uplands and ridges. Moist-dry deciduous forests are found in areas with a rainfall of 750-1000 mm (Lal, 1989).

Table 2.Distribution of Moist-dry deciduous forest in Karnataka

District	*Taluk*	*Rain fall (mm)*	*Dry period (Months)*	*Soil depth (cm)*	*Texture of the control section*	*Gravels (%)*	*Land form*
	Moist-dry deciduous forest						
Chamarajnagar	Kollegall	868	7-8	50-75	Clay	>35	Hills
Shimoga	Shikaripura	969	7-8	<25	Loam	>35	Ridges
Shimoga	Shimoga	963	7-8	25-50	Clay	>35	Rock land

Shimoga	Bhadravathi	830	7-8	>25	Loam	>35	Ridges
Belgaum	Belgaum	1293	7-8	>25	Loam	-	Mesas/ridges
Chickmagalur	Chickmagalur	921	5-6	>150	Clay	-	Ridges
Chickmagalur	N.R.Pura	1575	5-6	25-50	Clay	>35	Rolling
Chickmagalur	Tarikere	893	5-6	>150	Clay	-	Ridges
Mysore	H.D. Kote	816	6-7	100-150	Clay	-	Undulating uplands
Mysore	Periyapatna	849	6-7	>150	Clay	>35	Low hills
Mysore	Hunsur	836	6-7	>150	Clay(S)	-	Undulating plains
Gulbarga	Chincholi	1000	6-7	>150	Clay		Plateau
Gulbarga	Yadgiri	918	6-7	Rockland			Plateau
Bangalore (R)	Kanakapura	797	5-6	50-100	Clay	>35	Rolling lands

Scrub-Degraded Forest: The scrub/degraded forests (Table 3) are noticed in northern districts and to a lesser extent in southern districts of the state. At some places the soils are very deep to moderately deep, clay (Kandiustalfs) in Hoskote and Devanahalli Taluks, deep, gravelly/non-gravelly clay (Kandic/Rhodic Paleustalfs/Rhodustalfs/Haplustalfs) in Kunigal, Ramanagaram, Holenarsipur, Hassan, Belur, Bidar, Basavakalyan and Humnabad taluks, moderately deep, gravelly and non-gravelly clay soils (Haplustalfs and Paleustalfs) in Shapur, Gubbi and Alur taluks. This belt can be further divided into three distinct zones based on the length of dry period (Table 4).

Table 3.Distribution of Scrub/-Degraded Forest in Karnataka

District	*Taluk*	*Rainfall (mm)*	*Dry period (Months)*	*Soil depth (cm)*	*Texture of the control section*	*Gravels (%)*	*Land form*
	Scrub/-Degraded Forest						
Belgaum	Hukkeri	668	6-7	<25	Loam	-	Mesas/ridges
Belgaum	Soundatti	627	6-7	<25	Loam	-	Mesas/ridges
Bijapur	Bijapur	725	5-6	>150	Clay(S)	-	Plateau/Undulating interflues
Bidar	Bidar	911	6-7	100-150	Clay	>35	Plateau
Bidar	Basavakalyan	747	6-7	100-150	Clay	>35	Plateau
Bidar	Homnabad	773	6-7	100-150	Clay	>35	Plateau
Gulbarga	Chitapur	744	6-7	<25	Loam		Plateau
Gulbarga	Shapur	920	6-7	75-100	Clay	-	Undulating interflues
Gulbarga	Deodurg	774	6-7	50-75	Clay		Undulating interflues
Raichur	Lingsugar	624	8-9	50-75	Clay		Undulating interflues
Raichur	Raichur	710	7-8	100-150	Clay(S)		Undulating interflues
Bagalkote	Jamkhandi	556	8-9	<25	Loam	>35	Mesas/ridges

Bagalkote	Bagalkote	652	8-9	<25	Loam	>35	Mesas/ridges
Bagalkote	Badami	580	8-9	<25	Loam	>35	Ridges
Bagalkote	Bilgi	594	8-9	<25	Loam	>35	Mesas/ridges
Ballary	Hospet	718	8-9	75-100	Clay	>35	Mesas/ridges
Ballary	Sandur	822	6-7	25.-50	Loam	-	Mesas/ridges
Ballary	Kudligi	581	8-9	75.1	Clay	>35	Undulating interflues
Davanagere	Harpanahalli	753	6-7	>150	Clay	-	Undulating interflues
Chitradurga	Chitradurga	590	7-8	<25	Loam	>35	Ridges
Chitradurga	Challakere	449	8-9	75-100	Clay	>35	Undulating interflues
Chitradurga	Holakare	677	7-8	<25	Loam	>35	Ridges
Chitradurga	Hiriyur	552	7-8	<25	Loam	>35	Ridges
Hassan	Holenarsipur	810	5-6	100-150	Clay	>35	Gently sloping interflues
Hassan	Hassan	835	5-6	100-150	Clay	>35	Gently sloping interflues
Hassan	Belur	1026	5-6	100-150	Clay	>35	Gently sloping interflues
Hassan	Alur	966	5-6	75-100	Clay	-	Undulating interflues
Hassan	Arasikere	726	6-7	100-150	Clay	>35	Gently sloping interflues
Tumkur	Kunigal	850	6-7	100-150	Clay	-	Undulating interflues
Tumkur	Gubbi	810	6-7	>150	Clay	-	Ridges
Tumkur	Chikkanayakan ahalli	705	6-7	25-50	Clay	>35	Ridges
Tumkur	Sira	622	8-9	25-50	Clay	>35	Mesas/ridges
Kolar	Kolar	792	7-8	100-150	Clay	-	Gently sloping interflues
Kolar	Srinivaspur	770	7-8	100-150	Clay	-	Gently sloping interflues
Kolar	Mulbagal	805	7-8	>150	Loam	>35	Rolling lands
Kolar	Bangarpet	787	7-8	>150	Loam	>35	Rolling lands/ridges
Mandya	Mandya	712	7-8	75-150	Clay	-	Gently sloping interflues
Bangalore (R)	Magadi	996	6-7	100-150	Clay	>35	Rolling lands
Bangalore (R)	Ramanagaram	957	6-7	100-150	Clay	>35	Rolling lands
Bangalore (R)	Devanahalli	841	6-7	>150	Clay	-	Gently sloping lands
Bangalore (R)	Hosakote	865	6-7	>150	Clay	-	Gently sloping Plains

1. **Moist zone:** This zone includes area where the annual rainfall varies from 670-920 mm with a dry period of 6 to 7 months (mid November to mid June/early July). In these areas there are some reserve forests with moderately deep to very deep soils with fairly longer duration of growing season.

2. **Dry Zone:** This zone comprises the area where the annual rainfall varies from 650-865 mm with a dry period of 7 to 8 months (mid November to early July).

3. **Very severe dry zone**: This zone includes area where the annual rainfall varies from 486-624 mm, with a dry period of 8 to 9 months and more (November to August). Soils are very shallow (10-25 cm) to shallow (25-50 cm), both gravelly/non-gravelly clay and loamy (Lithic Ustorthents/Lithic Haplustepts/Lithic Camborthids). In this zone prolonged dry period and very shallow to shallow soils with intermittent rocky lands are the limitations for forest development.

Potential Area for Forest Development: Moderately deep (75 –100 cm), gravelly/non-gravelly soils and a dry period of not more than 6 to 7 months (or LGP of 5 to 6 months) are found to support good forest (moist/deciduous) vegetation. Such soil and climatic environment are found to occur in the following taluks; Gubbi, Kunigal, Bidar, Basavakalyan, Humnabad, Holenarsipur, Hassan, Belur, Alur, Magadi, Ramnagaram, Kanakapura, Devanahalli and Hoskote (Table 4). Presently in these areas the existing forest vegetation is of scrub and degraded type. Therefore, about 85,000 hectares are found as potential area for development of good forest cover.

The Karnataka forest department while implementing *Krishi Aranya Protsaha Yojane,* has to implement the promotion of forest species with consideration to soil climatic requirement for each tree species.

Conclusions

The long moist period with associated deep and very deep soils in Western Ghats and coastal tracts supported dense evergreen/semi evergreen forest. Moderately deep to very deep soils with moderate dry period of not more than 6-7 months supported moist/dry deciduous forest. Longer dry period of 8 months and above supported scrub/degraded type of forest vegetation irrespective of soil conditions. Gubbi, Kunigal, Bidar, Basavakalyan, Humnabad, Holenarsipur, Hassan, Belur, Alur and Magadi, Kanakapura, Devanahalli, Ramanagaram and Hoskote are found as potential areas for forest expansion.

Acknowledgements

The authors are thankful to Dr. H. Honnegowda, Ex-Director, Karnataka State Remote sensing Application Centre, for providing land use/land cover maps and to Dr. V.S. Prakash, Director, Drought Monitoring Cell for providing rainfall data for the study area. The word processing services rendered by Smt. Prabavathamma and map generation by Smt. K.Sujatha are duly acknowledged.

References

Drought Monitoring Cell (DMC, 2002). Rainfall data (1980-2002), Govt. of Karnataka, Cauvery Bhavan, Bangalore-1.

Higgins, G.M. and Kassam, A. H. (1981). The FAO Agroecological zone approach to determining of land potential. Pedologie, XXXI, 2:147 168.

Kramer, P.J. and Kozlowski, T.T. (1979). Physiology of woody plants, Academic Press, New York. 483 P.

KSRSAC (2006). Karnataka State Remote Sensing Applications Centre. Land use/Land cover maps of Karnataka.

Lal, J.B. (1989). Indias forests: Myth and Reality. Natraj Publishers, Dehradun.

Naidu, L.G.K. and Srinivas, S. Rajendra Hegde and Devaraja, M. (2006). Assessment of length of growing period (LGP) in different agro-climatic zones of Karnataka for crop planning. Mysore J. Agric. Sci. 40(4) 522.533.

Shivaprasad, C.R., Reddy, R.S., Sehgal, J.L. and Velayutham, M. (1998). Soils of Karnataka for optimising land use. NBSS Publ. 47b. National Bureau of Soil Survey and Land Use Planning. Nagpur, 111pp+4sheets of soil map.

Table 4. Potential areas for forest development in Karnataka

District	Taluk	Area (ha)
Bidar	Bidar	4,538
	Basavakalyan	1,606
	Humnabad	8,303
Hasan	Belur	4,887
	Hassan	3,362
	Holenarsipur	830
Tumkur	Gubbi	953
	Kunigal	7,414
Bangalore (Rural)	Devanahalli	1,745
	Hoskote	3,519
	Kanakapura	29,427
	Ramanagaram	9,932
Gulbarga	Shahpur	3,468
	Chincholi	5,470
Total		85,454

Preparation of Action Plan Inputs for Developmental Activities: A Case Study for Afforestation Planning using Geospatial Approach

D Chutia, C.Goswami, P. Rocky, J.Goswami, P.S.Singh, R.Das and S.Sudhakar

North Eastern Space Applications Centre (NESAC), Department of Space,
Government of India, Umiam-793103
E-mail: d.chutia@nesac.gov.in

Abstract

This paper conveys the strength of geospatial technologies for generating essential inputs for proper planning of afforestation in the district of East Khasi Hills of Meghalaya. Geospatial approach has been adopted to analyze, integrate and prioritize the various spatial and non-spatial parameters in order to model and generate the essential inputs for preparation of action plans. Open source GIS packages have been utilized for developing geoportal for information dissemination services.

Introduction

Many a times, the programs undertaken by the Government institutions to address specific problems of rural masses get poorly implemented due to insufficient technical inputs, lack of zeal and transparency in implementation and ineffective monitoring methods. These are found to be pronounced in Natural Resources Management (NRM) programs involving terrain dependent interventions for better sustainability (Diwakar and Maya 2010). Particularly, in the states of North Eastern Region (NER), in spite of tremendous information available in the custody of different stake holders and agencies in the tabular form on land and water resources, the preparation of important documents such as Detailed Project report (DPR) and master plan have not been generated properly due to lack of scientific approach and awareness among the people. DPR and master plan documents are the actual basis for implementation of any developmental schemes or plans of Government. In general, a DPR gives information on project overview, general description of the project area, baseline survey details, institution building and project management, action plans, capacity building, budget etc. Geospatial inputs forms the core of a DPR along with socio-economic data collected through Participatory Rural Appraisal (PRA) survey. For example, DPR of integrated watershed management programme is normally used to prepare through baseline/bench mark survey for physiography, climate, soil, land use, vegetation, hydrology and socio-economic data analysis.

North Eastern Space Applications Centre (NESAC) has generated good number of Natural Resources (NR) database for the state of Meghalaya in the areas of forestry, land use, agriculture, horticulture, urban planning, disaster management support etc in close collaboration with other ISRO/DOS Centres as well as Central/State agencies. Government of Meghalaya has been utilizing this information for preparation of DPRs specifically for soil and water conservation, forest and environment, watershed management etc. However, demand based, location specific and DPR oriented geospatial inputs are not readily available in the concerned user departments, agencies etc.

The present study highlights the strength of geospatial technologies for generating essential inputs for proper planning of aforestation in the district of East Khasi Hills of Meghalaya.

Study area

East Khasi Hills is one of the seven districts of the State of Meghalaya. The district occupies an area of 2748 sq km and lies between 25°07" and 25°41" N Latitude and 91°21" and 92°09" E Longitude. Shillong is the district headquarters. The district consists of seven Community and Rural Development blocks. Recently, one more block namely Khadarshnong - Laitkroh is made for which separate boundary is not available (Fig.1). So, for the purpose of data analysis we have taken seven blocks only.

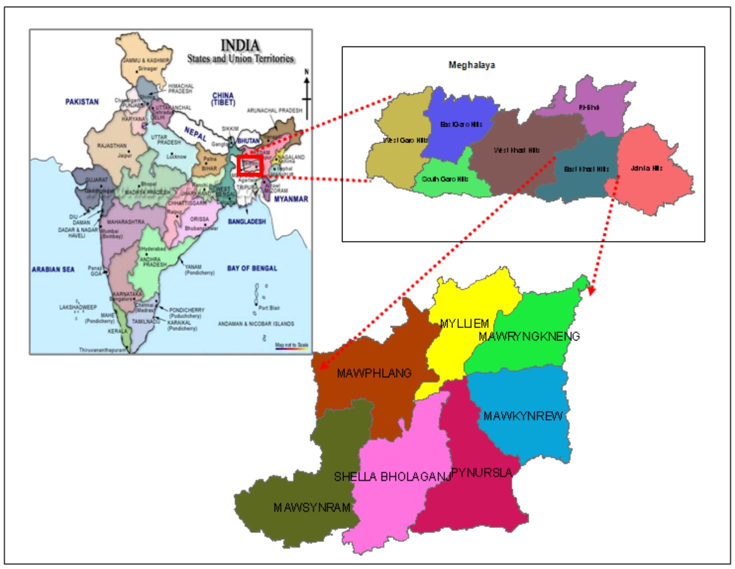


Figure 1: East Khasi Hills district of Meghalaya

East Khasi Hills district is covered under the Agro-climatic Region of Meghalaya-Mikir Region. Agriculture is the main occupation of the people of the district. Though, most of the population depends on agriculture, the total cropped area is only about 14.6% of the total geographical area of the district. On the other hand, shifting cultivation popularly known as *jhum* cultivation is the common agriculture practiced in the region (Bhatt *et. al.* 2001). Thus, shifting cultivation has endangered the sustainable ecological system (Rao *et. al.* 2011). Natural resources and virgin forests are under threat due to increased human activities, industrialization and sawing activities. These activities have led to partial deforestation and hampered the carbon and green house gas reduction ability of the natural and bounty forests.

In this context, the Government of Meghalaya has been entrusted with the task of formulation and implementation of schemes and projects not only to conserve soil, water and vegetation but also to promote environmental awareness so as to ensure sustainable development. The recent study shows that approximately 22% of total geographic area of East Khasi Hills district is suitable for planning of aforestation activities.

Geospatial approach

Existing natural resource databases on current land use, wastelands, soil, slope, ground water prospect and drainage at 1:50000 scale have formed the core primary input parameters. The figure 2 shows the land resource map of East Khasi Hills district.

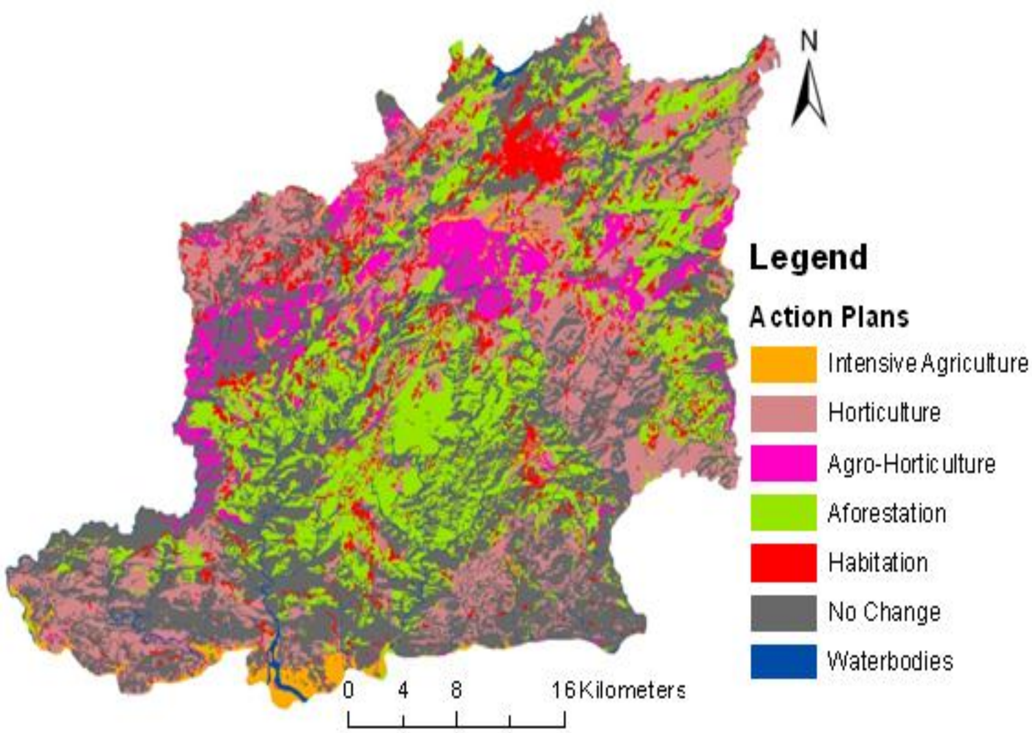


Figure 2 Land Resource Development map of East Khasi Hills
(Source: NEDRP, 2011)

A spatial model was built in the spatial analyst environment where various input parameters defined in the form of a criteria table has been incorporated into a weighted overlay function (Fig.3). The criteria table follows the specific guidelines of Integrated Mission for Sustainable Development (IMSD) for preparation of action plan inputs for aforestation. Incorporation of agro-climatic zones along with information on socio economic, proximity to roads and settlements has further enhanced the formulation of suitability criteria for the action plan in the model.

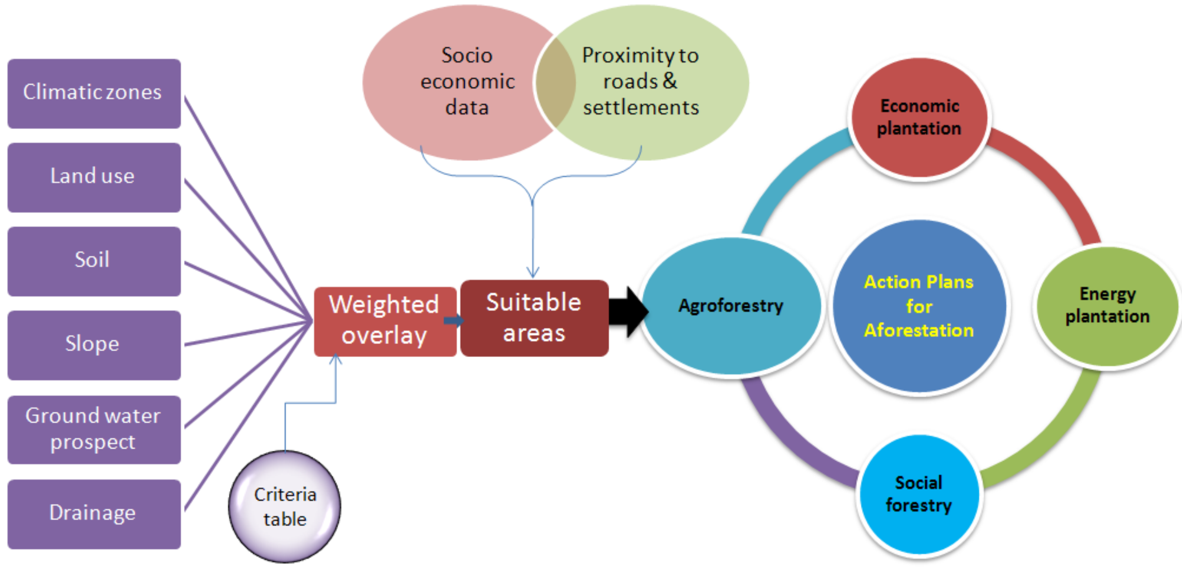


Figure. 3: Flowchart showing generation of inputs for aforestation

The information as and when updated is planned to be made available from a recently launched Space Based Information Support for Decentralized Planning (SIS-DP) programme at 1:10,000 scale and networked for easy access at Panchayat level for decentralized planning to uplift grassroots people. An example of action plan inputs for implementation of various developmental activities under aforestation in the district of East Khasi Hills district is highlighted in Figure 4.

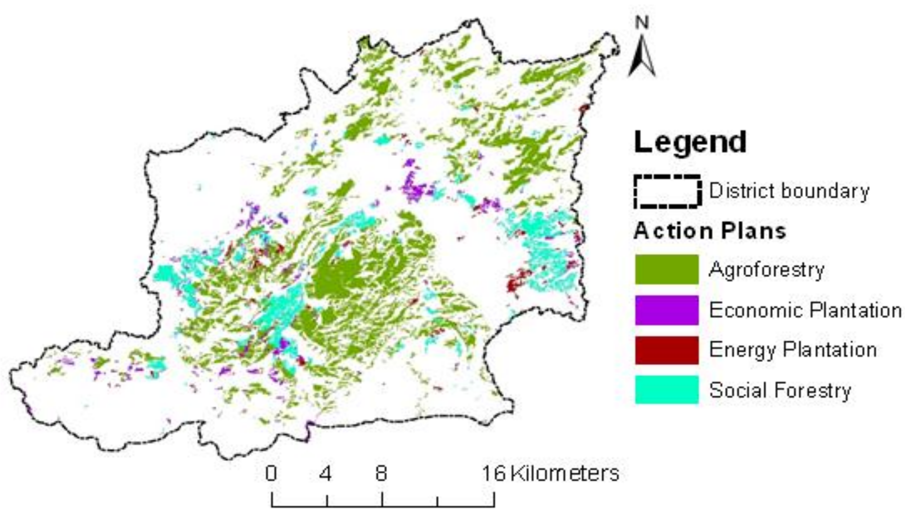


Fig. 4 Action plan inputs for aforestation

Open Sources GIS Environment

The action plan inputs for aforestation activities have been integrated into a geoportal developed using Open Source GIS packages under North Eastern District Resources Plan (NEDRP) programme. The NEDRP portal has been deployed in the district headquarter of East Khasi Hills in a standalone mode with a dedicated computer with printer and trained manpower to handle NEDRP portal. This model helps to disseminate relevant geospatial inputs to the hands of authentic users even inspite of lack of internet facility in some of the rural district headquarters of NER. Since, geo-processing services of NEDRP are demand oriented and need based, many line departments have come forward to have this portal in their office premises in addition to the portal available in the district headquarters because of its user friendliness and independent of any third party commercial software. It is also planned to incorporate various models in open source environment into the NEDRP portal so that user can prepare their action plans as per IMSD guidelines by integrating relevant NR layers.

Conclusions

According to the State of Forest Report 2009, there was a decrease of 70 sq km forest area in East Khasi Hills which may be due to illegal logging, conversion to other land use or mining activities. Out of the total geographical area recommended for aforestation in the district of East Khasi Hills, this work recommends 73% for agroforestry, 19% for social forestry, 4% for economic plantation and 4% for energy plantation under aforestation activities (Fig. 5).

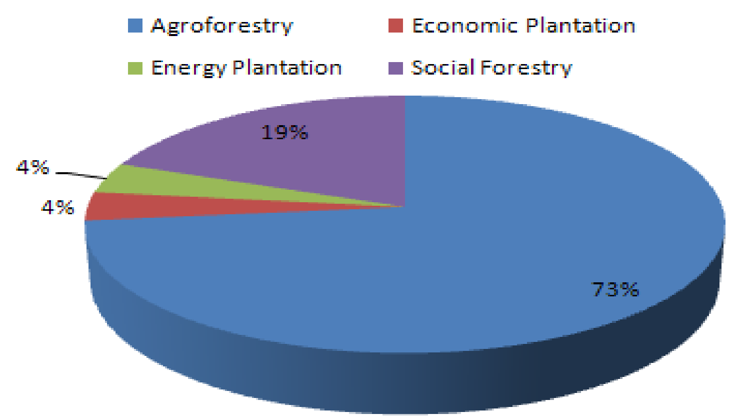


Fig. 5 Recommended distribution of aforestation activities

In order to meet the requirement of timber and fuel wood demands and to ameliorate the environment, the underutilized/unutilized wastelands could be put under afforestation activities with native species which will not only provide direct benefit but also other indirect benefits like ecosystem services and aesthetic value. In fact, agroforestry has a long tradition in NER region, where trees are integrated in the crop as well as livestock production system according to agro-climatic and other prevailing conditions. The district has also the potential for taking up social forestry activities in the community lands where the local villagers have a tradition of preserving forest in the form of sacred groves. Comparatively, very less areas have been indentified for energy plantation as they are recommended closer to the settlements to meet their fuel wood requirements. However, only 4% area has been recommended for economic plantation activities since the total forest blank area is less in the district.

References

Bhatt, B.P., R. Singh, Mishra, L.K, Tomar, J.M.S, Singh, M. Chauhan, D.S. Dhyani, S.K. Singh, K.A. Dhiman, K.R. and Dutta, M. (2001). Agroforestry research and practices: An overview. In: Steps Towards Modernization of Agriculture in NEH Region (eds N.D. Verma and B.P. Bhatt), pp 365-392, ICAR Publication, Meghalaya, India.

Diwakar, P.G. and Mayya, S.G. (2010). ICT and Geomatics process tools for Community centre Watershed Development. J. of Geomatics, 4(1):25-30.

NEDRP. (2011). North Eastern District Resources Plan, a project initiated by North Eastern Space Applications Centre (NESAC), Department of Space, Government of India.

Rao, M.G., Mukherjee, C., Bhasin, A., Barua, A., Anand, M., Pandey, R. and Srinavasan, R, (2011). Vision document for the state of Meghalaya.

RS and GIS Applications in Wetland Change Detection Analysis – A Case Study in Bhadravathi Taluk, Shimoga District

Govindaraju[1], Govindaiah, S.[2], Chandrashekarappa, K. N.[1], Jayakumar, P.D.[1]
Lingadevaru, D.C.[1] and Shruthi, P.

[1]*Department of Applied Geology, Kuvempu University*
[2]*Department of Studies in Geology, University of Mysore*
E-mail: drgov@yahoo.com

Abstract

Remote Sensing and GIS techniques are cost effective tools in identification, classification and monitoring of wetlands in which we can store and analyze the data of wetlands from time to time. It helps in accurate mapping and in the development of systematic planning and implementation of the same in various fields. The present study has helped in analyzing the data to prepare scientific planning for systematic development of wetlands in the study area. There are two types of inland wetlands tanks and irrigated land are the wetlands out of which change detection analysis has been carried out for the tanks in the study area. The majority of the tanks were drained or filled to create agricultural land, urbanization also causes indirect damage to these wetland systems which, directly leads to hydrological alterations.

Introduction

Wetlands are defined as 'lands transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface or the land is covered by shallow water' (Mitsch and Gosselink 1986). The value of the world's wetlands are increasingly receiving due attention as they contribute to a healthy environment in many ways. They retain water during dry periods, thus keeping the water table high and relatively stable. The various reservoirs, shallow ponds and numerous tanks support wetland biodiversity and add to the countries wetland wealth. It is estimated that freshwater wetlands alone support 20 per cent of the known range of biodiversity in India (Deepa and Ramachandra 1999).The interaction of man with wetlands during the last few decades has been of concern largely due to the rapid population growth - accompanied by intensified industrial, commercial and residential development further leading to pollution of wetlands by domestic and industrial sewage, agricultural run-offs having fertilizers, insecticides etc. Anthropogenic activities such as agricultural activities have caused a significant loss of wetland (Syphard and Garcia 2001). The majority of the wetlands were drained or filled to create agricultural land and more than 80% of all wetland conversions took place since 1980. The 1972 Clean Water Act drastically decreased the rate of wetland loss, although wetland alterations continue (Brown and Lant 1999).

In the present study an attempt has been made to study the wetland dynamics made through a combination of remote sensing, GIS analysis and field observation to understand the characteristics and dynamics of the wetlands in Bhadravathi taluk with particular emphasis on tanks, their spatial spread, extent of aquatic vegetation with in, qualitative turbidity levels (surface water bodies) and their changes from 2000, 2008 and in 2011.

Location and Extent of the Study Area

Bhadravathi taluk lies in the central part of the Karnataka State, in the south-east corner of the Shimoga district (Fig 1) between the latitude 13^0 42' 0" to 14^0 6' 35 and longitude 75^0 35' 24"to 75^0 52' 48". The Bhadravathi Taluk has an area of 675.08 square kilometers with 143 inhabited villages and one town.

The average **rainfall** of the area is 1029mm. The region receives rainfall from south west monsoon and slightly from north east monsoon with an annual rainfall season spreading over a period of 5 to 6 months. The South west monsoon occurs from June to September amounting to about 68% and northeast monsoon during October to November constituting about 32% of rainfall. In the last five years, this taluk received 900 mm of rainfall. Temperature varies from 8.9o to 40^0 C during the month of December. The percentage of **humidity** varies from 42 to 90.

Geologically the study area consists of schists and gneisses of Archean age and forms a part of Dharwar super group. Schistose rock includes interbeded volcano meta- sedimentary sequence of basaltic lava flows, quartz pebble, conglomerate, quartzite, phyllite and banded iron formation. The gneisses, which occur in this area, are the component of Peninsular Gneisses.

The **drainages** in the Bhadravathi taluk are mainly of dendritic type, which are mainly found in the hills and mound area of the forest region. Apart from this type trellis**,** angular and parallel types are also found in low-lying areas. The density of the drainages is more in high altitude when compared to low-lying landforms.

Materials and Methodology

Survey of India Toposheet No. 48 N/12, 48 N/16, 48 O/9, 48 O/10 48 O/13, of 1:50,000 scale and IRS LISS III satellite images of 2000, IRS-P6 LISS III image of 2008 and Satellite image of Google Earth 2011 have been used in the present study. ERDAS 9.2, ARCGIS 9.2, ARC VIEW 3.2a, and AUTOCAD MAP 2000 are the softwares used to analyze the data.

The comprehensive wetland information system for the effective management of wetland resources is developed by combing the remote sensing data and the database derived from the convectional methods. Wetland information system is a user friendly query module and has the information regarding the location, current status of water spread area as well as seasonal changes and quality especially turbidity and weed infestation. It enables the users to make simple queries and also helps in preparing action plan for monitoring and development of wetlands. It also has the option for updating of spatial as well as non-spatial data. A Schematic diagram (Fig.1) representing the methodology is shown in flow chart below.

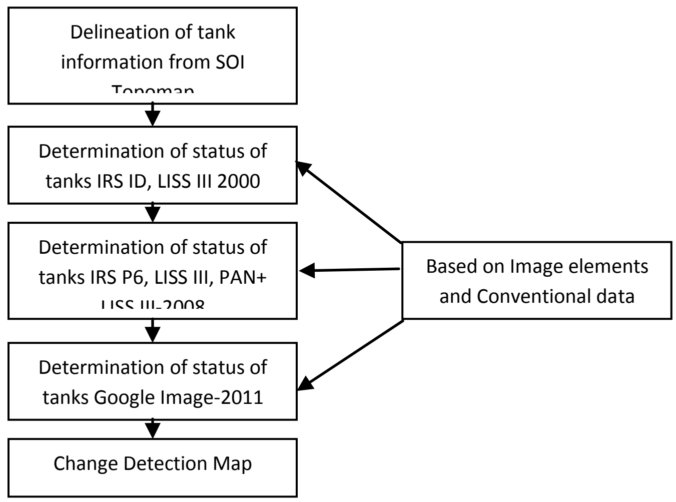


Fig.1. Flow chart of Methodology

Results and Discussion

The study reveals there are four types (Table 1) of wetlands in the study area. In this study we have done the change detection analysis only for tanks and the irrigated area are not considered because, they are maintaining almost same geographical area.

<table>
<tr><td rowspan="4">Inland wetland</td><td rowspan="2">Natural</td><td>Tanks</td></tr>
<tr><td>Irrigated land at river and stream courses</td></tr>
<tr><td rowspan="2">Man made</td><td>Reservoir</td></tr>
<tr><td>Canal command areas</td></tr>
</table>

Table 1. Wetlands of Bhadravathi Taluk

Wetlands (Tanks) in 1977: As per Survey Of India topographic sheets and data collected from the minor irrigation department, Bhadravathi taluk exhibits 266 tanks, out of which only five tanks are major, others are very small covering an area ranges from 0.002 to 0.89 Hectares, which are shown in the Fig 2 .

Wetlands (Tanks) in the year 2000: All the surface water bodies from the SOI topographic sheets were overlaid on the satellite image IRS LISS III 2000 (Fig - 3) to delineate water bodies like, weed infestation, dry, high turbid, low turbid, moderate turbid and encroachment using visual image interpretation keys (Fig.4). It has been estimated that the weed infestation is in about 591.7 Hectares (42.70 %). The agricultural encroachment covers an area of about 398.5 Hectares (28.80

%), Low turbidity in all tanks covers an area about 81.6 Hectares (5.9 %), High turbidity covers an area about 238.3 Hectares (17.2 %), medium turbidity covers an area about 52.8 Hectares (3.8 %) and dry area in about 22.6 Hectares (1.6 %) of total area of the tanks in the taluk. (table – 1).

Table – 1: Area Statistics of Tank Information in Year 2000 in Bhadravathi Taluk

Description	Area in Hectares	Area in Percentage
Weed Infestation	591.7	42.7
Encroachment	398.5	28.8
Low turbid	81.6	5.9
High turbid	238.3	17.2
Medium turbid	52.8	3.8
Dry	22.6	1.6
TOTAL AREA	**1385.5**	**100.00**

Wetlands (Tanks) in the year 2008: The surface water bodies in the form of tanks taken from the SOI Toposheet were overlaid on the IRS LISS III 2008 (Fig - 5) images to delineate weed infestation, encroachment, dry, high turbid, low turbid and moderate turbid area (Fig.6).It has been observed that the weed infestation is in 483.4 Hectares (34.9 %), Agricultural encroachment of about 383.2 Hectares (27.7 %), Low turbidity in about 110.7 Hectares (8.0 %), High turbidity in about 275.9 Hectares (19.9 %), medium turbidity in about 27.1 Hectares (2.0 %) and dry area in about 104.8 Hectares (7.6 %) of the total area of the taluk (table – 2).

Table – 2: Area Statistics of Tank Information in Year 2008 in Bhadravathi Taluk

Description	Area in Hectares	Area in Percentage
Weed Infestation	483.4	34.9
Encroachment	383.2	27.7
Low turbid	110.7	8.0
High turbid	275.9	19.9
Medium turbid	27.1	2.0
Dry	104.8	7.6
TOTAL	**1385.5**	**100.00**

Wetlands (Tanks) in the year 2011 The surface water bodies in the form of tanks taken from the SOI Toposheet were overlaid on the Google Earth image 2011 (Fig - 7) to delineate weed infestation, encroachment, dry, high turbid, low turbid and moderate turbid (Fig 8) .The analysis shows in weed infestation 460.5 Hectares (33.2 %) of the total area of the study. The Agricultural encroachment covers an area about 455 Hectares which is 32.8 %, Low turbidity in about 137.5 Hectares (9.9 %), High turbidity in about 197.7 Hectares (14.3 %), medium turbidity in about 28 Hectares (2.0 %) and dry area in about 106.8 Hectares (7.7 %) of the total area of study (table – 3).

Table – 3: Area Statistics of Tank Information in Year 2011 in Bhadravathi Taluk

Description	Area in Hectares	Area in Percentage
Weed Infestation	460.5	33.2
Encroachment	455	32.8
Low turbid	137.5	9.9
High turbid	197.7	14.3
Medium turbid	28	2.0
Dry	106.8	7.7
TOTAL	**1385.5**	**100.00**

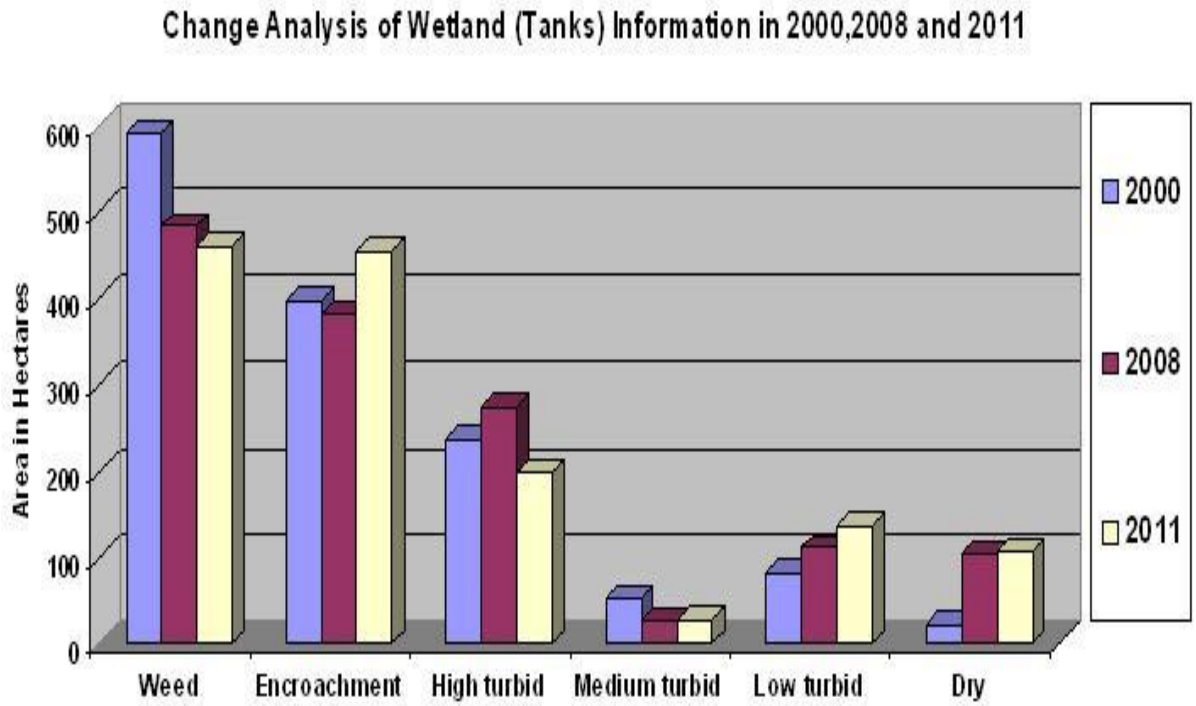
Change Detection Analysis

The area infested by weed has come down from 591.7 Hectares (2001) to 460.5 Hectares (2011).There is an increase in encroachment of tanks for agricultural use from 398.5 Hectares (2000) TO 455 Hectares in 2011. About 238.3 Hectares of tanks were affected by high turbidity in 2000, where as it is 197.7 Hectares in 2011, this indicates a slight decrease in the area affected. The area affected by moderate turbidity also show a decreasing tendency from 52.8 Hectares in 2000 to 28 Hectares in 2011.However, the data shows fluctuating tendency. The area affected by high turbidity shows increasing tendency from 110.7 Hectares in 2000 to 137.5 Hectares in 2011.

Dry: After analyzing from the year 2000 to 2011 we came to know that the dried area in all the tanks of Bhadravathi taluk in the year 2000 it exhibits area about 22.6 Hectares, in the year 2008 about 104.8 Hectares and in the year 2011 about 106.8 Hectares respectively. It indicates that slightly increase in the year 2008 and again slightly increased in the year 2011. The details of these are presented in the table 4 below.

Table 4 Change detection analysis of tanks in the year 2000, 2008 and 2011 (area in Hectares)

Classification	2000	2008	2011	Causes / Processes
Weed	591.7	483.4	460.5	Weed infestation and increase in turbidity level took place within the tanks due the sedimentation and encroachment within the tanks took place due the unauthorized agricultural activity
Encroachment	398.5	383.2	455	
High turbid	238.3	275.9	197.7	
Medium turbid	52.8	27.1	28	
Low turbid	81.6	110.7	137.5	
Dry	22.6	104.8	106.8	

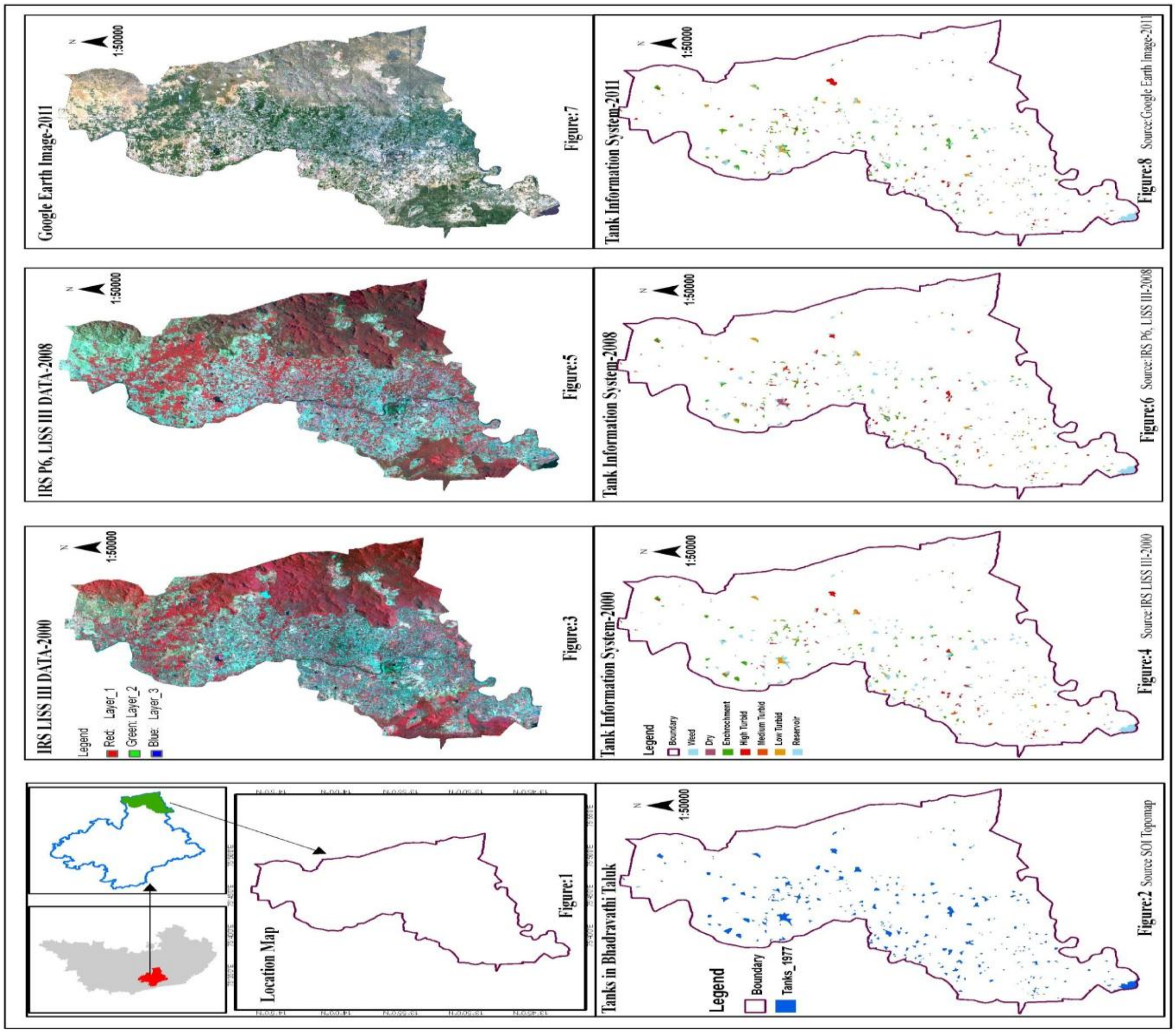


Conclusions

The present study demonstrates that Remote Sensing and GIS techniques are cost effective tools for identification, classification and monitoring of wetlands. It has helped in analyzing the wetlands to prepare scientific plans for systematic development of wetlands in Bhadravathi taluk. The majority of lost wetlands historically were drained or filled to create agricultural land, causing damage to wetland systems. After large areas of wetlands have been drained and destroyed, their importance has once again dawned back to mankind and efforts are being made protect the few remaining wetland although many wetlands are lost forever.

Acknowledgement

The authors take this opportunity to thank Chairman, coordinator (UGC-SAP) and all the senior faculties of the Department of Applied Geology, Kuvempu University for their encouragement and also indebted to UGC for the financial support to project No. KU/DV-4/07/2007-08.



References

Brown, P. H and Lant, C. L. (1999). The effect of wetland mitigation banking on the achievement of No-Net-Loss. *Environmental Management, vol 23:No.3, pp.33–45.*

Deepa, R. S and Ramachandra, T. V. (1999). Impact of Urbanisation in the interconnectivity of wetlands Paper presented at the National Symposium on Remote Sensing Applications for Natural Resources: Retrospective and perspective, (Jan 19-21, 1999) organised by Indian Society of Remote Sensing, Bangalore.

Mitsch, W. I and Gosselink, I. G .(1986) .*Wetlands*, Van Nostrand Reinhold, New York.

Syphard, A. D and Garcia, M. W. (2001). Human and beaver induced wetland changes in the Chickahominy River watershed from 1953 to 1994. *Wetlands, Volume: 21, Issue: 3, Pages: 342-353.*

Assessment of Spatial Changes in Coral Reef and Mangrove Environs of the Andaman Islands due to December 26, 2004 Sumatra Earthquake

Mahendra, R.S., Prakash, C. Mohanty, Hrusikesh Bisoyi, Sumisha Velloth, and Srinivasa Kumar, T.

Indian National Centre for Ocean Information Services (INCOIS), Hyderabad
E-mail: mahendra@incois.gov.in

Abstract

An archipelago island system of Andaman is consisting of 350 islands. The coastal environs of these islands are rich in bio-diversity. Most of the islands were rimed with fringing corals, and healthy mangroves were observed in the vicinity of the creeks. The Sumatra Earthquake on December 26, 2004 recorded a 9.3 Mw, not only generated devastating tsunami, but also created lot of tectonic disturbances in the Andaman region. As a result of this, northwestern parts of the land got uplifted above a meter from the earlier position. This resulted in lot of changes in the coastal environment. The shallow depth corals were exposed and degraded permanently. Moreover, the mangroves in the up streams were also degraded. A case study from the Interview Island in the northern Andaman has been selected to assess the changes. The assessment was carried out using the Remote Sensing and GIS techniques. The results help in understanding the spatial extent and the distribution of the damage caused due to this natural calamity on the coral and mangrove environment.

Introduction

Coastal resources are crucial factor to support life of coastal community. It is very essential for sustainable management of coastal resources to meet the present and future needs. The important coastal natural resources which are very much useful are Mangroves, Coral Reefs, useful Seaweeds, Wetlands, Minerals, Hydrocarbon and other organisms (Walters *et al.*, 1998; Jin *et al.*, 2002). The majority of human population (more than 60%) lives along the coastal zones and most of the communities and industries are depending on local resources for their livelihood. Mangrove and coral ecosystems are extremely important coastal resources. They are coastal ecosystems providing shelter for diverse habitats for different species and serves as a source of food, medicines, and forestry products. In addition to these mangrove and coral ecosystem, they also indirectly support to economic activity through nutrient recycling, water purification, and flood control. Coral Reefs and mangroves buffer along the specific coastlines act as a natural barrier for coast to protect from storm surges, Tsunamis, cyclones, floods, sea level rise, wave action and coastal erosion.

The mangrove and coral reef are the important natural resources that call for the immense attention towards their sustainable conservation. The remote sensing is a powerful tool to map these resources in order to assess the spatio-temporal changes. Besides, the Geographic Information

System (GIS) facilitates to extract the vital information out of the spatial datasets. There are several such works carried out on mangroves (Srinivasa Kumar *et al*., 2011; Blasco *et al*., 1998; Giri *et al*., 2007; Kathireshan and Rajendran 2005; Danielsen 2005) and coral reefs (Bahuguna *et al*., 2008; Mahendra *et al.,* 2008; Rajendran *et al*., 2008) monitoring using the geospatial techniques. However, the work on the exact quantification in terms of space and time was not brought out in this area. Hence, present study aims at demonstrating the technology to decipher the spatio-temporal changes in the coral and mangrove cover, due to 2004 Sumatra earthquake and tsunami in the Interview Island, Andaman. This study has brought out the accurate changes in the island due to 2004 tectonic disturbances with the aid of the satellite data from Landsat Enhanced Thematic Mapper (ETM) and Indian Remote Sensing Satellite (IRS) P6 Linear Imaging Self-scanning Sensor (LISS) III.

Study Area

The Andaman and Nicobar group of Islands are an example of archipelagoes system which covers about 350 islands (Bahuguna *et al.*, 2008). Interview Island lies in the northwestern part of Andaman Islands (Figure 1) in the Bay of Bengal. The geographical constraints of the Interview Island are 12.76 N to 13.00N latitudes and 92.64 E to 92.73 E longitudes. The island covers a total geographic area of about 88 km^2. The habitation in the island is nil except government and security officials. Andaman falls under tropical climatic condition experiencing a temperature within the range of 23°C to 31°C. There are no severe climate conditions in the region except for tropical storms and rains in late summers and monsoons.

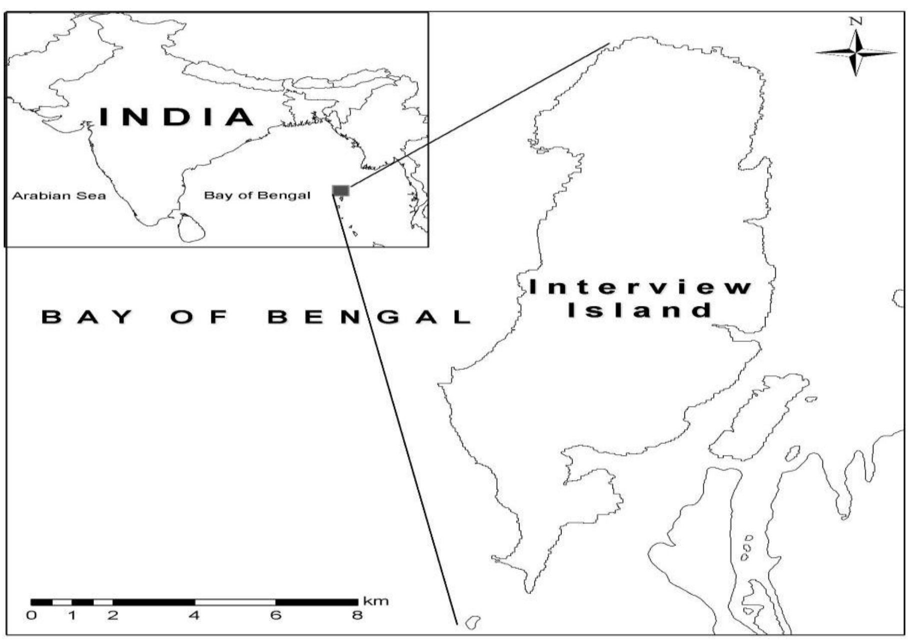


Figure 1. Map showing the study area

Data Used

The present study was carried out based on the available data (Table 1) with the aid of the in-situ observations. The Landsat ETM data acquired on February 07, 2000 (pre-tsunami) and IRS-P6 LISS-III data acquired on the February 06, 2006 (post-tsunami information) were used. The Landsat ETM data acquired on April 10, 2010 was used to assess the recent changes in the mangrove cover.

Table 1. Satellite data used for the study

Satellite	Sensor	Date of Acquisition	Spatial Resolution
IRS-P6 (Post Tsunami)	LISS-III	February 06, 2006	23.5 m
Landsat (Recent)	ETM	April 10, 2010	30 m
Landsat (Pre Tsunami)	ETM	February 07, 2000	30 m

Methodology

The spatiotemporal assessment of mangrove and coral reefs involves three main steps *viz*: pre-processing; processing and post processing. The pre-processing consists of geo-correction, area selection, radiance conversion and re-sampling. The Landsat ETM Ortho-rectified data acquired in 2000 and 2010 are downloaded from www.landsat.org website. Resourcesat-1 (IRS P6) LISS-III data of 2006 was obtained from the NRSC. IRS P6 LISS-III digital data of July 22, 2006 was geo-referenced for polynomial order 2 using Landsat ETM data

as the reference. A subset of a mangrove and coral reef area were extracted from all the images in order to minimize the classification inaccuracies. The appropriate band selection (Selvam *et al.*, 2003; Brian and Timothy, 1996; Green *et al*., 1998; Chauhan and Dwivedi, 2007; Srinivasa Kumar *et al.*, 2011) and the radiance conversion techniques (Lunetta, 1999; Chauhan and Dwivedi, 2007; Singh, 1989) were applied on the images before the classification. Then the LISS-III data of spatial resolution 23.5 m has been resampled to 30 m in order to be spatially comparable with ETM. The above two steps are making the multi-temporal and multi-resolution satellite data comparable spectrally and spatially respectively.

The processing of remote sensing data consists of classification and finalization of the classes using contextual editing. Iterative Self Organizing Data Analysis Technique (ISODATA) clustering was performed on individual images to segment them into possible classes, each depending upon the spectral signatures in green, red and infra-red bands. Using contextual editing the mangrove cover pertaining to the periods 2000, 2006 and 2010 were separated from other classes. The final classes of the coral eco-morphology were obtained by contextual editing with the aid of the ground truth information, to classify eco-morphological classes of coral reefs during 2000 and 2006.

In order to carryout post-processing, using GIS analysis, composites of the mangrove and coral eco-morphology composites were converted to Environmental Systems Research Institute (ESRI) shape files by raster to vector conversion techniques. These shape files were analyzed using GIS package ESRI Arc Map to assess the spatiotemporal changes in the coral and mangrove environs.

Results and Discussions

The current study focused on the assessment of the spatiotemporal changes in the coral reef and mangrove of interview Island before and after 2004 Sumatra earthquake. This earthquake has caused lot of tectonic disturbances in the region resulted in the land up lift (Toiba *et al*., 2006 and Rajendran *et al*., 2008) up to a meter and half. This has caused a catastrophic impact on the shallow corals resulting in the mass coral mortality. The change in coral eco-morphology (Figure 2B) was carried out using pre-earthquake (data acquired on 2000) and post-earthquake (data acquired on 2006). The results (Figure 2D) reveal that a total 17 km^2 area of corals were degraded and recorded as exposed coral reefs in 2006. It was the part of the healthy coral environment earlier (2000).

The earthquake caused devastating tsunami taking the life of several people and resources, which has not left even mangrove also. This impact is not that catastrophic when compared to coral. However mangroves were also recorded the spatial decline on relatively gradual time scale (Figure 2A). Hence the mangrove change study was further continued till 2010 to get clear scenario. The results of the spatiotemporal changes in the mangrove reveal net

spatial decline of mangrove cover was 4.48km^2 in the Interview Island (Figure 2C). The rate of decrease in the mangrove cover was 0.3km^2/y during 2000 to 2006. But it was 0.67km^2/y during 2006 to 2010 in a span of 4 years.

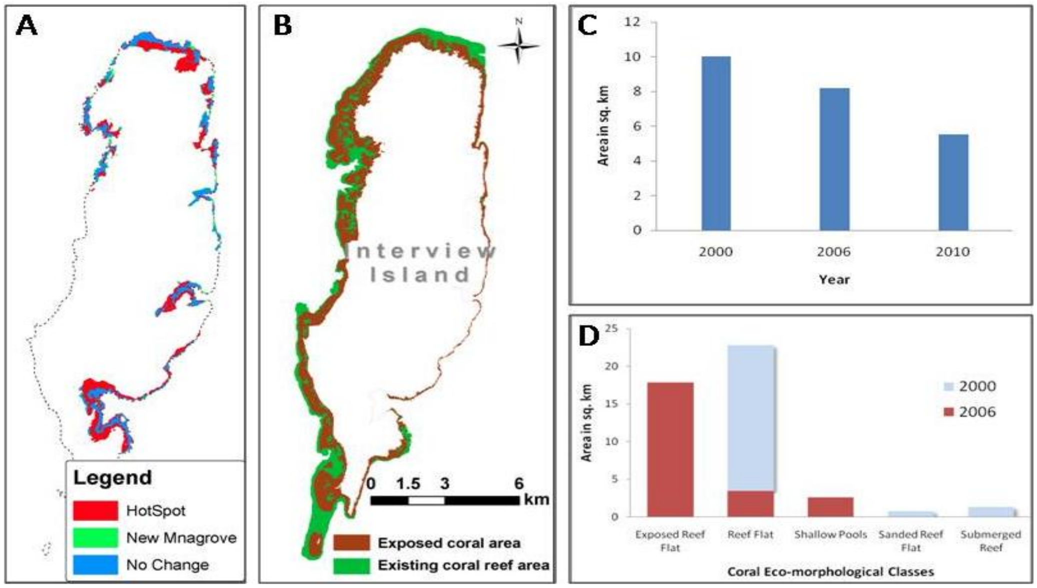


Figure 2 The plate showing the spatio-temporal changes in the mangrove cover (A) and coral eco-morphology (B). The bar diagrams representing the spatial changes in mangroves during 2000-2010 (C) and changes in the coral eco-morphology classes during 2000-2006 (D).

Conclusions

The present study aims at demonstrating the geospatial techniques such as remote sensing and GIS to quantify the impacts of natural disasters on the spatiotemporal changes in coral and mangrove environs. The data and techniques used in the study are able to quantify spatial changes at enhanced accuracy. Such studies are useful in understanding the damage caused on the important eco-systems. Further the study gives input to the eco-system modeling to understand diversity index and the implications on production in the coastal marine environment.

Acknowledgement

The authors would like to thank Dr. Shailesh Nayak, Secretary, MoES for encouragement. Authors are thankful to Director, INCOIS for facility and support. Thanks to CARI Andaman for support during in-situ campaign. Thanks to Global Observatory for Ecosystem Services (GOES), Michigan State University for the Landsat data

References

Bahuguna, A. Nayak, S. and Roy, D. (2008). Impact of the tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed

using RESOURCESAT AWiFS data, International Journal of applied Observation and Geoinformation, Vol. 10, pp. 229-237.

Blasco F, Gauquelin T, Rasolofoharinoro M, Denis J, Aizpuru M, Caldairou V (1998). Recent advances in mangrove studies using remote sensing data. Marine and Freshwater Research Vol. 49, No. 4, pp. 287–296.

Brian G. Long and Timothy D. Skewes (1996). A Technique for Mapping Mangroves with Landsat TM Satellite Data and Geographic Information System. Estuar Coast Shelf Sci Vol. 43, pp. 373–381.

Chauhan HB, Dwivedi RM (2007). Inter sensor comparison between RESOURCESAT LISS III, LISS IV and AWiFS with reference to coastal landuse/landcover studies. Int J App Earth Obs Geoinfo Vol. 10, No. 2, pp. 181-185.

Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A., Suryadiputra, N. (2005). The Asian tsunami: a protective role for coastal vegetation. Science Vol.310, pp. 643.

Giri, C., Bruce, P., Zhiliang, Z., Ashbindu, S. and Tieszen, L.L. (2007). Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuar Coast Shelf Sci Vol. 73, pp. 91-100.

Green, E.P., Clark, C.D., Mumby, P.J., Edwards, A.J. and Ellis, A.C. (1998). Remote sensing techniques for mangrove mapping. Int. J. Remote Sens Vol.19, No.5, pp.935-956.

Jin, J., Shenghong, R. and Lingjie, Z. (2002). A study on the cost of coastal zone resources (in Chinese with English abstract). Marine Environment Science, Vol.21, No.1, pp.63-67.

Kathiresan, K. and Rajendran, N. (2005). Coastal mangrove forests mitigated tsunami, Estuar Coast Shelf Sci Vol.65, pp.601-606.

Lunetta, R.S. (1999) Remote Sensing Change Detection; Environmental Monitoring Methods and Applications. In: R.S. Lunetta and C.D. Elvidge (Eds), Taylor & Francis, London, pp 318.

Mahendra, R. S., Bisoyi, H., Prakash, C. M., Velloth, S., Sinivasa Kumar T., Bahuguna, A. and Nayak, S., (2008). Spatio-temporal Variations in the Coral Environs of North Reef Island, Andaman: A Remote Sensing and GIS approach, *ISRS Symposium*, Ahemedabad, India.

Rajendran, K., Rajendran, K., Earnest, C.P., Ravi Prasad, A., Dutta, G.V.K., Ray, D. K. and Anu, R. (2008). Age estimates of coastal terraces in the Andaman and Nicobar Islands and their tectonic implications. Tectonophysics, Vol.45, pp.53–60.

Selvam, V., Ravichandran, K,K., Gnanappazham, L. and Navamuniyammal-Taramani, M. (2003) Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data. Curr Sci Vol.85, No.6, pp.795-797.

Singh A (1989) Review article—digital change detection techniques using remotely sensed data, Int J Remote Sens Vol.10, No.6, pp989–1003.

Srinivasa Kumar, T., Mahendra, R.S., Nayak, S., Radhakrishnan, K.R. and Sahu, K.C. (2011) Identification of hot spots and well managed areas of Pichavaram mangrove using Landsat TM and Resourcesat – 1 LISS IV: An example of coastal resource conservation along Tamil Nadu Coast, India. Journal of Costal Conservation, DOI: 10.1007/s11852-011-0162-3, In-press.

Tobita, M., Suito, H., Imakiire, T., Kato, M., Fujiwara, S. and Murakami, M. (2006).Outline of vertical displacement of the 2004 and 2005 Sumatra earthquakes revealed by satellite radar imagery, Earth Planets Space, Vol.58, e1-e4.

Walters, J.S., Maragos, J., Siar, S. and White, A.T. (1998) Participatory Coastal Resource Assessment: A Handbook for Community Workers and Coastal Resource Managers. Coastal Resource Management Project and Silliman University, Cebu City, Philippines.

Inventory and Assessment of Wetlands in Chikmagalur District using RS and GIS Techniques

Mohammed Saleem, I. Shaikh, Santhosh Kumar, B.C., Praveen, T. and Arun Kumar, T.D.

Karnataka State Remote Sensing Applications Centre, Bangalore, Karnataka
E-mail: salim_sirsi@yahoo.co.in

Abstract

To conserve and manage wetland resources, it is important to have inventory of wetlands and their catchments. IRS P6 LISS-III digital data of 1:50000 scale (pre and post monsoon) of Chikmagalur district, Karnataka was used for identifying wetlands. On-screen image interpretation techniques were adopted for identifying different wetland categories based on vegetation, visible hydrology and geography and also analysis of turbidity model using ERDAS imagine and Arc GIS. In Chikmagalur district, 1379 wetlands have been identified which covers an area of 23420 ha. This includes 963 wetlands which are smaller than 2.25 ha. The major wetland types are River/Stream (3146 ha), Reservoir/Barrages (12389 ha), Tanks/Ponds (6881 ha) and other minor wetlands 1004 ha. Wetland status with regard to open water and aquatic vegetation shows an area of about 3120 ha and 6560 ha respectively during post-monsoon and pre-monsoon period. The aquatic vegetation has increased more than double during post-monsoon season. Turbidity of the open water remained dominantly low in both the seasons.

Introduction

It is increasingly realized that the planet earth is facing grave environmental problems with fast depleting natural resources and threatening the very existence of most of the ecosystems. Serious concerns are voiced among scientists, planners, sociologists, politicians and economists to conserve and preserve the natural resources of the world. One of the difficulties most frequently faced for decision making is lack of scientific data of our natural resources. Often, the data are sparse or unconvincing and rarely in the form of geospatial database (map), thus open to challenges. The thrust of the present study is to have an appropriate geospatial database of natural resources that is based on unambiguous scientific methods. Inventory of wetlands of Chikmagalur district in Karnataka is an attempt in this direction.

Wetlands are transition zones between terrestrial and aquatic system where the water table is usually at or near the surface or the land is covered by shallow water. 'Wetland' is a generic term for water bodies of various types and include diverse hydrological entities, namely, lakes, marshes, swamps, estuaries, tidal flats, river flood plains, peat lands, shallow ponds *etc*. Wetlands must have one or more of the three attributes *viz*. the land supports predominantly hydrophytes; the substrate has predominantly undrained hydric soil; and the substrate is nonsoil saturated with water or covered by shallow water at sometime during the growing season of each year. Thus, wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry, dominant plants and soil or sediment characteristics. Because of their transitional nature, the boundaries of wetlands are often difficult to define. Wetlands do, however share a few attributes common to all forms. Of these, hydrological structure (the dynamics of water supply, storage and loss) is most fundamental to the nature of a wetland system. It is the presence of water for a significant period of time which is principally responsible for the development of a wetland.

To conserve and manage wetland resources, it is important to have inventory of wetlands and their catchments. The ability to store and analyse the data is essential. Digital maps are very powerful tools, because the feature on a map has geographical location and has a strong visual impact. Maps also give scope for monitoring and quantifying the change over time scale and assist in decision making. Recent years have seen advances in remote sensing and geographic information system (GIS) techniques for mapping various resources.

Objectives

The main objectives of the study are to map the wetlands on 1:50000 scale using two date (pre and post monsoon) IRS LISS-III digital data following a standard wetland classification system, integration of ancillary theme layers (road, rail, settlements, drainage and administrative boundaries) and Creation of digital database of wetlands for Chikmagalur district in GIS environment.

Study area

The Chikmagalur district lies in the south-western part of Karnataka State having a total geographical area of 7,201 sq km and a population of 11,40,905 (Census, 2001). It lies between 12°54'42'' and 13°53'53'' N latitudes and 75°04'46'' and 76°21'15'' E longitudes. It comprises of seven taluks *viz.*, Chikmagalur, Kadur, Koppa, Mudigere, Narasimharajapura, Sringeri and Tarikere (Figure-1a). Chikmagalur district is drained by Bhadra, Vedavati and Tunga rivers and has a major reservoir built across Bhadra river near Narasimharajapura and the other one is Jammada Halla Reservoir at Uggalapura, Tarekere Taluk.

Materials and Methods

IRS P6 LISS III data(23.5 m) was used to map the wetlands. The spatial resolution is suitable for 1:50,000 scale mapping. LISS III data of post- monsoon and pre-monsoon have been used for interpretation and analysis (Fig-1c & 1d). Surveys of India topographical maps of the year 1977 and 1978 were used. The image analysis was done using ERDAS Imagine, Arc/Info and Arc GIS softwares. The methodology adopted for inventory of wetlands is presented in Fig.2.

Mapping of wetlands

In the present study, the mapping of wetlands was done following digital data display and onscreen visual interpretation. Wetlands were identified based on vegetation, visible hydrology and geography. The five indices that enhance various wetland characteristics were used (National Wetland Atlas of Karnataka, 2010) and are given below:

i) Normalised Difference Water Index (NDWI) = (Green-NIR) / (Green + NIR)
ii) Modified Normalised Difference Water Index (MNDWI) = (Green-MIR) /(Green + MIR)
iii) Normalised Difference Vegetation Index (NDVI) = (NIR - Red) / (NIR + Red)
iv) Normalised Difference Pond Index (NDPI) = (MIR – Green / MIR + Green)
v) Normalised Difference Turbidity Index (NDTI) = (Red – Green) / (Red + Green)

The indices were generated using standard image processing software and stacked as layers. Various combinations of the indices/spectral bands were used to identify the wetland features of different seasons (Figs-1i & 1j). The following indices were used for various layer extractions. MNDWI, NDPI and NDVI images were used to extract the wetland boundary through suitable hierarchical thresholds. MNDWI was used within the wetland mask to delineate the water and no-water areas. NDPI and NDVI images were used to generate the vegetation and no-vegetation areas within a wetland using a suitable threshold. MNDWI image was used to generate qualitative turbidity level (high, moderate and low) based on signature statistics and standard deviation. In the False Colour Composite, these generally appear in different hues (Table 1).

Table 1: Qualitative ***turbidity ratings***

Sl No.	Qualitative Turbidity	Conditional criteria	Hue on FCC
1.	Low	$> +1\sigma$	Dark blue/blackish
2.	Moderate	$> -1\sigma$ to $<= +1\sigma$	Medium blue
3.	High/Bottom reflectance	$<= \mu - 1\sigma$	Light blue/whitish blue

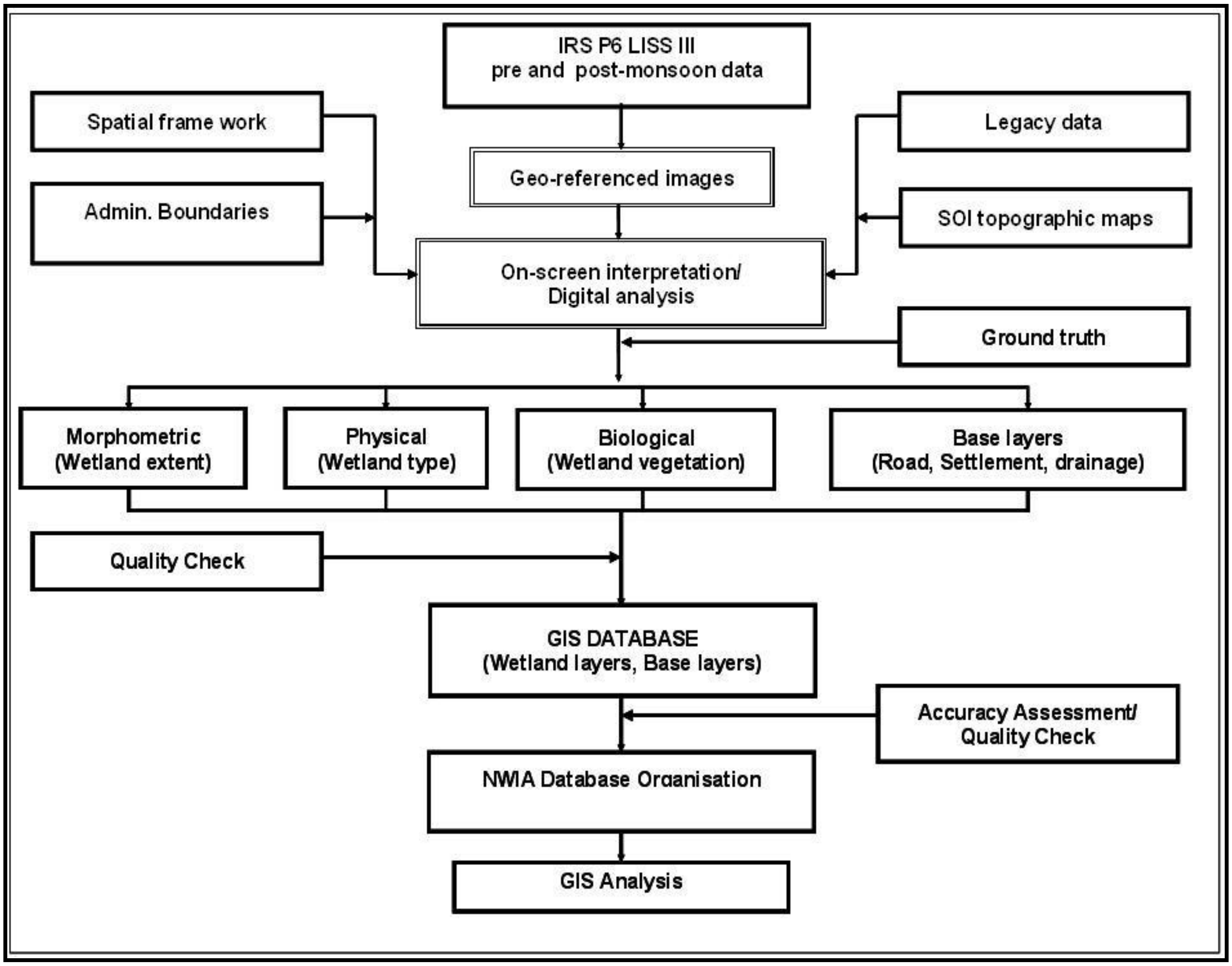


Figure 2 Schematic Flowchart showing the methodology adopted.

Results and Discussion

Area estimates of various wetland categories for Chikmagalur have been carried out using GIS layers of wetland boundary, water-spread, aquatic vegetation and turbidity. In the district of Chikmagalur, 1379 wetlands have been identified it includes 963 wetlands smaller than 2.25 ha. Total wetland area estimated is 23420 ha. Details of the wetland statistics is given in Table 2. The major wetland types are River/Stream (3146 ha),Reservoir/Barrages (12389 ha) and Tanks/Ponds (6881 ha). Analysis of wetland status in terms of open water and aquatic vegetation showed that around 3120 ha and 6560 ha of wetland area is under open water category during post-monsoon and pre-monsoon respectively. Qualitative turbidity analysis of the open water showed that low, moderate and high turbidity prevails.

Table 2 Area estimates of wetlands in Chikmagalur District

Area estimates of Wetlands in Chickamagalur ,Area in ha.							
Sl.no.	**Wettcode**	**Wetland category**	**No. of**	**Total wetland**	**% of**	**Open water**	
			Wetlands	**area**	**Wetland area**	**Premansoon**	**Postmansoon**
1	**1100**	**InlandWetlands - Natural**					
2	1101	Lakes / Ponds	5	20	0.09	16	12
3	1105	Waterlogged	3	10	0.04	19	10
4	1106	River / Stream	12	3146	13.43	2960	3005
5	**1200**	**InlandWetlands -Man - made**					
6	1201	Reservoirs/Barrages	2	12389	52.9	12284	7373
7	1202	Tanks/Ponds	393	6881	29.38	3506	1777
8	1203	Waterlogged	1	11	0.05	10	11
		Total - Inlands	416	22457	95.89	18795	12188
		Sub total	416	22457	95.89	18795	12188
		Wetlands (<2.25 ha), mainly Tanks	963	963	4.11	0	0
		Total	1379	23420	100.00	18795	12188
		Area Aquatic Vegetation				3210	6560
		Area under turbidity levels					
		Low				12581	6973
		Moderate				5384	3643
		High				830	1572

Table 2 Area estimates of wetlands in Chikmagalur District

Fig:1a

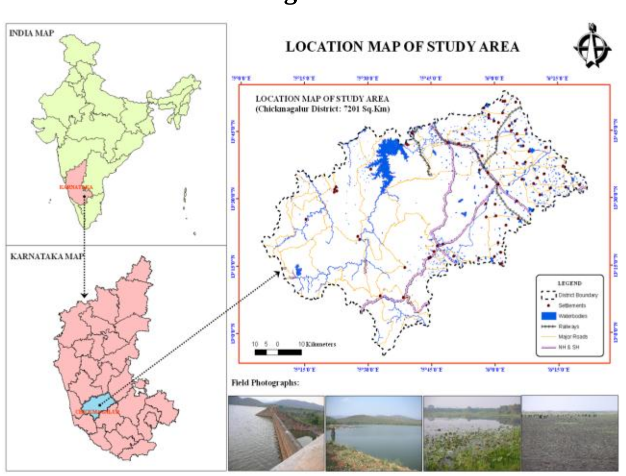


Fig:1b

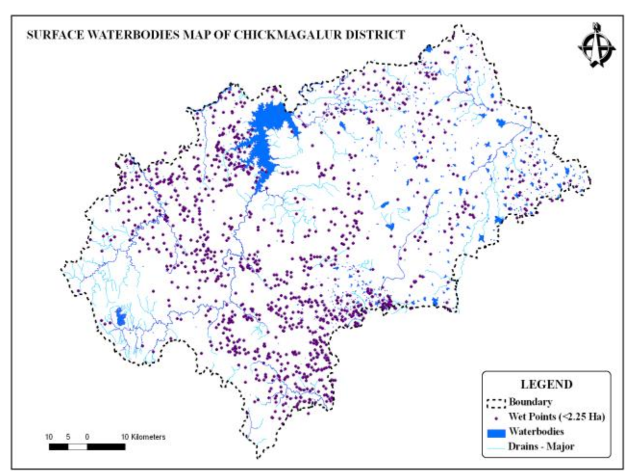


Fig-1c

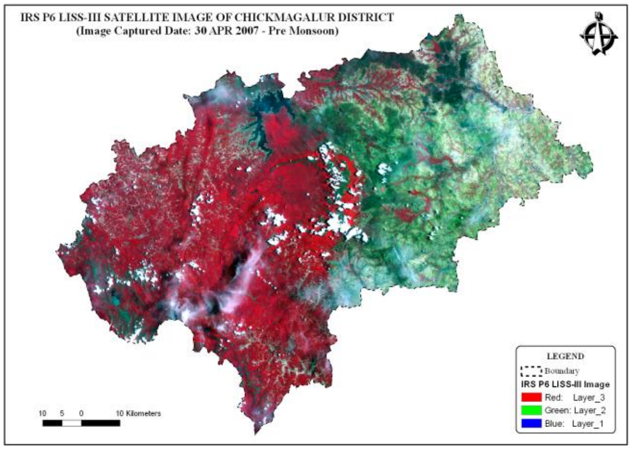


Fig-1d

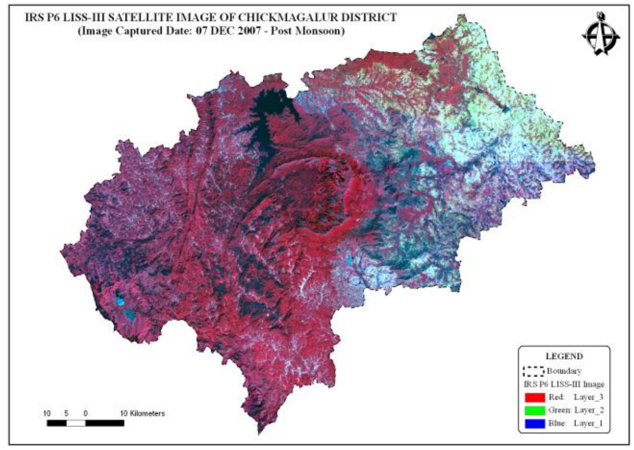


Fig-1e

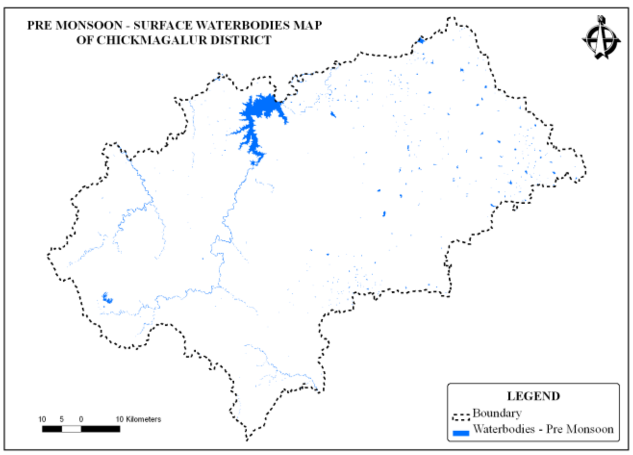


Fig-1f

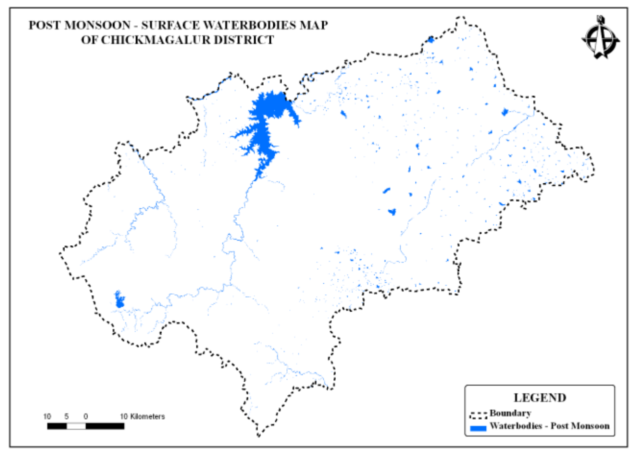


Fig-1g

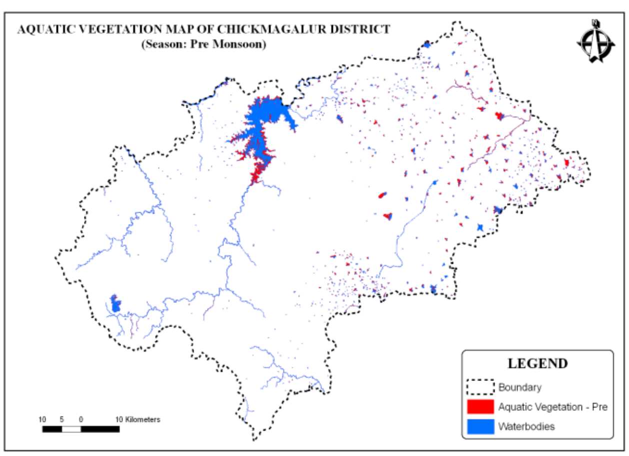


Fig-1h

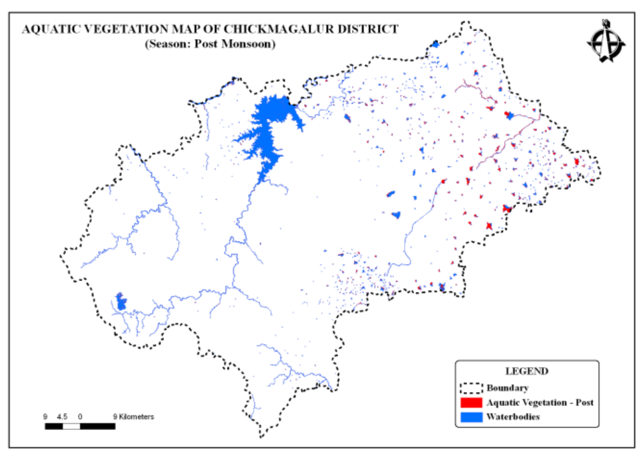


Fig-1i

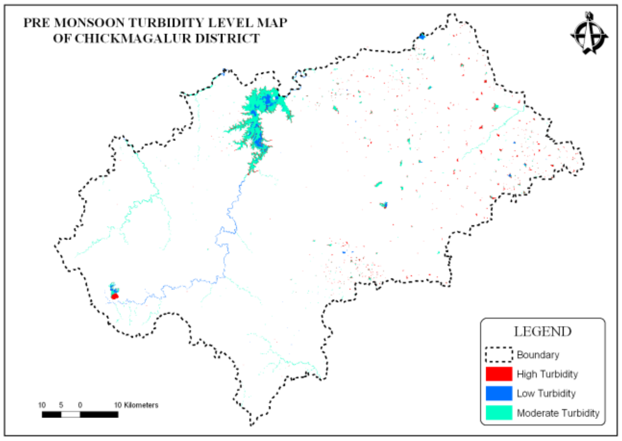


Fig-1j

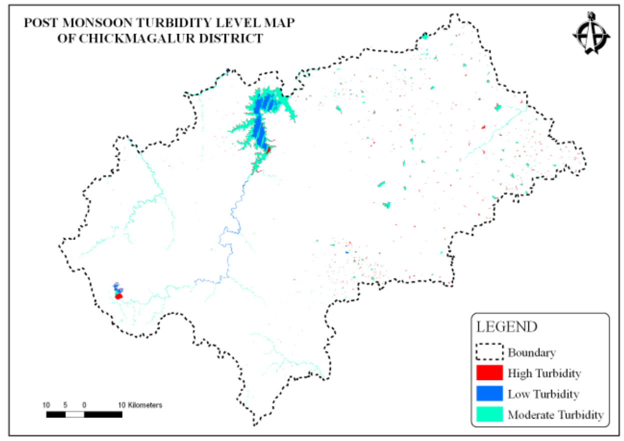


Fig. 1 ***1a***-Location map of the study area, *1b*-Surface water bodies and drainage network map, *1c*-premonsoon satellite image of IRS P6 LISS-III sensor, *1d*-postmonsoon satellite image of IRS P6 LISS-III sensor, *1e*-Surface water body map of pre-monsoon season, *1f*-Surface water body map of post-monsoon season, *1g*-Aquatic vegetation map of pre-monsoon season, *1h*-Aquatic vegetation map of post monsoon season, *1i*-Turbidity classification map of pre-monsoon season and *1j*-Turbidity classification map of post-monsoon season.

References

National Wetland Atlas of Karnataka (2010). (Karnataka State Remote Sensing Application Centre, Bangalore and Space application Centre, Ahmedabad).

Mapping of Ground Water Prospect Zones in Bazarhatnoor Watershed, Adilabad District, Andhra Pradesh Using Remote Sensing and GIS

G.Gautham, A.Nageswara Rao and K.Mruthyunjaya Reddy

A.P. State Remote Sensing Applications Centre, Swarnajayanthi Complex, Ameerpet, Hyderabad, Andhra Pradesh
E-mail: gautham_naru@yahoo.com

Abstract

It has been found that remote sensing, besides helping in targeting potential zones for ground water exploration, provides inputs towards estimation of the total ground water resources in an area, the selection of appropriate sites for artificial recharge and the depth of weathering in the area. By combining remote sensing information with adequate field data, particularly well inventory and yield data, it is possible to arrive at prognostic models to predict the ranges of depth, yield, success rate and types of wells suited for various terrains under different hydro geological domains. In the present study, an attempt has been made to evaluate the hydrogeological characteristics for ground water prospect of Bazarhatnoor watershed, Adilabad District using Remote Sensing and GIS techniques coupled with field surveys. The watershed is having an area of about 36 Sq.Km and lies between latitude 19^0 30' 30" to 19^0 26' 59" N and longitude78^0 18' 00" to 78^0 22' 25" E. Geologically the entire study area is covered by Deccan Basalts comprising nearly horizontal lava flows of late Cretaceous to early Eocene period. In Deccan Basalt terrain ground water occurs in the lava flows under semi confined conditions at deeper levels. Lithological characteristic indicate that the ground water is present in the joints in the vesicular, amygdaloidal basalt and in the jointed and fractured portions of the compact basalt flows. The ground water potential of the area has been assessed through integration of the hydrogeology, lineament, slope and aquifer thickness. The ground water potential zone map generated through the Hydro Geomorphology map, base maps and, remote sensing was verified with the yield data to ascertain the validity of the potential zones. The verification showed that the ground water potential zones demarcated through the map are in agreement with the bore well yield data. The above study has clearly demonstrated the utility of remote sensing and hydrogeological studies in the demarcation of the different ground water potential zones.

Introduction

The availability of surface and ground water governs the process of planning and development. The surface water resources are inadequate to fulfill the water demand for agriculture and other purpose. Productivity through ground water is quite negligible as compared to surface water, but ground water resources have not yet been properly developed through exploration. Keeping this in view, the present study has been made to select suitable sites for ground water exploration in hard rock areas using an integrated approach of remote sensing, GIS and hydro geological characteristics, and to evaluate the ground water potential of Bazarhatnoor watershed. The area falls under semiarid subtropical climate with average annual rainfall of 901 mm.

Study Area

In the present study, an attempt has been made to evaluate the hydrogeological characteristics for ground water prospect of Bazarhatnoor watershed, Adilabad District using Remote Sensing and GIS techniques coupled with field surveys. The watershed is having an area of about 36 Sq.Km and lies between latitude 19^0 30' 30" to 19^0 26' 59" N and longitude78^0 18' 00" to 78^0 22' 25" E (Fig.1).

Methodology

The study was carried out in the Bazarhatnoor watershed by using IRS-P6 Satellite LISS-IV Imagery (FCC- Geo-coded) generated from bands 1, 2 and 3 on the scale 1:10,000. Drainage map of the study area was prepared from the toposheet No 56 I/06 and 56 I/07 of Survey of India on 1:50,000 scale (Fig.2).

The thematic maps were prepared by using standard interpretation key such as colour, tone, texture, pattern of drainage, shape, topography etc. Thematic maps like Geology, Structural/Lineament, Drainage, Base and Land use maps were prepared using LISS IV image, and by integrating these maps hydro-geomorphological map was generated. The conventional information such as geological and hydrogeological information collected during the field checks were used in the finalization of the hydrogeomorphological map (Fig.3).

Results and Discussion

Geologically the entire study area is covered by Deccan Basalt formations comprising nearly horizontal lava flows of late Cretaceous to early Eocene period. These flows have been considered to be a result of fissure type of lava eruption during late Cretaceous to early Eocene period. The type of basalt occurring in the area is compact basalt, vesicular, amygdaloidal basalt and Tachylitic bands as observed in the well sections. Quaternary sediments are confined to the lower reaches, of the Kadem River. The area is traversed by various lineament and most of them are in NW-SE, NNE-SSW, NNW-SSE directions (Fig.4).

The lineaments are found to be better repositories of ground water (Murthy and Jayaram 1996). Lineaments look as narrow linear features with dark tone due to high moisture content and look red due to presence of vegetation. Presence of lineaments in a geomorphic unit increases the prospects of ground water. Lineament analysis for ground water exploration in Deccan basalt formations has considerable importance as joints and fracture serve as conduits for movement of ground water. It is not practical to map lineaments solely on the basis of satellite data without a thorough knowledge of the structural conditions in an area. For extraction of lineaments, the procedure of Moore and Waltz (1986) has been carefully matched with previously mapped structural features and a good degree of correlation between the three has been found.

In Deccan basalt terrain ground water occurs in the lava flows under semi confined conditions at deeper levels. Lithological characteristics indicate that the ground water is present in the joints in the vesicular amygdaloidal basalt and in the jointed and fractured portions of the compact basalts flows. The primary porosity in the basalts is associated with the vesicles, which are the pore spaces developed due to the escape of volatile gases when the lava erupts on the surface as a lava flow. This primary porosity in the basalt is naturally limited and related to the quantum of volatile gasses in the eruptive phase, which forms the basalt flow. The ground water in the study area therefore is restricted mostly to the zones of secondary porosity developed in these rocks due to fractures, joints and weathering. Two type of lava flows have distinct qualities as for as their porosity and permeability are concerned. These are described in detail below.

In amygdaloidal basalt flow the original gas cavities are filled up with secondary minerals obliterating original vesicular nature. Fresh amygdaloidal basalt will be free from joints and occur as homogeneous watertight mass (Karmarkar *et al*.(1994), Patil *et al*. (1999), and Babar (2001), (2002)). The vesicular amygdaloidal basalts are more susceptible for deep weathering. It is characterized by the formation of sheet joints. Basalt with that and weathered amygdaloidal basalts contains ground water. However, quantity of ground water depends upon the thickness of weathered zone.

It has been found that remote sensing besides helping in targeting potential zones for ground water exploration provides inputs towards estimation of the total ground water resources in an area, the selection of appropriate sites for artificial recharge and the depth of the weathering in the area. By combining remote sensing information with adequate field data, particularly well inventory and yield data, it is possible to arrive at prognostic models to predict the ranges of depth, the yield, the success rate and the types of wells suited for various terrains under different hydro geological domains. Figure 5 shows ground water potential zone in the watershed.

Conclusions

The ground water potential of the area has been assessed through integration of the hydrogeology, lineament, slope and aquifer thickness. The ground water potential zones map generated through the hydrogeomorphology map base map and remote sensing was verified with the yield data to ascertain the validity of the potential zones. The verification showed that the ground water potential zones demarcated through the map are in agreement with the bore well yield data. The above study has clearly demonstrated the capabilities of hydrogeological studies and remote sensing in demarcation of the different ground water potential zones.

References

APSRAC (1997). Integrated Study to combat drought Anantapur District, Andhra Pradesh; Technical report, 102p.

Bhave, K.N., Ganju, J.L. and Jokhan Ram (1989). Origin, nature and geologic significance of lilneaments In Regional Geophysical Lineaments. Their Tectonic and Economic Significance (ed.M.N.Qureshy and W.J.Hinze). Mem. Geol. Soc. India, pp.305.

CGWB (2010). Application of Remote Sensing and GIS in Water Resources Management.

Krishnamoorthy J and Srinivas G (1995): Role of geological and geomorphological factors in ground water exploration. A study using IRS LISS II data. Int. Jour. of Rem. Sens., V 16 (14): pp 2595.

Moore. G., and Waltz, F.A. (1986). Objective procedure for lineament enhance-ment and extraction, Photogrammetric Engineering and Remote Sensing, 49, pp 641-647.

NRSC (2010). Manual for National Geomorphologic and Lineament Mapping, 2010, Hyderabad.

NRSA (2007). Manual of National Wide mapping of Land degradation using Multi-Temporal Satellite Data, Department of Space, Hyderabad.

NRSA (2006). Manual of National land use land cover mapping using multi temporal satellite data, Hyderabad.

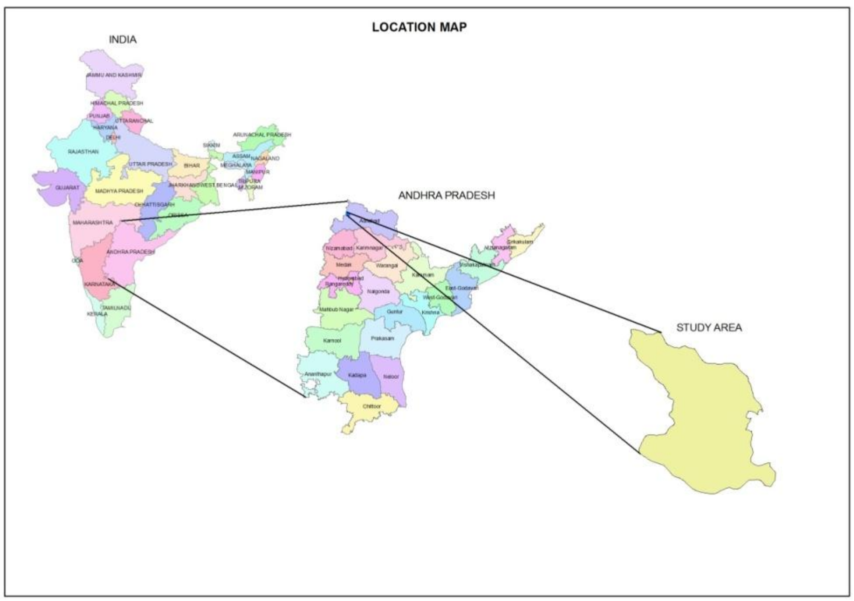


Figure 1 Location map of the study area

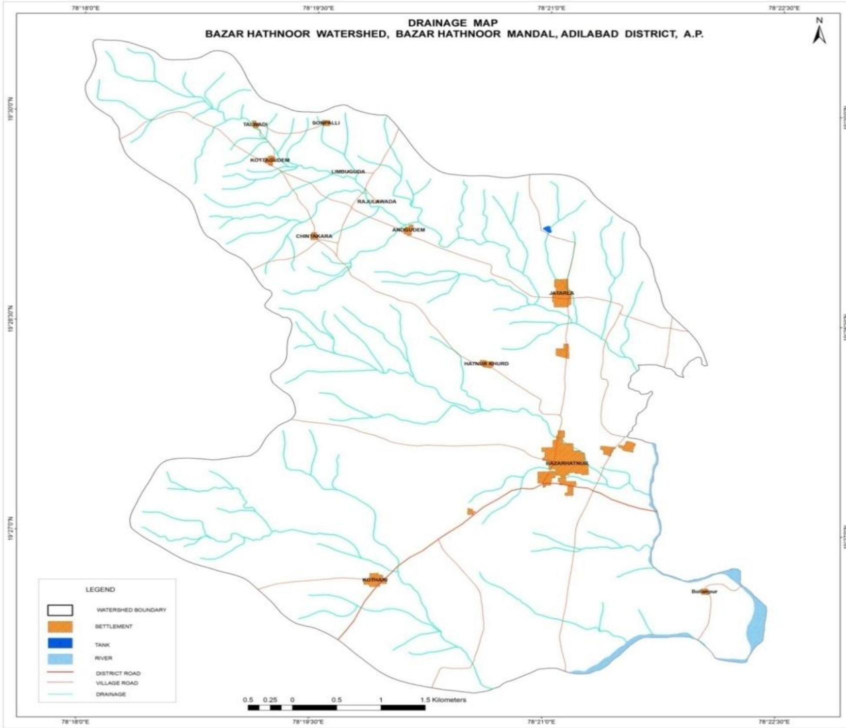


Figure 2 Drainage map of the study area

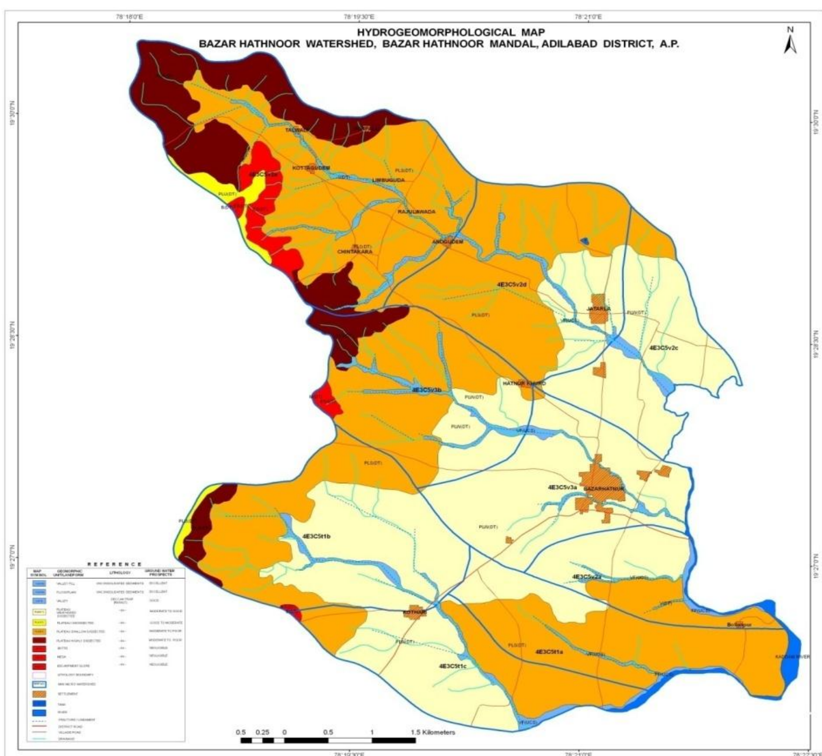


Figure 3 Hydrogeomorophological map of the study area

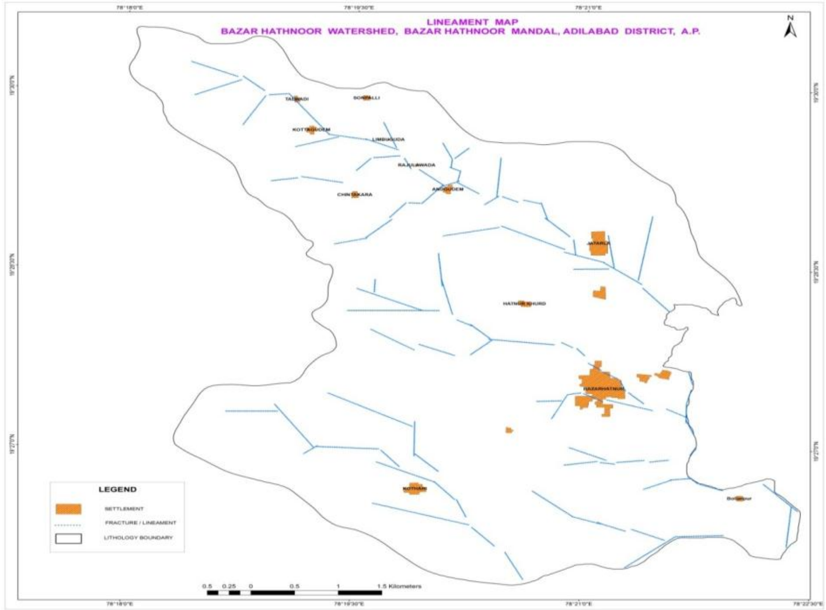


Figure 4 Structural/Lineament map of the study area

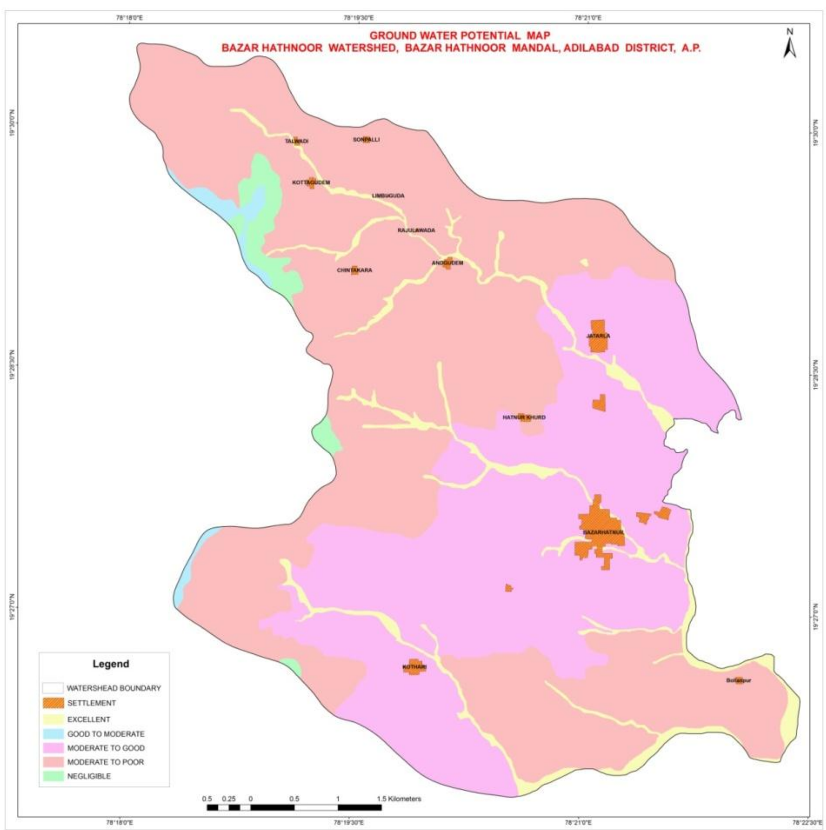


Figure 5 Ground water potential map the study area

Assessment of Drainage Network Derived from ASTER and SRTM Digital Elevation Datasets in a Tropical River Basin, Kerala

Babu, P., Gigo Pulikkottil[1], Ashitha, M. K.[1] and Girish Gopinath[2]

[1]*Department of Civil Engineering, Government Engineering College, Thrissur, Kerala*
[2]*Remote Sensing Cell, Centre for Water Resources Development and Management, Kozhikode, Kerala*
E-mail: gigopulikkottil@gmail.com

Abstract

Study of drainage network has pivotal role in any river basin management and planning practices. Deriving the drainage network manually from topomaps is tedious and time consuming task. Automated generation of drainage networks with powerful analytical functions in Geographic Information Systems (GIS) has reduced this and is very useful in deriving drainage maps. ASTER DEM can be a paramount tool for drainage network analysis of river basin, especially for mountain and pediment sectors. In this paper, study on drainage network of the Chaliyar river basin in Kerala was carried out with Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), Digital Elevation Model (DEM) and Shuttle Radar Topography Mission (SRTM) DEM, through Terrain Preprocessing and Spatial Analyst tools available in Arc GIS. Flow direction, flow accumulation, stream definition and stream segmentation were found out by terrain processing tool and stream ordering was done by Strahler method using spatial analyst tool. The number of first order streams derived from ASTER DEM was compared to drainage network of SRTM DEM. The elevation data from both ASTER DEM and SRTM DEM of the upstream part of the river basin shows more truthfulness than downstream segment.

Introduction

Digital Elevation Model (DEM) became the primary source of automated derivation of hydrological features, through different space born and aerial remote sensing platforms along with Geographic Information Systems (GISs). In the current scenario, Digital Elevation Models are available from different sources and at different spatial resolutions. Elevation data used to create DEM are available from topographic maps, LIDAR, stereo photogrammetry from aerial surveys, and resampled satellite images. DEMs are extensively employed in watershed modeling through derivation of flow networks and watershed boundaries for specified outlets using GIS technology [Tran Thi Thu Hien and Le Van Trung 2004]. An essential element to flow network derivation is a hydrologically sound DEM of the area of interest. Hence DEMs available from different sources needs to be assessed for the suitability of flow network derivation. Therefore in this paper the efficiency of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Global DEM and Shuttle Radar Topography Mission (SRTM) DEM are assessed by comparison of extracted river network.

Study Area

The Chaliyar River is the fourth longest river (169km) in Kerala (Figure 1). Total drainage area of Chaliyar river is 2,923sq km, out of which 2,535sq km is in Kerala and the rest in Tamil Nadu. It originates in the Western Ghats range at Elambalari Hills (11.183°N 75.817°E) located near Cherambadi town in the Nilgiris district of Tamil Nadu and flows through Malappuram District for most of its length and then it forms the boundary between Malappuram District and Kozhikode District for about 17 km before entering the city of Kozhikode for its final 10 km journey and finally empties into the Arabian Sea. Some of the Chaliyar's tributaries originate from Wayanad District and joins the main river in Malappuram. Its major tributaries are Cherupuzha, Iruvanjippuzha, Kuthirappuzha, Kuruvanpuzha, Kanjirappuzha, Karimpuzha, Pandippuzha, Neerppuzha, Karakkodan puzha, Maruthappuzha, Punnappuzha, Muthappanpuzha, Chalippuzha, Pulingappuzha, Kadungampuzha, Iruthullippuzha and Engappuzha. In the location map (figure 3), chaliyar basin falling within Kerala is shown as hatched area. The Area of Interest (AOI) of Chaliyar river basin on SRTM DEM and ASTER DEM are shown in figure 4 and figure 5.

Materials and Methodology

ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) is a Japanese on board sensor in the Terra satellite launched into Earth orbit by NASA in 1999 as part of NASA's Earth Observing System (EOS). ASTER covers a wide spectral region with 14 bands from the visible to the thermal infrared wavelengths; and provides stereo viewing capability for digital elevation model creation [https://wist.echo.nasa.gov.].

Bands 3N (nadir-viewing) and 3B (backward-viewing) of an ASTER Level-1A image acquired by the Visible Near Infrared (VNIR) sensor are used to generate the ASTER Digital Elevation Model (DEM). The Band-3 stereo pair is acquired in the spectral range of 0.78 and 0.86 microns with a base-to-height ratio of 0.6 and an intersection angle of about 27.7°. There is a time lag between the acquisition of the nadir and backward images of approximately one minute. The images are georeferenced to the WGS-84 datum and Universal Transverse Mercator (UTM) projection. The ASTER Global Digital Elevation Model (GDEM) was released to the public on 29 June 2009 and it covers the planet from 83 degrees North to 83 degrees South (99% of earth's surface) having a spatial resolution of 30m.

The objective of the Shuttle Radar Topography Mission (SRTM); a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) was to produce digital topographic data for 80% of the Earth's land surface (all land areas between 60° north and 56° south latitude) at 3 arc second resolution (approximately 90 m at the equator). The SRTM is projected into a geographic coordinate system (GCS) with the WGS84 horizontal datum and the EGM96 vertical datum. The USGS and the Consultative Group on International Agricultural Research - Consortium for Spatial Information (CGIAR-CSI) utilizes the NGA-distributed "Finished" grade SRTM and applies a post-processing hole-filling algorithm to address the data void regions remaining in the "Finished" grade SRTM DEM and is offering post-processed 3-arc second DEM data for the globe in 5 degree by 5 degree tiles [http://srtm.sci.cgiar.org].

The Area of Interest (AOI) was extracted initially from ASTER GDEM and SRTM DEM, using Extract by mask tool of Spatial Analyst Extension, available in ArcGIS 9.3 software (figure 2).

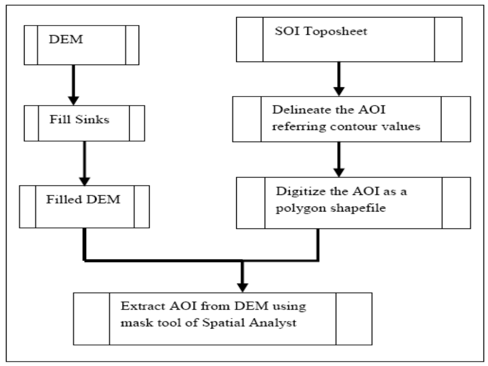


Figure 2: AOI Extraction

Assessment method employed to evaluate the ASTER DEM and SRTM DEM by automatic drainage network extraction using GIS technology comprises the following. automated extraction of drainage network from ASTER DEM using ArcGIS package, Automated extraction of drainage network from SRTM DEM using ArcGIS package and comparison of two results, arc Hydro tools (version 1.2) developed on top of the Arc Hydro data model; an application extension for ArcGIS software (version 9.3) recently released by ESRI (© 2002) was used to extract drainage network from ASTER Global DEM, in raster format with a 30m x 30m grid cell size. Method for automated drainage network extraction and stream involve series of steps (figure 3) starting with AOI of filled ASTER GDEM. The threshold for stream definition is defined as a number of cells (default 1% of total derived drainage cells). For comparing the performance of DEM, the size of the threshold was modified to reach the established stream order for the basin.

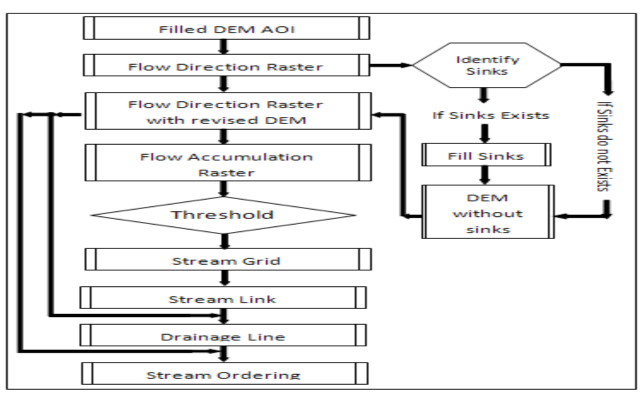


Figure 3: Conceptual work flow for Drainage Network Extraction and Stream ordering

For SRTM DEM, in raster format with a 90m x 90m grid cell size also, Arc Hydro tools was used with ArcGIS software (version 9.3). Method of automated drainage network extraction and stream ordering, followed a series of steps (figure 3) starting with AOI of filled SRTM DEM. For comparing the performance of DEM, the size of the threshold was modified to reach the established stream order for the basin. Both DEM was assessed by comparing the derived stream attributes. Centre for Water Resources Development and Management (CWRDM), Kerala has established the Stream order for tropical river basin in Kerala under consideration, in Water Atlas published in 1995. The threshold level required to attain the established stream order of the basin was compared as a fixed percentage of total drainage cells derived in both DEM. Obviously both networks contain errors, but to assess the performance of both source of Digital Elevation Model; derived stream attributes was compared as percentage difference between both DEMs.

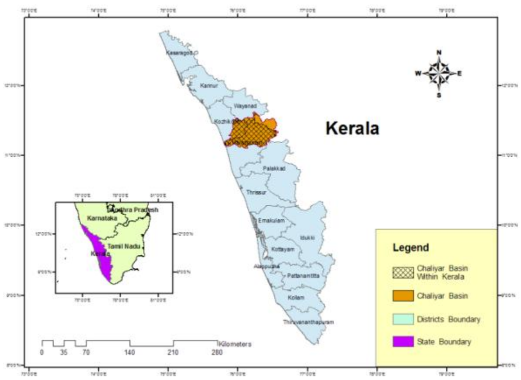


Figure 1: Location Map

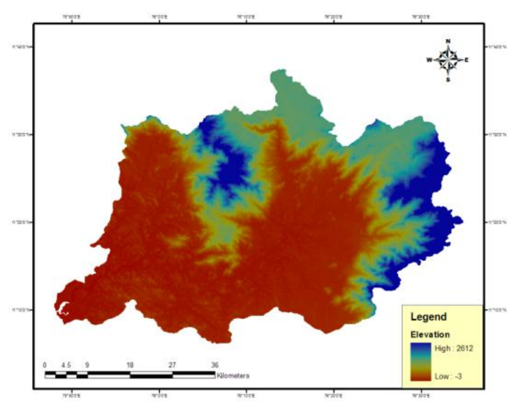


Figure 4: Chaliyar AOI (SRTM DEM)

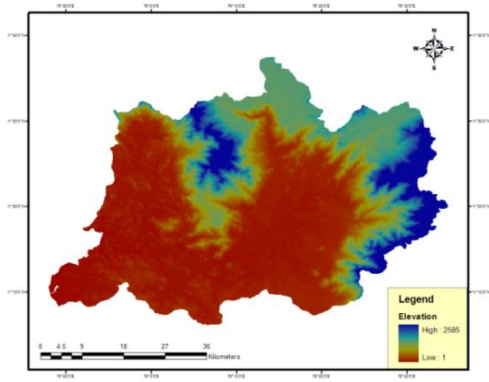


Figure 5: Chaliyar AOI (ASTER DEM)

Results and Discussion

Decrease of 'Stream Orders' and 'Length of Drainage Network' were resulted for higher threshold values. For ASTER DEM 2718282 drainage cells were derived through flow accumulation operation and for SRTM DEM only 311617 drainage cells were. This is due to the increased resolution of 30 x 30 grids for ASTER compared to 90 x 90 grids for SRTM DEM (i.e., derived drainage cells in ASTER was 9 times higher than that for SRTM DEM). For different threshold values, resulting network was higher for ASTER DEM. Comparing the flow accumulation pattern of ASTER and SRTM DEM (figure 6 and figure 7) it can be noticed that, towards the alluvial plains the drainage pattern of ASTER DEM shifts. This needs further analysis and research to identify the possible causes. It may be resolved by applying different threshold levels for mountain and pediment sectors compared to alluvial planes [Peter G. Chirico 2004].

Table 1: Comparison of Threshold Drainage Cells as Percentage of Total Drainage Cells in Both DEM

DEM	Threshold value (no of cells)	% of total drainage cells	Resulting Length of network (km)	Stream Order
ASTER	27	0.001%	15353.05	8
SRTM	3		13629.27	8
ASTER	109	0.004%	6093.59	7
SRTM	12		5918.13	7
ASTER	217	0.008%	4365.17	7
SRTM	25		4164.84	7
ASTER	353	0.013%	3431.94	6
SRTM	41		3311.08	6

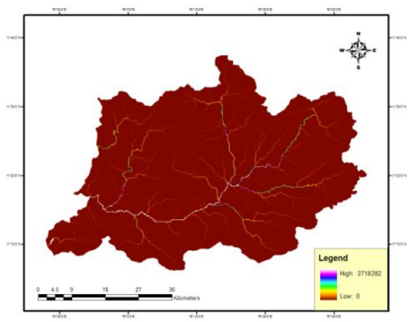


Figure 6: Flow Accumulation Pattern of ASTER DEM

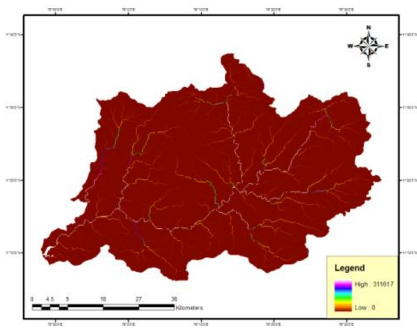


Figure 7: Flow Accumulation Pattern of SRTM DEM

Table 2: Drainage Network Length from ASTER and SRTM DEM for 0.001% Threshold level

Stream	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
ASTER	8762.	3299.4	1652.6	783	475.	174.	137.	68.1	**15352.9**
SRTM	7558.	3078.8	1479.8	751.	387.	151.	142.	80.2	**13629.4**
Difference	13.74	6.69	10.46	4.06	18.5	12.9	-3.35	-	**11.23**

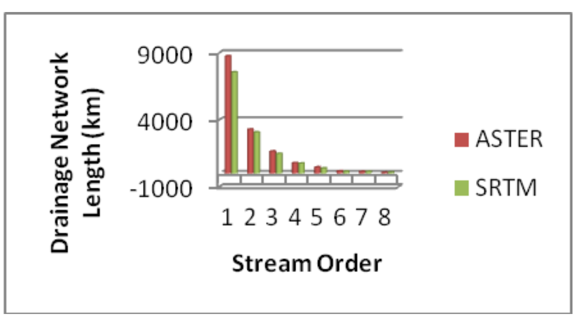


Figure 8: Graph comparing length of drainage network for 0.001% Threshold level

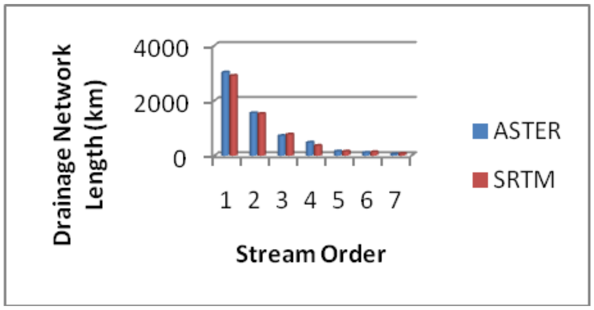


Figure 9: Graph comparing length of drainage network for 0.004% Threshold level

Table 3: Drainage Network Length from ASTER and SRTM DEM for 0.004% Threshold level

Stream Order	1	2	3	4	5	6	7	Total
ASTER	3026.9	1544.6	721.1	476	158	112.3	54.6	**6093.5**
SRTM	2901.4	1521.8	771.8	362.4	150.6	135	75.1	**5918.1**
Difference (%)	4.15	1.48	-7.03	23.87	4.68	-20.21	-37.55	**2.88**

Table 4: Drainage Network Length from ASTER and SRTM DEM for 0.008% Threshold level

Stream	1	2	3	4	5	6	7	Total
ASTER	2148.3	1114.7	560.7	328	105.3	54.1	54	**4365.1**
SRTM	2018.1	1024.5	591	268.3	164.8	25	73.2	**4164.9**
Difference	6.06	8.09	-5.4	18.2	-	53.79	-	**4.59**

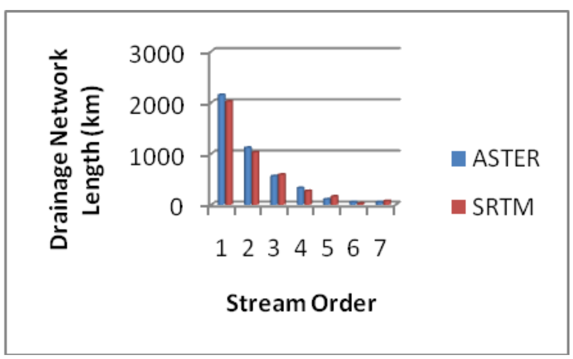


Figure 10: Graph comparing length of drainage network for 0.008% Threshold level

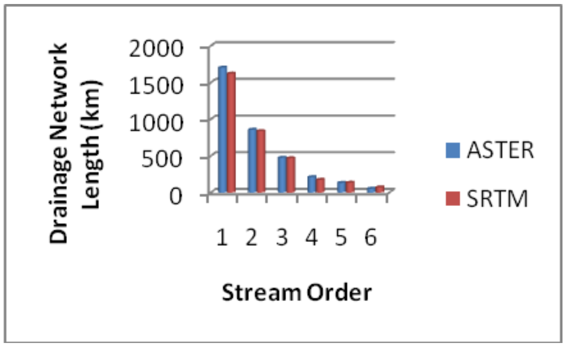


Figure 11: Graph comparing length of drainage network for 0.013% Threshold level

Table 5: Drainage Network Length from ASTER and SRTM DEM for 0.013% Threshold level

Stream	1	2	3	4	5	6	Total
ASTER	1703.2	856.9	474.3	211.5	132.1	53.9	**3431.9**
SRTM	1621.8	838.2	468.7	175.1	135.1	72.2	**3311.1**
Difference	4.78	2.18	1.18	17.21	-2.27	-	**3.52**

Drainage network derived from ASTER DEM shows more length for first order and second order streams at all threshold levels. Threshold levels were taken as fixed percentage of total drainage cells derived from DEM. The percentage difference in total length of derived network between ASTER and SRTM DEM is 11.23% at 0.001% threshold level and reduced to 3.52% at 0.013% threshold level. As the threshold level increase, length of derived drainage network show decreasing trend. Threshold levels vary from 0.001% to 0.013% of derived drainage cells in both DEM. At 0.001% threshold level, resulting stream order was 8th order network and at 0.013% threshold level, resulting stream network was of 6th order.

The river basin under consideration is a 7th order stream network as per Water Atlas 1995, published by Centre for Water Resources Development and Management (CWRDM), Kozhikode, Kerala. Hence the threshold level was kept within 0.001% to 0.013% range to keep the stream network as of 7th order for assessing the performance of ASTER and SRTM DEM. At 0.004% and 0.008% threshold levels, derived stream network was of 7th order. Total length of first order and second order streams were more in ASTER DEM compared to SRTM DEM at all threshold levels. But at 0.004% and 0.008% threshold levels, third order stream network were less in ASTER DEM. Fourth order network is more for ATSER DEM at all threshold levels. Another important aspect is less stream network was derived from ASTER DEM for 7th order streams. At other threshold levels also length of derived higher order streams from ASTER DEM were less compared to SRTM DEM.

Table 6: Drainage network from ASTER DEM at 0.009% threshold level

Stream Order	Count	Length (km)
1	9569	2028.99
2	4096	1024
3	2252	574.61
4	1077	277.02
5	489	120.78
6	54	26.15
7	180	53.97
Total	**17717**	**4105.52**

Maximum value of threshold level at which both DEM produced a 7th order stream network was at 0.009%. At 0.009% ASTER DEM derived network had 4105.5 km length whereas SRTM DEM derived network were only 3945.2 km long (tables 6 & 7).

Table 7: Drainage network from SRTM DEM at 0.009% threshold level

Stream Order	Count	Length (km)
1	4911	1899.43
2	2128	982.94
3	1301	548.36
4	586	255.73
5	408	161.07
6	40	24.76
7	232	72.86
Total	**9606**	**3945.15**

Minimum value at which both DEM produced a 7th order stream network was at 0.004%. At 0.004% ASTER DEM derived network had 6093.6 km length whereas SRTM DEM derived network were only 5918.1 km long (table 8 & 9).

Table 8: Drainage network from ASTER DEM at 0.004% threshold level

Stream Order	Count	Length (km)
1	23466	3026.92
2	10109	1544.65
3	4475	721.11
4	2913	476.03
5	933	158
6	505	112.28
7	268	54.59
Total	**42669**	**6093.58**

Table 9: Drainage network from SRTM DEM at 0.004% threshold level

Stream Order	Count	Length (km)
1	11584	2901.39
2	5348	1521.84
3	2781	771.81
4	1320	362.43
5	523	150.6
6	485	135
7	333	75.07
Total	**22374**	**5918.14**

The stream network derived from ATSER DEM for threshold level 0.009% of total drainage area also gives more length for lower order streams. Total length of first order streams at 0.009% from ASTER DEM is 2028.99 km compared to the 1899.43 km from SRTM DEM. But higher order streams shows instability in ASTER DEM. Derived 7th order stream length was 53.97 km at 0.009% threshold level from ASTER DEM whereas from SRTM DEM length of 7th order stream was 72.86 km. The stream network derived from ATSER DEM for threshold level 0.004% of total drainage area also gives more length for lower order streams. Total length of first order streams at 0.004% from ASTER DEM is 3026.92 km compared to the 2901.39 km from SRTM DEM. Derived 7th order stream length was 54.59 km at 0.004% threshold level from ASTER DEM whereas from SRTM DEM length of 7th order stream was 75.07 km. But first and second order stream length was more in stream network derived from ASTER DEM.

References

ASTER GDEM Validation Team: METI/ERSDAC, NASA/LPDAAC, USGS/EROS) (2009), ‘ASTER Global DEM Validation Summary Report’ - In cooperation with NGA and Other Collaborators.

ASTER Global DEM (August 25, 2011).

CGIAR SRTM 90m Digital Elevation Model. (August 25, 2011).

Peter G. Chirico (2004), 'An Evaluation of SRTM, ASTER, and Contour-Based DEMs in the Caribbean Region', U.S. Geological Survey (USGS), URISA Caribbean GIS Conference, September.

Tran Thi Thu Hien, Le Van Trung (2004), ‘ASTER Data in Monitoring Flood Application', International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences.

Identification of Ground Water Potential Zones Using High Resolution Satellite Data in the Desert Prone Area-A Case Study on Gorantla Watershed, Anantapur District, AP

G.Gautham, S.Swetha, A.Nageswara Rao and K.Mruthyunjaya Reddy

Andhra Pradesh State Remote Sensing Applications Centre, Swarnajayanthi Complex, Ameerpet, Hyderabad, Andhra Pradesh, India

E-mail: gautham_naru@yhoo.com, shavagoni.swetha@gmail.com

Abstract

An attempt has been made to explore the ground water potential of Gorantla Mandal, Anantapur District using RS and GIS Technique. Anantapur District is arid and knowingly drought affected district of Andhra Pradesh characterized by high temperature, frequent failure of monsoon, low humidity and high wind velocity. Hydro geo-morphological map has been prepared at 1:10000 scale using IRS-P6 LISS IV data to identify ground water prospects zones in the Gorantla watershed. Cadastral maps were superimposed over the hydro geomorphologic map to identify specific areas of ground water potential and prospects. Artificial recharge structures have been suggested. The study also indicates that the pre-dominantly ground water irrigated areas are along lineament and fracture system suggesting that lineament/fracture system are favorable for artificial recharge structures.

Introduction

Anantapur district is one of the four districts of Rayalaseema Region and the largest among the 23 districts of Andhra Pradesh. The district is economically backward and chronically drought affected. The district occupies the southern part of the State and is bounded on the north by Bellary district of Karnataka State and Kurnool district of Andhra Pradesh on the East by Kadapa and Chittoor districts of Andhra Pradesh and on the South and West by Karnataka State (Fig.1). The geographical area of the district is 19,197 sq km with a population of 36.39 lakhs. The population density, which was 54 persons per sq.km during 1901, has risen to 190 persons per sq km as per 2001 census. This has led to stress on available land and the size of land holdings has decreased considerably. Anantapur district forms the 2nd driest part of the country next to Jaisalmer of Rajasthan. The distribution of the rainfall in the district is erratic, uneven, and irregular. The district receives annual rainfall of 520 mm. which is the lowest in the state and second lowest in the country. The entire district is declared as arid due to severity of soil erosion, frequent failure of monsoon, decline in rainfall, low humidity, and vegetation degradation, over exploitation of ground water, high wind velocities etc.

Remote sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface. One of the advantages of using remote sensing data for hydrological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation, Satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of ground water like geology, structure, geomorphology, soil, land use / land cover, etc (Krishnamoorthy and Srinivas 1996). Hence, a study was made in Gorantla watershed with the aim of exploiting ground water potential.

Study area

The study area consists of Gorantla, Gownivaripalle, Kammavaripalle, Mareddipalle, Puleru, Vanavolu and Kamagareddipalle villages and lies between latitude 14^{0} 11' 35" to 14^{0} 03' 42" N and longitude 77^{0} 45' 31" to 77^{0} 52' 06" E (Fig 1).

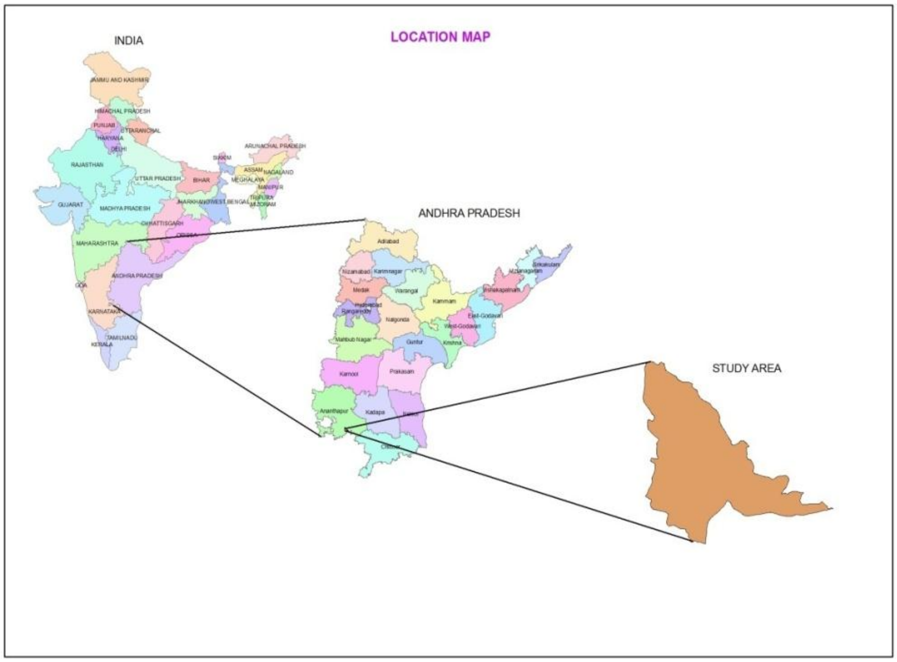


Figure 1: Location Map of study area

Methodology

The methodology involves generating of thematic maps such as geology, geomorphology, structural/lineament and drainage map using IRS-P6 LISS IV data at 1:10000 scale. The hydro geomorphology map (Fig.2) depicting ground water prospects was generated by integrating thematic maps. GIS technique is useful to derive and integrate geology, structural and geomorphological details. The various layers generated using remote sensing data like lithology, structure, geomorphology, lineaments etc. are integrated with already available information on slope, drainage density and other collateral data in a Geographic Information System (GIS) framework and analyzed with reference to the groundwater zones as well as artificial recharge sites.

To arrive at local specific recommendations at village level, the cadastral maps of Gorantla, Gownivaripalle, Kammavaripalle, Mareddipalle, Puleru, Vanavolu and Kamagareddipalle villages are superimposed over the hydro geomorphology map.

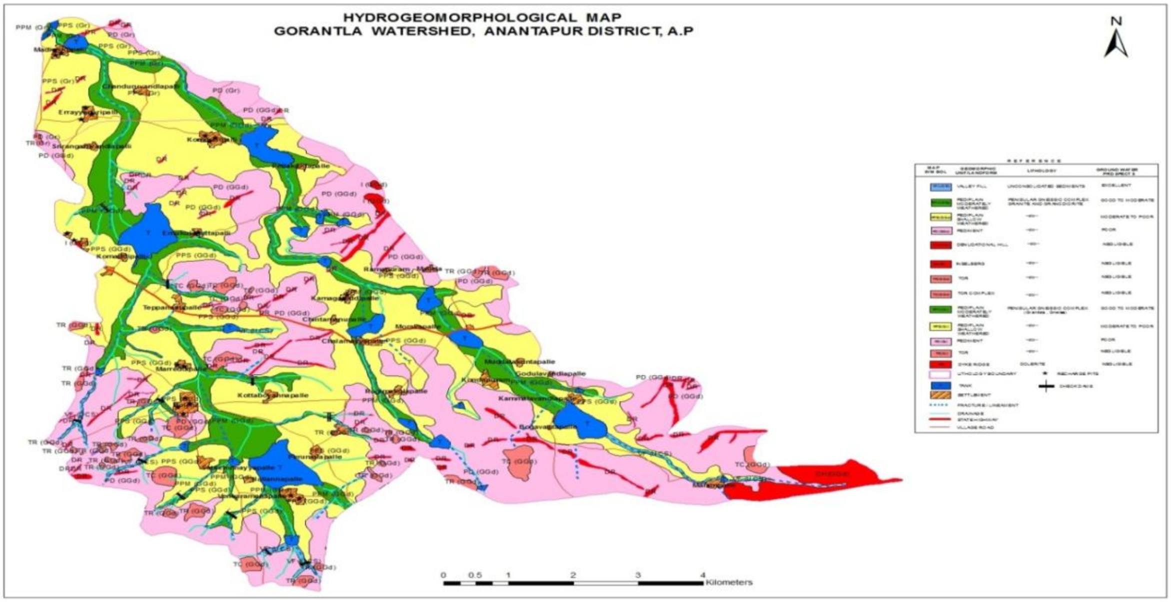


Figure 2: Hydro-geomorphological map of study area

Results and Discussion

The district is underlain by various geological formations ranging in age from Archaean to Recent. Major part of the district is underlain by the Granites Gneisses and Schists of Archaean and Dharwar Supergroup. North eastern part of the district is occupied by the quartzites, limestones and shales of Cuddapah and Kurnool Group of rocks. Alluvium is restricted to Pennar, Vedavati and Papagni rivers. Major part of the Gorantla watershed is underlain by Granites, Granodiorite, Hornblende - Biotite gneiss, Hornblende - gneiss, Biotite gneiss and Migmatites of Archaean age. Some of the dykes seem to act as barriers to the ground water movement so much that the areas of good ground water potential are found upstream of the dykes and low potential conditions are indicated downstream of the dykes. The NW-SE and E-W trending dykes act as barrier to the ground water flow in the area. The NE-SW and the N-S trending dykes usually follow stream courses and lineaments act as conduits for the flow of ground water (APSRAC Technical Report 1997).

Lineament analysis for ground water exploration in Peninsular granites and gneissic area has considerable importance as joints and fractures serve as conduits for movement of groundwater. For extraction of lineaments from images the Procedure of Moore and Waltz (1986) has been followed. In the watershed area, many lineaments are mapped using satellite data. In the watershed the lineaments are mostly trending NW-SE, NE-SW, N-S, and E-W direction (Fig. 3).

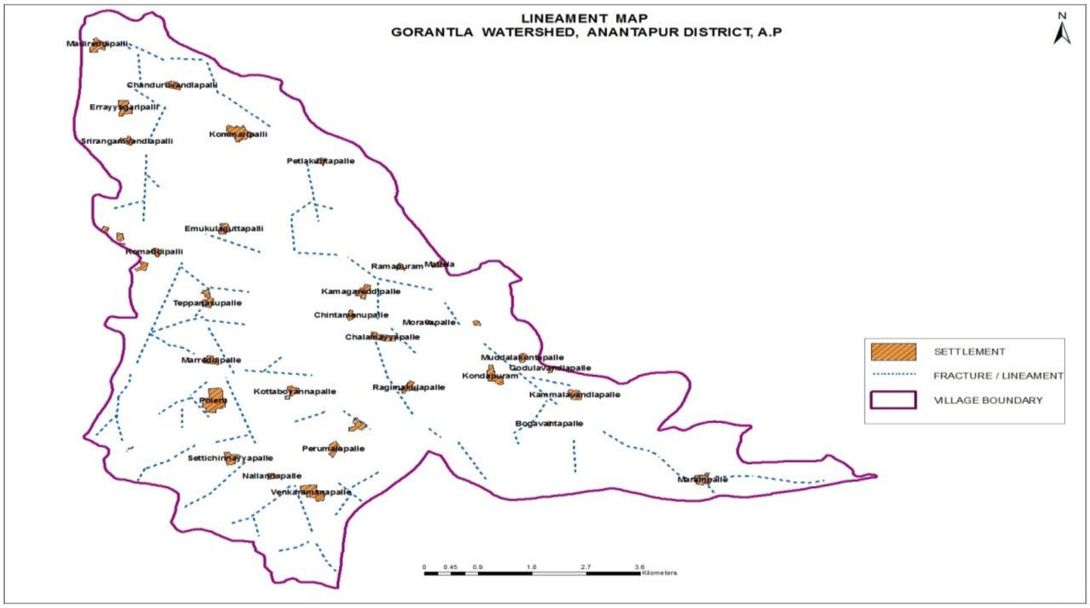


Figure 3. Lineament map of study area

Study of geological, hydrological, and meteorological data provides information on the parameters such as rock types, geological structures, landforms, and recharge conditions which control the occurrence and distribution of ground water. Remote Sensing based study has been carried out for hydrogeomorphological mapping to identify various landforms based on their groundwater prospects for tapping groundwater. Groundwater potential zones were delineated from hydrogeomorphology, structural information and from field well inventory data. The watershed is divided into 13 Hydrogeomorphic units based on landforms, geology, soils etc.

The major landforms of the area include shallow weathered pediplains, moderately weathered pediplains, denudational, residual hills, inselbergs, and pediment. The ground water prospects in shallow weathered pediplains are moderate to poor and while in moderately weathered pediplains the prospects are good to moderate. In pediments, the ground water prospects are negligible to poor while in hilly areas it is negligible to poor. Excellent groundwater prospects may be expected in the fracture valley depending upon the thickness of the weathered material.

In the watershed area, the groundwater occurs in the weathered and fractured rocks under water table and semi-confined to confined conditions. The study area is predominantly underlined by hard rocks which have very low permeability or transmissivity values. But, due to the development of secondary porosity with the introduction of fracturing and weathering, they have improved chances of tapping potential aquifers. The presence of dykes, quartz reefs etc. acting as barriers to ground water movement also has improved yield prospects from the aquifers. The degree of weathering in the hard rock's varies from a meter to as much as more than 15 m. The degree of fracturing and depth of fracturing vary from place to place. In general, as evidenced by CGWB exploratory drilling in the district, the intensity and occurrence of fracturing reduce after 60 m depth and mostly after 90 m depth.

Eastern and southern part of the study area consists of pediments and denudational hills with poor ground water prospects. In western part of the watershed the groundwater conditions is moderate to poor because of shallow weathered pediplain.

To arrive at local specific recommendations (water conservation methods) at village level, the cadastral map of Gorantla, Gownivaripalle, Kammavaripalle, Mareddipalle, Puleru, Vanavolu and Kamagareddipalle villages are digitized and overlaid on both image as well as watershed wise hydrogeomorphological map to identify / proposed rain water structures like check dams recharge pits etc. at cadastral level(Fig. 4). Rainwater harvesting structures like check dams, percolation tanks and farm ponds already exist. The construction of artificial recharge structures should be designed for 50% of non-committed run-off so as not to deprive the downstream watersheds.

The predominant groundwater irrigated areas along lineament, and facture systems brought out by satellite data interpretation are of immense use for taking up artificial recharge structures. The locations which are recommended for artificial recharge structures (check dams) are upstream of the irrigated areas and some recharge pits are proposed in and around the village settlement locations to recharge the ground water through surface runoff which is useful for sustaining the drinking water bore wells.

Conclusions

The study indicate that both high, moderate and low potential zones of ground water prospect areas are noticed in them, Rainwater harvesting or any other artificial recharge methods are more suitable to improve the ground water potential in low and moderate potential zones. Recharging process can be made effective and efficient to meet the demands of water for human consumption and irrigation purpose through planning and using appropriate scientific methods and tools.

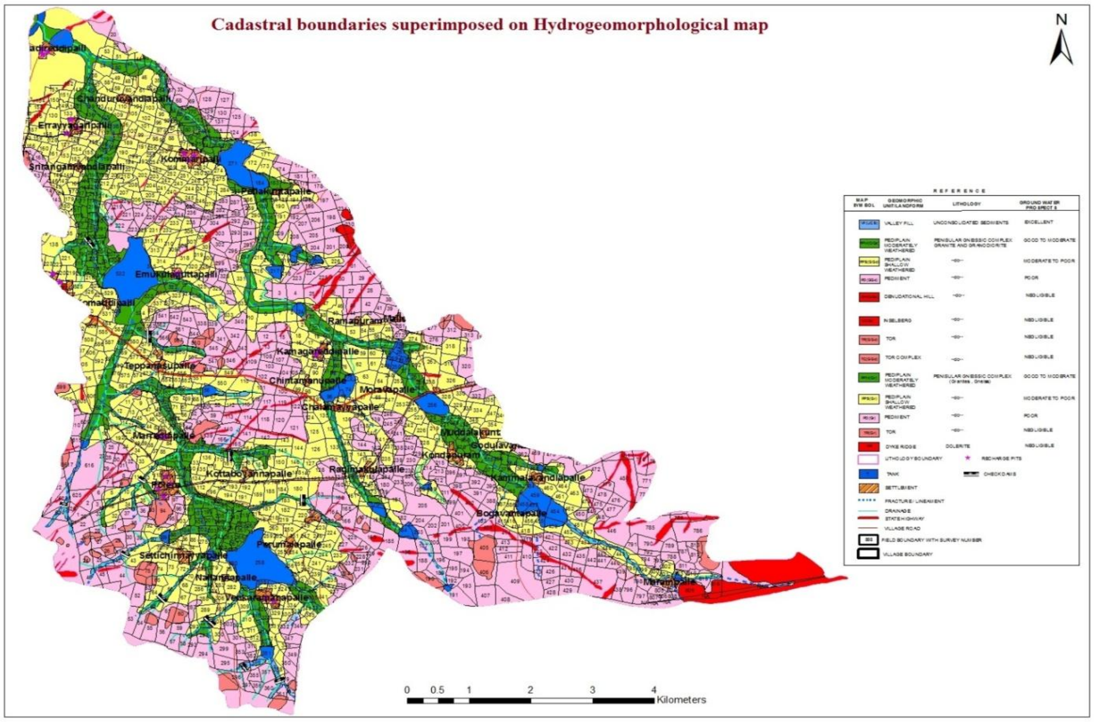


Figure 4 Cadastral boundaries superimposed on Hydrogeomorphological map

References

APSRAC, (1997). Integrated Study to combat drought Anantapur District, Andhra Pradesh; Technical report, 102p.

Krishnamoorthy, J and Srinivas, G (1995). Role of geological and geomorphological factors in groundwater exploration. A study using IRS LISS II data. Int. Jour. of Rem. Sens., V 16 (14): pp 2595.

Moore. G., and Waltz, F.A. (1986). Objective procedure for lineament enhance-ment and extraction, Photogrammetric Engineering and Remote Sensing, 49, pp 641-647.

NRSC Manual (2010). Lineament Manual for National Geomorphologic and Mapping, 2010, NRSC, Hyderabad.

NRSC Manual (2008). Manual on Ground water prospects mapping using Remote Sensing and GIS.

NRSC Manual (2006). Manual of National land use land cover mapping, using multi temporal satellite data.

Evaluation of Morphometric Parameters of Yerla River Catchment in Maharashtra from ASTER DEM

Surabhi Bhatt, Ahmed, S.A., Kiran Raj, S., Nischitha,V. and Abdul Karem, S.N.

Department of Applied Geology, Kuvempu University, Shankaraghatta-577 451
E-mail: sbhatt1712@gmail.com

Abstract

The development of new advanced techniques in Spatial Information Techniques such as remote sensing and GIS are effectively used for the extraction of information about spatial elements. DEM is one of the important sources in extraction of drainage network and is useful for determining the quantitative description of catchment geometry *ie.* morphometric analysis. The Yerla river catchment which is a part of Upper Krishna river basin in Maharashtra, India is selected for the present study to carry out the detailed morphometric analysis. The Yerla river catchment covers an area of 3045.36 km^2 and in Satara and Sangli district of Maharashtra. The analysis has revealed that the drainage network of the 7th order Yerla river exhibit dendritic to sub-dendritic drainage pattern. The bifurcation ratio varies from 3.0 - 4.9 indicating that the drainage has not been affected by structural disturbances. The catchment shows fine texture and poor stream frequency. The Circulatory and elongation ratio shows the catchment is almost elongated in shape. The results of this analysis would be useful in determining the catchment characteristics and distribution of stream network within the catchment.

Introduction

Morphometric analysis helps in better understanding of drainage morphometry on landforms and catchment characteristics (Sreedevi *et al.* 2009). Catchments are geographical drainage areas of the land surface that contribute flow to particular edges on the Hydro Network. Study of Catchment characteristics plays an important role in the hydrological response of the catchment. The accurate delineation of the catchment boundaries is the first important step in the determination of stream flow path and its contributing area.Remote sensing and GIS is an effective tool in extraction of spatial information particularly for the delineation of catchment boundaries (Ahmed *et al*. 2010; Bertolo, 2000). In recent years the use of GIS (Geographic Information System) has become increasingly popular and has facilitated much of the work of hydrologists in the scientific study and management of water resources. The use of DEMs (Digital Elevation Models) in particular has made watershed delineation a relatively smooth procedure. Digital elevation models (DEM) provide good terrain representation from which the watersheds can be derived automatically using GIS technology. The techniques for automated watershed delineation have been available since mid-eighties and have been implemented in various GIS systems and custom applications (Garbrecht and Martz, 1999).

The present study involves the geospatial technique to delineate the catchment boundary and evaluation of morphometric parameters derived from ASTER DEM. The morphometric parameters include basic parameters and derived parameters. The Basic parameters are Catchment area, perimeter, basin length, maximum and minimum heights and slope. The derived parameters are of linear (Stream order, stream length, Stream length Ratio, Bifurcation ratio and RHO-Co-efficient), areal (Drainage density, Drainage texture, Stream frequency, Elongation ratio, Circularity ratio and Form factor) and relief aspects (Basin relief, Relief ratio, Slope angle and Ruggedness number). The main aim of the present study is to delineate and analyze all the morphometric features derived from DEM and to establish the superiority of remote sensing and GIS techniques in deriving the morphometric features.

Study Area

The Yerla River is a tributary of the river Krishna, so this river catchment forms a part of Upper Krishna river basin. The river catchment is situated between the coordinates $74^0$6'0"E to $74^0$46'20" E longitude and $17^0$53'30"N to 17^0 3'5" N latitude and covers an area of 3045.36 km^2 in Satara and Sangli districtsof Maharashtra (Fig 1). Geologically the study area is comprised of basaltic lava flows of Deccan traps of upper Cretaceous to Eocene age. Moderately dissected plateau and fluvial valley with alluvial are the major physiographic features of the study area. Laterite covers plateau tops. Western border of the catchment receive heavy rainfall and the eastern part area receives medium rainfall. The main crops grown in the study area are Paddy, Jowar, Bajra, Oilseeds, Cereals, Wheat, Sugarcane and Grapes.

Material and Methodology

The Landsat ETM+ have been used as a base for delineation of catchment and for extraction of drainage networks. The delineation of Catchment boundaries and extraction of drainage network (Fig 5) has been made from the DEMs using automated procedures (ESRI 2009) in Arc GIS 9.3 environment, using Arc GIS Extension which requires the Spatial Analyst extension and Arc hydro. The Contour Map and Slope Map were created by Surface Analysis tools. The techniques adopted for watershed delineation consists of the following steps.

The first step in any of the hydrologic modeling is to fill the elevation grid. The "Fill" tool was used to fill sinks in the elevation grid which removes small imperfections in the data. Sink is a cell surrounded by higher elevation cells; the water trapped in it and cannot flow. Sinks (and peaks) are often errors due to the resolution of the data or rounding of elevations to the nearest integer value. The sinks need to be filled in to eliminate discontinuities in the drainage network. FILL is done either chopping off tall cells or filling in sinks (Fig. 2). After filling the DEM, then run the task "Flow Direction" tool (the second step) to create a grid of flow direction from each cell in the elevation grid to its steepest down slope neighbor.In a DEM grid structure, there exist at most 8 cells adjacent to each individual grid cell (Cells on the grid boundary will not be bounded on all sides). Accordingly, water in one cell travels in 1 out of at most 8 different directions in order to enter another cell. This concept is deemed as the 8-direction pour point model (Fig 3). In this grid representation, water at the center of the grid may flow only along one of the eight paths depicted by arrows. The number in each cell represents the direction water travels to enter the nearest downstream cell, and the numbering scheme has been set by convention. Depending on the direction of flow, the output grid will have a cell value at the center cell (Fig.3). If a cell flows northward, then in the output grid, the cell in its location will have a value of 64 (Fig.3). If the direction of flow for a cell is due north, then in the output grid, that cell's value will be 64. The resulting flow direction is encoded from 1 to 128 in different directions (Fig 3).

Flow Accumulation is the next step in hydrological modeling which is achieved by "Flow Accumulation" tool to create a grid of accumulated flow to each cell by the flow-direction grid and thus it is possible to sum the number of uphill cells that "flow" to any other cell. This summing can be done for all cells within a grid to create a "flow-accumulation" grid in which each cell-value represents the number of uphill cells flowing to it (Fig 4). Because a cell represents a geographic area (*i.e.*, each cell of a 30-meter resolution grid is 900 m^2), the flow-accumulation grid can be multiplied by this area to calculate the total drainage area. In addition, a grid representing a stream network can be created by querying the flow-accumulation grid for cell values above a certain threshold. In the present study the drainage network was extracted by considering the threshold value of 150 by a trial and error approach (Mark, 1983).Then assigning a numeric order to links in a stream network by Stream order tool. The drainage networks were classified into different orders by using Strahler method (Strahler, 1952).

The next step is to identify the watershed outlet grid, ensuring that it is located directly over a grid cell from the drainage network. Finally, the "Watershed" tool was used to delineate the watershed for the specified outlet. For delineating watershed, pour point should be selected. An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined. Boundaries (in grid format) were defined using Spatial Analyst. The watershed boundary and the stream grids were then vectorized to produce polygon and polyline themes, respectively, for further Morphometric analysis and comparison.

Results and Discussion

In the present study, the ASTER DEM is used for extraction of drainage network and the extracted drainages have been used for morphometric analysis.The morphometric parameters are categorized into basic parameters (Table 2) and derived parameters. The derived parameters are achieved through measurement of linear, aerial and relief aspects of catchment and slope contributions. The morphometric analysis for the parameters like linear, aerial and relief has been carried out using the mathematical formulae (Table 1) and the results are summarized in Tables 3, 4 and 5.

The Perimeter of the Yerla Catchment is 352.99kms and total catchment area is 3045.36 sq. km respectively. The Yerla catchment length is 105.27km. Stream order (Table 1) is a useful indicator of stream size, discharge and drainage area (Strahler, 1957). The stream orders of the study area are classified according to Strahler's (1964) method of classification. The Yerla is a 7th order catchment, with dendritic to sub-dendritic drainage network (Table 2). The inequality in stream frequency is due to variation in structural conditions of the region. In the study area the maximum frequency is observed in first order streams and also the stream frequency decreases as the stream order increases. This indicates the study area occupied by hillocks with moderate to steep slope as revealed by slope map and Contour map (Fig 6).

Stream length (Lu) is a total measured length of streams in a particular order. The total length of stream segments is high in first order streams and decreases as the stream order increases because of high relief along the northern part of the catchment and moderate to low relief along the other part of the catchment (Table 2). Stream length Ratio (RI) is defined as the ratio of the mean length of the one order to next lower order of stream segment (Table 1). The Rl between the streams of different order in the catchment area shows variation (Table3). There is a decreasing trend in the length ratio from lower order to higher order up to 6th order and sudden increasing in values in 7th order, this indicates the river is in mature stage. Bifurcation Ratio (Rb) is defined as the ratio of the number of streams of a given order to the number of streams of the next higher order (Schumn 1956). The Rb values of the study area are not in the same from one order to its next order(Table3).The values vary from 3 to 4.92 indicating negligible influence of geological structure (Ozdemir& Bird,2009). Large variations in stream frequencies between successively higher order stream result in higher values of birufucation ratios. This higher value of bifurcation ratios indicates that mature topography with higher degree of drainage integration. RHO-Co-efficient (RHO) is defined by Horton (1945) as the ratio between the stream length ratio (Rl) and the bifurcation ratio (Rb) (Table 1). This parameter determines the relationship between the drainage density and the physiographic development of a catchment which facilitate evaluation of storage capacity of drainage network (Horton, 1945). The climatic, geological, biological, geomorphological and anthropogenic factor determines the changes in the parameter (Mesa, 2006). The RHO of the catchment is 0.98 and this higher value indicates higher hydraulic storage during floods and attenuation of effects of erosion during elevated discharge (Mesa, 2006). Horton (1945) defined Drainage density (Dd) as the total length of a river (Lu) in a catchment divided by the total area (A) of the catchment (Table1). The density factor is related to Climate, types of rocks, relief, infiltration capacity, vegetation cover, surface roughness and run-off intensity index (Vittala *et al.* 2004). Normally Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. In this study Dd shows coarse drainage texture with low Dd value (Table 4) representing lower relief for the basin and lower discharge of water. Drainage texture (T) which is the total number of streams segments of all orders per perimeter of that area (Horton, 1945), which will be influenced by number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and storage of development (Smith, 1950). The soft and weak rocks unprotected by vegetation produce a fine texture whereas massive and resistant rocks cause coarse texture. The T of the whole catchment is 18.03 indicates the moderate to coarse texture. The stream frequency (Fs) is defined as the total number of stream segments of all orders per unit area (Horton, 1932). The Fs value of the catchment (Table4) shows close correlation with the drainage density values indicating the increase in stream population with respect to increase in drainage density. The poor Fs in the catchment is due to the agricultural land and steep barren slopes.

Elongation Ratio (Re) is defined as the ratio of the diameter of a circle having the same area as the basin and maximum basin length (Schumn, 1956) which reflects hydrological character of the basin. Generally, Re values varies from 0.6 to 1 over a wide variety of climatic and geological types. The value near to 1 is typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are generally associated with high relief and steep ground slope (Strahler, 1964). These values can be grouped into four categories namely (a) Circular (>0.9), (b) Oval (0.8 – 0.9), (c) less elongated (0.7-0.8) & (d) Elongated (< 0.7). The Re value of the Yerla catchment is 0.591 which indicate that the catchment is elongated with moderate relief and gentle slope. Circularity Ratio (Rc) is a dimensionless ratio to express the outline of drainage basin (Strahler, 1964). It is defined as the ratio of basin area to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953). The Rc is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the basin. The Rc value of the catchment is 0.31 which indicates that catchment is elongated with gentle slope and long main channel. Thus the catchment is at an early stage of topographical maturity. Form Factor (Ff) is defined as the ratio of basin area to square of the basin length (Horton, 1932). Ff represents the shape or outlines of a basin and is useful in predict the flow intensity of a catchment and has a direct linkage to peak discharge (Horton, 1945; Gregory & walling 1973). The Ff value of 0 indicates a highly elongated shape and the value of 1 a circular shape with high peak flow for short duration. The Yerla catchment having low Ff (Table 4) shows that elongated plain view of catchment, and with flatter peak flows of longer duration. The flood flows can be easily managed in this catchment.

Basin Relief (Bh) is the difference in elevation between the highest and the lowest points of the catchment (Table 1). Basin relief is an important factor in understanding the denudational characteristic of the basin. It plays a significant role in landforms development, drainage development, surface and subsurface water flow, permeability and erosional properties of the terrain. The Yerla catchment has moderate relief of 540. Relief Ratio (Rh) is defined as the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumn, 1956). It indicates the overall steepness of drainage basin and is an indication of intensity of degradation processes operating on slopes of the basin. In the study area the Rh value is very low i.e 0.01. The lower values of Rh indicate the presence of basement rocks which are exposed in the form of small ridges and mounds with lower degree of slope. The slope angle of the river in a basin is a morphometrical factor of hydrological relevance (Table 1). The slope angle of Yerla catchment (Table 5) that catchment is normally flat to undulatory. Ruggedness number (Rn) is the product of basin relief (H) and drainage density (Dd) (Table1). It indicates the structural complexity of the terrain in association with relief and drainage density. The higher values of ruggedness number clearly indicates uneven topography, lithological heterogeneity of terrain and high degree of dissection, whereas the moderate ruggedness number indicate partly the flat top surfaces or ridges and valley topography and moderate to moderately high degree of dissection . The lower values of ruggedness number indicate flat and undulating terrain and low dissection index. In the present study, the area shows moderate ruggedness value as 0.988.

Conclusions

Delineation of catchment boundary and extraction of drainage networks from topo-maps require time, precise workmanship and judgments of a cartographer; and fully depended upon the resolution of topo-maps. In contrast, an automated delineation using DEM by Spatial tools is more sophisticated, convenient, and can be circumvented the efforts in digitizing to incorporate with other GIS data.

Acknowledgement

We thank the Chairman, Department of Applied Geology, Kuvempu University for providing necessary facilities to carry out this work.

References

Ahmed S.A, Chandrashekarappa K.N, Raj S.K, Nischitha V and Kavitha G (2010). Evaluation of Morphometric Parameters Derived from ASTER and SRTM DEM – A study on Bandihole Sub-watershed Basin in Karnataka., J. Indian Soc. Remote Sens. Vol 38, pp.227–238.

Francesca Bertolo, (2000). Catchment Delineation and Characterisation, Catchment Characterisation and Modelling Euro Landscape Project, Space Application Institute, Joint Research Center Ispra (Va),Italy.

Garbrecht, J.; Martz L.W. Digital elevation model issues in water resources modeling. In: ESRI Users Conference, 19, 1999, San Diego. Proceedings...San Diego: ESRI, 1999. 866p.

Gregory KJ and Walling DE (1973). Drainage basin form and process: a geomorphological approach. Wiley, New York, pp 456.

Horton RE (1932). Drainage basin characteristics. Trans Am Geophys Union, vol 13, pp.350–361.

Mark DM (1983). Relation between field-surveyed channel network and map-based geomorphometric measures, Inez Kentucky. AmAssoc Geographers, vol 73(3), pp 358-372.

Mesa LM (2006). Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina)., J Environ Geol, vol 50(8), pp.1235–1242.

Ozdemir H and Bird D (2009). Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods., Environ Geol, vol 56,pp.1405–1415.

Schumm SA (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. GeolSoc Am Bull,vol 67, pp.597–646.

Smith KG (1950). Standards for grading texture of erosional topography., Am J Sci, vol 248, pp.655–668.

Sreedevi P.D, Owais S, Khan H.H and Ahmed S (2009). Morphometric Analysis of a Watershed of South India Using SRTM Data and GIS., J.Geological Society of India., vol.73, pp.543-552.

Strahler AN (1964). Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) Handbook of applied hydrology. New York, pp 4-404-74.

Vittala, S. S., Govindaonah, S. and Home Gowda, H,. (2004). Morpho-metric analysis of sub-watersheds in the Pawagada area of Tumkur district South India using remote sensing and GIS techniques., Journal of the Indian Society of Remote Sensing, vol 32, pp. 351-362.

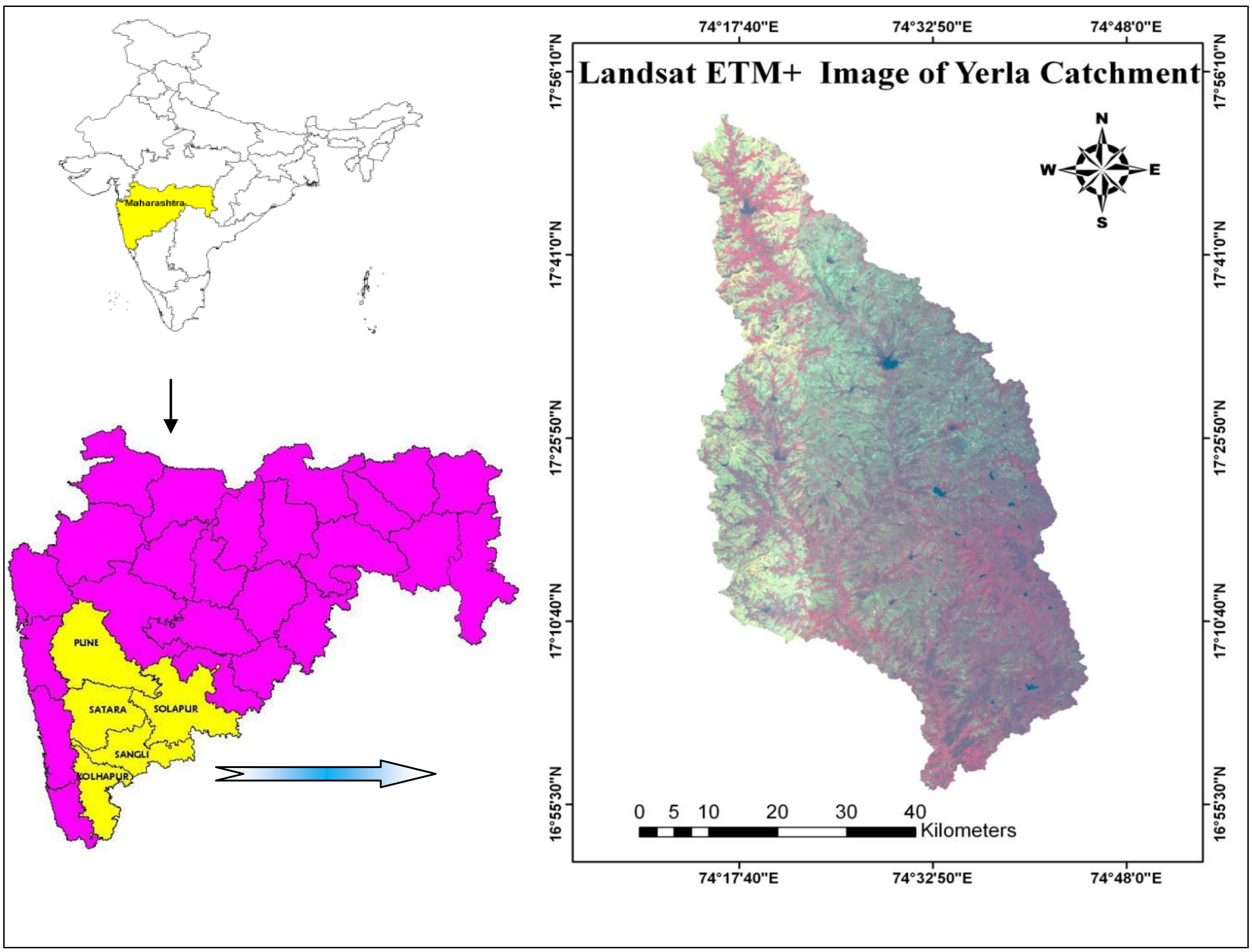
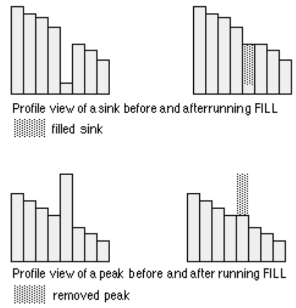
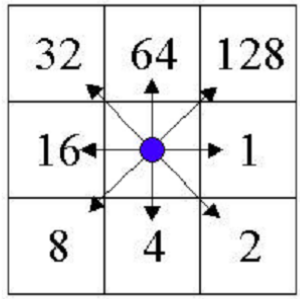


Fig 1: Location Map of the Yerla Catchment





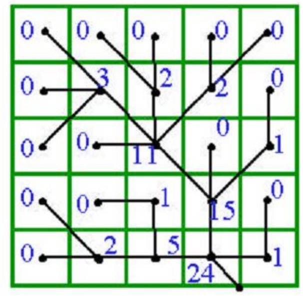


Fig 2: Fill Sinks. Fig 3: Flow direction in 8-Direction Fig 4:Flow Accumulation – number pour point model.ofcells draining to a given cell along the flow network.

Web Based Geospatial Technology for Water Resources Management

Nagraj, S. Patil and A.K. Gosain

Department of Civil Engineering, Indian Institute of Technology, New Delhi
Email: nagrajspatil@yahoo.com

Abstract

Water resources projects are inherited with overlapping and at times conflicting objectives. These projects are often of varied sizes ranging from major projects with command areas of millions of hectares to very small projects implemented at the local level. Thus, in all these projects there is seldom proper coordination which is essential for ensuring collective sustainability. Integrated water resources development and management is the accepted answer which in turn requires a comprehensive framework that can enable planning process involving all the stakeholders at different levels and scales. Such a unified hydrological framework is essential to evaluate the cause and effect of all the proposed actions within the drainage basins. The present paper describes a hydrological framework developed in the form of a Hydrologic Information System (HIS) which is intended to meet the specific information needs of the various line departments of a typical State connected with water related aspects. The HIS consist of a hydrologic information database coupled with tools for collating primary and secondary data and tools for analyzing and visualizing the data and information. The HIS also incorporates hydrological model base (SWAT model output) for indirect assessment of various entities of water balance in space and time. The framework showcases the mechanism to maintain and update the most accurate data and information required for planning and management. This framework provides a common information base to all the line departments and can serve as the first step towards true integrated approach. The paper presents the implementation of Web-based GIS (ArcGIS Server) and is available at *http://gisserver.civil.iitd.ac.in*. The aggregation of information is done by placing a database server and by adapting the Hydro data model. Implementation has been designed to ensure that internal GIS capabilities are shared with users in the line departments, while a Web-based platform is maintained for dissemination to external users.

Introduction

Integrated water resource management planning is a comprehensive planning process, involving all stakeholders within the drainage system, who together as a group, cooperatively work towards identifying the water resource issues and concerns, as well as developing and implementing plans with solutions that are environmentally, socially and economically sustainable at various levels of connectivity of the drainage system.

It is important to understand that integrated water resource management should not merely imply the maintenance of an inventory of different activities to be undertaken within a hydrological unit. It also requires the collation of relevant information needed to evaluate the cause and effect of all the proposed actions within the drainage basin. The watershed is the smallest unit where the evaluation of man induced impacts upon natural resources becomes possible. Therefore although the Panchayat (cluster of villages) remains the preferred implementation unit, the watershed should be the evaluation unit used in assessing impacts.

Since a watershed is considered as the smallest unit of a drainage basin, a hydrological framework that can keep track of the inter-connection of these units is essential. The impact resulting from action taken at the watershed level will be experienced at a higher level within the drainage basin, and the assessment of these impacts will require the availability of the framework. Such a framework will require regular maintenance and updating to reflect fully the most accurate ground truth data and the infrastructure requirements for planning and management of the relevant planning departments. Such a framework, once available, could be used by all the line departments and updated by the relevant departments which have designated jurisdiction over the data entry.

The development of Hydrologic Information System component is logical response to meet the specific information technology needs of the various line departments. A hydrologic information system consists of a hydrologic information database coupled with tools for acquiring data to fill the database and tools for analyzing, visualizing and modeling the data contained within it. This GIS portal *(http://gisserver.civil.iitd.ac.in),* for the general user, exposes Web Mapping Application for accessing Hydrological Information and Web based Interface applications based on the SWAT modeling.

Requirements of Hydrologic Data Model

Hydrologic Information Database must be carefully designed. A Hydrologic data model is an abstract database design developed by using a computer aided software tool which is physically implemented in a particular database system being locally employed. All tools developed for data acquisition, analysis and visualization depend on the way the data is structured in the database. Special interfaces to the database are needed for each information source and analysis task that defines how data is input or acquired from the database. One of the critical early tasks is the design of this data model. The hydrologic data model is required to be able to meet the following needs.

a) Represent hydrologic information in each phase of the hydrologic cycle. (atmospheric water, soil, water, surface water, ground water)

b) Be capable of tracking the movement of water and the transport of constituents across interfaces between phases of the hydrologic cycle, and accounting for the storage of water and transported constituents in each phase. (McKay,1991)

c) Allow for describing the horizontal flow of water through elements of the landscape, such as watershed to stream, to river or lake, to estuary, to bay, and finally to the ocean. (Abbott and Minns,1998; Naiman and Bilby,1998)

d) Be capable of integrating geospatial and temporal information.

e) Be able to deal with both continuous and discrete spatial representations of data and of the transformations of data from one spatial framework to another;

f) Be able to link data from different spatial scales, such as detailed descriptions of channel morphology on small stream reaches referenced to their correct location within the stream network of the basin. (Gupta *et al*.,1986; Quattrochi and Goodchild,1997)

g) Be able to deal with data of any desired time scale and manipulations to transform data from one time interval to another. (e.g. accumulation of daily data to monthly data, monthly data to annual data, etc);

h) Have a metadata component so that the lineage of how the data were produced can be traced.

In particular, it is necessary that the data model design are not only concerned with file formats data conversions, and the like, but also with the provision as to how these data are going to fit into analysis framework. In other words, a conceptual framework is needed that connects the data describing the hydrologic environment with the physical laws that govern how water moves (Gray *et al*., 1993). This is a challenging task, but a critical one since it forms the foundation for advancements in hydrologic knowledge built using hydrologic information infrastructure.

Arc Hydro a Specific Hydrologic data model

The Arc Hydro data model (Fig.1) developed at the University of Texas, USA, enables a watershed to be described in a single Geodatabase which can be used by GIS based hydrologic and hydraulic model to simulate watersheds. A data model is different from a simulation model since it provides a standardized framework for storing data where simulation models can both pull from and write. Arc Hydro, provides a means for linking simulation models through a common data storage system. Thus, a scheme that reflects temporal and geospatial hydrologic data was created to support surface water hydrology and hydrography modeling at any scale. Its benefits can be better seen on complex projects where an overwhelming amount of data may lower the efficiency and possibly jeopardize the results of a model simulation. Arc Hydro is a good hydrologic information system for retrieving and analyzing hydrologic data at the desktop.

The Arc Hydro data model divides water resources data into five components: Network – connected sets of points and lines showing pathways of water flow. Drainage- drainage areas and stream lines defined from surface topography. Channel- A 3-D line representation of the shape of river and stream channels. Hydrography- the base data from topographic maps and tabular data inventories and Time series (Tabular attributes data describing time varying water properties for any hydro feature).

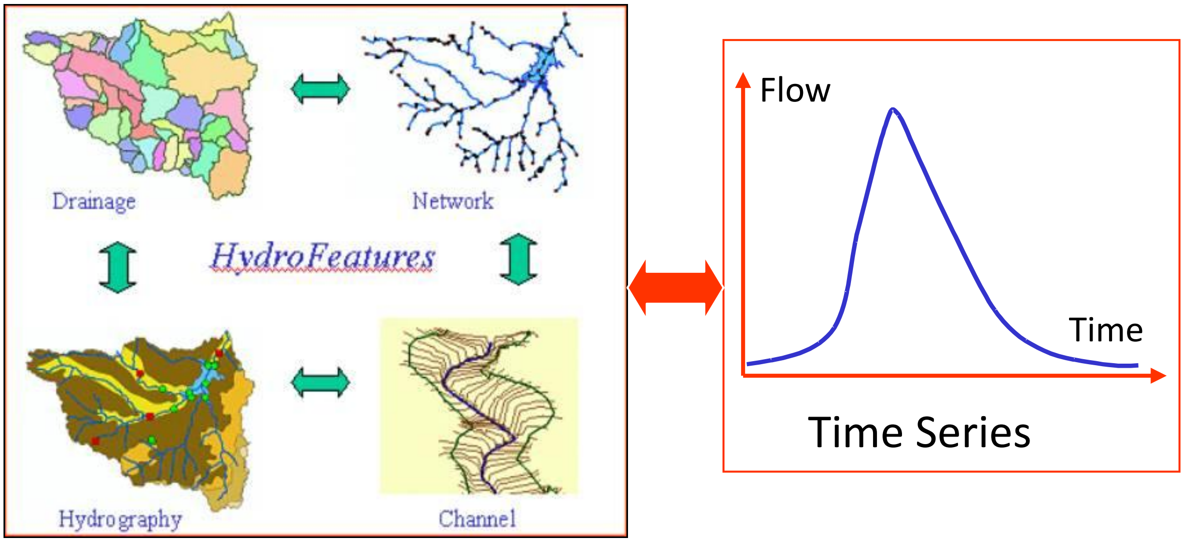


Fig. 1. Arc Hydro data model components (adapted from Maidment *et. al*., 2002)

GIS Sever

In different line departments it is a real challenge to minimize redundancy while ensuring that the right data is accessible in a timely and efficient manner. With hundreds of remote offices and thousands of internal and external GIS users at different levels of expertise and needs, it is important to overcome multiple barriers while designing enterprise GIS. The following are some of the essential attributes desired of such databases: Facilitate interdepartmental coordination through data sharing. Ensure that only the most recent GIS data is accessible to the users. Users should not be misled by multiple versions of the same data that is maintained by different branch offices. Ensure and ensure an acceptable level of computing performance in terms of speed, accessibility and reliability. Provide sensitive data to authorized users with appropriate protection to the sensitive elements while serving the portions of the same dataset that have no restrictions to general users.

One solution is to implement a server-based GIS that could cope with all the above desired attributes. The aggregation of information should be done at central place by placing a GIS server and database server for the purpose. Server-based GIS can be defined as centrally hosted GIS computing. Internal GIS capabilities are shared with users in the department network while a Web-based platform is also maintained for external users. GIS users are connected to the central GIS servers using desktop GIS software, Web browsers, and custom applications as depicted in Fig. 2.

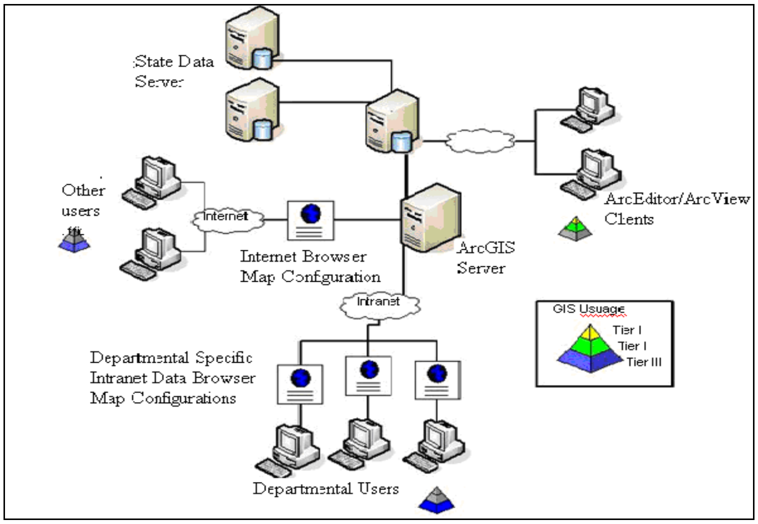


Fig. 2. Enterprise Wide Application Configuration

Data Storage, Sharing and Protection

In the present study it is proposed to store the GIS data in a geodatabase using ArcSDE and Microsoft SQL server. ArcSDE can be phased in as a spatial data access server that allows administering spatial data stored in a relational DBMS and shall provide access to data required for client applications. Because spatial data is stored as tables in a DBMS, the strengths of a DBMS (data storage, data integrity, and data security) can also be applied to the spatial data. By transferring almost all GIS data into the ArcSDE geodatabase, a centralized resource for geospatial data is created that can be accessed through the intranet and internet by various GIS applications and functionalities designed to serve its many GIS users.

Different departments are responsible for managing different data. Data Transformation Services (DTS) and the built-in import functionality of SQL Server could be used with ArcSDE geodatabase. This ability to create spatial views in ArcSDE geodatabase and control user rights through SQL Server has made it easier to deal with data protection. Several spatial views are created with information that is appropriate for general users while the original layers that contain sensitive information are password protected and accessible only to higher-level users with appropriate rights.

Distributing Data and GIS Functionality

Historically, most typical data requests for geospatial and tabular data are provided through manual processes such as phone calls or on-site visits. Traditionally, these requests would be handled by office personnel. This would require intermediate steps, discussions, and often multiple revisions before the final product is created. The advent and subsequent rise in Internet use opened new avenues for data requests as well as a whole new group of data requestors. Now, with the help of built-in functionalities and customized ArcGIS Server applications that use, NET technology and

Active Server Pages(ASP), allow enterprise GIS applications to be built that can be centrally managed and accessed via Web-based interfaces, custom applications, or traditional desktop GIS. Built on ArcObjects, ArcGIS server can provide all the strength of advanced GIS functionalities in a distributed multiuser setting. A user can generate custom maps and tables in real time. The data delivery mechanism is streamlined, user friendly, and cost-effective (Mehdi *et. al*., 2009).

Major Elements of Framework

The common framework for water resources planning and management requires creation of base layers at different scales so as to cater to the relevant problems at the respective scales. However, it is imperative that all these scales should merge through the GIS environment for aggregation and integration to be possible. It is intended to provide this framework at the State level and with implementation at various departments connected with water resources. The major elements of the framework include as show in the Fig.3.

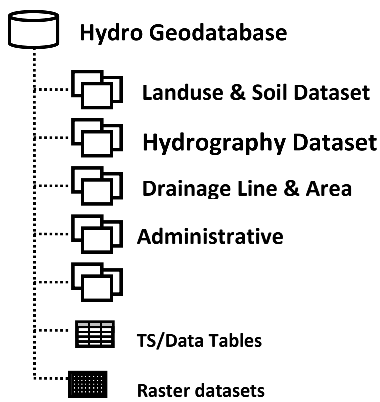


Fig. 3. Framework of Hydro Geodatabase

Arc Hydro data model could only meet the basic information. The Geodatabase was extended to capture the information related to administrative area, landuse, soil feature class and non spatial data related to socio-economics. Hydrography Dataset was also further extended to capture some of the feature classes like Dam, Canal, Water Body, Borewell, Hydro Projects, Irrigation Scheme, Water Supply Scheme, Sewage Treatment Plant, Industry, Rain gauge and Monitoring Point. Dam feature class is related with non-spatial data like Area Capacity, Water utilization, Sesimacity of Area, Reservoir (static data), Reservoir Water level, Power Projects. Canal feature class is related with non-spatial data like Canal Dimension and Discharge. Borewell feature class is related with non-spatial data like Discharge, Groundwater Table and Water Quality Parameter. Sewage treatment plant feature class is related with non-spatial data like sewage treatment plant discharge. Water treatment plant feature class is related Water Quality Parameters and Pump Station.

Drainage Line and Area Dataset consist of Basin, Catchment, Sub-Catchment, Watershed and drainage line. Administrative Dataset consist of feature classes like State, District, Tehsil, and

Village. Landuse and Soil dataset contains Landuse and Soil feature class. Other non-spatial data like Demography, Livestock data are collected from village and aggregated up to district level. Irrigated Area, Agriculture Area, Crop, Fertilizer, and Pesticide data are collected at the district level.

Web Interface for Water Resources Applications

In the present study the Hydro model has been implemented on Himachal Pradesh state as a case study. The principal departments that are responsible for water resources development in Himachal Pradesh for various purposes are the Irrigation and Public Health Department (IPH), Agriculture Department, Rural Development Department (RD) and Forest Department (FD).

A wide range of applications relevant for the planning and management of water resources is demonstrated using this framework built at the macro level as well as some patches developed at the larger scales. This web portal can be accessed by the request of the URL *http://gisserver.civil.iitd.ac.in*

IPH Department

As part of the demonstration, information from the IPH department pertaining to their activities was incorporated in the Web based GIS portal.

Fig.4 shows Web based Mapping Application on the irrigation schemes being operated by IPH department in respective village. It shows the watershed boundary, drainage line and irrigation scheme location feature class overlaid over village boundary. By using identify button on the irrigation scheme location, along with the attribute data of this feature class, it possible to obtain the attribute data of all the feature classes below it. This helps the user to get the detail information about the irrigation scheme, on which watershed the scheme is operating and the beneficiary village with population.

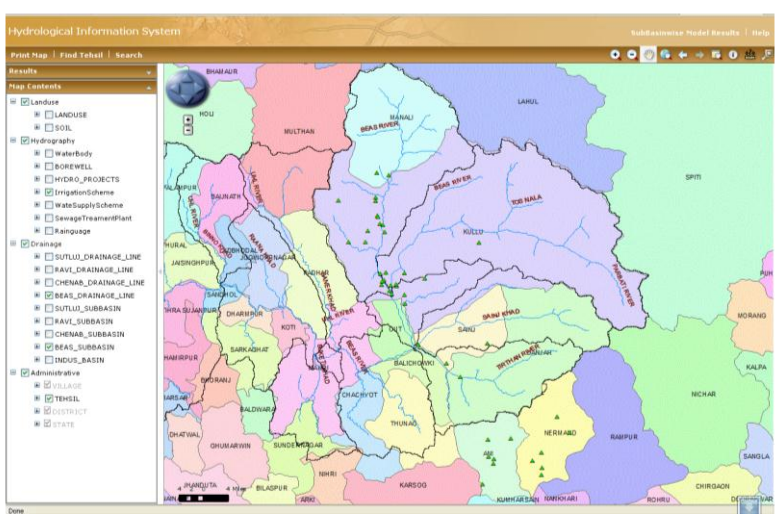


Fig. 4. Information of the Irrigation Schemes operated in the Himachal Pradesh by IPH

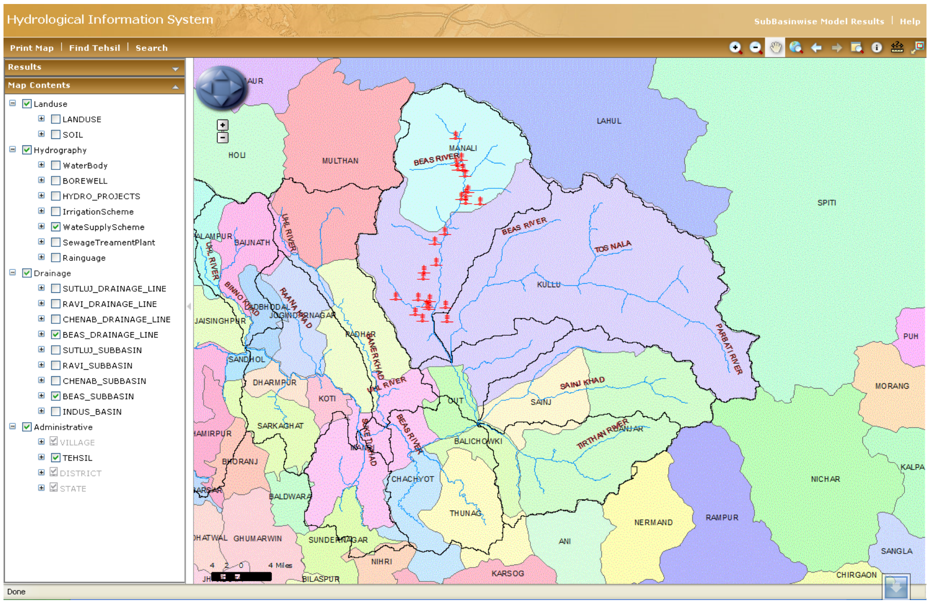


Fig. 5. Shows the water supply schemes operated in the state by IPH

Similarly the Fig.5 shows the water supply schemes operated in the state by IPH. The spatial data created can be used to view, and retrieve data, and generate the report on the ongoing activities. The spatial distribution of these schemes can be overlaid on the administrative maps to query on the village and population which are benefited under these schemes.

Model Base to Hydro Data Model

Arc Hydro data model structure could not support the SWAT model output which was essential for the present study. The Arc Hydro data model was further extended to support SWAT model output. The details of this development are out of scope of this paper.

SWAT Model

The Soil and Water Assessment tool (SWAT) (Arnold *et al.*, 1998) is a continuous-time, spatially distributed simulator of water, sediment, nutrients and pesticides transport at a catchment scale. It runs on a daily time step. In SWAT, a basin is divided into a number of watersheds. Within each watershed, Soil and Landuse maps are overlaid to create a number of unique hydrologic response units (HRUs). SWAT simulates surface and subsurface processes, accounting for snow fall and snow melt, vadose zone processes (i.e., infiltration, evaporation, plant uptake, lateral flows and percolation into aquifer). Runoff volume is calculated using the Curve Number method. Sediment yield from each sub-basin is generated using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1995). The model updates the C factor of the MUSLE on a daily basis using information from the crop growth module. The routing phase controls the movement of water using the variable storage method or the Muskingum method (Cunge, 1969; Chow., 1988).

Case Study

Indus River in north India is selected for the present study. The model set-up and runs were performed using SWAT hydrological model. The GIS interface of this model ArcSWAT provides an excellent platform for data management and result analysis. In the present study, two futuristic climate scenarios A2 and B2, and one baseline scenario BL has been used to address the uncertainty issues. Regional scale datasets used for model set-up were: land-use from global land cover fraction, soil from FAO and terrain model from SRTM. Primarily the water yield and evapotranspiration component of water balance were modeled for each of the sub-catchment. The modeled flow at the sub-catchment outlets were also evaluated for the various scenarios. To induce a level of confidence in the generated results, the basin was modeled using Indian Meteorological Department (IMD) gridded precipitation and temperature datasets. A good comparison was found between the baseline scenario (BL) results and observed dataset (IMD) results. This investigation would provide a good basis for selecting appropriate adaptation strategies to cater to the climate change impacts.

SWAT model version 2.1.3 is run on the desktop system, using the ArcGIS interface and the model results of Subbasin. Reach for monthly and daily time step was imported to Hydrological Information System (HIS) geodatabase.

Web Based GIS Interface for Analysis of Model Results

The web based Interface starts by the request of the URL http://gisserver.civil.iitd.ac.in/natcom. This interface was developed for viewing the model results of the respective Sub-Catchment. Fig.6 shows the user view of Indus basin. The user can zoom in further to view the catchment, sub-catchment and to the watershed level. The standardization of this drainage area was done by giving the unique identification numbers at different levels. These unique identification numbers along with sub-catchment name where used as reference for further analysis. Fig.7 shows the Web Mapping services of sub-catchment with unique identification number as their labels.

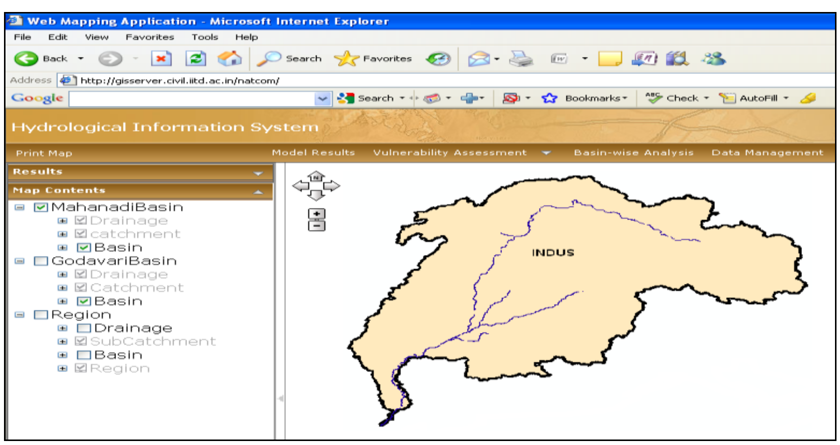


Fig. 6. User view of Indus basin

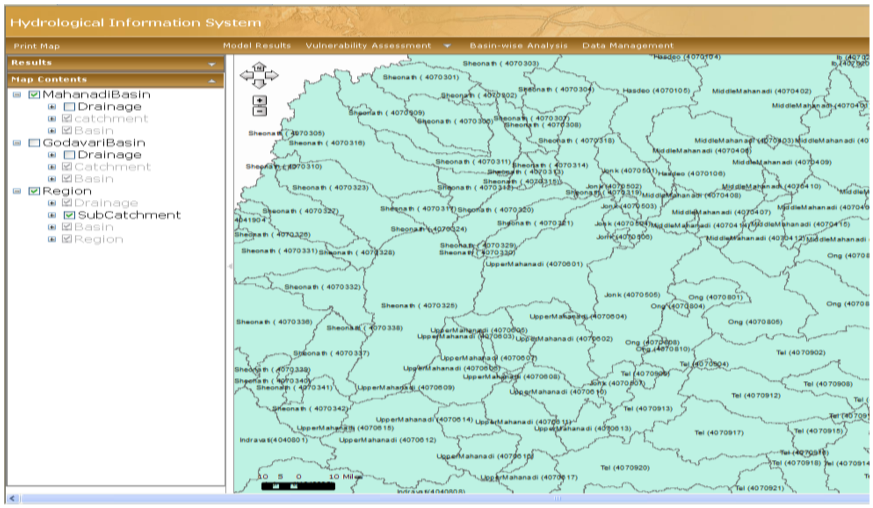


Fig. 7. User view of Sub-Catchment with unique identification number as their labels

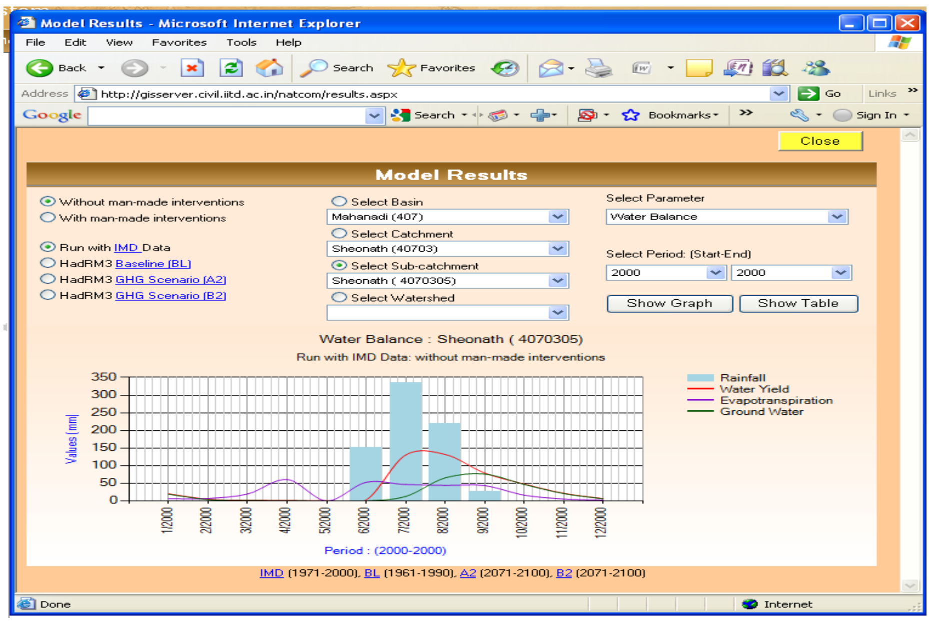


Fig. 8.Web Based interface to analysis the model results

Fig.8 shows the web based interface to analyse the model results. With this web based interface the user is given the option of analysis of the Catchment or Sub-Catchment or Watershed by selecting it, respectively. By selecting the radio button side to it confirms the respective selection. The user is also given the option to select the analysis of the SWAT model results with the different data set like India Meteorological Department (IMD) for the period of 1971 to 2005, HadRM3 baseline Scenario (BL) for the period 1961 to 1990 and HadRM3 GHG Scenario A2 & B2 for the period 2071 to 2100. It is important to assess the behaviour of the drainage area with and without man made intervention, so the web based interface is also designed with this concern. SWAT model gives many outputs parameters but only few parameters like Water Balance components, Flow, Water Quality parameters like Nitrite, Nitrate, Ammonium, Organic Nitrogen, Organic Phosphorus, Mineral Phosphorus, CBOD and Dissolved Oxygen, are given as option to user for analysis. The user is also given the option for the selecting the time during for the analysis. The selected parameters can be viewed through graphs or tables. This web based interface provides a robust frame platform for the assessing the status of water resources.

Conclusions

The development of a Geospatial Web Portal is proposed as the best solution to Hydrological Information and Data Management. The Web Portal built around a hydrological data model synthesizes data from diverse sources describing the water resource, provides visualization tools and link to externally modeled results. This Geospatial Web Portal would provide a robust platform for the planning, execution and monitoring of status of water resources.

References

Abbott, M.B., and A.W.Minns, (1998), “Computational hydraulics” (2nd Ed.), Ashgate Press, Aldershot, 557p.

Arnold,J.G., Srinivasan, R., Muttiah, R.S.., Williams, J.R., 1998. Large area hydrologic modeling and assessment- Part 1: Model development. Journal of the American Water Resources Association 34(1),73-89.

Chow,V.T., Maidment,D.R.,Mays, L.W.,1988. Applied Hydrology. McGraw-Hill, New York

Cunge, J.A., 1969. On the subject of a flood propagation method (Muskingum Method). Journal of Hydraulics Research 7(2), 205-230.

Gupta, V.K., I. Rodriguez-iturbe, and E.F.Wood, (1986), “Scale problems in hydrology.” Reidel Publishing Co., Dordrecht, 246p.

McKay, D., (1991), “Multimedia Environmental Models the Fugacity Approach”, Lewis Publishers, Boca Raton, FI, 257p.

Mehdi Mashud Khan, Angela Kneece, Ishwari Sivagnanam , Jared John Shoultz,2009. <http://www.esri.com/news/arcuser/0507/dhec.html> (accessed September 17, 2009)

Naiman, R.J. and R.E. Bilby, (1998), (ed.) “River Ecology and Ma nagement” Springer, New York, 705p.

Pinder,G.F.,(2002), “Groundwater Modeling using geographical information systems”, Wiley, New York, 231p.

Quattrochi, D.A., and M.F. Goodchild, (1997), “Scale and remote sensing in GIS”, Lewis Publishers, Boca Raton, FI.

River Variability Analysis in Parts of North Brahmaputra Plain, Assam: A Remote Sensing and GIS Approach

P. Phukon and Ratamali Machahary

Department of Geological Sciences, Gauhati University, Guwahati
E-mail: p_phukon@rediffmail.com

Abstract

The Dhemaji district in north Brahmaputra plain, Assam, is a perennially flood affected region with high intensity flash flood and sediment dispersal causing extensive changes to the fluvial landscape in recent times. Three sets of satellite images of compatible spatial resolution together with Survey of India topomaps in 1:50000 scale have been used to study six Himalayan tributaries of the Brahmaputra namely Jiadhol, Sisi, Dimu, Simen, Deka pam draining through this district to evaluate their spatio-temporal variability and influence on landscape change. The study shows extensive changes in the river regime over the period 1967-2010 by way of progressive extension of debouche point of the rivers and widening of the channel courses downstream. Increase in sediment dispersal by these rivers over time has led to rapid aggradations of many areas reducing their productivity. These areas have also contributed to a higher sediment input into the Brahmaputra river forcing a southward migration. Flashy nature of flow in the rivers due to high gradient, seasonality of discharge and catchment area tectonics are perceived to be the factors responsible for spatio temporal variability and sediment dispersal pattern by the present hydrologic regime in Dhemaji distict.

Introduction

The north Brahmaputra plain is part of the Himalayan foreland basin which was formed by flexure of the Indian lithosphere due to the rising Himalaya in Cenozoic time. A number of major trans-Himalayan drainage systems have debouched into the foreland basin and alluviated to form the present day elongated tract of Brahmaputra valley at the foothills of Arunachal Himalaya. As such, the evolutionary history of these rivers and evolution of the alluvial tract in general are closely linked to the Himalayan tectonics vis-à-vis sedimentation. Comprehensive literature dealing with either geology or geomorphology in north Brahmaputra plain is however very limited. Karunakaran and Ranga Rao (1976) gave an elaborate stratigraphic account of the north Brahmaputra plain followed by a major initiative by the Geological Survey of India (1977) under which the north Brahmaputra river basins namely, Subansiri, Jiabharali, Manas and Pagladiya were studied from geomorphological and hydrological point of view (Balasundaram and Murthy, 1977, Viswanathan and Chakrabarti 1977, Tak and Mehta, 1981). The river regime in the region which have been modulated by the tectonosedimentary episodes as well as climatic fluctuations, have however, not been rigorously studied so far inspite of the fact that the planform changes of the rivers in space and time have been intricately linked to the life and livelihood of the people in Brahmaputra valley.

Study Area

The Dhemaji district of Assam forming part of the North Brahmaputra plain at the foothills of Arunachal Himalaya (Figure 1A) presents a unique fluvial landscape formed by a number of south flowing Himalayan rivers viz., Jiadhol, Sisi, Jalkia suti, Sila suti, Dimu, Simen, Deka pam, Dikari, Depi and Silli river which debouch into the Brahmaputra that flows from north east to southwest along the southern fringe of the district. Many of the tributaries are seasonal while the major tributaries, although perennial, show strong seasonal fluctuation of discharge. Numerous fluviogeomorphological features viz., palaeochannels, sandbars, static waterbodies and natural levees etc. are found dotting the areas which are well discernible in topographic maps and satellite images. The whole district has been subjected to recurring high intensity flooding which in recent years have shown an increasing trend of intensity and frequency. The increasing flood frequency has severely affected the landuse pattern and livelihood of the people from this predominantly agrarian district. As such it is imperative to analyse the causal factors of the floods in the region and develop predictive model for spatiotemporal variability of the rivers. Satellite data that provide repetitive coverage are immensely useful in such studies. In this background the present study is aimed at evaluation of the river variability in terms of channel length and lateral change in Dhemaji district taking six major tributaries spread across the area viz., Jiyadhol, Sisi R, Dimu N, Simen R, Dikari R and Deka Pam (Figure 1B).

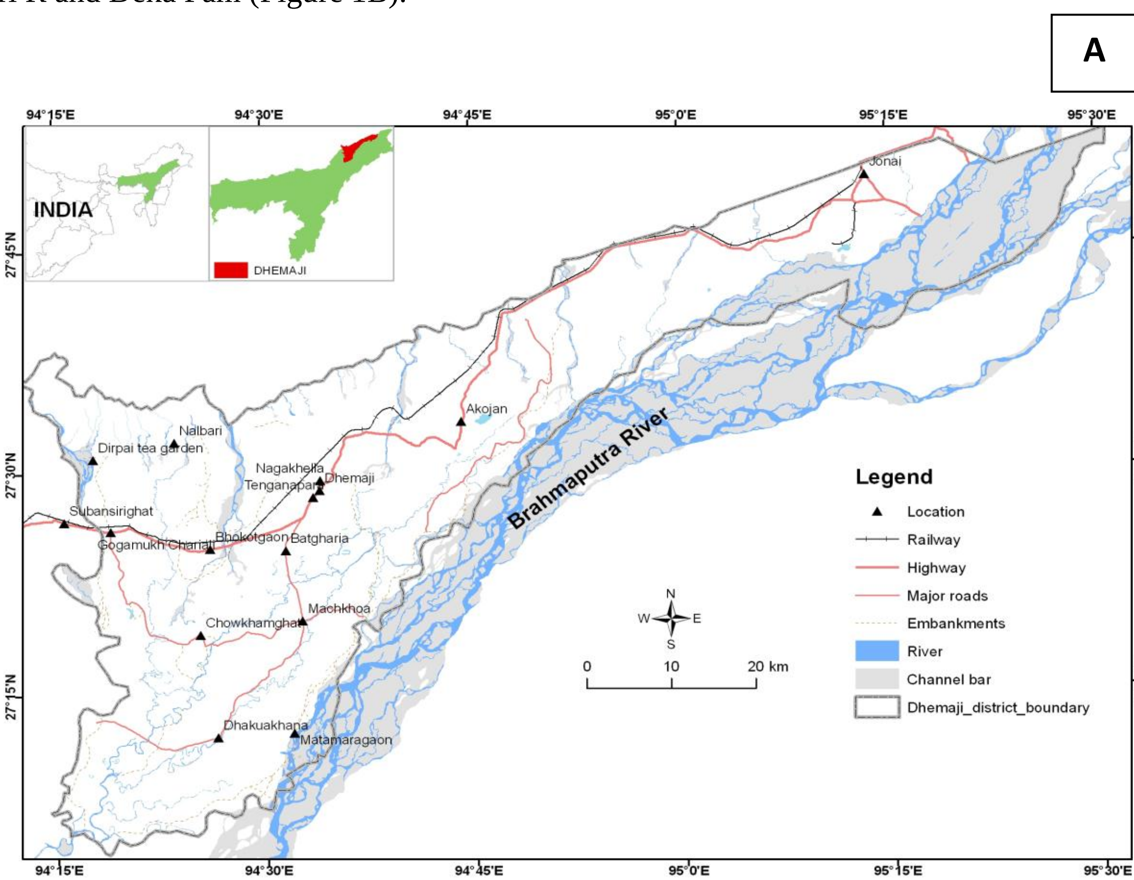
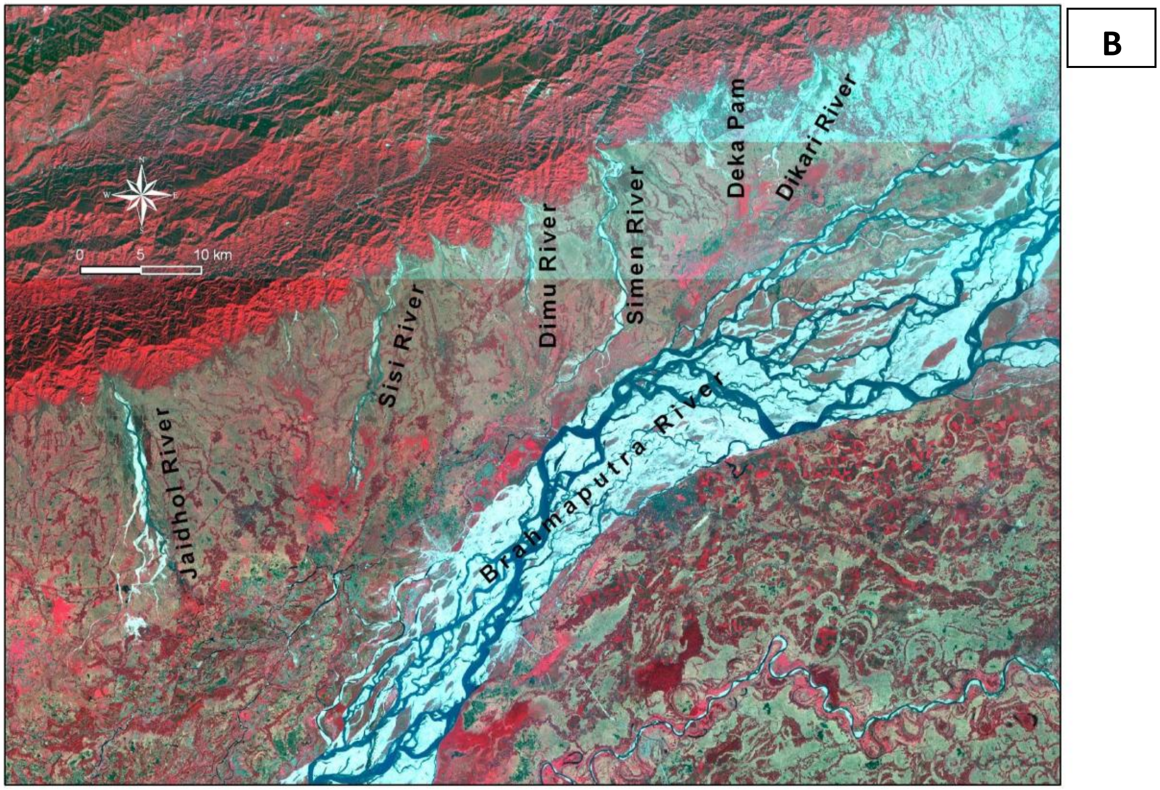


Figure 1. A. Location map of the study area



B. Satellite image (IRS LISS III FCC, Feb. 2010) showing the present configuration of the selected rivers for this study

Database and Methodology

The present study was carried out mainly through interpretation of satellite data and survey of India topographic maps (Table 1) followed by selective field documentation. Since geomorphological features are difficult and time consuming for direct field measurement and mapping, use of satellite image that gives synoptic view of a large area is found to be a more suitable and efficient method. A visual interpretation procedure was followed to extract information from the satellite images of different time which were then subjected to overlay analysis in GIS environment (ArcGIS 9.1) to decipher the spatiotemporal variability of the river regime. Geological Survey of India topographic maps (1:50000: 1963-70) were used as the earliest spatial reference data and all spatial data were brought into same platform with respect to the topographic maps in WGS84 datum (LCC projection). Six major tributaries viz., Jiya Dhol, Sisi, Dimu, Simen, Dikari and Deka Pam (Figure 1B) were studied from satellite images spanning over the period 2000-2010.

Table 1. Database details

Data type	Year	Source	Resolution/Scale
Topomap	1963-70	Survey of India	1:50000
ETM^+	2000	Open data source downloaded from internet	30m
IRS-P6 LISS III	2006	NDC, NRSA Hyderabad	23.5m
IRS-P6 LISS III	2010		

Results and Discussion

Changes in Channel Length

Length of the selected rivers from the mountainfront to their debouch point with the Brahmaputra were analysed from temporal datasets and the results are tabulated as given in Table 2 and presented in bivariate plots (Figure 2).

The length of the Jiadhol river was gradually increased from ~9km in 1967 to ~23km in 2000. Subsequently the length of the river further increased to 25.2 km and 33.3 km during 2006 and 2010 respectively. As such the length of this river becomes almost 3 times at present as compared to the 1967 length. The length of the Sisi river increased from 1967 to 2000 but decreases slowly from 2000 to 2006. In 1967 it was about 14.6 km which increased to 23.7 km in 2000 but decreased to 12.1km in 2010. Dimu river shows alternate decrease and increase of the river length. During 1967 length was 9.03 km but increases to 12.87 km during the period 2000 followed by a shortening episode during 2000-2006 with 10.3 km in length which was followed by increase in length to about 12.0 km in 2010. Overall analysis shows that the length of each of the selected rivers have increased with the exception of the Sisi river during the period of study (1967-2010) with remarkable steady increase in length of the Jiadhal river which is in the westernmost part of the district.

Table 2. Changes in length (kms) of the alluvial reaches between Arunachal foothills and Brahmaputra active floodplain during 1967-2010

Year	Jiadhol	Sisi (Gai)	Dimu	Simen	Deka Pam	Dikari
1967	8.99	14.55	9.03	14.57	6.73	6.34
2000	22.98	23.73	12.87	23	8.69	13.05
2006	25.22	21.71	10.3	29.73	7.24	11.55
2010	33.28	12.13	12.04	20.9	7.3	13.78

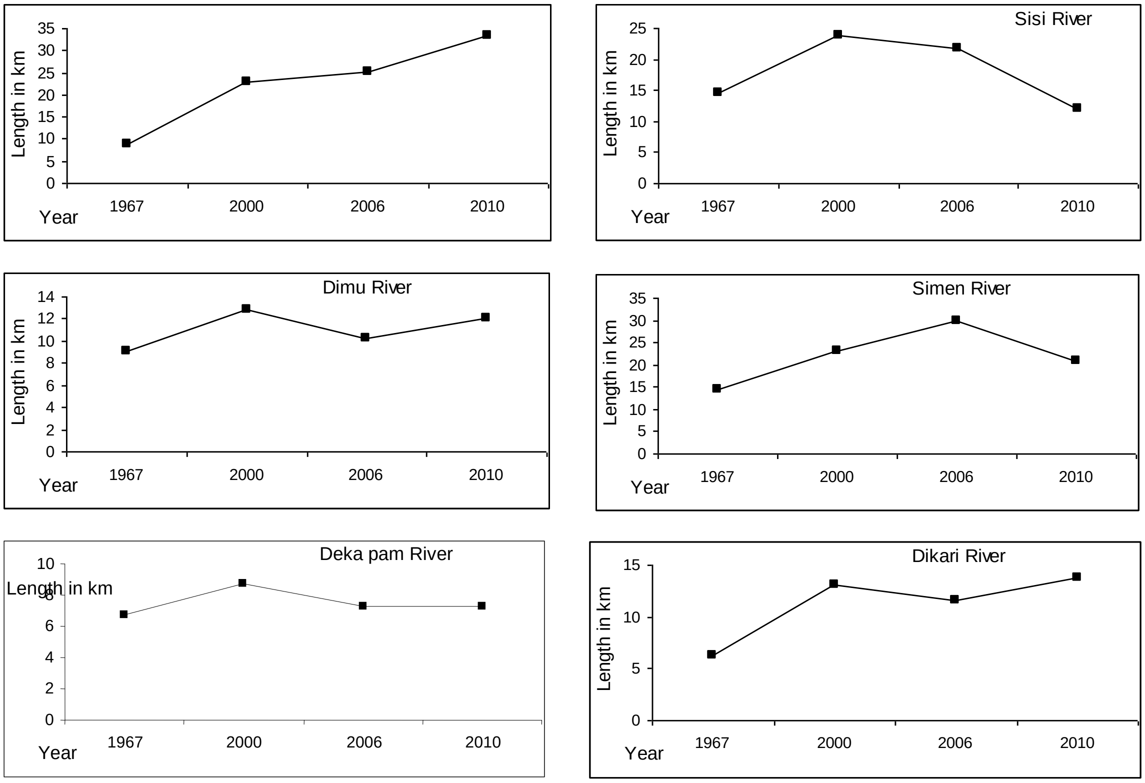


Figure 2. Changes in length (kms) of the selected rivers with time

Lateral Channel Change

Topographic maps (1963-70) show that the Jiadhol river was highly aggrading in nature and developed a number of braid bars downstream of the mountainfront with clear signature of sediment dispersal around the main channel. It also shows a persistent convexity towards east (Figure 1B). During subsequent period till 2010 the river extended the braided segment further downstream with a better developed thalweg but still maintaining an overall braided character. In 2000, the downstream extension joined a small tributary of the Subansiri River and then splits up into multiple channels before joining the Brahmaputra. Three representative reaches of this river can be demarcated along this river viz., the upstream reach north of the mountainfront where it is largely a bedrock channel, the braided segment downstream of the mountainfront and the segment adjacent to the Brahmaputra where the river takes a distributary nature. The Sisi river was well developed between the mountainfront and Lalunggaon (south) beyond which it merged into a swampy floodplain. Subsequently, as seen from the satellite data of the year 2000, the river extended further downstream upto Bormukali with active aggradation beyond which it merged with the Brahmaputra floodplain. Slightly north of Lalunggaon the river shows a persistent westward swing and ultimately merged with a small anabranching channel of the Brahmaputra. The Dimu river course showed a prominent eastward convexity in 1967 and was a single channel flow which transformed into a typical braided channel subsequently. The period of study (1967-2010) is characterised by channel widening, enhanced aggradations leading to development of a number of bars and multichannel flows. Downstream of Arsia Majhabari, the channel shifted eastward developing into a westward convexity around this area.

The Simen river also shows an eastward convexity and enhanced aggradation over time. Initially it drained into the Burhisuti, an anabranching channel of the Brahmaputra. However, subsequently, as seen from satellite data of the year 2000 and upto 2010, the Burhisuti became redundant and the Simen extended its course occupying the former Burhisuti developing into a much larger channel. High sediment dispersal contributed towards building up this extended segment of Simen river. The present channel downstream of Simenmukh is draining through the active floodplain of the Brahmaputra. The Dekapam river has a short alluvial reach between Arunachal foothills and the Brahmaputra floodplain draining into floodplain marshes around Gnopi. High rate of sedimentation is evident from the large abandoned sandsheets and shrinkage of the wetland to which it enters south of Gnopi. A remarkably straight NE-SW trending alluvial reach south of the mountain front and insignificant lateral shifting compared to other streams is observed in case of the Dekapam rver. In 1967, it was flowing towards the west and drained into a marshy land (Jamjing beel). In 2000, the river shifted towards the west and then took a bend towards the south in the downstream part. In 2006, the river abandoned the bifurcated channel and flowed through the former course towards the west. In 2010, the river further extended its course westward in the Jamjing beel flowing into a small stream joining the Brahmaputra River.

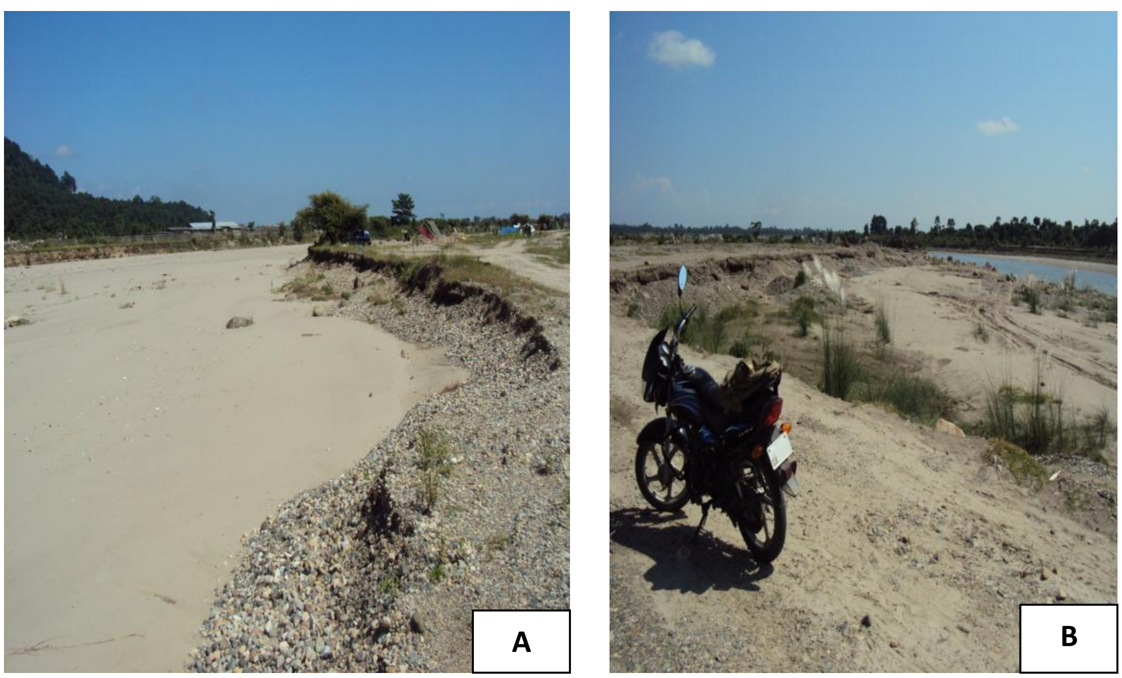


Figure 3 Lateral channel changes and aggradation in Dhemaji district (field documentation in 2011). A. premonsoon view of a channel which is now abandoned and a new channel (B) curved out causing a net lateral shift of about 300m. The Flow direction is towards south (bottom of the photograph).

Discussion

Fluvial landscapes provide an ideal terrain for process-response (Leopold et.al., 1964) analysis and thereby evaluate the controlling variables on landform development. Changes in plan view morphology (Leopold and Wolman, 1957), erosional and depositional processes and space-time variability are ubiquitous in an alluvial river with changes in their relative intensity and frequency. Large alluvial rivers (Schumm et al., 1994) provide trails of this variability which can be very well discernible through satellite images with its advantage of synoptic view and repetitive coverage. In general there is a balance between the net aggradation and erosion in a stable tectonic and climatic condition. This equilibrium is however disturbed by neotectonic activities and/or climatic fluctuations resulting in periodic variability in the intensity of construction or erosion processes which are reflected in morphological changes of river regime. The North Brahmaputra Plain (NBP) is part of the tectonically active Himalayan domain and climatically dominated by the strong south west monsoon that last during June-September bringing rainfall as much as 2000mm. As such the river regime is influenced both by tectonic and climatic factors. However, available records show that there is no significant change in monsoonal rain during last few decades while the river variability is more pronounced during this time suggesting an overwhelming influence of tectonism in landscape development in the region. It is plausible that the active tectonism in the Himalayan domain has led to enhanced sediment generation and gradient change in the rivers leading to the overall morphological changes downstream. Flashy nature of recurring floods lead to frequent lateral changes of these rivers and also result in deposition of large sand sheets which has buried large tracts of productive agricultural lands. The wider reaches between Brahmaputra floodplain and the Himalayan foothills are particularly vulnerable to lateral channel shift due to easily erodible banks composed of pebbly sand and gravels. Most of the rivers under study shows an overall increasing trend in length of the segments between mountain front and the debouch point i.e., between the Arunachal Himalaya foothills and the Brahmaputra. This increase in length is mainly due to extended segments along the active floodplain of the Brahmaputra and perceived to be the result of a general westward swing taken by these rivers occupying anabranching channels subparallel to the Brahmaputra. Significantly, the channels north of the world’s largest river island ‘Majuli’ have shrunk to very narrow anabranches and the floodplain has now emerged with increased siltation which has influenced the changes in the river regime flowing into the Brahmaputra from Arunachal Himalaya across the Dhemaji district. These rivers have also contributed to a higher sediment input into the Brahmaputra river resulting in more aggradation in northern side of the channel and forcing a gradual southward migration of the southern bank between Dhola and Dibrugarh (Phukon and Machahary, 2011).

Conclusions

This limited study has brought out the variability of the river regime in part of north Brahmaputra plain in space and time. It is observed that the river variability in the region is not following a particular pattern except their persistent westward swing adjacent to the Brahmaputra. There have been extensive changes in the river regime over the period 1967-2010 by way of progressive extension of debouche point of the rivers further south and south west as well as progressive widening of the channel courses downstream of the mountain front. The overall changes in plan form geometry and frequency of bar formation suggest enhanced sediment dispersal along these channels over time. Further, frequent breaching of the river banks and development of sand sheets over extensive areas is the result of flash floods which are recurring hazards affecting this region. Flashy nature of floods, strong seasonality of the flows together with erodible bank materials has resulted in the largely unpredictable behaviour of these rivers. Increase in the sediment dispersal by these rivers over time has led to rapid aggradations of many areas developing into huge sand sheets and thereby reducing productivity of large tracts of agricultural lands. Active tectonism within the realm of Arunachal Himalaya is perceived to be the principal causal factor in the river variability of the region.

References

Balasundaram, M.S. and Murthy, M.V.N. (1977). Contribution to Geomorphology and Geohydrology of the Brahmaputra valley, Miscellaneous Publication No. 32, pp1-290.

Geological Survey of India (GSI) (1977). Miscellaneous Publication No. 46.

Karunakaran, C. and Ranga Rao, A. (1976). Status of exploration for hydrocarbon in the Himalayan region- contribution to stratigraphy and structure, Geological survey of India, pp1-69.

Leopold L.B. and Wolman M.G. (1957). River Channel Patterns: Braided, meandering and Straight, U.S. Geological Survey Professional Paper, 282B, 85 p.

Leopold, L. B., Wolman, M. G. and Miller, J. P. (1964). Fluvial processes of Geomorphology, W. Freeman, Sans Francisco, pp. 522.

Phukon, P. and Machahary, Ratamali (2011). Erosional vulnerability of the Brahmaputra river between Dibrugarh and Dhola, Assam: A Remote Sensing and GIS based study, Insignia, Vol. II, pp.

Schumm, Stanley A. and Winkley, Brien R. (1994). The Variability of Large Alluvial Rivers, American Society of Civil Engineers, New York, 467p.

Tak M.W. and Mehta P.N. (1981). A note on the Photogeomorphic studies of Jia Bhareli Basin, Brahmaputra Valley, Miscellaneous Publication No. 46, Geological Survey of India, pp 53-66.

Viswanathan, T. V., Chakrabarti, C. (1977). Fluvial processes, Geomorphology and Geology of Jiabhrali basin, Publication No. 46, Geological Survey of India, pp 123-167.

Synergistic Use of Multispectral EO-1 ALI, Landsat-ETM+ and Hyperspectral Hyperion Data and GIS for Regolith Landform Mapping in Arid Region: Implication for Groundwater Exploration

G. Balamurugan[1], V. Thirukumaran[2] and K. Santhanam[3]

[1]*Centre for Remote Sensing and Geoinformatics, Sathyabama University*
[2]*Department of Applied Geology, Government Arts Collage, Salem*
[3]*Centre for Water Research, Sathyabama University*
E-mail: remotebalag@gmail.com

Abstract

Availability of new generation of Hyperspectral sensors such as the Hyperion has lead to new challenges in the area of rock types and related land cover mapping. In the present study, Hyperion data and relevant Hyperspectral techniques are being evaluated with regard to their utility in mapping the surface distribution of geological and Regolith landforms in semi arid environment for the purpose of groundwater exploration. A series of Hyperspectral unmixing processing was taken and the results were compared to the simulated conditions. Various image enhancement techniques like PCA, Decorralation Stretch and Band Ratioing are applied. The E0-1 ALI and HYPERION data were able to differentiate different regolith-landform units and its related groundwater occurrences in arid region. All this has taken place across a vast array of bedrock types, including regolith-dominated areas extremely prospective for groundwater exploration. Results shows that successful discrimination of geological and soil units could allow for the improved mapping of bedrock exposures as well as the determination of the fractional compositions of highly weathered regolith landforms that extend across study area.

Introduction

Knowledge of the distribution of regolith materials (*regolith architecture*) provide information on active landscape processes, as well as past processes that have contributed in the evolution of a landscape. This information is vital for understanding issues such as the movement of water through the landscape, and the current distribution and properties of soils. The chemistry of the regolith, and therefore of the soil, can differ significantly from that of the parent rock due to chemical weathering processes. This effort, at the same time, provides information to establish a hydrogeologic conceptual model and a simulated mode for evaluating potential yield of ground-water resources within the study region. An attempt is made here to study Landsat-TM and Hyperion data for its effectiveness as a suitable remote sensing instrument used in regolith-landform mapping. A range of iterative processes have been compared to determine the most suitable data interpolation techniques to map the regolith in an arid landscape. The success of the mapping was intended to show the usefulness of Hyperspectral data as a groundwater exploration tool.

Aim and Objectives

The objective of this study is to explore the synergistic use of Landsat TM and E0-1 ALI Multispectral and HYPERION Hyperspectral data for Regolith Geological mapping and its hydrogeological characteristics in highly weathered Semi arid terrain.

The specific objectives of the study are: to find out the potential of Landsat-TM and E0-1 ALI multispectral and HYPERION Hyperspectral data for the purpose of Regolith Geological mapping. to suggest appropriate satellite data and corresponding digital image processing techniques for different Regolith features. To evaluate the Regolith Profile and groundwater occurrences in highly weathered hard Rock terrain in Arid region.

Study Area

The study area is located in Vellore district, Northern Tamilnadu, between latitudes, 13o12’32” N and longitudes, 78° 24′ 16”E in the west of Vellore city figure 1. Study area covers an area of 764 sq km with a variety of geological formations, climatic conditions and vegetation types (i.e., forests, scrublands, grasslands and agricultural lands). Physiographicaly the study area is an undulated terrain. Diversity in land forms of study area has resulted in a variety of forest and agricultural systems in the region. Generally subtropical climate prevails over the district. The temperature rises slowly to maximum in summer months up to May after which it drops slowly. The mean maximum temperature ranges from 28.2oC to 36.5o C and the mean minimum temperature from 17.3oC to 27.4oC.

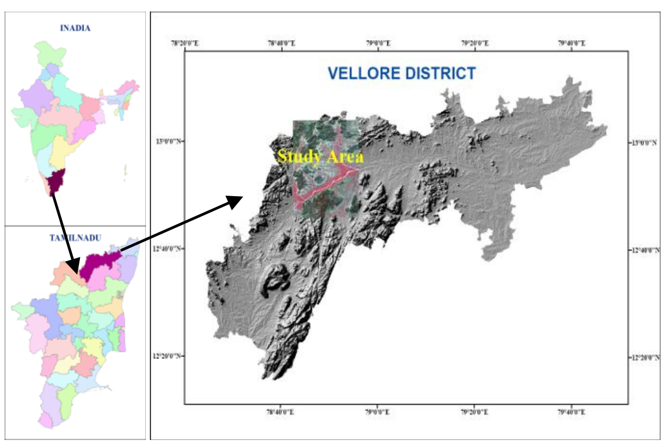


Figure.1. Location map of the Study area

Geological Setting

Geologically the study area consists of mainly Charnockite, Fissile hornblende-biotite gneiss and, sand and silt. Mountains with dense and scattered vegetations, weathered and solid rocks, complex slopes with exposures, south and north looking faces, and various soil types (alluvial, colluvial and/or residuals) with varying depth normally show a great variability.

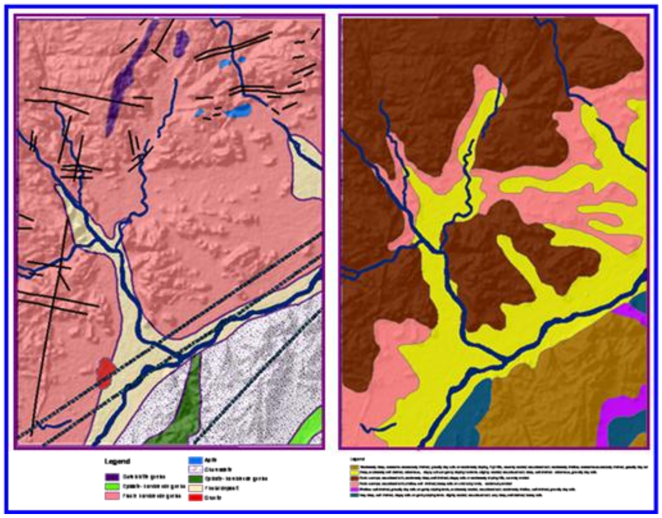


Figure.2. A Lithostructural and soil Soil map of the Study area

Regolith and Hydrogeological Landscapes

Water plays a critical role in regolith development- even in arid environments- and surface sub-surface flows are themselves modified by the structural make up of the regolith. For example, groundwater may flow through both *in situ* and transported regolith at variable depths, as well as out-flowing as springs on the ground surface or taken up by vegetation (figure.3). The Hydrogeological-Landscape framework (HGL) builds on the groundwater flow system (Coram 1998; Walker et al 2003) framework that was developed approximately 10 years ago– primarily to assist in the management of groundwater salinity. The Hydrogeological-Landscape framework is a broad, all encompassing entity which accommodates all forms of water flow (surface, interflow and groundwater flow). Hydrogeological-Landscape Units (HGLU) integrate information on Lithology, bedrock structure, regolith (including soils), landforms, climate (including rainfall, seasonality, evaporation) and vegetation (figure 3). These components influence, greater or lesser degrees, the recharge, transmission, storage and discharge characteristics of a particular hydrological system. The HGL concept has been developed for upland erosional landscapes (such as where hill slopes have a major control on water movement) as documented here; however, it has also has the potential to be applied to depositional settings.

Data Used and Methodology

Landsat TM and ETM + were used in this study. The Landsat TM image (Path143, Row 51) of 24-02-2001 was downloaded from GLCF (Global Land Cover Facility). The Advanced Land

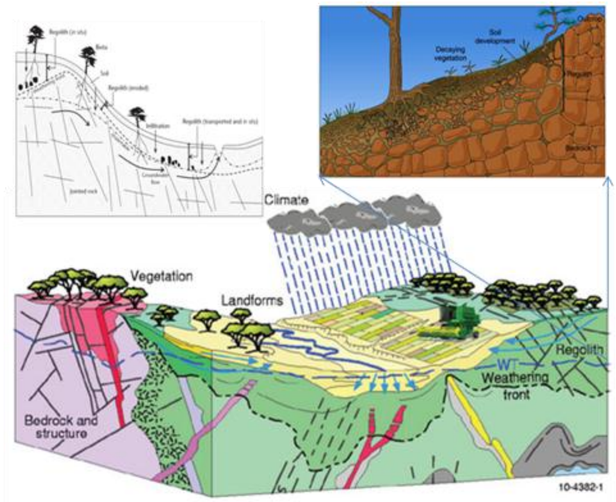


Figure 3. Factors influencing surface and groundwater movement and storage. Bottom picture. The effect of groundwater in regolith processes. top left picture. (after Taylor and Eggleton, 2001).

Imager (ALI) satellite sensor was designed in part to provide future data continuity with the Landsat record (Figure5). Although the EO-1 ALI swath width (37 km) is more restricted than that of Landsat (185 km), and ALI acquisitions must be scheduled in advance, the ALI sensor is pintable. The spectral range and spatial resolution of bands for each sensor are given in Table 2. The ALI measures solar irradiance in 9 multispectral bands between 0.433 and 2.35 μm, providing 3 more multispectral bands than Landsat TM or ETM+. The spatial resolution of the panchromatic (PAN) band is 10 m, compared to the 15 m resolution of the ETM+ panchromatic band. Furthermore, ALI data are 16-bit rather than 8-bit, offering greater dynamic range. ALI and HYPERION data was downloaded from USGS earth explorer .The Hyperion instrument was designed as a technology demonstration and provides high-quality calibrated data for Hyperspectral application evaluation (Pearlman et al. 2003a). Hyperion is a high-resolution Hyperspectral imager capable of resolving 220 spectral bands (from 0.4 to 2.5 mm) with a 30m spatial resolution and a nominal spectral resolution of 10 nm. The instrument, which operates on the push broom principle, can represent one 7.5km 6100km land area per image and can provide detailed spectral mapping across all 220 bands with high radiometric accuracy. Topographical data ASTER-DEM (30m). Spectral band characteristics of three sensors are given in Table. 1.

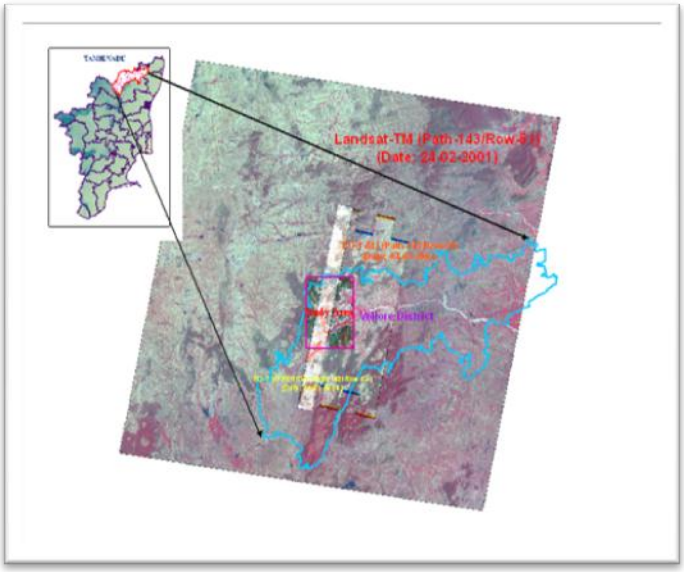


Figure5. Landsat TM and E0-1 ALI and Hyperion Data Coverages of the Study area

Table 1: Band Characteristics for LandsatTM and Earth Observation-1 ALI and Hyperion sensors

Spectral Zone	ALI (30 M Resolution)		TM (30 M Resolution)		HYPERION (30 M Resolution)
	Bands	wavelength	Bands	wavelength	Bands
VNIR	MS-1'	-	-	-	11-16
	MS-1	0,450-0.515	1	0,450-0,520	9&10
	MS-2	0,525-0.605	2	0,530-0,610	18-25
	MS-3	0,630-0,690	3	0,630-0,690	28-33
	MS-4	0,775-0,805	4	0,780-0900	42-45
	MS-4'				49-53
SWIR	MS-5'				106-115
	MS-5	1,550-1,750	5	1,550-1,750	141-160
	MS-7	2,080-2,350	7	2,090-2,350	193-219

Data processing and interpretation for this work were performed at the Center for Remote Sensing and Geoinformatics at Sathyabama University Chennai, Tamilnadu. ERDAS IMAGINE 9.1 and ENVI 4.7 were the main software packages used for the image processing. The overall methodology for this study is presented in Figure 6. Processing of Hyperspectral data requires different approaches in comparison to multispectral data. The idea behind Hyperspectral data is to identify the composition of superficial materials based on their spectral signature in the 0.400 to 2.500 µm wavelength range. For this purpose, some sort of comparison between pixel spectral signatures (unknown) and spectral signatures of reference materials (known) needs to be made, in order to establish quantitatively how similar a pixel is compared to the reference materials. The image processing of satellite data was carried out in two steps. Initially, we started with the preprocessing procedures and then we continued with the main image processing steps.

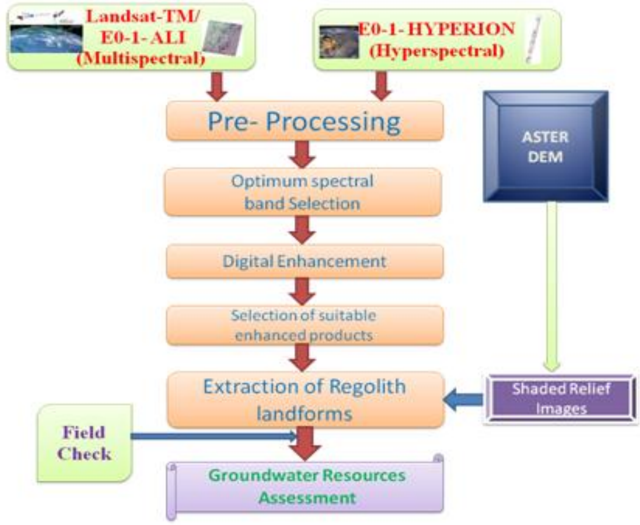


Figure6. Hyperspectral data processing methods for Regolith mapping for Groundwater resources assessment

Pre Processing

For quantitative analysis of surface reflectance, removing the influence of the atmosphere is a critical pre-processing step. To compensate for atmospheric effects, ENVI's atmospheric correction module, FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) which incorporates the MODerate resolution atmospheric TRANsmission 4 (MODTRAN 4) radiation transfer code is needed to compute an estimate of the true surface reflectance. Processing hyperspectral data requires different approaches in comparison to multispectral data. The idea behind hyperspectral data is to identify the composition of superficial materials based on their spectral signature in the 0.400 to 2.500 µm wavelength range. For this purpose, some sort of comparison between pixel spectral signatures (unknown) and spectral signatures of reference materials (known) needs to be made, in order to establish quantitatively how similar a pixel is compared to the reference materials.A selective image processing technique (SIPT) is a new approach in Envi4.7, which gives rise to valuable results in this work. The SIPT and the visual interpretation of the constructed false colour composite (FCC) and ratio images led to discriminate and delineate the lithologic units and Regolith Landforms of the study area.

Optimum Spectral Band Selection

Band selection was performed based on Hyperspectral data taken at 400 - 900 nm spectral range for Regolith Land covers in arid region. The training statistics were assembled from each band for each land cover. A decision must be made to determine the most suitable bands for discriminating the land cover classes in the imagery. For this purpose, the Principal Component Analysis (PCA) was performed to obtain new channels in the classification process (table 2). The first four PCA channels of each date having total variance higher than 99% were used within the analysis. In addition to PCA channels, most effective bands were identified through examining class reparability based on the divergence of the class signatures. As a result, a subset of best three bands was extracted for each scene.

Table 2: optimum spectral bands selected for Landsat and Earth Observation-1 ALI and Hyperion sensors in this studies

Spectral Zone	E0-1-ALI	Landsat-TM	HYPERION	
VNIR	1p	MS-1	10	VNIR_1
	1		14	VNIR_1
	2	MS-2	22	VNIR_1
	3	MS-3	31	VNIR_1
	4	MS-4	44	VNIR_2
	4p		51	VNIR_2
SWIR	5p		110	SWIR_2
	5	MS-5	149	SWIR_3
	7	MS-7	207	SWIR_4

Composition of RGB Composites

Several RGB composites were constructed in an effort to examine their efficiency in the detection of the Regolith land covers. For the Landsat-TM image with acquisition date 24-02-2001, the RGB composites have been the most successful for the detection of the geomorphological features. Similarly, RGB composites of HYPERION image were able to detect the Regolith landforms. The selection procedure using the statistical techniques was applied in ALI and Hyperion data that covers the most prominent Land cover types in study area.

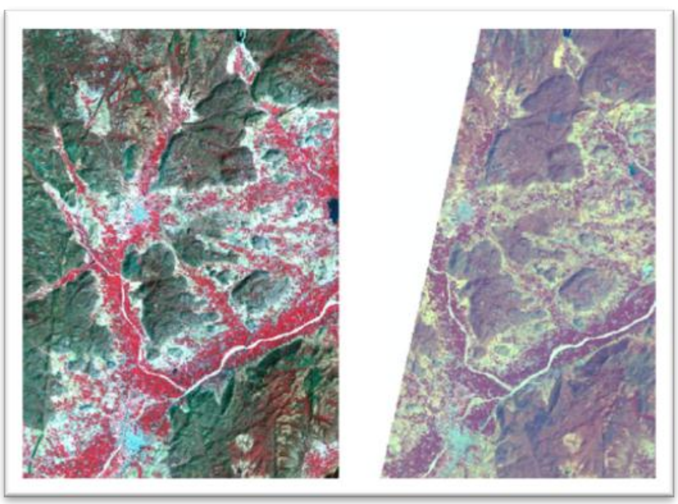


Figure 7. Landsat TM FCC (4-3-2VNIR) left image, Earth observation 1- ALI 5-4-2 SWIR/VNIR) Right image

Figure 8. HYPERION FCC (22-31-44VNIR) left image, (110-149-207 SWIR) Right image.

Principal Component Analysis

Principal component analysis (PCA) was performed with the six reflective bands of ETM+, and a number of different three-band PC color composite combinations were created and analyzed for their content. After transformation the data were subjected to histogram equalization to enhance spectral differences in the terrestrial materials. Several color combinations of PC images were assessed. The most informative PC color composite for study area is that of PC 1, 2 and 3 in RGB. The Colluvial Landcover could be easily demarcated by PCA FCC 4-3-2 (Figure 7& 8.), due to the association of vegetation all along the channels.

Decorrelation Stretch

The Decorrelation stretch (DS) conducted on ETM+ bands 4, 5 and 2 and ALI and HYPERION is shown in Figures 9& 10. Better Regolith contrast was obtained when compared, for instance, with the standard band combination of PCA images. Moreover most of the Regolith units in the study area are discernible in the image.

Results and Discussion

The general philosophy to regolith mapping involves the use of a range of more readily available surrogates, such as geology, landforms, soils and vegetation, to infer likely regolith properties and architecture. The use of landform as a surrogate is common in regolith mapping in Arid Region, as described by Pain *et al*. (2000). Regolith information can aid in understanding many landscape processes that are relevant to natural resource management. Regolith architecture has a major influence on the movement of water and solutes that enter the unsaturated zone from our land management practices, and on groundwater recharge and discharge. The regolith provides vital information for predicting the distribution of soil properties. It retains a record of past processes that have shaped the landscape, which may have contributed to a more complex distribution of materials than modern landforms indicate.

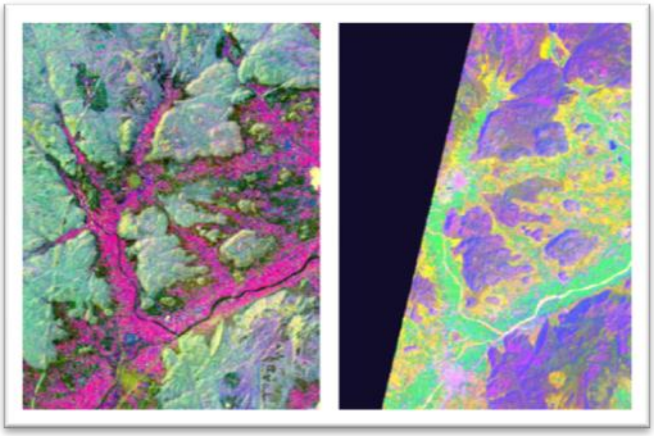


Figure. 9. Decorrelation stretched Landsat-TM (4-3-2) left image Earth observation-1 (5-4-3 SWIR/VNIR) right image.

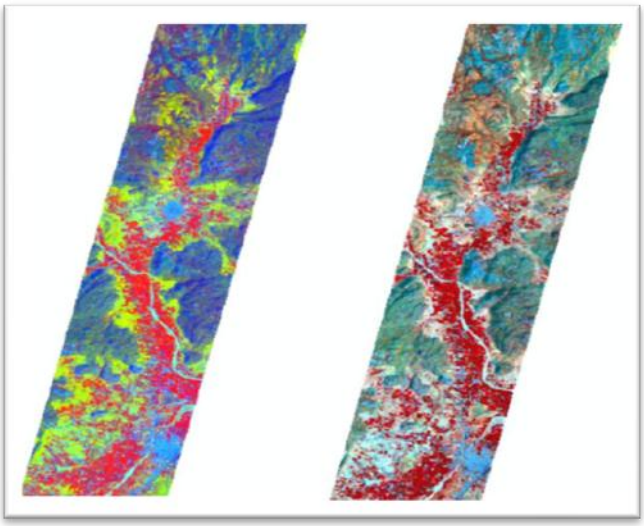


Figure 10. Decorrelation stretched HYPERION (22-31-44VNIR) left image (110-149-207SWIR) right image

The Landsat and ALI, Hyperion data was to prepare regolith-landform maps to show the relationships between the bedrock, regolith and mineralisation. RGB false colour composite band combinations, including Decorrelation Stretch and Principal Component Analysis were used for classification of units in the making of the regolith map (Figure 11).

Weathered Bedrock contains a vast array of bedrock lithologies and structures which have variable responses to weathering, and therefore different weathering morphologies and landscape expressions. Bedrock lithologies such as fissile biotite gneiss and charnockite tend to be moderately to highly weathered in surface exposures, extensive fracturing and sheared fabrics that facilitate the access and through flow of weathering solutions. High relief areas, such as the northern part of study area mostly consist of highly weathered bedrock. Moderately to highly weathered bedrock is mostly exposed on the flanks subdued landscape expression (such as low rises of erosional plains) or buried by transported regolith (such as underlying many valley systems). Alluvial landforms include small drainage depressions and alluvial channels incising bedrock highs, and wide channels with alluvial plains draining the bedrock highs, the alluvial sediments within the bedrock-dominated areas and a wide range of alluvial sediments occur in the region, associated with both the modern and ancient drainage systems.

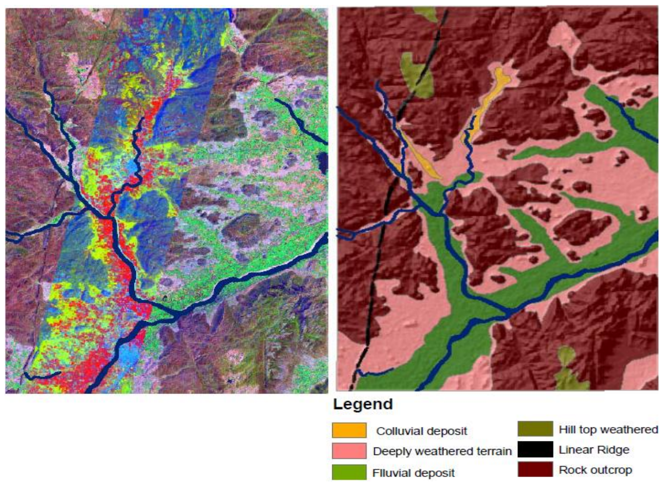


Figure11. Regolith map of the Study area. right image. Enhanced Landsat TM and and Hyperion Data Left image.

Colluvial sediments in the region are derived from denudational processes and are extremely widespread across the region, typically extending from the upper slopes of rises down towards the axes of adjacent valley systems where they then typically contribute to alluvial sediments. Many of the features previously described as ‘alluvial fans’, largely consist of lobes of sheetwash deposits. They include a wide range of locally derived lithologies (clays, silts, sands and pebbles), and the composition of clasts is highly variable and depends on the nature of the local substrate.

Regolith and Hydrogeological Characteristics

In general, the hard rock formations do not have good groundwater potential, still integrated studies help to ascertain presence of hidden water bearing formations. Advanced Hyperspectral Remote Sensing and GIS proves to be an effective tool to locate the productive zones. The various Regolith units are classified as favorable, moderately favorable and poor zones of groundwater (Figure 12). Groundwater development is promising in the floodplains, alluvial plains and valley fills that are associated with thick alluvium and weathered material that has high porosity and permeability characteristics. Only a small area is occupied by these landforms, and hence favorable zones of groundwater are very limited in the study area. A large part of the area is occupied by pediments, pediplains, structural hills, which do not favor much infiltration and hence are generally not favorable for groundwater exploration. The study reveals that a large part of the area has good to moderate groundwater producing potential.

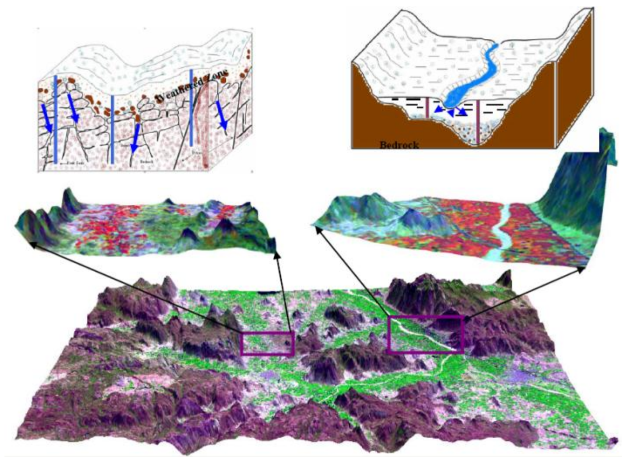


Figure 12. Regolith Landscape setting and hydrogeological characteristics of the study area.

Conclusions

Regolith-landform mapping involves the identification of landforms, rock outcrops and the portrayal of regolith units. Much information about potential areas for groundwater exploration can be gained by interpretation of surface features on Multispectral and Hyperspectral satellite images. Images extracted from Landsat, ALI, Hyperion remotely sensed data are used for the recognition and interpretation of basement outcrop, Soils, and geomorphology. Geological units were identifiable, as were regolith-landformunits and groundwater occurences. TM and Hyperion data has shown its effectiveness in regolith-landform mapping. Results defined areas of calcrete suitable for Regolith mapping. Results of fieldwork analysis confirmed that groundwater potential maps could be produced with a Deeply weathered Regolith profile.

References

Shih-Meng Hsu , Chien-Chung Ke , Yen-Tu Lin , and Ji-Jao Huang (2011).Ground-water Exploration in Regolith-bedrock Aquifer: A Case Study in the Basins of Mid-Jhuoshuei River and Beigang River, Central Taiwan. Geophysical Research Abstracts Vol. 13, EGU2011-3140.

Butt, C.R.M., Lintern, M.J., and Anand, R.R. Evolution of Regoliths and Landscapes in Deeply Weathered Terrain— Implications for Geochemical Exploration.

Heinson. Geologic and regolith mapping for mineralexploration in the Gawler Craton of South Australia using Hyperion and other remote sensing techniques. IEEE Explorer.

Simon N. Benger. Remote Sensing of Vegetation Surrogates for Regolith Landform Mapping. IEEE Explorer.

Callist Tindimugaya, Regolith importance in groundwater development. 21st WEDC Conference sustainability of Water and Sanitation Systems.

Application of Remote Sensing data for Glacial Studies – An Overview

Pratima Pandey and G. Venkataraman

Centre of Studies in Resource Engineering (CSRE), IIT, Bombay
E-mail: prathimapandey@iitb.ac.in

Abstract

The glacier study is important in the sense that it has a direct relation with climate change. Glaciers are a mirror reflector of climate change and the information about the climate and its changing behavior can be inferred by studying glacier and its response. Glaciers can be considered as a fascinating laboratory for studying climate change processes. There is a strong coupling between energy exchange, melt of snow and ice, and albedo. Studies of glacier can reveal problems and issues related with climate which are difficult to understand directly otherwise.

The glaciers in general are located at the higher altitude which makes them inaccessible. Also, the weather and climate near the glaciers are harsh and it is very difficult to survive there for more than few days. Logistically and financially also it is very difficult to study the glaciers and its behaviors directly. In that case, remote sensing data with their synoptic view proved very useful for studying glaciers. Remote sensing approaches allow for regular monitoring of alpine glaciers and their properties with availability of appropriate spatio-temporal data with large coverage and at regular intervals. The present papers peek into the use of remote sensing data for glacier study.

Introduction

The glaciers are highly sensitive to climate change and are good indicator of the energy balance (Oerlemans, 2005). Because of their repetitive coverage, synoptic view and up-to-dateness, remote sensing has a great potential in the glacier study. Satellite remote sensing provides an efficient tool to study the changing environments of glaciers which are usually located in the remote, inaccessible areas. Satellite data makes it possible to monitor the glacier continuously which is otherwise difficult due to inhospitable environments. The advent of satellite remote sensing has opened up the possibility of data acquisition in such terrains at regular intervals.

The advent of satellite remote sensing has opened up the possibility of data acquisition in such terrains at regular intervals. For glacier study, both optical as well as microwave data are important and provide valuable information. Optical remote sensing data analysis has been used for mapping glacial landforms, snow cover extent and glacier inventory (Kulkarni, 1991). Microwave remote sensing have advantage over optical remote sensing owing to the fact that microwave can penetrate cloud cover. But both microwave and optical data compliments each other for glacier study. The present paper is a review of the remote sensing application for glacier study and how remote sensing makes it possible to study the different parameters of the glacier have been discussed.

The glacier study by remote sensing is based on the fact that different features have different and unique reflectance and albedo system. A snow cover insulates the ground, and fresh snow reflects up to 80% or more of the incoming solar Energy which compares drastically with only 20% or less for bare ground [Weller and Holmgren, 1974]. This allows us to identify various surface types and differentiate them from each other (Konig et al., 2001). The spectral property or surface albedo of glaciers governs their separatibility from other covers on remote sensing images. For glaciers to be detected from remotely sensed materials, they must be spectrally discernible from the air or space. Theoretically, it is feasible to study glaciers by means of remote sensing (Jay Gao and Yansui Liu, 2001). The different features and properties of glacier studies through remote sensing are discussed.

Glacier morphological study

The various glaciers zones and features to be detected by remote sensing were first proposed by Ostream (1975) and they have been mapped with optical sensors, passive microwave sensors and synthetic aperture radar (SAR). The major geomorphologic features observed in Indian Himalaya are snow cover area, terminal, lateral and medial moraines, moraine damned lakes and snout of the glacier. Moraines are the glacier deposits which consist of dirt, rock flour and boulders. Identification of these features on satellite images depends upon spectral reflectance from these features. The glacier features like ablation area, accumulation area, glacier boundary, equilibrium line, snow line, moraines and moraine-dammed lakes are identifiable in an image by using standard combination of bands (Kulkarni and Bahuguna, 2001).

Glacier mapping and monitoring

Due to its synoptic view remote sensing is best for studying the glacier evolution, its temporal variation and change over the time. Optical data can be used for the inventory and the mapping of glaciers. The mapping of glacier involves estimation of its total area, ablation area, accumulation area and position of its snowline altitude. These features of glaciers are identifiable in a satellite image. For mapping of the glacier, the satellite data of August- September is used in case of Himalayan glacier, for during this period the glaciers are exposed to the maximum and it is easy to identify them in the satellite images. By using standard band combinations it is possible to delineate a glacier area from surrounding rock bodies. Accumulation area involves the area where accumulation of snow takes place. Accumulation normally takes place at or near the glacier surface (Paterson, 1994). Accumulation area has very high reflectance. Spectral reflectance is higher in all three bands. Hence it appears white on the FCC and is easily delineated. Ablation includes all processes by which snow and ice are lost from the glacier. The ablation area is the lower part of the glacier. Glacier ice has substantially lower reflectance than snow, but higher than rocks and soil of the surrounding area. It has a rough texture and gives green-white tone on FCC and can easily be differentiated from the accumulation area and surrounding rock and soil. Figure 1 shows the different zones of glacier as seen in satellite image.

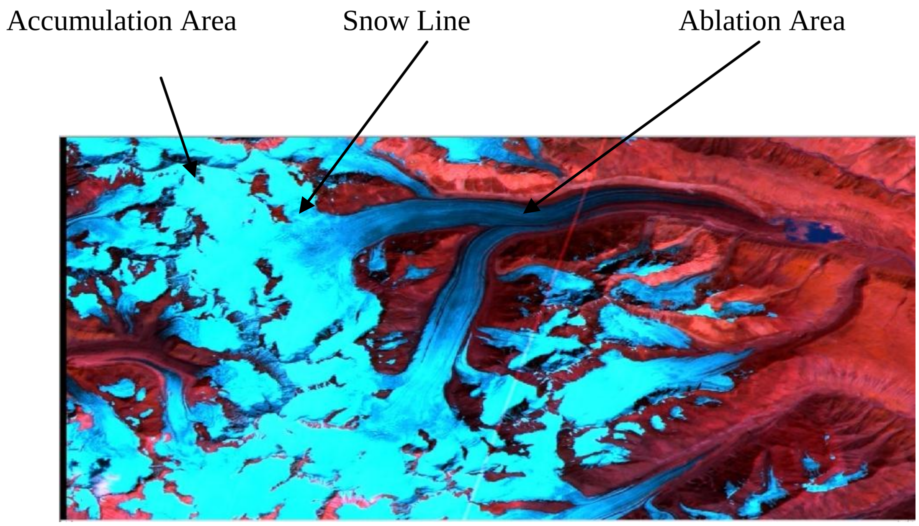


Figure 1: different zones of a glacier in satellite image

The monitoring of glacier is basically studying the change in the length and area of a glacier over the past years. The study of monitoring a glacier provide us the information of state of a glacier, like if the glaciers are increasing in length and size or decreasing over the past years. The increase or decrease of a glacier depends on the climate. So, by studying the glacier length and size information on climate can be inferred.

Snow mapping or snow/ice differentiation

The snow cover mapping is useful to estimate the total snow cover extent, which is a very essential input for the projection of snow melt run off estimation. The cloud and snow have similar reflectance characteristics in visible and near infrared region. Therefore it is difficult to map seasonal snow in the presence of cloud. The discrimination between snow and cloud can be done using various techniques involving band rationing. One such method is discussed below.

Snow /cloud Discrimination using NDSI

The basic principle behind snow and cloud discrimination is that snow reflects less energy in SWIR band and higher in visible and NIR band. There are various ways for discriminating between snow and cloud, like texture analysis, association with shadow and by using multi-temporal analysis. (Kulkarni, 2001). The reflectance of snow in Short Wave Infrared (SWIR) band is very low because the absorptive coefficient of ice is very high. Water clouds and ice clouds on the other hand are more strongly reflecting than snow in the SWIR region because water is less absorptive than ice and small ice crystal in cirrus clouds are more reflecting than the larger snow grains (Dozier, 1984).The most efficient way of snow/ cloud discrimination is using SWIR band.

The technique developed for snow/cloud discrimination is based upon Normalised Difference Snow Index *(NDSI)*.

NDSI = (Green Reflectance – SWIR Reflectance) / (Green Reflectance + SWIR Reflectance)

The utility of NDSI for snow cover mapping is based upon snow reflectance characteristics. Snow reflectance is high in visible and low in SWIR region. The utilization of middle infrared has additional advantage, as cloud reflectance is high in this band. This helps in discriminating between snow and cloud. Therefore, NDSI is also useful for snow-cloud discrimination. Additional advantage of NDSI is delineation and mapping of snow in mountain shadows. Field and satellite observations suggest that NDSI values in shadows and non-shadows are same. This is possible due to reflectance from diffuse radiation in shadows areas. A snow map prepared from AWiFS data of 2006 of part of Chandra sub basin is shown in figure 2. The white part shows the snow and the black part shows the non snow area of the region.

Figure 2: snow map of part of Chandra sub basin.

Study of Glacier Mass Balance

Mass balance of a glacier is usually referred as total loss or gain in glacier mass at the end of hydrological year. It is the change in mass per unit area over a period of time. It is the difference between the amount of snow and ice accumulation on the glacier and the amount of snow and ice ablation (melting and sublimation) lost from the glacier. Accumulation includes all processes which add snow and ice to the glacier, such as snowfall, avalanches, rime and freezing of rain, and ablation includes all processes by which snow and ice are lost from the glacier: melting, run off, evaporation, snowdrift, and calving (Paterson, 1994). The part or area of the glacier where snow is only added and there is no mass loss is accumulation area. Usually it is the top portion of the glacier. The area of the glacier where the mass lost of the glacier is more than the mass gain is ablation area. This is the lower area of the glacier. The line which separates the accumulation area from ablation area is known as equilibrium line. The mass balance is often expressed in meters water equivalent per year (m w.e.a–1), and is normally measured over a balance year, which starts and ends at the end of the ablation season.

Glacier mass balance can be directly measured by placing stakes in the snow or in the ice. It is the most authentic method to measure the mass balance of a glacier. But logistically and financially it is very difficult to monitor glaciers on periodic basis. Also it is a very cumbersome and troublesome method. Remote sensing has the advantages of giving a synoptic view of the earth on regular basis. The mass balance of a glacier can be estimated indirectly by using remote sensing data. There are broadly two methods of estimating mass balance involving remote sensing data, a) AAR-ELA method described by Kulkarni (1992), and b) DEM method.

a) AAR method of mass balance estimation

The accumulation-area ratio (AAR) is the ratio between the accumulation area and the area of an entire glacier (Meier and Post, 1962).

AAR = Accumulation area/ Total area of glacier

Accumulation area is defined at the end of hydrological year and is separated by the equilibrium line from the ablation area i.e. September.

The difference in the reflectivity of the ice (ablation area) and snow (accumulation area) can be used to delineate the transition between the accumulation and ablation zones. The imaginary line which separates accumulation area from ablation area is known as snowline. Snow line at the end of ablation season can be taken as equilibrium line. The characteristics of the glacier surface in the accumulation zones are distinct from the ablation zone in imagery, allowing a possibility to determine the snowline by remote sensing. Ice and firn have an albedo of 50% or less and the seasonal snow has the albedo of 90%. So the snow line dividing the two zones can be determined remotely. Visual interpretation technique can be applied for snow line determination on satellite images. GIS can be used in order to calculate the total area of glacier and snowline altitude on each satellite image.

In the study of mass balance of Himalayan glacier, Kulkarni (1992) has established a relation between observed field mass balance and the accumulation area ratio (AAR). Such a relationship can be established from long term field measurements. Once the relationship between field mass balance and AAR is established, mass balance can be computed from the AAR obtained from remote sensing. The AAR from remote sensing can be obtained by estimating the total area of the glacier and the accumulation area of the glacier and then dividing the accumulation area by total area.

b) DEM method of mass balance estimation

Digital Elevation Models provide information about the elevation of surfaces. DEM of different years can be taken and an elevation change on glacier surface can be estimated. The change in the elevation of glacier surface over the years can be converted to mass balance by using the density of snow and ice. High resolution elevation data are available such as Shuttle Radar Topography Mission (SRTM) C-band data, ASTER GDEM and also ASTER DEM generated from stereo data, Cartosat-1 and 2 DEM generated from stereo data, ERS-1/2 TanDEM, TanDEM-X and digital elevation model generated from topographic maps. The temporal DEMs can be used to estimate the mass balance change in glaciers and a time series of mass balance can be established using them.

Conclusions

The paper overviews the use of remote sensing data for study of alpine glacier. The remote sensing offers an alternative and promising method for the glacier study when it becomes difficult to study them by going on field. Different parameters of glaciers can easily be studied by remote sensing method which otherwise had been impossible. Mass balance, glacier advance/retreat, snow extent and run off are some of very important parameter which is directly related to climate. The run off estimation of glacier influence the hydrology of the region. Remote sensing data and tools provide a very efficient method for studying these parameters.

References

Dozier J. (1984). Snow reflectance from LANDSAT-4 TM. IEEE Transactions on Geosciences and Remote sensing, Vol. GE-22, No. 3, May 1984, pp 323-328.

Gao., J. and Y. Liu. (2001). Applications of remote sensing, GIS and GPS in glaciology: a review. Progress in Physical Geography 25,4 (2001) pp. 520–540.

Konig., M., J.G. Winther and E. Isaksson. (2001). Measuring Snow and Glacier Oce Properties from Satellite. Reviews of Geophysics3,9,1 / February2 001 pages 1-2 7.

Kulkarni, A.V. and I.M. Bahuguna (2001). Role of satellite image in snow and Glacial investigations. Geological Survey of India Special Publication, 53, 233-240.

Kulkarni, A.V. (1992). Mass Balance of Himalayan Glaciers Using AAR and ELA Methods. Journal of Glaciolology**,** 38 (128), 101-104.

Kulkarni, A.V. and A.M. Buch (1991). Glacier Atlas of Indian Himalaya. SAC/RSA/RSAG-MWRD/SN/05/ 91, 62p.

Oerlemans, J. (2005). Extracting Climate Signals from 169 Glaciers records. Science 308, 675-677.

Ostream, G. (1975). ERTS data in glaciology, an effort to monitor glacier mass balance from satellite imagery. Journal of Glaciology, 15, 403-415.

Paterson, W.S.B. (1994). The Physics of Glaciers, 3rd ed.. Pergamon: Oxford.

Weller, G., and B. Holmgren(1974). The microclimate of the Arctictundra,J . Appl. Meteorol.1, 3(8), 854-862.

Geo-Morphological Mapping of Eastern Parts of Chittoor District, AP using Remote Sensing and GIS Techniques

A.Mariya Raju, G.Arun Kumar, B.Sunanda, A.N. Rao, C.V.S. Sandilya and K.M.Reddy

A.P. State Remote Sensing Applications Centre, Swarnajayanthi Complex, Ameerpet, Hyderabad, Andra Pradesh
E-mail: sangeethxavierraj@gmail.com

Abstract

Chittoor district is one of the chronically drought affected Rayalaseema Districts of Andhra Pradesh. It covers a geographical area of 15,152 sq. km and Situated between 12° 37' and 14°00' North latitudes and 78°03' and 79°55' Eastern longitudes. The eastern/southern parts covering parts of Puttur, Karvetinagar, Satyavedu, Tottambedu and Srikalahasti areas were taken up for study. The southern tip of the well-known Kadapa Basin falls in the Northeastern part of the district, which comprises of Shale and quartzite of Bairenkonda Formation, and Shale's/phyllite and limestone of Cumbum Formation. The rocks of Gondwana Super group occur non-conformably over the PGC in southeastern part of the district, represented by Satyavedu Formation (Under Gondwana) and comprise mottled, ferruginous quartzite and conglomerate. Laterite capping occurs over Gondwana formations. Large tracts of Alluvium occur along the major streams, which belong to Recent Age. In this paper an effort has been made to bring out the tectonic depositional environment of the Nagari basin which forms the part of the southern Kadapa basin.

Introduction

Geomorphology and Structure of an area reflects the tectonic and setup of a particular area. The high resolution satellite data helps in mapping the geological and geomorphological variations in a regional level for an area which in other way reflects the tectonic setup. Remote sensing with GIS proved to be a good tool in mapping a particular area for such an endeavor.

Study area

The study area (Fig 1) falls between North Latitude 13^0 $54'$ to13^0 $51'$ and East longitude 79^0 $29'$ to 79^0 $52'$ covering. the form parts of Survey of India toposheets 57o/9, 57o/10, 57o/11, 57o/12, 57o/13, 57o/14, 57o/15, 66c/2, and 66c/3 covering of Puttur, Karvetinagar, Satyavedu, Tottambedu, Buchinaidukhandriga, KV puram, Nagulapuram, Nagari, Narayanavanam, Nindra, Pichatur, Renigunta, Vadamalapeta, Varadaiahpalem,Vijay puram, Yerpedu, and Srikalahasti.

Aim and Objective

The objective of the work is to bring out the geomorphological variations, tectonic and depositional environment of the Nagari basin which forms the part of the southern kadapa basin.

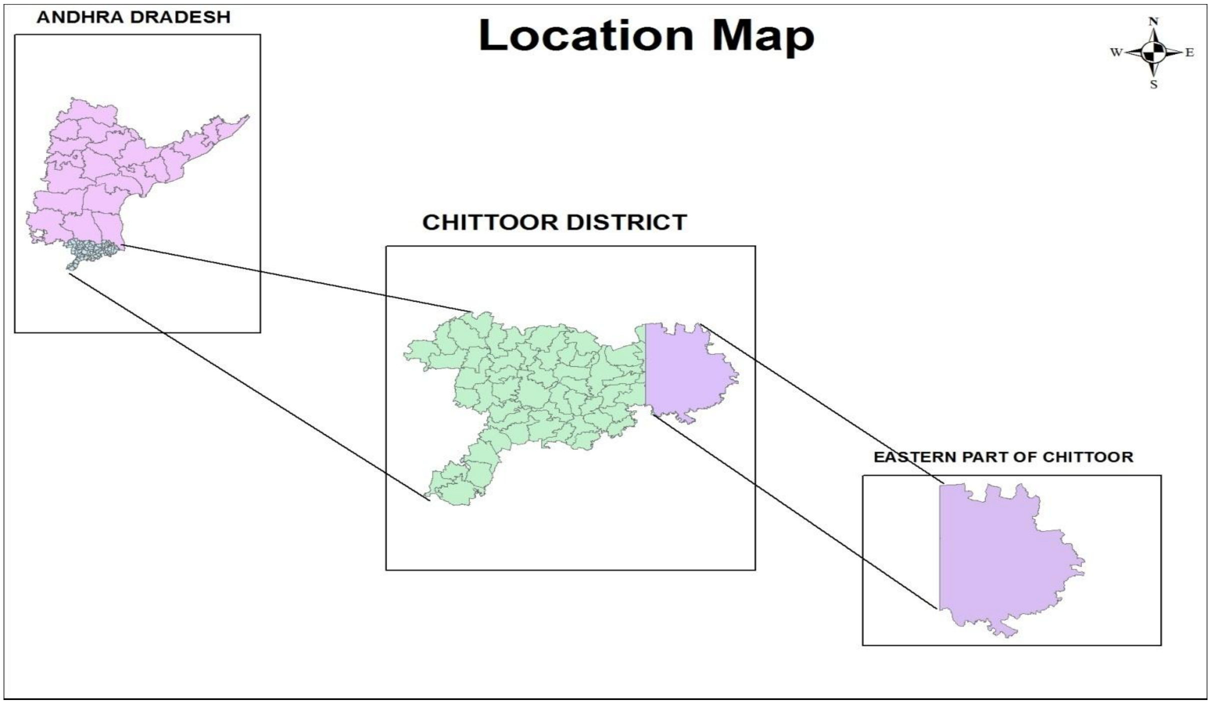


Fig.1. Location Map

Data and Methodology

The Satellite imagery LISS 3 and LISS 4(23.5m. and 5.8m resolution data) of 2006,2009 supplied by National Remote Sensing Centre is used for 1:50,000 scale base line feature data capture covering the proposed study area. Ground truth data(photographs, etc.) and GPS control points, collected during field survey in the study area is incorporated into the geodatabase. The map is generated in LCC projection with WGS84 datum. 1:50,000 scale grid is generated for the 2D mapping of study area. The methodology is basically a systematic procedure evolved to prepare a tectonic map using satellite data and GIS techniques in conjunction with limited field work. Various steps involved in the preparation of tectonic prospects maps are furnished as a flow chart in (Fig.2).

GIS technique is useful to derive and integrate geology, structural and geomorphological details. The various layers generated using remote sensing data like lithology/ structure, geomorphology, lineaments etc. are integrated with already available information on slope, drainage density and other collateral data in a Geographic Information System (GIS) framework and analyzed with reference to the groundwater zones as well as artificial recharge sites. The total methodology can be divided into two main parts. The first part deals with the delineation of hydro geomorphic units considering parameters influencing the hydro geological properties. It consists of a) preparation of individual thematic maps i.e. lithology, geomorphology, structures, base map details based on the visual interpretation of standard false colour combination (FCC) of satellite data in conjunction with limited field/existing data, and b) Derivation of geomorphic units by integrating the thematic data.

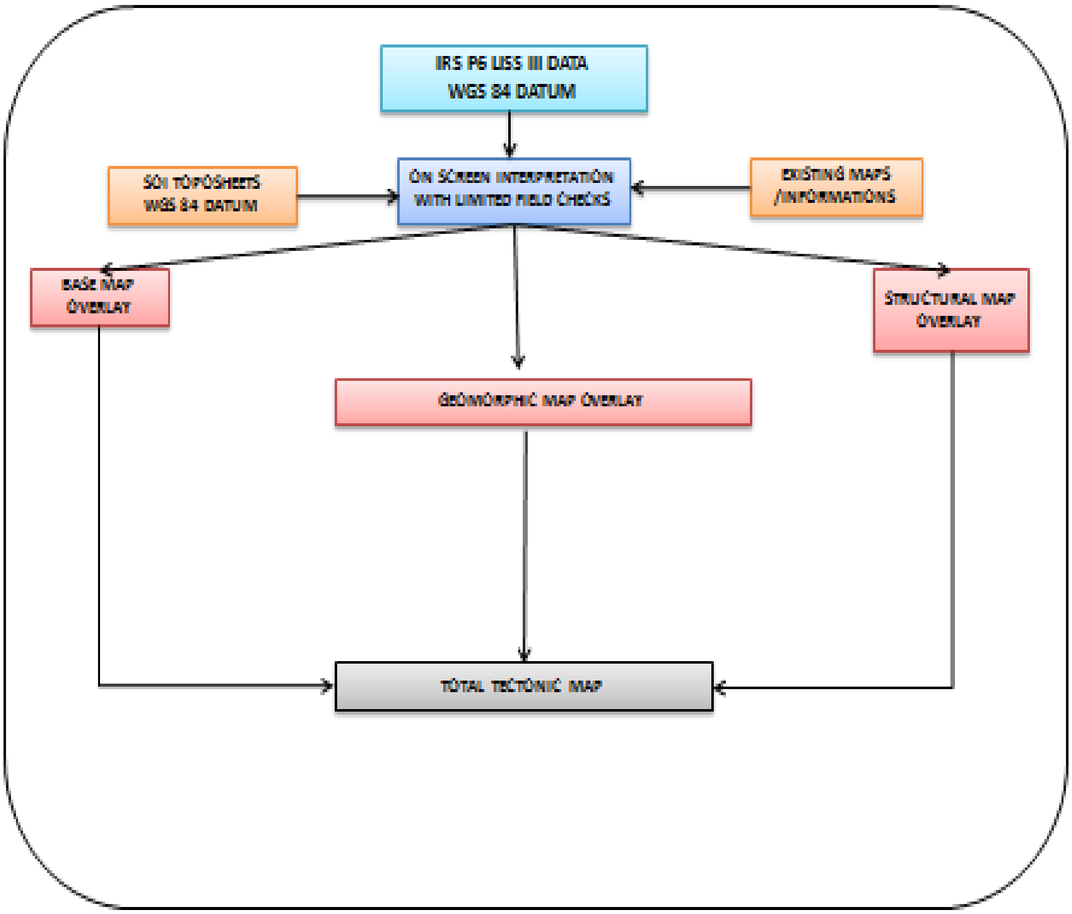


Fig.2. Flow Chart Showing of the Methodology

Results and Discussion

Rocks of Achaean, Proterozoic, Jurassic - Cretaceous, and Tertiary - Quaternary age are exposed in the study area (Fig 3). The PGC comprises a complex assemblage of gneissic variants of granitic rocks which occupy almost the study area. PGC in the area is represented mostly by biotite-hornblende gneiss, biotite granite and migmatites. The southern tip of the well known Cuddapah Basin comprising of shales and Quartzite of Bairenkonda Formation, rest unconformably over the PGC and linear ridges to the south of Kalahasti forming liear.

The rocks of Gondwana Super group occur non - conformably over the PGC in the south-eastern part of the study area, represented by Satyavedu Formation (upper Gondawana) and comprise mottled, ferruginous quartzite and conglomerate with plant fossils. Laterite capping occurs on Gondwana sandstones. Large tracts of alluvium occur along the major streams which are the recent deposits.

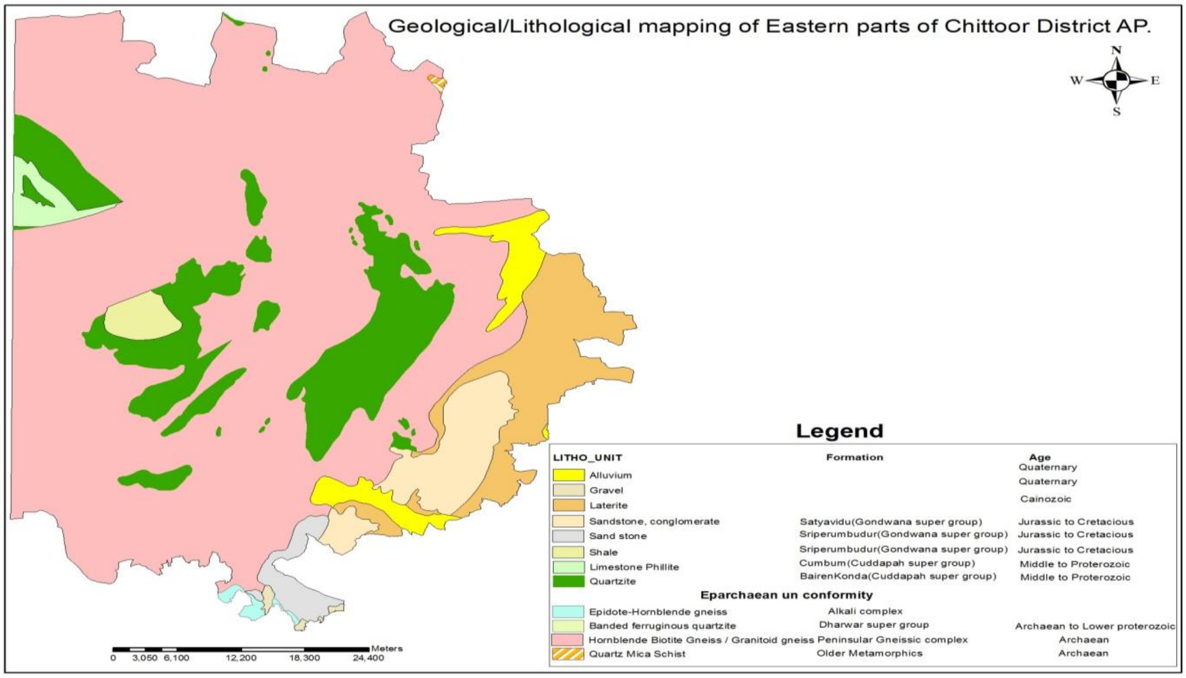


Fig.3. Geological/Lithology Map

Geomorphologically, the study area is characterised by a vast pediplains-pediment complex on Proterozoic and pre- Proterozoic rocks (Fig 4). The pre- Proterozoic rocks which are represented by older granitic gneiss, forms denudetional land forms which are of pediplains and pediment nature. A portion of pre- Proterozoic rock, within which are seen prominent linear structural ridges trending E-W and NE-SW and these linear structural ridges form the first phase of land forms which represent doubly plunging anticline and synclines. The Nagari quartzite's forming double plunging synclinal structures, rests on pre-Proterozoic rocks. These structures indicate that they are formed as a stable flat form and later folded to doubly plunging synclinal in second phase of land form generation. According to the famous "Wool ridge concept" of land form generation they can be classified in to second phase anticline and synclinal land forms, which form a classical example of matured topography. This second phase of land form also occurs in southern Cuddapah comprising of Nagari and Pullampeta formation at Nandaluru, Rajampeta. But the major deference in both of them are, the above said formation are denuded but in the study area they are resistant because of stable quartzite which generally form synclinal cuestas. These land forms which reflects the undisturbed stable environmental conditions under which Quartinary material formed under oxidising conditions.

In addition to the above land forms, marine sequence of upper Gondwana sand stones of cretaceous age are exposed to east of these formation at Satyavidu which are laterites of highly dissected Plateaus. The study area is also criss-crossed by NE-SW, NW-SE, E-W oriented of lineaments faults (Fig 5). The southern tip of Cuddapah basin comprising Quartzite and Shales of Bairenkonda formations rest non conformable over the peninsular complex forming on outlier.

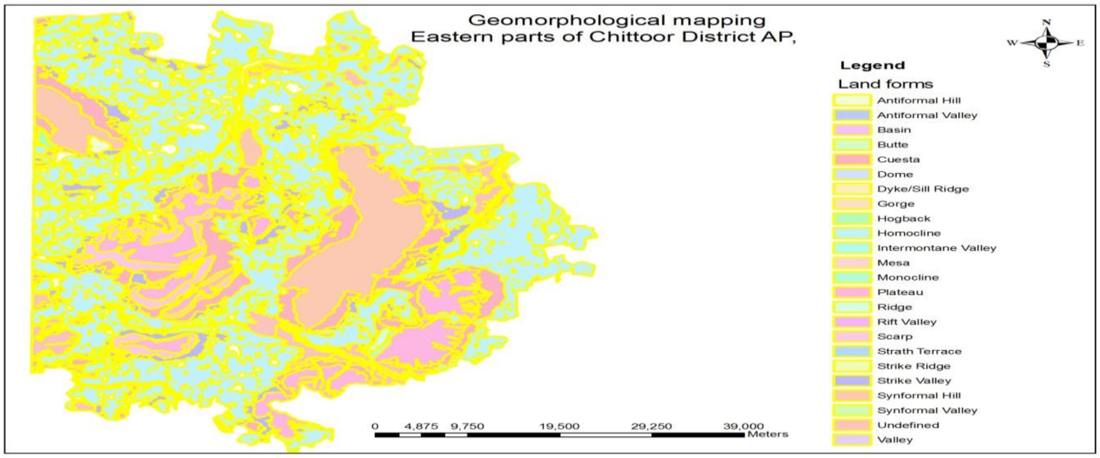


Fig.4. Geomorphological Map

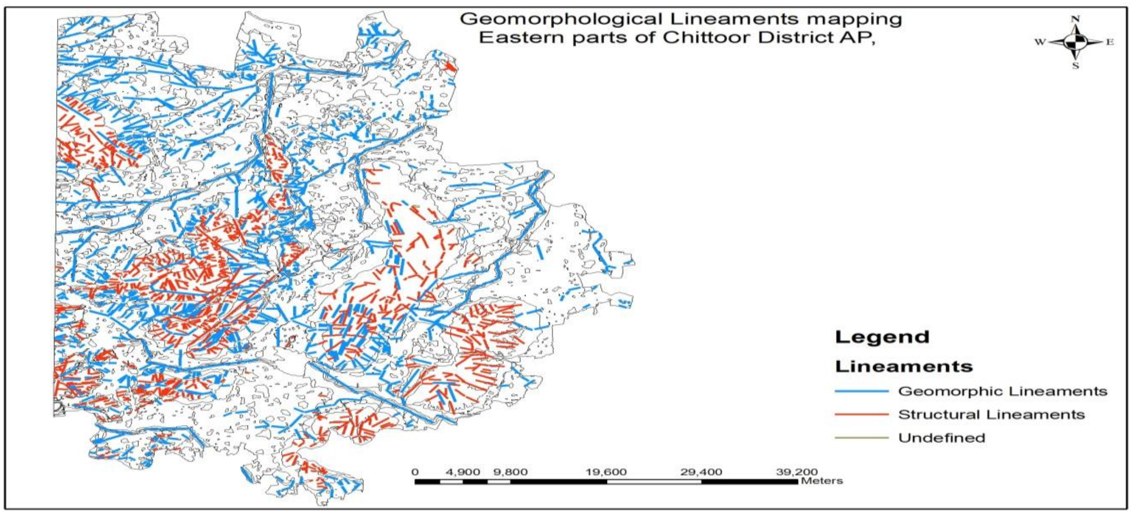


Fig.5. Structures/Lineaments Map

Conclusions

The study area comprises of Achaean, Proterozoic, Jurassic to Cretaceous and Tertiary Quaternary formations. The southern tip of Cuddapah basin comprising quartzite's and Shales of Bairenkonda formations rest non conformably over the peninsular complex forming on outlier. Maraine upper Gondwana with highly dissected lateritic above said outlier. Geomorphologically pre- Proterozoic are highly weathered pediplainal pediment Granitic structural linear ridges are exposed. The Nagari quartzite's forms resistant beds on double plunging anticline and synclinal forming first phase of land forms on the above said structural hills.

Acknowledgement

We thank the Dr. B.K.Nagaraja Rao, Consultant, for providing valuable suggestions for completing this paper.

Challenges in Master Plan Preparation using High ResolutionImagery in India

K. Pratheep Moses and Monsingh D.Devadas

Department of Planning, School of Architecture and Planning, Anna University, Chennai
E-mail: moses14@rediffmail.com

Abstract

Preparation of Master Plans with the help of the high resolution satellite imagery is a contemporary one. While preparing Master Plans, high resolution satellite imagery usually helps in the preparation of land use maps and preparation of Digital Elevation Model. Master plan requires existing land use map prepared on cadastral base. Cadastral maps were prepared way back in 1920's to 1930's. At the time of preparation of cadastral map, ordinary theodolites and chains were used for preparing the maps. The maps prepared using these instruments are of less precise in nature. Likewise, the high resolution satellite imagery has also got some lacunae such as, distortions in area, location and shape. Land use map prepared using cadastral map and high resolution satellite data doesn't match exactly because of the terrain, the camera angle of the satellite imagery, the distance of the satellite from the earth and less precise cadastral data. The land use map prepared using high resolution imagery with cadastral village map as the base and the land use map prepared using the traditional cadastral map only as the base may not bring in large differences in the preparation of proposed land use map for the preparation of Master Plans in small scale. Therefore, this paper is an attempt to give a clear picture of the advantages and disadvantages of using high resolution satellite imagery in the preparation of Master Plans.

Introduction

Gone are the days, when master plans are prepared using cadastral maps after the advent of high resolution satellite imagery (Ravindra Kumar Verma, 2008). All over India, the catch phrase as cited here is catching up, "Master Plans are to be prepared with the help of satellite imagery". Existing land use map is to be prepared using cadastral map as the base. Cadastral maps are prepared way back in 1920's to 1930's (Pandey, 2008). At the time of preparation of cadastral map, ordinary theodolites and chains were used for preparing the maps. The maps prepared using these instruments are of less precise in nature (Asima Misra, 2000). Likewise, the high resolution satellite imagery has also got some lacunae such as, distortions in area, location and shape (Bolstad, 2007). Therefore the question of jellying of cadastral data with the data prepared from high resolution satellite is to be done with great difficulty (Nair, 2002). When doing so, the accuracy of the existing land use map prepared using the high resolution imagery and the cadastral map is a questionable one. Therefore, this paper aims to bring clarity of thought on the usage of satellite imagery in the preparation of Master Plans.

Master Plan preparation stages in India

In India, Master plans are prepared for a period of 20 years. The stages in which Master Plans are prepared in Tamil Nadu, India are as given in TamilNadu Town and Country Planning Act, 1971. Delineation of planning area may vary for different cities due to its size, complexity and location, but overall the composition of the Master plan remains the same.

Satellite Imagery and its usage in Master Plan Preparation

High resolution satellite imagery has changed the way in which Master Plans are prepared in a traditional way. Previously, if present land use plans are to be prepared for a large town it will take years to complete. Now a days with the advent of high resolution satellite Imagery, present land use maps can be prepared within 3 months for the same area. It also helps to reduce the human error in preparing present land use map. Further, it also helps the planners to get a bird's eye view of the area to be planned. If two high resolution satellite images are taken at two different angles, Digital Elevation Models can be prepared which will help the planner to get an idea about the terrain. Though, there are many advantages, there are some disadvantages due to the misfit of satellite imagery on the cadastral map. If the above problems are sorted out, in a technical manner, it will help the planner to gain confidence of what he is going to deliver in the Master Plan.

High Resolution Satellite Images and their Accuracies

High resolution satellite imagery is defined as one which possess a resolution of less than or equal to 1 m. High resolution images have inherent problems of terrain distortion and camera tilt. These affect the distance with which features on the satellite imagery are displayed. This can be rectified to some extent with the help of digital elevation model and control points.

Accuracy of Cadastral Map

Cadastral system is built upon the 'cadastre'. The Cadastre is a parcel based and upto date land information system. For each parcel, there will be a field measurement book sketch (Fig.1) and details regarding the parcel, ownership, land use, area extent, type of soil and type of irrigation will be available in *Adangal* Record. In the preparation of cadastral map, village boundaries were marked professionally by theodolite and chain and thereafter *thalayari* (revenue official in charge of the village) marked the internal boundaries with the use of chains. The purpose of cadastral system in India was to get revenue from the parcels (Nag, 2003). Cadastral data was prepared more than 40 years back. At that point of time, less precise instruments like theodolites and chains were used to map the parcels in the map. Therefore, if we plot cadastral parcel from the data available in the field measurement book sketch, the chances of error are (+) or (-) 5%. In an urban area, 100 to 150 cadastral parcels will be put together based on the continuity and contiguity to form a Block Map (Fig. 2). The Block Map so formed is useful to identify the piece of land in that particular urban area. For the preparation of Ward Map, whole to part procedure was undertaken; therefore ward as a whole, the error percentage will be within 5% to 10%.

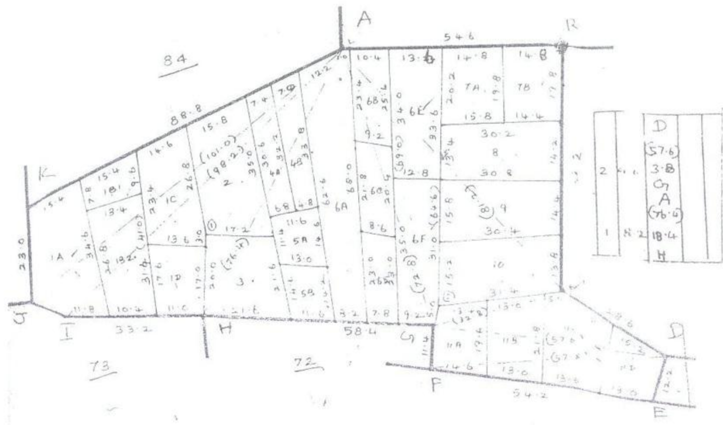


Figure 1 – Field Measurement Book Sketch

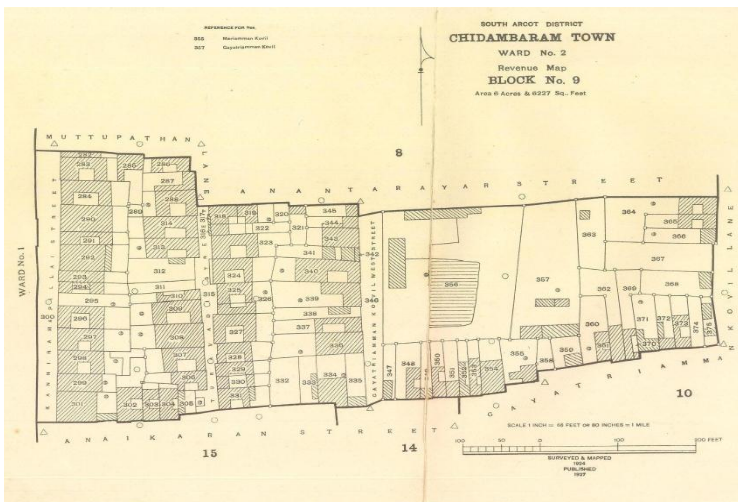


Figure 2 – Block Map

Present Land use Plan Preparation

The steps involved in the preparation of present land use for the preparation of a Master Plan are as below:

a. Collection of Ground Control Points for georeferencing with high resolution satellite imagery
b. Georeferencing of satellite Imagery
c. Merging of village cadastral maps
d. Georeferencing and digitizing of cadastral maps with respect to satellite Imagery
e. Preparation of georeferenced cadastral maps in GIS format
f. Printing of georeferenced satellite Imagery

g. Drawing of Builtup area in printed georeferenced satellite Imagery
h. Collection of land use particulars for building foot prints collected
i. Preparation of land use map in GIS format
j. Preparation of Infrastructure map
k. Overlay of digitized georeferenced cadastral map and land use map in GIS format
l. Preparation of land use map on cadastral background
m. Submission of land use map along with land use register.

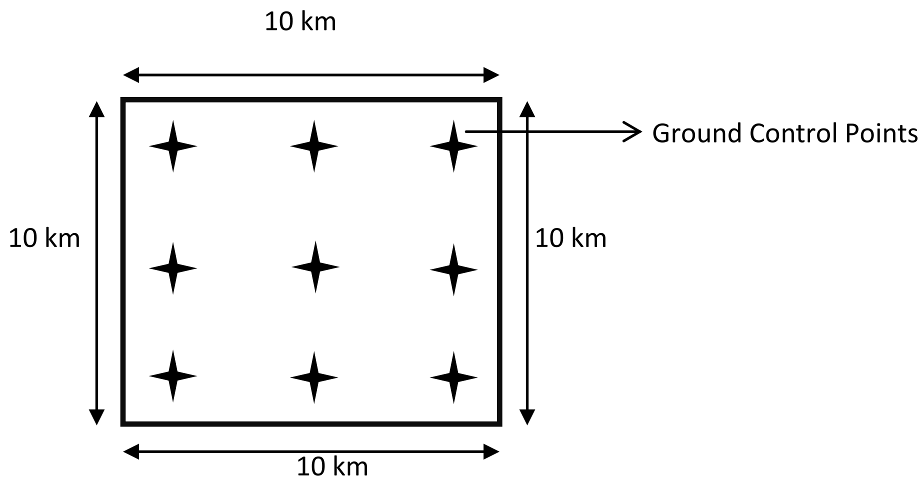


Figure 3 – Distribution of Ground Control Points

Collection of Ground Control Points to geo-reference high resolution satellite imagery

The general thumb rule followed to georeference satellite imagery is to collect 9 points using Differential Global Positioning System for every 100 sq km in a spatially distributed manner as shown in Fig. 3. Ground Control Points are usually located on junctions of roads, water bodies, land marks, road bends and important land marks etc. (Punmia, 2002). After locating the ground control points on the satellite Imagery, using DGPS, control points are to be collected on the marked places.

Geo-referencing of satellite imagery

Using the ground control points collected on the ground, raw high resolution satellite imagery is geo-referenced. Care should be taken that the root mean square error doesn't cross one. If it crosses one, the points which create error are to be re-examined on the ground using DGPS. After necessary corrections, the raw satellite imagery is to be geo-referenced to correct the errors already which have already crept in.

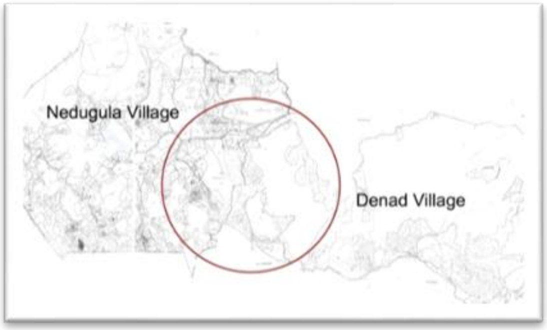


Figure 4 – Mismatch between Village maps

Figure 5 - Mismatch between Village maps

Merging of Village Cadastral Maps

Present land use map is to be prepared on cadastral base. Therefore it is imperative that we join all the village maps/block maps. The hard copy village/block maps are to be scanned and joined in Adobe Photoshop software. The village/block maps are not joining with each other because of the mismatch between the boundaries (Figure 4 and 5). This mismatch is perceived while joining because of the inaccurate survey conducted for the preparation of village map/block map.

Georeferencing and digitizing of Cadastral maps with respect to satellite imagery

The cadastral maps are then georeferenced with the help of the georeferenced satellite imagery. The root mean square error will be more than 5 because of the mismatch between the satellite imagery and cadastral map. The errors are due to cadastral map prepared using obsolete methods and the terrain. The georeferenced cadastral map is then digitized in GIS software and the attribute Survey No is added as non-spatial data and kept ready for integration with the land use prepared from high resolution satellite imagery.

Drawing of Builtup Area in printed Georeferenced satellite imagery

In high resolution satellite imagery, draw backs such as shadow effect and identification of boundaries is difficult in dense areas (Fig. 6). In Vijayawada town area, the density per sq km is 20000. In that case as shown in the figure, in continuous builtup area, it is difficult to identify the boundaries. Adding to that, shadow effect also decreases the chances of onscreen mapping. In this case, the method suggested is to cut the georeferenced satellite imagery into tiles of 0.25 sq km in the scale of 1:1500 and hard copy of high resolution satellite imagery is generated for the same. The hard copy georeferenced satellite imagery is overlaid by an opaque sheet. On ground, it will be difficult to map only with the help of high resolution satellite imagery. Therefore, it is suggested that the surveyor move on to one of the tallest buildings and capture the building foot prints on the opaque sheet to the accuracy of 85-90%. This method was adopted in the preparation of present land use map for Master Plan of Vijayawada and was found to be a successful one to overcome the difficulties in high resolution satellite imagery.

Figure 6 Quick Bird Satellite Imagery of Vijayawada Town

Collection of Land Use Particulars for the Building foot Prints collected

As the same surveyor, who collects the building foot print cannot collect simultaneously the land use particulars; one more surveyor is required to collect the land use. The surveyor who collects the land use has to cross check the building foot prints and has to give unique number to the parcels before collecting the land use data. The land use attributes so collected are then typed in excel format and kept ready for integration to the spatial data.

Preparation of Land Use Plan in GIS format

The building foot prints so collected in the opaque sheets are scanned and geo referenced by taking points from the already geo-referenced merged cadastral data. The geo referenced scanned opaque sheet is then digitized in GIS software and then the land use attributes so collected in excel format is attached with the spatial data.

Preparation of Infrastructure Map

Infrastructure details such as water supply lines and sewerage network are collected from the Municipality/Corporation, as we cannot depend on high resolution satellite imagery for these details. In India, water supply lines are laid 20 – 30 years back and no records are available for the laid lines. Therefore, the water supply line technician who knows where the water lines are laid, the depth at which it is laid, pipe thickness and the placement of valves is requested to mark it on the hard copy high resolution satellite imagery. The spatial data so collected is then transferred on top of the land use spatial data collected. As all underground drainage networks are recently laid, this data is available with the Municipality/Corporation. The data thus collected from the municipality is mapped in GIS format. Other details such as street lights and open sewer details are collected along with the land use data and mapped in GIS format.

Overlay of digitized georeferenced Cadastral and land use maps in GIS format

In Chidambaram, Tamil Nadu, India, the Block map (Cadastral Map in Urban Area) (Fig. 2) was prepared in the year 1929, therefore all updates such as land transfers and subdivision wouldn't be shown in the block map. As there are no alternative data for the case study area in Chidambaram, Block maps (Cadastral Map in Urban Area) Number 2 (Fig. 2) was scanned and then georeferenced to trace it to its original place on the earth and to have the original scale. The geo referenced Block Map is then digitized in the GIS software (Fig.7).The high resolution Quick Bird satellite imagery for the small area is then georeferenced and by keeping the high resolution satellite imagery as the base, land use parcels are digitized in GIS. Land use parcels cannot be digitized at ease, in the dense core area of the city because of the proximity of the built space over another built space. This can be visualized in the satellite Imagery. Therefore high resolution satellite imagery cannot be relied upon at this current juncture. The problems visualized can be rectified to some extent by the following procedure. The hard copy of the georeferenced satellite imagery has to be taken to the ground for ground verification. Since the built-up spaces are very close by and as such boundaries cannot be visualized clearly in the satellite imagery, the surveyor has to go to the top of one of the high rise structure in the nearby locality and mark the boundaries of the built up spaces on the hard copy of high resolution satellite imagery. After this process, the hard copy of the satellite imagery has to be scanned, georeferenced and then digitized. The digitized map is then taken to the ground for updating the land use particulars for the preparation of present land use map. Further, due to the inherent errors in the Block map and the high resolution satellite imagery, when it is overlaid in the GIS Environment, they will have a misfit (Fig. 8 & 9). Therefore, assigning land use to a particular cadastral parcel becomes difficult, because 75% of the land use will be in a cadastral parcel and remaining 25% will be in another parcel (Fig. 8). To solve the problem, it is best to find out and identify where the major portion of the land use falls on the cadastral map and assign the major land use to the cadastral parcel (Fig. 10) (Vijayawada IIndMaster Plan 2005). Therefore in a dense area, high resolution satellite imagery may not help the urban planner to prepare existing land use plan; further data such as boundary of parcels, land use has to be supplemented with the help of ground truth verification by a surveyor. It is highly understandable that the existing land use prepared through cadastral map (old method without satellite Imagery) or through cadastral map and high resolution satellite imagery, the output is the same.

Source: Google Earth, Quick Bird Satellite Imagery

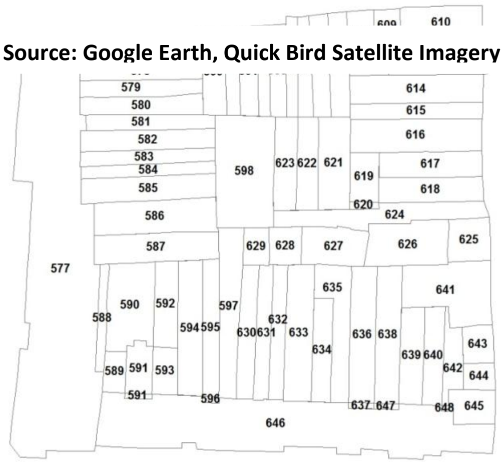


Figure 7 – Cadastral Map

Figure 8 – Satellite Imagery overlaid with Cadastral parcels

Figure 9 – Mismatch of land use and Cadastral data

Figure 10 –Present Land Use Plan Preparation

Source: Google Earth, Quick Bird Satellite Imagery

Conclusions

If we browse through the steps in the preparation of present land use map, one can visualize the inaccuracies that would have crept in the process. To conclude, one can say the output prepared through high resolution satellite imagery or only through cadastral map will be of same quality. Therefore the urban planner shouldn't think that if we are using high resolution satellite imagery, we are doing things very accurately to the tune of 100%. Rather, the urban planner should think the use of satellite imagery as an additional input to prepare better future plans.

References

Asima Misra, D. J. (2000). Land Record Information Management System (LRIMS) - A conceptual framework. *GIS Development.net*, 1-4.

Bolstad, P. (2007). GIS fundamentals: a first text on geographic information systems, third edition. Ashland,Ohio: Eider Press.

Government of Tamil Nadu (1971). The Tamil Nadu Town and Country Planning Act, Chennai: Tamil Nadu Government.

Nag, D. (2003). Cadastral Template-India, Country Report, Melbourne: PCGIAP-Working Group 3 "Cadastre", Department of Geomatics, The University of Melbourne, FIG-Commission 7 "Cadastre and Land Management".

Nair, S. B. (2002). Application of Satellite Imagery and GIS in the preparation of Development Plan: A Case study of Tirupati Region. Indian Cartographer, 246-253.

Pandey, K. P. (2008). Urban Cadastral Mapping using Very High Resolution, Journal of the Indian Society of Remote Sensing, 283-288.

Punmia, B.C. (2002). Surveying Volume 1. New Delhi: Laxmi Publication (P) LTD.

Ravindra Kumar Verma, S. K. (2008). Application of Remote Sensing and GIS Techniques for Efficient Urban Planning in India, Geomatrix '09' (pp. 1-23). Bombay: Centre of studies in Resource Engineering, IIT, Bombay.

VGTMUDA. (2005). Vijayawada IInd Master Plan. Vijayawada: VGTM Urban Development Authority.

Remote Sensing, GIS and GPS based approach for Urban Growth Analysis – A Case Study of Davanagere City in Karnataka State using Spatial and Temporal Data

Govindaraju[1],Govindaiah, S[2]., Chandrashekarappa, K. N., Lingadevaru[1], D.C., Jayakumar, P.D[1]. and Leela, K. S[1].

[1]*Department of Applied Geology, Kuvempu University*
[2]*Department of Studies in Earth Science, University of Mysore*
E-mail: drgov@yahoo.com

Abstract

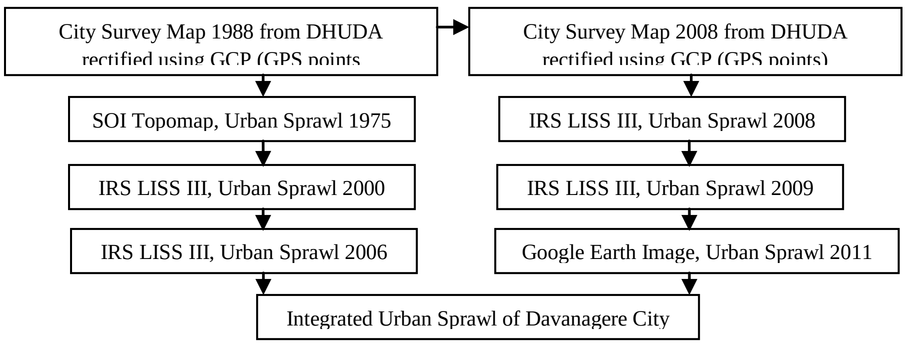
Cities often experience growth either physically or by population or by a combination of both. Urban sprawl which refers to the outgrowth of urban areas is caused by uncontrolled population and uncoordinated urban planning. This outgrowth seen along the periphery of cities, along highways connecting a city and lacks basic amenities like sanitation, treated water supply, primary health centre etc and loss of agricultural land, open space in and around urban areas. The problem created by the haphazard and unrestricted growth of city aggravates irregular and chaotic development of residential, industrial and commercial areas resulting in traffic bottle necks and slums. GIS and remote sensing techniques with collateral data help in analysing the growth pattern and extent of sprawl (Sudhira *et al.*,2004). With the spatial and temporal analyses, it is possible to identify the pattern of sprawl and subsequently predict the nature of future sprawl. In this study, SOI topomap 48N/15, satellite data of IRS LISS III (2000, 2006 and 2009) and Google Earth Image (2011) were used for the preparation of urban sprawl map of Davanagere city using softwares like ERDAS 9.2, ARCGIS 9.2 and AUTOCAD MAP 2000. The analysis has revealed that the city has been growing especially during the last decade. The urban growth took place as concentric /radial development and most of the productive agricultural lands are converted permanently into urban lands. Davanagere city as per 1988 city map, had 40.06 sq km, but after becoming district headquarters, the city administrative limit has extended to 75.45 km^2.

Introduction

Urban sprawl takes place engulfing and absorbing the hitherto highly productive agricultural lands, converting them permanently into urban lands (Gopal Rao, 1994). Urban sprawl is generally believed to result from poorly planned large-scale new residential, commercial and industrial developments in areas not previously used for urban purposes. Over the past 50 years, the process of urbanization, suburbanization, counter-urbanization and re-urbanization has allowed for urban expansion into rural areas taking the form of low-density development, predominantly single family residential subdivisions and strip commercial development. The result of this development process is commonly called urban sprawl. In this form, urbanization spreads outwards in a haphazard pattern consuming more land than is necessary and creating excessive public costs for community facilities and services (Sudhira *et al*, 2003). Urbanization takes place in either a radial direction around a well-established city or linearly along the highways over a given period of time. Clearly, radial and linear are just two types of map patterns that sprawl can take place. According to the 2001 Census, almost 34 percent of the population live in urban centres in the state of Karnataka.

Materials and Methods

To analyze the urban sprawl and pattern both spatially and temporally during the years 1975, 2000, 2006, 2008, 2009 and 2011, the following data of SOI topomap 48N/15 (1975), City Survey and Settlement location map (1988), IRS LISS III image(2000, 2006, 2009) and Google Earth image of 2011 were used. Softwares like ERDAS 9.2, ARC GIS 9.2, and AutoCAD MAP 2000 were used. The methodology adopted for the present study is shown in the flow chart below.



Study area

The study area is located between the Latitudes 14^0 29^1 33,51 and 14^0 31^1 $8^{11}$and longitudes 75^0 52^1 50^{11} and 75^0 57^1 36^{11}. The city as per 1988 which covers an area about 40.06 km^2 has changed after Davanagere become an individual district. After that, the city limits have extended to an area about 75.45 km^2 as shown in the Figure 1. The city of Davanagere is located at a distance of about 260 km from the state capital of Bangalore. It is nestled at the foothills of the Western Ghats. Previously, it was famous for its cotton mills, hence it is also called as 'Manchester of Karnataka' or textile capital of South India. Davanagere City Municipal Council came into existence on 7th Aug, 1951. Later, it is upgraded as Davanagere City Corporation on 6^{th} Jan, 2007. Presently, it has been divided into 41 corporation wards for administration.

Results and Discussion

The study revealed that urban sprawl took place in Davanagere gradually from 1975 to 2011 because of its development in business, industries and educational facilities leading to increase in its population. The results obtained are presented below.

Urban sprawl of Davanagere city in 1975

The administrative boundary of Davanagere city is taken from the city survey map was rectified using ground control points and later overlaid on SOI topomap on 1:50,000 scale to delineate the sprawl area. It has an area of 10.31 km^2 which is 25.73% within the administrative boundary of 40.06 km^2(Fig .2).

Urban sprawl of Davanagere city in 1988

Davanagere city area is taken from Davanagere – Harihara Urban Planning map of 1988 on 1:6000 scale was rectified using ground control points (GPS points) to delineate the sprawl area of the city. It has an area of 15.39 sq km which is 38.41% within the administrative boundary. The sprawl that took place from 1975 to 1988 is recognised as concentric type of growth in which industrial zone and Devaraj Urs lay out came into existence (Fig .3).

Urban sprawl of Davanagere city in 2000

The city boundary taken from the city survey map was rectified using ground control points and later overlaid on IRS – LISS III satellite image of 2000 (Fig. 5) on 1:50,000 scale to delineate the sprawl area of the city using image elements like tone and texture. It has 21 sq km area (52.42%) within the administrative boundary. The sprawl that took place from 1988 to 2000 is recognised as concentric type of growth comprising Mandakki batti, Saraswathinagara, Chikkammanni Devaraj Urs, Anjaneya lay out, and Shamanuru Shivashankarappa lay outs. The Vidyanagar area is further extended towards national highway in ribbon type of growth (Fig .6).

Urban sprawl of Davanagere city in 2006

The administrative boundary from the city survey map was rectified using ground control points and later overlaid on IRS – LISS III satellite image of 2006 (Fig.7) to delineate the sprawl area of the city using image elements like tone and texture. It has 23.3 sq km which is 30.88% within the notified administrative boundary of about 75.45 sq km. The sprawl developed from 2000 to 2006 with an increased area of about 2.3 sq km due to the establishment of Medical College and Hospital at national highway and Ashraya lay outs (Fig .8).

Urban sprawl of Davanagere city in 2008

The administrative boundary of Davanagere city taken from Davanagere – Harihara Urban Planning map of 2008 at 1:10000 scale has been rectified using ground control points to delineate the sprawl area of the city (24.07 sq km) which is 31.90% within the administrative boundary. The sprawl developed from 2006 to 2008, is about 0.77 sq km, which is due to the formation of DCM lay out, SS lay out and Nijalingappa lay out (Fig .9).

Urban sprawl of Davanagere city in 2009

The administrative boundary of Davanagere city taken from the city survey map is rectified using ground control points and later overlaid on IRS – LISS III satellite image of 2009 (Fig.10). The sprawl area of the city is 27.64 sq km, that in about 36.63% within the administrative boundary.

The sprawl developed from 2008 to 2009 with an area increase of about 3.63 sq km which is due to Karur industrial area coming into existence. Apart from this, there is a concentric growth in all sides of the city (Fig. 11).

Urban sprawl of Davanagere city in 2011

The administrative boundary of Davanagere city taken from the city survey map is rectified using ground control points and later overlaid on Google Image of 2011 (Fig. 12) to delineate the sprawl area of the city. It extends to about 31.27 sq km which is 41.44% in the administrative boundary. The sprawl developed from 2009 to 2011 with an area increase of about 3.63 sq km. The growth happened in concentric form in all sides (Fig. 13).

Integrated Urban Sprawl Map of Davanagere city

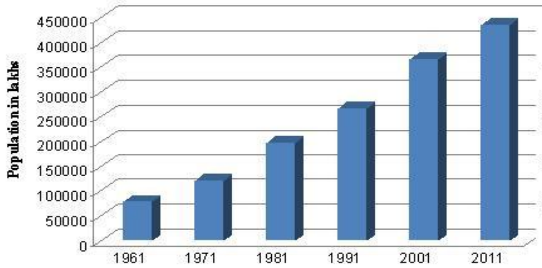
The integrated urban sprawl map(Fig.14) of Davanagere city is prepared by integrating all the urban sprawl maps *viz.*, of 1975, 1988, 2000, 2006, 2008, 2009 and 2011 using ARC-GIS. The integrated urban sprawl map shows that there is an increase in the urban area every year from 1975 to 2011 with concurrent increase in population (Table 1). The urban expansion of Davanagere city from 1975 to 2011 is given in Table 2.

Table 1 Population growth of Davanagere city form 1961 to 2011
(Source: Department of Statistics, Davanagere)

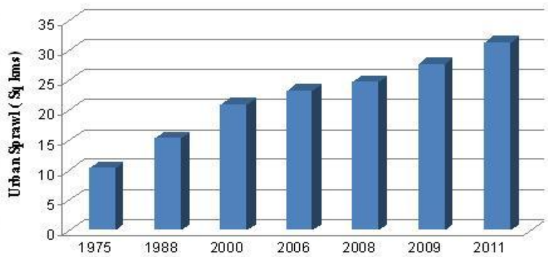
Year	1961	1971	1981	1991	2001	2011
Population	78,124	1,21,110	1,96,621	2,66,082	3,64,523	4,35,138

Table 2 Urban sprawl Of Davanagere City from 1975 to 2011(sq kms)

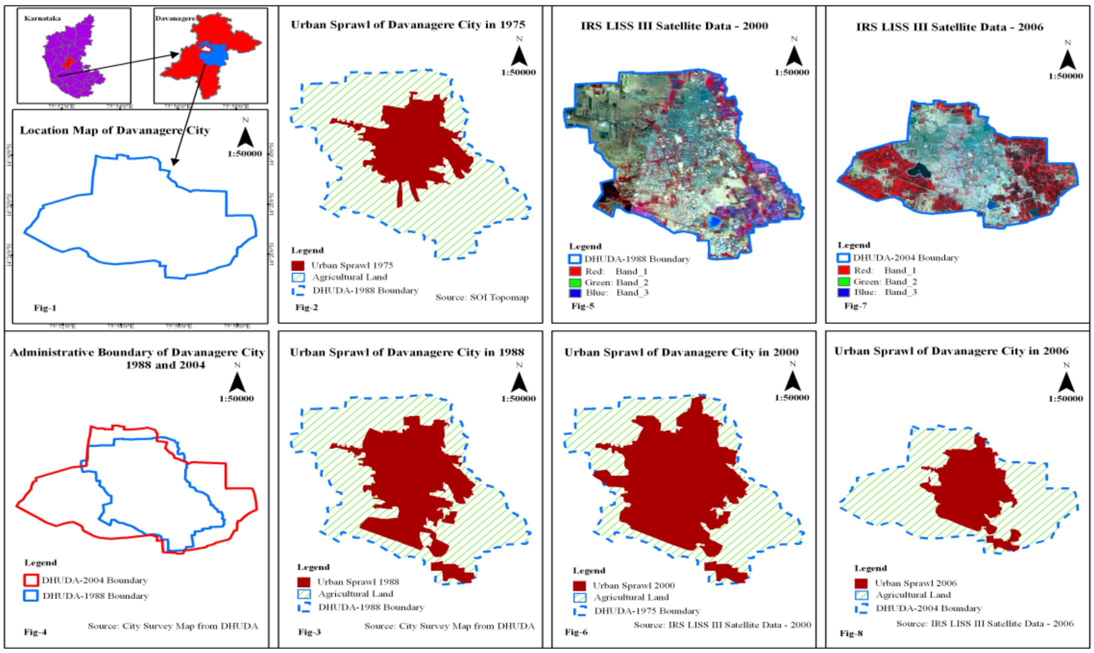
Sl.no	Year	City limit	Sprawl area	Percentage	Sprawl area
1	1975	40.06	10.31	25.73	Sprawl taken from SOI topomap
2	1988	40.06	15.39	38.41	Industrial Area and Devaraj Urs Lay out
3	2000	40.06	21.00	52.42	Mandakki batti and Saraswathinagara, Chikkammanni Devaraj Urs lay out, Anjaneya lay out, Shamanuru Shivashankarappa lay out.
4	2006	75.45	23.30	30.88	Hightech Hospital at national high way and Ashraya lay outs and GMIT
5	2008	75.45	24.07	31.90	DCM lay out,SS lay out,Nijalingappa lay out
6	2009	75.45	27.64	36.63	Karur industrial area
7	2011	75.45	31.27	41.44	All sides of the city

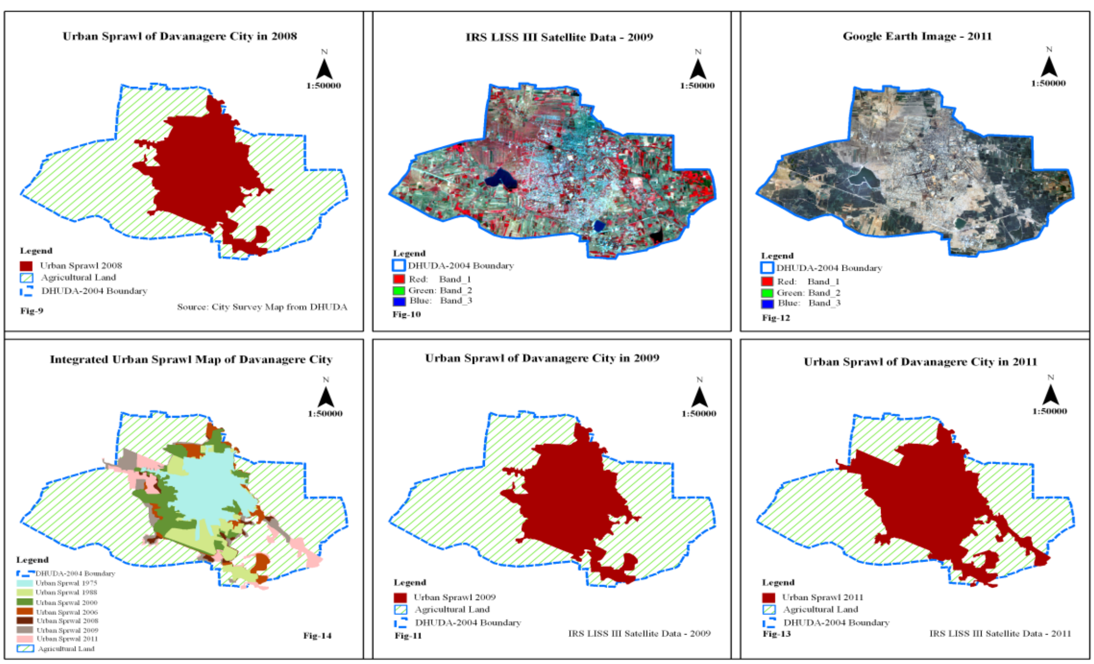


Population growth of Davanagere City from the year 1961-2011



Urban sprawl Of Davanagere City from the year 1975 - 2011.





Conclusions

Satellite data help significantly in demarcating the urban spread and using temporal images, it has been possible to monitor the urban growth and changes in land use structure. The analysis has revealed that the city has been growing especially during the last decade. Most of the growth took place in the form of concentric development. Use of city survey and settlement map with GIS technology and GPS provides information about the development of the city. The administrative boundary of Davanagere city as per 1988 city map was 40.06 sq km, but after becoming district headquarters, the city administrative limit extended to 75. 45 km^2. The study revealed that rapid development of city with increase in population enhanced the demand for basic amenities like employment, business opportunities, educational facilities and other industrial centers. Many of the non-cultivating owners of lands and their dependants also live in towns engaging themselves in various kinds of urban business. The town life is dependable and easy – going as compared with the uncertainties and hardships of agricultural life is also responsible to a certain extent for the drift in population. Urban sprawl takes place engulfing and absorbing these hitherto highly productive agricultural lands and converting them permanently into urban lands.

Acknowledgement

The authors take this opportunity to thank Chairman, Coordinator (UGC-SAP) and all the senior faculty of the Department of Applied Geology, Kuvempu University for their encouragement.

References

Gopal Rao, K. (1994). Monitoring and Assessment of Urban Environment from Space. “Remote sensing for environment and managemet”(ed) Mehrotra and Suri, Indus Pub. company, New Delhi.

Sudhira., H.S., Ramachandra, T.V. and Jagadish, K.S. (2003). Urban Sprawl pattern recognition and modelling using GIS, GIS@development, Map Asia conference on Urban Planning, pp 245-254.

Sudhira,H.S. Ramachandra,T.V. Jagadish,K.S. (2004). Urban sprawl: metrics, dynamics and modelling using GIS, International Journal of Applied Earth Observation and Geoinformation, 5 (2004) pp 29–39.

Sudhira, H.S., Ramachandra,T. V., Jagadish, K. S. and Karthik, S. Raj (2003). Urban Growth Analysis Using Spatial and Temporal Data. Photonirvachak - Journal of the Indian Society of Remote Sensing, 31 (4) pp. 299-311.

Remote Sensing and GIS based Surface Runoff Estimation for Cochin Corporation with special emphasis on the Impact of Temporal Variation in Land Use

Archana, M. Nair, George Baysil and Kalaraj, S.

Central Geomatics Lab, Centre for Earth Science Studies, Akkulam, Thiruvanathapuram
E-mail: archana.nair@cess.res.in & archana.nair@gmail.com

Abstract

As the global urban population rising exponentially, half of the world population is currently living in cities. At the present rate of urban population growth, it is increasingly difficult to find and utilize new sources of water necessary to satisfy the growing demand. The growth of urban areas result in significant changes in the physical properties of the land surface. The consequence is increase in area of impervious surface resulting in enhanced surface runoff. Increased surface runoff would eventually result in alteration of the prevailing hydrologic system. The present study is an attempt to quantify the impact of land use changes due to urbanization on surface runoff and thereby to study the emerging challenges it imparts on the conventional water management practices. The study area is Cochin City, one of the fast developing second tier metros in India. The present study estimates the seasonal and yearly runoff volume of Cochin Corporation using SCS-CN method. In this method, land use as well as soil data were used to estimate the runoff volume. Daily rainfall data for the past 30 years as well as soil map of the study area were collected from different sources. The land use maps for the study area were prepared from Survey of India toposheets as well as satellite data. Recent land use maps were generated using Quick Bird image that has a high spatial resolution. Runoff depth and volume was calculated for various land use categories. An attempt was also made to study the impact of high resolution land use classification on the run off volume. The significant finding from the study was the observation of approximately 40% increase in the runoff volume when a high resolution land use classification was used. It was also observed that open spaces and marshy land was converted into builtup areas that resulted in a considerable increase in runoff volumes in the past few years.

Introduction

One of the simplified definitions of urbanisation is the process of artificial land use alteration during time. Temporal dimension of urbanization is usually quantified by a design period, defined as a period of time in which reliable forecast of urban changes can be made. It usually ranges between 15 and 25 years. Conversion of natural surfaces to less- or non-pervious artificial surfaces is responsible for increase in both the storm water runoff rates and the total runoff volumes resulting in a decline in the natural water storage capacity of the soil. Natural storage in a watershed is being made available by the effects of infiltration, vegetation wetting, interception and depression storage. An often neglected fact is the change of natural water storage as a consequence of urbanization. Urbanization causes significant changes to the temporal characteristics of runoff from an area such as shortening the runoff travel time resulting in flash floods. The risk of flooding is defined as a function of both the probability of a flood happening and its impact. In urban areas, the impact can be very high because the areas affected are densely populated and contain vital infrastructure. The amount of rainwater running off the surface into drains and sewers increases dramatically as new development covers previously permeable ground. The proportion of impermeable ground in existing developments is increasing as people build patios and pave over front gardens. Urbanisation is also responsible for an alarming increase of pollutants in natural water bodies. Storm water runoff may contain organic wastes, nutrients, bacteria and suspended solids. Climate models predict that heavier showers and hotter summers are expected to put more pressure on urban drainage. Increase in surface runoff results in alteration of the prevailing hydrologic system. The present study focuses on the quantification of the changes in land use pattern and its impact on the surface runoff which inturn has a direct impact on the hydrologic system of the study area.

Berthier *et al*. (2006) explained that the hydrological behavior of urban areas can no longer be restricted to the runoff of rainwater on impervious surfaces which constitutes the dominant flow component for design purposes. Ragab *et al.* (2003) exemplify that urban surfaces such as road pavements and parking lots are not completely impervious and observed that 6–9% of the total annual rainfall on a paved street infiltrates and that 21–24% of it evaporates. Several studies were carried out in India to improve the runoff models using SCS-CN method for different watersheds in many parts of the country. Among the various studies, a few of the recent studies used Curve Number (CN) method to derive runoff volume. Geetha *et al.* (2008) derived a conceptual model based on SCS-CN concept for long-term hydrologic simulation. The model was capable to derive a better match to the observed runoff as well capable of finding out the dormant or dominant processes involved in the runoff. Patil *et al*. (2008) estimated the surface runoff using Curve Number techniques (ISRE-CN) and developed a model using the in-built macro programming language Visual Basic for Applications (VBA) of ArcGIS® tool to estimate the surface runoff by adopting one of the most widely used NRCS-CN technique and its three derivatives. In the present study, runoff volume was calculated based on the land use pattern as derived for the year 1965 from the topographic sheet for 2005, and for 2010 from Quick bird satellite image.

Study area

The study area is Cochin City *alias* Kochi Corporation which lies between 9˚55′ and 10˚04′ N Latitude and 76˚14′ and 76˚20′E Longitude. The Cochin city comprises of Mattanchery, Fort Cochin, part of the main land Ernakulum and a group of islands. Arabian Sea and Vembanad Lake envelops the city all along the western boundary. The City is divided into two blocks by the Cochin backwater (Azhi) as Vypeen Kara on the northern side and Fort Cochin on the southern side. Major rivers such as Periyar and Muvattupuzha drain into the Vembanad Lake at Cochin. Much of the area lies at sea level and is plain land having natural facilities of drainage in the form of backwaters, canals and rivers. Geologically, recent sediments cover major part of the study area. Charnockites as well as gneiss are sparsely distributed in the study area. The entire western part is covered by recent sediments. Since much of the area is low lying plain, flooding is a recurring natural calamity. Salt water intrusions destabilizing the existing fresh water table and shortage of potable drinking water during peak summer are added troubles encountered in the study area. Since Arabian Sea and Vembanad Lake surround the western boundary of the city, the runoff travel time is very less. In spite of the fact that the study area receives a very heavy rainfall during the monsoon, the area faces shortage of potable drinking water during peak summer. One of the reasons could be attributed to the short span of travel time needed for the surface runoff water to reach the Ocean. In such a situation, new development that increases the percentage of impermeable surface can cause more problems regarding drinking water shortage.

Methodology

Runoff is that portion of precipitation that flows over land surfaces toward larger bodies of water. Before runoff can occur, rainfall must satisfy the immediate demands of infiltration, evaporation, interception, surface storage, and surface detention and/or channel detention. In 1972, the U.S. Soil Conservation Service suggested an empirical model for rainfall abstractions which is based on the potential of the soil to absorb a certain amount of moisture. On the basis of field observations, this potential storage S (millimeters or inches) was related to a Curve Number (CN) which is a characteristic of the soil type, land use and the initial degree of saturation known as the antecedent moisture condition. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The curve number is based on the area's hydrologic soil group, land use treatment and hydrologic condition. Although, the method is designed for a single storm event, it can be scaled to find average annual runoff values.

The runoff equation is

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad \text{------------------------------ Eq :1}$$

Where, Q is runoff, P is rainfall and S is the potential maximum soil moisture retention after runoff begins. I_a is the initial abstraction or the amount of water before runoff such as infiltration or rainfall interception by vegetation; and it is generally assumed that $I_a = 0.2S$

The runoff curve number CN is then related as

$$S = \frac{1000}{CN} - 10 \quad \text{----------------------------------- Eq : 2}$$

CN has a range from 30 to 100 with lower number indicating low runoff potential while larger numbers indicating higher runoff potential. Most urban areas are only partially covered by impervious surfaces, hence the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sand and gravel) than in watersheds predominantly of silts and clays which generally have low infiltration rates.

Hydrological soil groups were assigned to the study area based on comparison of the characteristics of unclassified soil profiles with profiles of soils already placed into hydrologic soil groups .Most of the groupings are based on the premise that soils found within a climatic region that are similar in depth to a restrictive layer or water table, transmission rate of water, texture, structure, and degree of swelling when saturated will have similar runoff responses. The slope of the soil surface is not considered when assigning hydrologic soil groups. Antecedent Moisture Condition (AMC) refers to the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial absorption and infiltration are governed by AMC. For purposes of practical application, three levels of AMC are recognized by SCS as given in Table1. The major factors that determine the CN are the hydrologic soil groups (HSG). The CN value was identified when the antecedent moisture condition is AMC II. The conversion of CNII to other two AMC conditions can be made through the following correlation equations. In the present study, runoff was not calculated for a particular watershed, instead it was calculated based on the land use pattern. In an urbanized area, the primary factor that influences the runoff is land use changes. In a growing or expanding city, many major changes occur to the land use and this results in an increased volume of surface runoff. If proper storm water management practices are not adopted, this may result in frequent flash floods and can result in depletion of ground water. Quick bird image was used to study the land use pattern of the study area for the year 2005 as well as 2010. As the resolution is high, details such as buildings and other infrastructure are easily visible. The landuse/landcover mapping was done at a scale of 1:4000, classifying them into various classes such as industrial, commercial, residential, mixed crops, water bodies etc. The Survey of India toposheets of scale 1:50000 were used to prepare the land use map of the area for the year 1965.Due to the small scale of toposheets as compared to the satellite image, only major land use classes could be mapped for 1965. The daily rainfall data of the study area for a 30 year period from 1980 to 2010 was collected from India Meteorological Department. The daily rainfall data was used to calculate the AMC for the rainfall event under consideration. The AMC is determined by considering the 5 day rainfall prior to the day under consideration.

Table: 1 AMC Condition

AMC type	Total rainfall in previous 5 days
I	Less than 36 mm
II	36 to 53 mm
III	More than 53 mm

For AMC I

$$\frac{CN_{II}}{2.281 - 0.01281\, CN_{II}}$$

For AMC III

$$\frac{CN_{II}}{0.427 + 0.00573\, CN_{II}}$$

Results and Discussion

The study area is highly urbanized. The area mainly consists of residential, commercial and industrial areas which cover majority of the area. Some of the other prominent land use classes in the area are mixed crops and coconut plantations. The land use pattern showed a significant change from 1965 to 2005 and again from 2005 to 2010. The land use in 2005 and 2010 were classified as residential, commercial, industrial, and road network among built-up areas as well as mixed crops, coconut plantation, mangroves and fallow land among non-built-up areas. Due to the comparatively lower scale, the information available on toposheets, the land use was classified into fewer categories namely residential, mixed crops, paddy, water body and open space.

The change detection in land use was achieved by overlaying the land use maps of 1965, 2005 and 2010 (Fig.4). The categories into which the various land use classes changed were identified. The areas occupied by different land use classes in 2005, 2010 and 1965 were calculated, which is a direct indication of the changes in pervious and impervious areas over the years, and its impact on runoff volume. Rapid urbanization in the area is particularly evident from the increase in areas of residential,commercial and industrial areas. The open space and marshy areas have shown significant decrease in area over the years. The study of temporal variation in land use has shown an increase of 12% in built-up area from 1965 to 2010. The built-up area has increased from 36% to 48% over the period. In the period from 2005 to 2010, an increase in built-up area of 2% is noticed.

The runoff volume on a yearly and seasonal basis is calculated for each of the landuse maps of 1965, 2005 and 2010 using daily rainfall data for a period of 30 years from 1980 to 2009. The calculation is done in such a way that the daily rainfall and its corresponding AMC are considered. The runoff volume calculated for the corresponding land use pattern is given in Table 2. The area within non-builtup includes water body which forms almost 20% of the study area.

Table 2 Runoff volume for changing land use pattern

Year	Non-builtup (km2)	Builtup (km2)	Non-builtup (%)	Built up(%)	Average runoff volume(Mm3)
1965	59.93	36.51	62.14	37.87	94.32
2005	50.35	46.09	52.20	47.81	116.05
2010	48.37	48.07	50.15	49.87	117.83

To study the impact of higher resolution land use classification in runoff volume, a sensitivity analysis was carried out for a small area named “Thopumpady”, which showed significant increase in built-up density in recent times. The mapping was done both in high and low resolution. The polygons of the low resolution map were subdivided for improved accuracy. The runoff volume calculated from the higher resolution map was found to be 39.38% higher than that calculated from low resolution data.

Conclusions

The land use pattern in the area has changed considerably since 1965. The built-up area has increased from 36.51 km^2 in 1965 to 46.09 km^2 in 2005 and 48.07 km^2 in 2010. The most significant changes were observed in residential, commercial and industrial areas causing significant increase in impervious surfaces in the study area. The open spaces and marshy areas are being converted into built-up areas, particularly into residential apartments. This increase in built-up area has resulted in an increase in runoff volume of 23.5Mm^3 in the last 45 years. The built-up area has increased by 2% in the last 5 years resulting in an increased runoff volume of 1.8 Mm^3. The runoff volume is found to be highest in the months of June to September and coincides with the southwest monsoon season which causes the highest rainfall in the region. The seasons “February to May” and “October to January” showed considerably lower runoff volumes. The study also conducted a sensitivity analysis to study the impact of high resolution mapping on runoff volumes. The study concluded that using high resolution land use maps significantly improves the accuracy of runoff calculations. The runoff values calculated using low resolution maps and high resolution maps showed a difference of 39.38% in runoff volume.

References

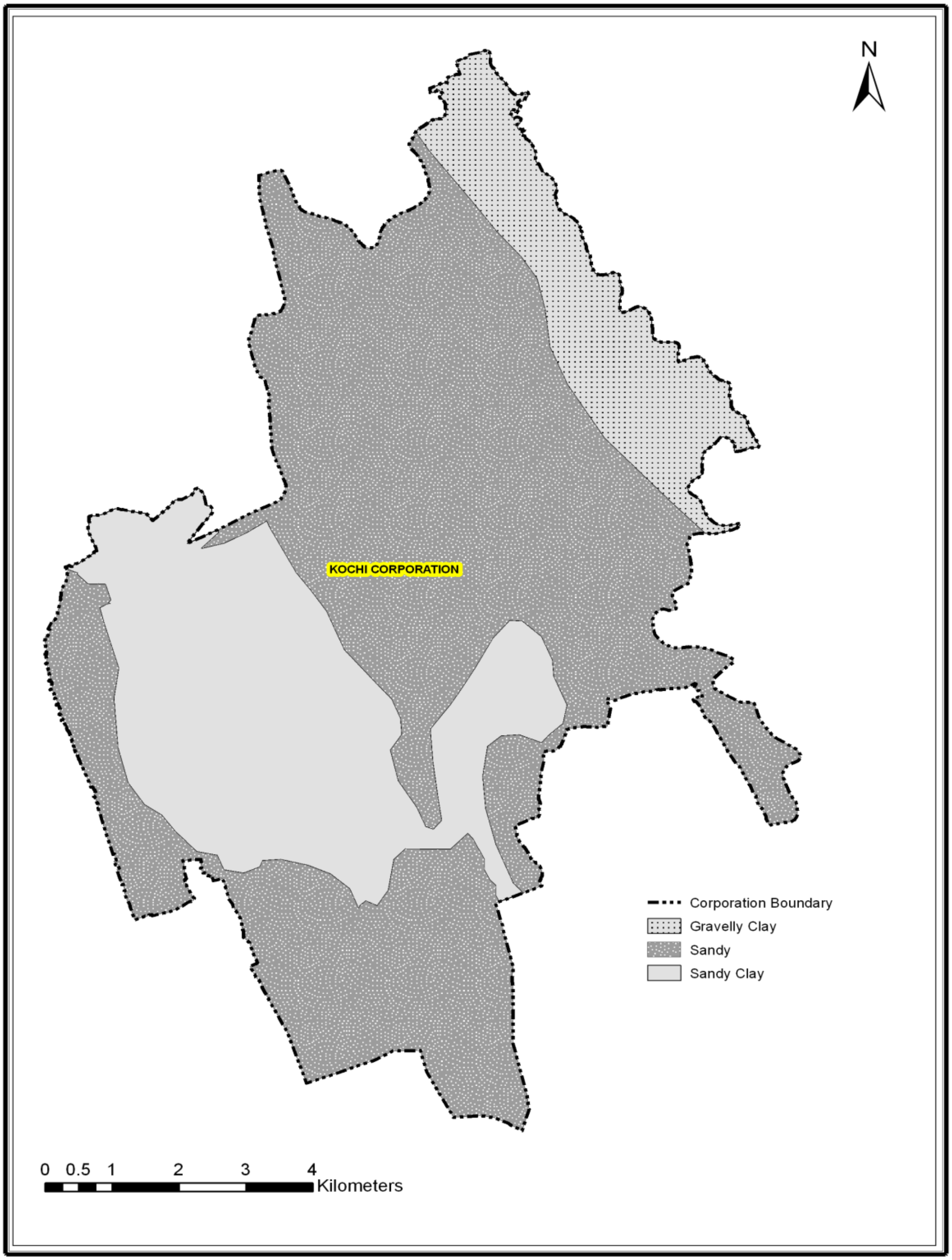
Berthier, E., Dupont, S., Mestayer, P.G., Andrieu, H., (2006). Comparison of two evapotranspiration schemes on a sub-urban site. Journal of Hydrology, 328, 635–646.

Geetha, K., Mishra, S. K., Eldho, T. I., Rastogi, A. K., and Pande, R. P. (2008). SCS-CN-based continuous Simulation Model for Hydrologic Forecasting, Water Resource Management, 22, 165–190.

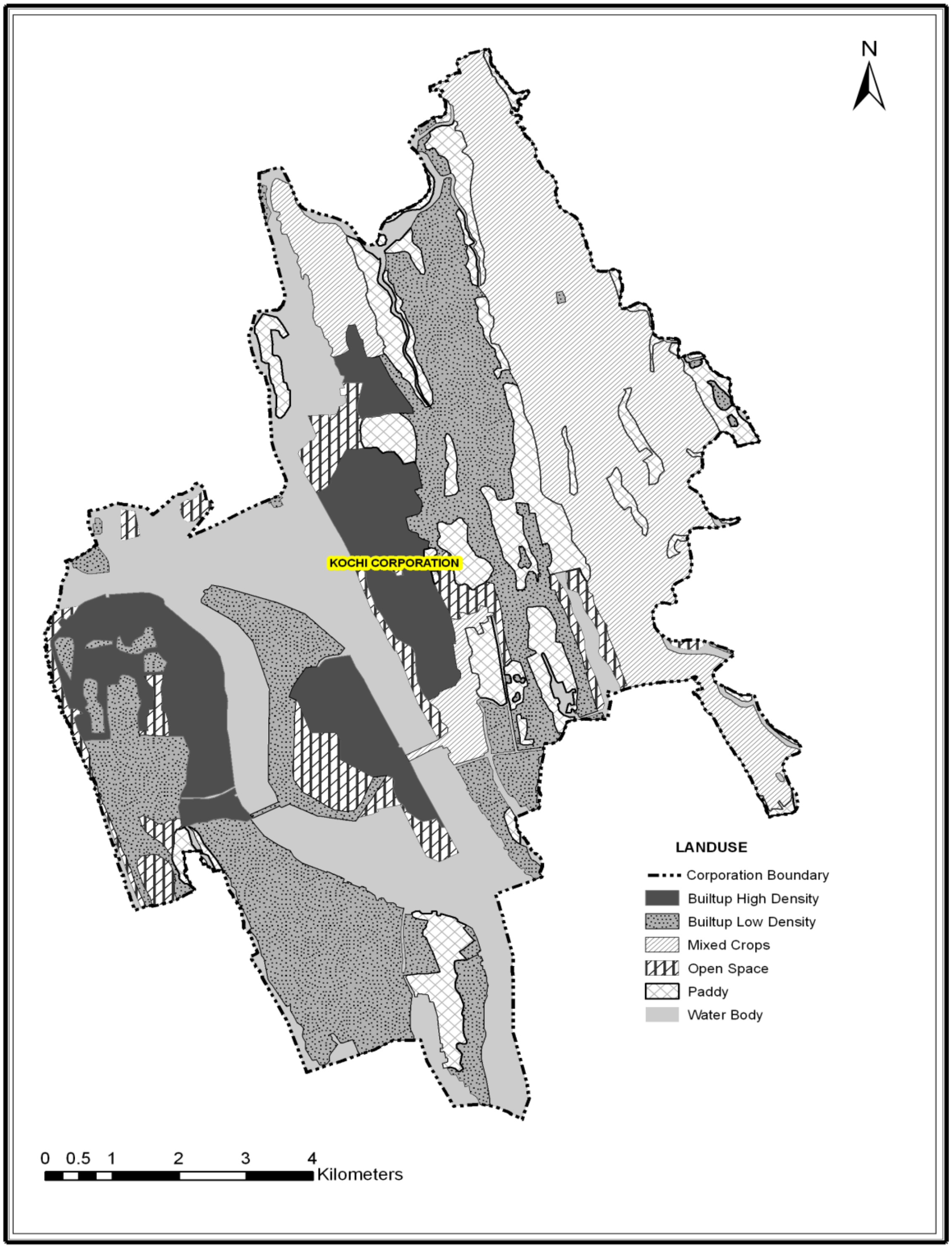
Patil , A. Sarangi , O. P. Singh , A. K. Singh , T. Ahmad (2008). Development of a GIS Interface for Estimation of Runoff from Watersheds. Water Resource Managment (2008) 22:1221–1239.

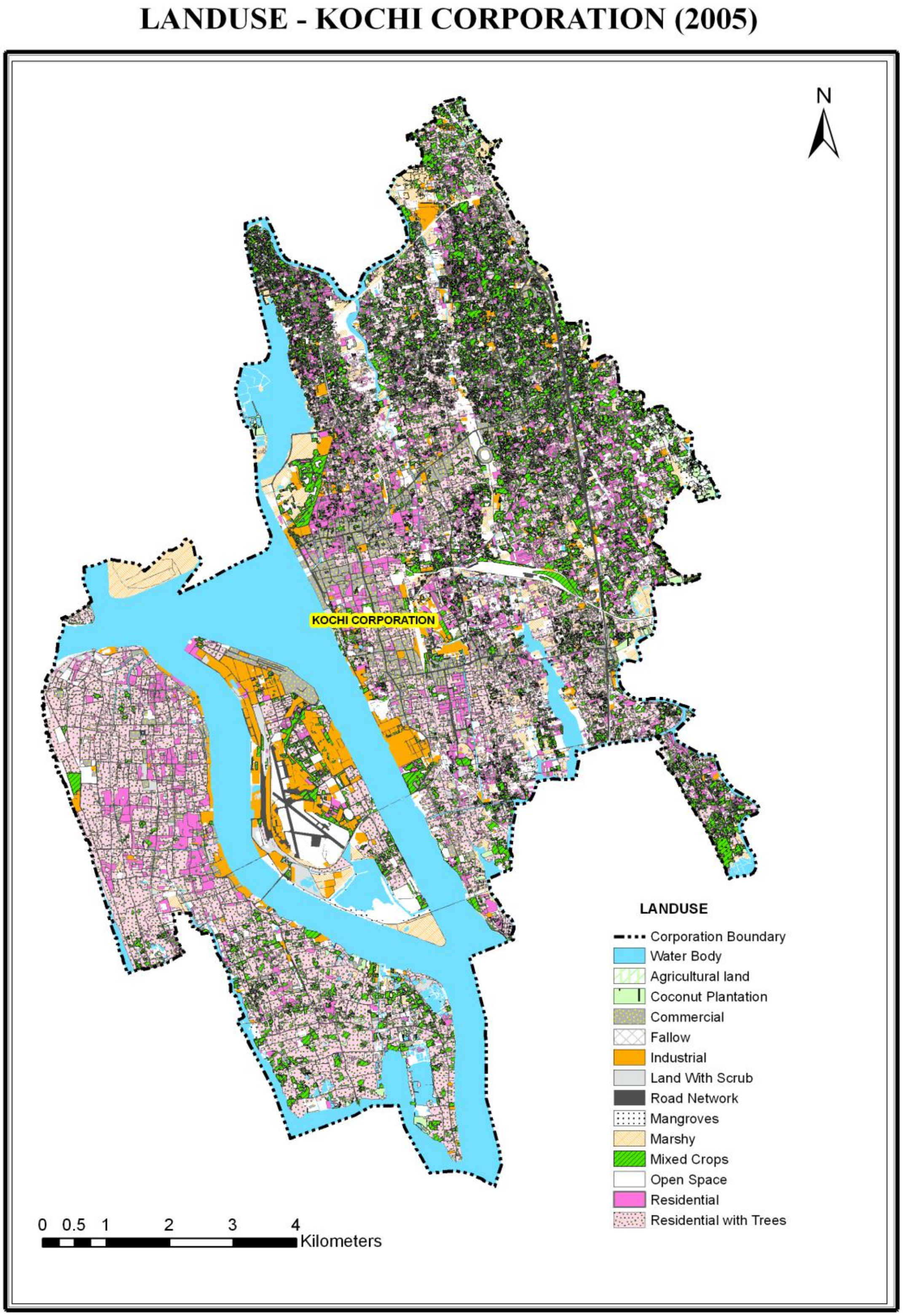
Ragab, R., Rosier, P., Dixon, A., Bromley, J., Cooper, J.D., (2003). Experimental study of water fluxes in a residential area: 2. Road infiltration, runoff and evaporation. Hydrological Processes 17, 2423–2437.

SOIL - KOCHI CORPORATION

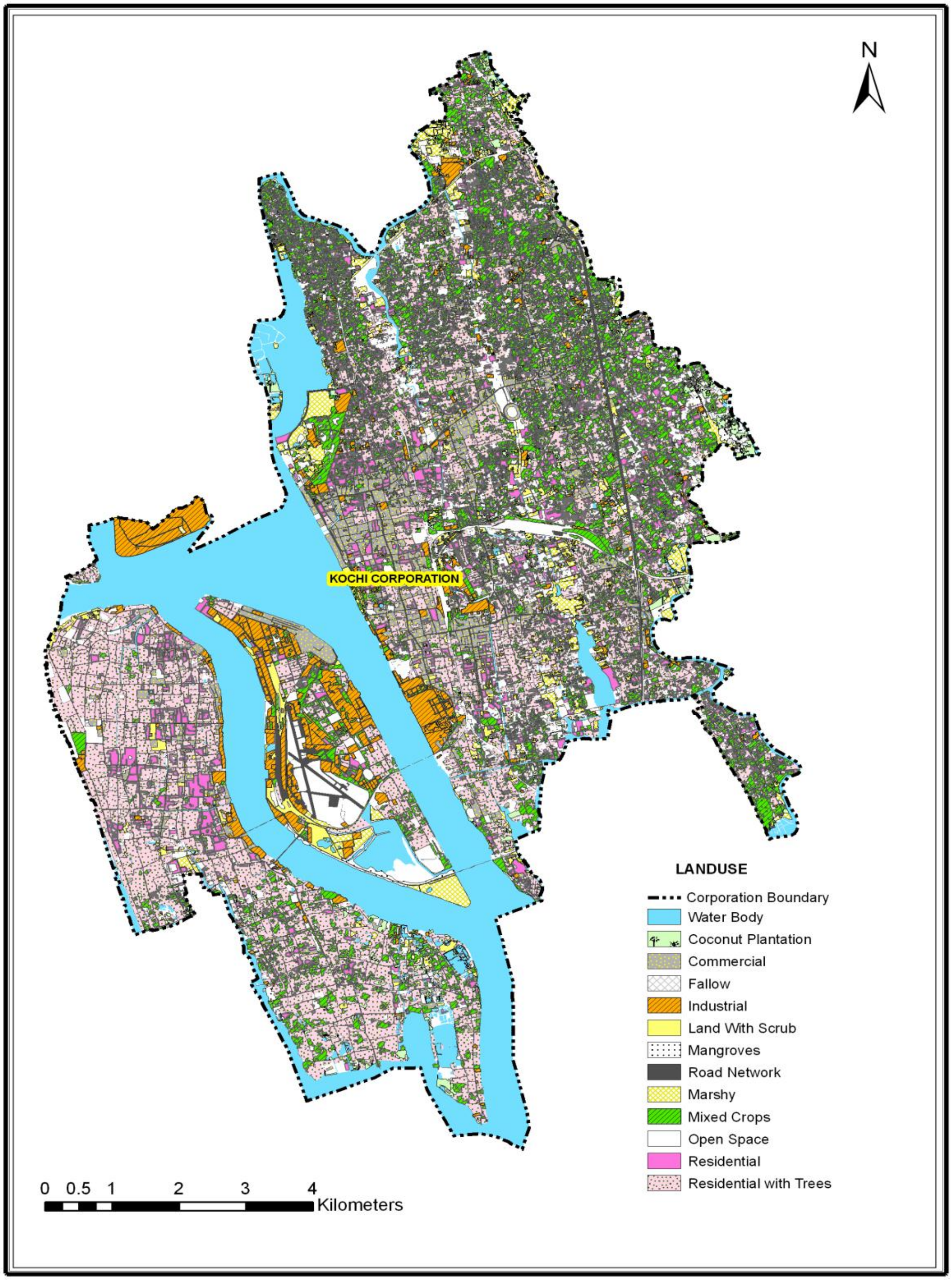


LANDUSE - KOCHI CORPORATION(TOPOSHEET)




LANDUSE - KOCHI CORPORATION (2005)
N
KOCHI CORPORATION
LANDUSE
Corporation Boundary
Water Body
Agricultural land
Coconut Plantation
Commercial
Fallow
Industrial
Land With Scrub
Road Network
Mangroves
Marshy
Mixed Crops
Open Space
Residential
Residential with Trees
0 0.5 1 2 3 4
Kilometers

LANDUSE - KOCHI CORPORATION (2010)



Air Pollution Monitoring in Central Business District of Ernakulam City using Geographic Information System

M.S. Saran[1], D. Robinson[1] and Arun Anat[2]

[1]National Transportation Planning and Research Centre, Sastra bhavan, Pattom, Trivandrum, Kerala
[2]Centre for Environment and Development, Cochin, Kerala
E-mail: saran.ms@gmail.com

Abstract

Monitoring the spatial distribution and concentration of pollutants is a task of great practical importance in order to control and contain air pollution. GIS is a modern technological tool which has wide range of application in many disciplines like ecology, agriculture, public health, tourism and transportation. The present study is an attempt using to evaluate the spatial variations of air pollution around central part of Ernakulam city taking SOx, NOx, SPM and RSPM parameters. The main objective of the study is to find out the monthly variation of air pollutants surrounding the monitoring station and to depict the overall pollution of the study area. The study area was classified into five zones based on pollution - i) very low pollution zone, ii) low pollution zone, iii) moderate pollution zone, iv) high pollution zone and v) very high pollution zone based on the pollution index. The study revealed that major industrial belts have the highest intensity of pollution. The urban commercial centres were found to be close behind in contamination levels, though not as intense as the industrial strips. The study on the whole gives a general perspective on the present air quality condition and encourages making provision for further monitoring to bring down the concentration levels to ambient conditions.

Introduction

The world is facing different environmental challenges due to accelerated phase of development activities undertaken by human beings. Pollution of environment by means of air, water and land is on the rise. Air pollution problem is a worldwide catastrophe affecting both the developed and developing nations alike. Pollutants to environment are induced by vehicles, industrial development, construction activities, rapid and unplanned urbanization. There is an urgent need to monitor the spread of pollutant, so that remedial measures can be adopted to preserve our health and environment. The geoinformation sciences has become the vital element in integrating transport, land-use and environmental decision making systems (Geerlings and Stead, 2003; Sperling et. al, 2004). It has brought to the forefront the role played by it in assisting policy making and the importance to quantify the uncertainties associated with environmental process models. GIS is an efficient tool to track, monitor and measure the pollutants in the atmosphere. GIS can manage statistical and spatial data, which helps to frame relationship between air quality status and occurrences of deficient human and environmental health.

Study Area

The study area is located in the heart of Ernakulam District, which falls in central Kerala and is known as the economic capital of the state. Edappally is selected as the nodal point for the study. Edappally is located in Cochin Corporation. To monitor the spread of pollutants, 12 km buffer zone which contains 7 monitoring stations around Edappally is taken for the study (**Figure 1**). Edappally is located within the latitudinal extent of 10° 01' 11"N and longitudinal extent of 76° 18' 25" E. The area falls in Survey of India toposheet number 58 B/8 and 58 C/10 on 1:50,000 scale.

Objectives

The main objective of the study is to analyse the air pollution distribution in the study area on a seasonal basis for a time period from January 2007 to April 2008 using GIS, based on hourly, weekly and monthly data acquired from seven air quality monitoring stations distributed in the study area. The other objectives of the present study are: to locate the monitoring stations in the study area using Global Positioning System (GPS), to develop geospatial air pollutant distribution models for different pollutants - SO_x, NO_x, RSPM and SPM and to create an overall pollution distribution map of the study area between January 2007 to April 2008 by ranking the parameter maps.

Methodology

The methodology adopted for the study is given in Figure 2. Data required for the study was collected from Kerala State Pollution Control Board (KSPCB). Seven monitoring stations falls in 12 km buffer zone around Edappally. The monitoring stations are Eloor – I, Eloor – II, Kalamassery, Irumpanam, M G Road, Ernakulam South and Vytilla. Pollution data for Sulphur Oxides (SO_x), Nitrogen Oxides (NO_x), Respirable Suspended Particulate Matter (RSPM) and Suspended Particulate Matter (SPM) were collected from the monitoring stations. Monitoring is done twice a week and the average for the month is found out. Field survey was undertaken to locate the seven monitoring station using Magellan hand held GPS. Base maps of the study area were prepared on a scale of 1:12,500 using IRS IC satellite image. Toposheet of the study area was used to georeference the satellite image. All the thematic layers required for the study were generated from the satellite image.

The analysis for estimating the distribution of air pollutants was done using the spatial analyst extension of ArcGIS 9.0. Various capabilities of GIS were utilized for the study, which included locating monitoring stations, developing spatial air quality variation trends in the study period for the various parameters and finally creating the total pollution distribution map for the study area in the chosen time span.

In order to represent the spatial distribution and variation of pollution parameters raster maps were generated for each parameter (SOx, NOx, RSPM and SPM). Maps were generated at an interval of three months starting from January 2007 to April 2008. The months selected for the study are January 2007, April 2007, July 2007, October 2007, January 2008 and April 2008. Raster maps were created using Inverse Distance Weighted (IDW) deterministic interpolation method which involves assigning values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface. It estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight it has in the averaging process or vice versa. Pollution distribution raster maps of each pollution parameters were thus created. In order to classify the raster maps into 8 categories, reclassify option in Spatial Analyst extension of ArcGIS software was used.

Each individual pollution parameter rasters were combined to obtain the overall distribution of pollution during the study months. Weightages were assigned to each parameter based on their significance. The weightages given were 40%, 30%, 20% and 10% for SO_x, NO_x, RSPM and SPM respectively. Raster calculator within Spatial Analyst Extension was used to combine all the layers together. Month wise pollution distribution maps thus obtained were combined together using Raster Calculator to obtain the final pollution distribution map for the time period of January 2007 to April 2008.

The Air Pollution Index (API) a standardized indicator for interpreting the air quality status (**Table 1**) was used to classify the study area into five pollution zones. The zones are i) very low pollution zone, ii) low pollution zone, iii) moderate pollution zone, iv) high pollution zone and v) very high pollution zone.

Table 1 Air Quality Index

SL No	Index Range	Air Quality
1	Less than 20	Very Low Pollution
2	20 – 25	Low Air Pollution
3	25 – 30	Moderate Air Pollution
4	30 - 35	High Air Pollution
5	Above 35	Very High Air Pollution

Results and Discussion

The result of the study is analysed in two ways, namely, monthly variation trend of the individual pollution parameters and overall air pollution variation in the study period.

Sulphur Oxides (SOx)

Sulphur Oxides mainly occur in the atmosphere due to factory emissions as well as emissions from diesel vehicles. The analysis result shows that the highest concentration of SOx was found in the Eloor industrial belt (Figure 3). Throughout the study period, Eloor region has shown little variation in the pollutant concentration. The concentration was slightly higher in July 2007 in the region. This may be due to the higher industrial production during that period. Whereas monitoring stations in Vytilla, Irumpanam and Kalamassery has shown comparatively lower concentration of sulphur oxides in all the months of the study. Eloor region has over a 100 large scale as well as small scale industries which include chemical, agricultural and aluminum, plastic industries etc, an outcome of which can be seen in the form of heavy pollution in the area. This inversely affects the health conditions in the area leading to diseases that affect the respiratory tract and cause permanent lung damage, Bronchitis, Emphysema, and Asthma. It also results in plant growth reduction.

Nitrogen Oxides (NOx)

It is more than apparent that the major contributor to the haze and the poisons in the air in urban areas are not due to factory emissions but automobiles– cars, buses, trucks, three-wheelers and two-wheelers. There is no dispute over the fact that more than half the pollution load in our metropolis is due to automobile exhaust. Mobile sources are responsible for more than half of all nitrogen oxide emission in the region. The ambient air quality of Ernakulam has deteriorated with an increase in the number of vehicles in urban space. M G Road and Ernakulam South monitoring stations recorded the highest concentration of NOx throughout the study period (**Figure 4**). These areas are the commercial hub of the district and hence the traffic congestion in these areas are relatively high. A number of respiratory diseases, chest congestion, eye irritation, and headache affect the people inhaling these emissions. Eloor shows slightly higher concentration of NOx in January 2007, 2008 and July 2007. The production in these factories may have been very high during those months.

Respirable Suspended Particulate Matter (RSPM)

RSPM is one of the most menacing pollutants in terms of its effect on health. Bits of carbon, ash and oil emitted specially from diesel-driven vehicles. They range in size from 15 to 2.5 micrograms per cubic meter and are fine enough to be deeply respirable. It is mostly generated as a product of industries such as plastics, metals etc. Vehicular emissions also form a part of its production. RSPM distribution in the study area shows a varying trend in the entire study area. In general the distribution is highest in the areas surrounding the industrial belts of Eloor (**Figure 5**).

Urban regions marked out by the monitoring stations at M G Road and Ernakulam South also shows considerable amount of RSPM in the months of January 2007 and October 2007. In April 2007 RSPM concentration was found to be highest in Kalamassery region.

Suspended Particulate Matter (SPM)

SPM mainly includes particulate matter less than 10 micrometer in size. Human activities, such as the burning of fossil fuels in vehicles, power plants and various industrial processes generate significant amount of aerosols. It is measured in terms of smoke and dust.

SPM concentration in the study area reveals month wise variation in the distribution at different sampling points. The months of January and April 2007 shows higher SPM concentration in Vytilla region. SPM concentration is highest in Eloor during July 2007, January 2008 and April 2008 (**Figure 6**). Since these are the pre-monsoon periods, the suspended particulate matter might be high in the atmosphere. Vytilla junction and M G Road are areas with high vehicle congestions. The ill effects of inhaling particulate matter include asthma, lung cancer, cardiovascular issues, and premature death.

Overall Air Pollution Variation Trend

Month wise air pollution distribution maps were generated by compiling the layers of each pollution parameter of that particular month (**Figure 7**). During the months of January 2007 and 2008, April 2007 and 2008, October 2007, Eloor industrial region has reported the highest concentration of pollutants. During these months the industrial production in this area was comparatively high. Urban areas such as M G Road and Ernakulam South have shown high pollutant concentration in January 2007 and April 2007 compared to January 2008 and April 2008. Vytilla and Irumpanam areas are predominantly residential; hence the pollution in these parts is relatively low compared to other parts of the study area. The general ambience of the area has remained more or less unchanged from January 2007 to January 2008.

Final pollution distribution map of the study area from January 2007 to April 2008 were generated by combining the month wise pollution distribution maps (**Figure 8**). Study area was classified into five zones based on the Air Pollution Index (API). The zones are: very low pollution, low pollution, moderate pollution, high pollution and very high pollution. Eloor – I and Kalamassery regions were found to have exceptionally damaging conditions of pollution.

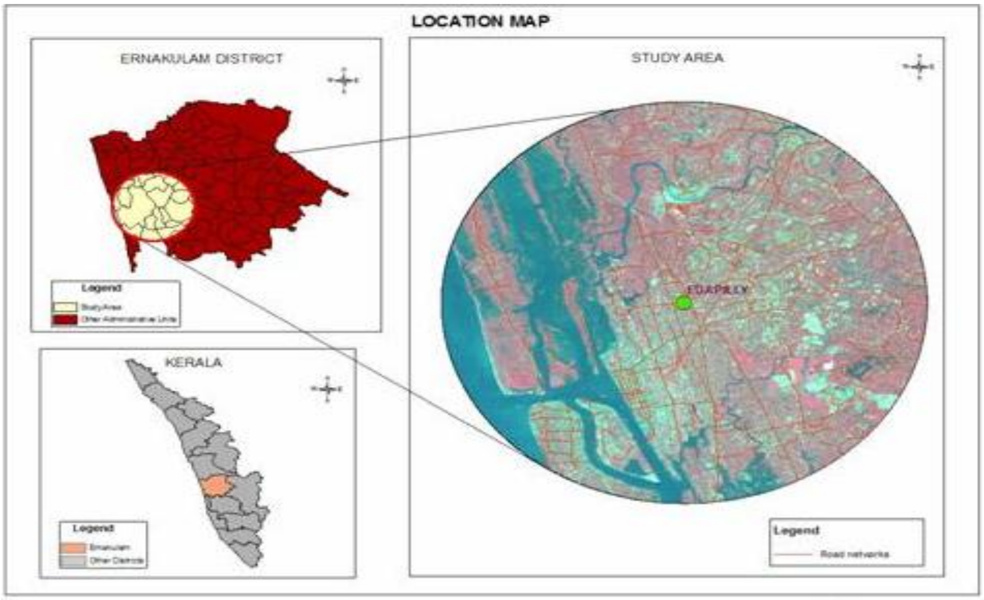
This is mainly due to the presence of a number of small scale as well as large scale industries in the area including chemical, agricultural, fertilizer, metal, plastic factories etc. They may be responsible for the presence of RSPM as well as SOx in the adjacent environment. M G Road and Ernakulam South stations are also showing unhealthy conditions of air pollution. These areas include the main bottlenecks of the city thereby increasing vehicular emissions which may differ based on vehicle speed, engine technology, fuel quality and age of the vehicles. Pollution from vehicles is shown through symptoms like cough, headache, nausea, irritation of eyes, various bronchial problems and visibility, which result due to vehicular discharges like CO, unburned HC, Pb compounds, NOx, soot and aldehydes, among others, from the tail pipes of vehicles. Eloor – II monitoring station as well as its surrounding area have only moderate contamination levels in the air. This is relatively safe though there may be certain minor illness such as irritation of the eyes, cough, allergies etc. Vytilla and Irumpanam areas have relatively good air quality as per the index. Hence the risk factors relating to presence of air pollutants is relatively low in these regions.

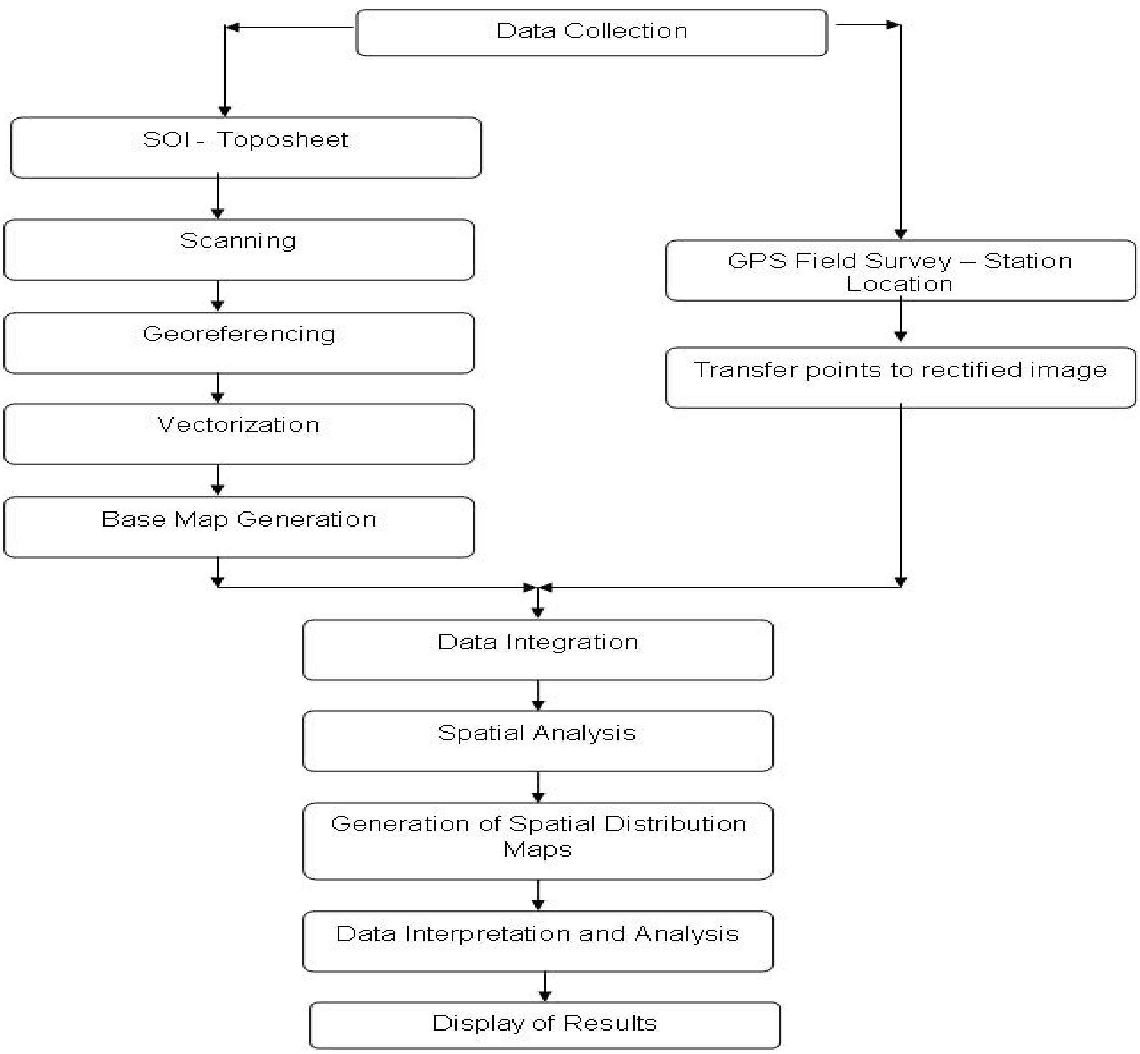
Conclusions and Recommendations

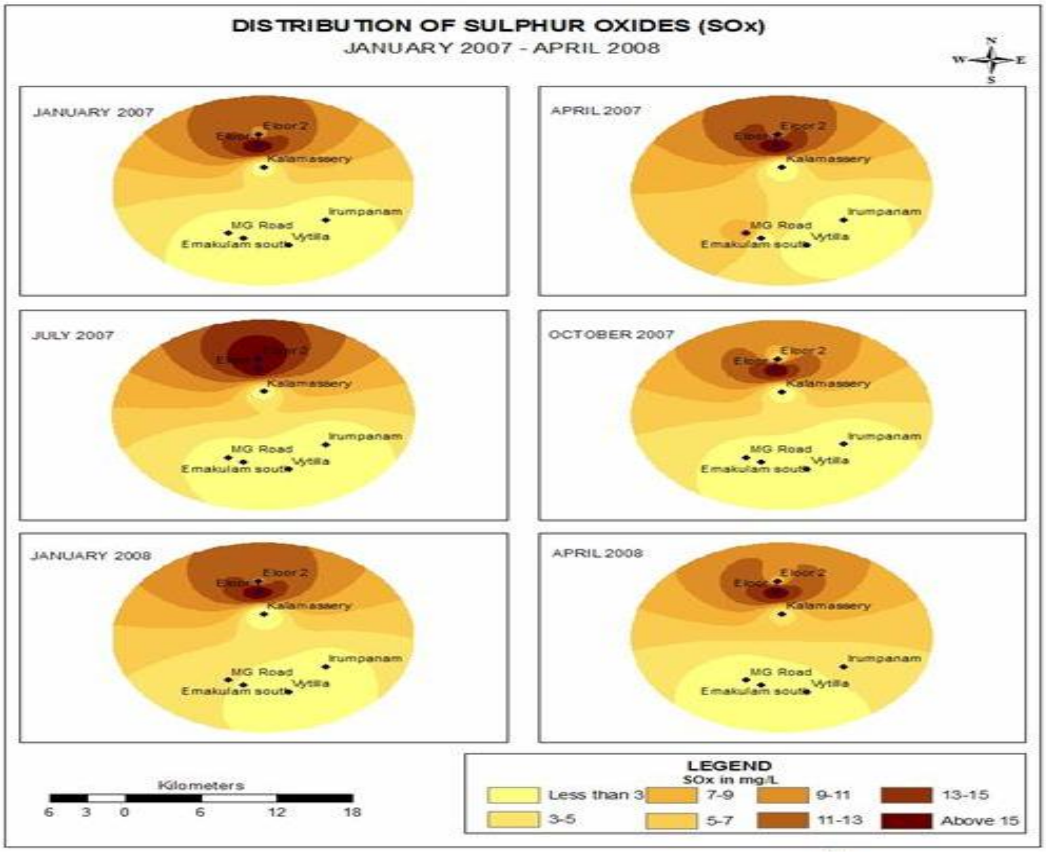
This study has made an attempt towards modeling the spatial variation of air pollution concentration originating from the various sources in selected monitoring station in Ernakulam district during the study period. Layers were generated and overlayed to obtain the final air pollution distribution. The study shows that the industrial belt of Ernakulam is more prone to pollution. Also the urban regions are affected to an extent due to the increasing traffic and subsequent congestion. The seasonal air pollution surfaces generated proves to be useful for a wide range of purposes such as health risk assessment of the population within the study area, establishing and monitoring air quality standards, evaluation of transport policies and monitoring the industries. The number of sampling points in the study can be increased in order to obtain more precision. For higher accuracy, the study can be extended to incorporate meteorological parameters like wind direction, wind speed, temperature, altitude which affect pollutant dispersion. It is possible to improve the spatial predictions of air pollution levels by deriving an empirical regression model of the relation between pollutants and independent variables can be conducted as the next step of this research.

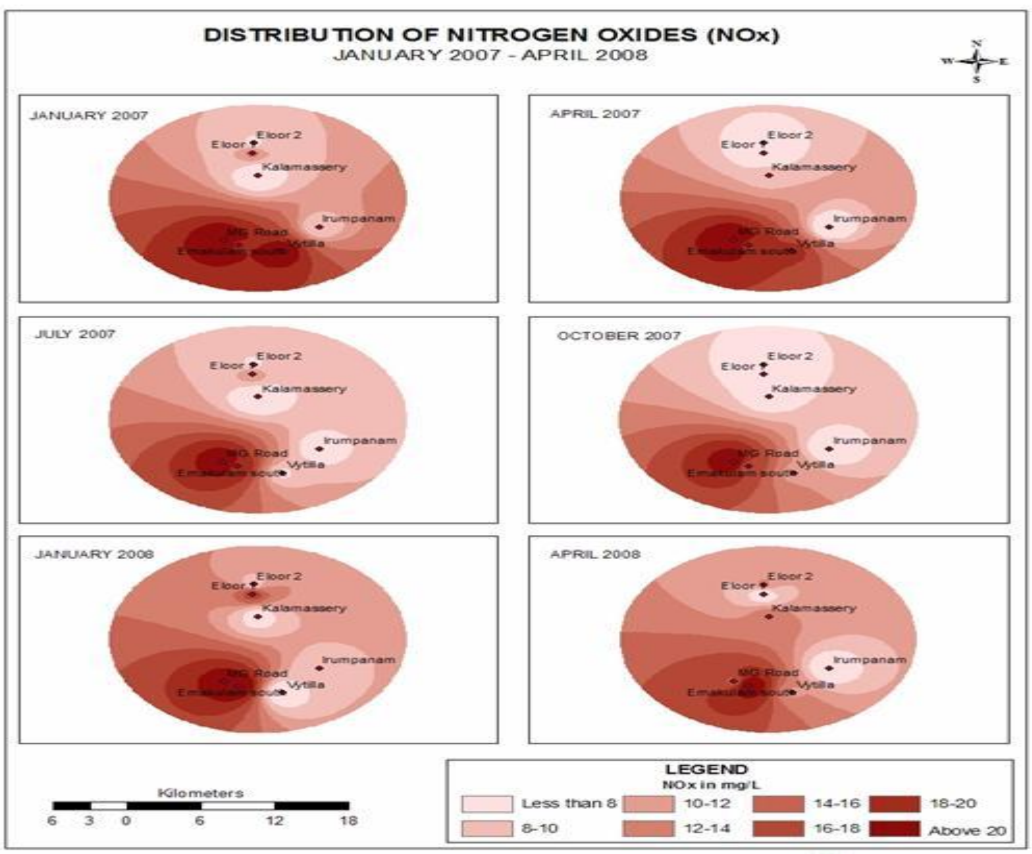
Acknowledgements

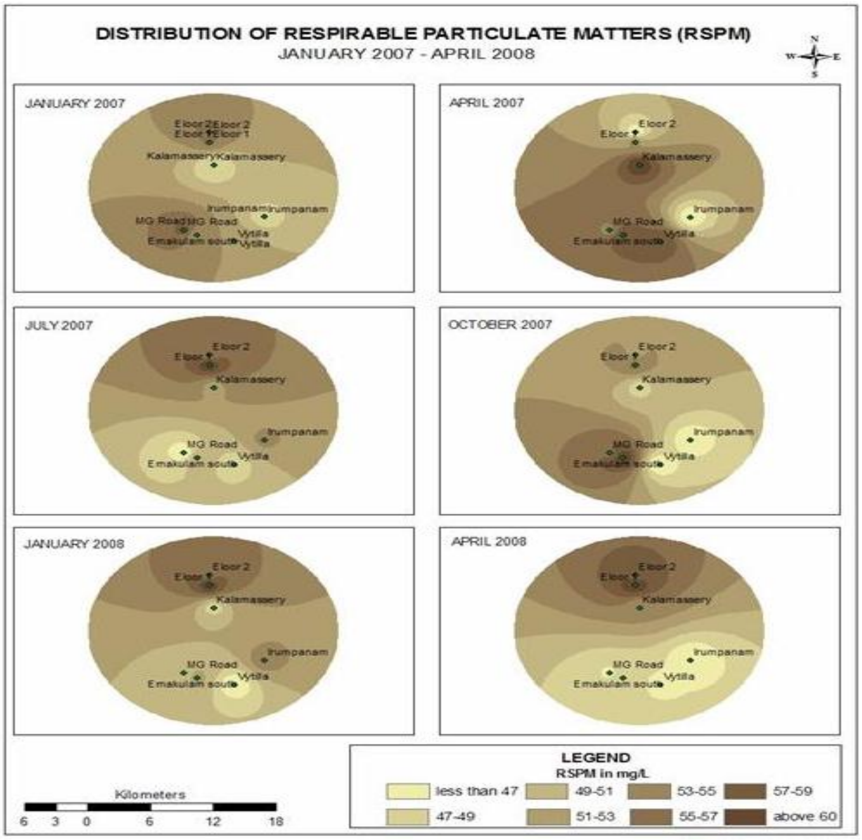
We would like to thank the Director NATPAC for extending us all the support to publish this work and Executive Director CED for supporting us to undertake this study successfully. Special thanks are extended to Kerala State Pollution Control Board for providing us all the relevant data without which the study would not have been possible.

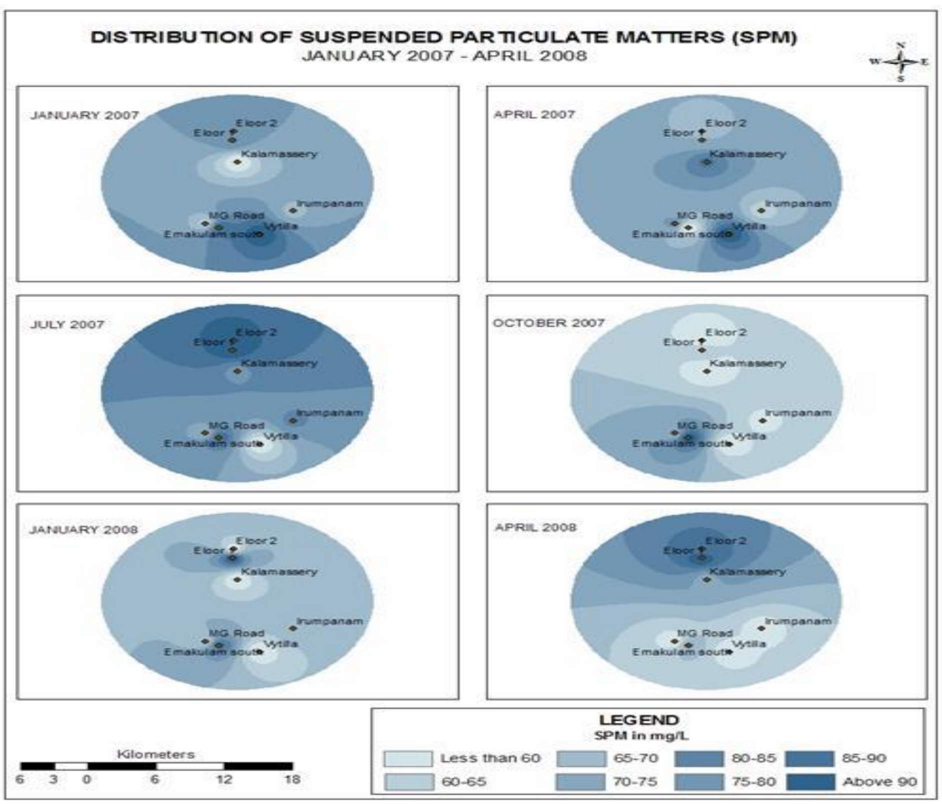

LOCATION MAP
ERNAKULAM DISTRICT
STUDY AREA
KERALA
Legend
Legend
Legend

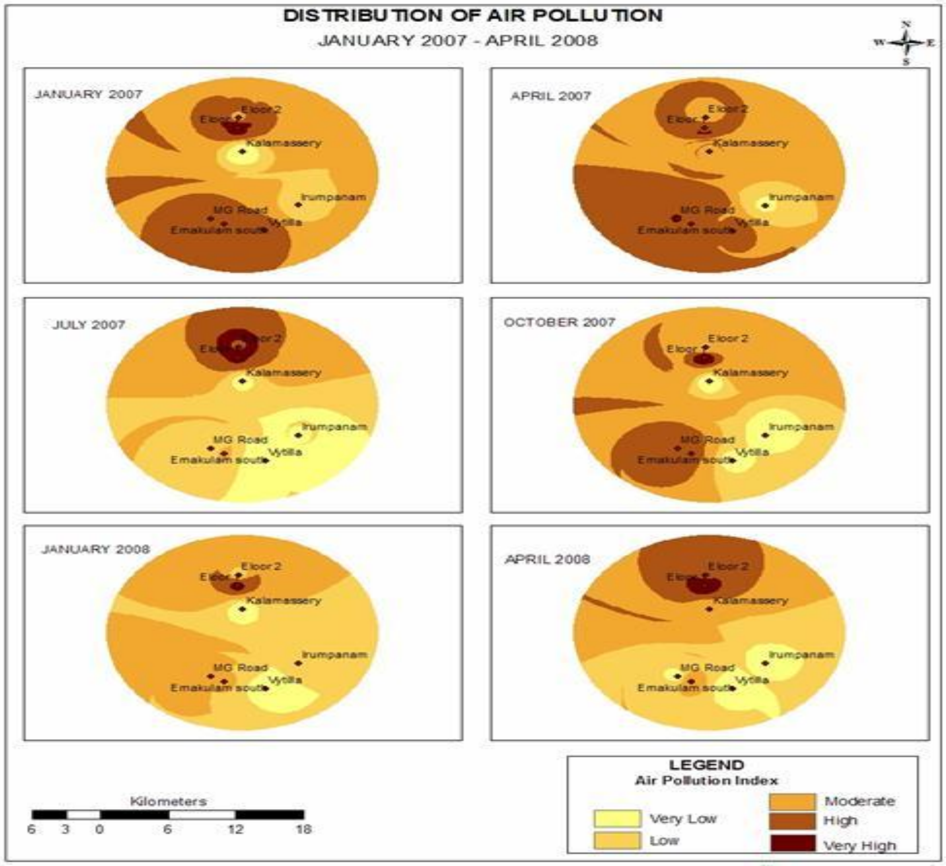

Data Collection
SOI - Toposheet
Scanning
Georeferencing
Vectorization
Base Map Generation
GPS Field Survey – Station Location
Transfer points to rectified image
Data Integration
Spatial Analysis
Generation of Spatial Distribution Maps
Data Interpretation and Analysis
Display of Results

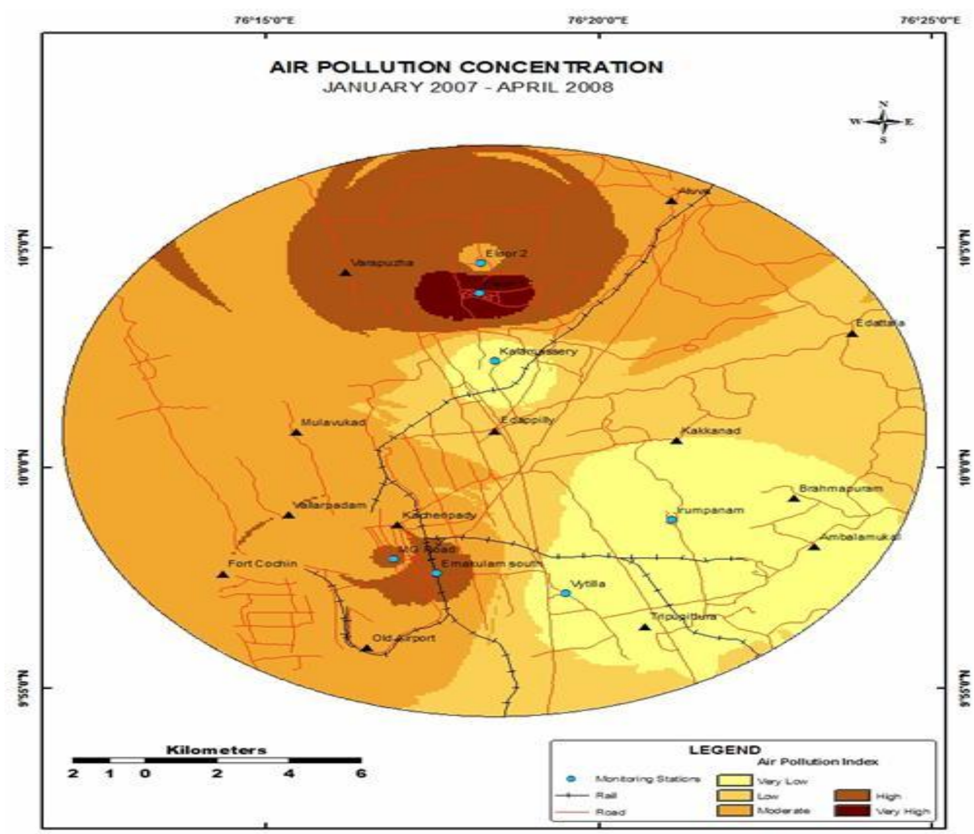

DISTRIBUTION OF SULPHUR OXIDES (SOx)
JANUARY 2007 - APRIL 2008
JANUARY 2007
APRIL 2007
JULY 2007
OCTOBER 2007
JANUARY 2008
APRIL 2008
Eloor 2
Eloor
Kalamassery
Irumpanam
MG Road
Vytilla
Ernakulam south
Kilometers
6 3 0 6 12 18
LEGEND
SOx in mg/L
Less than 3
3-5
7-9
5-7
9-11
11-13
13-15
Above 15


DISTRIBUTION OF NITROGEN OXIDES (NOx)
JANUARY 2007 - APRIL 2008
JANUARY 2007
APRIL 2007
JULY 2007
OCTOBER 2007
JANUARY 2008
APRIL 2008
Eloor 2
Eloor
Kalamassery
Irumpanam
MG Road
Vytilla
Ernakulam south
Kilometers
6 3 0 6 12 18
LEGEND
NOx in mg/L
Less than 8
8-10
10-12
12-14
14-16
16-18
18-20
Above 20


DISTRIBUTION OF RESPIRABLE PARTICULATE MATTERS (RSPM)
JANUARY 2007 - APRIL 2008
JANUARY 2007
APRIL 2007
JULY 2007
OCTOBER 2007
JANUARY 2008
APRIL 2008
Eloor 2
Eloor
Kalamassery
Irumpanam
MG Road
Vytilla
Ernakulam south
LEGEND
RSPM in mg/L
less than 47
47-49
49-51
51-53
53-55
55-57
57-59
above 60
Kilometers
6 3 0 6 12 18


DISTRIBUTION OF SUSPENDED PARTICULATE MATTERS (SPM)
JANUARY 2007 - APRIL 2008
JANUARY 2007
APRIL 2007
JULY 2007
OCTOBER 2007
JANUARY 2008
APRIL 2008
Eloor 2
Eloor
Kalamassery
Irumpanam
MG Road
Vytilla
Ernakulam south
LEGEND
SPM in mg/L
Less than 60
60-65
65-70
70-75
80-85
75-80
85-90
Above 90
Kilometers
6 3 0 6 12 18


DISTRIBUTION OF AIR POLLUTION
JANUARY 2007 - APRIL 2008
JANUARY 2007
APRIL 2007
JULY 2007
OCTOBER 2007
JANUARY 2008
APRIL 2008
Eloor 2
Kalamassery
Irumpanam
MG Road
Vytilla
LEGEND
Air Pollution Index
Very Low
Low
Moderate
High
Very High
Kilometers
6 3 0 6 12 18


AIR POLLUTION CONCENTRATION
JANUARY 2007 - APRIL 2008
76°15'0"E
76°20'0"E
76°25'0"E
10°5'0"N
10°0'0"N
9°55'0"N
Eloor 2
Varapuzha
Edattala
Mulavukad
Edappilly
Kakkanad
Brahmapuram
Vallarpadam
Kacheripady
Irumpanam
Ambalamukal
MG Road
Fort Cochin
Ernakulam south
Vytilla
Old Airport
Kilometers
2 1 0 2 4 6
LEGEND
Air Pollution Index
Monitoring Stations
Rail
Road
Very Low
Low
Moderate
High
Very High

Web GIS for Bruhat Bengaluru Mahanagara Palike

D. Vinutha and B. P. Lakshmikantha

Karnataka State Remote Sensing Applications Centre, Bangalore, Karnataka
E-mail: vinuthadevkumar@gmail.com

Abstract

Web based GIS is a way to introduce e-delivery into the operation of BBMP via geographical data sharing within the organization and with the outside world. "Web GIS for BBMP" is a complete guide to the Bangalore wards information including Corporators details, BBMP schools, colleges, hospitals found in these wards. The population in these wards based on the 2001 census data, have also been shown. Along with these, the citizen friendly Bangalore One centers have also been depicted. The tools and the tabs developed in the application provides for the easy access of the data reducing time and efforts to reach it.

Introduction

Bangalore also known as **Bengaluru** is the capital of the Indian state of Karnataka. It covers a total area of about 741 sq km spread across the 198 wards. These wards are administered by Bruhat Bengaluru Mahanagara Palike(BBMP). The BBMP's website hosts all the information relevant to these wards in the form of tables. However accessing the required information from the website is time consuming and laborious for citizens. Keeping all these factors in view, Web GIS for BBMP has been developed. This application gives information about all the 198 wards, its jurisdiction, corporator's information, Census details. BBMP's educational and health care structures i.e., schools, colleges and hospitals have been depicted. The ten Citizen Service Centers (CSC) set up by BBMP to address public woes have also been depicted. Along with these, the citizen friendly Bangalore One centers have also been shown. The access of the map and the associated attribute data has been made easier and faster by providing relevant tools and tabs on the web page.

Study Area

The area chosen for the present study is Bangalore city. Bangalore is situated in the heart of the south Deccan plateau in peninsular India to the South eastern corner of Karnataka State at an average elevation of about 900 meters covering an area of about 741 sq km. Bangalore is considered to be climatically a well favoured city. The study area includes the BBMP region of Bangalore depicted in the following figure 1.

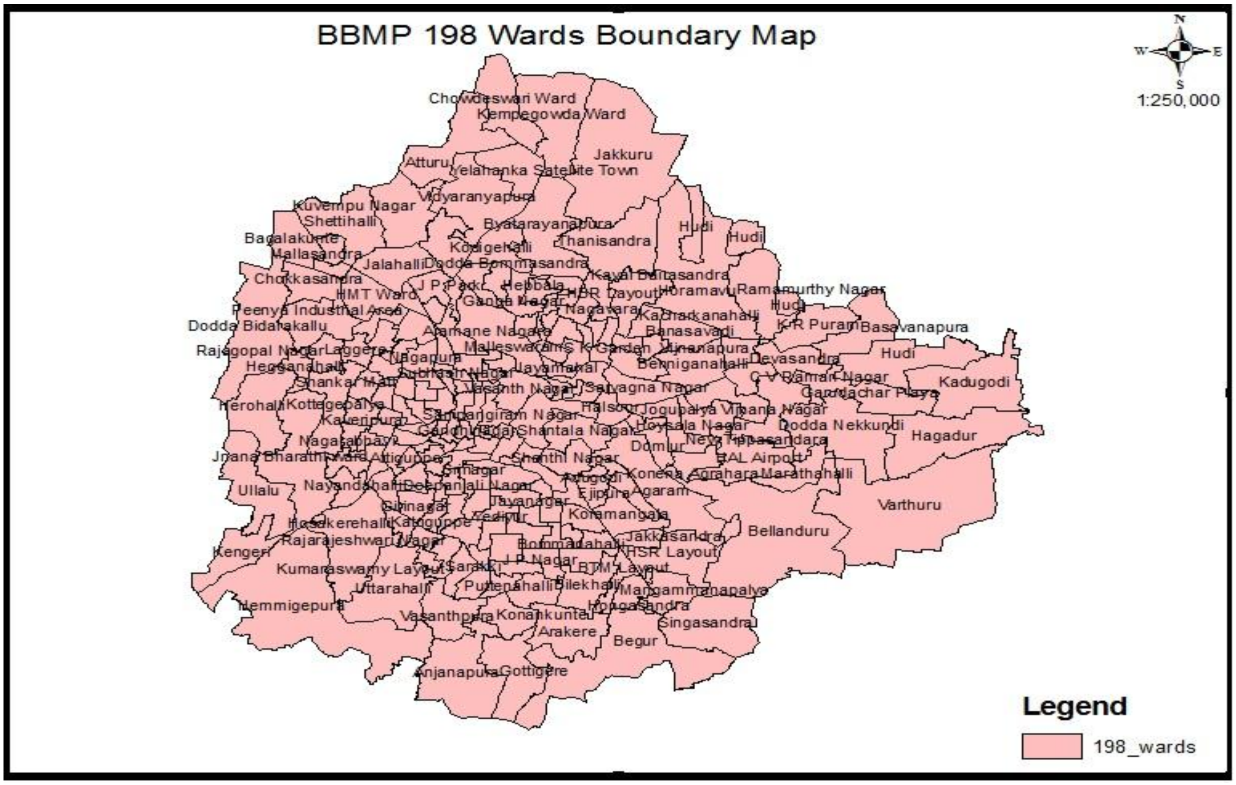


Fig. 1: Study area BBMP region of Bangalore

Data Used & Methodology

The spatial data source used for the present study is the 198 wards boundary map acquired from BBMP. The non-spatial data source includes BBMP Corporators list, BBMP Schools list, BBMP Colleges list, BBMP Health Centers list, Citizen Service Centres (CSC) list, Census Report, Bangalore One Centers list.

The software used for this project includes ArcGIS 10 Desktop Applications- Arc Catalog, Arc Map; ArcGIS 10 Server, ArcSDE, Microsoft SQL Server 2008, Microsoft Visual Studio 2010, Javascript, JQuery, VB.Net, ASP.Net. The Arc GIS 10 desktop functionalities- Arc Catalog and Arc Map were used for the creation and edition of the geographical data. The ArcGIS 10 Server was mainly used for publishing the maps as a web service. Esri's ArcSDE, spatial database engine manages spatial data in a relational database management system (RDBMS) and enables it to be accessed by ArcGIS clients. The Microsoft SQL Server 2008 used for creating, managing and querying the database. The Microsoft Visual Studio 2010 is an integrated development environment (IDE) platform used for developing web application. Javascript is a powerful scripting language used for client side scripting. JQuery coding language was used for its fast access. ASP.Net is the web application framework used for developing dynamic web pages. The detailed methodology followed in the present application is depicted in the flowchart represented in figure 2.

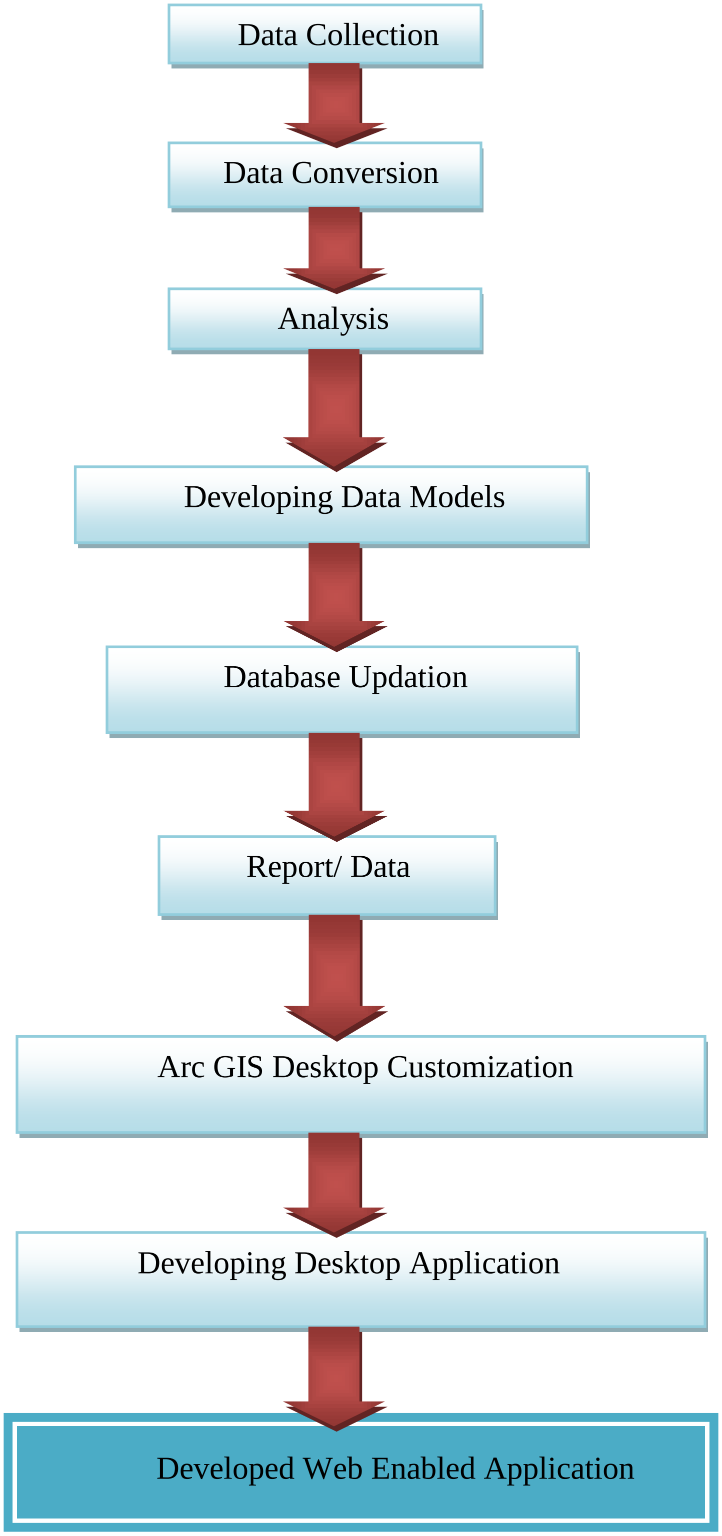


Fig. 2: Flowchart of detailed Methodology

Results and Discussions

Much recent attention has focused on developing GIS functionality in the Internet, Worldwide Web, and private intranets and is sometimes termed as WebGIS. Web GIS for BBMP provides the foundation for integrating municipal services of BBMP. The importance of such an integrated web applications has been emphasized by Lalan Kumar (2005). He reported that Integrated GIS offers the best possible solutions in order to meet the evolving challenges of municipal departments by developing an information system that provides information of utilities along with the base maps. He has mentioned that this can be achieved by integrating the map in digital form along with the data that is provided by the local department together into GIS for further use.

The results involve development of tools such as Zoom-In, Zoom-Out, Pan, Zoom Out to Full Extent, Left Extent, Right Extent, Select Tool, Search. These tabs mainly help in ease of access. Zoom-In tab is used to Zoom-in the map. There are two ways in which this tool can be used. One is by single left clicking and the map will Zoom-in and re-center where it is clicked. The second is to draw a rectangle around the area which we want to display and the map will Zoom-in to the area of the rectangle. The Zoom-Out tab is used to Zoom-out the map. One is by single left clicking and the map will Zoom-out and re-center where it is clicked. The second is to draw a rectangle around the area we want to display and the map will Zoom-out to the area of the rectangle. Pan tool is used to move around the map without changing the scale. With this tool selected left-click and drag the map to move it around.

Zoom out to Full Extent tool in the toolbar will zoom the map all the way out to the full extent. Left Extent tool used to showcase the map's previous extent. Right Extent tool used to showcase the map's forward extent. The Select tool enables the user to click on any part of the map and the information pertaining to it is displayed on to the right. The Search tool enables the user to search any ward, based on the Ward ID. A small window appears on the center of the screen prompting the user to enter the Ward ID (Fig 3).

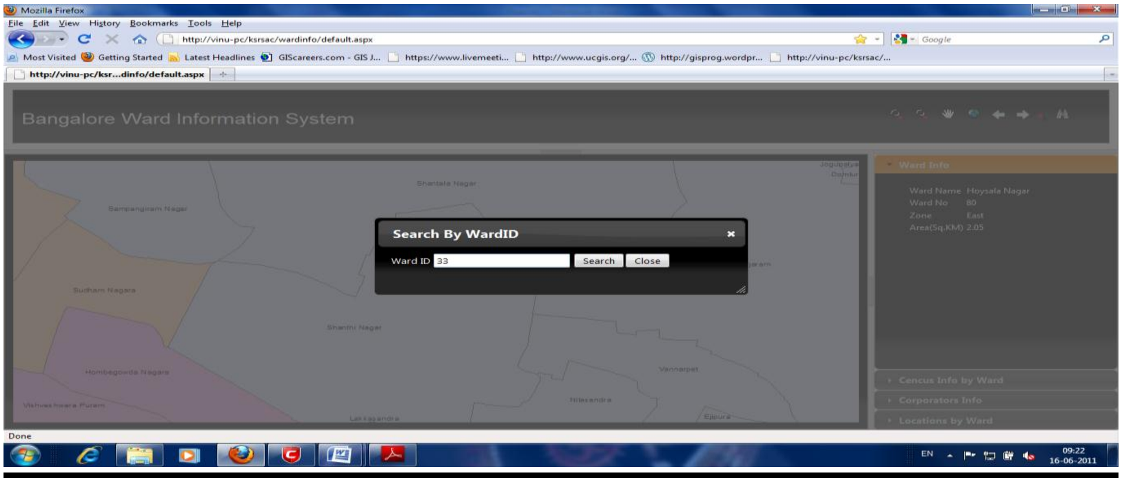


Fig. 3: Search Window

There are several mini tabs on the right side of the map display frame which gives several information pertaining to the wards. The tabs include Ward Info, Census Info by Ward, Corporators Info, Locations by Ward, CSC (Citizen Service Centers, BBMP Nursery Schools, BBMP Primary Schools, BBMP High Schools, BBMP Colleges, BBMP Health Centers, Bangalore One Centers (Fig4). A similar kind of application has been developed by the Municipal Corporation of Delhi (MCD) as "MCD on GIS" (http://app.mapmyindia.com/mcdApp/) in co-operation with Map My India. This displays the ward, zone or colony map depending on the search provided displaying only the spatial data.

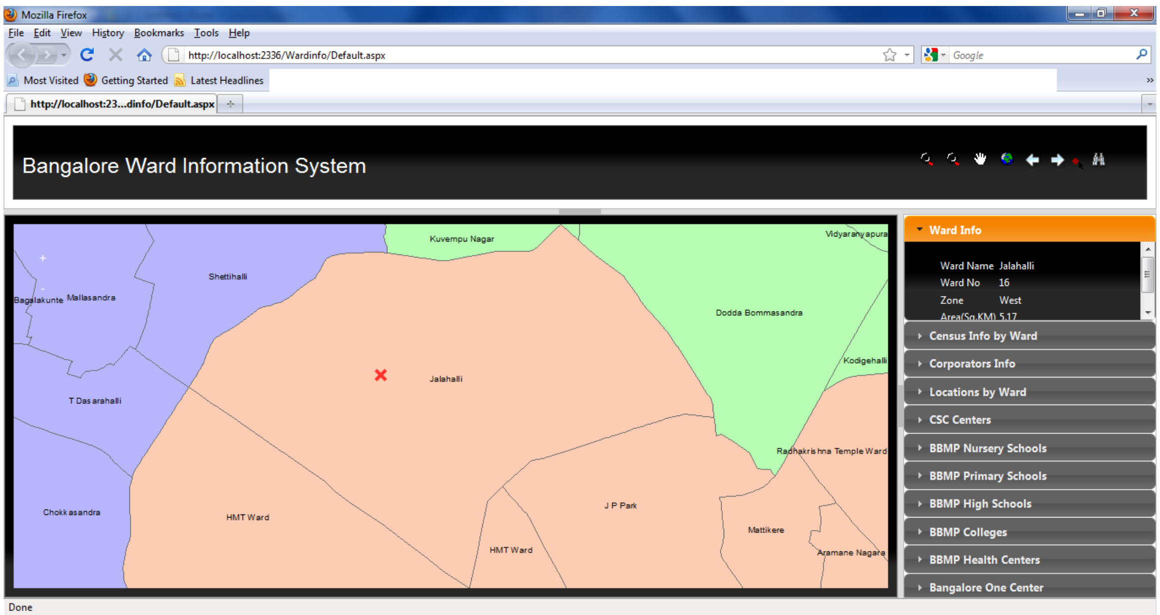


Fig 4: Results

In the present application, Ward Info tab gives information like Ward name, Ward number, Zone and the area of the ward. Census Info By Ward tab gives the census information of the ward, based on the several parameters like Total Population, SC(Scheduled Caste), ST(Scheduled Tribe), No_HH(Number of Households), Male Population, Female Population, Male_SC, Female_SC, Male_ST, Female_ST. Corporators Info tab gives the ward's corporator's information like Corporator name, address, phone number along with the photo of the corporator. Locations by Ward tab gives information of the localities that falls under a particular ward. CSC (Citizen Service Centers) tab gives us information on the 10 CSC centers established by BBMP. If a particular ward has the CSC Center established, then that information can be found under this tab.

BBMP Nursery Schools tab gives us information on the nursery schools established in a ward. BBMP Primary Schools tab gives information on the Primary schools set up by BBMP in a ward. BBMP High Schools tab gives information on the BBMP High schools set up by BBMP in a ward. BBMP Colleges tab gives information on BBMP Colleges. It includes ward name, college name and the address of it. BBMP Health Centers gives details of the health centers set up by

BBMP can be obtained from this tab. It includes information like ward name, category (Health Center/ Dispensaries/ Referral Hospitals/ Maternity Centers), and address. Bangalore One Centers tab gives details of citizen friendly Bangalore One Centers found in the wards. Similar kinds of applications have been developed in other parts of the world for example by the City Council of Newcastle, UK and by the City Council of Waterloo, Canada.

Conclusions

Municipal corporations deal with enormous spatial as well as non-spatial data from various sources. Spatial data is available in the form of maps, satellite data and aerial photographs while non-spatial data is available as various reports attribute information from various sources. Integrating this data over single common platform helps in analyzing the information as well as making some important decisions. Web Based GIS for BBMP is an Interactive web application which is useful to both the BBMP as well as the public. It is very useful for planners, decision makers and the public in general. It can be accessed by many users from anywhere over the internet. It minimizes time and effort to reach data. It has a collective and comprehensive database.

There is a tremendous scope for expanding the area as well as including more of information. The suggestions that can help enhance the application to a better level of implementation would be embedding several layers like Roads map, Streets map, Parks, Lakes, Property Boundaries, Polling areas. Several Projects taken up in the wards can be listed along with details such as Date of beginning of project, Budget, Proposed completion date and many other parameters related to it. Important facilities available in these wards like police stations, Emergency services, Fire stations, Restaurants, libraries, etc., can also be depicted.

References

Census Report (2001), Government of India (GoI), India.

Floyd F Sabins(1996), Remote Sensing- Principles and Interpretation, W.H.Freeman and Company, 3rd Edition.

Lalan Kumar (2005), Strategies for better GIS Implementation at Dhanbad Municipality, 8th Annual Map India 2005 International Conference.

Ravindra Kumar Verma, Sangeetha Kumari and R K Tiwari(2008), Application of Remote Sensing and GIS Technique for Efficient Urban Planning in India.

Envirocloud: Lending Voice for Conservation and Management of Urban Trees

Nishadh, K.A., P.Balasubramanian and Azeez, P.A.

Sálim Ali Centre for Ornithology and Natural History, Anaikatty PO, Coimbatore, T.N.
E-mail: nishadhka@gmail.com

Abstract

Large-scale development in mobile communication and computation technology provides immense potential in collecting and curetting environmental observations from sensors as well as citizen scientist in India. Volunteered geoinformation collected through SMS, and other widely available communication means will provide basic data for environmental research. Moreover, the community involvement in this endeavor will provide a means for wide social awareness and participation in local environmental management and conservation. Community involvement can play a very essential role in the process of better comprehension of social ecosystem and informed management and conservation initiatives. Models of community participation, open and cloud source initiatives backed by interactive internet, web 2.0 can provide the workable community involvement model for the above said restrain process. The objective of the present paper is to understand the application of those widely practiced models for improving environmental awareness among users of public transportation system by providing location based information service about scheduled reaching of bus in particular bus stop and in turn requesting their contribution in environmental observation. At large, by doing so the model envisages to create a platform for community involvement for environmental awareness and increase the usability of low ecological foot print transportation system. This paper presents a model for adaptive management of urban social ecosystem by inculcating community involvement and economic viability in it by utilizing the communication and computation technology.

Introduction

The ever increasing per capita consumption of key natural resource has considerable pressure on its conservation, management and at largely hampers its sustainability. Past reductionist attempts on natural resource management mostly resulted in failure gives rise to a strong realization that the need of paradigm shift in conservation and natural resource management. Ecosystem approach is widely considered as the culmination of that shift (Holling 2001). Inculcating adaptive system characteristic in social ecosystem to withstand disturbances while still retaining its fundamental structure, function, and internal feedback is to be the nearly achievable aim of natural resource management (Jasanoff *et al.* 1997). This necessitates need of system level understanding of local social ecosystem, harmonization of conflict between social ecosystem and search for balance between consumption and conservation of natural resources for sustainable development.

Sustainable development is all about creating opportunity for social ecosystem to make it adaptable to forces of change (Jorgensen and Bendoricchio 2001). It requires close collaboration among community and scientific establishments, interdisciplinary approach and competences. Grouping the people together from different disciplines and social backgrounds is an essential thing in this regard. It requires the need to study social ecosystem, understanding dynamic processes that lead to collapse, adaptation or recovery of the same system. It should be simple and dynamic as related to the situation by connecting with policies, actions taken in social sphere and evaluating the pluralistic future vision. The uncertainty in the ecosystem has to be aptly considered by generating Pluralistic maps (models) of same phenomenon. To make that kind of models it need to have as much observation as possible on functioning of social ecosystem for generating dynamic perception, social consensus and adaptive strategy (Gadgil et al., 2003, Okolloh 2009).

Creation of widely accessible spatial data infrastructure of local environment will be a way around for this by making web of various sensors and sensor networks deployed to monitor the environment with different objectives and specification.Localized contextual knowledge is essential for co adaptive management (Gadgil *et al.* 2003). It requires of grouping of diverse source of spatial data about a locality to make it an interoperable and to provide holistic understanding of the social ecosystem dynamics. The information thus generated has to be shared in such a way that to create alliances between scales and organization of social ecological system. Harnessing the cloud sourced information will be a better way to collect local information in the scenario of prevailing uncertainty other than sensor data. Because it gives pluralistic view, community involvement and thus increases the community trust on the whole system encapsulated for generating information (Meinke 2006). Envirocloud using those models act as a information infrastructure to be able to cloud source environmental observation from community as well as from varied type of distributed sensors to give holistic information about the dynamism of the local social ecosystem, and to provide essential information to implement adaptive characteristics in it.

The community, by social learning using those information can appreciate the functionality, interdependence of social ecosystem, its complexity, dynamism and uncertainty (Meinke 2006). Thus the community can acquire customized adaptive management measures by innovate, experiment and adapt to the situation given by the comprehension of current social ecological system state. This necessitates the requirement of credible, usable, dynamic, open-access information about functioning and state of social ecosystem. Recent developments in information technology especially in personal communication and computational techniques provide the needed facility to procure those information. The infrastructure thus created reflects the analogy of cloud and rain event, where the adaptation can be seen as the shower of rain and events happening for that such innovations as lightning, experiments as turbulence and cloud formation as predicisance of adaptation. This paper presents a model for adaptive management of certain components of urban social ecosystem by inculcating community involvement and economic viability in it. It also discusses the environmental balance theory for interlinking the components, and ensure economic viability of the model. This paper's objective is to discuss, the interlinked adaptive management of urban forestry and public transportation system in Coimbatore city, third largest urban conglomerate in the state of Tamil Nadu.

Model premise

The model looks for the dynamic information procurement about two interrelated components of Coimbatore regional community that is its urban forestry and public transport system. The adaptive management of both components can be achieved by generating community concern on urban forestry and real time information about public transport system (city bus fleets). In Indian scenario the former two components are very closely interrelated. Road widening as a measure of rapid development, pose considerable destruction of trees culturally planted on the side of roads, whereas the dependency on personal transportation increases because inadequate public transportation necessitating of widening the roads and thus destruction of urban forestry.

Coimbatore is one of the high vehicles to population ratio city in country. High density of personal vehicles in narrow roads exerts pressure on widening of roads and cutting of road side trees. Within a last couple of years more than 1500 road side trees are chopped for road widening of main artillery roads of Coimbatore. Around 90% of services are provided by government owned Tamil Nadu State Transport Corporation (TNSTC) and remaining by private players. Services are provided in 228 different routes by a total of 506 buses with range distance coverage of 7-30km. The bus stops and modern waiting sheds are available in the city limits with minimal distance range of 0.5-1 km and estimated number of 750-1000 unique bus waiting sheds.

Model Components

The model comprised of urban forestry, public transportation system, real time air pollution monitoring and environmental balance index generation in which former two acts as participating variable component in the model. The figure-1 depict the components of the model. The aim of the model is to procure dynamic data from these components into distributed data warehouses and disseminate the relevant information from the data into end users of community. Cloud sourcing can be used for generating community concern on urban forestry. Implementation will be by inviting participation of volunteers to share their environmental observations on urban forestry. Procurement of observations will be by using open source cloud source software Ushahidi (Okolloh 2009). The cloud sourcing will be maintained by including widely available communication facilities such as SMS. The environmental observation will be task based voluntary participation in which people will be asked to look for certain characteristics in particular, urban tree in their locality which will require simple to moderate level close observation of the tree. The networking of public buses (Public Transportation System) is for better tracking of their current position and generating better utility and planning opportunity for end users. Implementation will be carried out in two phases: procurement of static information about public bus transportation route, timing etc and disseminating those information into end users through SMS messaging on request, which acts as Location Based Information (LBS) for end user. The inter linkages between these components can be generated by open source and cloud source community involvement (Fig 2). For implementing those models following methods can be executed.

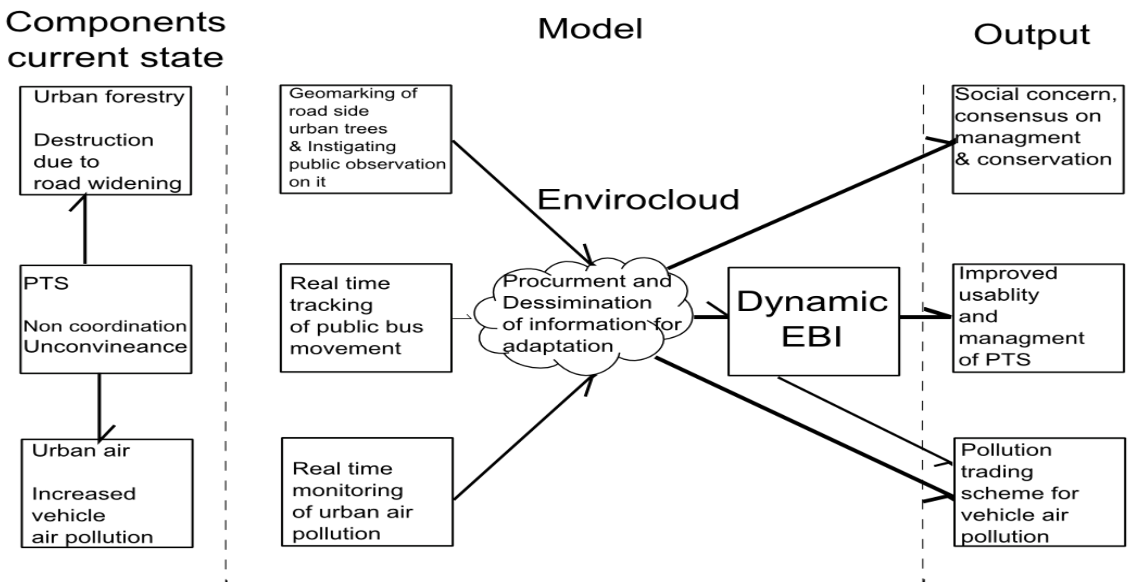


Figure-1. Model components and its inter linkage. PTS- Public Transporation System, EBI-Environmental Balance Index

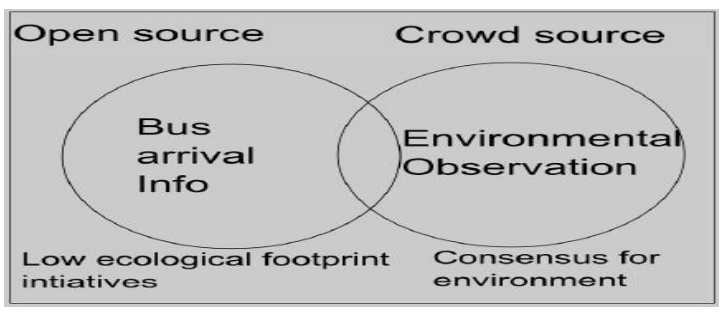


Figure 2 The community development models for implementation.

Geo coding of bus sheds: Bus waiting shed will be the confluence point of community and potential audience for the environmental awareness. For environmental observation it acts as a point in point count method. The geocode will be the key to retrieve the tree data base created and provide the LBS service. Every waiting shed will be geocoded with four digit codes, comprising first two letter of reaching destination from urban center and a double digit numeric for each stop numbered from destination to urban center. The geocode of the specific bus shed will be popularized by pasting the code in bus waiting shed, creating an SMS application to retrieve the geocode by sending bus stop name, publishing it in web as route maps.

Biodiversity aware waiting shed: Data (tree diversity) will be collected within the surrounding visible circumference of bus waiting shed. Each tree will be geotagged with Google maps application programming interface by specifying the position related to the circumference (Degree or clock position) of waiting shed. The photographs taken for each tree from waiting shed as focal point will be geotagged and visualized in web map. All the data will be stored in MySQL, offline and uploaded in popular web applications such as flickr, Google maps, document and published in biodiversity portals such as Western Ghats biodiversity portal.

The LBS bus timing information for each bus waiting shed will be created by involving Google transit partner program. The process includes developing general transit feed specification for each bus route with defining variables such as location of bus stop, schedule of the each bus etc. It also involves Validating and testing the transit feed, hosting it in web server and make arrangements with Google to publish as Google transit feeder for city bus route planning. This framework will be used to retrieve the information about likely bus arrival related to time and location of bus shed as LBS service to its user. The information will be hosted in MySQL and retrieved by using key, geocode of the waiting shed. Enhancement of this facility for real time tracking of buses can be carried out by implementing the GPRS enabled mobile based tracking facility in each PTS buses. Real time information about bus movement gives tools to search the availability of public transport and planning facility for user and it gives further advantage of situational management for public transportation managers to make their business sustainable.

The economic viability of these components can be improved by generating the real time air pollution monitoring of urban space for pollution trading mechanism through Environmental Balance Index (EBI) (Figure 3) (Taras, 2010). The surveillance camera installed in traffic islands can be used for real time tracking of particulate matter (PM 10)in urban air (Jacobs *et al.* 2009, Wong *et.al.* 2009). From the regression between the relationship between measured reflectance components from camera photograph and measured value of PM10, it can deduce the current concentration of it in urban air. The already installed surveillance camera can be used to connect by sensor web enablement specification and the real time monitoring of the PM 10, which has adverse health effect can be deducted.

The Environmental Balance Index (*EBI*):

$$EBI_t = \frac{ERI_t}{EEI_t},$$

ERI_t – intensity index of production of services to ecosystem

EEI_t – intensity index of consumption of ecosystem services

The value of ***EBI<1***, indicates that the intensity of consumption of ecosystem services exceeds the corresponding efforts on recovery and protection of ecosystems. Or in other words – Environmental debtor.

The value of ***EBI=1*** is an indicative of environmental neutrality.

The value of ***EBI>1***, indicates that the intensity of the production of services to ecosystem exceeds the intensity of consumption of ecosystem services. Or in other words – Environmental creditor.

Figure 3 The EBI calculation methods as given by Taras 2010.

Conclusions

This paper provides a glimpse of community involvement models and application of technological development for natural resource management and conservation. By practical implementation it can generate an unique experience which provides a new form of strategy that can be well practiced for creating a favorable situation for sustainable development and adaptive urban community.

References

Gadgil, M., P. Olsson, F. Berkes, and C. Folke (2003). Exploring the Role of Local Ecological Knowledge in Ecosystem Management: Three Case Studies, Navigating Social-ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, UK, 189–209.

Holling, C.S., (2001). Understanding the Complexity of Economic, Ecological, and Social Systems, Ecosystems, 4, 390–405.

Jacobs, N., W. Burgin, N. Fridrich, A. Abrams, K. Miskell, B.H. Braswell, and others (2009). The Global Network of Outdoor Webcams: Properties and Applications, in Proceedings of the 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, pp. 111–120.

Jasanoff, S., R. Colwell, M.S. Dresselhaus, R.D. Goldman, MRC Greenwood, A.S. Huang, and others (2066). Conversations with the Community: AAAS at the Millennium, Science, 278 (1997).

Jorgensen, S.E., and G. Bendoricchio (2001). Fundamentals of Ecological Modelling (Elsevier Science), XXI.

Meinke, H., R. Nelson, P. Kokic, R. Stone, R. Selvaraju, and W. Baethgen (2006). Actionable Climate Knowledge: From Analysis to Synthesis, Climate Research, 33, 101.

Okolloh, O..(2009). Ushahidi, Or'testimony: Web 2.0 Tools for Crowdsourcing Crisis Information, Participatory Learning and Action, 59, 65–70.

Wong, CJ, MZ MatJafri, K. Abdullah, and HS Lim (2009). Temporal and Spatial Air Quality Monitoring Using Internet Surveillance Camera and Alos Satellite Image, in Aerospace Conference, IEEE, , pp. 1–7.

Taras, B. (2010). On the Theory of Environmental Balance.

GIS Based Desktop Application for Crime Analysis and Reporting Engine

B.P. Lakshmikantha[1], Vinay Kumar, A.[1], Sanjay Sahay[2] and Suresh, P.[2]

[1]Karnataka State Remote Sensing Applications Centre, Bangalore, Karnataka
[2]State Crime Records Bureau, Dept. of Police, Govt. of Karnataka
E-mail: laxmikantha_bp@rediffmail.com, vinaykumar2162@gmail.com

Abstract

G-CARE is a desktop based Geographic Information System (GIS) Application. The application was developed by using Microsoft Visual Studio 6.0 and Arc GIS. Microsoft Visual Studio 6.0 was used to design a user interface and coding was done with Visual Basic 6.0 language. The important modules developed were Crime Analysis, Village Analysis, Hotspot Analysis and Data Capture. The application was developed to retrieve the information easily to analyze the situation which inturn will help easy and fast decision making in the State Crime Records Bureau (SCRB). The information stored in the Crime Criminal Information System (CCIS) database can be viewed with respect to the spatial background. The software architecture is network enabled which means that the CCIS data (SQL Server database) can be derived from any system in the network to the particular desktop where the application is installed. The client system must have Windows Operating System above the 2000 version and must be connected to the network server (if the CCIS database is in a system other than the local machine).

Introduction

G-CARE is a desktop based Geographic Information System (GIS) developed for the State Crime Records Bureau, Karnataka State Police. Different features can be seen on map as well as their ancillary information also can be viewed. The information stored in the Crime Criminal Information System (CCIS) database can be viewed with respect to the spatial background.

Different features can be classified with different symbology based on the CCIS information. The software converts the data into information very easily and in presentable form. The information can be analyzed, shown on the map and printed. G-CARE allows viewing of all the police station boundaries, their circles and subdivisions upto the district level. On click of a mouse, the information is on your desktop.

Objectives

The present study was carried out with the major objective of digitization of police station boundary from village maps and integration with road maps and administrative boundaries, crime related database creation (police station, circle, sub division wise) and customization of the requirements as per SCRB and deployment of the developed package at the district head quarters.

Data Used

- ➢ Base maps of the study area on 1:50000 scale and also on 1:2000 scale for Commisnorates.
- ➢ Police station boundary maps provided by SCRB.
- ➢ Crime Criminal Information System (CCIS) data provided by SCRB.
- ➢ Longitude and Latitude readings collected for each police station and for FIR using the Global Positioning System (GPS).
- ➢ Access database created for each village of the study area.
- ➢ Working plans of all police stations.

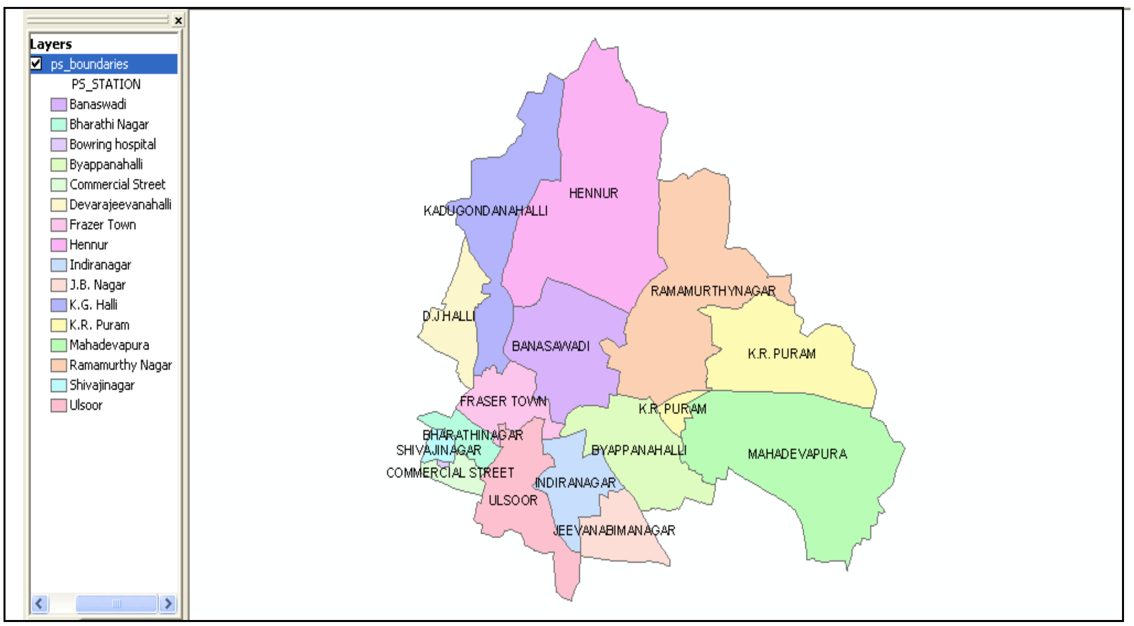


Fig. 1 Police station boundaries map of the study area

Table 1 List of thematic layers used

Sl. No	Polygon	Line	Point
1	Police Station Boundaries	State Highways	Police station locations
2	Circle Boundaries	Metalled roads	Settlements
3	Subdivision Boundaries	Unmetalled roads	Crime Locations
4	Villages	Cart tracks	Crime Points
5	Water Body	Drainages	
6	Topo Grids		

Preparation of thematic layers

The following workflow (Fig.2) has been adopted to generate various thematic layers (Table 1) required as input data for development of GIS based Crime Analysis Reporting Engine Desktop application.

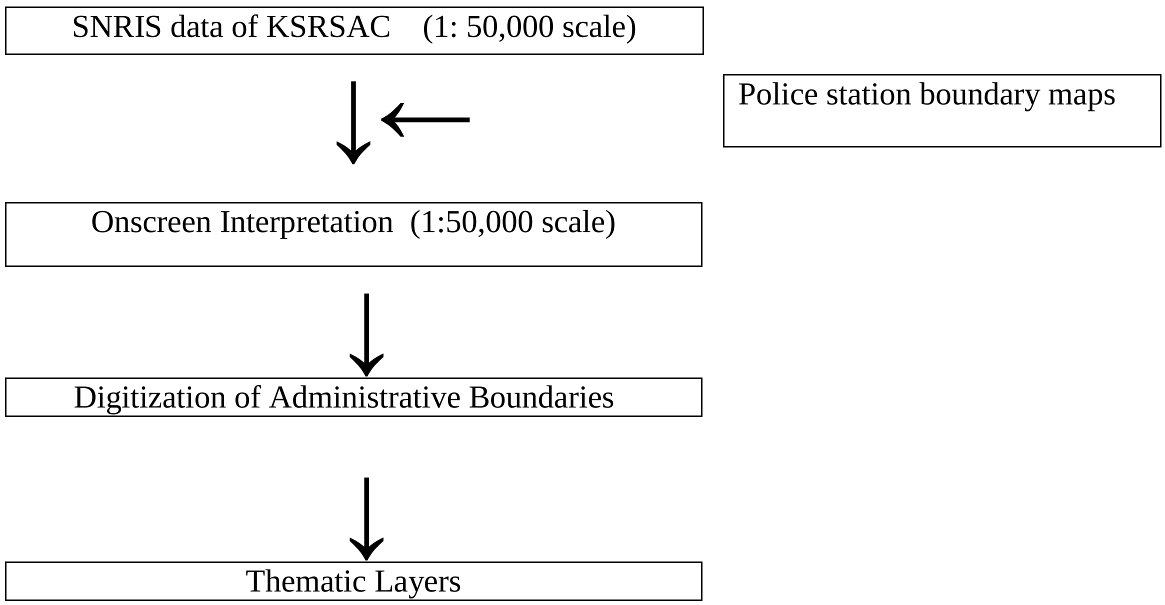


Fig 2 Workflow for preparation of thematic layers

Technology and Software used for development of G-CARE

GIS based Crime Analysis Reporting Engine is developed (Fig.3) by using Microsoft Visual Studio 6.0 and Arc GIS [SDE, desktop, catalog]. It is a useful tool to access spatial and non spatial data and gives information of police station boundaries, roads, rail and water bodies.

This system has been developed mainly using button controls which is very easy to operate.

- Arc Map – For creating Shape files
- ArcSDE – For creating tables
- Microsoft SQL 2000 – For Database connection
- Visual studio 6.0 – For creating desktop application and coding

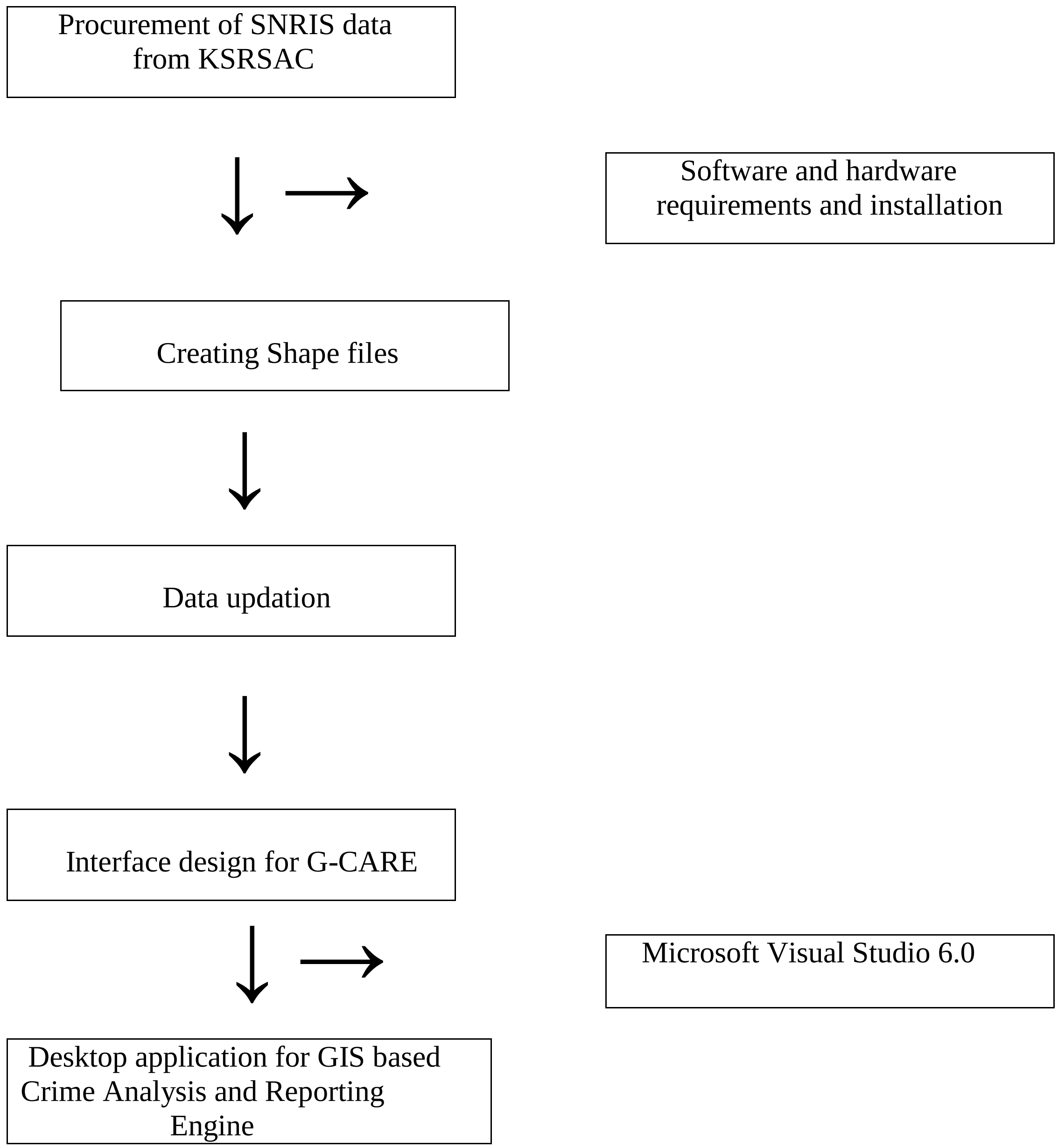


Fig 3 Steps involved in Development of Desktop Application

Results

Results of the Application are explained in detail. It includes following queries.

Crime_Analysis

In Crime Analysis module, the external data is queried according to the user defined criteria and the results are displayed on the map with the help of graphs. SQL server database created for each of the police station is the external source of data.

Count of Police Stations This is a simple query for getting the count of the police stations inside the area of interest.

Crime Density This query is for obtaining the total count of cases occurred in each unit of the area of interest.

Crime Pattern This query is for obtaining the total count of cases according to the different Crime types occurred in the selected boundary.

Heinous Crime This query is for obtaining the total count of heinous crime types occurred in the area of interest.

Road Accidents This query is for obtaining the total count of road accidents occurred under different sections in the area of interest.

Property *vs* Crime:

This query is for obtaining the total count of crimes related to property under four different criteria in the area of interest.

Automobiles Crime This query is for obtaining the total count of crimes related to automobile crimes with different search criteria in the area of interest.

Date or Year-wise Crime This query is for obtaining the total count of crimes according to date/year-wise in the area of interest.

Review This query is for obtaining the review of crime year-wise in the area of interest.

Village Analysis In Village Analysis module, the external data is queried according to the user defined criteria and the results are displayed on the map with the help of graphs. The access database created for each of the police station is the external source of data.

Population Density The villages get coloured according to different population densities. The classification gives the information of how many villages belong to a particular class.

Population Literacy The villages get coloured according to different population literacy rate. The classification gives the information of how many villages belong to a particular class.

Voters The villages get coloured according to the total number of voters. The classification gives the information of how many villages belong to a particular class.

Polling Booths The villages that are normal, sensitive and hyper sensitive are coloured differently according to the number of polling booths that are present in each village.

Village sensitivity All the villages get coloured according to the 5 classes *ie* Normal, Criminal, Naxal affected, Crime Prone and Communally Sensitive settlements.

Village Disaster Susceptibility All the villages get coloured according to the Floods, Industrial Hazards and Forest Fire.

Religious Festival All the Religious Festivals occurring in a selected month will appear. The selected festival boundaries of the villages which belong to that month get highlighted.

Data Capture There has been an initiative from the SCRB to conceive the G-CARE as an investigative tool. The first step towards it is the creation of point data by capturing each and every FIR number with the exact location on the map. There can be two methods for capturing the data, one by m anually marking the points on the map with the help of additional
data like roads, settlement points, water body layers etc. and by entering the GPS points in terms of latitude and longitude.

Hot Spot Analysis The main aim of Hotspot Analysis is to identify the spot of repeated occurrences of particular crime/s over a district boundary. The spot where there is a high concentration of occurrences will be indicated for which the necessary action can be taken to prevent the crime. The input to this module is the points that are marked through manual marking and the points which are downloaded using the GPS readings. Necessary care has to be taken that FIRs which have the Crime detail form filled in will only be valid for the analysis. The rest, even if they are marked will be of no use until and unless the same is filled.

Conclusion

The software is aimed at easy data management and updation, analyzing crime trends and patterns. Efforts were also made to relate the socio-economic, demographic and electoral information. The GIS based crime analysis and reporting engine could provide useful information in further developing Web Based Application.

References

http://www.gisdevelopment.com
http://www.mapobjects.com
http://www.esri.com
http://www.microsoft.com

Towards a Better Tour Experience using Mobile GIS and other Wireless Technologies

Shivanna and Aziz Musthafa

Department of Marine Geology, Mangalore University,Mangalagangotri, Karnataka
E-mail: shivannag@rediffmail.com & azizmusthafa@gmail.com

Abstract

Tourism is one of the highest income generating industries in the twenty-first century. Travel, like many other aspects of daily life is being transformed by technology revolution. When travellers are visiting new places, they need many geo-related services during the trip. For example, when a traveller on his way to his destination may check what's the shortest way to reach the destination and the traffic situation. When the traveller is in site he needs local attractive activities information, narration about important tourist spots and also parking place or restaurant. With the enormous progress in mobile communication and mobile GIS technology achieved in the recent years and as almost all are carrying mobile phones, it would now be possible to provide right information in right time to the traveller and it would make travellers visiting foreign environments to feel as if they are there in their home environments.

The purpose of this paper is to explore the mobile GIS capabilities and potentials in identifying tourism resources, providing spatial explanations and assisting travellers to avoid traffic congestion and to take optimal path to destination. GPS-enabled mobile GIS could present stored attribute information about nearby places of interest and objects, according to specified user preferences and interests, be it for architecture, historic landmarks or birth places of great people. The attribute information in question could range from simple age of the monuments attributes from a GIS building layer to actual tourist information systems based on sets of objects selected to suit tourist segments with specific preferences or backgrounds. Mobile phone equipped with basic GIS software has the potential of acting as a tourist guide that provides deeper insight into sites of specific interest to the traveller. Further, 3G phones enable much faster and better quality mobile access to the Internet. A proposed architecture for the design, usability, portability, functionality and implementation aspects are investigated.

Introduction

Technology has greatly changed the way the people travel today. Cutting edge mobile applications offer the promise of flexibility and connectivity for travellers. As mobile technology evolves, travel programs will take advantage of new functionalities for improved communication and enhanced tour experience. People increasingly rely on their mobile devices not only for day-to-day activities but also leisure activities such as tour. Dramatic improvements in technology are transforming smart phones into multimedia devices that will also function as direction finders, paperless boarding passes, room keys, traveller security enhancers and payment methods. Travel suppliers and travel intermediaries are rapidly introducing and enhancing their services incorporating all these functionalities. It is clear that mobile technology is expected to have a major impact on how travel is booked, managed and paid for. Similar to the advent of online booking a decade ago, the enhanced web-browsing capabilities of mobile devices provide a significant opportunity to manage travel programs. Mobile travel services will enable corporations to gain more control over traveller behavior during the trip and bring more efficiencies into the travel process.

Mobile applications with Geographical Information Systems strive to provide a toolbox of techniques and technologies of wide applicability for the achievement of better tour or travel management. People the world over nowadays just do not take holiday trip for rest and recreation. They like to educate and enlighten themselves. Mobile services appear to be an obvious choice for travel and tourism as the travellers are on the move. A tour and a tourist is a unique combination, therefore we have to provide information according to the local needs of the traveller. Providing context specific information containing maps is bandwidth intensive. With the advent of high-bandwidth networks with wide coverage such as 3G makes tour experience a better one. Some of the tour applications can be downloaded onto the device, while others use an information server which stores the data and provides it to the device when requested so that information can be dynamically adapted.

Growth of wireless technology

According to a research firm IDC, the global mobile phone market ballooned in the first quarter of this year growing 19.8 per cent year-over-year, mostly due to the meteoric rise of smart phone shipments, especially in emerging markets. According to the firm’s Worldwide Mobile Phone Tracker, vendors shipped 371.8 million units in Q1 of 2011 as compared to 310.5 million units in the first quarter of 2010. Newer models are being equipped with advanced features such as GPS, Wi-Fi or social networking which are greatly expanding their capabilities. In essence, the web itself is being reconfigured for mobiles. More challenging is the lack of standards within the mobile device industry which comprised of numerous handset makers, operating systems, carriers and networks. This definitely has an impact on how mobile technology supports the business traveller today, but as carriers invest in faster networks, mobile services will improve and will get increasingly user-friendly and secure.

Mobile GIS – providing spatial application to everyone

The technology of GIS has undergone rapid development over the past three decades and in the process has transformed itself from mainframe-based systems to internet-based distributed systems operating on a variety of hardware platforms. During this period, GIS applications have also changed from the static compilations of the specialist to applications supporting the everyday lives of everyone, everywhere, all the time.

Mobile GIS refers to the access and use of GIS data and functionality through mobile and wireless devices such as mobile laptop computers, tablet PCs, PDAs and Web-accessible smart phones. They differ from traditional GIS and Internet GIS in that they utilize wireless networks and small screen mobile devices. Mobile GIS applications development requires a complete rethink of existing GIS models, although they are essentially a ‘repackaging’ of Internet GIS for mobile devices, offering functionality similar to Internet GIS applications that utilise the thin client model (Peng & Tsou, 2003).

Given these needs, it is not surprising that the driving force behind the development of Mobile GIS has been the needs of people on the move. Mobile GIS has also enabled users with small screen mobile devices to access GIS applications and spatial information that was previously restricted to fixed desktop or workstation applications. The widespread use of mobile phones, especially smart phones, and the increasing use of PDAs for managing day to day activities has also led to the extension of Mobile GIS applications for consumers. Mobile tourists have different requirements from those of tourists searching the internet. They are often very busy/distracted - looking around, navigating etc. They want maps that are easy to read on the small screen with easily legible text and high colour contrast for outdoor use (Hjelm 2002). Mobile tourists want short, directed text and the ability to find out further information if they wish; simple interfaces and personalised information delivery; applications that work first time (‘out of the box’), every time and they must offer significant advantages over traditional printed tour guides and internet applications(Umlauft *et al*,2003).

Web and Travel intermediaries

Current web based applications mainly support the traveller in the planning or pre-tour phase with little support during the on-tour and post-tour phase of the tourist activity. It might seem strange that many Travel Management Companies or Travel intermediaries have not adopted mobile applications to a greater extent. Tourism is both a leading revenue generator worldwide and an umbrella industry that enhances regional, small to medium enterprises, cultural, sports and many other industry sectors. The touring life cycle can be segmented into three phases (Robert Barta *et al*, 2009). They are Pre-tour – data management, On-tour (during tour) – data delivery and Post-tour – data sharing or reminiscing. Pre-tour encompasses many internet enabled information sharing processes. Data management is the crucial information activity in this phase. This involves creation of registration, preference profile of user, search for point of interest, location and post registration services like reminder service, discount offers etc. On-tour phase spans the time when the tourist visits, wanders, stays and generally is at places of interest. This involves providing support while navigating and narration of places of interest. Dissemination of relevant data with reference to user context is of great of importance here.(Grün *et al*,2008). Post-tour takes in after tour experience and can involve sharing of information. This involves taking feedback and recreate experiences.

An attempt has been made to provide context relevant, customized to users on the move. This is the need of the hour, because there is a paradigm shift from package travellers to independent travellers. The characteristics of such travellers are that they never want to tie down to set itineraries and destinations, they want flexibility. Most of the travellers do not have much time to spend on planning a trip or time to waste during a trip. The nature of tourism is changing and such services are able to meet the needs of the new types of travellers.

The system can support not only the leisure traveller, but also the business traveller who is extremely time poor and needs to be able to navigate unfamiliar environments in a very timely fashion. While the needs of both types of travellers are different, Mobile GIS has the potential to improve the experiences of both. Most importantly, these services can improve the safety of all travellers by providing better access to safety information and emergency services. The ability to track/monitor the movements of consumers also provides a means for managers to better understand the tourists and their movements and improve services to meet user needs. It can also offer a superior means of minimizing the impact on the environment, and alerting managers of potential negative impacts or dangers. The ability to track travellers also enables faster response to emergency situations.

Applying context awareness to the mobile application could help in map reading and in addition, the navigation and the usability of the map may be improved. The topographic data set given by GIS providers alone will not satisfy the users' needs, especially without a legend and with the other limitations on map presentation. Therefore, the solution must include both topographic data sets and more enriched information, related to the user's surroundings. Context-aware applications must perform three tasks. Firstly, they must capture low-level contextual information from different sources, (for example, GPS coordinates or user preferences). Secondly they must identify what needs (driving, pedestrian or on beach) to be captured in order to create high-level contextual information which is more relevant to the application. For example, GPS coordinates can be transformed into a complete address and physical, temporal and semantic relationships can be deduced from the initial low-level context values. Finally, this interpreted information must be supplied to the application as depicted in Figure 1.

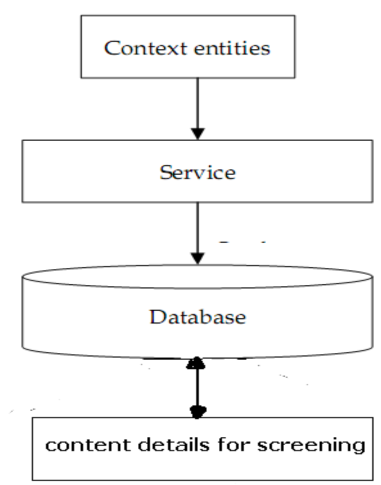


Figure 1 Context awareness tour management system

Users may access different data and exploit different aspects of an application. For example in one context, a traveller driving a car wants to get driving direction, application must give him optimum path to destination considering traffic congestion, while in a different context the same person may go on hiking , now the application must give him directions to scenic spots.

Mobile GIS and Travel Service Dissemination

Much tourism information is spatial with specific coordinates which lends itself to displaying map form. Application utilizes the user's geographic location to provide important information about services or points of interest. Therefore, we adopt a mobile GIS as a platform for integrating user preferences and the spatial characteristics of scenic spots to improve guiding services. Information services and guiding information for specific scenic spots at a tourist destination are a basic service provided by the administration. In this study, we utilize mobile GPS and GIS techniques to develop a useful tour guiding system designed to meet tourist demands. The objective of this study is to provide a solution which integrates GPS and GIS technologies for a tour management system. The aim is to provide tourists with real-time temporal and spatial guiding information for scenic spots and routine navigating. The tour guiding system has navigation functions, interpretative information, digital maps and optional guided route selections for tourists.

Figure 2 shows architecture for enhancing tour experience through an web portal of tour intermediary or tour operator. GIS can be used as a multi-media tool for displaying and guiding spatio-temporal relationships between scenic spots. GPS can be used to locate outdoor locations and provides simple spatial information to individuals. The GPS receivers can be used to collect time, local coordinates and speed at regular sampling periods. Due to the lack of real-time tour guiding systems, we adopt GIS techniques with GPS functions to develop a location-based mobile tour guiding system that must be able to represent and interpret scenic spots. Both vector and raster data models are used in the location-based tour guiding system to give a complete presentation of location information. This scheme relies on a GIS database and GPS signals to provide attribute, spatial and temporal data to tourists. The contents of the guiding information (attributes, spatial and temporal data for time and location) change as the tourists move. GPS signals provide real-time continuous location information. GIS techniques are used to integrate the map database and multi-media interpretative information spatially.

The major architectural components include:

- A thin client terminal hosting a downloadable application. The client terminals periodically send location updates to the network.
- An application server runs at tour mediary's portal that delivers Web content prioritized according to user preferences. The application server formats the generated information content and adapts it for display on the client terminal.

- A context and profile manager at server side tracks the user's dynamic context as well as static preferences (such as favoured cuisine) in a user profile.

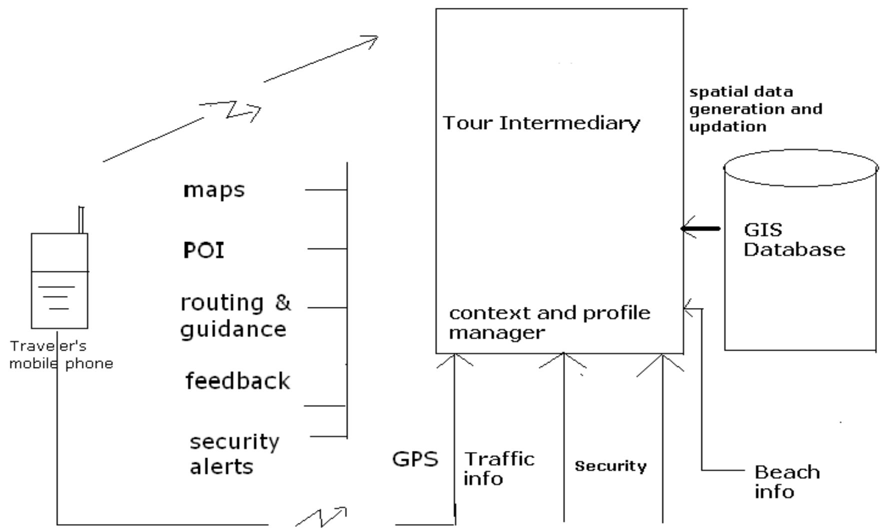


Figure 2 Architecture for tour management system

The way context and profile manager evaluates a context is shown Figure 3. For a mobile application, several aspects of context can be considered such as the characteristics of the particular mobile device (storage and screen size) and network (bandwidth), context of the application (requirements in storage, download and display capability), context of the user of the system (eg. time, location, interests), context of information objects (eg. location). The handling of the concept data depends on the intended usage. For tourism applications, user context can be static or fluent. Static context is relatively stable, eg. user interests, personal background etc. It can have different versions that may be captured in user roles (user as private traveller or in business context). Fluent context typically changes continually, eg. time, location, and direction of a particular user. Sight context can be distinguished in being general and relatively fixed (eg.location, opening hours) or current and pertinent to this user. Current sight context is derived from the interaction of user context (time and weather) and sight context, eg. sight popularity combined with the user's own interests.

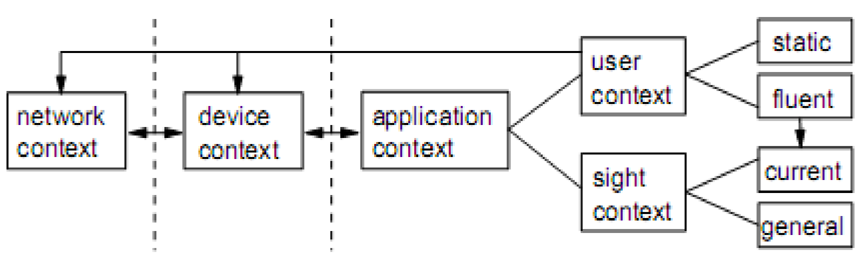


Figure 3 Factors that influence context evaluation

Implementing application

Mobile devices which suffer from less CPU power and memory should act as a thin client, *ie.* all application logic resides on the server-side and the client just renders the presentation through a browser. In this case, however, a permanent network connection is required which might be problematic due to well-known problems such as loss of network connection or limited bandwidth. In contrast to that, a thick client is capable of processing content data and composing a presentation on the client side calling for appropriate computational power. When catching technologies are applied, a thick client can overcome the before mentioned network limitations. Application developed does a balance, considerable work is done at client side. Prospective tourists have to download application on to their personal cell phones with a GPS function. The hand-held mobile device on which the tour guiding system is to be installed must be equipped with a GPS receiver. It has four modules,

a. User Interface module which runs on the user's hand-held mobile device and provides the user with an interface to the tour management system. He registers and provides information regarding his purpose of trip whether it is leisure, pilgrimage or adventure and his interests and preferences are stored. Context-awareness can help improve user interaction by knowing *apriori* the user's situation, personal preferences, information interests and environment conditions so that the user doesn't have to specify these constraints and information delivery is automatically adapted to his circumstances. Users want to receive information about resources that match their personal tastes such as nearby restaurants (vegetarian or non vegetarian) that offer their preferred cuisine.

b. GPS interface module which runs at server receives GPS signals and obtains the tourist's real-time position.

c. Route interface module at server provides guided routes of a tourist area. This is dynamic as it considers real time traffic situation before providing route information.

d. Query interface accepts queries from the user and returns information regarding scenic spots in different formats (pictures and text for maps, audio and text for narrations) based on the result of the query. The tourist can use the querying interface to select the scenic spot of interest as shown in Figure 4. The screen-shot shows the types of multimedia guiding methods for him to choose from.The tool tip to select the place of interest is arrow. If he clicks on arrow on the selected scenic spot on the screen of the guiding system, then click on the tab for Pictures, Audio, Information or Video to acquire detailed interpretative contents on the selected scenic spot. The displayed map is refreshed automatically either as soon as the user performs an explicit map action, eg. panning or periodically to reflect the movement of the user. The user is able to adjust the refreshing period to his speed of movement.

Figure 4 shows the screenshots of the tour management system. The application has four tabs which provide pictures (maps), narration (audio), information (textual) and video of the places of interest.

Figure 4 Sample Screenshots of the application

Congestion in the road ahead would be informed to tourists. The system will also remind tourists when they approach within 500 m of the red warning boundary for dangerous areas like wildlife sanctuaries and dangerous spots in beaches thus minimizing accidents. Furthermore, after a tourist chooses a planned guiding route, the system judges whether the tourist is on the right route or not. The system offers an immediate warning when tourists deviate from the scheduled route. Alerts can be sent almost instantly to the traveller's phone by text message or email, advising on a disruptive event or potential crisis that might impact them. By contacting security alert services, travel managers can ensure their travellers can be contacted on a 24/7 basis. Table 1 lists the features provided in the application.

Feature	Example
Routing	Best route under normal conditions, penultimate choice in case of traffic congestion
Navigation	Driving, hiking, beach tourism and pedestrian directions
Tour-guide	A pre-defined tour
Concierge services	Where is the nearest vegetarian restaurant?
Travel reminiscence	Comment on the visit. Provide mashup site where anyone can create and share routes for hiking or cycling and beach vacations
Travel recommendations	Endorsement of others on particular itinerary
Emergency response	Call for assistance when car breaks down
Safety alerts	Preventing accidents at beaches and wildlife sanctuaries
Security alerts	Warning about unforeseen circumstances like riots
Marketing	Receive information on special tour offers
Tracking	Tracking the location of a tourist along a beach

Table 1 Features provided in the application.

Finally beach tourists will be provided with information like UVrays, tides, temperature, sunset, sunrise and moon phases.

Conclusions

The paper presents a framework for mobile tour management particularly focused on user context. It supports a wide-range of different functionality. Context-awareness is given focus wherein interaction between users and applications is enhanced by the perception of the surrounding environment. Application provides map based user-friendly information on navigation. The displayed map is refreshed automatically as soon as the user performs an explicit map action like panning or zooming. Mobile GIS based tour management system with inherent technical challenges due to mobility and network vulnerabilities would immensely enhance the experience of the traveller.

References

Grün, C., Pröll, B., Retschitzegger, W., Schwinger, W., Werthner, H.(2008) Assisting Tourists on the Move - An Evaluation of Mobile Tourist Guides. Mobile Business, 2008, ICMB 7th International Conference, July 2008.

Hjelm, J. (2002) Creating Location Services for the Wireless Web: Professional Developer's Guide. New York: Wiley ,p 247

Peng, Z. and Tsou, M. (2003) Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks. New York: Wiley.

Robert Barta, Christina Feilmayr and Christoph Grun (2009) Covering the Semantic Space of Tourism- An Approach based Modularized Ontologies, Proceedings of the 1st Workshop on Context, Information and Ontologies, June 1, 2009, Heraklion, Greece.

Umlauft, M., Pospischil, G., Niklfeld, G. and Michlmayr, E. (2003) LOL@, a Mobile Tourist Guide for UMTS, *In*: H. Werthner and E.Veit (Eds). Information Technology & Tourism, Congnizant, USA.

Web Based GIS for Tourism in Mysore and adjoining Mandya District

Khadijahtul Kubra Asra[1], B. P. Lakshmikantha[1] and N. L. Rajesh[2]

[1]*Karnataka State Remote Sensing Applications Centre, Bangalore, Karnataka*
[2]*Dept. of SS and AC, Agricultural College, UAS, Raichur, Karnataka*
E-mail: laxmikantha_bp@rediffmail.com

Abstract

Tourists need well-organized information on their fingertips, anywhere and anytime, to orient themselves in a place that is entirely new for them. The potential of GIS in resolving complex issues of tourism is increasingly acknowledged. Moreover, GIS allows policy makers to easily visualize the problems in relation to the existing trends and thereby enable policy makers to more effectively target the resources. The present study on "Web Based GIS for Tourism in Mysore and adjoining Mandya district" deals with developing a GIS based tourism application and displaying it on web, which is enabled with modules for query and analysis. It is developed with the state-of-the-art mapping server technology. It provides the users with an innovative way to access the spatial and non-spatial information on the history and heritage of Mysore city. It will also provide the basic information on the city which is required by a tourist. This includes the location of various religious places, hotels, hospitals, banks, police stations, petrol bunks, theatres *etc.* In addition, the important tourist places of adjacent Mandya district were also mapped and loaded in the application, which would enable the tourists visiting the nearest tourist places of Mandya district from Mysore city in the available time frame.

Introduction

Tourism is an important industry for any healthy economy providing a steady inflow of money to local business. Segments such as hotels, tour operators, airlines, shipping etc., are significant contributors to this revenue. Indian tourism industry is the second highest foreign exchange earner for the country. In terms of visitor numbers, India is eleventh among Asia Pacific countries. Karnataka is ranked as fourth most popular destination for tourism among the states of India. With its 507 out of the 3600 centrally protected monuments, Karnataka has the second highest number of protected monuments in India next to Uttar Pradesh. The cultural capital of Karnataka is Mysore which has a number of historical and heritage buildings. The royal city of Mysore is well renowned for *Dasara* festival and is a favoured tourism destination throughout India.

Paper maps which are usually provided have many limitations such as limited amount of details, difficulty in locating one's own position on the map or difficulty in searching for a place of interest. In recent years, there has been a huge development in information technology. GIS technology can provide robust tools with wide applicability for tourism development. The present study on "Web based GIS for Tourism in Mysore and adjoining Mandya District" aims at providing a GIS based application which enables the user to view a high resolution QuickBird satellite image of Mysore city, overlaid with the city-road layer enabling tourists to orient themselves to the place. It also provides search functions to locate various places of interest. It provides tools to zoom in, zoom out and pan the map. It aims at providing spatial and non-spatial information on tourist places not only in Mysore city but also the neighbouring Mandya district. The application is also useful in providing information of services which include hotels, banks, hospitals, petrol bunks, temples, mosques, churches etc.

Study Area

The area chosen for the present study is Mysore city. It was the former Capital of the State of Karnataka before it was shifted to Bangalore. It is now the headquarters of Mysore district with a population of over seven lakhs. Mysore district is located between latitudes 11°45' to 12°40' N and longitudes 75°57' to 77°15' E (Fig.1). It is bounded by Mandya district to the northeast, Chamrajanagar district to the southeast, Kerala state to the south, Kodagu district to the west, and Hassan district to the north. It has an average altitude of 770 m and is situated in the southern region of the state of Karnataka, at the base of the Chamundi Hills and spreads across an area of 128.42 km². Mysore has several lakes, prominent among them are the Kukkarahalli, Karanji and Lingambudhi lakes. Mysore is situated between the rivers Cauvery and Kabini which are a source of drinking water to the city. The summer season is from March to June followed by the monsoon season from July to November and the winter season from December to February. The average annual rainfall is 798.2 mm.

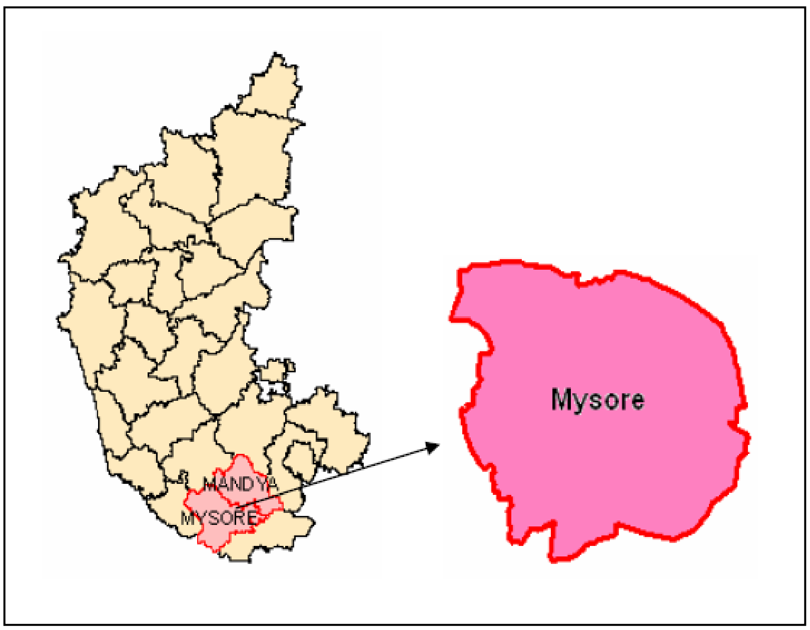


Figure 1.Location map of Mysore and Mandya districts

Materials and Methods

High resolution Quick Bird multi-spectral satellite image (spatial resolution of 61 cm) was used to interpret and generate maps of various spatial features. Field survey was carried out for collecting pictures and attribute information of various features which includes places of interest, places of worship, hotels, area names, banks, hospitals, petrol bunk, police station, post office and cinema theatres. The information on various heritage buildings and tourist places in Mysore and Mandya districts were collected from the Department of Tourism, Govt. of Karnataka. For map generation Erdas imagine 9.2 and ArcGIS 9.2 were used. For Interface Generation (web based interface), Net (Asp.Net) was used. A systematic procedure was followed for generating various thematic map layers. The satellite image (Quick bird, 2005) procured was loaded to the computer system and then the image was processed using ERDAS Imagine software. Image geometric correction was done using ortho-rectification method. Prior to the ortho-rectification, the reference points were collected using DGPS survey in Mysore city and adjacent Mandya district. Geo-referencing of satellite image allows it to be viewed, queried and analyzed with other geographic data having similar projection system. After geo-referencing the image, each pixel has a real-world coordinate value assigned to it.

Visual image interpretation of satellite image was done using image interpretation elements. It was examined to identify the objects and to judge their significance. In this process, a map layer was generated having prominent visible tourist's spots on the satellite imagery as well as maps of different utilities. Ground truth survey was carried out to update the interpreted objects / features. Interpretation was carried out based on the prior knowledge of their locations and also associated buildings, sometimes the colour and shape were also helpful. Some of the examples are the Karanji Lake, Crawford Hall, Deputy Commissioner's Office *etc.* were recognized based on its size and shape.

The geo-rectified Quick Bird satellite imagery was opened in ArcGIS Desktop 9.2. The GIS layers generated in shape file format (*.shp*) is given in Table 1. These GIS layers were mapped using ArcGIS suite applications. ArcCatalog was used for creating new shapefiles, managing the spatial data assets and viewing the metadata, where as the ArcMap was used for the editing purpose. The non-spatial data collected from field survey were attributed to the respective spatial features using a common ID field in GIS environment.

Table 1. GIS Layers is in shapefile.

1. **Mysore City**

a) Polygon data	Mysore district boundary, City boundary
b) Line data	City roads
c) Point data	
Places of Interest	Tourist Spots

	• Heritage Buildings • Recreational parks Places of worship • Temple • Mosque • Church • Jain Mandir • Hindu Temples • Ashrama • Hotels • Economy • Luxury • Budget • Others (unranked) • Banks • Hospitals • Petrol bunk • Police Station • Post Office • Cinema Theatre

2. Mandya District

a) Polygon data	District boundary
b) Line Data	Major Roads
c) Point data	Places of interest: Similar class of point layers as that of Mysore city were generated for adjacent Mandya district.

Web Application Development

ArcGIS server 9.2 was used to serve the map to the Web server via application logic. These maps were displayed on the web application developed using API (Application Programme Interface). The project coding was carried out using Application logic. The application was written in Asp.Net coding using web forms in order to create a web based application. Web pages giving information on all the tourist spots, heritage buildings, hotels, modes of transport etc were created using Asp.Net. Different steps involved in developing Web Application are given in Fig.2. Web server was created to provide a specific kind of services to client software running on other computers. The server was enabled to manage and share web based applications accessible anytime from any computer connected to the internet.

Microsoft Internet explorer is used which provides graphical interface that lets users click buttons, icon and menu options to view and navigate web pages.

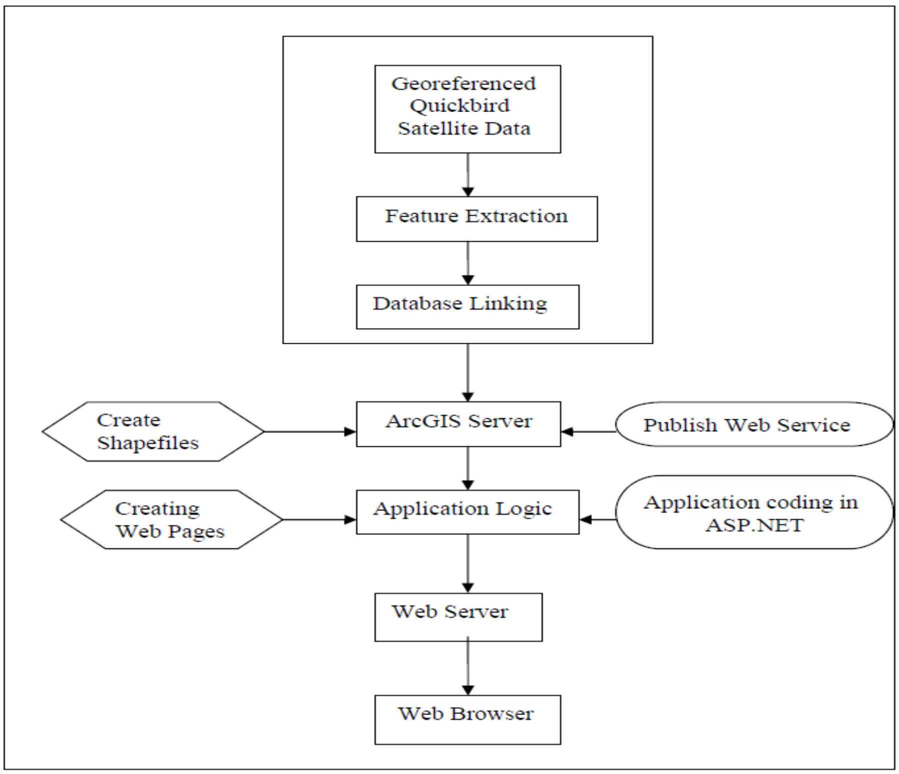


Figure 2 .Steps followed in developing web application

The details of interface development used for the web application are given below.

The 3-tier architecture (Fig.3) concept is followed for the development of the Web based Internet application. The architectural components are,

Back end Tier

This tier is not visible to the end user and it is the place where the data i.e. both the map data and its attributes are stored. The map is stored as an .mxd file in GIS platform. The features extracted from the satellite data in ArcMap are stored as Shapefiles.

Application Business Tier

The application is coded in Asp.Net code and appropriate data is extracted from the back end and is presented to front end interface in such a way that it can display required data to the user. The user requirement specification includes functional requirements like the find tools searching and locating every feature of the map. The control tool bar menu requirements consists of ‘Zoom’, ‘Pan’, ‘Full-extent’ and ‘Select’ functions.

The Front end Tier

This is the interface where the data from the application layer is converted to give a visual interface; mostly it is a web browser. It is here that the user is able to use the application and derive results.

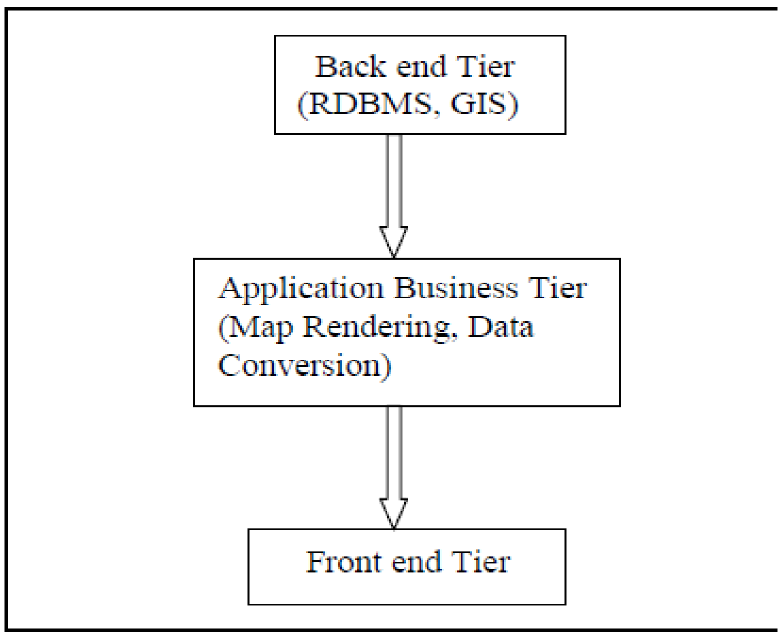


Figure 3. Software Application Architecture

User Interface

The user interface (Fig.4) is developed to provide the means of:

- Input, allowing the users to manipulate the system
- Output, allowing the system to produce the effects of the users' manipulation.

The interface developed for providing tourism information is user friendly and will enable the user to understand and use the tools easily.

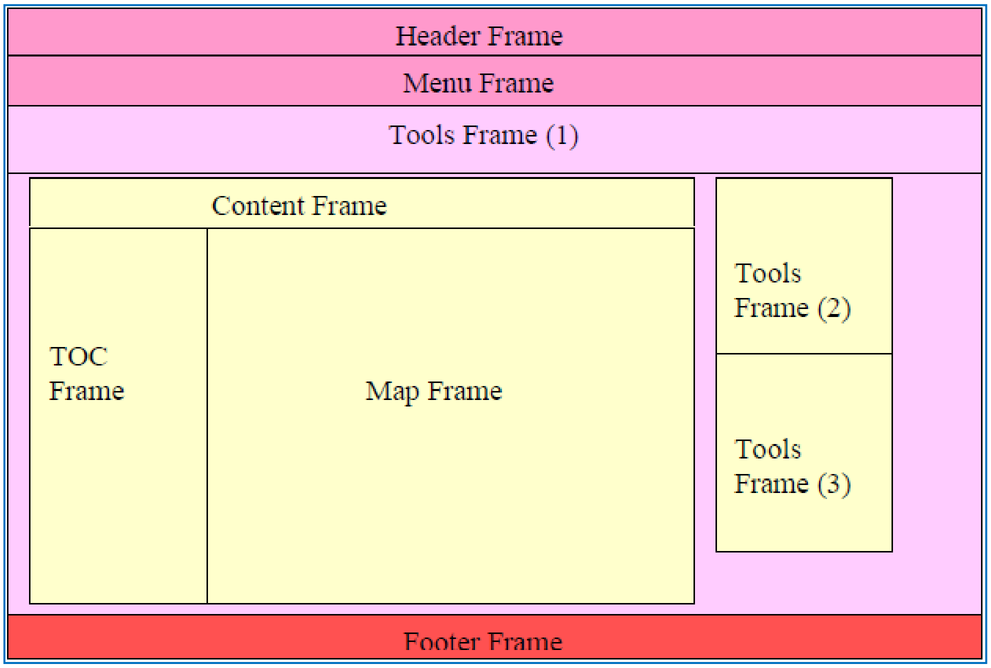


Figure 4. Layout view of the user interface

Results and Discussion

The study resulted in providing information about Mysore tourism, which is not confined only to tourist spots and the heritage sites of Mysore, but also includes the basic information required by a tourist such as roads, hotels, hospitals, banks, cinema theatres, post office, police stations etc. This will help a tourist to locate tourist places along with the utility services.

In the present study, Web application is developed by using ArcGIS Server 9.2 and Microsoft Visual Studio .NET 2005. This application provides the user with different functionalities like map tools, search functions, map navigation tool, overview map *etc.* These functionalities will enable the user to view all the layers and to use the map tools that are present using the basic control tool bar functionalities such as zoom-in, zoom-out, pan and full extent. The details of the advance map tools developed are discussed below.

"Search" function

On clicking the 'SEARCH' button the user is able to view a search page, which allows the user to choose the fields to query. The fields can either be only tourist places or query to find the location of hotels or to locate other services like hospitals, petrol bunks, banks etc. Apart from the given search option, the user can also choose to "view the map" of Mysore city and utility services.

Functionalities of the interface

The various functionalities that are provided to the users are given in Table 2 and the same is depicted in Figure 5 as screen shot of the application at runtime;

Table 2 Functionalities of the Interface

1	Navigation
2	Query Attribute Task and Result
3	Scale bar
4	Overview Map
5	Table of Content
6	Tool bar
7	Map Control

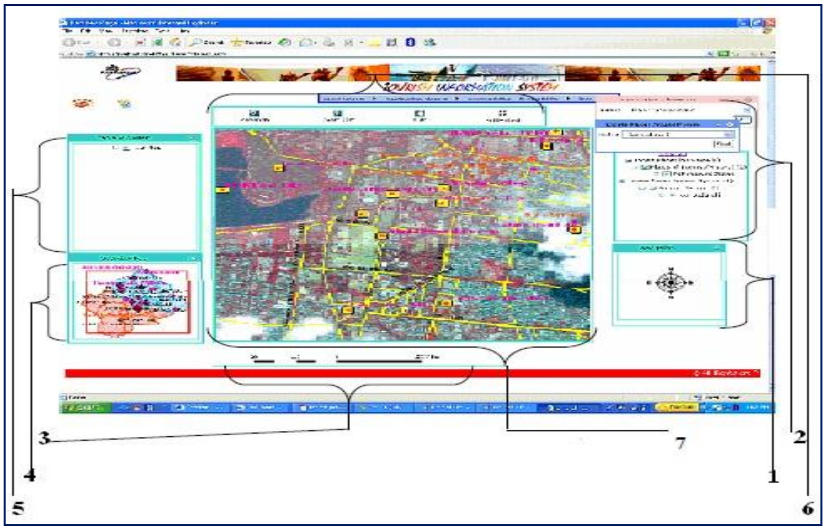


Figure 5 Screen-shot of application at runtime

The 'Query Attribute Task' allows the user to select the desired place from the dropdown list and find its location on the map. The user can highlight the selected place by selecting the checkbox from the displayed in task result through query which will enable the user to zoom in to the selected place on the map. Map tips enable the user to get direct information of the place by clicking on the yellow button on each tourist place. It displays the name of the place and concise information about the place.

The tourism industry is notably information dependent and needs new ways to deal with its vitality and scale. The integration of multiple technologies including remote sensing, GIS, tourism information systems and Internet has given an exciting new access to tourism information. In Karnataka, no earlier attempt has been made to develop a Web based GIS for Tourism in Mysore and adjoining Mandya District. The findings of the present study with previous works are discussed here.

Ravi *et al.* (2001) developed a Multimedia-based City Information System (MmCIS) for Hyderabad. The system provides a variety of information about the city, its history, and its citizen services through the friendly medium of interactive multimedia. Multimedia, with its human-oriented interfaces such as text, pictures, video and sound is the ideal medium of delivery to a large cross section of users. The present study not only provides information about the history and culture of Mysore, but also provides spatial information and pictures of tourist spots and heritage buildings in and around the city. It also provides information on location of hotels, hospitals, banks, petrol bunks, post offices and theatres.

Duran *et al*. (2004) developed a web based Information system for tourism resorts; it allows the users to perform a geographic search for tourism objects. It allows the integration of GIS data and tourism data on Web so that the data can be shared by more number of people. The present study is also web based and allows any user to search for tourism objects in and around Mysore. The application also enables the user to view a high resolution Quick Bird satellite image of Mysore which helps the user visualize most of the ground features.

Longmatey *et al*. (2004) discusses the application of GIS and multimedia tools for archiving, analyzing and displaying of tourism information for the efficient management and promotion of the tourism industry in Ghana. With the application of GIS, it was possible to answer spatial queries and view images, text, tables, diagrams and it also enabled showing the shortest path, location of hotels, tourist sites, price quotations and so forth. The present study enables the user to obtain spatial information of not only tourist objects but also important services required like hospitals, banks, petrol bunks etc.

Conclusions

The study represents a future where GIS can be used day - in - day out for various purposes including Tourism. The web based information provided in this study will help to attract more tourists by providing user friendly interactive information system and to take necessary steps to strengthen the existing facilities for tourists. In future, the necessary adaptations can be made for the application developed concerning the user interface and its usability. The application can be extended for the entire state of Karnataka providing path cover of all the heritage places along with route finding services and additional information with features like supermarkets, shopping malls etc. can also be included.

References

Duran, E., Zeker D. and Shrestha, M. (2004). Web Based Information system for Tourism Resorts; A case study for Side, XXth ISPRS Congress, P 90 ff, Vol.- XXXV-B8, July 2004.

Longmatey, D., Amoako-Atta, S. and Benjamin, K. P. (2004). Management and Promotion of Tourism in Ghana: A GIS Approach, ESRI User Conference, 2004.

Ravi, K. K., Narayanan, P. J. and Jawahar, C.V. (2001). A Multimedia-based City Information System, IETE Technical Review , Vol. 18, No. 4, Jan, 2001, pp. 333-336.

Mapping the Ancient Fort of Chitradurga using GIS

N.S.Nalini and M.B.Rajani

National Institute of Advanced Studies, Indian Institute of Science Campus, Bangalore-560012
E-mail: arnalinins@gmail.com

Abstract

Chitradurga is well known for its seven tiered fort and is referred to as 'Ukkina kote' (steel fort) in Kannada literature. The town is about 200kms away from Bangalore and is the head quarters of Chitradurga district. These structures date back to 16^{th} century AD and encompass several temples and monuments. The maps of 18^{th} century AD provide lot of information about these archaeological sites. This paper discusses about the integration of information from various sources and demonstrates the analytical power of GIS in archaeological studies, and effectiveness of 3D visualization for hilly terrains.

Introduction

Chitradurga district extends from 13˚34' - 15˚ 02' latitude and 75˚ 37' - 77˚ 01' longitude and is in the state of Karnataka in southern India. Entire district is in the valley of river *Vedavathi*. The rocky hill range stretches in southeast to northwest direction, consisting of rocky surfaces that are not covered by soil or vegetation. The altitude of the area is 2383feet from mean sea level. *Jogi maradi* is the highest point in the entire hill range with a height of 3863feet. Chitradurga was called by several names during the rule of different rulers like *Hidimbapattana*, *Chinmuladri*, *Bemmettana kallu*, *Soolagal*, *Perumalepura*, *Chitrakaldurga Mallarayana durga* . Tippu named it *Farukhabad*. Chitradurga Fort was built in parts by the *Palegar Nayakas*, Hyder Ali and Tipu Sultan, between 10th-18th centuries AD. It comprises a series of seven enclosure in the fort. This seemingly impregnable fort has 19 gateways, 38 posterior entrances, a palace, a mosque, granaries, oil pits, 35 secret entrances, four secret tunnels and water tanks. The rulers of this fort built 2000 watch towers to guard and have a clear look at any potential intruders. There are many temples in the fort. Among them Hidimbeshwara, Ekanatheshwari, Sampige Siddeshwara, Gopalakrishna, Phalguneshwara are important ones. The fort has a total area of 300acres and a length of 8 kms (Nayak, H.M. (ed.) 1974).

Objectives

The main objective of this investigation is to analyze the extent of encroachment and destruction of heritage site due to modern development and urbanization and to develop 3D perspective views of the landscape to distinguish the temporal changes in the landscapes.

Materials and Methodology

Geographical Information System (GIS) is a technology which allows integration of information from variety of sources. Thus, information collected from old maps, old paintings, satellite images, ground truth through GPS and Google earth images help us in the simulation of ruined archaeological sites like Chitradurga using GIS.

The information from spatial and nonspatial sources, such as old maps, old paintings, historical texts along with satellite images are useful and ground truth through GIS to ascertain the changes in the landscape. Spatial data are obtained from Google earth images and Survey of India toposheets. Old surveyed map of Chitradurga: Plan of Principle Points Batteries and Works on Chitel-Droog, surveyed in June 1800 and, two old paintings: North view of Chiteldroog by Lt. Rowley Engineer in 1803 and View of Chiteldroog from the east, 1801 which are available in British library web site are used.

The area of interest was marked in Google earth. The zoom was adjusted to get clear view of the temples and monuments. Number of scenes covering the area was extracted. The scenes were mosaiced in Photoshop and georeferenced with Google earth coordinates using Erdas Imagine 9.2 software. The old map was downloaded as a high resolution image to get good clarity and it was georeferenced. All the layers of the fort walls along with the monuments, water bodies, moats, pathways and roads were digitized using Geomatica software.

Results and Discussions

The fort is known as 'Elu suttina kote' which means seven tiered fort and only five tiers standing now. The first two tiers are almost completely ruined or non-existent. Only the entrance gates of these tiers are standing in a fairly good condition. A surveyed map of 1800 AD was downloaded from the British library web site along with two paintings of 1801AD and 1803AD. The temples and the monuments, though in ruins, show marvellous architectural details of Vijayanagara period. It is very important to preserve these heritage sites as one can see very clearly encroachment by settlements almost from all directions. The old map of 1800 AD (Figure 1), prepared by British surveyors, shows all the tiers of the fort with remarkable clarity. Apart from the well known seven tiers of the fort, one more tier, a mud fort wall, outside the first one can be noticed. The existence of this wall is perhaps not documented anywhere in the literature. This wall starts from the northeast corner of the first tier and runs to a short distance in the northerly direction. Then turns west, which is a long stretch and ends with a small hillock comprised of huge boulders. Google image does not show any traces of this wall. But fig-1 gives us an idea about the original total extent of Chitradurga fort. The map Legend says that this mud-wall enclosure of the petta is entirely uninhabited since the war of 1791-1792. The settlements within the fort, doddapete and chikkapete that are mentioned in the literature and not visible now can be easily identified in this map. Fort walls were digitized as different layers using GIS tools. These layers were then overlaid on the Google earth image and found that their locations are displaced by few meters. This could be due to differences in the map projections. Scales of the two images were also different which added to the displacement.

Figure 1: Old map with digitized layers

All the monuments marked in the maps were also digitized. There are only few monuments shown in the map compared to the number that exists in the fort. The pathways that were used to enter the fort and the roads are clearly marked in the map which gives a good comparison with the present modifications in the layout. On the contrary, one would see more details of the fort in the google earth than in the old map. For instance there are more number of bastions in the southern part of the fort seen in google earth image than what is shown in the old map. The reason for this could be that this part of the hill is very steep and has highest elevation. Legend of the old map also mentions that this is the highest point or rock. The rugged terrain might have made surveying very challenging for the British. Using satellite images for mapping such terrains may be more beneficial.

Digital Elevation Model (DEM) is a 3D perspective generated using Erdas software to visualize any region in 3 dimensions. It is particularly useful for viewing a hilly and rugged terrain. DEM can be generated using contours of Survey of India map or using stereo pairs of the satellite image. Different methods of DEM generation are discussed by Rajani [2008]; Parmegiani and Poscolieri [2003]. In the present study the 20m interval contours has been digitized to generate DEM. A virtual fly through was generated by overlaying the georeferenced image on DEM. This can be viewed as a three dimensional image in the virtual GIS window of Erdas Imagine software. A fly through was run by digitizing the flight path and adjusting the parameters like look azimuth, look pitch, AGL (Above Ground Level), ASL (Above sea Level), roll, speed and FOV(Field Of View). There are two old paintings of the fort, as viewed from the eastern and northern directions. Fly through was adjusted to match the views (Figure 2) of the old paintings and thereby comparing the change in the landscape.

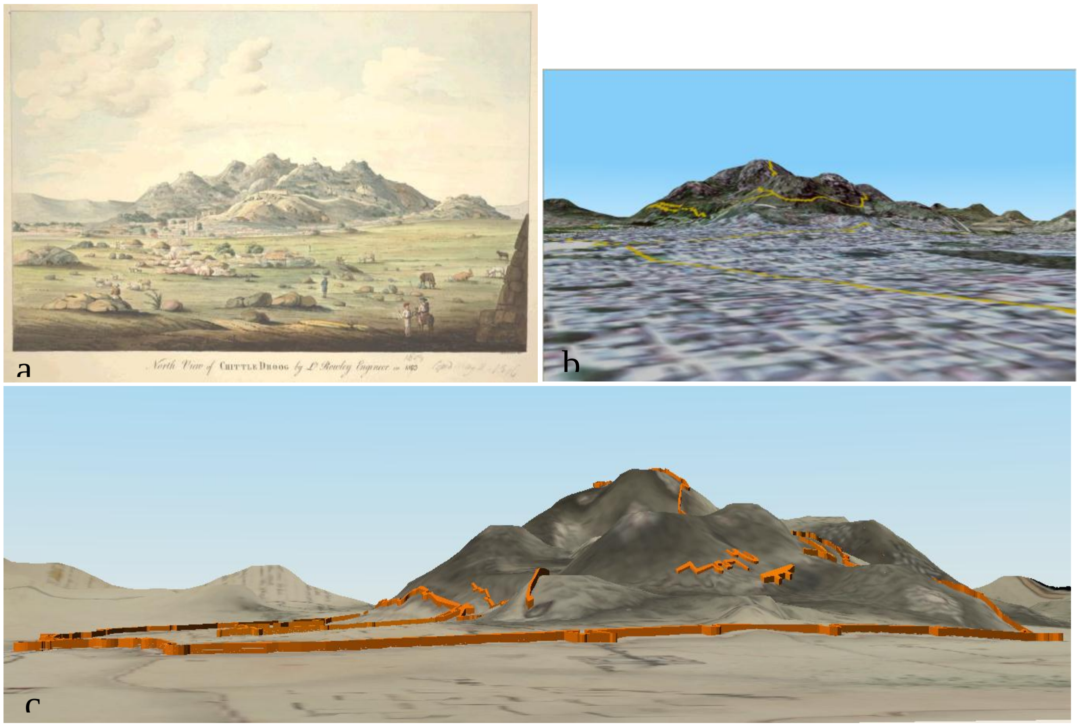


Figure 2: a) an old painting "North view of Chiteldroog by Lt. Rowley Engineer in 1803" (b) simulation of the view of the old painting using DEM and google image, (c) simulating the view of old painting by draping old map [1] on DEM

Conclusions

Many heritage sites in India are getting destroyed due to urbanization. The new technologies like GIS and remote sensing make it possible to restore the dilapidated archaeological sites like Chitradurga with the help of old maps and old paintings. The study enabled to visualize the entire fort as it was built with all the monuments. The digitized layers of the monuments were overlaid on the DEM to see the location of the monuments with respect to the elevation of the hill. It is very interesting to see all the important structures like palace, temples and the storage houses that are located on top of the hill and protected by the fort walls, whereas the town is situated at the foot hill. The palace is so strategically located that it is protected on all the sides by well guarded bastions. Also it is very interesting to see how they harvested the rain water to overcome the shortage of drinking water on top of the hill. A huge pond, Gopalakrishna honda, in the central portion where the water gets collected from the sloping sides of the hill, was constructed. The water overflowed from this pond to Akka–Tangi honda at the lower level, then to Seenirina honda which is outside the fort forming part of the moat. From the views that were generated using fly through, it was easier to gauge the urban encroachment of the heritage site. Virtual fly through is generally used to study landscapes and it is particularly useful to hilly terrains. Two layers of fort wall have been completely destroyed with out any traces of its existence.

Acknowledgement

I thank Director, NIAS for his support and guidance to carry out this research work. I also thank Dr Rajani for her invaluable guidance and support for this work.

References

Mohan, Madan., (2004). 'Historical Information System for surveying Monuments and Spatial Data Modelling for Conservation of Cultural Heritage in Delhi'. Proceedings of workshop on Archaeological Surveys, Athens, Greece.

Nayak, H.M. (ed.) (1974). Kannada Vishwakosa (in Kannda), ,Institute of Kannada Studies, University of Mysore, Mysore, India. Vol.7, pp 401.

Parmegiani, N. and Poscolieri, M. (2003). 'DEM data processing landscape archaeology analysis (Lake Saven- Armenia)'. The international Archives of Photogrammetry, Remote sensing and Spatial Information Sciences.

Rajani, M.B., Patra, S.K. and Verma, M. (2008). 3D perspective views and their applications to Archaeology: A case study on the site of Badami. in Lasaponara, R. and Masini, N. (eds) Proceedings of Workshop on Advances in Remote Sensing for Archaeology and Cultural Heritage Management, Rome.

Takase, Y., Yano, K., Kawahara, N., Koga, S., Nakaya, T., Kawasumi, T., Isoda, I., Inoue, M., Kawahara, D., Iwakiri, S., (2004). 'Reconstruction and visualization of Virtual Time-Space of Kyoto' A 4D-GIS of the city'. XXth ISPRS Congress proceedings, Commission 5, Vol XXXV, Part B5, p 609ff.

The Significance of Automatic Weather Stations at Historic Monuments and Approach to Append Archaeological Conservation

K.S. Rana, Shilpa Raturi and M.P. Sujith

Archaeological Survey of India, Dehradun-248001, Uttarakhand, India
E-mail: dirsci.asi@gmail.com

Abstract

The atmosphere weather conditions and its deviation from ideal situations are known to be detrimental for historic monuments' preserved status. The utility of Automatic Weather Stations to reckon the extrinsic environmental factors and detection of its periodicity, assumes much significance. In the case of Heritage Sites, keen observation of measurements of temperature, humidity, wind speed, wind direction and rainfall for the different seasons imply valid information that add much technical know how to formulate measures to tackle the conservation problems. With the installation of AWS in the world heritage Monuments in India and its utility for measurement of macro and microclimatic data enables in formulation of appropriate conservation measures. The data of automatic weather stations are being studied and found to be rewarding, in conservation policy making.

The increasing industrial activities for development purposes viz. mining, installations of thermal power projects etc. in close proximity with the heritage monuments also compels the air pollution impacts assessment and defining the permissible levels of air pollution. The repercussions of the sand laden wind originating from river bed and open mining areas have become a potential threat to the heritage buildings in India in the form of wind erosion. A close monitoring is envisaged by Archaeological Survey of India in this regard. The installation of AWS at the heritage monuments of India ISRO has helped us to compile of the weather data. We look forward for better collaboration with other scientific and space in this regard.

Introduction

India is enriched with a vast cultural heritage which encompasses tangible as well as intangible cultural heritage. The tangible heritage includes the earliest rock cut arts, at Bhimbetka graduating into expansive built up heritage of varied compositional materials. The inorganic and organic characteristic of the building materials be it mud, bricks, stones, wood, metal, paintings on a range of substrate viz. mud, plaster, rocks, stone surfaces are constantly exposed to the changes in their micro as well as macro climate. The dynamic relationship between the environmental parameters, and the cultural heritage substrates is a continuous interaction which may or may not affect the preservation state of the monuments. The optimum conditions for existence of the substrates in stable condition are dependent upon the ambient air qualities and micro climate parameters viz. temperature, humidity etc. The awareness towards the study of impact of air pollutions on human life form has also percolated to the study of state of deterioration of monuments world over and the need to assess the air pollutants impact on it state of preservation.

Further the ever increasing industrialization and growth of our country has led to situations where the industries are being set up in close vicinity of the monuments. The Ambient Air Quality Impact of these establishments is essential to be monitored on a regular basis, where the role of Automatic Weather Station is useful in identification, prediction and evolution of critical variable and also identify the potential changes of Air Quality as a result of industrial activity. This paper is an attempt to emphasis the significance of installing Automatic Weather Stations and utilizing these effectively to assess the impact of air pollution and develop an proactive approach to append Archaeological Conservation.

Functional Environment and Air Pollutants Cumulative Impact

The Atmospheric weather conditions and their deviations from ideal condition, are major concerns for the performance of the materials which constitute the heritage monuments, sites, the museum exhibits as well as the excavated sites. The functional environment of a particular object is not necessarily the same as that of the area in which the object is found. The interaction of air pollutants with the building components is not only dependent on the nature of the material surface and the air pollutants present but also the prevailing physical parameters. Hence the micro meteorology, physical parameters such as wind direction, wind speed, temperature, relative humidity and rain fall are needed to be essentially monitored. Also the Air Quality monitoring of parameters viz. suspended particulate matter, respirable particulate matter, Sulphur Dioxide (SO_2) and Oxides of Nitrogen (NO_x) needs to be simultaneously monitored. As the air borne pollutants both chemicals and particulate matter do not significantly interact with the substrate materials in dry state. The presence of optimum moisture and temperature conditions are essential for the deterioration or corrosion process to be initiated and continued. This presence of humid conditions may affect the substrate either directly or indirectly based upon changes in physical chemical state of substrate along with the creation of conducive conditions for growth of biological agents. The physical phenomena’s that may result in adverse effects are surface tension variations, dissolutions, crystallization, membrane formation, capillary movement and transportation of dissolved salts, surface depositions, corrosion and changes in volumes of the substrate. The chemical phenomena’s may lead to formation of altered states which may be inert and restrict further deterioration. Many a times the resultant reactant products are washed out in presence of water which aggravates and contributes in continuation of the deterioration process.

The commonly employed building materials at the heritage site in India are categorized as lime plaster, lime mortar, mud plaster, stones, metals and wood. However the surfaces may be smooth or decorated with fine carwings; exposed or covered with lime plaster paintings executed either directly or with a ground over laid upon on the substrate surface. Further there are organic adhesive employed in paintings, inlay decorations, surface coatings of organic and inorganic character.

The weathering of ancient lime plaster and mortar is caused on exposure of these materials in presence of moisture to SO_2 gas which chiefly reacts with the calcium carbonate and results in formation of Calcium Sulphite which is further oxidized to Gypsum. The increase in crystal aggregate of Gypsum leads to large expansion and spalling of plasters surfaces, while pores solution formed behind the Gypsum crust has a low evaporation rate that freezes and it creates physical stress lending to damage to the material. The dolomitic lime reacts with sulphite and produces Magnesium Sulphite, which upon loss of water, leads to destruction of cohesion in the substrate material. Further due to higher solubility of Magnesium Sulphite the deterioration mechanism is further activated by the leaching process in presence of rain.

The impact of weathering agents on stone, a major building material used in built up heritage in India has been under extensive studies. The effect of air pollutants in presence of optimum water & temperature condition has been well documented. The presence of moisture in air leads to dissolution of Carbon dioxide in water forming a weak acid which dissolves the carbonates of Calcium & Magnesium in stone. The oxides of nitrogen in atmospheric processes are converted into nitric acid, which is highly detrimental to stone substrate as it leads to dissolution of carbonate with formation of nitrates. The sulphur present in the atmosphere in presence of moisture may react with stone especially in SO_2 & SO_3 state which results in formation of H_2SO_3 & H_2SO_4. These acids act upon Calcium Carbonate to form Gypsum and eventually contribute towards the deterioration of the materials.

Figure 1 Coastal Monument Mahabalipuram wind erosion and high humidity conditions.

Figure 2 Salt efflorescence causing exfoliation and exposed pulverization of stone structure.

The historical monuments in the high attitude region of Jammu Kashmir & Himachal Pradesh region are built with usage of local mud as building material. As the region until a few decades ago did not receive any rainfall these structures have survived through centuries without much deterioration. However, the climate change in the recent years with rainfall appearing in more regular periods has led to destabilizing these built up material and enhanced their deterioration. The frequent swelling of mud bricks and plaster with absorption of water followed by drying cycle is resulting in appearance of crack and deterioration of the material.

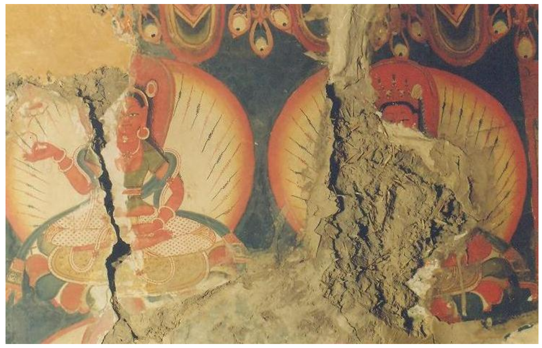


Figure 3 Mud Plaster deterioration

The usage of metals viz. copper, iron, silver etc. in heritage buildings is known from ancient times as of dowels, decorative pieces etc. The weathering of these metals is caused by chemical action of pollutants especially SO2 in presence of high humidity. The effect of sea salts on metal is known to be corrosive. The sea spray from close proximity sea is responsible for significant corrosion.

Micro Metrology Parameters Impact

The weather conditions and its periodic and non periodic alterations remain the first and foremost contributing factor and act as catalyst for aberrations and associated damage caused to tangible cultural properties. The impact of temperature, relative humidity and their frequent fluctuations, daily gust wind and continuous sunshine have a cumulative irreversible impact. The havoc caused by natural calamity through acid rains and green house gas emission is crucial and phenomenal with respect to time, though the former easily gets ignored and latter gets much attention, the analysis of these features in Indian context answers many an unraveled areas of information regarding the deterioration of building materials in Indian Monuments.

The fluctuation of temperature (diurnal temperature) catalyses the breaking away of minerals by chemical and mechanical decay, and also in many cases turns out to be great threat for organic materials preserved in museums such as paper paintings and pencil/charcoal drawings. This has a direct relationship with entropy factor of thermodynamics. The change in temperature alters the moisture content in the pores of materials and also affects the solubility’s of salts and gases which accelerates undesirable chemical reaction and hastens hydrolysis. As the entropy of the individual mineral particles is unique the movement or disorder caused due to temperature will be varying. Thus decay of stone, lime mortar or metal antiquities can be attributed to the diurnal temperature in the ambient conditions. The natural creation of hairline cracks and crevices on the ground layer of painting in Srirangapatana in Karnataka and Lepakshi in Andhra Pradesh can also be correlated to this factor. Similarly many monuments with wall paintings viz. Ajanta, Tanjavur, Santhinikethan of the country faces these challenges. The rise in temperature along with high humid conditions accelerates mold growth and this will cause insect attack on organic materials (like canvas, paper, palm leaves) incognito creating an ecosystem in or around the cultural property. This is visible in loosened and hanging canvas paintings of Srirangapatana (fig. 1,2,3,4) which was conserved by Archaeological Survey of India in the year 2009-11. The temperature humidity fluctuation is substantiated from the graph obtained for these parameters from the monument. The Temperature variation range from 12.5° C to 35° C and Relative Humidity varies from 20 to 85% (Fig 7.1 & 8).

Figure 4 Deteriorated canvas paintings of Srirangapatana, Karnataka

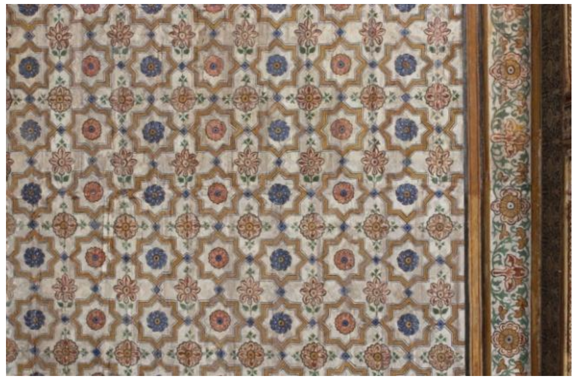
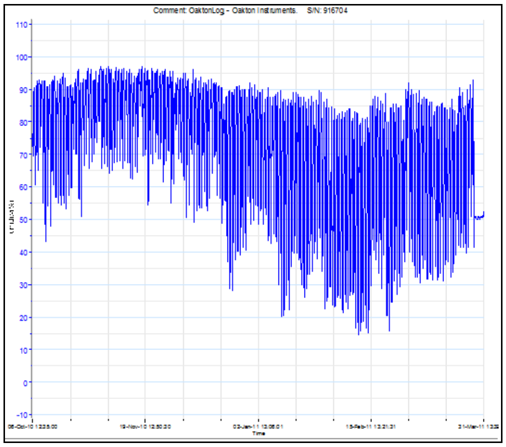


Figure 5, Conserved canvas paintings of Srirangapatana, Karnataka

The water present in the environment results in humidity which causes migration of soluble salts from the subsoil and building materials. Upon evaporation of water the salts absorb carbon dioxide from the air, and are crystallized as surface deposits. The pressure exerted by these salts causes fissures (Fig 3) or fine cracks and pulverization of the mortars surface, defacing the aesthetics of the monuments. The alternate dry and wet weather conditions are accompanied by dissolution and crystallization cycle resulting in extensive deterioration of structural material. The dissolved atmosphere gases in the rainwater eg. SO_3 causes attack on materials as it forms harmful acids with water. The loss of adhesion & cohesion of plaster and its separation and micro vegetation growth is also due to humidity in environment.

Figure 6 Micro vegetation growth on stone surface

Figure 7 Automatic Weather Station (AWS) at Pattadakkal



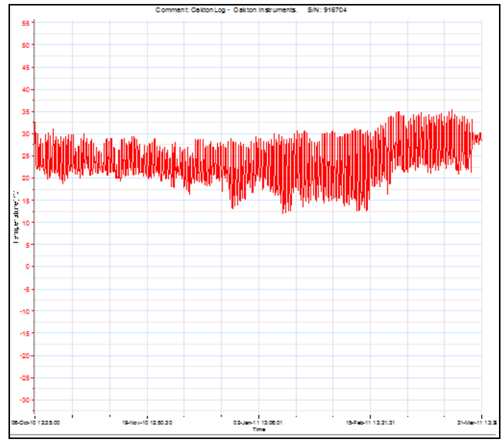


Figure 7.1 Relative Humidity Fluctuations in Srirangapatana, Oct 2010 to March 2011

Figure 8 Temperature Fluctuations in Srirangapatana Oct 2010 to March 2011

Relative humidity is a measure of content of water vapour present in comparison with the amount required to produce saturation at the same temperature and pressure. The amount of water content at a site varies with change in relative humidity. Higher the RH of the material more the water content increases in object and hence more are the chances of the decay. This creates inevitability of RH monitoring and conditioning in the case of museum objects and cave paintings. There are number of cases where in humidity became a crucial factor for deterioration of museum objects. The high humid condition due to proximity of sea in Goa (Depicted in data down loaded from AWS at Old Goa-graph (fig 9 & 10) creates a amiable atmosphere for bio deterioration in Goa monuments especially in case of wooden objects.

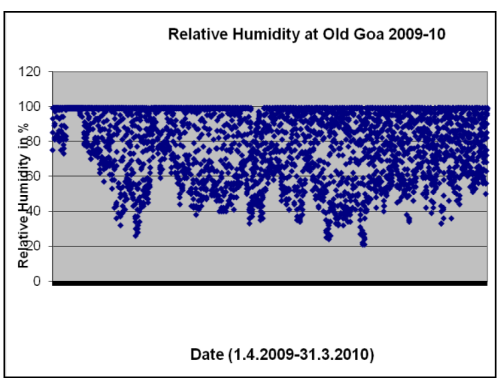


Figure 9

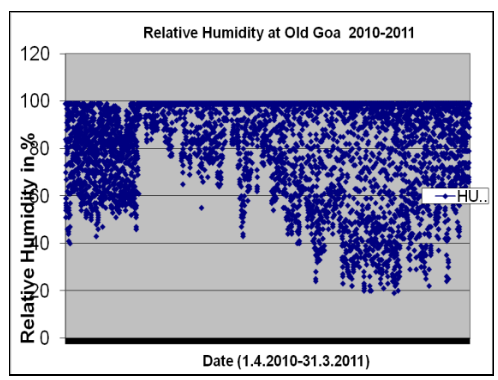


Figure 10

Wind is a dynamic phenomenon that fluctuates randomly and is graphically represented by speed versus time. The turbulence of natural wind and structure induced wind pressure are the reasons for impacts due to wind. These are prominent in the exterior parts of the monuments observed as erosion on side walls and roof. In case of tall monuments the dynamic forces acting along the direction of wind and cross wind dynamics impact the structure. The sand laden wind has abrasive action eroding the carvings on the stone surfaces of the monuments. Weakening of the jointing materials due to excessive evaporation and dry blowing winds leads to leaching out of the soluble material. This results in loss of the adhesion of the stone blocks which causes collapse of the stone blocks. The collapse of the main temple of Konark can be attributed to this phenomena, a better understanding of wind speed from wind data can bring light to this effect (Fig 11 & 12).

Figure 11 &12 Abrasive action of the air borne salt particles striking especially at the higher portion of the temple structure.

Erosion of sediment from river bed or soil present in the location of stone monuments, that were used for erection of big monuments or accumulation of sand or soil during construction in the past and its transportation through the wind flow (sand laden wind) causes heavy damage to the stone monuments. The data downloaded from Automatic Weather Station (AWS) installed (with the help of ISRO) at Pattadakkal World Heritage site shows that (fig. 7, 13, 14) the wind flow (speed max. 12 m/s in the year 2009-10 and 7.8 m/s in the year 2010-11) is prominent at angles 100° - 240°.The damage found in the lower parts of Mallikarjuna and Virupaksha temples of Pattadkal Heritage site is because of impact of wind erosion. In the case of monuments at Red Fort Delhi, the impact of wind erosion at the lower parts was physically found to be uniform in all directions and the AWS substantiates the inference (fig. 15 & 16).

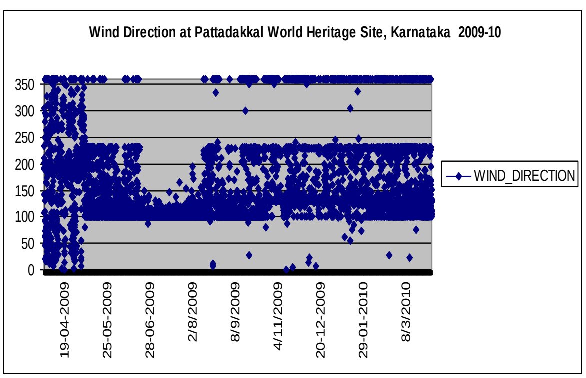


Figure 13, Wind Direction at Pattadakkal 2009 -10

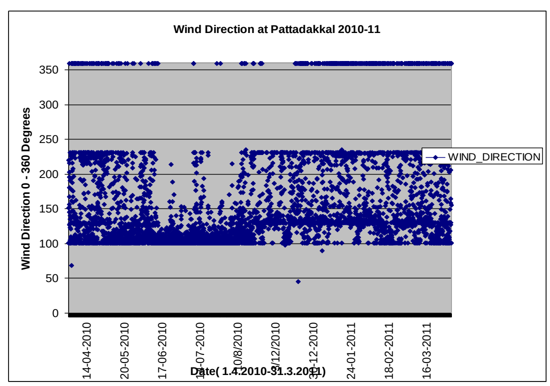


Figure 14, Wind Direction at Pattadakkal 2010-11

All chemical reactions are influenced by light. Natural as well as artificial light has detrimental effect on materials especially organic materials. The pigments when exposed to UV Light not only gets discoloured but also results in breaking of chemical bonds in the materials which leads to deteriorating materials. The scientific resins and varnishes also breakdown in presence of UV light. The natural light is essential for biological growth which may be hastened ceasing deterioration of building materials.

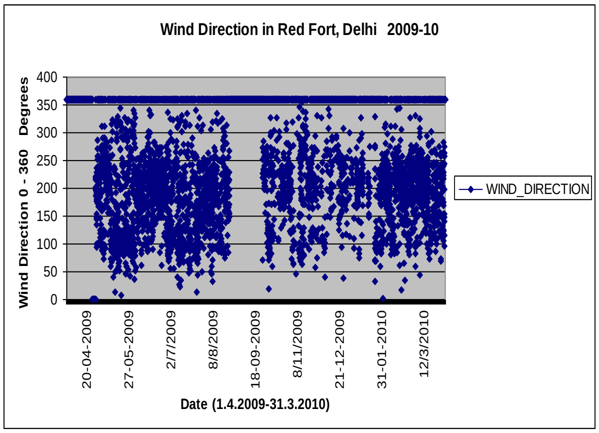


Figure 15, Wind Direction at Red Fort, 2009 -10

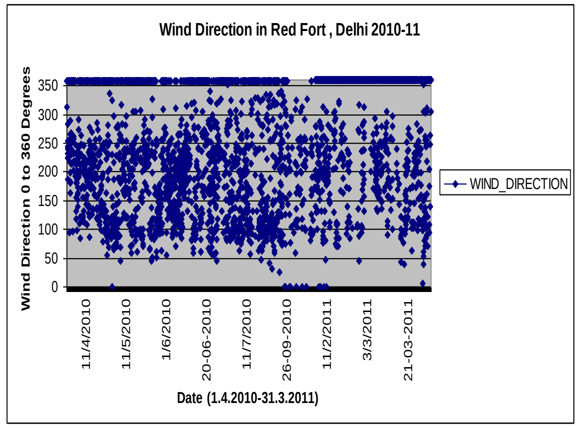


Figure 16, Wind Direction at Red Fort, 2009 -10

Conclusions

The ascertaining of meteorological factors as well as Air Pollutants leading to the cumulative impact on deterioration of built tangible heritage and remedial measures to annual these are highly important in the conservation point of view, especially to maintain the cultural heritage and passing the same to our future generations. The help of meteorological data in this regard is vital. The analysis of these data collected and its interpretation with the aid of experts in weather monitoring will be of great use for Archaeological Survey of India.

Advances in Land Cover Extraction from Remote Sensing Data

Manoj K. Arora

Department of Civil Engineering, I I T Roorkee, Roorkee 247 667
E-mail: manoj.arora@gmail.com

Abstract

Availability of accurate and up-to-date land cover information is central to both military and civilian applications. From civilian point of view, it is a desired input parameter for a number of agricultural, hydrological and ecological models. All the natural resources management, planning and monitoring programs depend on accurate land cover mapping. Most of the military operations are also terrain sensitive and therefore accurate knowledge of existing terrain conditions is of paramount importance.

Remote sensing images due to their synoptic view, map like format and repetitive coverage are a viable source of gathering effective land cover information. The Landsat MSS and TM (now ETM+ also), SPOT (HRV and PAN) and IRS (LISS and PAN) have had wide success in the production of land cover classification. A number of statistical classification algorithms (classifiers) such as Maximum Likelihood Classification (MLC), Minimum Distance to Means, Discriminant Analysis etc may be used. Many-a-times, digital classification solely on the basis of statistical analysis of spectral response may not truly represent the ground conditions. Therefore, the inclusion of ancillary (non-spectral) information from other sources such as Digital Elevation Model (DEM), geological and soil maps may be a more powerful way of characterizing the classes of interest. Moreover, due to the widespread availability of Geographic Information System (GIS), the digital spatial data have become more accessible than before. Therefore, greater attention is now being paid to the use of ancillary data in land cover classification using remote sensing.

However, due to different nature of these data sets, a significant problem arises when the ancillary information is combined with the remote sensing images. The statistical classifiers have limitations in handling data at different scales, measurement units and uncertainty. A number of machine learning approaches such as neural network, support vector machines, genetic algorithms, knowledge based and evidential reasoning may be utilized to perform multi-source classification. Their major appeal is mainly based on their distribution free assumptions. Further, these also permit the information to be gathered consistently and objectively from data of varying type, format and scale of measurement. In this paper, a brief overview on remotely sensed derived land cover extraction using advanced image classification techniques is presented.

Introduction

Accurate land cover and land use information is a key to many diverse applications such as forestry, hydrology, agriculture, environment, geology and ecology. Various natural resource management, planning and monitoring programs depend on accurate information about the land cover in a region. Remote sensing data from different satellite and aircraft based sensors are attractive for deriving effective land cover information. Typically, the pixels of the remote sensing image are grouped into meaningful and homogeneous land cover classes using digital image classification techniques. The objective of land cover classification is to classify each pixel into only one class (crisp or hard classification) or to associate the pixel with many classes (fuzzy or soft classification). The classification may be based on unsupervised or supervised learning. Due to the complex nature of spectral signatures in heterogeneous environments, it is often unrealistic to expect land cover types to be directly identifiable by unsupervised learning. Therefore, generally, supervised learning is performed. A set of areas of known class membership (training areas) for each land cover type (gathered from the ground data such as field surveys, previously compiled maps and aerial photographs) is selected. Standard statistical parameters are then derived from these training data for each land cover class. These training data statistics are used to allocate each pixel in the remotely sensed image to the class with which they show the greatest similarity.

However, in spite of the wide spread developments in remote sensing data acquisition capability, the accuracy of land cover extraction from remote sensing data has not improved significantly. The reason may partly lie in the inadequacy of efficient data/image processing, analysis and presentation techniques. The availability of huge satellite datasets at a variety of spatial, spectral and temporal resolutions and those obtained from other sources has posed new challenges. Satellite data, when combined with information from other sources and an understanding of the processes of change can be used to drive models projecting future land use change. To achieve this, advanced, intelligent and computationally efficient classification techniques play a key role.

There are a number of supervised and unsupervised image classification techniques, each having their own merits and demerits in terms of efficiency and accuracy. Maximum Likelihood Classifier (MLC), *k*-means classifier, neural network, knowledge based expert systems, fuzzy set based classifier are some popular image classifiers. MLC is the most widely used supervised classifier under Gaussian distribution assumptions for the data. However, sometimes the spectral properties of the classes are far from the assumed distribution (eg. in complex and heterogeneous environments). For instance, many pixels actually record the reflectance from a number of different classes. Many pixels are, therefore mixed because the boundaries of mutually exclusive classes meet within the area of the pixel (boundary pixels) or a small proportion of the classes exist within the major classes (subpixel phenomenon). The result is large variations in the spectral reflectance value of the pixel. The percentage of mixed pixels in an image is also directly related to the spatial resolution of the image. The majority of the classifiers allocate mixed pixels to only one class, thereby reducing the information content within the mixed pixel. Therefore, error is likely to occur in the classification of images that contain a large proportion of mixed pixels.

Non-parametric classifiers may be useful when the data distribution assumptions are not satisfied. A non-parametric classifier that has been viewed as the replacement for MLC is the neural network classifier that is also capable of including data from different sources. Often, land cover classification performed solely on the basis of the statistical analysis of spectral reflectance values does not truly represent the ground conditions. Therefore, the inclusion of ancillary (non-spectral) information from other sources such as the Digital Elevation Model (DEM) and/or geological and soil maps and also from other sensors may be a more powerful way of characterizing the land cover classes of interest.

During the last decade, much research on supervised image classification has been directed towards analyzing the performance of neural networks, particularly the feed-forward multi-layer networks based on back propagation algorithm. A number of studies have shown that the neural network classifier has problems in setting various parameters. These include the choice of network architecture, training sample size and longer learning time. Within the last few years, another non-parametric classification algorithm - the decision tree classifier has become more popular due to its simplicity of use and its performance which is comparable to or even better than neural classifiers. Despite their simplicity, decision tree classifiers may present problems in formulating a huge number of production rules particularly in case of hyperspectral data.

Recently, Support Vector Machines (SVM) have been applied for image classification applications. SVM were originally introduced and first applied to classification problems as an alternative to neural network classifiers. Their high generalization ability has inspired recent work on computational speed up as well as on the fundamental theory of model complexity. There are many issues related to the implementation of the SVM algorithm. The foremost is the choice of the optimization procedure, where a number of options exist. Further, SVM was initially designed for binary (two-class) problems. When dealing with several classes, an appropriate multi-class SVM is required to be developed.

No image classification is complete until an assessment of accuracy has been performed. Accuracy serves as the basis for the analysis of errors, which may creep in during the classification process due to complex interactions between the spatial structure of landscape, sensor resolutions (spatial, radiometric and temporal) and classification algorithms. Indeed, much research has been conducted on devising a number of accuracy measures for both crisp and fuzzy land cover classifications. A glimpse of the accuracy assessment procedures shall also be provided in this paper.

Advances in Digital Image Classification for Land Cover Extraction

Artificial Neural Network Classification

Artificial neural networks have the capability to generalize the relation between the evidence (eg. remote sensing data) and the conclusion (eg. land cover classification) without developing any mathematical models. Thus, unlike statistical parametric methods, they do not assume that the data follow a distribution. Typically, a supervised neural network such as an MLP consists of three layers; an input layer, a hidden layer and an output layer (Fig. 1). The input layer receives the data (*ie* the multi-spectral remote sensing image). As a result, the units in the input layer equal the number of bands used for the classification. Unlike input layer, hidden and output layers process the data. The output layer produces the neural network results. The number of units in the output layer is generally equal to the number of classes to be mapped. Therefore, the number of units in the input and output layers are fixed by the application designed. Selection of the number of hidden layers and their units is a critical step for the successful operation of the neural network. Using too few units in the hidden layer may result in inaccurate classification as the network may not be powerful enough to process the data. On the other hand, by using a large number of hidden units, the computational time becomes huge. It may also result in the network being over-trained. The optimum number of units in the hidden layer is often determined by trial and error, though some empirical relations do exist.

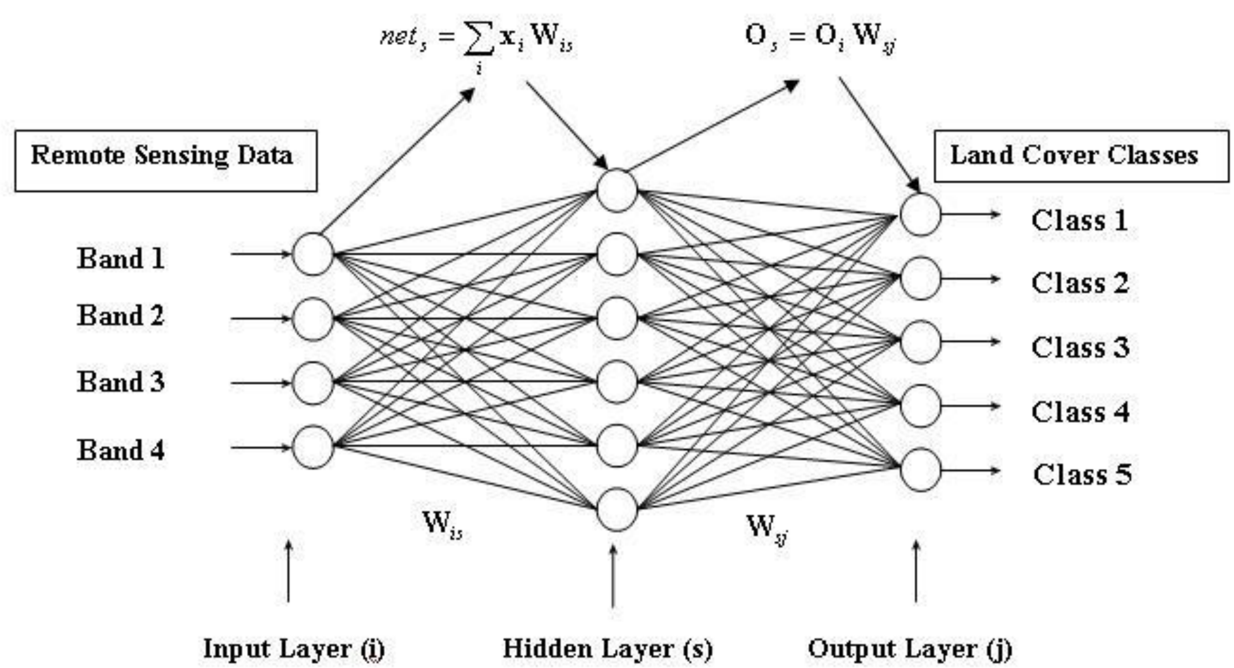


Figure. 1 A typical artificial neural network for land cover classification

The back propagation learning algorithm is a generalized least squares algorithm that adjusts the connection weights between units to minimize the mean square error between the network output and the target output. The target output is known from reference data. Data provided to input unit are multiplied by the connection weights and is summed to derive the net input to the unit in the hidden layer. Each unit in hidden layer computes a weighted sum of its inputs and passes the sum *via* an activation function to the units in the output layer through weight vector. There are a range of activation functions to transform the data from hidden layer unit to an output layer unit. These include pure linear, tangent hyperbolic, sigmoid functions etc. Although, the use of these functions may lead to difference in accuracy of classification, sigmoid function has been widely used. Outputs from the hidden units are multiplied with the connection weights and are summed to produce the output of the unit in the output layer. An error function, determined from a sample of target (known) outputs and network outputs is minimized iteratively. The process continues until the error converges to some minimum value and the adjusted weights are obtained. The target vector is determined from the known class allocations of the training pixels, which are coded in binary form. After computing the error of the network, it is compared with the limiting error of the network (a very small number ≈ 0.001 is generally chosen). If the computed error is less than or equal to the limiting error, the network training is stopped otherwise the error is back propagated to the units in the hidden and the input layers. The connection weights are updated after several iterations. The number of iterations may vary from one dataset to the other, and is generally determined by trial and error. Once the error vectors are computed, the weight updation takes place for the next iteration. The next iteration starts with a new set of weights and parameters and the process is repeated till the convergence is achieved and the adjusted weights are obtained. At this stage, the network is assumed trained. The adjusted weights are then used to determine the outputs of the unknown pixels of the image. The network outputs are called as activation levels. For hard classification, the pixel is allocated to the class with the highest activation level whereas for soft classification, these activation levels are scaled from 0 to 1 for a pixel to produce soft outputs.

Nevertheless, neural network algorithms are successful in classifying complex dataset, however, they are slow during training phase and setting parameters during training is also difficult.

Support Vector Machines Classification (SVM)

SVM is relatively a new concept for classification and regression problem. SVM has its origin in statistical learning theory which aims to create a mathematical framework for learning from input training samples with known identity and predict the outcome of data points with unknown identity. An SVM is based on Structural Risk Minimization (SRM) to achieve the goal of minimizing the bound on the VC- dimension and the empirical risk both at the same time. An SVM is constructed by finding a linear separating hyperplane to separate classes of interest. The linear separating hyperplane is placed between classes such that the data belonging to the same classes are placed on the same side of the hyperplane and the distance between the closest data vectors in both the classes is maximized. In this case, called the linearly separable case, the empirical risk is set to zero, and the bound on the VC-dimension is minimized by maximizing the distance between the closest data vectors of class 1 and class. When the classes in the dataset are mixed (*ie* erroneous or noisy data), these cannot be separated by a linear separating hyperplane. This case is known as the linearly non-separable case. In a linearly non-separable case, the empirical risk is controlled by the slack variables and the regularization parameter. Often, a linear separating hyperplane is not able to classify input data (either noiseless or noisy), but a non-linear separating hyperplane can. In non-linear case, the input data are transformed into a higher dimensional space that spreads the data out such that a linearly separable hyperplane can be obtained. Figure 2 illustrates the concept of an SVM where two classes of data sample vectors are denoted by “open circles” and “star”.

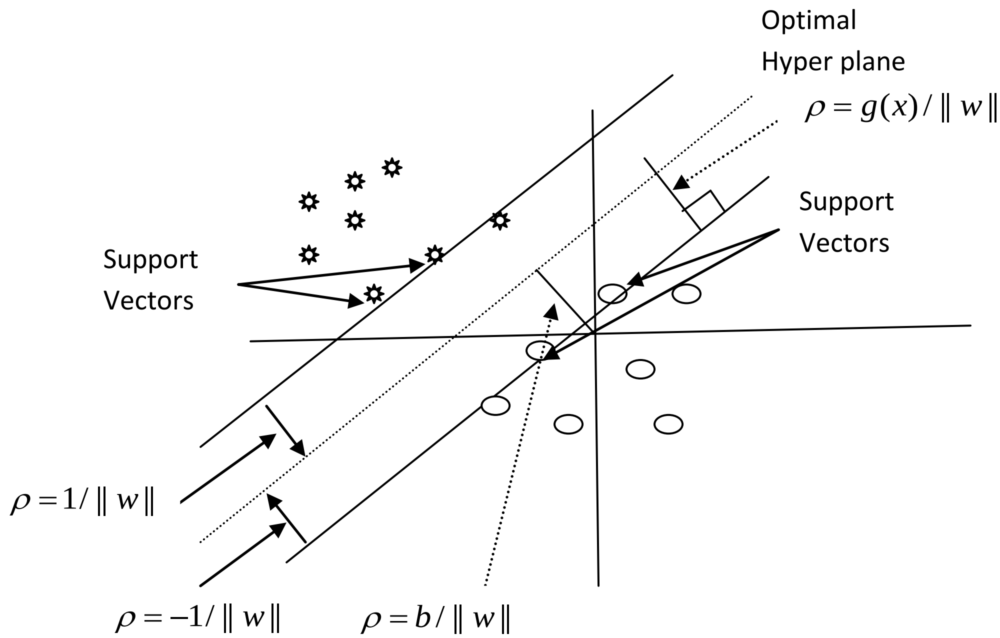


Figure 2. Illustration of an SVM (Linearly Separable Case)

However, in many applications, some data sample vectors fall in the other class or on the wrong side of the hyper plane (Fig. 3). These data sample vectors can be considered to be either bad or confusing data sample vectors and they cannot be linearly separated. In this case, the SVM developed for linear separable problems must be re-derived to take care of such confusing data sample vectors. In doing so, a new set of positive parameters and referred to as slack variables are introduced to measure the deviation of data sample vector from the ideal condition of linear separability.

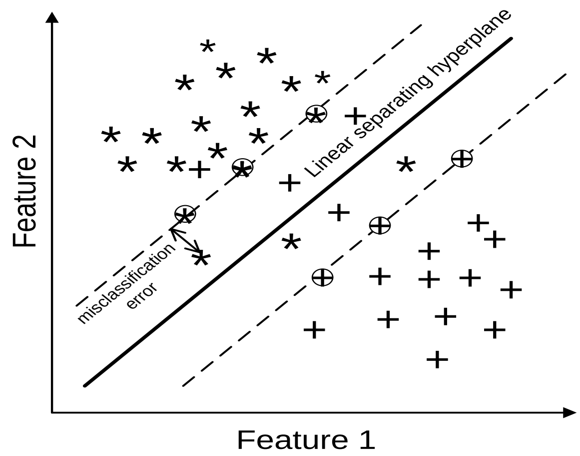


Figure 3. Illustration of an SVM (Linearly Non-Separable Case)

There are instances where a linear hyperplane cannot separate classes without misclassification. However, those classes can be separated by a nonlinear separating hyperplane. In fact, most of the real-life problems are non-linear in nature. In this case, data are mapped to a higher dimensional feature space with a nonlinear transformation or kernel function. In the higher dimensional space, data are spread out, and a linear separating hyperplane can be constructed. For example, two classes in the input space of Figure 4 cannot be clearly separated by a linear hyperplane but a nonlinear hyperplane can make them separable.

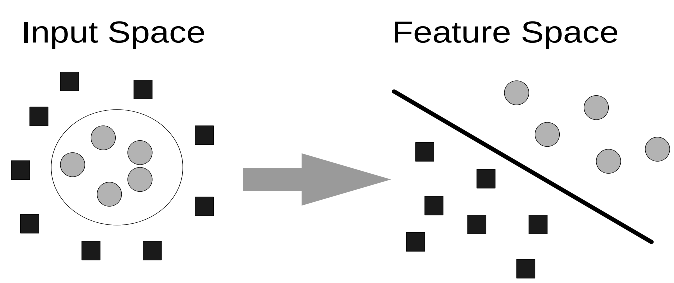


Fig. 4 Non-Linear Case. Mapping nonlinear data to a higher dimensional feature space where a linear separating hyperplane can be found

Examples of some well-known kernel functions are provided in Table 1. The selection of a suitable kernel function is essential for a particular problem. For example, the performance of the simple dot product linear kernel function may deteriorate when decision boundaries between the classes are non-linear. The performance of sigmoid, polynomial and radial basis kernel functions may depend on the selection of appropriate values of the user-defined parameters, which may vary from one dataset to another.

Table 1 Example of some kernel functions

Kernel function	Definition	Parameters
Linear	$\mathbf{r_i} \cdot \mathbf{r_j}$	
Polynomial	$(\mathbf{r_i} \cdot \mathbf{r_j}+1)^d$	d is appositive integer
Radial Basis Function	$\exp\left(-\frac{\lVert r_i - r_j \rVert^2}{\sigma^2}\right)$	σ is a user defined value
Sigmoid	$\tanh(\kappa(\mathbf{r_i} \cdot \mathbf{r_j}) + \Theta)$	κ and Θ are user defined values

Originally, SVMs were developed to perform binary classification, where the class labels can either be +1 or -1. However, applications of binary classification are very limited. The classification of a dataset into more than two classes called multiclass classification is of more practical relevance and has numerous applications. A number of methods to generate multiclass SVMs from binary SVMs have been proposed by researchers. These include one against the rest, pairwise classification, multi-class objective function etc.

Evidential Reasoning Classification

The mathematical theory of evidential reasoning refers to the Dempster-Shafer theory, proposed by Shafer as an extension of Dempster's rule of combination. The theory provides a general heuristic basis for combining information from independent sources and can be applied to any problem where a choice is to be made from a set of well known alternatives based on information from various sources (eg. various bands of multi or hyper spectral data).Thus, the theory of evidential reasoning is best applicable in problems where pieces of information from different sources have to be aggregated to make a decision. Remote sensing image classification can be considered as a process of selecting one (a class) from few alternatives (all possible classes) by aggregating pieces of information from different sources (*ie* different bands or ancillary data), thereby indicating the suitability of the theory of evidential reasoning for such a task.

Each band of a multi-spectral image and/or each ancillary data used in the classification process may be considered as an independent source of information. The application of evidential reasoning in any domain requires the creation of a mass function. Separate mass functions need to be defined for every class in each input source. In the context of supervised image classification, the mass function may be generated from the training data. These mass functions are combined using orthogonal summation to result into a single mass function, which represents the required information. The mass function refers a basic probability assignment, but it does not represent probability in the classical sense. Suppose a choice has to be made between elements of a set $X=\{x1, x2, x3 \ldots\}$ based on some available information. Here, the mass function is a mapping from power set, the set of subsets, of X to the range [0, 1].

In case of image classification, deriving mass function actually implies training of the classifier and the mass functions derived may be referred to as training signatures. The mass function can be derived from frequency of occurrence of each possible DN value of pixels in the training data set as mass function. Frequency of occurrence of the DN values in the training data of each class is the most recommended form of deriving mass function for image classification. For one band, the mass function of a class *c*, for a DN value *x* is given as,

$$m_c(x) = \frac{Number\ of\ \ pixels\ with\ value\ x\ in\ training\ data\ of\ class\ c}{Total\ number\ of\ \ pixels\ in\ training\ data\ of\ class\ c} \qquad (1)$$

Clearly, the frequency of occurrence of DN values in each class in each input source is to be determined. However, in the above stated method, the training data of a class may not include all possible DN values in it, resulting in very low or even zero frequency for certain DN values, even though the data may belong to that class itself. For example, let the DN values 30 and 32 exist in the training data set of a class with high frequency. Naturally, the value 31 is also expected to be in the same class, but it may not be present in the selected training sample. This leads to a situation where values 30 and 32 will be classified to the correct class, but not the value 31, resulting in the classification error or an unclassified pixel. *BIN transformation* is the method to get over the above mentioned shortcoming. Here, the evidence is propagated from each value to its neighbors, over a range defined by the *bin size*. Thus, the frequency obtained for values 30 and 32 will be propagated to the value 31 thereby increasing the mass function for this value, which may result into the correct classification for the value 31 and hence an increase of classification accuracy may be obtained. After the application of bin transformation, the resulting frequency distribution shall be able to represent the characteristics of the class in that band more effectively as the missing values have also got represented. These frequencies are taken as the training signatures and the class allocation is done based on this. Training of ERC yields mass functions as training signatures, one mass function for each class in each band. From this mass function, a unique class has to be allocated to each pixel. This is accomplished by combining mass function values for that pixel for each class in each band together. The combining process is based on orthogonal summation, also known as Dempster's rule of combination. The output of this combining process will be a posterior probability vector for each pixel, having one value for each class. The pixel will be allocated to the class which has the maximum *a posterior* probability.

Decision Tree Classification

Decision tree, having its origin in machine learning theory, is an efficient tool for the solution of classification and regression type problems. The application of decision tree is purely based on the machine learning so that the classification process is supervised in general. From the input training data, it extracts the information and makes a model in a form of some decision rules, which are used to produce a classification. For understanding the theory of decision tree classifier, basic data structure principle, *ie* Tree need to be understood. For storing the data in the memory and retrieving it in an efficient manner, this data structure is very useful. Every operation of searching, sorting, memory management, file handling can be handled by the tree structure. This is an effective way to break the complex decision problem into small set of rules. Analysis of a tree is a process that allows one to examine decisions in a structured and efficient manner. Hence, the tree structure can be used in decision making problems such as image classification.

A decision tree is composed of a root node, a set of interior nodes and terminal nodes called “leaves”. The root node and interior nodes referred collectively as non-terminal nodes are linked into decision stages. The terminal nodes represent final classification. The classification process is implemented by a set of rules that determine the path to be followed, starting from the root node and ending at a terminal node, which represents the label for the object being classified. At each non-terminal node, a decision has to be taken about the path to the next node.

Decision tree classifier can also be regarded as the extension of the Rule-Based classifier or the knowledge based classifier. In the Rule-Based classifier, the classification rules are created on the basis of knowledge provided by experts. Then, these rules are implemented in the corresponding tree model. At every node, there are some rules which explain the whole decision process. A rule-based classifier is a technique for classifying records by using a collection of “if - then - else” type of rules. Decision tree is an alternative for this kind of classifier in which inductive learning from the data may be helpful for generating decision rules automatically from the data itself. For automatic construction of decision tree, artificial intelligence theorems have been used to generate tree model by some machine learning and data mining techniques. To construct a classification tree using the heuristic approach, it is assumed that a training data set consisting of input data and their corresponding class labels is available which is called feature set that is selected on the basis of problem-specific knowledge. The decision tree is then constructed by recursively partitioning the training data set into purer and more homogenous subsets on the basis of a set of tests applied to one or more attribute values at each branch or node in the tree. This procedure involves three steps: (i) splitting nodes, (ii) determining which nodes are terminal nodes and (iii) assigning class label to terminal nodes. The assignment of class labels to terminal nodes is straightforward: labels are assigned based on a majority vote or a weighted vote when it is assumed that certain classes are more likely than others. If the target variable is categorical, then a classification tree is generated. To predict the value (category) of the target variable using a classification tree, use the values of the predictor variables to move through the tree until a terminal (leaf) node is reached and then predict the category shown for that node. If the target variable is continuous, a regression tree is generated. When using a regression tree to predict the value of the target variable, the mean value of the target variable of the rows falling in a terminal (leaf) node of the tree is the predicted value.

Linear Mixture Modeling

The Linear Mixture Model (LMM) is widely used for the decomposition of the class proportions of mixed pixels. The LMM assumes that the spectral response of an individual pixel (*ie* the digital number, DN) is a linear sum of the mean spectral responses of its components (*ie* land cover classes) weighted by their relative proportions on the ground. Two more constraints are also generally applied. The first constraint states that the class proportions of pixels cannot add up to more than one hundred percent and the second constraint states that all the class proportions of mixed pixels are non-negative. Mathematically, LMM in matrix notation, for n bands and c land cover classes may be written as,

$$\mathbf{x} = Mf + e \tag{2}$$

where M is the matrix of end member spectra, f is the vector of class proportions of the pixels and e the vector of errors. In the end member spectra matrix, columns represent the spectral response of classes and may be obtained either from average spectral response of pure pixels of each class in the image which is similar to finding training pixels in MLC. The end member spectra may also be estimated from laboratory and field spectral measurements of the classes or by performing principal component analysis on the dataset.

In general, the solution of Equation 2 will be unique if $c = n + 1$. For $c < n + 1$, infinite number of exact solutions may be anticipated. However, when $c > n + 1$, there will be no exact solution. If the first condition is satisfied (*ie* $c = n + 1$), the solution of LMM may be obtained from a series of linear equations. In the second condition (*ie* $c < n + 1$), there are fewer unknowns than equations. Hence, a least squares adjustment is performed to compute class proportions f by minimizing the sum of squares of the noise or error. The unconstrained least squares solution of Equation 2 is given by

$$f = (M^T \Sigma_p^{-1} M)^{-1} M^T \Sigma_p^{-1} \mathbf{x} \tag{3}$$

Fuzzy c-means Clustering (FCM)

FCM is an iterative clustering method that may be employed to partition pixels of remote sensing image into different class membership values. The key is to represent the similarity that a pixel shares with each cluster with a function (membership function) whose values lie between zero and one. Each pixel will have membership in every cluster. Memberships close to unity signify a high degree of similarity between the pixel and that cluster. The net effect of such a function for clustering is to produce fuzzy c-partitions (U) of a given data. A fuzzy c-partition of the data is the one which characterises the membership of each pixel in all the clusters by a membership function which ranges from zero to one. Additionally, the sum of the memberships for each pixel must be unity. This is achieved by minimizing the generalized least-square error objective function

$$J_m(U,V) = \sum_{i=1}^{N} \sum_{j=1}^{c} (\mu_{ij})^m \left\| \mathbf{x}_i - v_j \right\|_A^2 \tag{4}$$

subject to constraints,

$$\sum_{j=1}^{c} \mu_{ij} = 1 \quad \text{for all } i \tag{5a}$$

$$\sum_{i=1}^{N} \mu_{ij} > 0 \quad \text{for all } j \tag{5b}$$

$$0 \le \mu_{ij} \le 1 \quad \text{for all } i, j \tag{5c}$$

where $\mathbf{x}_i$ is the vector denoting spectral response of a pixel *i* (*ie* a vector of spectral response of a pixel in various bands of a multi-spectral remote sensing image), *V* is the collection of vector of cluster centres, v_j, μ_{ij} are class membership values of a pixel (members of fuzzy *c*-partition matrix), *c* and *N* are number of clusters and pixels respectively, *m* is a weighting exponent ($1 < m < \infty$), which controls the degree of fuzziness, $\|\mathbf{x}_i - v_j\|_A^2$ is the squared distance (d_{ij}) between $\mathbf{x}_i$ and v_j, and is given by

$$d_{ij}^2 = \|\mathbf{x}_i - v_j\|_A^2 = (\mathbf{x}_i - v_j)^T A (\mathbf{x}_i - v_j) \tag{6}$$

where *A* is the weight matrix.

Once all parameters in Equation 4 are defined, the fuzzy *c*-partition is obtained through an iterative process of optimisation using the following two equations. The cluster centres are updated by

$$v_j = \frac{\sum_{i=1}^{N} \mu_{ij}^m \mathbf{x}_i}{\sum_{i=1}^{N} \mu_{ij}^m} \tag{7}$$

and the class membership matrix μ_{ij} is obtained by

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{d_{ij}^2}{d_{ik}^2} \right)^{1/(m-1)}} \tag{8}$$

where

$$d_{ik}^2 = \sum_{j=1}^{c} d_{ij}^2 \tag{9}$$

The class membership values of a pixel denote the class proportions which in turn may represent the soft classified output for a pixel.

Assessment of Classification Accuracy

Classification accuracy assessment typically involves the comparison of the class allocation made by the classifier with that obtained from the ground data. An error matrix is a cross-tabulation of the thematic classes on the classified image and the ground data. The elements of this matrix generally indicate the number of samples (*ie* pixels, polygons) of the testing data. The columns of the error matrix generally define the ground data while the rows define the classified image that have a particular combination of allocation in the classified image and ground data albeit both are inter-changeable. The error matrix is then used to derive numerous measures of classification accuracy. It may, however be emphasised that the formulation of the error matrix is based on the selection of appropriate sampling design and that each testing sample is associated with one class in the classified image and one class in the ground data (*ie* crisp classifications).

Accuracy Measures for Per Pixel Classifications

The most widely used measure namely, Overall Accuracy (also referred to as percentage correct allocation) is the ratio of number of correctly classified samples (*ie* the sum of diagonal elements of the error matrix) to the total number of samples in the testing data set. It is the measure of the classification as a whole. It, however has a tendency to be biased towards the class with large number of testing samples. This situation occurs when some classes occupy large portion of the area than others. Moreover, it does not take into account the off-diagonal elements of the matrix which represent mis-classification errors. These errors may be grouped into two, namely, error of omission and error of commission. The former represents those testing samples pertaining to an actual class which the classification has failed to recognise (*ie* off-diagonal column elements) while the latter refers to those testing samples which the classification has incorrectly assigned as belonging to the particular class of interest (*ie* off-diagonal row elements). However, the interpretation of omission and commission errors is often a source of confusion to the user, and therefore, it may be more expedient to have simple measures of individual class accuracies. The concept of Producer's Accuracy and User's Accuracy may be advanced. The producer's accuracy is so called because the producer (or originator) of the classified map is typically interested in how well the samples from the ground data can be mapped using remotely sensed data. In contrast, the user's accuracy is an indication of the probability or reliability that a sample from the classified map actually represents that class on the ground. From the error matrix, the producer's accuracy may be determined by dividing the number of correctly classified samples of a class by the column total (column marginal). The user's accuracy may be determined by dividing the number correctly classified sample of a class by the row total (row marginal). Thus, producer's and user's accuracies, in fact, determine the accuracy of a map on per-class basis.

However, these measures of accuracy, whether for whole map or for an individual class, do not take into account the proportion of agreement between the data sets (*ie* classified and ground data) that is due to chance alone, and, therefore, tend to overestimate the classification accuracy. The Kappa Coefficient of Agreement introduced to the remote sensing community in the early

1980's has become a commonly used measure of accuracy. Its popularity arises primarily because all the elements of the error matrix and not just the diagonal elements contribute to its calculation and because it compensates for the chance agreement. Thus, kappa generally represents the proportion of agreement obtained after removing the proportion of agreement by chance. Typically, the value of kappa ranges from 0 to 1. Thus, a value of 1 indicates full agreement. *K* can also be negative which signifies a less than a chance agreement. Sometimes, it is represented as percentage also to be compatible with other accuracy measures.

Other variations of kappa coefficients such as Weighted Kappa and Conditional Kappa also exist in the remote sensing literature but their use have been limited to only one or two studies. Weighted kappa does not treat all the disagreements equally and give more weightage to some agreements which are more serious than others. While kappa coefficient and weighted kappa are designed to evaluate the accuracy of the whole map, conditional kappa is derived to indicate the accuracy of the map on per-class basis. In fact, conditional kappa more closely relates to the user's accuracy.

Accuracy Measures for Fuzzy Classifications

The error matrix based measures are generally applicable for the evaluation of the crisp classifications which assume that the classes are discrete and mutually exclusive. In case of fuzzy classification, the accuracy evaluated from error-matrix based measures may not be appropriate. Other accuracy measures are therefore sought.

This may be achieved by measuring the difference or distance between the fuzzy classification output and the fuzzy ground data. A number of distance measures such as L_1 and Euclidean Distances may be utilised. The objective is to quantify the closeness of probability distributions of observations represented by the two fuzzy outputs. The concept of entropy may further be advanced to use another measure of closeness called the Cross-Entropy or the Directed Divergence. The cross-entropy for each pixel may be estimated from the probabilities of class membership in fuzzy classification output and fuzzy ground data. Lower the value of the distance or cross-entropy, higher is the classification accuracy. Summary statistics, such as the mean cross-entropy may be used to describe the accuracy of the overall classification or for individual classes. Another alternative to indicate the accuracy of fuzzy classification is to compute Root Mean Square Error from fuzzy classification output and fuzzy ground data. Lower is the root mean square error, higher will be the accuracy. The measures for the evaluation of the accuracy of fuzzy classifications discussed so far are generally applicable for the evaluation of accuracy of the whole classification. A Correlation Coefficient may also be derived from the fuzzy classification output and the fuzzy ground data. The higher the correlation co-efficient, higher will be the classification accuracy of that class. However, the data should satisfy the desired statistical assumptions in order to apply this measure effectively.

Recently, the concept of Fuzzy Error Matrix (FERM) has been put forth to assess the accuracy of soft classification. The layout of a fuzzy error matrix is similar to the traditional error matrix that is used for assessing the accuracy of hard classification. The exception is that elements of a fuzzy error matrix can be any non-negative real numbers instead of non-negative integer numbers. The elements of the fuzzy error matrix represent class proportions corresponding to the reference data (*ie* soft reference data) and classified outputs (*ie* soft classified image) respectively. Thus, fuzzy error matrix can be used to derive a number of accuracy measures similar to the ones obtained from traditional error matrix for hard classification. Therefore, the FERM based measures appear more appropriate for the assessment of accuracy of soft classification than the distance measures and correlation coefficients.

Conclusions

In this paper, an overview of some advanced classifiers for land cover extraction from remote sensing data is provided. The assumptions and limitations of each were also highlighted. Some of these classifiers have now been utilized by the remote sensing community for producing land cover classification from multi and hyperspectral images with varied results. Some of the results from these classifiers have been presented during the keynote address. Further, since accuracy assessment of land cover forms an important component of any remote sensing image classification process, the procedures for the assessment of accuracy of per-pixel and sub-pixel classification were also discussed. It is desirable to use appropriate accuracy assessment procedure for effective quality assessment of land cover extraction from remote sensing data.

Land Use and Land Cover classification through Decision Tree classifiers

P. K. Srimani[1] and Nanditha Prasad[2]

[1]*Bangalore University, DS, Bangalore*
[2] *Department of Computer Science, Govt. Science College, Bangalore*
Email: profsrimanipk@gmail.com, nandithaharsha@gmail.com

Abstract

Decision tree classification algorithms have significant potential for land cover and land use mapping, but few studies have assessed the use of decision tree classifiers. In this paper, the standard Decision tree algorithms used for land cover mapping are evaluated and compared using remotely sensed data. Here multi-spectral IRS-1D/LISS III image is used as an experimental data. Land cover and land use maps are derived by using J48, BFTree, REPTree and SimpleCart algorithms with same set of training samples. The results of these classifiers are compared and evaluated based on True Positive, False Positive, Prediction Accuracy and Learning Time metrics. Classification accuracy achieved by decision tree classifier are compared with those achieved by the most widely used Maximum likelihood classifier and results of this analysis show that the Decision tree classifier consistently outperform the Maximum likelihood classifier. The results of this study also show that Decision tree classifiers have several advantages for remote sensing applications by virtue of their relatively simple, explicit, and intuitive classification structure.

Introduction

Image classification is one of the primary tasks on satellite images that is being used to categorize further for use in soil and land management, land degradation, urban planning, forest management, environmental monitoring etc. Image classification is a method by which labels or class identifiers are attached to individual pixels on the basis of their characteristics. These characteristics are generally the measurements of their spectral response in various bands. Traditionally, classification tasks are based on statistical methodologies such as Minimum Distance-to-Mean, Maximum Likelihood and Mahalanobis Distance Classification (Mather and Paul, 1987). These classifiers are generally characterized by having an explicit underlying probability model which provides a probability of being in each class rather than simply a classification. The performance of this type of classifier depends on how well the data match the pre-defined model. If the data are complex in structure, then to model the data in an appropriate way can become a real problem (Tso and Mather, 2001). In order to overcome this problem, non-parametric classification techniques such as Artificial Neural Network (ANN) and Rule-based classifiers are increasingly being used. Decision Tree classifiers have, however, not been used widely by the remote sensing community for land use classification despite their non-parametric nature and their attractive properties of simplicity, flexibility and computational efficiency in handling the non-normal, non-homogeneous and noisy data, as well as non-linear relations between features and classes, missing values and both numeric and categorical inputs (Pal and Mather, 2003, Friedl and Brodley, 1997).

The objective of this study is to evaluate the use of decision tree algorithms for classifying land cover and land use on the chosen area. In this paper, we evaluate the performance of a set of decision tree classifier algorithms namely J48, BFtree, REPTree and Simple Cart on the same training sample (DeFries *et al*., 2000). Based on the performance criteria and evaluation results, classification rules generated from best algorithm for land use and land cover classification over the LISS-III image are implemented using Expert Classifier to obtain classified image of the study area. Further accuracy assessment is performed over the classified image to evaluate the results (Congalton, 1991). The study area is H D Kote taluk of Mysore district of Karnataka.

Materials and methods

The IRS-ID LISS III image (Fig. 1) of the above area of February 2005 was used for the study. A false color composite (FCC) image was generated using bands 3,2,1 of the satellite data. Survey of India toposheets were used as reference data.

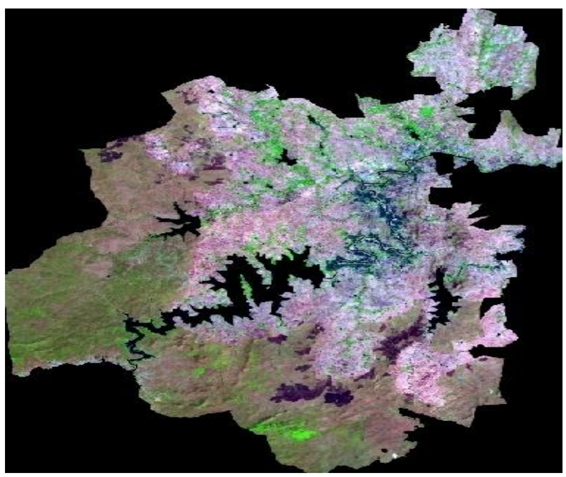


Figure 1 LISS-III Image of H.D Kote

Decision Tree Classifiers (DTC)

Decision tree classifier, a machine learning algorithm, is a knowledge based data mining technique. It is an efficient tool for land cover classification. It is a hierarchal top-down approach, in which decision rules are defined by combination of several features and a set of linear discriminate functions are applied at each test node, where a binary decision is made for splitting a complex decision into several simpler decisions so as to separate either one class or some of the classes from the remaining classes. In this approach, the feature of data is a predictor variable (A variable analogous to the independent variable in linear regression and used for predicting the value of the target variable) whereas the class to be mapped is referred to as target variable. It performs binary recursive partitioning to allocate automatically maximum information carrying feature for the classification and discards remaining features at that transitional stage, thereby increases computational efficiency (Xu *et al*., 2005,) (Tso *and* Mather, 2001).

J48 (C4.5 Decision Tree Revision 8)

J48 algorithm is the Weka implementation of the C4.5 top-down decision tree learner proposed by Quinlan. The algorithm uses the greedy technique and is a variant of ID3, which determines at each step the most predictive attribute and splits a node based on this attribute. Each node represents a decision point over the value of some attribute (Pal and Mather, 2002). J48 attempts to account for noise and missing data. It also deals with numeric attributes by determining where thresholds for decision splits should be placed. The main parameters that can be set for this algorithm are the confidence threshold, the minimum number of instances per leaf and the number of folds for reduced error pruning (Sam Drazin and Matt Montang and Quinlan, 1992).

Best First Tree (BFT)

BFTree is a best-first decision tree learner and it is a learning algorithm for supervised classification. Best-first decision trees represent an alternative approach to standard decision tree techniques such as the C4.5 algorithm since they expand nodes in best-first order instead of a fixed depth-first order. A method used in the BFT (Best-First Tree) algorithm adds the best split node to the tree in each step. The best node is the node that maximally reduces impurity among all nodes available for splitting (ie not labeled as terminal nodes) (Witten and Frank, *2005 and* Shi, 2007).

Reduced Error Pruning Tree

REPTree is a simple and fast decision tree learner. It builds a decision/regression tree using information gain/variance and prunes it using reduced-error pruning (with back-fitting). The algorithm only sorts values for numeric attributes once. Missing values are dealt with by splitting the corresponding instances into pieces (Sam Drazin and Mat Montang and Witten and Frank, *2005*).

Simple CART

The CART (Classification and Regression Trees) algorithm is a binary decision tree that is constructed by splitting a node into two child nodes repeatedly. A set of observations and associated variables are given. The algorithm finds a way of using variables to partition the observations into homogeneously distributed groups, then use groups to predict observation (Sam Drazin and Matt Montang).

Maximum Likelihood Classifier (MLC)

The Maximum Likelihood Classification tool considers both the variances and covariance of the class signatures when assigning each cell to one of the classes represented in the signature file.

A statistical decision rule that examines the probability function of a pixel for each of the classes and assigns the pixel to the class with the highest probability. The classifier assumes that the training statistics for each class have a normal or 'Gaussian' distribution. However many are not, radar statistics in particular. Training statistics with bi- or tri-modal histograms are not suitable as they indicate non-homogeneity within classes and are non-'Gaussian'. The classifier then uses the training statistics to compute a probability value of whether it belongs to a particular land cover category class. This allows for within-class spectral variance. The image analyst can use *a-priori* knowledge to weigh the probability function. (G) MLC usually provides the highest classification accuracies. Accordingly, it has a high computational requirement because of the large number of calculations needed to classify each pixel (Tso and Mather, 2003).

Methodology

In this study, the image was preprocessed using ERDAS 9.2. Considering the ground characteristics, land cover and land use is classified into eight types namely Irrigated land with crop, Irrigated land without crop, Burnt land, Dry forest, Evergreen forest, Upland agriculture, Water bodies and Others like roads, villages etc. A training data consisted of 2253 samples belonging to these eight classes is prepared using the spectral (RGB) values of pixels of the satellite image. The classification rules are then derived using J48, BFtree, Reptree and Simple cart decision tree algorithms, implemented in the WEKA software. The results of the decision tree classifiers are compared and analyzed based on TP (True positive) and FP (False Positive), Prediction Accuracy and Learning Time to build the model. Among these classifiers, J48 produced the best results in all aspects. The J48 generated classification rule set are imported into ERDAS Imagine Knowledge Engineer Module and the considered satellite image is classified to the decision tree classified image. Maximum likehood classification (MLC) was carried out using the signature file.

To evaluate the accuracy of the classified image “Accuracy Assessment” tool in ERDAS 9.2 is used. To compute the accuracy, Stratified random sampling is done on the classified image. Applying the reference image classification, 256 random points with a minimum of 10 per class are generated. The same is verified against the corresponding toposheet. The reference values are recorded in the Accuracy Assessment table. From the error matrix, Overall accuracy and Kappa values are computed using user’s accuracy and producers’ accuracy for each class.

Results and Discussion

Performance Criteria

In this section, Decision tree classifier J48, BFtree, REPTree and Simplecart are evaluated on 2253 samples of training data. To compare the classifiers, TP (True positive) and FP (False Positive), Prediction Accuracy and learning time to build the model in seconds for each algorithm are considered. These parameters shown in Table 1 are the most important criteria for considering the best algorithm for classifying the land cover and land use of the considered image. As shown in Table 1, it is clear that J48 has taken 1.69 seconds to build the model for Decision Trees. Table 1 shows the Evaluation criteria for Decision rules. Besides, it is very important to record Prediction Accuracy (PA Accuracy = Total correctly classified instances/Total instances) * 100) for each algorithm. In the selection process, any algorithm is disqualified if it's PA is too low, despite its outstanding performance in classifying one or more land cover and land use classes.

Evaluation criteria	Decision Trees classifiers			
	J48	**BFTree**	**Rep Tree**	**Simple Cart**
Time Taken to Build Model (Secs) (TTBM)	1.69	0.94	0.14	1.45
Correctly Classified Instances (CCI)	2193	2182	2133	2166
Incorrectly Classified Instances (ICCI)	60	71	120	87
Rules Generated (RG)	80	108	89	61
Prediction Accuracy (PA)	97.33	96.84	94.67	96.13

Table1 Evaluation Criteria for Decision Tree Algorithms

Decision Tree Classifier Algorithms

The J48 Classifier achieved the highest Prediction Accuracy of 97.33% in 1.69 seconds with 2193 Correctly Classified Instances as shown in Table 1. BFTree has the next highest accuracy result of 96.84% among the other Decision trees. REPTree has achieved 94.67% and simple cart, 96.13% accuracy. BFTree shows the next higher Correctly Classified Instances. The accuracy rate of REPTree classifier is the lowest among the four Tree classifiers. A total of 80 rules is generated by J48 Decision Tree classifier.

J48 Decision Tree Classified Image

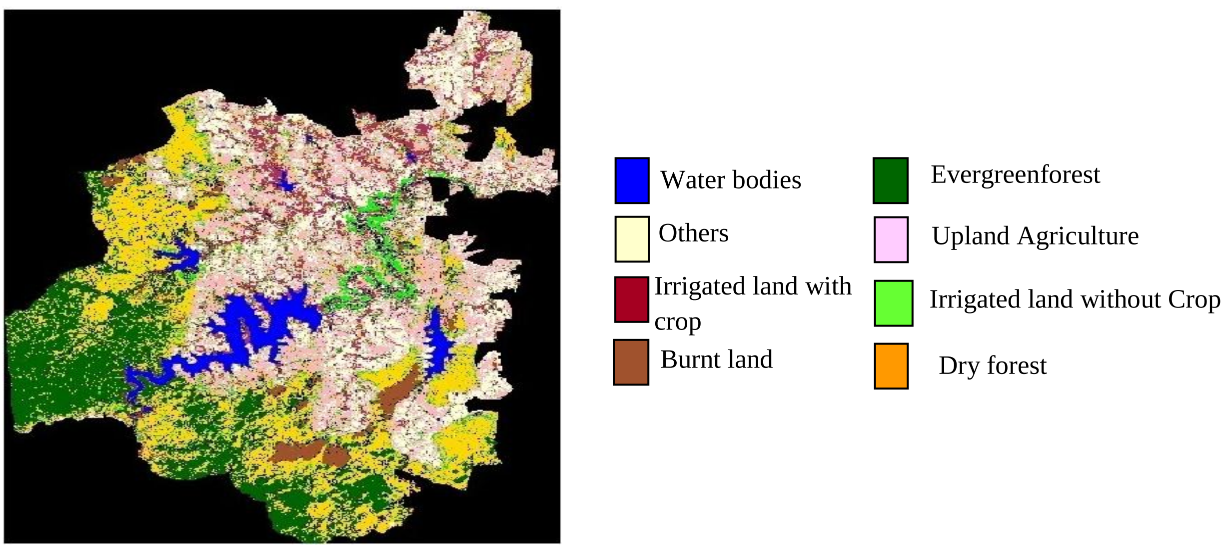


Figure 2 Classified Image using J48 DTC

Using ERDAS 9.2 knowledge Engineer a knowledge base is created using J48 generated classification rules are applied over the LISS-III image to obtain the decision tree classified image. The Figure 2 is the classified image obtained by applying Decision Tree classifier method.

Accuracy assessment is carried out over the classified image which has overall classification accuracy of 87.11% and kappa of 0.8515.

Table 2 Accuracy of J48 Decision Tree Classifier

Class Names	Reference total	Classified total	Number of correctly classified	Producers accuracy	Users accuracy
Water bodies	24	23	22	91.67	95.65
Burnt land	22	20	19	82.36	95.00
Irrigated land without crop	25	28	22	88.0	78.57
Evergreen forest	36	35	32	88.00	91.43
Dry forest	42	45	41	97.62	91.11
Others	37	36	30	81.08	83.33
Upland agriculture	42	40	35	83.33	87.50
Irrigated land with crop	28	29	22	78.57	75.86
Total	**256**	**256**	**223**		

DTC did not provide satisfactory results in distinguishing Evergreen forest and irrigated land with crops due to the overlapping of spectral values. However, accuracy for Others and upland agriculture is relatively less because of similar scattering mechanism. Classes with uniform distribution like water, dryforest have been classified correctly. All results are above 80% except user's accuracy on irrigated land without crop (78.57) and Irrigated land with crop (75.86%). The overall accuracy is 87.11%. Based on above the analysis, it can be concluded that this DTC model can fill the requirement of classifying land cover and land use of the considered image.

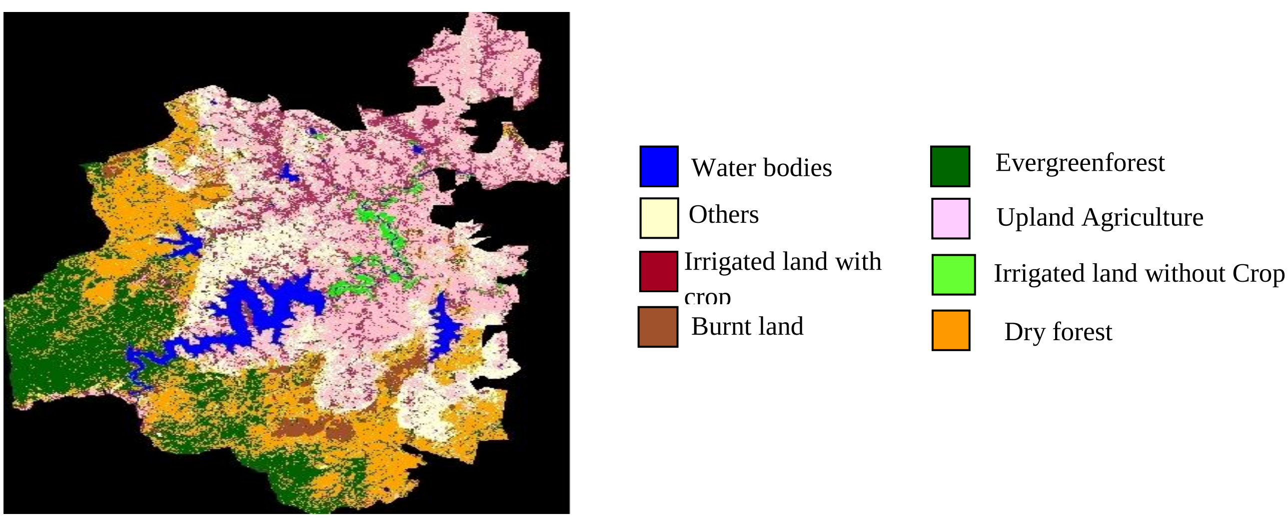


Figure 3 Classified Image using MLC

Classes	Reference total	Classified total	Number of correctly classified	Producers accuracy	Users accuracy
Water bodies	15	14	13	86.67%	92.86%
Burnt land	11	11	10	90.91%	90.91%
Irrigated land without crop	9	8	6	66.67%	75.00%
Evergreen forest	38	41	34	89.47%	82.93%
Dry forest	56	51	48	85.71%	94.12%
Others	57	67	50	87.72%	74.63%
Upland agriculture	31	35	31	100.0%	88.57%
Irrigated land with crop	39	29	25	64.10%	86.21%
Total	**256**	**256**	**217**	–	–

Table 3 Accuracy of MLC Classifier

MLC Classified Image

MLC provided satisfactory results in distinguishing evergreen forest, dry forest, water bodies and burnt land classes which is presented in Figure 3. However, accuracy for the irrigated land with crops, others and the irrigated lands without crop is relatively less when compared to the above mentioned classes due to the small variation in the spectral signatures. Further, Producer's accuracy for the irrigated land without crops and irrigated land with crop classes are relatively less when compared to the above mentioned classes.

Conclusions

Decision tree classifiers can perform automatic feature selection and complexity reduction, while the tree structure gives easily understandable and interpretable information regarding the predictive or generalization ability of the data. DTC computational time is minimal. Some of the popular machine learning decision tree classifiers is presented in this paper for land cover classification. This classification scheme is applied to LISS-III data. Eight classes are identified. Each class is categorized with its own set of classification rules due to its specific scattering behaviour. The results show good classification accuracy for each class. The highest accuracy has been obtained by applying the J48 decision tree algorithm with a user-defined training set on the LISS III data. In addition, the classifiers are compared based on True Positive, False Positive, Prediction Accuracy and Learning Time metrics. DTC J48 performed better in all metrics and had a prediction accuracy of 97.34 and Kappa of 0.9685. The Decision tree classified image indicated an Overall Accuracy of 87.11% and Kappa statistics as 0.8515. The classes which have uniform distribution over the study area have been classified correctly in both the classifier, than those classes which are scattered in the study area. For these scattered classes, DTC performance is better than that of MLC. It can be concluded from the study, that decision tree classification algorithm performed better than MLC as DTC does not depend on *a-prior* model, it is dynamic in nature. Overall, almost all the classes perform better under DTC than that of MLC. Also the study indicates that DTC can provide an accurate and efficient methodology for classification of remotely sensed data.

References

Congalton, R G. (1991). A review of assessing accuracy of classification of remotely sensed data, Remote sensing of Environment, 37, 35-46.

DeFries, R., Cheung-Wai Chan, J. (2000). Multiple Criteria for Evaluating Machine Learning Algorithms for Land Cover Classification from Satellite Data, Remote Sensing of Environment, 74: 503-515.

Friedl M. A. and Brodley, C. E. (1997). "Decision tree classification of land cover from remotely sensed data," Remote Sensing of Environment, vol. 61, pp 399-409.

Mather P.M. and Paul, M. (1987). "Computer Processing of Remotely-Sensed Images," St. Edmundsbury Press Ltd., Bury St. Edmunds, Suffolk, Wiley and Sons, ISBN: 0471-90648-4,.

Pal.M and Mather, P. M. (2003). "An assessment of the effectiveness of decision tree methods for land cover classification," Remote Sensing of Environment, vol. 86, pp 554-565.

Pal.M and Mather, P. M. (2002). “A comparison of Decision Tree and Back Propogation Neural Network Classifiers for Land Use Classification”, Geo Science and remote Sensing Symposium, IEEE International proceedings, Vol–I, pp 503-505.

Quinlan, J.: C4.5: (1992). Programs for Machine Learning, Morgan Kaufmann,Burlington,MA,USA.

Shi, H. : Best-_rst (2007), Decision tree learning.

Sam Drazin and Matt Montang. Decision Tree Analysis using WEKA, University of Maimi.

Tso B. and Mather, P. M. (2001). Classification Methods for Remotely Sensed Data. London and New York: Taylor & Francis, New York.

Witten, I.; Frank, E. (2005). Data Mining: Practical Machine Learning; Tools and Techniques. 2ed. Morgan Kaufmann, Burlington, MA, USA.

Xu M.P. Watanachaturaporn, Varshney, P. K. and Arora, M. K. (2005). "Decision tree regression for soft classification of remote sensing data," Remote Sensing of Environment, vol. 97, pp 322-336.

A Comparative Study of Two Measures of Thematic Uncertainty in Remote Sensing Image Classification

M.S. Ganesh Prasad[1] and Manoj, K. Arora[2]

Department of Civil Engineering, The National Institute of Engineering, Mysore – 570 008
Department of Civil Engineering, Indian Institute of Technology,Roorkee, Roorkee
E-mail: ganeshprasad@nie.ac.in & manojfce@iitr.ernet.in

Abstract

Thematic maps produced from multi and hyper spectral remote sensing images are widely used in many application areas such as hydrology, geology, forestry etc. These maps inherently contain uncertainty due to various reasons, which degrades the quality of maps and subsequently hampers the decisions based on these data. Traditional way of representing the quality of maps is to report overall accuracy of the map, which, however, does not depict the spatial distribution of quality. It would be more expedient to use pixel-wise uncertainty as a means of quality indicator of a thematic map. This can be achieved through a number of uncertainty measures. In this paper, two measures viz. *exaggeration uncertainty* and classification *uncertainty*, as defined in the IDRISI software have been assessed to bring out similarities and relations between them. It has been found that Exaggeration *uncertainty* is similar to *classification uncertainty*, as defined the in IDRISI software.

Introduction

The use of multi and hyper spectral remotely sensed images to extract thematic information *via* digital image classification techniques is now quite common. However, errors may occur between real world and their digital portrayal in the form of thematic maps. It has been well recognized that for proper decision making, the fitness for use of maps derived from remote sensing images needs to be assessed (van der Wel *et al*. 1998). Evans (1997) stated that "we have a responsibility to map consumers to provide information about the reliability of mapped data and its representation so that decisions based on maps are made with knowledge of the map's limitations'. Thus, a statement of quality of maps is desired. Quality of maps derived from image classification can be assessed using two parameters, namely accuracy and uncertainty. The widely accepted method for assessing the accuracy of thematic maps derived from remote sensing data has been the error matrix (Congalton and Green, 1999). Classification accuracy is the main measure of quality of thematic maps produced and required by the users and helps to evaluate the fitness of a map for a particular application (Foody, 2008). However, classification accuracy is associated with many problems although being simple in concept (Foody, 2002) and is often perceived as being inadequate for many users (Townshend 1992, Gallego 2004).

In recent years, uncertainty as a quality assessment tool has become a key subject in remote sensing studies and has attracted attention of many researchers (Canters, 1997; Kiiveri, 1997; Foody, 2002). The term uncertainty covers a broad range of concepts including error and accuracy. Where accuracy is known objectively, it can be expressed as error, where it is not, the term uncertainty may apply (Hunter and Goodchild, 1993). A number of indices based on several theories may be adopted to quantify uncertainty at pixel scale. Further, pixel scale uncertainty measurement approaches can be used to depict the spatial distribution of uncertainty.

The aim of this paper is to discuss two uncertainty measures *viz.* the *exaggeration uncertainty* and *Classification Uncertainty* as defined in IDRISI image processing software and to bring out similarities and relation between them. This paper is organized into three sections: uncertainty in image classification process, notations used in this paper and the measures of uncertainty considered for the present study. A comparison of these measures is made based on hypothetical examples and the relation between them is established.

Uncertainty in remote sensing image classification

Uncertainty in remote sensing image classification may broadly be represented in two ways, *viz.* positional and thematic uncertainty. Positional uncertainty is the result of errors introduced in geometric processing of images including resampling, where as thematic uncertainty results due to errors in image classification. The presence of positional uncertainty in images may also have an impact on the thematic uncertainty. Therefore, focus is placed here on understanding thematic uncertainty as a key feature of assessing the quality of thematic maps produced from remote sensing image classification.

Uncertainty in remote sensing image classification may occur at different levels of abstraction and processing. These include data acquisition, pre-processing, georeferencing, resampling, class definition, training, allocation and testing stages of image classification etc. (Foody and Arora, 1996). For example, it is quite common that the classification process may neglect the fuzzy character of the environment thereby introducing uncertainty in class allocation, particularly in case of coarse spatial resolution images which contain large number of mixed pixels at the scale of measurement. The hard classification of such images results in erroneous classification, as the pixel is allocated to the class, which has highest proportion within the class. The outputs from soft classification in the form of fraction images reflect the class proportions within a pixel. The fraction images may be obtained through a number of soft classification methods such as fuzzy c-means clustering (Bezdek *et al*. 1984), linear mixture modeling (Settle and Drake, 1993), artificial neural networks (Foody, 1996) and possibilistic c-means clustering (Foody, 2000), support vector machines (Brown *et al.* 2000; Varshney and Arora, 2004) etc. The class proportion outputs of a pixel (pixel membership vector) may also be used to indicate thematic uncertainty (Ibrahim *et al.* 2005).

Typically, a pixel membership vector derived from soft classification contains values indicating partial membership in *n* classes. In such a situation, the information from the membership vector of a pixel lacks clarity and does not provide any specific evidence which may help in assigning the pixel to a particular class. Since, the pixel exhibits its association with several classes in terms of partial membership values, uncertainty in class assignment takes the form of *ambiguity*. Larger is the set of membership values for a pixel, lesser is the precision of information available from the membership vector and hence, more non specific will be the information associated with the pixel. Therefore, uncertainty in allocating pixel to one specific class may be represented by measures of *ambiguity* such as *entropy* (Maselli *et al.* 1994), Quadratic score (Glasziou and Hilden, 1989; Fatemi *et al.* 2004), *non- specificity*, *U-uncertainty* (Dubois and Prade 1987; Ricotta, 2005) and *confusion index* (Burrough *et al.* 1997).

Let μ_{jk} be the class membership value of j^{th} pixel in k^{th} class, with $k = 1, 2, \ldots n$ classes and $0 \le \mu_{jk} \le 1$ with the normalization constraint of $\sum_{k=1}^{n} \mu_{jk} = 1$, which is generally imposed in soft classification. Further, let $\mu(C) = \{\mu_j^1, \mu_j^2, \mu_j^3, \ldots\ldots\ldots\mu_j^n\}$ be an ordered (in descending order) fuzzy set having class membership values of a pixel *j* in which the numbers 1,2…*n* indicate first highest membership, second highest membership (μ_j^n will obviously be minimum).

Exaggeration uncertainty

Defuzzification is performed to derive a hard or crisp product from a soft classification process. Generally, the defuzzification involves transforming the fuzzy partition into a crisp one by converting multi-class representation of pixel to one class. This is done by assigning the pixel to the class to which it has highest membership value. Even if the pixel does not have full class membership, it is assumed to have full membership in that class. The error due to this assumption may lead to *exaggeration uncertainty* (*E*). Zhu (1997) provides formulation for *exaggeration uncertainty* as,

$$E = (1 - \mu_j^1) \tag{1}$$

where μ_j^1 is the maximum membership value for the pixel *j*.

Exaggeration uncertainty describes the uncertainty in terms of disagreement in assuming that a pixel has full membership in a class to which it is allocated. The minimum value of *E* is 0, when the pixel has class membership value equal to 1, indicating that there is no exaggeration of class membership value in assigning the pixel to that class. On the other hand, *E* may have maximum value as 1, when there is a situation of assigning the pixel to a class to which it has zero class membership. However, in soft classification, this situation may rarely occur and therefore may be considered as purely hypothetical situation. It may also be observed from equation (1) that *exaggeration uncertainty* of a pixel is inversely related to the membership value. Higher the membership in the allocated class, lesser will be the *exaggeration uncertainty*.

Classification uncertainty

In the IDRISI software, a measure of *classification uncertainty* (*CU*) (Eastman, 2003), given by equation (2) has been provided. It measures the degree to which no class clearly stands out above the others and is given as,

$$CU = 1 - \frac{\mu_j^1 - \frac{\sum_{k=1}^{n} \mu_{jk}}{n}}{1 - \frac{1}{n}} \qquad (2)$$

where μ_j^1 is the maximum membership value for the pixel j , $\sum_{k=1}^{n} \mu_{jk}$ is the sum of membership values for the pixel and n is the number of classes. The logic of using this measure is explained as follows. The numerator of the second term expresses the difference between the maximum set membership value and the total dispersion of the set membership values over n classes. The denominator of the second term expresses the extreme case of the difference between a maximum set membership value of 1 and the total dispersion of that over all classes. The ratio of these two expresses the degree of commitment to a specific class relative to the largest possible commitment that can be made. The *classification uncertainty* is the complement of this ratio. The minimum value of *classification uncertainty* (*CU*) is equal to 0, when the pixel has full membership value of 1 (i.e., μ_j^1 =1) in one of the classes. Maximum value of 1 will be reached when the pixel exhibits equal membership values in all the classes ($\mu_{jk} = \frac{1}{n}$ for all k = 1,2,….n).

Comparison of uncertainty measures with hypothetical examples

Let there be two cases, where a pixel is assigned hypothetical class membership values, as per the number of classes in the area,

(i) *Case I: four classes* (n=4)

(ii) *Case II: five classes* (n=5)

The assumed class proportions in the second case remains the same as in the first case, except the addition of one class with zero membership value. Under each of these cases, for different values of highest membership values ranging from 0.25 to 1, thematic uncertainty value associated with this pixel is determined via measures of uncertainty as given by equations (1) and (2). The thematic uncertainty values for these cases are given in Tables 1 and 2.

Table 1 Uncertainty as computed by different measures (Case I)

Class proportions				Uncertainty measure	
				E	***CU***
1	0	0	0	0	0
0.9	0.05	0.05	0	0.1	0.133
0.8	0.1	0.1	0	0.2	0.266
0.7	0.15	0.15	0	0.3	0.4
0.6	0.2	0.2	0	0.4	0.533
0.5	0.25	0.25	0	0.5	0.666
0.4	0.3	0.3	0	0.6	0.8
0.3	0.25	0.25	0.2	0.7	0.933
0.3	0.3	0.3	0.1	0.7	0.933
0.25	0.25	0.25	0.25	0.75	1

Table 2 Uncertainty as computed by different measures (Case II)

Class proportions					Uncertainty measure	
					E	***CU***
1	0	0	0	0	0	0
0.9	0.05	0.05	0	0	0.1	0.125
0.8	0.1	0.1	0	0	0.2	0.25
0.7	0.15	0.15	0	0	0.3	0.375
0.6	0.2	0.2	0	0	0.4	0.5
0.5	0.25	0.25	0	0	0.5	0.625
0.4	0.3	0.3	0	0	0.6	0.75
0.3	0.25	0.25	0.2	0	0.7	0.875
0.3	0.3	0.3	0.1	0	0.7	0.875
0.25	0.25	0.25	0.25	0	0.75	1

It may be observed from Tables 1 and 2 that the *Exaggeration uncertainty* is dependent on highest membership value only and it remains the same in both the cases, as the highest membership values considered are the same. It may also be observed that, *E* increases as the highest membership value decreases. However, *classification uncertainty* (*CU*) is higher than *exaggeration uncertainty* (*E*) in both the cases. The values of *classification uncertainty* (*CU*) in Table 2 are less than the corresponding values in Table 1, although class proportions are same in both the cases. The main reason for this is the increase in the number of classes (from n=4 to n=5 in this example), and hence it can be stated here that *CU* decreases as the number of classes increases. This can be observed in Figure 1. For a given maximum membership value (e.g. 0.5), and for n=2, the value of *CU* is 1 and it decreases as the number of classes increases and for n=10, CU is 0.55. Further, *classification uncertainty* depends not only on the number of classes, but also on the highest membership value. In Figure 1, *classification uncertainty* (*CU*) decreases with the increase in the number of classes for a given highest membership value.

Relation between *E* and *CU*

Apparently, there appears to be a similarity between the *exaggeration uncertainty* (*E*) as provided by equation (1) and *classification uncertainty* (*CU*) estimated using equation (2) since both these measures are dependent on highest membership values. However, the difference between these two measures as observed from example cases *I* and *II* is that *CU* shows a decreasing trend with the increase in number of classes. Whereas *E* is completely independent of number of classes. Another difference that was observed is that the values of *CU* are higher than the values of *E* in both the example cases. To explore a possible relation between *E* and *CU*, *we* assume that, in soft classification, when the normalization constraint is imposed, the sum of class membership values for a pixel is equal to 1 i.e. $\sum_{k=1}^{n} \mu_{jk} = 1$. In that situation, equation (2) becomes,

$$CU = 1 - \frac{\mu_j^1 - \frac{1}{n}}{1 - \frac{1}{n}} \tag{3}$$

Simplifying and rewriting equation (3) as,

$$CU = \frac{n(1 - \mu_j^1)}{n - 1} \tag{4}$$

From the comparison of equations (1) and (4), it is clear that the *classification uncertainty* is nothing but the *exaggeration uncertainty* multiplied by a factor *n*/ (*n*-1). This multiplication factor which is always greater than 1 is the reason for higher value of *CU* than *E*. It may be noted that for *n*=2, the classification uncertainty *CU* will be twice the corresponding *exaggeration uncertainty E*. This comparison leads to a conclusion that the information conveyed by classification uncertainty (*CU*) is similar to exaggeration uncertainty (*E*), but on a different scale.

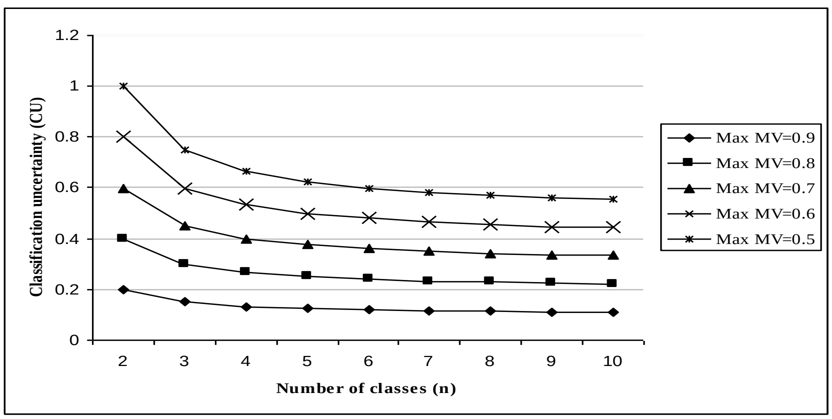


Figure 1.Variation of classification uncertainty (*CU*) with number of classes and highest membership value

Conclusions

Thematic uncertainty mainly results due to errors in image classification and is predominant in coarse resolution images containing large number of mixed pixels. Therefore, soft classification methods are becoming popular in deriving accurate land cover maps. The output from soft classification may also be used to indicate uncertainty in classification. Several measures of uncertainty in the classification process have been derived under different theoretical framework. In this paper, a comparison of two measures of classification uncertainty was made to bring out the similarities between them. Measures such as e*xaggeration uncertainty* and *classification uncertainty*, as defined in IDRISI software were selected for this purpose. Hypothetical examples were used for comparison and it was observed that these two measures are similar in conveying uncertainty information but on different scales. *Classification uncertainty* (*CU*) estimates values higher than *exaggeration uncertainty* (*E*) by a factor *n*/*n*-1, where *n* is the number of classes.

References

A-Xing Zhu (1997). Measuring uncertainty in class assignment for natural resource maps under fuzzy logic. Photogrammetric Engineering and Remote Sensing, Vol. 63(10), pp 1195-1202.

Bezdek, J.C., Ehrlich, R. And Full, W. (1984). FCM: The fuzzy c-means clustering algorithm. Computers and Geosciences, Vol. 10, pp 191-203.

Brown, M., Lewis, H.G., and Gunn, S.R. (2000). Linear spectral mixture models and support vector machines remote sensing. IEEE Transactions on Geosciences and Remote Sensing, Vol. 38, pp 2346-2360.

Burrough, P.A., Van Gaans, P.F.M., and Hootsmans, R. (1997). Continuous classification in soil survey: spatial correlation, confusion and boundaries. Geoderma, Vol. 77, pp 115-135.

Canters F. (1997). Evaluating the uncertainty of area estimates derived from fuzzy land cover classification. Photogrammetric Engineering and Remote Sensing, Vol. 63(4), pp 403-414.

Congalton, R.G., Green, K. (1999). Assessing the accuracy of remotely sensed data: Principles and practices. Lewis Publishers.

Dubois, D., Prade, H. (1987). Properties of measures of information in evidence and possibility theories. Fuzzy Sets and Systems, Vol. 24, pp161-182.

Eastman, J.R. (2003). IDRISI Kilimanjaro Guide to GIS and Image Processing. Clark Labs, USA, pp 210-211.

Evans, B.J. (1997). Dynamic display of spatial data-reliability:does it benefit the map user? Computers and Geosciences, Vol. 23(4), pp 409-422.

Fatemi, S.B., Mojaradi, B., Varshosaz (2004). Introducing an Accuracy Indicator Based on Uncertainty Related Measure. In: XXth ISPRS Congress, Istanbul, Turkey, Commission 4, pp 974-979.

Foody, G.M. (1996). Relating the land cover composition of mixed pixels to artificial neural network classification output. Photogrammetric Engineering and Remote Sensing, Vol.62, pp 491-499.

Foody, G.M., Arora, M.K. (1996). Incorporating mixed pixel in the training, allocation and testing stages of supervised classification. Pattern Recognition Letters, Vol.17, pp 1389-1398.

Foody, G.M. (2000). Estimation of sub-pixel land cover composition in the presence of untrained classes. Computers and Geosciences, Vol.26, pp 469-478.

Foody, G.M. (2002). Status of land cover classification accuracy assessment. Remote Sensing of Environment, Vol. 80, pp 185-201.

Foody, G.M. (2008). Harshness in image classification accuracy assessment. International Journal of Remote Sensing Vol.29, pp 3137-3158.

Gallego, F.J. (2004). Remote sensing and land cover area estimation. International Journal of Remote Sensing. Vol. 25. pp 3019-3047.

Glasziou, P., Hilden, J. (1989). Test selection measures. Medical Decision Making, Vol. 9, pp 133-141.

Hunter, G.J., Goodchild, M.F. (1993). Managing uncertainty in spatial data bases: Putting theory into practice. Journal of the Urban and Regional Information Systems Association, Vol. 5(2), pp 55-62.

Ibrahim, M.A., Arora, M.K., Ghosh, S.K. (2005). Estimating and accommodating uncertainty through the soft classification of remote sensing data. International Journal of Remote Sensing, Vol. 26(14), pp 2995-3007.

Kiiveri, H.T. (1997). Assessing, representing and transmitting positional uncertainty in maps. International Journal of Geographic Information Science, Vol. 11(1), pp 33-52.

Maselli, F., Conese, C., And Petkov, L. (1994). Use of probability entropy for the estimation and graphical representation of the accuracy of maximum likelihood classification. ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 49, pp 13-20.

Ricotta, C. (2005). On possible measures for evaluating the degree of uncertainty of fuzzy thematic maps. International Journal of Remote Sensing, Vol. 26(24), pp 5573-5583.

Settle, J.J., Drake, N.A. (1993). Linear mixing and the estimation of ground cover proportions. International Journal of Remote Sensing, Vol. 14, pp 1159-1177.

Townshend, J.R.G. (1992). Land cover. International Journal of Remote Sensing. Vol.13. pp 1319-1328.

Varshney, P.K., And Arora, M.K. (2004). Advanced Image Processing Techniques for Remotely Sensed Hyper spectral Data. Heidelberg: Springer Verlag.

Van Der Wel, F.J.M., Linda, C., Ben, G.H. Gorte (1998). Visual exploration of uncertainty in remote sensing classification. Computers and Geosciences, Vol. 24(4), pp 335-343.

Application of Image Resampling Methods in Satellite Remote Sensing

C.J., Jagadeesha[1], Madhukar Shastry[2] and Prabhuraj, D.K.[2]

[1]Regional Remote Sensing Centre-South, Bangalore-37
[2]Karnataka State Remote Sensing Applications Centre, Bangalore
E-mail: madhukar_bn@rediffmail.com

Abstract

This paper aims to present a review of resampling methods which can be adopted for satellite remote sensing images. Image resampling is the mathematical technique used to create a new version of the image with a different width and / or height in pixels. Interpolation is the process of determining the values of a function at positions lying between its samples. Sampling the interpolated image is equivalent to interpolating the image with a sampled interpolating function. Image registration is the process of overlaying two or more images of the same scene taken at different times, from different view points, and / or by different sensors. It geometrically aligns two images- the reference and sensed images. In the interaction between interpolation and sampling aliases occur on some occasions. Majority of the registration methods consists of the steps like feature detection, feature matching, transform model estimation and image resampling and transformation. The proprietary software's available in India for image processing which are capable of doing image registration do not provide us with performance metrics for assessing the resampling methods used. In this paper we have applied performance metrics (on satellite images) for use in analysing the resampling methods. This we hope will enhance understanding of the classified images characteristics in a quantitative manner.

Introduction

Digital images are generated from sensed (remotely) data. The output of most sensors is a continuous voltage wave form whose amplitude and spatial behavior are related to number of photons sensed. Creating a digital image involves two processes a. sampling; b.quantization.An image is continuous with respect to the x and y coordinates and also in amplitude. Digitizing the coordinate values is called sampling. Digitizing the amplitude values is called quantization (George Joseph, 2009). Resampling a satellite remote sensing image, turns out to be the resampling on a two dimensional image which can be broken down into two one- dimensional resampling passes. In one pass, horizontal resampling is performed producing an image with a different width but the same height. In the next pass, this intermediate image is resampled vertically, changing its height while leaving the width the same. This is computationally much more efficient than trying to combine the work into a single pass (Thomas Lillesand *et.al*, 2007). Upsampling involves interpolating between the existing pixels to obtain an estimate of their values at the new pixel locations. Downsampling involves computing a weighted average of the original pixels that overlap each new pixel. Color images are treated like three black and white images which are separated from the original image, individually resampled, and finally recombined to create the final image (Charles Elachi,1988).

Interpolation is the process of determining the values of a function at positions lying between its samples. It achieves this process by fitting a continuous function through the discrete input samples. This permits input values to be evaluated at arbitrary positions in the input, not just those defined at the sample points (Robert A.Schowengerdt,1997). While sampling generates an infinite bandwidth signal from one that is band limited, interpolation plays an opposite role: it reduces the band width of a signal by applying a low pass filter to the discrete signal. That is, interpolation reconstructs the signal lost in the sampling process by smoothing the data samples with an interpolation function (Rafael.C *et.al*, 2009).

Image registration is the process of overlaying two or more images of the same scene taken at different times, from different view points, and / or by different sensors. It geometrically aligns two images- the reference and sensed images. Image registration can be of four main types according to the manner of the image acquisition [3]. They are: Images of the same scene are acquired from different viewpoints, (multi view analysis), Images of the same scene are acquired at different times, (multitemporal analysis), Images of the same scene are acquired by different sensors, (multimodal analysis), and Images of a scene and a model of the scene are registered (scene to model registration). Majority of the registration methods consists of the following four steps.

1. Feature detection: Salient and distinctive objects (closed boundary regions, edges, contours, line intersections, corners etc.,) are manually or, preferably, automatically detected. For further processing, these features can be represented by their point representatives (centres of gravity, line endings, distinctive points), which are called control points (CPs) in the literature.

2. Feature matching: In this step, the correspondence between the features detected in the sensed image and those detected in the reference image is established. Various feature descriptors and similarity measures along with spatial relationships among the features are used for that purpose (R.Michael Hord,1986).

3. Transform model estimation: The type and parameters of the so called mapping functions, aligning the sensed image with the reference image, are estimated. The parameters of the mapping functions are computed by means of the established feature correspondence.

4. Image resampling and transformation: The sensed image is transformed by means of the mapping functions. Image values in non-integer co-ordinates are computed by the appropriate interpolation technique (Anil.K.Jain, 1989).

The choice of an interpolating function to be used for Resampling methods depends upon the task being performed. This project tries to examine the behaviour of 6 interpolation methods, viz., Nearest Neighbourhood, Bilinear, Bicubic Convolution, Cubic B-Spline, Sinc, and Lanczos interpolation techniques, and tries to compare these methods by applying them on satellite images (of Bangalore) of the same scene. The satellite image used in this project is of LISS III satellites. Though visual interpretation plays a key role, the performance of the algorithm cannot be analyzed by it alone. Standard metrics which help in analyzing the performance of the algorithm are the answer to this burgeoning question. The interpolation methods are compared based on various Performance Metrics, such as, Computation Time, Entropy, Normalized Least Squares Error, and Peak Signal to Noise Ratio (PSNR), and aims to propose an optimal method amongst them. It is vital to note that software packages like ERDAS IMAGINE, etc., offer immediate solutions, but for proper understanding and analyses of these techniques, a detailed evaluation of the working of these methods based on standard performance metrics should be done; and our project aims to accomplish this goal. The same is done using MATLAB R2007b software package.

Interpolation Methods

Here we discuss about the various interpolation techniques used in this project.

Nearest Neighbourhood Interpolation Method

Nearest-neighbour interpolation (also known as **proximal interpolation or point sampling**) is a simple method of multivariate interpolation in one or more dimensions.

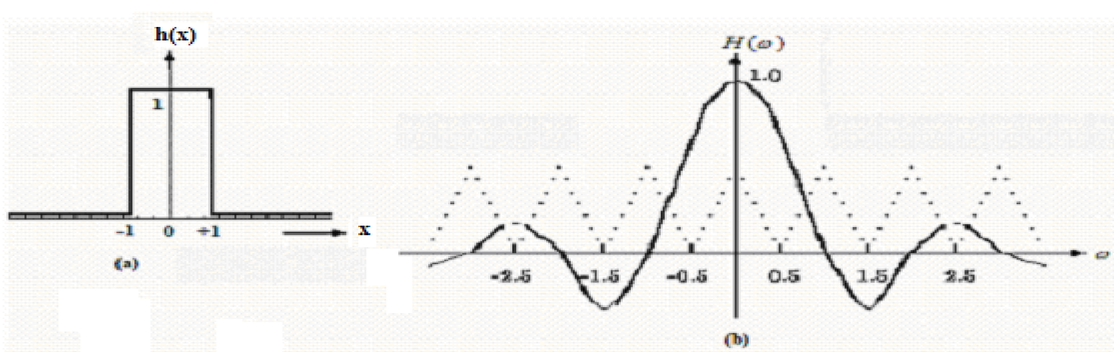


Figure 1.1 Nearest Neighbour Interpolation (a) Synthesis function, (b) Fourier Spectrum

In nearest neighbour interpolation, the Fourier transformation of a square pulse is equivalent to a sinc function whose gain in the pass band quickly falls off (Figure 1.1). Besides, it has prominent side lobes (C.R.Appledorn, 1996). Another effect caused by this method is that the resampled image will be shifted with regard to the original image by the difference between the positions of the coordinate locations. Nearest neighbour interpolation (blue lines) in one dimension on a (uniform) dataset (red points) is shown in Figure 1.2.

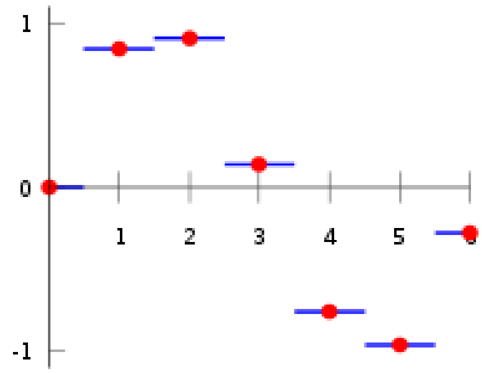


Figure 1.2 Nearest Neighbour Interpolation (blue lines) in one dimension on a (uniform) dataset (red points).

Nearest-neighbour interpolation can result in a spatial offset error by as much as $\frac{1}{\sqrt{2}}$ pixel units. Spatial offset error is defined as the high-intensity or low-intensity pixels at the center of the image matrix due to improper scaling, (typically dc) during interpolation. Also, nearest-neighbour interpolation results in a lot of data shuffling, and the image is highly cluttered and prone to noises. This also results in jaggedness and this loss cannot be compensated. Nearest neighbour interpolation is thus d.c. interpolation method. The spatial support is 1. The rate of convergence of the resulting interpolant will be $O(\Delta^1)$. Here, O denotes Landau's order symbol, and Δ is the inter-sample distance. This has the effect of simply making each pixel bigger.

An example of nearest neighbour interpolation of a random set of points (black dots) in 2D is shown in Figure 1.3. Each coloured cell indicates the area in which all the points have the black point in the cell as their nearest black point (William.K.Pratt, 2009). Nearest Neighbour Interpolation on a uniform 2D grid (black points) is depicted in Figure 1.4.

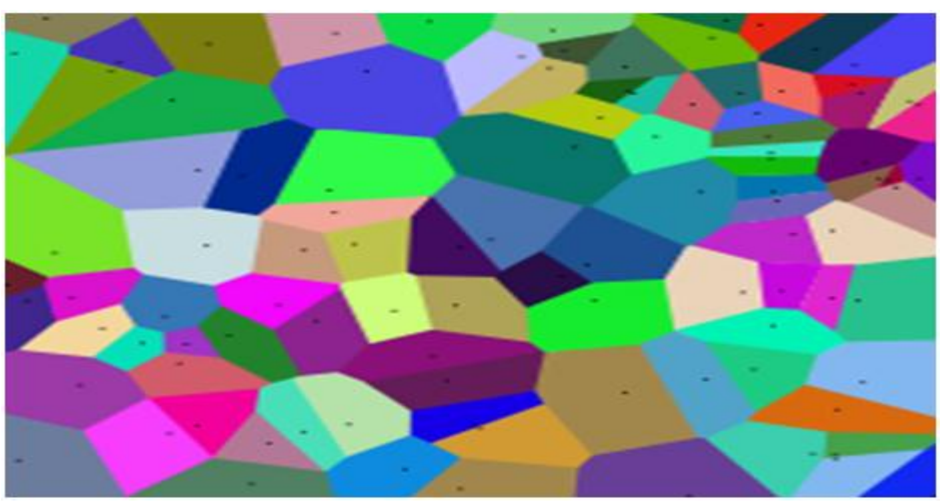


Figure 1.3 Example of Nearest Neighbour Interpolation of a random set of points (black dots) in 2D

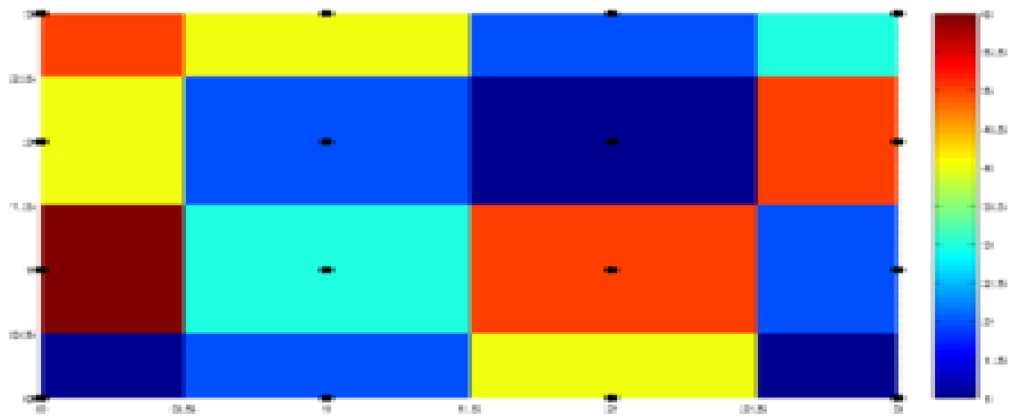


Figure 1.4 Nearest Neighbour Interpolation on a uniform 2D grid (black points)

Bilinear Interpolation

In mathematics, bilinear interpolation is based on the principle of Linear Interpolation in 1D. In bilinear interpolation, the key idea is to perform linear interpolation first in one direction, and then in the other direction. This makes use of a *4* x *4* pixel neighbourhood for interpolation. Bilinear Interpolation works with the assumption that surface is continuous and the neighbouring points are related. Bilinear Interpolation uses a distance weighted average when interpolating an unknown value (Anil.K.Jain,1989).

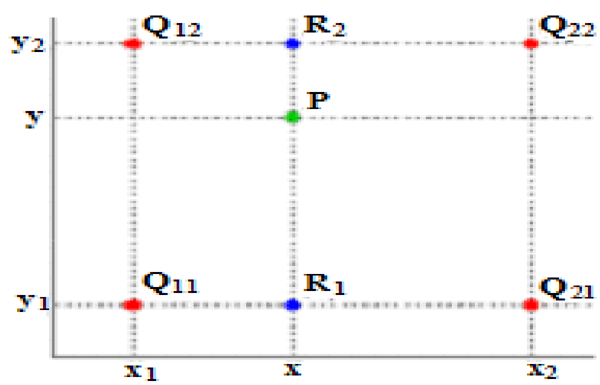


Figure 1.5 Bilinear Interpolation (graphical analogy)

If we choose a coordinate system in which the four points where *f* is known are (0, 0), (0, 1), (1, 0), and (1, 1), then the interpolation formula simplifies to

$$f(x,y) \approx f(0,0)(1-x)(1-y) + f(1,0)x(1-y) + f(0,1)(1-x)y + f(1,1)xy$$

Or equivalently, in matrix form, we get

$$f(x,y) \approx \begin{bmatrix} 1-x & x \end{bmatrix} \begin{bmatrix} f(0,0) & f(0,1) \\ f(1,0) & f(1,1) \end{bmatrix} \begin{bmatrix} 1-y \\ y \end{bmatrix} \qquad \dots (1)$$

The spatial support is 2, smoothness or regularity is C^0 and the convergence rate is $O(\Delta^2)$.

When an image needs to be scaled up, each pixel of the original image needs to be moved in a certain direction based on the scale constant. However, when scaling up an image by a non-integral scale factor, there are pixels (i.e., *holes*) that are not assigned appropriate pixel values. In this case, those *holes* should be assigned appropriate RGB or gray scale values so that the output image does not have non-valued pixels (Thomas J.Trainer and Fang-Kuo Sun, 1991).

Unlike other interpolation techniques such as nearest neighbour interpolation and bicubic interpolation, bilinear interpolation uses only the 4 nearest pixel values which are located in diagonal directions from a given pixel in order to find the appropriate colour intensity values of that pixel (C.R.Appledorn,1996).

Bilinear interpolation considers the closest 2 x 2 neighbourhood of known pixel values surrounding the unknown pixel's computed location. It then takes a weighted average of these 4 pixels to arrive at its final, interpolated value. The weight on each of the 4 pixel values is based on the computed pixel's distance (in 2D space) from each of the known points.

Bicubic Convolution Interpolation

Bicubic Convolution interpolation is one of the most common interpolation methods in two dimensions. With this method, the value $f(x, y)$ of a function f at a point (x, y) is computed as a weighted average of the nearest sixteen samples in a rectangular grid. Here, two cubic interpolation polynomials, one for each plane direction, are used. The bicubic algorithm is frequently used for scaling images and video for display. It preserves fine detail better than the predominant bilinear algorithm. Bicubic interpolation results in an interpolating function which is continuous, has continuous first partial derivatives, and has continuous cross derivatives everywhere (Philippe Thevenaz *et al*, 2000).

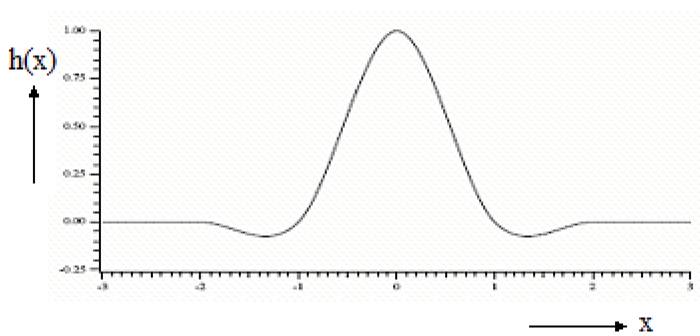


Figure 1.6 Cubic Convolution Interpolation Kernel (with a $= -\frac{1}{2}$.)

The performance of Cubic Convolution interpolation is better than nearest-neighbour and bilinear interpolation. Since we have to take into account 16 data points for interpolating, we need to solve sixteen simultaneous equations, which is a time consuming event. But since this is a tedious procedure, the method is implemented recursively in software. The spatial support is equal to *(n+1)*, the smoothness or regularity is C^{n-2}, and the convergence rate is $O(\Delta^3)$.

1.2.4 Cubic B-Spline Interpolation

Splines, which were invented by Schoenberg in 1946, constitute an elegant framework for dealing with interpolation and discretization problems. They are widely used in computer-aided design and computer graphics. Indeed, B-Splines offer the best cost-performance tradeoffs among available interpolation methods. Typical application areas where splines find use are: image reconstruction from projection data, sampling grid conversion, geometric correction, visualization, rigid or elastic image registration, and feature extraction including edge detection and active contour models (E.H.W.Meijering,1999).Researchers then studied and developed many algorithms of splines for different applications afterwards. Among these algorithms, cubic B-Splines show the most optimum characteristics. The use of cubic B-splines in image interpolation and digital filtering was pioneered by Hou and Andrews.

Splines are piecewise functions (often polynomials) with pieces that are smoothly connected together. So there are several basis (synthesis) functions instead of one. These pieces may or may not overlap. Basis splines (B-Splines) are one of the most commonly used families of spline functions. They can be derived by several self-convolutions of a basis function. By convention, their symbolic representation is β^n, where, $n \in N$ is not a power, but an index called the degree of the spline. In our project, we use Cubic B-Spline. Mathematically, this is nothing but fourth order B-Spline that is called Cubic B-Spline. Since these functions are piecewise polynomials of degree n, they are globally symmetric and *(n - 1)* times continuously differentiable (E.H.W.Meijering, 1999).

The B-Spline of smallest degree is almost identical to the nearest-neighbour basis function. They differ from one another only at the transition values, where we ask that be symmetric with respect to the origin (is not), and at the same time that it satisfies the partition of unity. Thus, contrary to the nearest-neighbour case, it happens in some exceptional cases (evaluation at half-integers) that interpolation with requires the computation of the average between two samples. We set n = 3 and obtain the equation for cubic B-Splines (M.Unser, 1993).

Sinc Interpolation

The name sinc function derives from its classical name as the sine cardinal (or cardinal sine) function. A plot of the sinc function to the left and right of the origin t = 0 is shown in Figure 1.7. Note that peak is at amplitude 1, and zero-crossings occur at all nonzero integers. The sinc function can be seen as a hyperbolically weighted sine function with its zero at the origin cancelled out. The sinc function is the impulse response of the ideal low pass filter, which cuts off at half the sampling rate. In addition, there is no way to tune the performance to any specific application: it is either a sinc (or approximation thereof), or it is something else. Ideally, the sinc function provides error-free interpolation of the band-limited functions. As far as classical physics is concerned, this transition is abrupt and cannot be expressed as a band-limited function. The second difficulty is that the support of the sinc function is infinite (M.Unser, 1993). Hamming and Kaiser windows are used in this project.

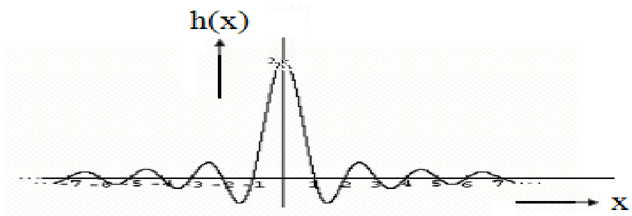


Figure 1.7 Sinc synthesis function.

Lanczos Interpolation

Lanczos resampling is an interpolation method used to compute new values for sampled data. It is often used in multivariate interpolation, for example for image scaling (to resize digital images), but could be used for any other digital signal. The Lanczos kernel indicates which samples in the original data, and in what proportion, makes up each sample of the final data. The filter is named after Cornelius Lanczos because he showed how to use Fourier series and Chebyshev polynomials for various problems where it was not used before.

The Lanczos filter is a windowed form of the sinc filter, a theoretically optimal "brick-wall" low-pass filter. The sinc function is infinite in extent, and thus not directly usable in practice. Instead, one uses approximations, called windowed forms of the filter, as discussed in window functions: filter design, and the Lanczos filter is one such windowing. The windows vanish outside of a range, and using larger ranges allows one to improve accuracy in exchange for more computation. Some have compared the Lanczos filter favourably with simpler filters or other windowings of sinc, finding it the "best compromise" among filters considered (M.Unser,1993).

Performance Metrics used

It is a well known fact that visual interpretation plays a vital role in deciding about the quality of the image. But it must be noted that sometimes visual interpretation alone does not quantify the image's quality and the applied algorithm's performance; the use of some standard measures for assessing the algorithm's performance also are needed. These measures serve as a basis for analyzing and inferring about the algorithm's performance. So, along with visual interpretation, these performance metrics are also used in practice to assess the overall working of the applied image processing algorithm. Some standard remote sensing digital image processing softwares like ERDAS IMAGINE though they give some requisite results desired, do not tell the software's user about the performance metric used. This is because of the propriety rules of the software manufacturer. But at times, the result so obtained using ERDAS IMAGINE may or may not give satisfactory results for the application at hand. Hence, comparison or evaluation of the algorithms applied on the image based on different performance metrics is an inevitable and invaluable tool for further assessment and research. The different performance metrics discussed in our project are Computation Time, Entropy, Normalized Least Squares Error (NLSE) and Peak Signal to Noise Ratio (PSNR)

Computation Time

The time taken by the interpolation method to perform the interpolation of the given image is the computation time. It is used as a performance metric for comparing different interpolation methods that have been applied to the given satellite images. The lesser the time taken by the interpolation method, the faster is that method. The cost of implementation of the method is also related to the computation time of it. Of course, the computation time is expressed in seconds.

Entropy of an Image

Entropy is one of the 4 performance metrics that has been used in this project. This is taken from Information Theory and Coding. Information Theory gives some important concepts that are very much useful in digital representation of images. Next, we define *Information.* Suppose there is a source (such as an image) which generates a discrete set of independent messages (such as gray levels) r_k, with probabilities p_k, k = 1, 2, … L. Then, the information associated with r_k is defined as, $I_k = -\log_2 p_k = \log_2 \frac{1}{p_k}$ bits. Since $\sum_{k=1}^{L} p_k = 1$, each $p_k \leq 1$ and I_k is nonnegative. This definition implies that the information conveyed is large when an unlikely message is generated. I_k is also referred to as **"Amount of Uncertainty" or "Amount of Surprise" or Self Information."** If the emitted symbols are statistically independent, that is to say that any symbol being produced does not depend in whatsoever manner on the symbols that have already been produced, then, the source are called **discrete Memoryless or Zero Memory Sources**.

Normalized Least-Squares Error (NLSE)

The Normalized Least-Squares Error (NLSE) between 2 images is defined as,

$$e_{NLSE} = \frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} |F(m,n) - \hat{F}(m,n)|^2}{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} |F(m,n)|^2} \qquad \ldots (2)$$

NLSE should be minimum as far as possible between the input image and the output image.

Peak Signal to Noise Ratio (PSNR)

The phrase peak signal-to-noise ratio, often abbreviated PSNR, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale.

The PSNR is most commonly used as a measure of quality of reconstruction in image compression etc. It is most easily defined via the mean squared error (MSE) which for two M x N monochrome images I and K where one of the images is considered a noisy approximation of the other is defined as:

$$MSE = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\| I(i,j) - K(i,j)\|^2 \quad \ldots (3)$$

The PSNR is defined as:

$$PSNR = 10\log_{10}\left(\frac{MAX_I^2}{MSE}\right) = 20\log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right), \quad \ldots (4)$$

Here, MAX_I is the maximum pixel value of the image. When the pixels are represented using 8 bits per sample, this is 255. When normalized, MAX_I = 1. More generally, when samples are represented using linear PCM with B bits per sample, MAX_I is 2^B-1. The PSNR is given in decibel units (dB), which measure the ratio of the peak signal and the difference between two images. An increase of 20 dB corresponds to a ten-fold decrease in the Root Mean Square (R.M.S) difference between two images. There are many versions of signal-to-noise ratios, but the PSNR is very common in image processing, probably because it gives better-sounding numbers than other measures.

Results and Validation

LISS III image obtained from Regional Remote Sensing Service Centre south is the input (or original) satellite colour image which is of size 282 x 248 x 3, which is in "TIFF" format. We have applied various interpolation methods on this image such as Nearest Neighborhood interpolation, Bilinear Interpolation, bicubic convolution Interpolation, Cubic B-Spline Interpolation, Sinc Interpolation and Lanczos Interpolation.

Entropy of input image in bits/symbol for 3 planes: -

R = 5.4580

G = 5.9800

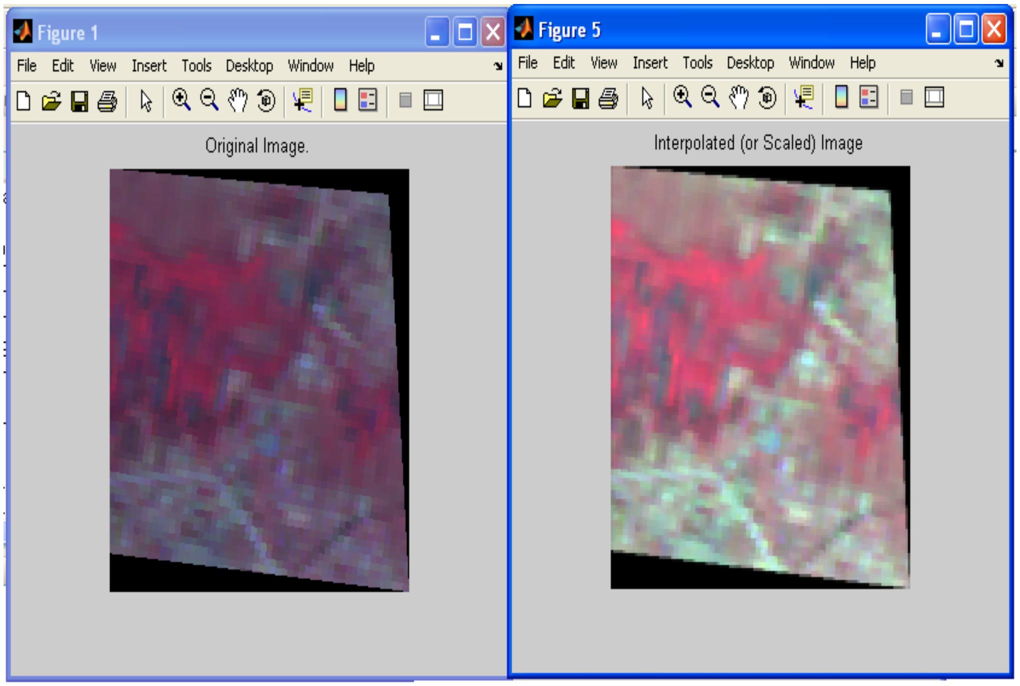
B = 5.7905

Downsampled image size: - 124 x 121 x 3.

The input image is downsampled by the required integer factor and on this, we apply various interpolation techniques as outlined before. The results are tabulated in Table 1.2.

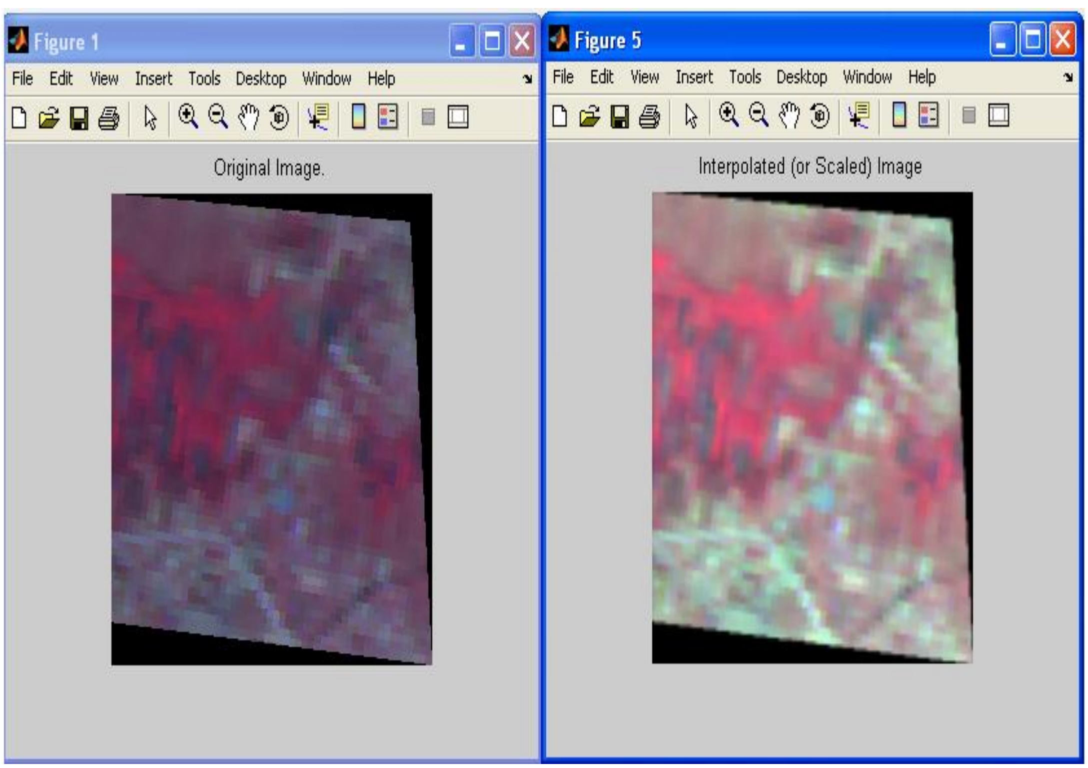
Intp method	Nni	Blt	Bct	Cbs (Polynomial of degree 5)	Sinc	Lt
Entropy of output image, in bits/symbol.	R = 5.5837, G = 6.0756, B = 5.9356	R = 5.6391, G = 6.1279, B = 5.9897	R = 6.3358, G =7.0679, B = 6.5373	R = 6.4332, G = 7.1254, B = 6.5987	**HAMMING** R = 6.3827, G = 7.0488, B = 6.5569 **KAISER** R = 6.4073, G = 7.0551, B = 6.5844	R = 6.5558, G = 6.9486, B = 6.6039
PSNR (in dB)	R = 4.21, G = 5.50, B = 5.62	R = 4.14, G = 5.43, B = 5.60	R = 4.17, G = 5.43, B = 5.46	R = 3.82, G = 5.15, B = 5.25	**HAMMING** R = 4.21, G = 5.31, B = 5.45 **KAISER** R = 4.20, G = 5.28, B = 5.40	R = 5.63, G = 6.95, B = 6.97
NLSE	R = 0.9868, G = 0.9843, B = 0.9883	R = 0.9867, G = 0.9841, B = 0.9882	R = 0.9895, G = 0.9893, B = 0.9892	R = 0.9891, G = 0.9875, B = 0.9921	**HAMMING** R = 0.9869, G = 0.9840, B = 0.9881 **KAISER** R = 0.9877, G = 0.9856, B = 0.9887	R = 0.9890, G = 0.9868, B = 0.9901
Time taken for implementation (in seconds)	3.299496	3.650121	3.950121	12.737286	**HAMMING** 3.962224 **KAISER (β = 0.5)** 5.623799	3.479394

Table 1.2 Result of appling interpolation techniques to LISS III image



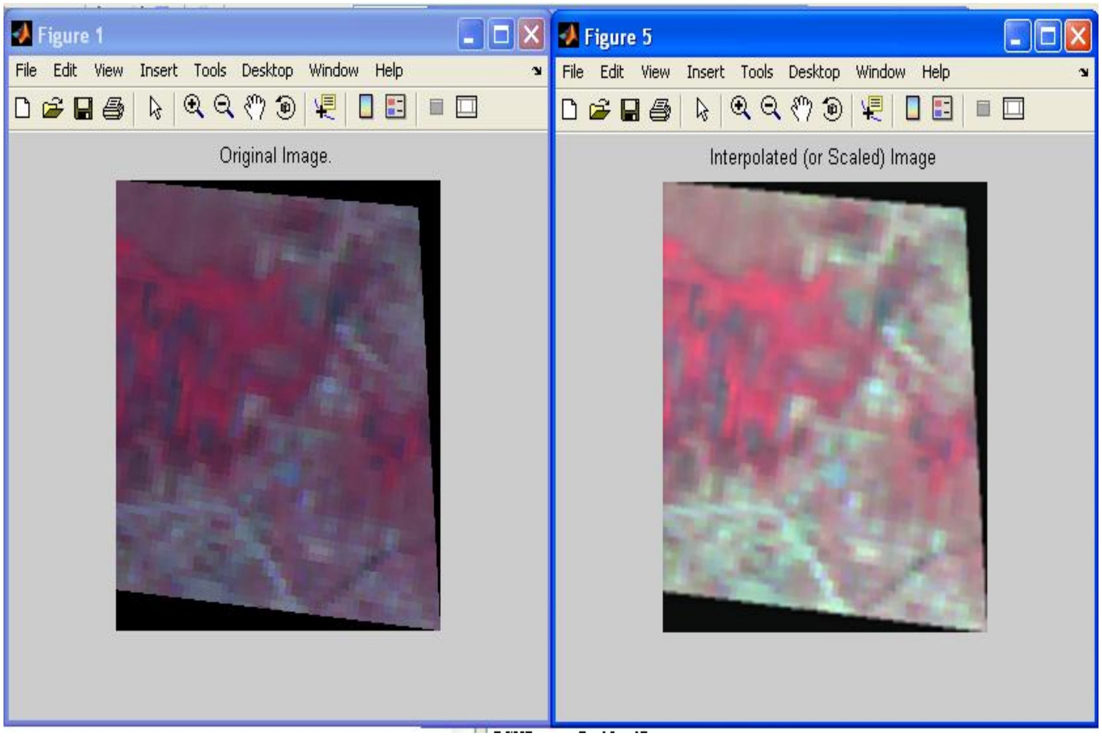
a	b

Figure 1.8 Nearest Neighbourhood Interpolation for LISS III Image



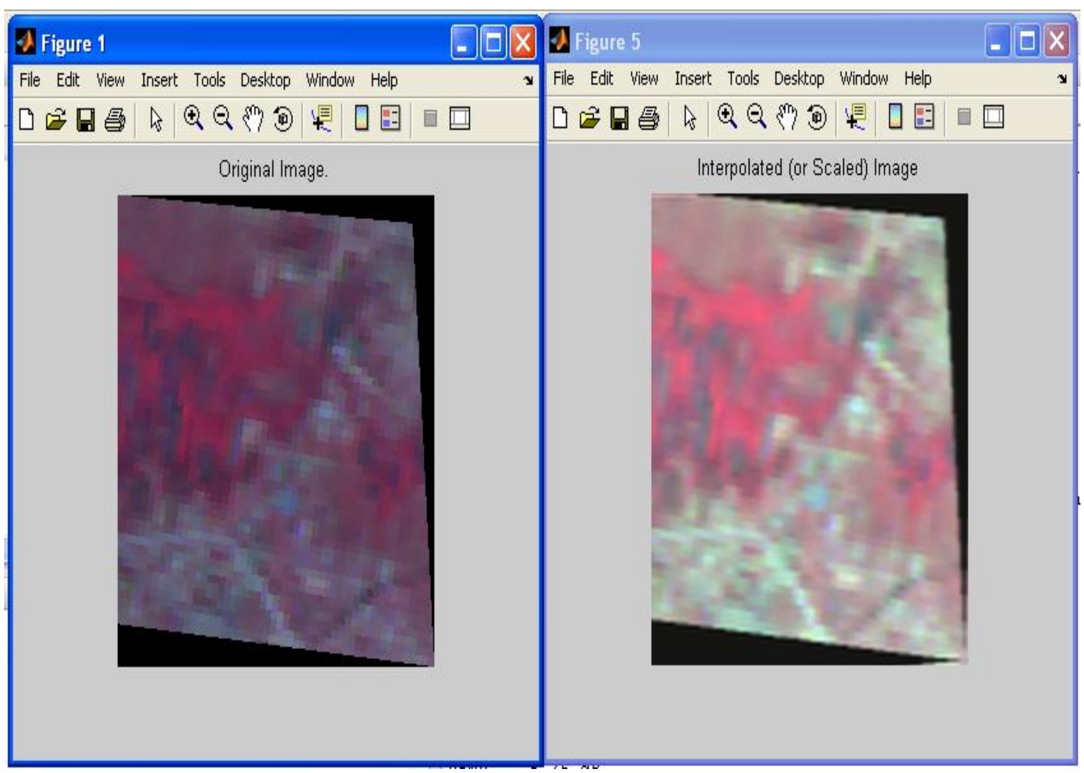
a	b

Figure 1.9 Bilinear Interpolation for LISS III Image



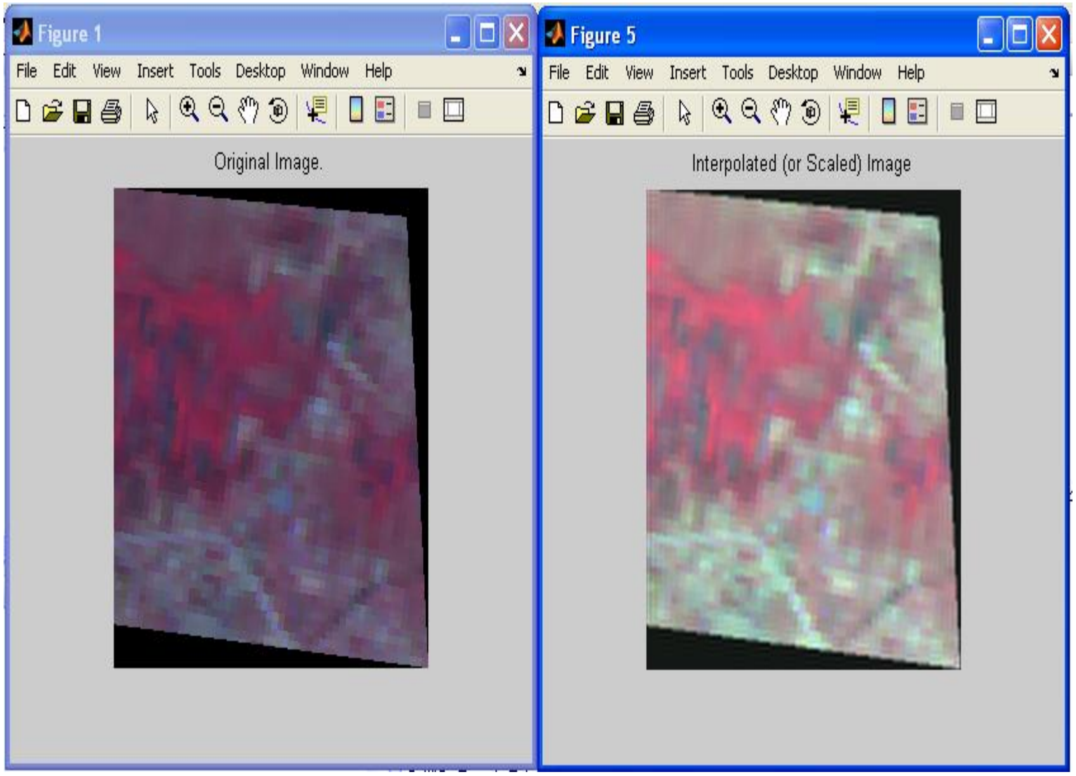
a	b

Figure 1.10 Bicubic Convolution Interpolation for LISS III Image



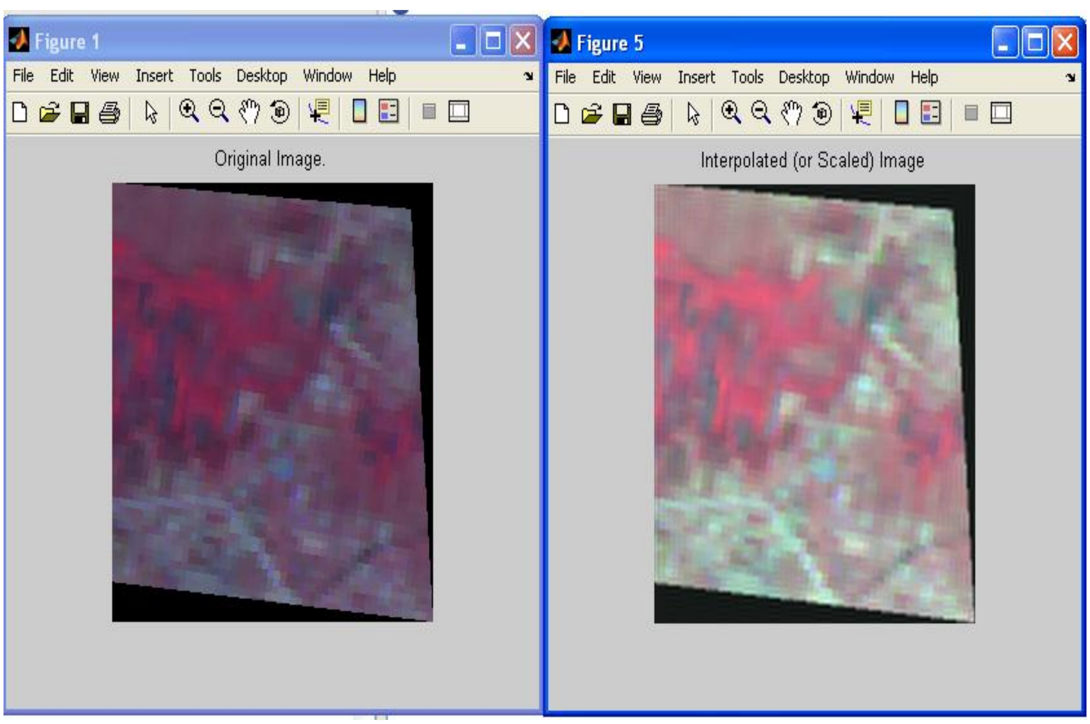
a	b

Figure 1.11 Cubic B-Spline Interpolation for LISS III Image (Polynomial of Degree 5)



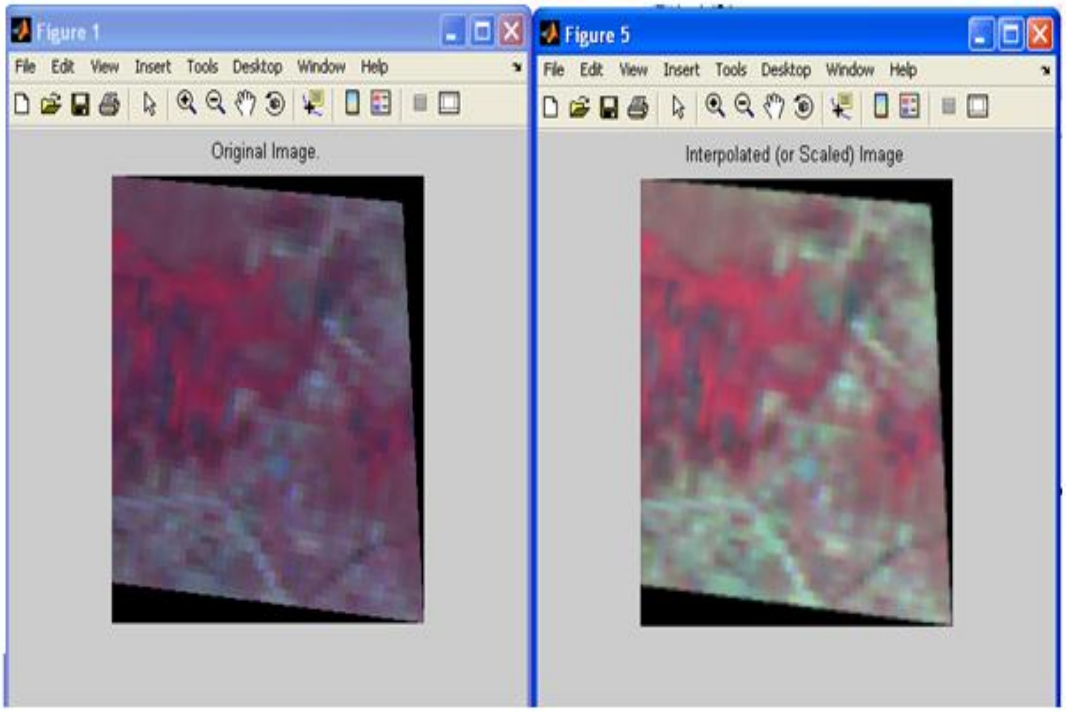
a	b

Figure 1.12 Sinc Interpolation for LISS III Image (Hamming Window)



a	b

Figure 1.13 Sinc Interpolation for LISS III Image (Kaiser Window with $\beta = 0.5$)



a	b

Figure 1.14 Lanczos Interpolation for LISS III Image

Conclusions and Future Scope

The following are the conclusions that are obtained:

Nearest-neighbour interpolation results in a lot of data shuffling, and the image is highly cluttered and prone to noise. This results in strong blurring and aliasing effects in the interpolated image. Nearest neighbour interpolation method also produces a checkerboard effect that is particularly objectionable at high factors of magnification.

Bilinear interpolation results in strong attenuation of high frequencies and blurring of images. The low pass aspect of bilinear interpolation results in artefacts mostly near the edges. It takes more time than nearest neighbourhood technique to get implemented. Although we are using the most efficient bicubic convolution kernel, i.e., Key's kernel, the central part of the interpolated image results in little blurring. Some amount of blocking artefact also occurs. It takes more time and cost for implementation than its 2 predecessor methods. Again, it is quite complex than its 2 predecessor methods.

Cubic B-Spline Interpolation also reduces blurring, blocking artefacts to a very large extent, and the quality of the image is very good. It is most complex algorithm. Cost of implementation is more and it depends upon the order of the Cubic B-Spline polynomial. Time taken for implementation is more. It is more mathematically involved than its predecessor methods. More the order of the polynomial, more the complexity of the algorithm. No sinc-based interpolation results in an acceptable quality with regard to its computational demand (because of filter order N). In addition, this family of synthesis functions is difficult to handle analytically (difficult to get closed-form solutions).

Sinc function has infinite length in spatial domain, i.e., the ideal sinc function is IIR by nature. In general it can only be approximated, thus reintroducing a certain amount of aliasing and blurring. Another drawback of the sinc function is that it decays only slowly, which generates a lot of ringing. Because the Lanczos kernel assumes negative values for $a > 1$, output values can be negative even with non-negative input, a condition called undershoot. Negative values are out of bounds for image signals and cause clipping artefacts. Negative lobes also induce ringing artefacts. However, both undershoot and ringing are reduced compared to the (non-windowed) sinc filter, due to the windowing. Cubic B-Spline Interpolation is the best interpolation method and it is the optimal method for getting excellent expected results. The output image quality is also good when Cubic B-Spline Interpolation method is used. Also, the entropy of the output images are higher than that of the input image, which is the desired result. Irrespective of the type of image interpolation used, the need of the application and visual perception play an important role in choosing the appropriate interpolation method irrespective of its pros and cons. Lanczos interpolation gives good results, but it needs to be exploited properly in Digital Image Processing, when used for Remote Sensing Applications.

Future work may involve the implementation of resolution synthesis algorithm, which performs better than conventional interpolation techniques. One can evaluate the performance of resolution synthesis algorithms not only on RGB colour space, but also on other colour spaces such as HSV, YIQ and CMY, HSI, and YCbCr colour coordinate systems. Since the interpolation kernels (Fourier Transform or Fourier Integral based interpolation kernels) that are presently used are constant, we can go for more sophisticated variable interpolation kernels, such as Wavelet Transform based interpolation techniques whose kernels are variable and the choice of the Mother Wavelet can also be chosen by the designer according to his/her requirements.

Acknowledgements

The authors acknowledge the General Manager, RRSC-S who permitted this work to be carried out at their Centre.

References

Anil. K. Jain, (1989). Fundamentals of Digital Image Processing, Prentice Hall of India Private Limited, New Delhi, India.

C. R. Appledorn (1996). A New Approach to the Interpolation of sampled data, IEEE Transactions on Medical Imaging, Vol. 15, pp. 369-376.

Charles Elachi, (1988). Spaceborne radar remote sensing: Applications and techniques, IEEE Press, New York, U.S.A.

E. H. W. Meijering, W. J. Niessen, M. A. Viergever (1999). The Sinc-Approximating Kernels of Classical Polynomial Interpolation, IEEE International Conference on Image Processing - ICIP '99, vol. III, IEEE Computer Society Press, Los Alamitos, CA, pp. 652-656.

George Joseph, (2009). Fundamentals of Remote Sensing, 2nd Edition, Universities Press, Hyderabad, India.

John R Jensen, (2007). Introductory Digital Image Processing: A Remote Sensing Perspective, 3rd Edition, Pearson Publication, New Jersey, U.S.A.

M. Unser, A. Aldroubi and M. Eden, (1993). B-Spline Signal Processing: Part I—Theory," IEEE Transactions on Signal Processing, vol. 41, pp. 821–832.

M. Unser, A. Aldroubi and M. Eden, (1993). B-Spline Signal Processing: Part II—Efficient Design and Applications, IEEE Transactions on Signal Processing, vol. 41, pp. 834–847.

Philippe Thévenaz, Thierry Blu, and Michael Unser (2000). Interpolation Revisited, IEEE Transactions on Medical Imaging, Vol. 19, No. 7, pp. 739-758.

Robert A. Schowengerdt, (1997). Remote sensing Models and methods for image processing, 3rd Edition, Academic Press, New York, U.S.A.

R. Michael Hord, (1986). Remote Sensing: Methods and Applications, John Wiley and Sons, Inc, New York, U.S.A.

Rafael. C. Gonzalez and Richard. E. Woods, (2009). Digital Image Processing, 3rd Edition, Pearson Education, Inc, New Delhi, India.

Thomas Lillesand, Ralph W. Kiefer and Jonathan Chipman, (2007, New Delhi). Remote Sensing And Image Interpretation, 5th Edition, Wiley India Inc Limited.

Thomas J. Trainer and Fang-Kuo Sun, (1991). Image resampling in remote sensing and image visualization applications, Proc. SPIE, Vol. 1567, 650; doi:10.1117/12.50853.

William. K. Pratt, (2009). Digital Image Processing, 4th Edition, John Wiley and Sons (Asia) Private Limited, Singapore.

A Study on Surface Displacement Estimation using Differential SAR interferometry in the Himalayan Region

Atanu Bhattacharya, [1] Manoj, K. Arora[2] and Mukat, L. Sharma[1]

Earthquake Engineering Department, Indian Institute of Technology, Roorkee, India
Civil Engineering Department, Indian Institute of Technology, Roorkee, India
Email: manoj.arora@gmail.com, atanudeq@gmail.com, sharmamukat@gmail.com

Abstract

The occurrence of great earthquakes in the Himalaya and the subsequent heavy loss of life and damage to the property make it imperative to actively seek reasons and remedial measures. The observation of strong motion and aftershock sequences as well as the investigation of the destruction from these earthquakes, provide the disciplines of seismology and earthquake engineering with informative and valuable data, experiences and lessons, and raise a number of important scientific challenges. One major challenge is that the large earthquakes have long recurrence intervals at any specific place, whereas most of the classical Probabilistic Seismic Hazard approaches make use of short catalogue as basis for the prediction models. The information on displacements from ground measurements is still too scarce in time and spatial coverage to provide convincing evidences. While we believe that technologies such as Synthetic Aperture Radar interferometry will prove even more useful in the future.

However, in India, the use of this technique for surface displacement studies is still in its infancy. During the past few decades, the Himalayan region has been studied fairly extensively in terms of present ongoing deformations. In this research work a study area along the Himalayan Frontal Fault has been selected for pre earthquake displacement study using Synthetic Aperture radar interferometry technique. It is one of the most imperative areas in India now a day, because it was identified as the likely location of the next major earthquake. Displacement rate of 8-12 mm/year in N140E direction of Indian plate towards the Tibetan plate has been obtained.

Introduction

The Himalayan tectonic zone, being a collision plate boundary, is manifested with a number of north-dipping thrusts that are exposed at the surface. The ongoing northwards drift of Indian plate makes the Himalaya geo-dynamically active. To understand the physical process of seismic activities, the knowledge of three manifestations of the process in terms of displacements in pre-earthquake, during the earthquake and post-earthquake, are of paramount importance. The information on displacements from ground measurements is still too scarce in time and spatial coverage to provide convincing evidences. Most displacement estimation techniques rely on detecting the motion of geodetic reference points such as benchmarks. Until recently, such measurements were typically carried out by triangulation surveys. The surveys, however, provided displacement information on point by point basis. Presently, Global Positioning System (GPS) surveys are in vogue for most surface displacement measurement studies but these also provide displacement information on point basis only. Therefore, new technologies are required to fill this gap.

Synthetic aperture radar interferometry (InSAR) can be considered as an alternative to overcome the above mention gap. The interferometric SAR and differential SAR techniques have being frequently used for the pre and post earthquake deformation measurements. Possibilities have been explored by various workers to assess the use of DInSAR for displacement measurement due to earthquakes. The InSAR technique is now applied widely in characterizing the coseismic deformation field resulted from earthquakes, fault geometry and slip distribution (Zebker *et al.* 1994; Wright *et al.* 2003; Fialko 2004 etc); postseismic deformation and relaxation, and interseismic creep (Massonnet *et al.* 1993; Burgmann *et al.* 2002; Jonsson *et al.* 2002; etc.). However, the use of DInSAR for pre earthquake surface displacement study is still in its infancy.

Therefore, in this study an attempt has been made to revisit the pre earthquake surface displacement along HFF using InSAR technique. The results from this study shall assist in accounting for the pre-earthquake displacements in a seismically active region of the Himalaya, which accounts for the strain buildup in the region.

Study Area

In this study we have selected a study area along the HFF, India for its great importance. This area was attractive for this study for several reasons. It is one of the most imperative areas in India now a day, because it was identified as the likely location of the next major earthquake (Kumar et al. 2001). More over the ongoing collision of India into Eurasia has resulted in three major earthquakes along the Himalayan front during the past 100 years (Seeber and Armbruster 1981). From east to west, the sequence includes the 1905 Kangra earthquake (Ms ~7.8), the 1934 Bihar-Nepal earthquake (M = 7.7 ± 0.2), and the 1950 Assam earthquake (Mw ~8.6) (Pandey and Molnar 1988; Ambraseys and Bilham 2000; Bilham 2001). Although none of the earthquakes are reported to have produced primary surface rupture (Seeber and Armbruster 1981). Kumar et al. (2003) described the late Quaternary expression of the HFF at seven sites and demonstrated that the HFF is not blind but is a very active growing fault system. Due to the great seismological importance of HFF, the area along HFF has been selected for displacement study. The geographical and the areal extent map of the study area are shown in Figure 1.

Dataset

Two single look complex (SLC) images obtained from C-band sensor of ERS-1 satellite were used in this study. GAMMA-ISP/DIFF-GEO software (Wegmuller and Werner, 1997) was used for processing. ERS-1 images (Track: 062 and Frame: 2997) were acquired on 02–12–1992, 17–03–1993 respectively. The image acquired on 02–12–1992 was considered as the master image whereas, 17–03–1993 image was considered as the slave image.

Apart from SAR images, an a priori available SRTM DEM georeferenced in geographic latitude and longitude coordinate were used to remove the topographic phase. These DEM had a grid size of 90×90 m and a height standard deviation approximately of ±16 meters in plane terrain.

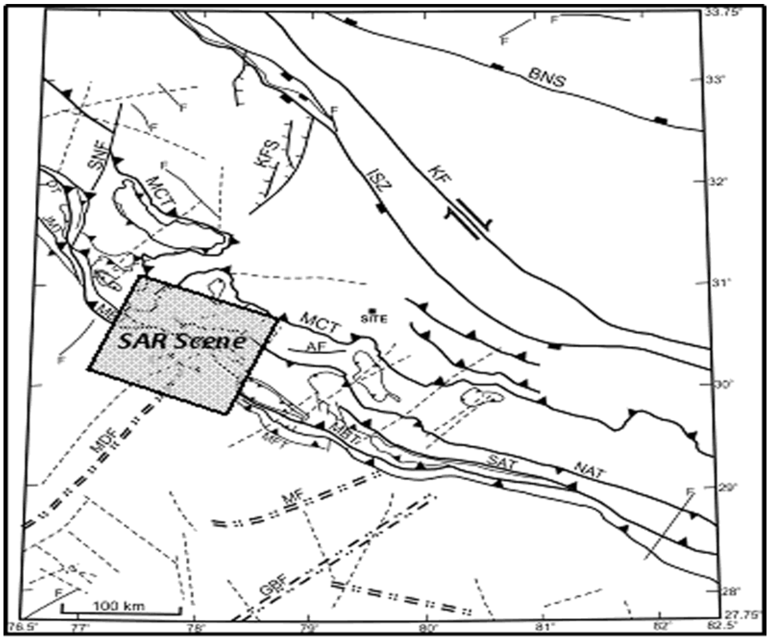


Figure 1: The geological map of the study area showing areal extent of SAR images.

The inset shows the area considered for pre earthquake study. BNS: Banggong-Nujiang Suture; KF: Karakoram Fault; ISZ: Indus Suture Zone; KFS: Kaurik Fault Syatem; MCT: Main Central Thrust; DT: Drang Thrust; JMT: Jwala Mukhi Thrust; AF: Alaknanda Fault; NAT: North Almora Thrust; SAT: South Almora Thrust; RT: Ramgarh Thrust; MBT: Main Boundary Thrust; MDF: Mahendragarh Dehradun Fault; MF: Moradabad Fault; GBF: Great Boundary Fault

SAR Interferometry processing

The relatively recent methodology of surveying land deformation by using the space-borne SAR instrument has gained wide interest. The satellites carrying SAR instruments have a repeat cycle of 25–35 days, giving a unique opportunity to perform long-term monitoring of selected areas. InSAR is a technique that exploits the phase difference between two complex SAR images, captured at different times (e.g. Massonnet & Feigl, 1998; Rosen et al., 2000). The two SAR images are generally acquired from slightly different imaging geometries. Deformation mapping using InSAR has been proven capable of giving relative Line Of Sight (LOS) deformation measurements with accuracy on the order of centimetres to millimetres. However, retrieval of terrain deformations requires the SAR images to be taken from exactly the same position in space at two different times. Unfortunately in practice it is highly improbable that the sensor will return exactly to the same position twice. This causes the presence of a topographic component in the measured interferometric phase, which adds up to the deformation information. The topographic contribution can be separated and subtracted from the deformation by differential technique which is used in this study. An a priori DEM in radar coordinate system was used to extract topography related phase signal. Further, this topographic phase information was subtracted from the one of interest, leaving in this latter only the deformation signal. This technique is known as 2-pass DInSAR.

The first step of 2-pass DInSAR was to transfer the SRTM DEM coordinate into radar coordinate system in order to extract the topography related phase signal. Before that an interpolation technique was used to fill the missing data associated with the available DEM. A forward geocoding method was used to transform the DEM product from map to radar coordinate system. The DEM in UTM coordinate system and radar coordinate system are shown in Figure 2(A-B).

The matching of the two images or coregistration consists essentially in determining the transformation which brings one of the two images, called slave, to be superimposed on the other, the master. In registration the interferometric images were registered to each other at a high degree ($1/8^{th}$ of a pixel) of coregistration accuracy using cross correlation intensity (CCI) algorithm.

After the co-registration of the images, multi-look complex interferograms as well as intensity images were generated. In this study, 4-20 multi-looking was used (4-look in range direction and 20-look in azimuth direction) in order to make the pixel dimension as 80×80 meters. A complex interferogram was generated by point-wise complex multiplication of corresponding pixels in master and slave images, as given in Equation (1).

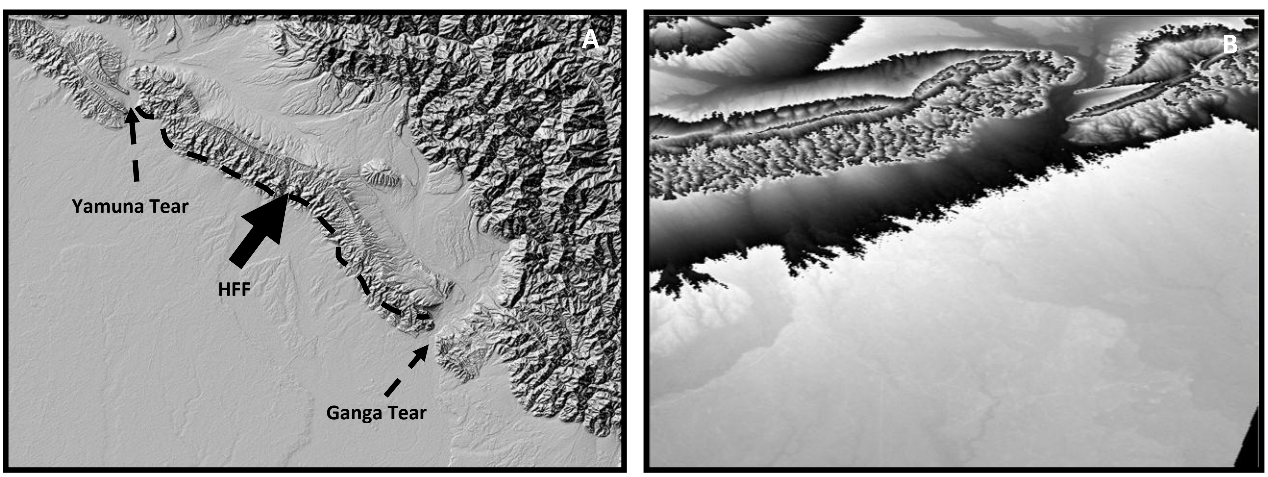


Figure 2: (A) SRTM Digital elevation Model (DEM) in UTM coordinate system and (B) Digital elevation Model (DEM) in radar coordinate system used in this study

$$F_1F_2^* = |F_1|\exp(j\varphi_1)|F_2|\exp(-j\varphi_2) = |F_1||F_2|\exp[j(\varphi_1 - \varphi_2)] \quad (1)$$

where F_1 and F_2 are the single look complex value of a pixel in master and slave image, '*' indicates the complex conjugate. Further, to counteract the influence of the bright point target that might otherwise impact the calculation of the fringe SNR, the interferogram was normalized by the intensities of master and slave images. The normalized interferogram was generated using the Equation (2) and shown in Figure 3A.

$$G(j,k) = \frac{|F_1||F_2|\exp[j(\varphi_1 - \varphi_2)]}{\sum_i^N F_1(i)F_1(i)^* \times \sum_i^N F_2(i)F_2(i)^*} \quad \text{......} (2)$$

where $\sum_i^N F_1(i)F_1(i)^*$ and $\sum_i^N F_2(i)F_2(i)^*$ are the multi- or N-look intensities of master and slave image respectively. In addition, a set of intensity images were also generated and shown in Figure 3B. The high decorrelation effect due to the topography and vegetation cover can be observed from the interferogram.

The interferogram still contained a strong contribution due to the slant range geometry of the system. The effect is particularly visible in the interferometric phase. It can be shown that even for a perfectly flat terrain the side-looking configuration of the radar system causes the slant range distance of the sensor from the terrain to vary passing from the near range to the far range of the swath. This effect is called flattening of interferogram. Due to the flat earth effect, the fringe density of the interferogram may be high, which may introduce complexity in phase unwrapping process. Therefore, before phase unwrapping process, the interferogram needs to be flattened through proper modeling. In this study, an ellipsoidal earth model of orbit based algorithm was used for interferogram flattening. The flattened interferogram is shown in Figure 4A.

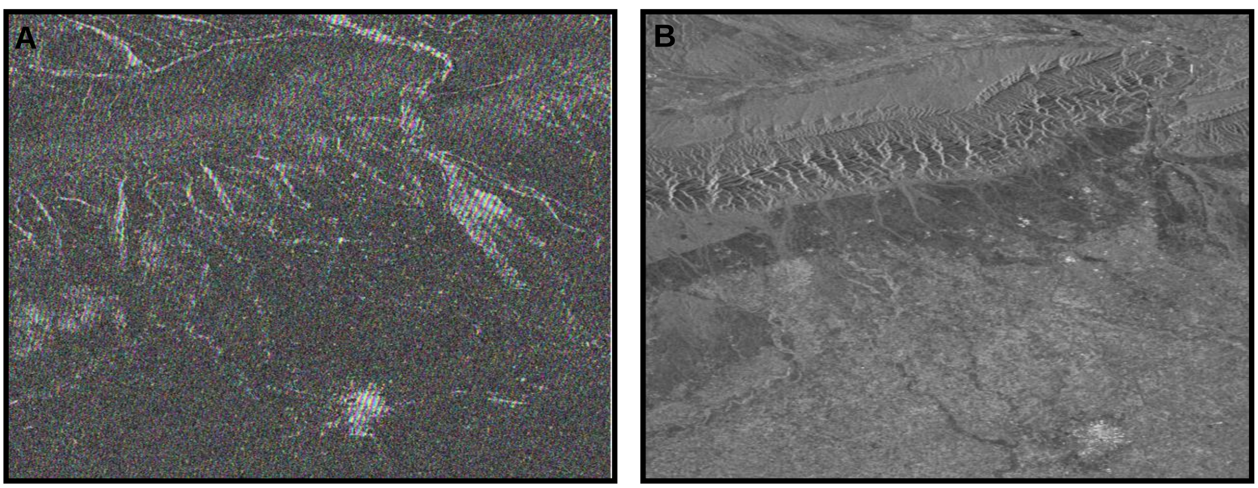


Figure 3. (A) Normalized Complex Interferogram and (B) Coregistered Intensity images of HFF using ERS-1 dataset

Since InSAR is a coherent technology, the most important constraint for the radar echo is coherence. For a pair of SLC images the correlation coefficient (γ) is defined as

$$\gamma = \frac{\langle E_1 E_2^* \rangle}{\sqrt{\langle |E_1|^2 \rangle \langle |E_2|^2 \rangle}} \quad \text{......} (3)$$

The average coherence was also been found to be low (Figure 4B, which may not be adequate for phase unwrapping. Therefore, an adaptive filtering algorithm proposed by Goldstein and Werner (1998) was used to significantly improve fringe visibility resulting in reduction of noise introduced by temporal or baseline related decorrelation. The algorithm is based on smoothing the spectrum of the interferogram *Z(u,v)* in patches using the amplitude of the spectrum. The spectrum is weighted by multiplication with its own intensity to the power of an exponent ∞

$$Z^{/}(u,v) = Z(u,v)\left|Z(u,v)\right|^{\alpha} \qquad (4)$$

where $Z^{/}(u,v)$ is the spectrum of the filtered interferogram. This algorithm was used to enhance the signal (assumed to have strong amplitude), and suppress the noise (assumed to have significantly lower amplitude) in the spectrum. In this way the filter was used in non-isotropic manner and changes its nature according to the characteristics of the terrain (Hanssen, 2001). Further, a smoothened interferogram was also produced from this filtering algorithm. The smoothened interferogram and improved coherence images are shown in Figure 5A and Figure 5B respectively.

After getting the smoothened interferogram, phase unwrapping of the image was carried out. In this study, minimum cost flow networking (MCF) algorithm, proposed by Costantini (1998), was used for phase unwrapping. The MCF algorithm can be considered as a global minimization problem with integer variables. To produce a consistently unwrapped solution, integer phase cycles are added to the each edge of the unwrapping grid.

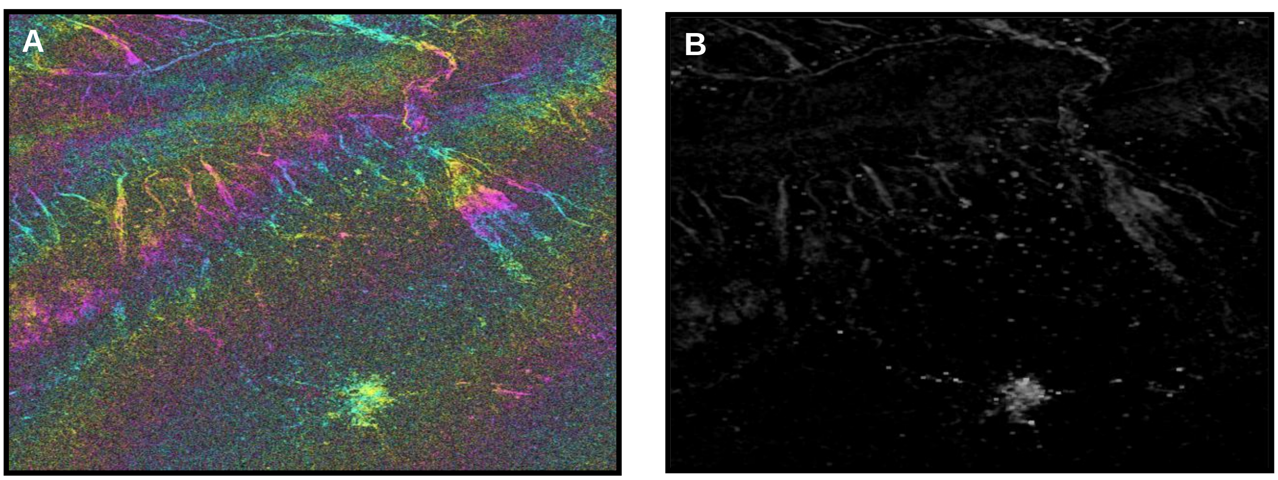


Figure 4: (A) Flattened Interferogram and (B) Initial Coherence image of HFF Area using ERS-1 dataset

The actual differential interferogram was obtained by subtracting the phase information from SRTM DEM from the interferometric phase and then multiplying with a factor $\frac{\lambda}{4\pi}$, the displacement was determining (Usai, 2001). The displacement map in line of sight direction thus produced was then geocoded using a set of GCP's and shown in Figure 6A. The geocoded displacement map in ground range (Figure 6B) direction was also generated using the radar geometry and LOS displacement. These maps clearly portray significant displacements on the surface of earth along HFF.

Results and discussion

The geocoded displacement images were interpreted in details which are discussed in following paragraphs. From the geocoded displacement maps, shown in Figure 6A and Figure 6B, displacements of an area extended approximately 25 km from HFF were estimated. During three and half month duration, the mean values of displacements along LOS and ground range direction were obtained as 4.03±1.01mm and 11.08±4.0 mm respectively.

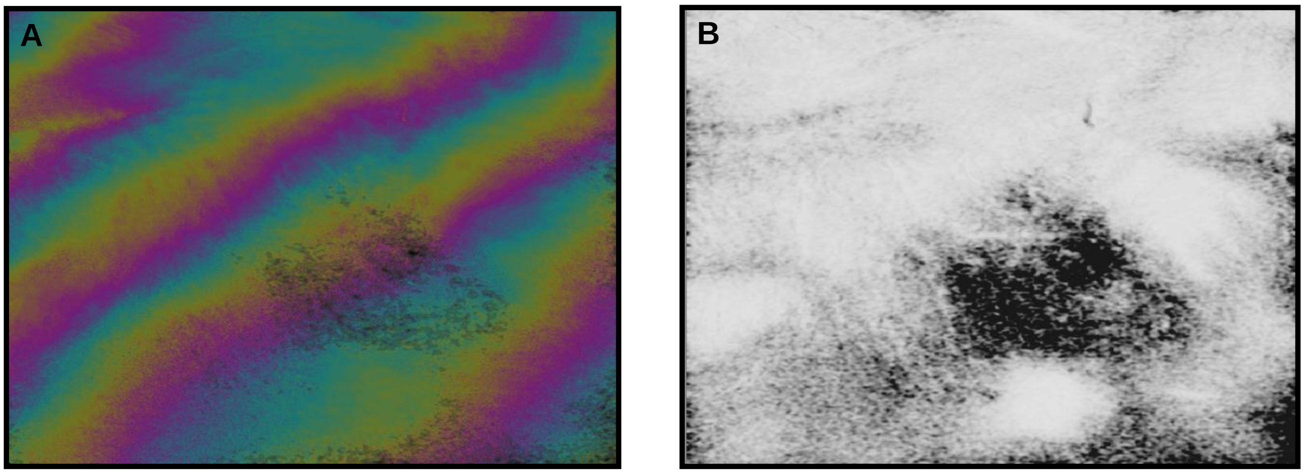


Figure 5: (A) Filtered interferogram and (B) Coherence image after applying adaptive filter of the study area using ERS-1 dataset

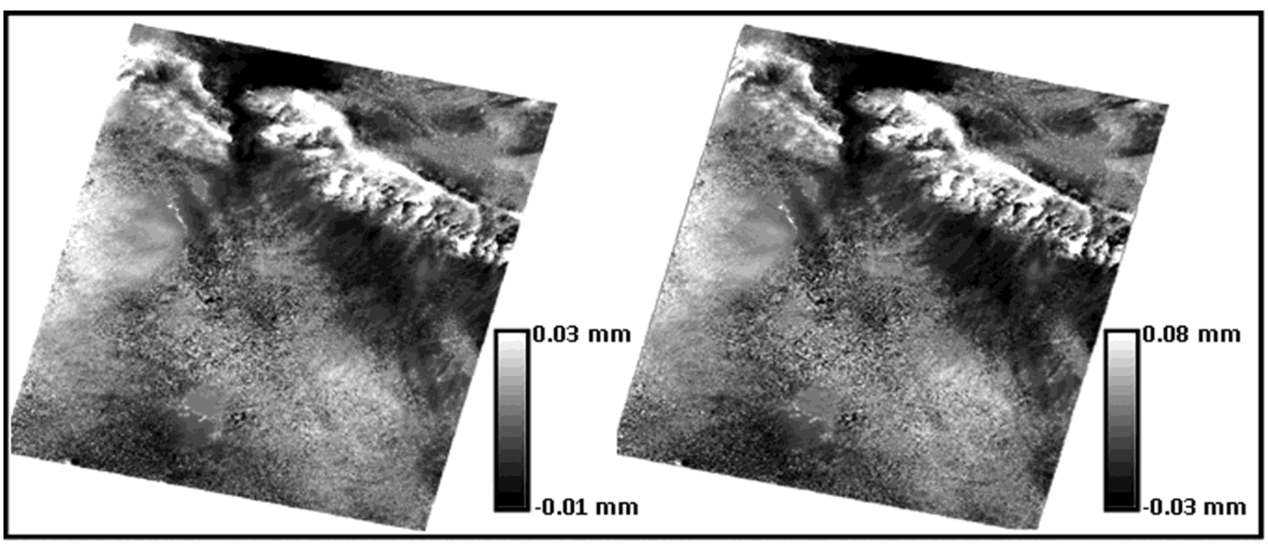


Figure 6: Geocoded displacement map (A) Line of sight (LOS) direction and (B) Ground range direction

The orientation of the image was estimated with respect to the true north direction (N14^{0}E). The horizontal displacement of Indian plate towards Tibetan plate along this north-east direction (N14^{0}E) was also estimated, as demonstrated in Figure 7. To achieve this, the projection of LOS displacement in the ground range direction was determined by knowing the radar mean look angle (21^0). Thus, an average displacement rate of 2.6±0.8 mm in N14^{0}E direction of Indian plate for three and half month duration (which can be approximated to 7-12mm displacement rate per year) towards the Tibetan plate was obtained. However, the present convergence rate is relatively lower than the reported convergence rate along HFF based on the offset of late Pleistocene and Holocene sediments (Wesnousky *et al.* 1999; Lave and Avouac, 2000; Kumar *et al.* 2001). A wealth of geophysical evidences demonstrate that the top surface of India's basement rock flexes and slides beneath the Himalaya, not steadily but in lurches during great earthquakes which may result in spatially varying deformations along the Himalaya (Bilham *et al.* 2001) which in turn is supported by a wide range of observed convergence rates of different portions of the Himalaya reported by Kumar *et al.* 2003. It is worth noting that the present estimated convergence rate using InSAR technique are relatively lower with respect to previous studies. Various explanations can be given for this low convergence rate. Bilaham and Ambrasys (2005) have tried to re-evaluate the convergence rate between India and Tibet for the past five centuries. Averaged over the entire Himalaya, the calculated rate (<5 mm/yr) was found to be less than one third of the convergence rate observed from GPS measurements in the past decade (18 mm/yr). The absence of repeated rupture anywhere in the Himalaya shows that DInSAR derived displacement as obtained in this study appear to be correct if explanations for the missing slip are excluded. The results reinforce the idea of 'velocity deficit' coined by Bilham and Ambrasys (2005) which interpret the low value of deformation to be absorbed either by an aseismic process in the form of geological deformation (folding, thickening and other forms of plastic deformation) or slow aseismic slip, or it may be recovered in the form of displacement delivered by a future earthquake driven by elastic strain. The low values emphasize the need to study the long period energy release by revisiting the already acquired data in the Himalayas. Nevertheless, the convergence rate in this study, in general, is in agreement with convergence rate reported by Lyon-Caen and Molnar (1985); Molnar, 1990); Jackson & Bilham, 1994; Bilham *et al.* 1997, 1998; Larson *et al.* 1999; Banerjee and Burgmann, 2002. Thus, a significant conclusion drawn from this study may be the building up of slow strain across the locked portion of the Himalayan thrust system south of the Greater Himalaya.

Conclusions

An advanced remote sensing technique, namely 2-pass DInSAR, has been used to estimate the surface displacement on a seismically active region of the Himalaya between Ganga and Yamuna Tear. An average displacement rate of 2.6±0.8 mm in N14^{0}E direction of Indian plate for three and half month duration, which can be approximated to 7-12mm displacement rate per year, towards the Tibetan plate has been obtained. However, the present convergence rate is found to be relatively lower than the reported convergence rates along HFF. An endeavour has been made to understand the relatively low convergence rates in this area with respect to previous studies. To attribute the low values many studies in the area are required to be carried out including the possibilities of occurrence of silent/quite earthquakes, aseismic slip, differential movement of Delhi Hardwar ridge etc. In view of the contemporary seismicity and conspicuous displacements, study of long term observations of this surface movement is recommended to be carried out to reveal the dynamic process in this region. This may require a time-series analysis of DInSAR data.

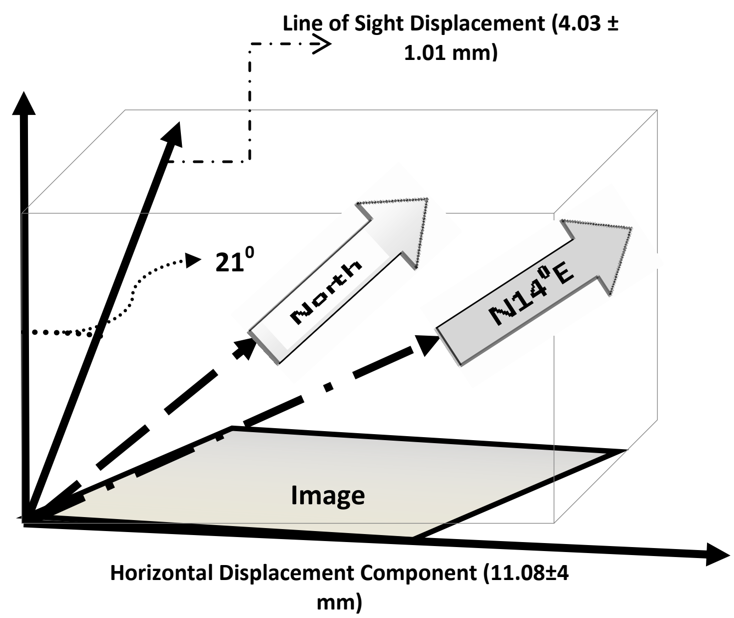


Figure 7: Depiction of displacement components in different direction

Acknowledgements

The SAR images have been procured by Eurimage S.p.A Club, Rome, Italy for the research work. The processing has been done on GAMMA_ISP/DIFF_GEO software procured under Department of Science and Technology (DST) funded research scheme.

References

Banerjee, P., and Burgmann, R. (2002). Convergence across the northwest Himalaya from GPS measurements, Geophysical Research Letters 29 (13), 1,652-1,655.

Besse, J., and Courtillot, V. (1989). Paleogeographic maps of the continents bordering the Indian Ocean since the early Jurassic, Journal of Geophysical Research 93 (B10), 11,791-11,808.

Bilham, R., Larson, K., and Freymueller, J. (1997). GPS measurements of present-day convergence across the Nepal Himalaya. Nature 386, 61-64.

Bilham, R., Blume, F., Bendick, R., and Gaur, V.K. (1998). Geodetic constraints on the translation and deformation of India, implications for future great Himalayan earthquakes, Current Science 74 (3), 213-229.

Bilham, R., and Gaur, V. K. (2000). Geodetic contributions to the study of seismotectonics in India, Current Science 79 (9), 1,259-1,269.

Bilham, R., Gaur, V.K., and Molnar, P. (2001). Himalayan Seismic Hazard, Science, 293, 1442-1445.

Bilham, R., and Ambraseys, N. (2005). Apparent Himalayan slip deficit from the summation of seismic moments for Himalayan earthquakes, 1500-2000, Current Science 88 (10), 1,658-1,663.

Burgmann, R., Ayhan, M.E., Fielding, E.J., Wright, T.J., McClusky, S., Aktug, B., Demir, C., Lenk, O., and Turkezer, A. (2002). Deformation during the 12 November 1999 Du¨zce, Turkey, Earthquake, from GPS and InSAR Data, Bulletin of the Seismological Society of America 92 (1), 161–171.

Costantini, M. (1998). A Novel Phase Unwrapping Method Based on Network Programming. IEEE Transactions on Geoscience and Remote Sensing 36 (3), 813-821.

Dewey, J. F., Cande, S., and Pitman, W. C. (1989). The tectonic evolution of the India/Eurasia collision zone, Ecolgae Geologicae Halvetiae 82 (3), 717-734.

Fialko, Y., Simons, M., and Agnew, D. (2001). The complete (3-D) surface displacement field in the epicentral area of the 1999 Mw 7.1 Hector Mine earthquake, California, from space geodetic observations. Geophysical research letters 28 (16), 3,063-3,066.

Gabriel, A.K., Goldstein, R.M., and Zebker, H.A. (1989). Mapping small elevation changes over large areas: differential radar Interferometry, Journal of Geophysical Research 94, 9,183-9,191.

Goldstein, R.M., and Werner, C.L. (1998). Radar Interferogram filtering for Geophysical Applications, Geophysical Research Letters 25 (21), 4,035-4,038.

Hanssen., R.F. (2001). Radar Interferometry, Data Interpretation and Error Analysis, Kluwer Academic, Netherlands, 53-54.

Jackson, M.E., and Bilham, R. (1994). 1991-1992 GPS measurements across the Nepal Himalaya, Geophysical Research Letters 21(12), 1,169-1,172.

Jonsson, S., Zebker, H., Segall, P., and Amelung, F. (2002). Fault Slip Distribution of the 1999 M_w 7.1 Hector Mine, California, earthquake, Estimated from Satellite Radar and GPS Measurements, Bulletin of the Seismological Society of America 92 (4), 1,377–1,389.

Kumar, S., Wesnousky, S.G., Rockwell, T.K., Ragona, D., Thakur, V.C., and Seitz,G.G. (2001). Earthquake Recurrence and Rupture Dynamics of Himalayan Frontal Thrust, India, *Science*, 294, 2,328-2,331.

Kumar, S., Wesnousky, S.G., and Rockwell, T.K. (2003). The Himalayan Frontal Thrust (HFT) is not blind, Earthquake Geology in Reverse Faulting Terrains, Seattle Annual Meeting, Session 24,Washington, November 2-5.

Kumar, S., Wesnousky, S.G., Rockwell, T.K., Briggs, R.W., Thakur, V.C., and Jayangondaperumal, R. (2006). Paleoseismic evidence of great surface rupture earthquakes along the Indian Himalaya, Journal of Geophysical Research 111(B3), B03304- B03322.

Kumar, S., Wesnousky, S.G., Jayangondaperumal, R., Nakata, T., Kumahara, Y., and Singh, V (2010). Paleoseismological evidence of surface faulting along the northeastern Himalayan front, India: Timing, size, and spatial extent of great earthquakes, Journal of Geophysical Research 115 (B1), B12422-B12441.

Larson, K. M., Burgmann, R., and Bilham, R., and Freymueller, J. T. (1999). Kinematics of India_Eurasia collision zone from GPS measurements, Journal of Geophysical Research 104 (B1), 1,077-1,093.

Lave, J., and Avouac, J.P. (2000). Active folding of fluvial terraces across the Siwaliks Hills, Himalayas of central Nepal, Journal of Geophysical Research 105 (B3), 5,735-5,770.

Lyon-Caen, H., and Molnar, P. (1985). Gravity anomalies, flexture of the Indian plate, and the structure, support and evaluation of the Himalaya and Ganga Basin, Tectonics 4, 513-538.

Massonnet, D., Rossi, M., Carmona, C., Adragna, F., Peltzer, G., Feigl, K., and Rabaute, T. (1993). The displacement field of the Landers earthquake mapped by radar Interferometry, Nature 364,138-142.

Massonnet, D., Feigl, K., Rossi, M., and Adragna, F. (1994). Radar interferometric mapping of deformation in the year after the Landers earthquake, Nature 369, 227-230.

Molnar, P. (1990). A review of the seismicity and the rates of active underthrusting and the deformation of the Himalaya, Journal of Himalayan Geology, 1, 131-154.

Ni, J., and Barazangi, M. (1984). Seismotectonics of the Himalayan Collision Zone, Geometry of the Underthrusting Indian Plate beneath the Himalaya, Geophysical Research Letter, 89 (B2), 1,147-1,163.

Pandey, M.R., Tandukar, R.P., Avouac, J.P., Lave, J., and Massot, J.P. (1995). Interseismic strain accumulation on the Himalayan crustal ramp (Nepal), Geophysical Research Letters, 22 (7), 751-754.

Paul, J., Burgmann, R., Gaur, V. K., Bilham, R., Larson, K. M., Ananda, M .B., Jade, S., Mukul, M., Anupama, T. S., Satyal, G., Kumar, D. (2001). The motion and active deformation of India, Geophysical Research Letters, 28 (4), 647-651.

Rosen, P.A., Hensley, S., Joughin, I.R., Li, F.K., Rodriguez, E., Goldstein, R.M., and Madsen, S.N. (2000). Synthetic Aperture Radar Interferometry. Proceedings of IEEE. 88 (3). 333-382.

Seeber, L., and Armbruster, J. G. (1981). Great detachment earthquakes along Himalayan arc and long term forecasting, Earthquake prediction: An international review, D.W.Simpson and P.G.Richards ed., Maurice Ewing Series, American Geophysical. Union, Washington, United States, 259-277.

Sridevi, J. (2004). Estimates of plate velocity and crustal deformation in the Indian subcontinent using GPS geodesy, Current Science, 86 (10), 1,443-1,448.

Thakur, V. C. (2004). Active tectonics of Himalayan Frontal Thrust and Seismic Hazard to Ganga Plain, Current science, 86 (11), 1,554-1,560.

Usai, S. (2001). A New Approach for Long Term Monitoring of Deformations by Differential SAR Interferometry, PhD Thesis, Delft University Press, 21-24.

Wegmuller, Urs., and Werner, C. (1997). Gamma SAR Processor and Interferometry Software. Third ERS Scientific Symposium, Florence, Italy, 1,687-1,692.

Wesnousky, S.G., Kumar, S., Mohindra, R. and Thakur, V.C. (1999). Uplift and convergence along the Himalayan Frontal Thrust of India, Tectonics, 18 (6), 967-976.

Wright, T. J., Lu, Z., and Wicks, C. (2003). Source model for the Mw 6.7, 23rd October 2002, Nenana Mountain Earthquake (Alaska) from InSAR. Geophysical Research letters, 30 (18), 1,974-1,977.

Zebker, H.A., and Goldstein, R.M. (1986). Topographic Mapping from Interferometric Synthetic Aperture Radar Observation, Journal of Geophysical Research, 91(B5), 4,993-4,999.

Zebker, H.A., Rosen, P.A., Goldstein, R.M., Gabriel, A., and Werner, C.L. (1994). On the derivation of coseismic displacement fields using differential radar interferometry: The Landers earthquake, Journal of Geophysical Research, 99 (B10), 19,617-19,634.

SAR Applications in Snow

G. Venkataraman
Centre of Studies of Resources Engineering,
Indian Institute of Technology Bombay, Mumbai - 400076
E-mail: gv@iitb.ac.in

Introduction

This lecture elucidates the recent developments in the application of Microwave Remote Sensing techniques particularly space borne synthetic aperture RADAR (SAR) systems for snow studies. SAR is an active system imaging the earth's surface in day and night, in all weather, through cloud or haze and their spatial resolution is compatible with the topographic variations in the Himalayan region. Currently space borne synthetic aperture RADAR data are widely used to map glacier covered area in alpine and Himalayan regions and also to develop algorithms to infer geophysical parameters. Back scatter image of RADAR is extremely useful for the quantitative estimation of snow pack characteristics like snow wetness, snow grain size, snow density and snow water equivalence which are essential for hydrologic applications.

SAR data can also be useful to map snow cover and also identify different types of snow. Multi-temporal SAR data have great potential in mapping glacier facies which has distinct advantage in the glacier mass balance estimation.

Radar Data Processing Methodology

For any meaningful and quantitative analysis of Radar images, it is necessary to convert the DN values of these intensity images into their corresponding radar backscattering coefficient (σ^o) values. A variety of factors influence backscatter strength including satellite ground-track, incidence angle, radar polarization, surface roughness and the dielectric properties of the surface. Different objects having same digital number may likely to correspond to different backscatter values. Hence, more accurate analysis on microwave remote sensing image can be done on backscatter value images. For example, Advanced Synthetic Aperture Radar data processing methodology is given in this chapter. As described in ESA document (Rosich *et al.*, 2004) , the backscattering coefficient (σ^o) values of ASAR are obtained by combining the radar average pixel intensity and the incidence angle (I_j) at each pixel location, where the angle of incidence is obtained from the ASAR header data using interpolation method.

Radar average pixel intensity was then converted into backscatter coefficient (σ_0) using the following equation (Rosich *et. al.*, 2004).

$$\sigma_j^{o} = \frac{\langle DN^2 \rangle}{K} \times \left(\frac{Rd}{Rref} \right)^4 \times \left(\frac{1}{G^2} \right) \times Sin(Ij) \text{ for APS Mode} \quad (1)$$

$$\sigma_j^{o} = \frac{\langle DN^2 \rangle}{K} \times \left(\frac{Rd}{Rref} \right)^3 \times \left(\frac{1}{G^2} \right) \times Sin(Ij) \text{ for IMS Mode}$$

Where I_j is the incidence angle at the j_{th} range pixel (the angle between radar line of sight and vertical when assuming a flat earth or it is equivalent to look angle).K is the absolute calibration constant, $<DN_2>$ is average pixel intensity, G_2 is two-way antenna gain at distributed target look angle, Rd is distributed target slant range distance and Rref is reference slant range distance. All Images were multi-looked 5 times in azimuth and 1 time in range direction. Originally the image size is 24886 lines by 6033 pixels. After multi-looking and also removing non-overlapping portion of the image, the size of the image is 4997 lines by 6033 pixels. The final spatial resolution is about 19.5 meters in azimuth and 7.8 meters in range. All the images were subjected to speckle suppression using Frost filter (Frost *et al.,* 1982) with window size 3 x 3, coefficient of variation and smoothing parameter using ERDAS Imagine radar module. The backscatter intensity images were converted into backscattering coefficient by taking $10.Log_{10}$ (σ_{0j}).

Using slant-to-ground range correction tool, the satellite data are projected into ground distance. Each pixel represents a specific area on the ground. Multi-look images are projected from slant-to-ground range. The input (slant range) pixel size 7.8 m is converted into given output (ground range) pixel size 19.5 m using satellite parameters like near range look angle, satellite height, slant range pixel size, and near slant range. After slant to ground range correction, finally spatial resolution of image is about 19.5 meters in azimuth and 19.5 meters in ground range and the size of the image is 4983 lines by 3685 pixels.

Due to the oblique incidence of SAR beam the terrain features become distorted in the image. This terrain distortion correction is performed by relating each pixel in the SAR image into cartographic reference system using high precision DEM and knowledge of the imaging and processing geometry. Among the above parameters geometric structure of the target plays an important role to correct the radar backscatter coefficient values. The topographic effect can be removed from the backscatter coefficient values by considering the local incidence angle. The corrected backscatter intensity image was converted into backscattering coefficient by taking $10.Log_{10}$ ($\sigma^{0}{}_{i}$). Finally, real time snow parameters collected on these dates at different locations have been considered forcalculating Snow parameters and corresponding backscattering values were obtained from the corrected SAR backscattering images.

Microwave Interaction with snow

Microwave interaction with snow (Fig.1) depends on dielectric and geometric properties of the object. Sensor properties also influence the target response to incident wave. In the case of snow covered terrain, different processes contribute to the total backscattered signal from the snow is sum of scattering from air-snow, volume scattering in the snow layer and scattering from the snow-ground attenuated by snow layer (Ulaby *et al*, 1986).

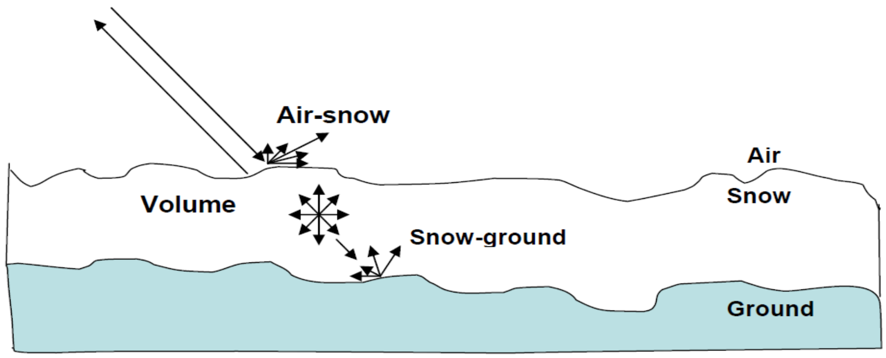


Fig.1. Microwave interaction with snow covered terrain

$$\sigma^0(\theta) = \sigma_s^0(\theta) + \sigma_v^0(\theta') + \frac{\gamma_s^2(\theta')}{L^2(\theta')}\sigma_g^0(\theta') \qquad (2)$$

Where $\sigma_{0sa}(\theta)$ is surface scattering by the air-snow interface, $\sigma_{0s}(\theta')$ is the volume backscattering by the snow layer, $\gamma(\theta')_s$ is the power transmission coefficient for the air-snow boundary, $L_2(\theta')$ is the one-way loss factor of the snow layer, $\sigma_{0g}(\theta')$ is the scattering coefficient of the ground surface, and θ' is the transmission angle in the snow layer.

Information about the extension and the properties of snow-covered areas are very important for climatological and hydrological investigations. Because the physical mechanisms governing the backscattering from natural snow cover are complicated, unequivocal relationships between snow pack properties and SAR observations do not exist (Strozzi and Matzler, 1998). Hence, an intensive study is required for proper understanding of the interaction between microwaves and snow cover. These studies can proceed in two different ways.

For dry snow cover the backscattering from the snow surface may be neglected and the total backscattering is a combination of volume scattering from snow and surface scattering from the round. In *wet snow*, the absorption loss is high and the scattering from the snow ground interface may be neglected. The presence of liquid water content increases the absorption coefficient. Therefore, the volume scattering albedo is inversely correlated to snow wetness and snow density. At constant wetness and density, the volume scattering albedo increases as the size of the scatterers or their size variation increases, because, as Rayleigh scattering theory explains, the scattering coefficient is proportional to the third power of the scatterer's radii for a given volume fraction (Shi and Dozier, 1995).

Snowpack characteristics

Empirical Relations

On the experimental side, insitu backscattering measurements of a homogeneous scene are made and the snowcover characteristics are collected simultaneously (Strozzi and Matzler, 1998). These measurements can be used in developing empirical models for snow parameters.

Backscattering from a snow covered terrain depends on (i) sensor parameters which includes frequency, polarization and viewing geometry, and (ii) snow pack and ground parameters which includes snow density, liquid water content, ice particle size and shape, surface roughness parameters, stratification also.

Inversion Algorithms

Inversion Model for dry Snow density

Microwave interaction with snow depends on dielectric and geometric properties of the snow. Sensor properties also influence the target response to incident wave. In the case of snow covered terrain, different processes contribute to the total backscattered signal. 1) Scattering at the air-snow interface. 2) Scattering inside the snow layer due to ice particles and at density boundaries. 3) Scattering at the snow-ground interface. Total backscattering from the snow is sum of scattering from air-snow, volume scattering in the snow layer and scattering from the snow-ground attenuated by snow layer (Ulaby *et al.,* 1986). Due to large penetration (approximately 10m at 200 kg/m^3 snow density, see Fig. 2) at C-band, in dry snow layer and small contribution of air/snow interface scattering in total backscattering from dry snow, we can neglect the air/snow interface scattering contribution from the total backscattering coefficient (Fig.3) (Shi et. al., 1990). Therefore total backscattering coefficient for dry snow is the sum of two main components i.e. snow volume backscattering and snow ground backscattering.

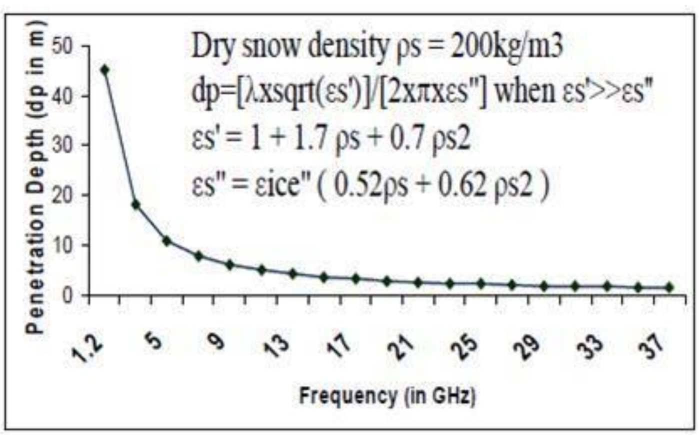


Fig.2. Plot between frequency and penetration depth

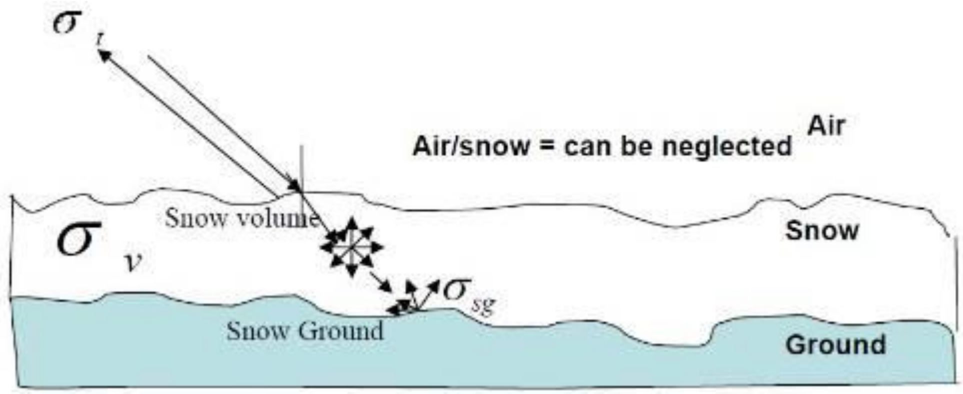


Fig.3. Backscattering from dry snow covered terrain

Under an assumption that snow surface has no significant air/snow interface scattering and angle of refraction remains constant in dry snow pack, total backscattering from the dry snow pack can be defined as

$$\sigma_t^{pp}(k,\theta) = \sigma_v^{pp}(k_1,\theta_r) + \sigma_{sg}^{pp}(k_1,\theta_r) \qquad (3)$$

In Eq. (3) σ_t, σ_v and σ_{sg} are total backscattering, volume backscattering and snow ground interface backscattering coefficients respectively. pp is either VV or HH. k and k_1 are the incident wave number in the air and in snow pack respectively. θ is incident angle and θ_r is angle of refraction.

The incident angle at air-snow interface and the angle of refraction in the snow layer and snow-ground interface can be related by the Snell's law. The observable change of wavelength at different density in snow layers is found at L-band (Shi and Dozier, 2000) by comparing the difference between incident angle at air-snow interface and at snowground interface with different snow density (100 - 500 kg/m^3). For a given snow density, incident angle at the snow surface causes the change in the incident angle in the snow layer. These changes are observed at L-band propagation wavelength by Shi and Dozier (Shi and Dozier, 2000). Therefore these changes can also be considered at C-band because C-band has lower penetration capability as compared to L-band. Hence C-band is more sensitive for above mentioned changes as compared to L-band. Since both the angle of refraction and wavelength shifts are only a function of the snow dielectric constant, which is mainly governed by the snow density, it is possible to estimate snow density by using C-band ASAR data.

For developing an algorithm for snow density estimation, we used the first order volume scattering model and the integral equation method with an exponential correlation function for the surface backscattering contribution from the snow–ground interface. Both models depend on the four unknown functions viz. dielectric constant, incident angle, volume scattering albedo and root mean square height and surface correlation length. In case of snow-ground interface using best pair of polarization, the unknown can be reduced to only dielectric constant and incident angle. In the case of volume backscattering, using volume backscattering ratios, the unknown can be reduced to only dielectric constant and incident angle. In the final term combining both volume backscatter and snow-ground scattering only two functions viz. incident angle and dielectric constant remain (Singh and Venkataraman, 2009).

$$\sigma_t^{AP(vvhh)} = \frac{\sigma_t^{hh} \times \left(\frac{|T_{vv}|^2}{|T_{hh}|^2} \right) \times \left(\frac{|\alpha_{vv}|}{|\alpha_{hh}|} \right) + \sigma_t^{vv}}{\left(\frac{|T_{vv}|}{|T_{hh}|} \right) \times \left(\frac{|\alpha_{vv}|}{|\alpha_{hh}|} \right) + 1} \qquad (4)$$

Where

$$\begin{cases} \alpha_{hh} = \dfrac{\cos\theta - \sqrt{\varepsilon_s - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_s - \sin^2\theta}} \\ \alpha_{vv} = (\varepsilon_s - 1)\dfrac{\sin^2\theta - \varepsilon_s(1+\sin^2\theta)}{\left[\varepsilon_s\cos\theta + \sqrt{\varepsilon_s - \sin^2\theta}\right]^2} \end{cases} \qquad (5)$$

T_{vv} and T_{hh} are Fresnel transmission coefficients, θ is incidence angle and it can be replaced by Snell's law i.e. $\sin^2\theta = \varepsilon_s \sin^2\theta_r$ in Equation (5). By knowing the incident angle, Equation (4) can be used to estimate the dielectric constant of the snow which can be directly related to snow density using Looyenga's semi-empirical formula given by (Looyenga, 1965)

$$\varepsilon_s = 1 + 1.5995\rho_s + 1.861\rho_s^3 \qquad (6)$$

Integral equation method based algorithm is given which has been developed for retrieval of snow density from polarimetric data at C-band. An algorithm is also applied on radar backscattering coefficient for the estimation of snow permittivity and snow density in Himalayan region. The color-coded estimated density value image for part of the study area is shown in Fig. 4. ASAR estimated values for snow density have been validated by *insitu* measurements recorded concurrently with ENVISAT ASAR pass in the study region. The absolute error between field measured and estimated snow density was observed to be 24.38 kg/m^3. It indicates that the algorithm works well for the seasonal fresh snow cover.

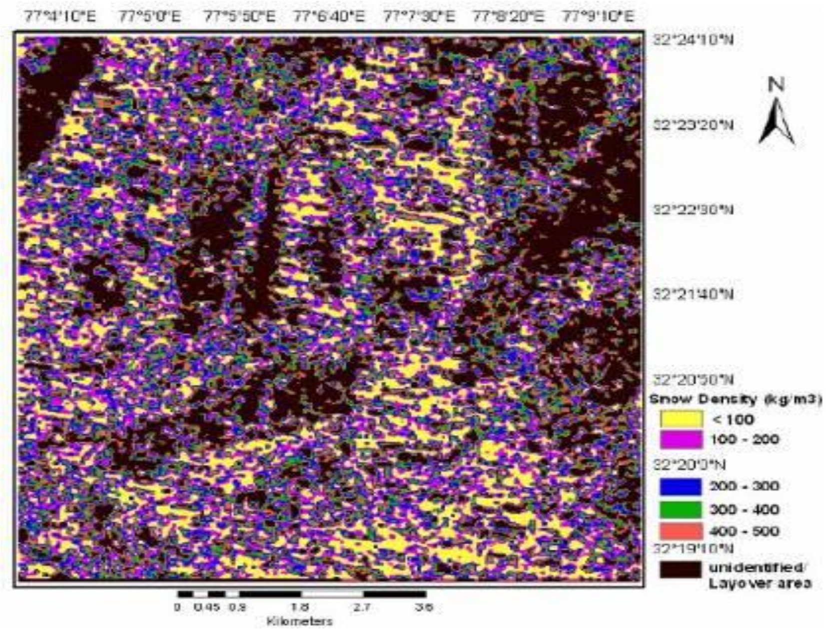


Fig.4. Snow density maps derived from ASAR image of 24-12-07

The model does not require roughness properties. This investigation shows that this algorithm can be used for estimating dry snow density. The model can be applied to the seasonal snow cover when the snow is dry where the subsurface is soil or rock. Furthermore, effect of vegetation cover on snow density mapping may be included for accurate mapping of snow cover in vegetated area. Best range of incident angle will be found out for this model because this model is dependent on incident angle.

Inversion model for wetness estimation

In this study we have used Integral Equation Method based inversion model which has been developed (Shi and Dozier, 1995), for retrieval of snow wetness from polarimetric data at C-band. This model includes two main scattering components (snow volume backscatter and surface backscatter from air/snow interface) for wet snow (Fig.5).

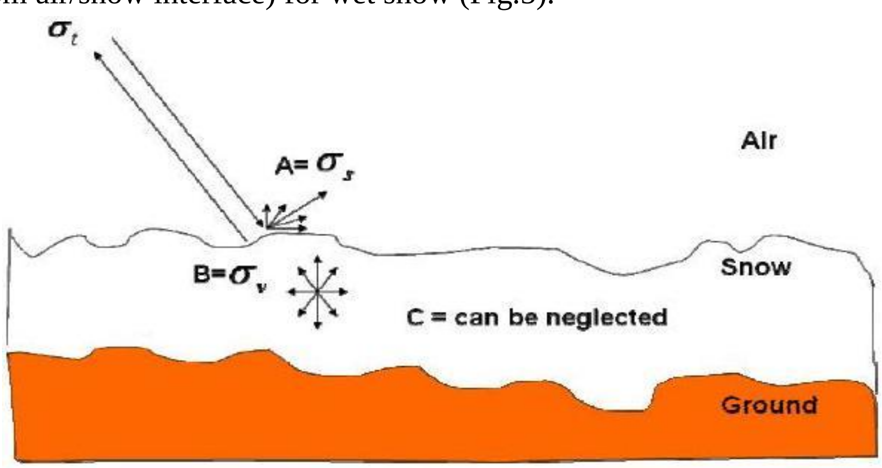


Fig.5. Backscattering from wet snow covered terrain

The first order volume scattering and surface scattering models depend on the four unknown functions viz. dielectric constant, incident angle, volume scattering albedo and root mean square height and surface correlation length. In the case of surface backscattering through simplified non linear regression equations and also using best pair of polarization, the unknown can be reduced to only dielectric constant. In the case of volume backscattering, using volume backscattering ratios the unknown can be reduced to only dielectric constant and incident angle. In the final term combining both surface and volume backscatter only two functions namely incident angle and dielectric constant will remain. Knowing the incident angle, we can solve snow permittivity which can be directly related to snow wetness.

Equations (7) can be used to estimate the permittivity of the snow:

$$M_1\left[a_{vx}\,\mathrm{Re}\left[\alpha_{vv}\alpha_{hh}^{*}\right]\left(a_{vhx}D_{RS}-D_{TS}\right)+b_{vx}M_2\right]$$
$$=M_2\left[a_{vx}(\theta i)\mathrm{Re}\left[\alpha_{vv}\alpha_{hh}^{*}\right]+\frac{b_{vx}M_2}{a_{vhx}D_{RS}-D_{TS}}-D_{TV}\left|\alpha_{vv}\right|^2\right] \quad (7)$$

Where
$$M_1=\sigma_t^{vvhh}-D_{TV}\sigma_t^{vv}$$
$$M_2=\sigma_t^{vv}+\sigma_t^{vv}-D_{TS}\sigma_t^{vvhh} \quad (8)\ \&\ (9)$$

$$D_{TS}=\frac{D_{TV}+D_{TH}}{D_{TV}D_{TH}} \quad (10)$$

$$D_{RS}=\frac{\left|\alpha_{vv}\right|^2+\left|\alpha_{hh}\right|^2}{\mathrm{Re}\left[\alpha_{vv}\alpha_{hh}^{*}\right]^2} \quad (11)$$

$$D_{TV}=\frac{\sigma_v^{vvhh}}{\sigma_v^{vv}}=\frac{\mathrm{Re}\left[T_{vvhh}\right]^2}{T_{vv}^2} \quad (12)$$

$$D_{TH}=\frac{\sigma_v^{vvhh}}{\sigma_v^{vv}}=\frac{\mathrm{Re}\left[T_{vvhh}\right]^2}{T_{vv}^2} \quad (13)$$

$$\sigma_v^{vvhh}=\mathrm{Re}\left[S_v^{vv}S_v^{hh*}\right] \quad (14)$$

and the coefficient $a_{vx}(\theta i), b_{vx}(\theta i)$ and $a_{vhx}(\theta i)$ are provided in the appendix of Shi and Dozier (1995). Fig.6 shows ASAR estimated snow wetness image based on modified Shi and Dozier (1995) inversion model.

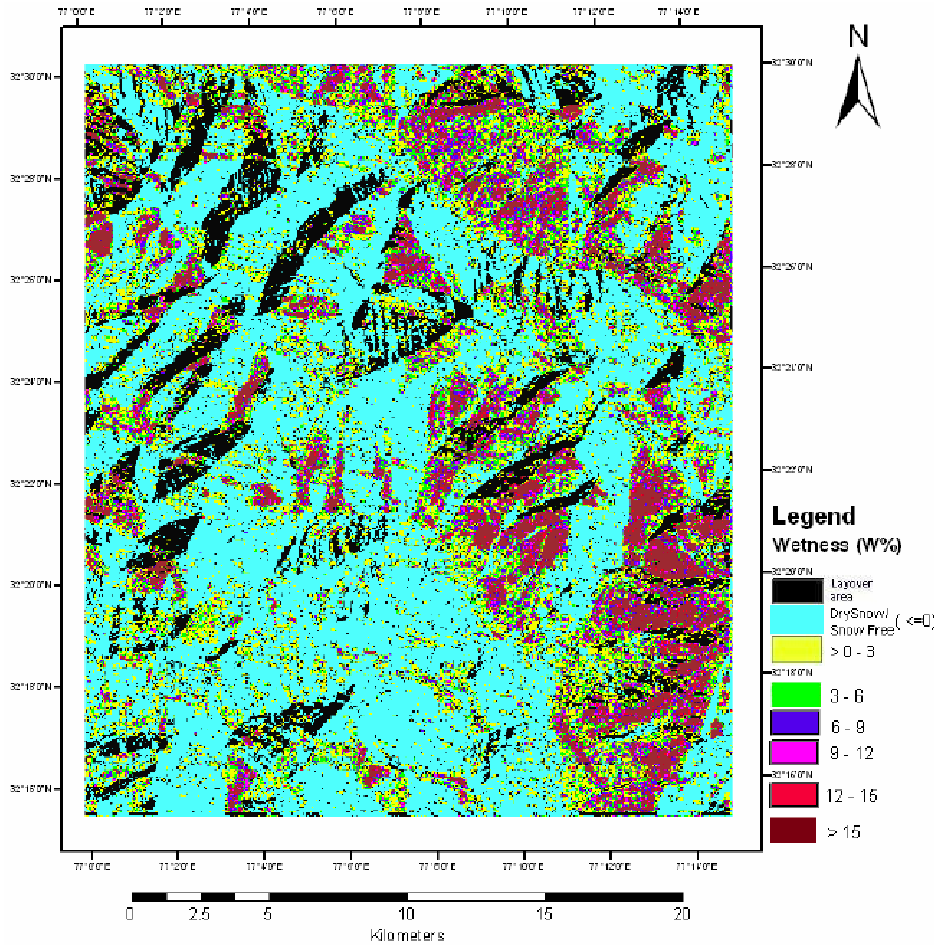


Fig.6 ASAR derived Snow wetness map of 27-02-2006

Model for grain size estimation

A dry snow layer is a heterogeneous medium composed of ice particles with different size and microstructures. When snow is dry, the principle mechanism is volume scattering from the snow pack, and the most important variable are density and grain size. Backscattering increases as the snow grain size increases. Based on Raleigh scattering, the backscattering coefficients for dry snow can be can be written as

$$\sigma_{ds}^{0} = \frac{4\prod^{3} r^{3} \left| \frac{\varepsilon - 1}{\varepsilon + 2} \right|^{2} \cos\theta^{'}}{\lambda^{3} \left| \mathrm{Im}\left\{ \frac{\varepsilon - 1}{\varepsilon + 2} \right\} \right|} \qquad (15)$$

For example, λ is C-band ASAR wavelength (λ = 0.056 m, and incidence angle varies from 15^{0}-45^{0}) and measured average dielectric constant is 1.76 -0.00029j. Using equation (15), we can estimate grain size.

The colour-coded grain size value image is shown in Fig. 7. The comparison of ASAR Cband estimated value with field grain size measurement shows an absolute error of 0.045 mm and relative error 9.6%. Backscattering coefficient increases as the grain size increases.

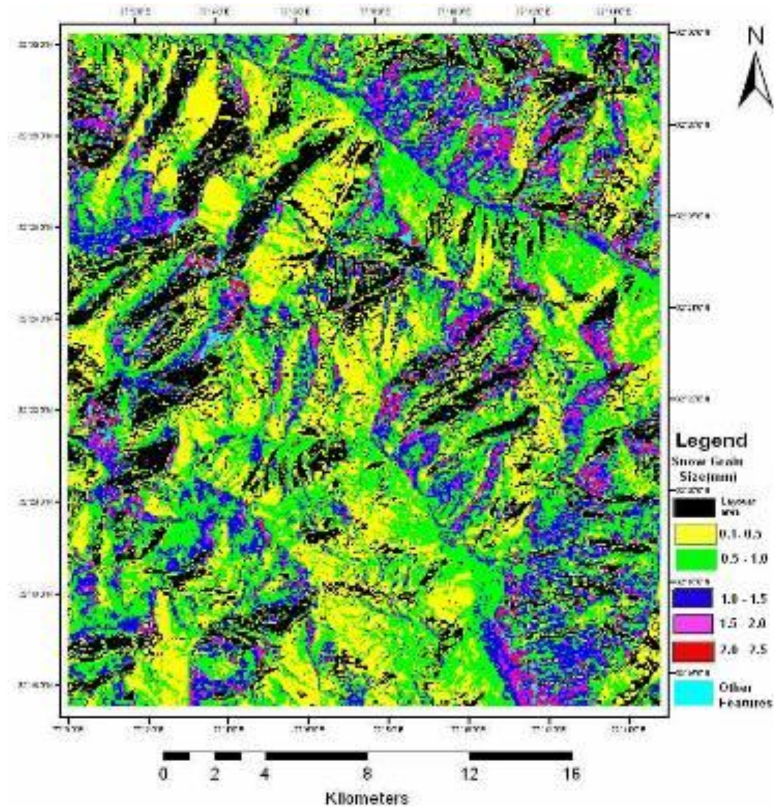


Fig.7. Snow grain size map derived from ASAR image of 31-01-2006

Seasonal Snow Cover Mapping

Snow Mapping using Single Polarization SAR Images

Rott *et al.* (1988) developed a snow mapping procedure in which actual image and simulated image are used. The simulated image is generated using local incidence angle map of the area using DEM and some constant parameters which depends on surface type. Rott et al. (1988) used the following equation for the simulation of (σ^0).

$$\sigma^0(\theta_i) = a\exp\left(\frac{\theta_i}{\varphi}\right) + c\sqrt{\cos}\,\theta_i \qquad (21)$$

where σ^0 is the radar cross-section in units per m^2, θ_i is the local incidence angle of the radar beam and a, c and φ are constant values for a particular surface type. For moraine and rock surfaces, the values a = 0.35, c=0.55 and φ = 10^0 were used by Rott *et al*. Rott *et al*. used C-HH polarized data and simulated data with the following conditions to map snow covered area for $\sigma^0_{hh} / \sigma^0_{sim} \leq 1.8$ snow and ice free

for $1.8 < \sigma^0_{hh} / \sigma^0_{sim} < 3.5$ glacier ice

for $3.5 < \sigma^0_{hh} / \sigma^0_{sim}$ snow

Rott *et al*. compared SAR classified results with that of TM and found that snow surface was underestimated in the SAR classification. Shi and Dozier (1993) and Shi et al (1994) used a different function for snow mapping using single polarized data. The normalized σ_{0n}

$$\sigma^0_n = \sigma^0(\theta_i) / f(\theta_i) \qquad (22)$$

Snow Mapping using Multifrequency and Polarimetric Data

Rott *et al.* (1992) used polarmetric data for snow cover mapping. Based on the depolarization properties of the radar signal, they used the following equation for mapping snow cover. If the backscattering power satisfies the following condition,

$P_{HV}/P_{VV} < m$ snow covered (23)

where m = 0.04 was used. P_{HV} is received power of cross-polarization and P_{VV} is copolarization data at C-band. Shi *et al.* (1994) also used the same procedure and their results are in agreement with Rott *et al.* (1992).

Snow Mapping using Repeat-pass SAR Observations (Single Polarization)

This method was developed by Rott and Nagler (1992) and Rott & Nagler (1993) and used with ERS-1 SAR data. It is based on the fact that dry snow is not discriminated against snow free ground during winter as the dry snow is transparent at C-band. Images acquired during snow-free conditions are usually taken as reference image. However, wet snow strongly reduced the backscattered signal. Images acquired during wet conditions are usually known as wet snow images. The change in σ_0 between snow and reference images leads to the detection of wet snow. By combining ascending and descending pass data, they could map snow cover even in layover and shadow areas. Nagler and Rott (2000) used threshold value -3dB for wet snow mapping aftercomparing the results with snow classification using TM data. The wet snow cover maps of May 19, 2007 and May 12, 2007 for ASAR and PALSAR are shown in Fig.8 respectively.

Koskinen *et al.* (1997) suggested an algorithm which is optimized to detect snow in forested areas. By conducting a pixel wise comparison between the two reference images and the current image, the equation for the relative fraction of snow free ground is given by:

$$F_g = 100 \frac{\sigma_i^0 - \sigma_w^0}{\sigma_g^0 - \sigma_w^0} \% \qquad (24)$$

$\sigma_i^0 \sigma_w^0 \sigma_g^0$ are the backscattering during snow melt, and at the beginning of the snow melt period and for snow-free ground respectively.

Luojus *et al.* (2006) demonstrated a two step technique for mapping wet snow cover over Boreal forest in Finland using ERS-2 multi-temporal data sets. The first step is the forest canopy compensation. This is done by nonlinearly fitting ERS-2 measured data with a semi-empirical forest-backscattering model (Pulliainen et al. 2003) and information with forest stem volume to estimate the backscattering signal at ground surface and the volume backscattering signals, the two-way transitivity of the forest canopy. In the second step, the fraction of wet snow covered area SCA is calculated.

$$SCA = \frac{\sigma_{surf}^0 - \sigma_{ground-ref}^0}{\sigma_{snow\_ref}^0 - \sigma_{ground-ref}^0} 100\% \qquad (25)$$

Where σ_{surf}^0 is the estimated backscattering coefficient at ground surface, $\sigma_{ground-ref}^0$ is the reference signal from the snow-free ground, and $\sigma_{snow-ref}^0$ is the reference signal from the wet snow ground. One reference image describes the signal with fully wet snow cover situation and the other describes the snow-free at the end of the snow melting season. In addition to these two reference images, this method requires forest-stem volume distribution.

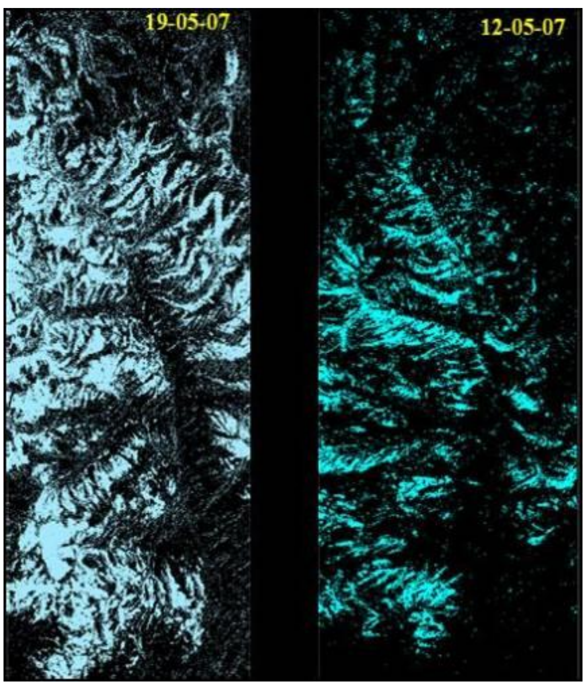


Fig.8. Single Polarization Repeat passes method for wet Snow Cover Discrimination

Snow Mapping using Repeat-Pass Interferometric Techniques

An Interferometry SAR technique for topographic mapping of surface does not only produce a high resolution DEM but also gives the information about changes on the surface during the repeat pass cycle of satellite from the correlation properties of the radar echo. The measurement of interferometer correlation provides the information of changes during the time scale of the satellite repeativity and size scale on the order of a SAR wavelength. The coherence measurement between two repeat passes provides another useful measurement for snow cover mapping over large area. Strozzi et. al. (1999) analyzed the ERS-1/2 tandem data and observed that coherence can help separate wet snow from other surface where backscatters do not discriminate snow from other surface.

The basis of InSAR is phase comparison over many pixels. This means that the phase between scenes must be statistically similar. The coherence is a measure of the phase noise of the interferogram. The interferometric coherence is defined as the absolute value of the normalised complex cross correlation between the two signals. The correlation will always be a number between 0 and 1. If the pixels are similar this will result in a high correlation and good results. If the pixels are not similar i.e. not correlated at a certain degree then the phase will vary greatly and the result will be noise, we talk then about decorrelation.

Theoretical and experimental studies have shown that coherence is determined by the spatial baseline of the interferometric pair, the time separation of the images, topographic effects, and noise sources. The change of backscattering characteristic at surface will cause the change of coherence degree at the separate time. Integrating the backscattering intensity, we can make classification using the difference of coherence degree for different surface type. The technique is based on coherence between two images acquired at different dates. The coherence may vary depending on the melting of snow, forest growth, precipitation, soil moisture and movement of the glaciers. Through this technique, wet snow covered areas can be identified through coherence change. Rao *et al.* (2008) observed poor coherence in most of the areas if the interval between two dates is more than 30 days. Limitations of this technique are that two images are to be acquired in a short interval with same viewing angle and swath mode. Presently, almost all satellites give data in the interval of 11 to 46 days.

Coherence measurement using repeat pass SAR observations indicate low values for both wet and dry snow covers. The radar echoes get decorrelated for measurements between wet snow cover and bare ground. This happens mainly because radar signal can penetrate few centimeters in wet snow cover and hence the radar senses two different targets. In case of dry snow the dominant scattering is from the interface of snow ground. Decorrelation occurs in dry snow mainly due to volume scattering from the snow layer and changes the local incidence angle. The coherence degrees of interferometric pair can be calculated for different types of surface at different time interval. However, the amount of decorrelation is expected to be relatively smaller because radar senses same target with same scattering mechanism (only change in magnitude). The glacier is varied coherence degree according to the moving state. The correlation of snow is relatively lower due to the change of snow surface and roughness caused by snow and snow melting. Coherence images of Gangotri glacier obtained using ERS-1&2 tandem data of March 25 and 26, 1996 in ascending mode, ENVISAT ASAR 35 day interval data of July 9 and Aug. 13, 2003 in descending pass and ENVISAT ASAR 70 day interval data of May 19, 2004 and July 28, 2004. We acquired the nearest IRS –LISS III image to verify the classification accuracy.

Coherence images of Siachen glacier with April 1 &2, 1996 ERS-1 and 2 tandem pair, May 2&3, 1996 tandem pair, ASAR 70 day interval and ASAR 350 day interval data are shown in Fig.9 to Fig.14 respectively. This measurement indicates that the coherence degrees of objects are high in the ERS SAR pairs due to short time interval and relatively short baseline. For snow and glacier region, snow melting and glacier movement will result in large decorrelation. Fig.16 and Fig.19 show good coherence over the glacier area due to little glacier movement and insignificant changes of snow in one day. The value of coherence over the glacier area is greater than 0.7 and some area with range from 0.4 to 0.6 was also found and surrounding snow area of glacier, value is less than 0.4 for ERS -1/2 one day difference tandem data where as ASAR 35, 70 days difference coherence value over the glacier area and surrounding snow area is less than 0.4. The wet snow cover over the glacier and non-glacier area can be discriminated from other targets using degree of coherence because wet snow metamorphism changes the scattering geometry therefore coherence is lost. But the decorrelation of time and baseline should be reasonable. Short time interval pair between snow and non-snow cover is better for separating snow from other targets.



Fig. 9. Coherence image,Coherence image for one day difference ERS-1/2 tandem data over Gangotri glacier area	Fig. 10. Coherence image for 35 days difference ENVISAT-ASAR repeat pass data over Gangotri glacier. Due to large movement/changes of glacier/snow in 35 days, coherence is lost on the glacier bed/ snow cover area	Fig. 11. Coherence image for 70 days difference ENVISATASAR repeat pass data over Gangotri glacier. Due to large movement/changes of glacier/snow in 70 days, coherence is lost on the glacier bed/ snow cover area.

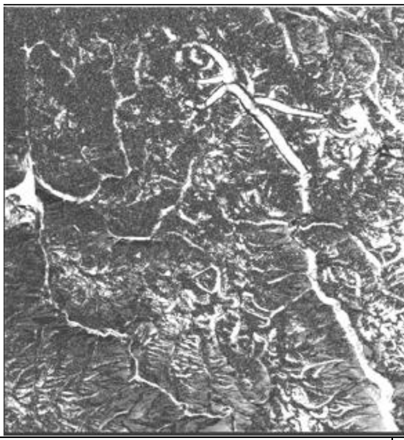


Fig. 12. Coherence image for one day difference ERS-1/2 tandem data over Siachen glacier area

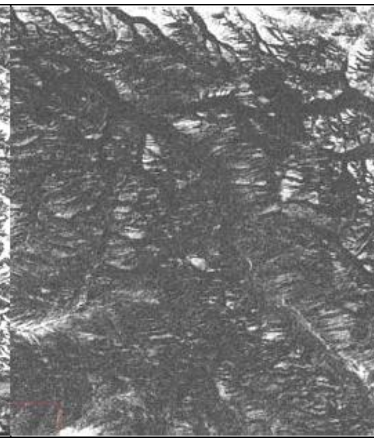


Fig. 13. Coherence image for 35 days difference ENVISAT-ASAR repeat pass data over Siachen glacier. Due to large movement/changes of glacier/snow in 35 days, coherence is lost on the glacier bed/ snow cover area.

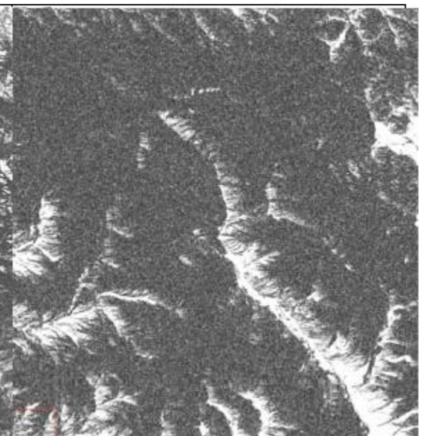


Fig. 14. Coherence image for 70 days difference ENVISATASAR repeat pass data over Siachen glacier. Due to large movement/changes of glacier/ snow in 70 days, coherence is lost on the glacier bed/ snow cover area.

Eigen values based Algorithm for Snow cover Mapping

The proposed algorithm flow chart for discriminating snow from other features is shown in Fig.15. Eigenvalue based polarization fraction image (Fig.16) shows that the snow cover area has high polarization fraction value as compared to other targets. Therefore, polarization fraction parameter can be used for snow discrimination from other targets. Fig. 16 shows the high PF value over lower central part of image but this of image is snow free and it is covered by layover affected area due to low incident angle of ALOSPALSAR and high topography of Himalaya. Hence there is need to explore supporting parameters to discriminate snow cover properly. In this investigation, eigenvalue images of coherency matrix have been generated and based on these images other parameters namely entropy (H), anisotropy (A), scattering mechanism angle (alpha), (1-H) and H (1- A), Lunenburg anisotropy, Radar Vegetation Index (RVI) have been studied. These parameters have been analyzed to find out which one can support the results of snow discrimination obtained through polarization fraction. Entropy, H(1-A), Lunenburg anisotropy, and RVI show low values over the snow cover due to pure target and high value over the other distributed targets (e.g. ablation area of debris covered glacier and vegetation). On the other hand anisotropy and asymmetry give high value over snow area. All of these parameters are also capable to discriminate snow from other targets but do not have a proper range to suppress layover affected snow free area from snow.

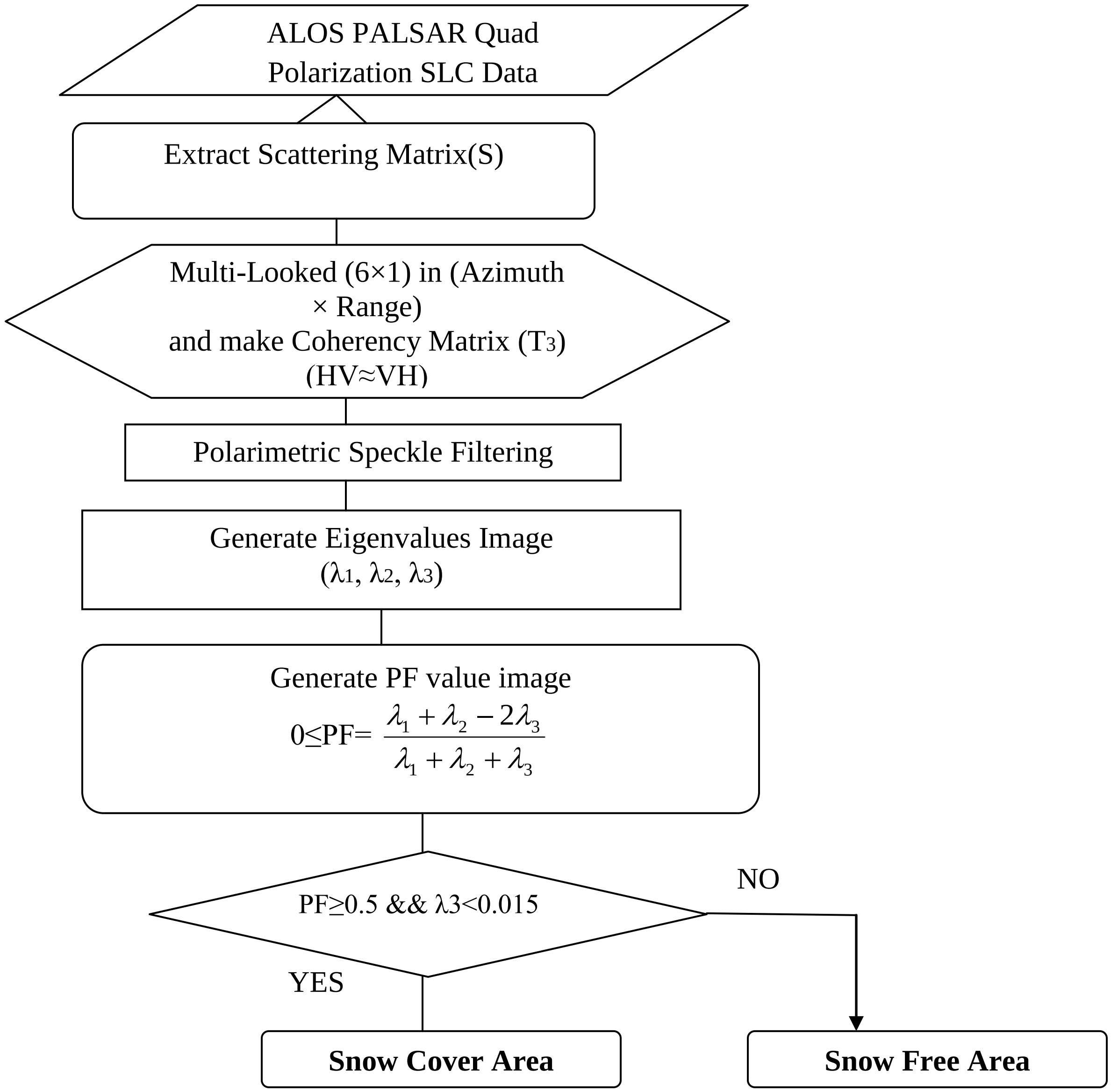


Fig.15. Methodology flow chart of Snow Index Development

Eigenvalues λ_1, λ_2, λ_3 show the sufficient range for suppressing this unwanted area from the snow cover area and showing very high value of layover affected area in image. It was found that Normalized λ_1 is varying a low range (0 to 0.56) variation as compared to λ_2 range (0 to 0.80) and λ_3 (0 to 1) range for selected region (affected by topographic distortion), which is not able to discriminate snow from other targets. λ_2 range is mixing with layover affected area in the upper part of image, whereas normalized λ_3 have wide range from 0 to 1, which is able to separate the affected area and other features. Hence, Normalized λ_3 has been used to support the discrimination of snow using fractional polarization value. Thus, Radar Snow Index (RSI) has been developed using eigenvalues of coherency matrix of polarimetric SAR data.

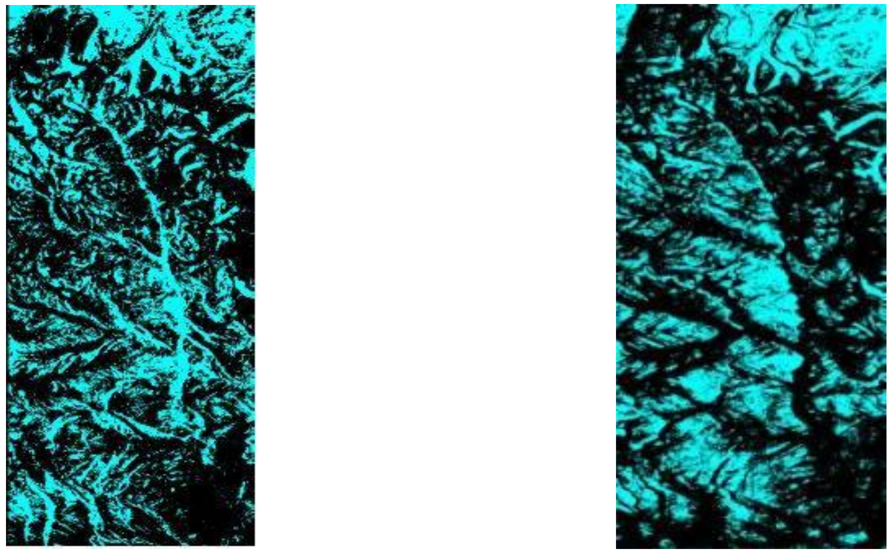


Fig. 16. (c) PF (Cyan >0.6 and Black <=0.6) (d) Snow Cover using developed RSI

References

Frost V. S., Stiles J. A., et al., 1982. A model for radar images and its application to adaptive digital filtering of multiplicative noise, IEEE Trans. Pattern Anal.Machine Intell., Vol. PAMI-4, 157-166.

Koskinen J.T., Pulliainen J.T., and Hallikainen M.T., (1997), The use of ERS-1SAR data in snow melt monitoring, IEEE Trans. Geosci. Remote Sensing, Vol.35, No. 3, pp. 601-610.

Luojust K., Puliiainen J.T., Metsamaki S., and Hallikainen M.T., (2006), Accuracy assessment of SAR data based snow-covered area estimation method, IEEE Trans Geoscience and Remote Sensing, 44(2):277-287.

Looyenga H., “Dielectric constant of heterogeneous mixtures,” Physica, Vol.21, pp. 401–406, 1965.

Nagler T. and Rott H., (2000), Retrieval of wet snow by means of multi-temporal SAR data, IEEE Trans. Geosci. Remote Sensing, Vol. 38, No. 2, pp. 754-765.

Pulliainen J.T., Engdabi M., and Hallikainen M.T., (2003), Feasibility of multitemporal interferometric SAR data for stand-level estimation of boreal forest stem volume, Remote Sensing of Environment, 85:397-409.

Rao Y.S., Kumar V., Singh Gulab, G. Venkataraman and Snehmani (2008), The loss of coherence in the InSAR images of Himalayan Glaciers, Proceedings of international workshop on Snow, Ice, Glacier and Avalanches, held at IIT Bombay during Jan. 7-9, 2008, pp.232-239.

Rosich, B. and Meadows, P., 2004, “Absolute calibration of ASAR level 1 products”, Issue 1, Revision 4,ESA, Noordwijk, the Netherlands, Tech. Note ENVI-CLVL-EOPG-TN- 03-0010.

Rott H., and Nagler T. (1992), Snow and glacier investigations by ERS-1 SAR, First results in Proc. 1st ERS-1 symposium, ESA SP-359., Nov. 4-6, 1992, ESA, pp.577-582.

Rott H. and Nagler T., (1993), Capabilities of ERS-1 SAR for snow and glacier monitoring in Alpine areas, Proc. 2nd ERS-1 Symposium, Hamburg 11-14 Oct. 1993, ESA pp. 965-970.

Rott J., Davis R., and Dozier J., (1992), Polarimetric and multi-frequency SAR signatures of wet snow, Proc. IGARSS'92, pp. 1658-1660.

Rott H., Matzler N., Strobi D., Bruzzi S., and Lenhart K., (1988), Study on SAR land applications for snow and glacier monitoring, Contact Report 6618/85/F/FL(SC), ESA, 1988.

Shi J., Dozier J. and Rott H. (1994), "Snow mapping in alpine regions with synthetic aperture radar", IEEE Trans. Geoscience and Remote Sensing, Vol. 32, No. 1, pp. 152–158.

Shi J. and Dozier J., (1995), "Inferring snow wetness using C-band data from SIR-C's polarimetric synthetic aperture radar", IEEE Trans. Geoscience and Remote Sensing, Vol. 33, pp. 905-914.

Shi J., Dozier J.and Davis R. E., "Simulation of snow-depth estimation from multi-frequency radar," in Proc. IGARSS'90, pp. 1129–1132.

Shi J. and Dozier J., "Estimation of snow water equivalence using SIR-C/X-SAR – part I. inferring dry snow density and subsurface properties," IEEE Trans. on Geosci. Remote Sens., Vol.38 (6), pp. 2465-2474, 2000.

Shi J. and Dozier J. (1993), Measurements of snow and glacier-covered areas with single polarization, Ann. Glaciol., 17, pp.72-76.

Singh Gulab and Venkataraman G., "Snow density estimation using polarimetric ASAR data", Proc. Micowave08, pp.463-466, 2009.

Strozzi, T. and Matzler, C., (1998), "Backscattering measurements of alpine snow covers at 5.3 and 35 GHz", IEEE Trans. Geosci. Remote Sensing, Vol. 36, pp. 838-848.

Strozzi, T. , Wegmuller, U. and Matzler C., "Mapping wet snow covers with SAR interferometry," Int. J. Remote Sensing, ser. Nr. 12, vol. 20,pp. 2395–2403, 1999.

Ulaby, F. T. Moore, R. K. and Fung, A. K, Microwave remote sensing, active and passive, Vol. III, Artech House, (1986).

Author Index