Environmental and human determinates of vegetation distribution

in the Hadhramaut region,

Republic of Yemen

by

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Declaration

I declare that this thesis has been composed solely by me. The work and results reported within are my own, unless otherwise acknowledged.

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Abstract

The principal objectives of the research are to analyse the distribution and dynamics of plants of the Hadhramaut region and to evaluate the role of the physical parameters and human action on their distribution, survival and conservation. The study area is located in Hadhramaut Governorate and lies in the eastern part of the Republic of Yemen. This is a remote and inaccessible region; however, there has been rapid development in recent years with the discovery of oil, which has had a significant effect on the vegetation and landscape. The Hadhramaut region represents an important area of eastern Yemen, linking eastern and western phyto-geographical units, representing a key transition zone between northeast Africa and Southeast Asia. Previous studies in the study area have only dealt with individual species and there has been no complete botanical survey. Recent floristic studies are turning up new species with many endemic and near endemic plant species.

The Hadhramaut region is a desert region, dissected by deep valleys where agriculture is possible and the main towns are surrounded by rocky, dry limestone plateaus. The northern section passes into the deserts of the Rub ‘al Khali or Empty Quarter. Hadhramaut has a long history of human occupation with ancient civilisations well reflected in the archaeological records. Archaeological sites suggest that agriculture, with a related development of irrigation technology, was more widespread during a period when rainfall was more abundant.

Initially, a reconnaissance survey of the whole Hadhramaut Governorate was undertaken, leading to the selection the Wadi Hadhramaut for detailed study. Within this study area, three sites were selected for intensive survey. These sites were considered representative of the major landforms and vegetation of the area and reflect the principal patterns of land use. The three sites represent tracts of land that were either unaffected, undergoing change or already altered as a result of oil-related development. Transects were designed to cross each site, from the valley bottoms to the plateau surfaces, passing across the representative landforms and vegetation. Surveys were made of the vegetation associations, their structure and biodiversity, as well as their relationship with environment and human impact. Two preliminary transects were made across the entire region, from the southern coast to the plateau in the northwest and from east to west, in order to place the study area in a regional context.

The research is the first detailed vegetation survey in the Hadhramaut region and has revealed relevant data that can be used for further studies in similar habitats or for further management and conservation activities. In the study area, major vegetation associations, their composition and biodiversity were identified and in addition, vegetation and land use maps were generated including local endemic, near-endemic and rare plant species.

About 469 plant species have been identified from the Hadhramaut region. There are 107 taxa which are endemic and near-endemic; 68 of these are endemic to Yemen, of these 41 are confined to Hadhramaut region.

A total of 134 species belonging to 42 families (about 30% of flora of Hadhramaut region) were recorded in the study area and, of these, seven species are endemic to Yemen (four of them endemic to Hadhramaut region). The study revealed 15 vegetation associations and thirty sociological species groups. The main wadis are covered by desert alluvial shrubland

comprising *Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus, Boerhavia elegans* and *Dichanthium insculptum* with scattered trees of *Acacia campoptila.* In contrast, much of the fertile lands of the main wadis, such as the bottom of the rocky slopes, are intensively cultivated with palm trees and other annual crops, notably sorghum and wheat. The rocky slopes facing the main wadis and the plateau surface are covered by stony and gravelly desert vegetation dominated by herbaceous plants, namely *Stipagrostis hirtigluma, Farsetia linearis, Aristida triticoides, Fagonia paulayana, Boerhavia elegans* and *Dichanthium insculptum.* Within the plateau there are some sloping sites and secondary wadis which support dense vegetation. The vegetation here comprises shrubland or grassland dominated by *Jatropha spinosa* with *Zygophyllum decumbens, Commiphora foliacea, Commiphora kua, Maerua crassifolia. Dichanthium insculptum, Stipagrostis hirtigluma* and *Farsetia linearis.*

The research in the Hadhramaut region has revealed the importance of this region in terms of plant biodiversity, and particularly of endemic, rare and near-endemic species, which urgently require further management and conservation activities.

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Abdul Wali Ahmed Al Khulaidi

Glossary

Hima: An Arabic term for protected areas, it is exclusively for the conservation of natural resources, wildlife and forests.

Mahajer: A local Arabic name for protected areas that are located on mountain slopes or on land adjacent or around cultivated fields. These protected areas are applied for a certain period, mostly in rainy season and mainly used for grazing.

Sabakha or Sabaka: an Arabic term for a marsh or bare mud covered by salt crust sue to evaporation (Murray, 1951; Scholte et al., 1991)

Abiotic: non-living components that affect the living organisms such as soil, pH, water, light, temperature and topography (Rojas et al., 2001; Deyn et al., 2004).

Biodiversity: The variety of all living things; the different plants, animals and micro organisms, the genetic information they contain and the ecosystems they form.

Biotic: living components that affect the living organisms such as plants, animals and human activities (Deyn et al., 2004).

CITES: Convention on International Trade in Endangered Species of Wild Flora and Fauna, it is the main tool for controlling international trade in wildlife. CITES species is the species that grouped according to how threatened they are by international trade.

Cliff: nearly vertical rocky slopes facing the main wadis.

Diversity: Diversity is a measure of the number of species within a unit area and has been used by different plant ecologists to evaluate plant species in different ecosystems of the world

Dwarf shrubland: A group of small shrubs usually less 0.5m tall, forming more than 10% cover. Trees and shrubs generally less than 10% cover).

Edaphic factor: Any physical or chemical property of the soil that influences plants growing in it (Rajakaruna, 2004) by controlling the floristic and the structure of the vegetation (Beadle, 1953).

Endangered: A species present in such small numbers that it is at high risk of extinction in the near future (Hunter, 2002).

Endemic species: Species exclusively native to a place or a species that is unique to that place or region, found naturally nowhere else.

Escarpment: steep to moderately steep slope mountain or cliff, facing mainly south.

Ex-situ conservation: maintaining organisms outside of their natural habitats (Hunter, 2002).

Evenness: How equally abundant are each of the species in a community.

Extinct plant: The last remaining member of the plant species had died, or is presumed to have died beyond reasonable doubt (Hunter, 2002).

Frequency*:* Frequency is defined as the number of times a plant species is present within a given number of sample quadrats of uniform size placed repeatedly across a stand of vegetation (Mueller-Dombois et al. 1974; Daubenmire, 1968).

Graasland: A group of herbaceous (herb, grass), forming more than 10% cover. Trees, shrubs, and dwarf-shrubs less than 10% cover.

Hamada or hammada: is Arabic for ‘stone desert’ and is applied to surfaces covered by stone fragments and pebbles. Hamada consists mostly of fine particles and soil produced by weathering (Zohary, 1962; Batanouny, 1981)

Importance Value*:* Importance values refer to how important a species is in terms of the structure of a community or species composition (Nautiyal et al., 2003

Kareef: Depression for rainwater catchments systems

Number of individuals*:* Number of individuals refers to the density of each species that been recorded in the sample sites during the vegetation survey.

Plant association: A group of plant species or a plant community that occupies the landscape

Plateau: A relatively flat upland surface, often rocky in Yemen.

Rock outcrop: Big bare rock found on the surface of rocky slope mountains**.**

Secondary wadi: It is the inter-plateau wadi or a “Canyon”, with very steep to moderately steep rocky slopes.

Shrubland: A group or individual of Shrubs generally greater then 0.5m tall, forming more than 10% cover, trees generally less than 10% cover.

Sociological plant species: Group of plant species that show a similar distribution across the sample plots or group of plant species (taxa) that are more or less similar in behaviour (Zonneveld, 1986)

Species accumulation curves*:* This is a method for determining whether the sampling is sufficient to have collected all the plant species from a region or for comparing species richness between different communities (Moreno and Halffer, 2000; Willott, 2001).

Species richness*:* Refers to the number of species present in a community (Krebs, 1999).

Total Vegetation %: It is a totals of the trees, shrubs, dwarf shrubs and herbaceous.

Vulnerable plant: Plant faces a high risk of extinction in the medium-term

Wadi: An Arabic term for a valley or streambed in that remains dry except during the rainy season.

Woodland: A group or individual trees usually less than 7 m tall, forming 15-40% cover. The shrub cover is less than 10%.

List of Acronyms

AREA	Agricultural Research and Extension Authority
CBD	Convention on Biological Diversity
DNO	Det Norske Oljeselskap AS
DOVE	Dove Energy Limited
EPA	Environmental Protection Authority
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GSPC	Global Strategy for Plant Conservation
ITCZ	Inter-Tropical Convergence Zone
IUCN	Interntional Union for Conservation of Nature and natural resources
OECD	Organization for Economic Co-operation and Development
RBGE	Royal Botanic Garden of Edinburgh
RSCZ	Red Sea Convergence zone effect
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture
WWF	World Wildlife Fund

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Chapter 1: Introduction

1.1. Introductory comments

The Hadhramaut region is one of the least known regions of the Middle East yet lies on a highly significant path way of plant dispersal from the Arabian Peninsula to the Horn of Africa and from the Indo-Gangetic marchlands to the Mediterranean. It is an area that has been occupied by human settlement for millennia, but where climate has changed radically over historical time and where the current vegetation is a reflection of harsh physical environmental conditions and increasing human pressure. The impact of recent human disturbance has increased stresses on the fragile biota and makes taxonomic recognition of plant resources an urgent priority.

The climate of the study areas is arid and semi-arid characterised by high temperatures and low average annual rainfall below 100 mm per year. As a result of the climate and the harsh landscape, which consists of desolate limestone plateaus, relatively fertile wadis and areas of desert with sand-dunes and gravel plains, plants have developed ingenious mechanisms to survive.

Like dry savanna woodland, the vegetation in the main wadis consists of open woodland with low woody-herb cover and scattered thorny trees (e.g. *Acacia campoptila*, and *Ziziphus leucodermis*). The vegetation of the plateau consists mainly of communities dominated by grassland species with trees and shrubs on the plateaus confined to secondary wadis and steep slopes.

The study area shows distinctive patterns of plant distribution relating which relate to the different vegetation associations. There are changes in vegetation associations across the area; a short drive or walk across the plateau and main wadi reveals gradational changes in the vegetation associations from one end to the another, and even from one side of a road or wadi to the other. Generally the vegetation of the plateau is sparse and dense vegetation is confined mainly to areas where moisture is available, such as depressions and seasonal drainage lines.

The vegetation of the study areas has never been systematically studied or surveyed by botanists. Botanically it is the least-known area of the Arabian Peninsula, representing perhaps the least explored region in South West Asia (WWF, 1994). Almost 40 endemic plant species are known from the Hadhramaut region (Miller, 1991), however, this figure was certainly an underestimate and this figure can be at least doubled. Earlier botanical studies concentrated on checklists or general descriptions of the vegetation of certain habitats, without following any rigorous scientific methodology.

1.2. Research aims

The principal objectives of the research are to analyse the distribution and dynamics of the plants of the Hadhramaut region, and to evaluate the role of physical parameters and human actions on the vegetation. The area selected for detailed study is representative of the Hadhramaut as a whole and is further subdivided into 3 sites for intensive survey.

1.3. Context

Hadhramaut has a long history of human occupation. The development of ancient civilisations is well reflected in the archaeological records. Archaeological sites suggest that agriculture, with a related development of irrigation technology, was more widespread during a period when rainfall was more abundant; this goes back perhaps as early as 7000 – 8000 B.P (McCorriston, 2000). The decline of vegetation, population, and collapse of agriculture was possibly due to reduced precipitation and evaporation from the Indian Ocean associated with the weakening of the Indian-African monsoon system at the end of the last ice age (Moehl, 1996). Today, oil exploration and population pressure are putting enormous pressures on the natural resources of the region. Oil exploration activities have caused major impacts to the soil surface, ground water and local ecosystems in the region. The impacts on the landforms, soil, vegetation, habitat, and cultural resources are already obvious in many parts of the study sites. Thus the status of the vegetation cover is at present precarious and evidence of changes in species distribution and abundance is highly relevant to the discussion of vegetation conservation and management. The study area is important for a number of reasons:

(a) It is a key transition zone between northeast Africa and southwest Asia.

(b) It is an area that has never been systematically studied or surveyed by botanists.

(c) Previous studies have concentrated only on preparing reconnaissance checklists of the flora and general descriptions of the vegetation.

(d) Botanically the region is the least-known of the entire Arabian Peninsula and possibly the least explored in South West Asia (WWF, 1994).

(e) A considerable number of endemic plant species are known from the area (Miller, 1991).

(f) Human population and settlement in the region is low but have a distinct impact on plant life and distribution. Oil exploration has had a recent but significant impact on the vegetation.

1.1.3. Hypotheses

It is intended to test the following hypotheses:

1. The number and abundance of individual plant species has varied over time, especially over the past two decades.

2. Plant communities and vegetation structure have remained relatively constant over the same period, although the populations of different plant species and their local distributions has changed.

3. Human activity has exploited the plant resources of the entire area but has preferentially targeted particular types of vegetation.

1.1.4. Research questions

In order to test these hypotheses and to achieve the principal aims, several specific questions will be addressed:-

- What are the types of vegetation, the structure of plant communities and their distribution?
- What is the composition and diversity of plant species?
- Which areas have the greatest diversity?
- What are the principal physical and anthropogenic factors affecting contemporary plant distributions?
- To what extent have the plants and plant communities changed over the past few decades and historically?

- What are the processes affecting vegetation change?
- What has been the nature of land use change and how has it affected plant composition and distribution?
- To what extent can this information helpfully inform conservative and management users?

1.1.5. Structure of the thesis

In the first chapter the characteristics of the study area and the main problems are explained. The achievements and the limitations of previous studies on the vegetation in the Hadhramaut region and Yemen are evaluated in Chapter 2. The general characteristics of the vegetation, their significance, and the endemic and near- endemic plants of Hadhramaut region are discussed with recommendations for conservation and management in Chapter 3. Chapter 4 discusses the floristic analysis and the biodiversity of the study sites. The floristic associations, vegetation structure and environmental factors of the study sites are explained in Chapter 5. In Chapter 6, the vegetation and the distribution of plant species of Hadhramaut region are presented in maps. The thesis ends with Chapter 7 which comprises discussion and conclusion.

1.4. Characterization of the Wadi Hadhramaut study area

1.4.1. Introduction

The Republic of Yemen is located at the South-Western edge of the Arabian Peninsula between 12°40 and 19° N latitude and between 42°30 and 55° E longitude . Besides the mainland, it includes many islands, the larger of these being Soqotra in the Arabian Sea and Kamaran in the Red Sea. The country is divided into 21 Governorates, with a total area of 547,000 km² (approximately 55 million hectares).

Hadhramaut Governorate, where the study area is located, lies in the southeast of Yemen, between the latitudes 14-19 degrees north and the longitudes 48-51 degrees east (Figure 1.1). It is bordered by Saudi Arabia to the north, the Al Mahra Governorate to the east and the Shabwa Governorate to the west. It extends northwards deep into the Empty Quarter (Rub' Al Khali) with its southern coasts overlooking the Arabian Sea, however the dominant feature is the Jol, a desolate limestone plateau, which dominates the centre of the governorate.

Hadhramaut is the largest Governorate in the Republic of Yemen, at about 161,749 km² (about 30% of the whole area of Yemen), it reaches over 2500m above sea level and includes some areas of the Empty Quarter in the north and coastal areas in the south. The directorates are divided into two main groups: 14 directorates in Wadi Hadhramaut and surrounding desert areas, 13 directorates in the coastal plain and facing mountains and 2 directorates on the Soqotra archipelago (Central Statistical Organisation, 2001).

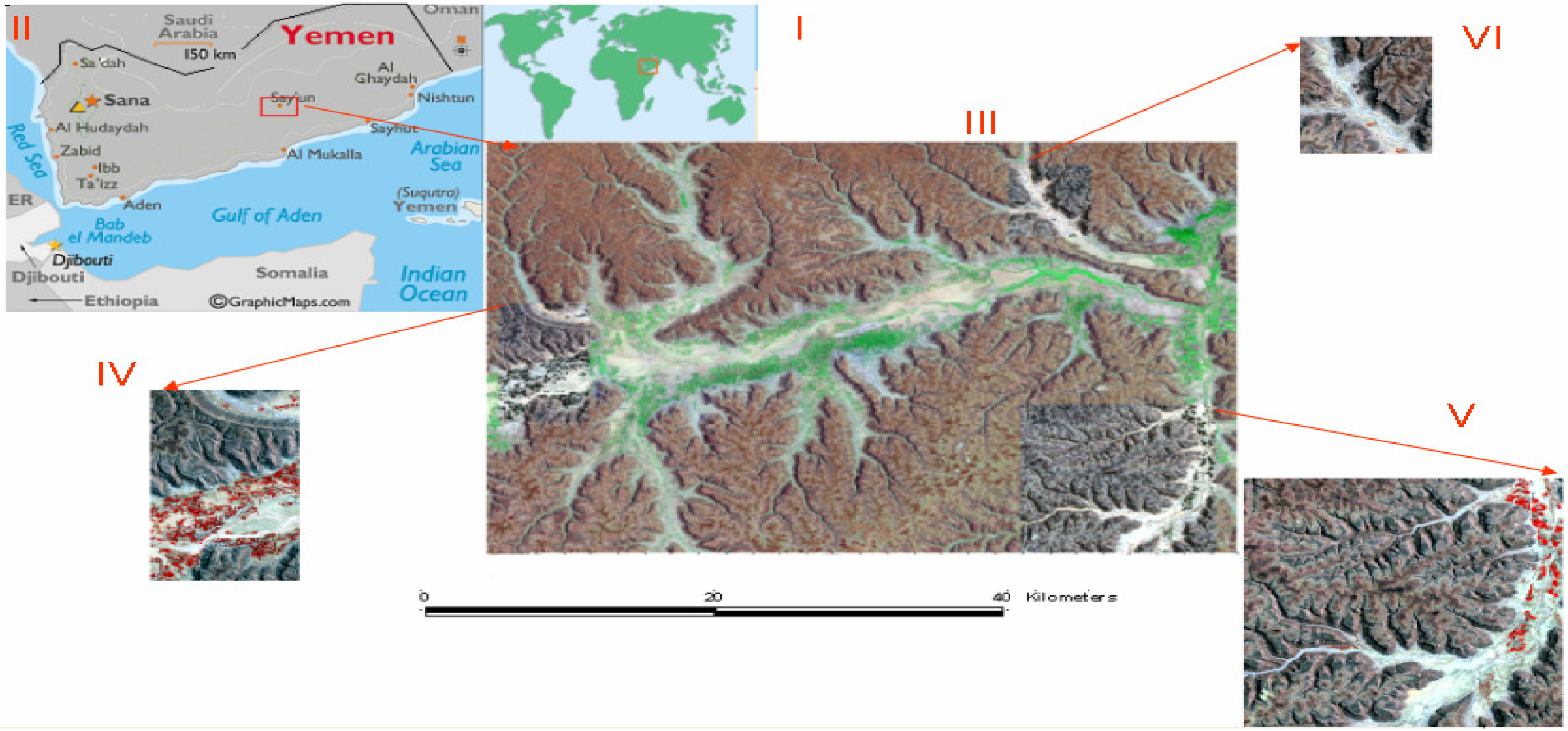


Figure 1.1. The location of the study area and of the 3 study sites. (I) regional context, (II) Yemen and neighbouring states (GraphicMaps.com), (III) the study area, (IV to VI) the 3 study sites in details (landsat TM of 1998). The red (false colour) and the green (true colour) on the satellite images represent the cultivated fields.

1.4.2. Landscapes and topography

The Plateaus

The Oligocene-Miocene plateau (SELKHOZPROMEXPORT, 1984) is divided into the northern and southern plateaus of the Jol by one wadi (MAW, 1996), named Wadi Hadhramaut in the upper section and Wadi al Masila in the lower section. The altitude of the southern Jol ranges between 860 and 1580 m and is higher than the northern jol, which rarely exceeds 1200m (Figure 1.2). The altitude in the northern Jol, where study areas 1 and 3 are located, decreases gradually towards the Rub al Khali desert in the north-east and increases in the west towards the Ramalat Assaba'tain desert. The southern plateau increases in height towards the south. The plateau was compressed during the Tertiary into broad anticlines and synclines (DOVE, 2001) and comprises an undulating, almost flat surface, dissected by numerous deep narrow secondary wadis (drainage lines) that flow to the main Wadi Hadhramaut. All drainage lines flow north into the Wadi Hadhramaut before flowing again east to Wadi Masila and then south east to the coast (Figure 1.3).

The wadis

There are also many large wide wadis, the biggest of which is Wadi Hadhramaut and its many tributaries. Wadi Hadhramaut has an almost flat bottom with steep sidewalls, it varies in width, from 1.5 km in the east to 6 km in the west and lies about 300 to 400 m below the level of the plateau. The wadis are cut by unstable rocky drainage lines; the natural vegetation is mainly concentrated along the sides of these drainage lines but dense vegetation may develop in certain locations, where favourable moist conditions occur. The altitude of the bottom of Wadi Hadhramaut ranges from between 600 to 800m (Figure 1.2). The headwaters of Wadi Hadhramaut open westward into a wide desert plain called the Ramlat Assaba'tain. The Wadi Hadhramaut is considered to extend between Wadi Saar in the west to just west of Tarim in the east (SOGREAH, 1979).

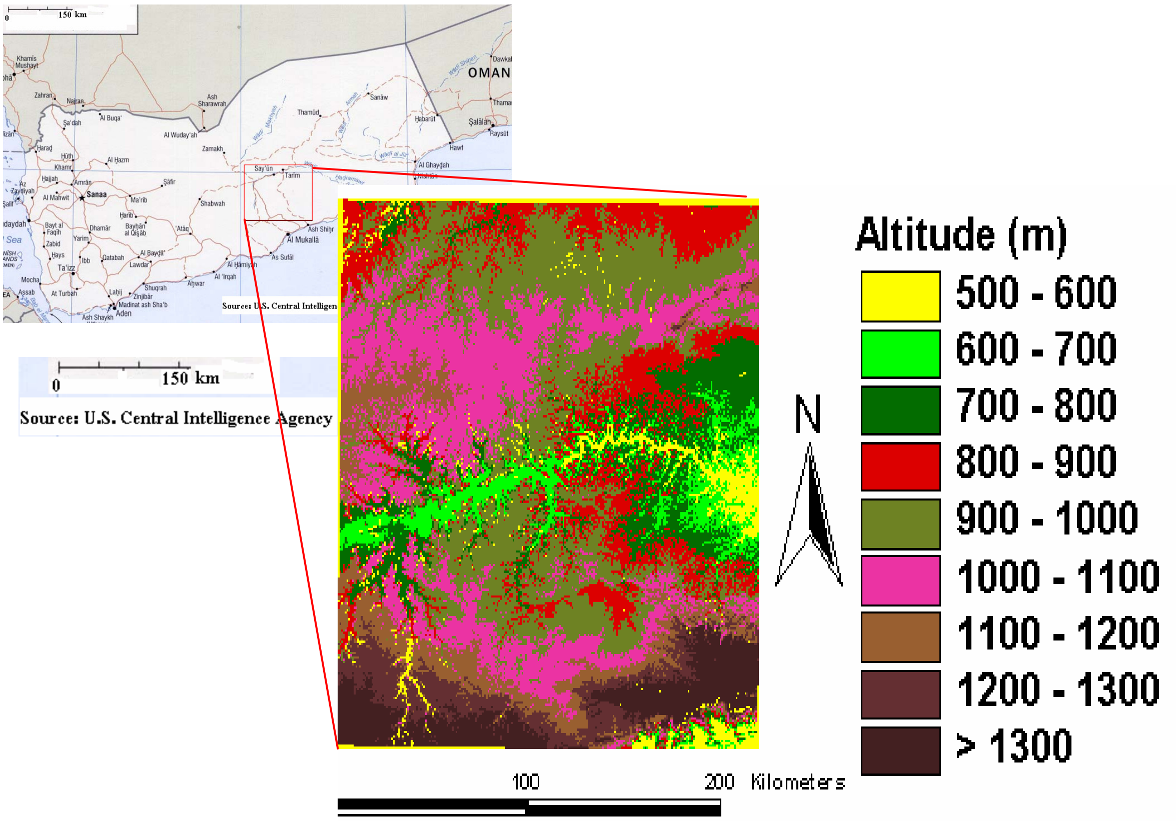


Figure 1.2. The altitude of W. Hadhramaut and surrounding plateaus, including the desert of Ramlat Assaba'tain (west). The altitude ranges between 500 to 1300m asl. This altitude image was generated using the available DEM image and the softwares of ERDAS IMAGINE 8.4 and ArcView 3.2a.

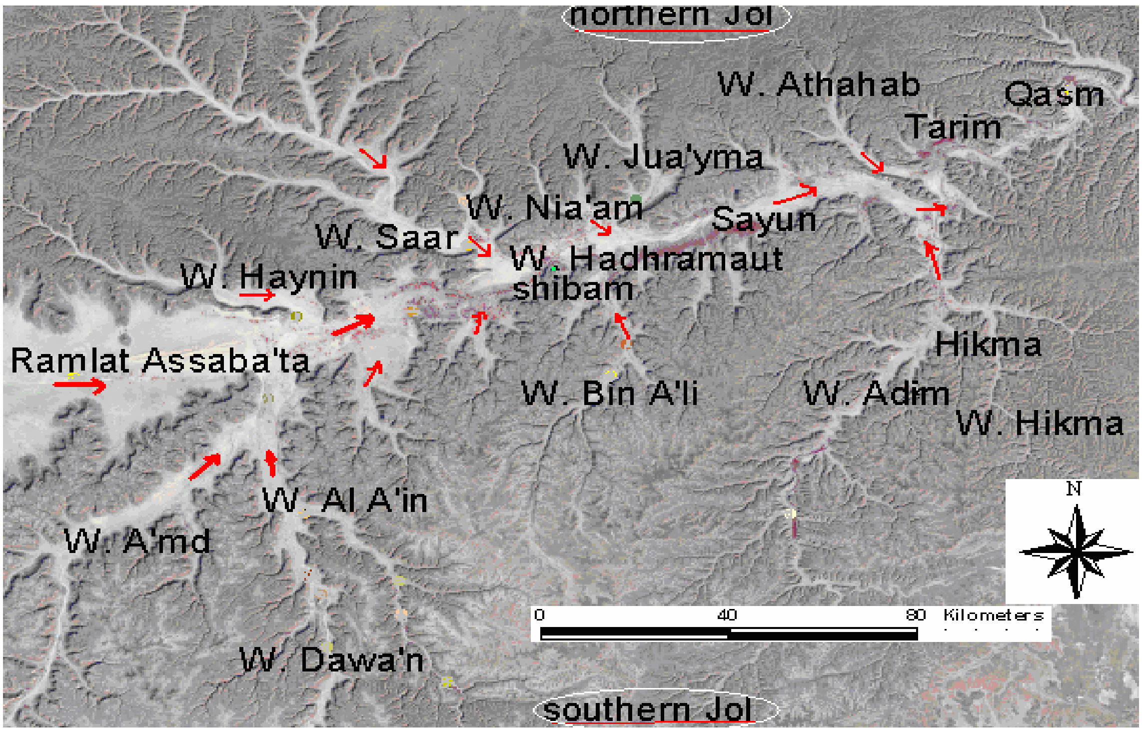


Figure 1.3. Wadi Hadhramaut with its tributary wadis. Wadi Hadhramaut divides the plateau region into two. The altitude of the southern plateau increases towards the south and the northern plateau decreases towards the north. Periodic surface flow.

1.5. The study sites

Generally the topography of the 3 detailed study sites is very similar and comprises the following (Figure 1.4).

1.5. 1. Main wadi

This is nearly flat and is cut by deep drainage lines (wadi beds) where most of the natural vegetation is concentrated. The width of the wadi varies from three to five km in site 1, from 0.64 km to 1 km in site 2 and from 1.5 to 3 km in site 3. The terrain is generally flat but cut by drainage lines that are covered by bare stones and gravels. The slope percentage of the wadi ranges between 1 and 3% facing east, north and north-east. The altitude ranges between 673 and 733 m asl. The wadi bed cuts into the valley of the main wadi, dividing it into flood plains and terraces on either side. In some locations, this wadi bed runs close to the mountain slopes. The main wadi contains terraces, sandy plains, depressions, and some bare land. Almost all of the agricultural fields are located in the main wadi.

1.5.2. Slopes facing the main wadi and its tributaries:

These are steep to moderate steep rocky slopes, with slope percentages ranging between 20% and 60%. The surface cover is very shallow and is mostly rocky (87 – 93%), sometimes covered with large bare rock outcrops (5 – 9%).

1.5.3. Cliffs:

These are very steep to vertical bare rocky areas facing the main wadi.

1.5.4. Plateaus:

These are undulating to almost flat rocky areas with gradients range between 1% and 3%, dissected by numerous drainage lines (secondary wadis). The Wadi Hadhramaut divides the plateaus into southern and northern sections, the distance between both plateaus is wider to the west towards the Ramlat Assaba'tain desert plain. The northern plateau slopes to the south east, towards the Wadi Hadhramaut, with altitudes ranging between 910 and 995 m asl at the west corner and between 903 and 955 m asl at the east corner. The southern plateau slopes to the north east, towards the Wadi Hadhramaut with altitudes ranging between 858 and 977 m asl.

1.5.5. Slopes on plateaus:

There are steep to moderately steep rocky slopes (gradients between 20% and 50%) on the plateaus. Their surfaces are shallow and very rocky (between 95% – 97%) with large rock outcrops (between 1% and 4%). The lengths of the slopes range from 50 m to almost 400 m.

1.5.6. Secondary wadis on the plateaus:

These are canyon-like valleys with undulating to almost flat rocky surfaces with gradients of 1% to 5%. Most of the surface is covered by bare rocks. These secondary wadis flow into the main Wadi Hadhramaut and its tributaries.

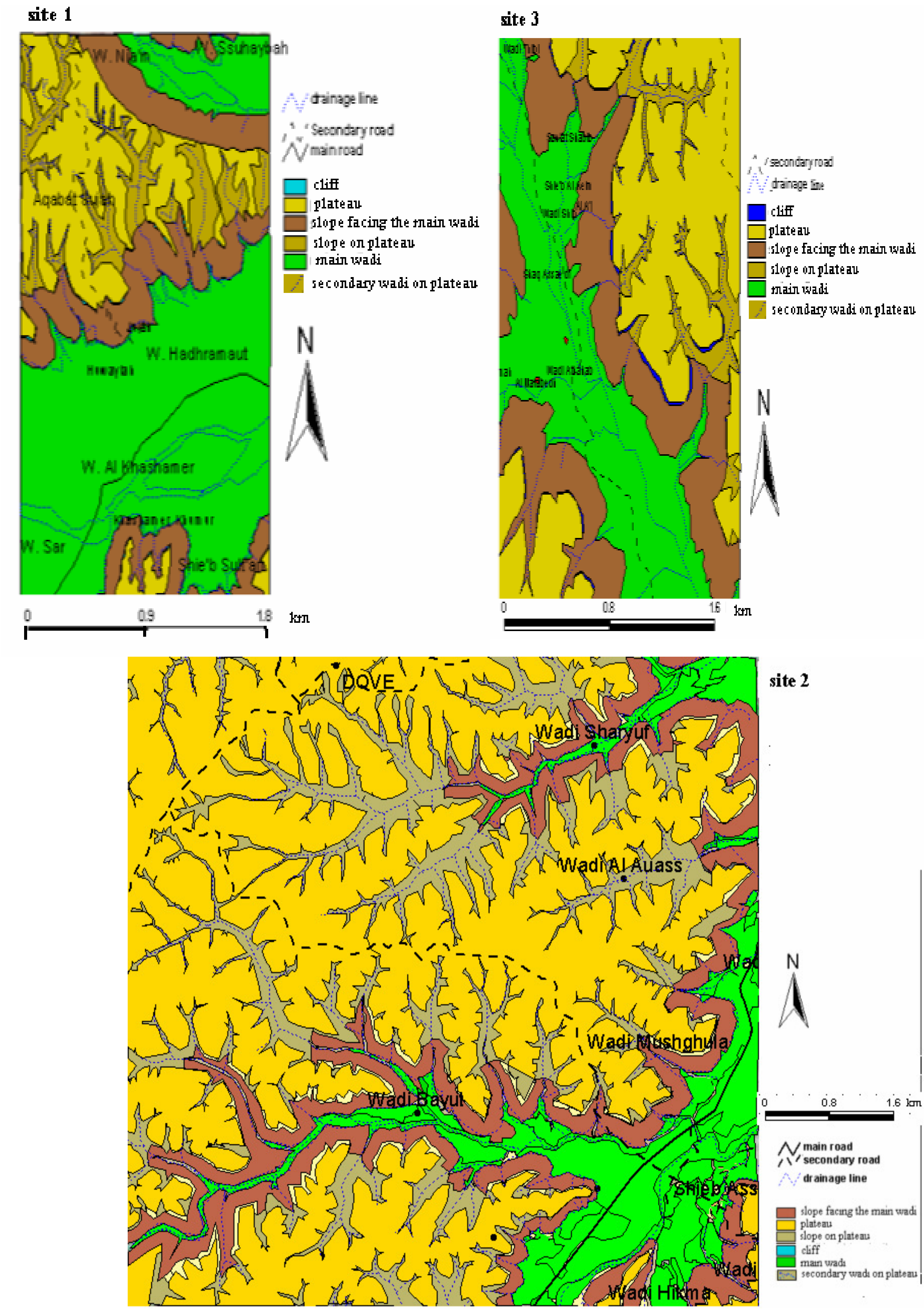


Figure 1.4. Maps illustrating the main topographical units of the study sites.

1.6. Climate

1.6.1. Introduction

Climate has a major influence over plant distributions throughout the area. It is known that climate has changed considerably, particularly as regards air temperature and precipitation during the Holocene (Anderson, 1997). Scientists have hypothesized that the climate of the region would have been wet during a period beginning 13 000 BP to about 9000 BP (Kenneth et al., 2001). They suggested that the present desert climate of Arabia probably began about 6000 BP and has continued to gradually dry out to the present time.

Today Yemen has a predominantly semi-arid to arid climate, with rain during spring and summer. The annual rainfall rises from less than 50 mm along the Red Sea and Gulf of Aden coasts to a maximum of 500-1000 mm in the western highlands and decreases steadily to below 50 mm towards the eastern desert.

Yemen's climate is affected by three large bodies of water (Ayele and Al Shadily, 2000):

- the Indian Ocean (including the Gulf of Aden and the Arabian sea),
- the Red Sea which contributes to the spring rainy season (March-May) and
- the Mediterranean Sea,

The presence of the Red Sea produces what it is called Red Sea Convergence zone effect (RSCZ) and contributes to the first spring rainy period between March and May. Monsoonal winds reinforce the Inter-Tropical Convergence Zone (ITCZ) effect during summer, causing a second rainy period between July and September. (Ayele and Al Shadily, 2000).

Dry climates predominate in Yemen. According to Koppen's climate classification system (1936), almost the entire area of Yemen belongs to the climate class Bwh of tropical / subtropical desert (Ayele and Al Shadily, 2000). Some zones, such as the Ibb area (about 193 km south of Sanaa, the capital) have a relatively high rainfall and a steppe climate (Bsh). The Empty Quarter (Ar Rub'al Khali) represents a low-latitude desert (Walker, 1998) or hyper-arid (AREA, 1999; Mandaville, 1986) and the coastal area represents the tropical semi-desert type.

There are differences between various authors over the definitions of aridity and the boundaries of arid regions; and so these terms and boundaries have to be treated with caution (Furley, 1983). The definition of arid lands used by researchers has also varied according to the aims of the enquiry (Heathcote, 1983). Aridity is measured in terms of the ratio of rainfall to potential evapotranspiration. Aridity is usually taken as a situation in which rainfall is less than half the value of potential evapotranspiration (Findlay, 1996). According to Isani (1999) and Cook and Warren (1973), arid regions are defined as barren lands lacking enough water for vegetation to grow. Arid regions within deserts are usually identified using a combination of average precipitation, evaporation, and temperature features (Havstad, 1999), and characterised by low precipitation, which is usually associated with considerable insolation (Isani, 1999). More generally though, arid regions are defined as areas receiving less than 250 mm of annual precipitation over a long-term average (Havstad, 1999) or between 125 mm and 380 mm (Furley, 1983). Arid regions can be divided to five climatic classes (Cloudsley, 1976):

1. Tropical or subtropical deserts
2. Cool coastal deserts
3. Rain shadow deserts
4. Interior continental deserts
5. Polar deserts

Some classifications divide deserts into three classes: semi-arid with annual rainfall less than 600mm, arid with annual raingall less than 200mm and hyper-arid with annual rainfall less than 25mm (and where rainfall occurs only sporadically over for long periods).

The Agricultural Research and Extension Authority (AREA) divided the Hadhramaut region into three Agro-climatic Zones (AREA, 1999) as follows:
Zone 1 represents Wadi Hadhramaut and the surrounding plateaus (700-1100 m asl)
Zone 2 represents the coastal areas (0-200 m asl)

Zone 3 represents the Ramlat as Saba'tayn (in the western part of Wadi Hadhramaut) and the Empty Quarter (the northern part of Wadi Hadhramaut) (800-1100 m asl).

Zone	Annual rainfall (mm)	Potential evaopo-transpiration mm/year	Mean Relative humidity	Sunshine hours/day	Average temperature per year
1	50-125	1650-1800	20-40%	8.5-10.5	31˚C
2	10-200	1400-1600	60-80	8.5-10	31˚C
3	< 100	2000	20-3-	9-10.5	30

Table 1.1. Main Agro-climatic Zones of Hadhramaut le 1.1 (AREA, 1999)

1.6.2. Hadhramaut

The Hadhramaut is an arid region characterised by low rainfall, high temperatures and high evaporation. One Arabic Omani proverb (Hawley, 1978) which reflects the cruel environment of the Hadhramaut is:

"Escaping from death, he got lost in the Hadhramaut."

Rainfall

Rainfall in the area occurs primarily because of convective storms and is generally infrequent, of short duration and of high spatial variability modified by the monsoon system (Komex International Ltd, 1999). Weather records in the Hadhramaut cover only the last 64 years. The main weather stations are located in Sayun (Wadi Hadhramaut) and in Al Rayan (coastal area); 27 new rainfall stations were established recently by Wadi Hadhramaut Agricultural Development Project in different locations of Wadi Hadhramaut and its tributaries (Figure 1.5), 14 stations were established in 1985 and 13 in 1989.

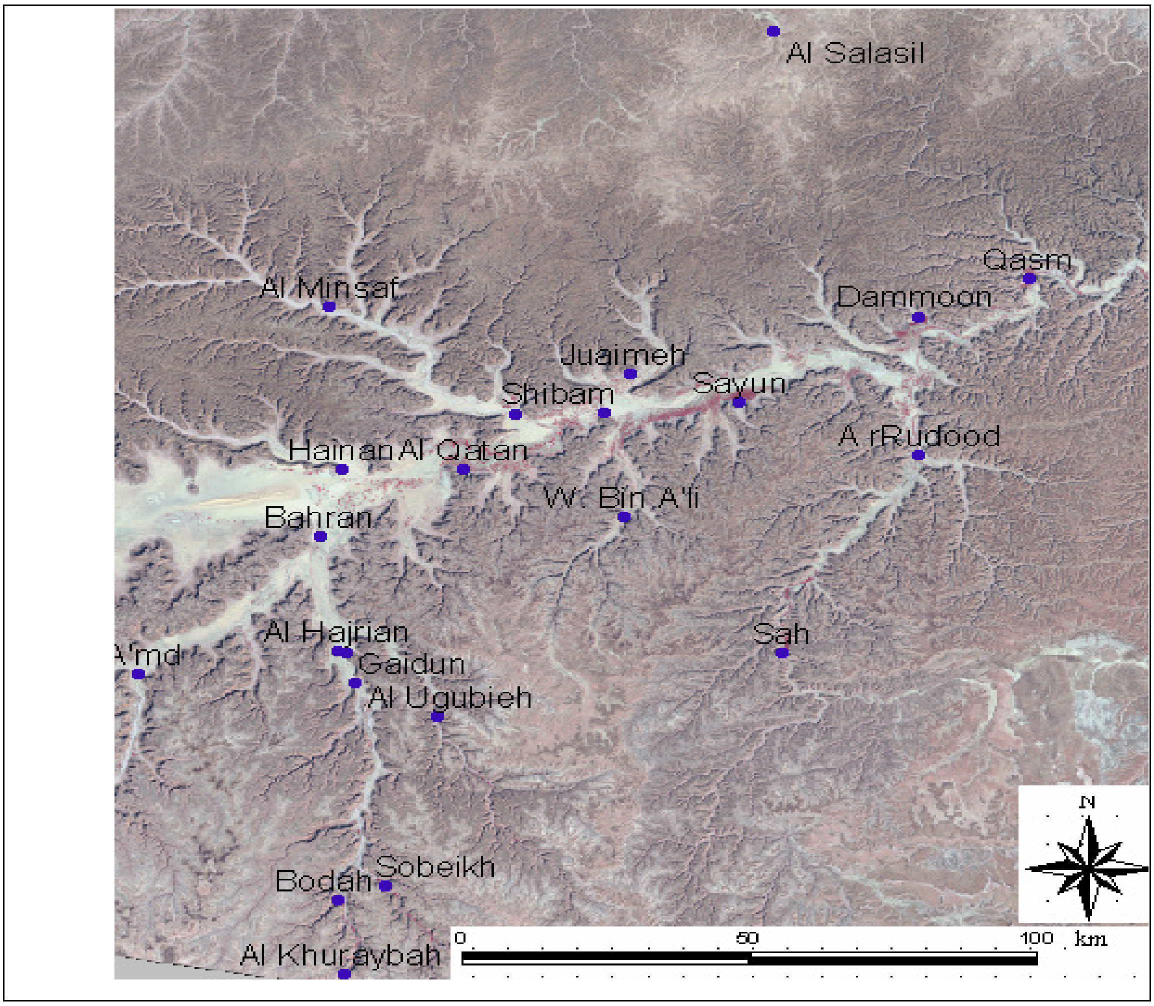


Figure 1.5. The location of the weather stations in Wadi Hadhramaut and its tributaries. All stations except Sayun have only recently been established by Wadi Hadhramaut Agricultural Development Project.

The average annual rainfall in Wadi Hadhramaut is 74.2 mm with average annual temperature of about 27 Cº. 83% of the annual rainfall falls in the warmest 7 months (spring and summer). The average temperature of the coldest month is 22.3 Cº. Therefore, based on the climate classification evolved by Koppen's (1936), Wadi Hadhramaut belongs to the arid Bwh climate type. Despite the presence of the oil industry on the plateau since 1995, there is no climatic data for the plateaus; nevertheless, the plateau is regarded as a trade wind desert (Kanfoush, 1998). According to a map produced by Cook & Warren (1973), the whole of the Hadhramaut is located within arid lands. The western border of the study area 1 (Ramlat Assaba'tain desert), is covered by sand dunes and is characterised by an annual rainfall of less than 30 mm representing a hyper-arid area.

The climate classification of UNESCO 1979 (Table 1.2), which is based on the ratio between average annual precipitation (P) and annual potential evapotranspiration (Eo) (Table 1.1), defines Wadi Hadhramaut as arid and the desert area west of the wadi as hyper-arid. More accurate definitions cannot be given because of the following reasons:

- Only one weather recording station in the study area has complete rainfall data stretching over a long period; other locations have only recent rainfall data (for a short period of not more than 4 years and often with a lot of gaps in the records).
- No accurate or complete data is available for some years
- A variation in annual rainfall data from year to year is very obvious

Name	index
Hyper – arid	0.03
Arid	0.25
Semi - arid	0.5
Sub humid	0.75
Humid	0.75

Table 1.2. UNESCO (1979) climate classification based on the ratio between average annual precipitation (P) and annual potential evaporation (Eo).

According to rainfall data from 28 stations (Appendix 2) provided by the Wadi Hadhramaut Agriculture Project, some areas receive on average less than 50 mm a year, which classifies them as deserts (Hamis, 1979); these areas are mainly located in the northern and eastern part of the study area.

The variation in annual precipitation is striking. It is noted from information provided by the meteorological station at the Agricultural Research and Extension Authority in Sayun, Wadi Hadhramaut, that in the last 22 years, the highest annual rainfall recorded was 175.6 mm, diminishing gradually in volume to 1989 with a low of 8.4 mm in 1988. Spring (March to April) and Summer (July to August) are the peak periods with average monthly rainfall between 7.8 and 17 mm (Appendix 1 and Figures 1.6 & 1.7).

As in all arid and desert regions (Harris 1979, Western, 1988), the rainfall distribution in Sayun, varies from one year to the next and from one month to another (Figures 1.6 and 1. 7). Monthly precipitation is also variable in both amount and time of occurrence from year-to-year, the average ranging from 0.1 mm in December to 17 mm in March. The maximum monthly rainfall occurred in March 1989 when 112 mm was recorded.

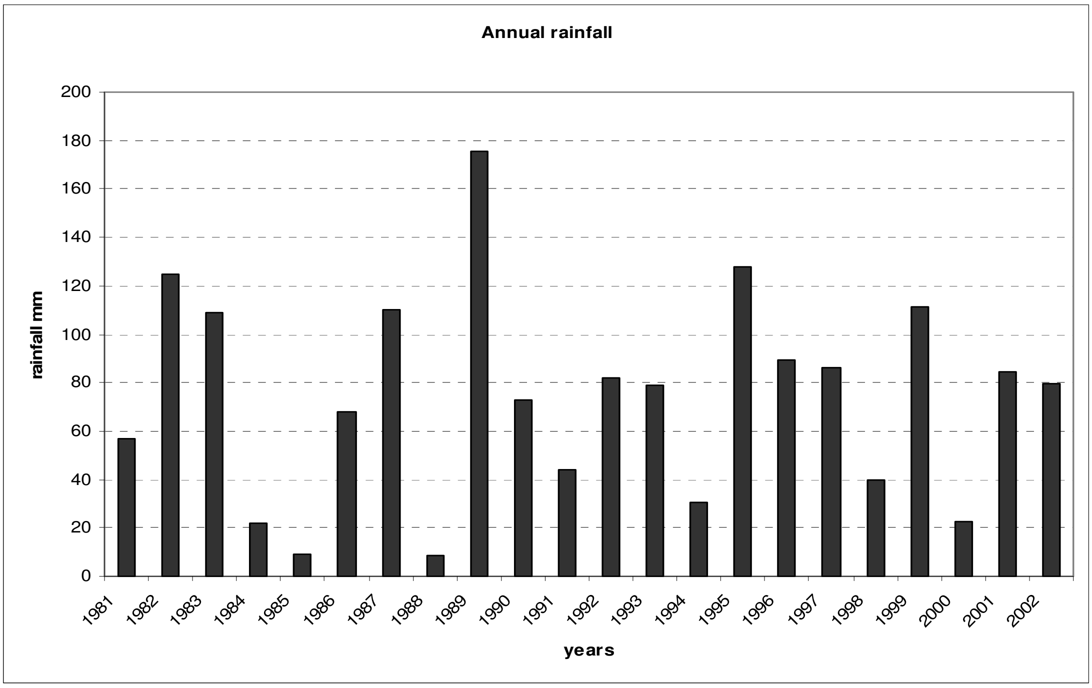


Figure 1.6. Annual rainfall of Sayun weather station. The rainfall distribution varies from one year to another, the highest annual rainfall recorded was in 1989 and the lowest was in 1988.

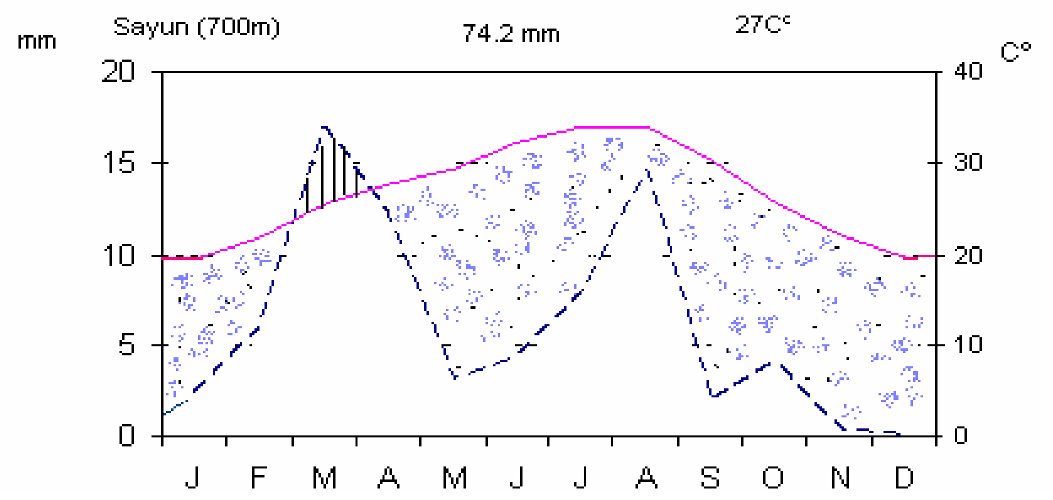


Figure 1.7. A climate diagram of mean monthly rainfall (the lower line) and mean annual temperature (the upper line) for Sayun. Names from left to right are: the station with elevation above sea level, mean annual rainfall and mean annual temperature. The dotted area represents the dry period while the vertical lines indicate periods of moisture surplus; it can be seen that for most of the year the area is in moisture deficit). Most of the rain in the study areas falls during the summer when the temperatures are high there is also a period of rain in March when the temperature is lower.

Evaporation

The average monthly evaporation ranges between 4.5 to 6 mm/day in winter, and between 7.5 to 9.7 mm/day during spring and summer (Figure 1.8). Generally average annual evaporation exceeds the average annual rainfall except in 1989 (Figure 1.9). The annual evaporation from an open stretch of water in Sayun was 2550 mm/year (SOGREAH, 1979). The study area has a potential evapotranspiration (PET) ratio in the range of 3 to 3.5 mm/day during the cool period and 6 to 6.5 mm/day during the months June-July, while the coastal area has PET ratio of 3 to 4 mm/day during the cool period and 4.5 to 5 mm/day during the months June-July.

Figure (1.10) shows the variation in potential evapotranspiration (PET) and precipitation for the study area (Sayun) and for coastal area (al Rayan).

Figure 1.8. Average monthly evaporation for Sayun. It ranges between 4.5 to 6 mm/day in winter, and between 7.5 to 9.7 mm/day during the spring and summer.

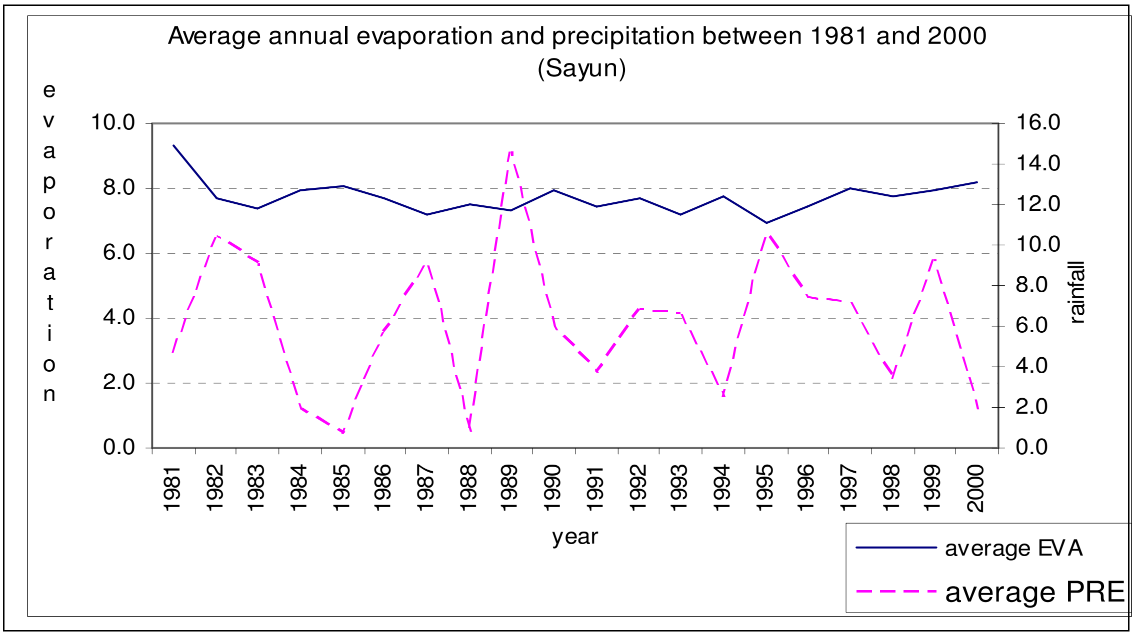
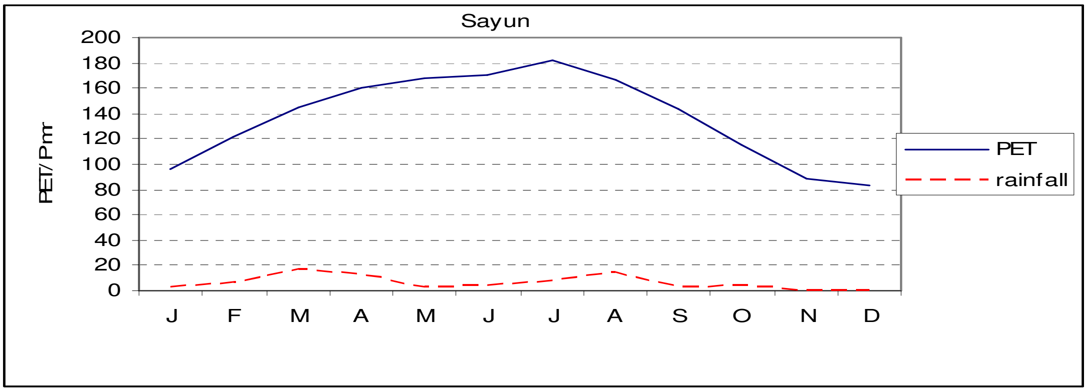


Figure 1.9. Average annual evaporation (EVA) and precipitation (PRE) between 1981 and 2000 (Sayun). Generally average annual evaporation exceeds the average annual rainfall (except in 1989). The rates of evaporation range from between 0.2 and 2 times the mean annual rainfall. In summer, when evaporation is highest, there is a moisture deficit in the soil, and plants must be able to stand severe drought for several weeks.



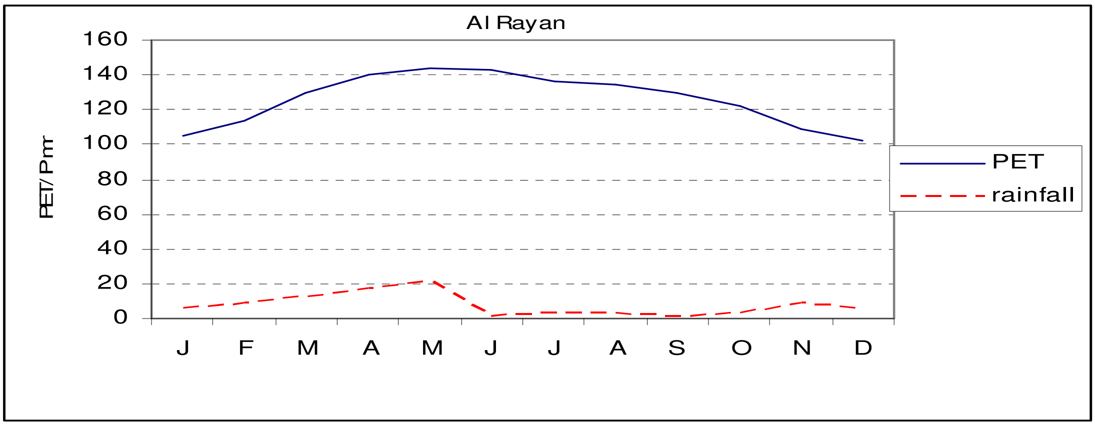


Figure (1.10): monthly evapotranspiration (PET) in relation to monthly rainfall for 2 stations in Hadhramaut region. PET exceeds the monthly rainfall in both Sayun (the study area) and Al Rayan (the coastal area). Averaged is over 20 years for Sayun and over 13 years for Al Rayan.

With regard to the PET data, Figure 1.10 shows that rainfall in both Sayun and Al Rayan areas is insignificant. The calculation of evaporation and infiltration at the end of 60 days in wadi basins shows that evaporation losses (60 mm) are almost negligible compared to infiltration (1.5 m) (SOGREAH, 1979).

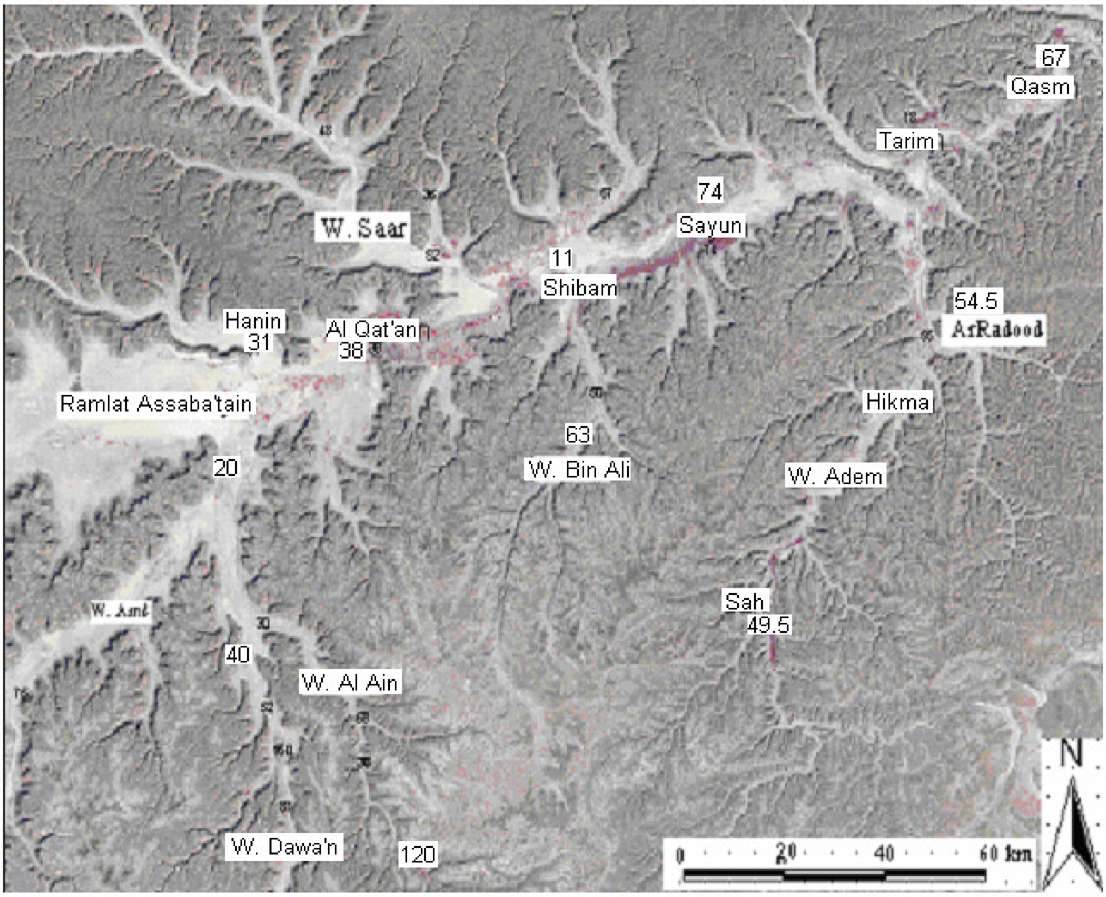


Figure 1.11. Average annual rainfall of different locations along Wadi Hadhramaut, based on the data collected between 1985 and 2000 by the Wadi Hadhramaut Agriculture Project (see Appendix 1). The 30 mm isohyet in Wadi Hadhramaut runs in the west (the beginning of Ramlat Assaba'tain desert). The 50 mm isohyet passes almost through the main Wadi Hadhramaut, then the isohyet lines increase from 60 mm to almost 300mm towards the southern plateau. The average annual rainfall at Wadi Amd (west) is about 80 to 100 mm, and at WadiDawa'n and Wadi Ala'in around 200 to 300mm. The 60 mm isoheyt runs through Wadi Bin A'li, and at Hikma and ArRadood villages (Wadi Adim). Compared to the southern plateau, the northern plateau has low rainfall, the average annual recorded in the wadis of the northern plateau (from Wadi Saar towards the east) is about 60 mm, and the average from Wadi Saar towards west is 40 mm, assuming that the annual rainfall on the northern plateau surface at the top is more than the wadi bottom down, the annual rainfall on the plateau may estimated to be 70 mm. SOGREAH (1979) also suggested that the annual rainfall on the northern plateau is less than 70 mm. During the floods of 7th April 1977, a total depth of 35.5 mm of rainfall was collected at Sayun and the volume was 40 mm3 in Adim and 4 mm3 in Shibam (SOGREAH 1979).

It is not only the lack of rainwater in the study areas which is a problem, but also the fact that rainfall does not occur regularly. The rainfall of the study area is characterised by poor distribution over a month with a long dry periods (see Appendix 3

3). The devastating floods which occasionally occur in the main wadis may be explained by high intensity of rainfall on the catchments of the wadis on the plateau and slopes. As a result of this high intensity of rainfall infiltration decreases and runoff increases. However, records showing the rate of the rainfall per hour are not available so it is not possible to get an accurate measurement of the rainfall intensity. Generally, as in other desert areas in the world, the important limiting factor in the study area is the quantity of moisture available to the plant. In order to survive in this climate, a plant must, on one hand, utilize the little rainwater available to it, and on the other hand, survive the very long dry periods.

Temperature

The mean monthly maximum temperature ranges between 29˚C to 35˚C in winter and 37 to 43 ˚C in summer. The mean monthly minimum temperature ranges between 9.8 ˚C and 16 ˚C in winter and between 18 ˚C and 26 ˚C in summer. The hottest months in the region are June and July. The average mean monthly temperature over 21 years at Sayun ranges from 19 ºC in January to 34 ºC in July and August. The average maximum monthly temperature exceeds 42 ºC in July and August and drops below 10 ºC in January (Table 1.3 and Figure 1.12). The average monthly relative humidity ranges between 29 in July and 47 in January (Figure 1.13).

Years		J	F	M	A	M	J	J	A	S	O	N	D
1981-2002	mean	19	22	25	28	29	32	34	34	30	26	22	20
	maximum	29	32	35	37	40	42	43	43	40	35	32	29
	minimum	9.8	13	16	18	20	23	26	25	21	16	12	10

Table 1.3. Monthly temperature data between 1981 and 2002 at Sayun weather station.

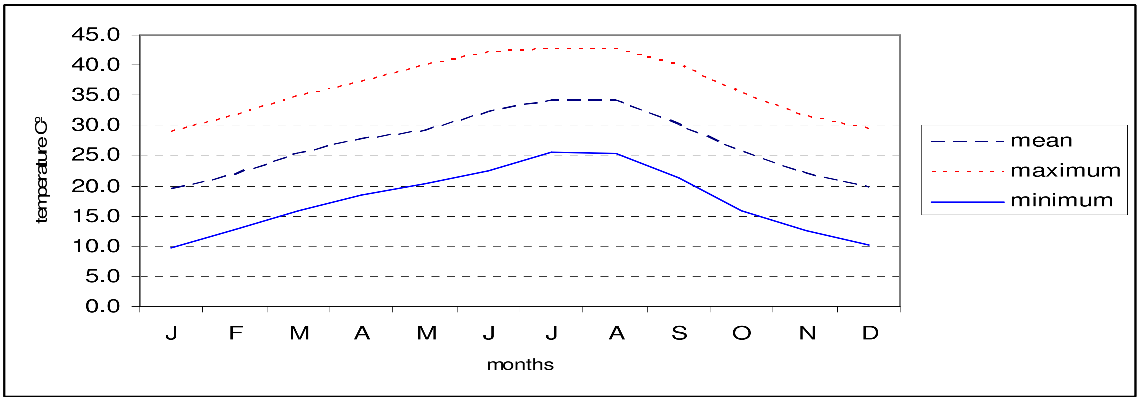


Figure 1.12. Average monthly temperatures data between 1981 and 2002 at Sayun weather station.

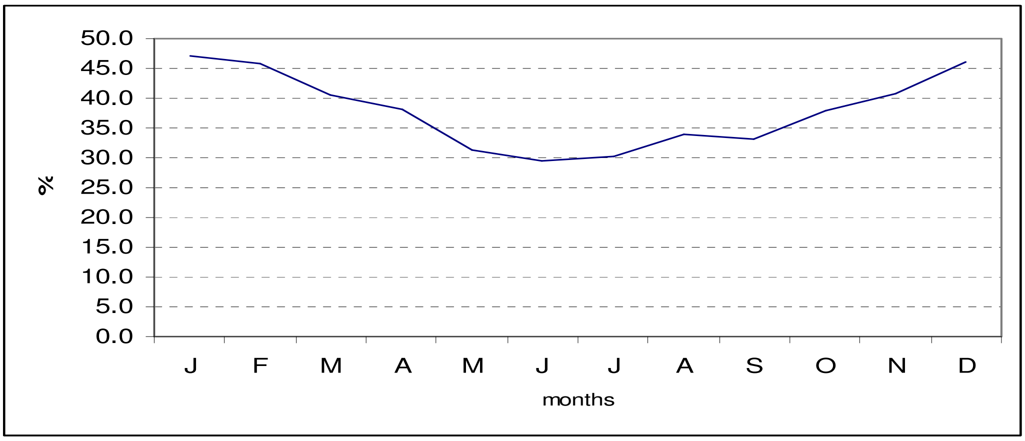


Figure 1.13. Average monthly relative humidity at Sayun weather station.

The rainfall in the study areas mainly falls in summer when the temperature is very high, the rate of evaporation exceeds rainfall throughout the year, In such environmental conditions, much of the rainfall is returned to the atmosphere by evaporation and only vegetation which is adapted to a dry environment can survive. Many plants found in the arid climate that characterizes Wadi Hadhramaut have ecological adaptations that help them to survive (see chapter 7).

In arid regions, the quantity of rain is less important than the amount of water remaining in the soil after evaporation, and thus available to plants. The amount of this remainder is a function of the soil texture; coarser soils hold more water below the surface, so unlike in a humid environment, clay soils are actually the driest environments in arid regions (FAO, 1989.). The depth of wetting the arid and semiarid zones will depend on soil type and rainfall distribution (Fischer and Turner, 1978). Sandy textured soil and loamy fine sand have high permeability and coarse texture. Sandy loam and loamy textures are dominant in the study sites.

Unlike conditions in temperate regions, the rainfall distribution in arid zones varies from one year to another and from summer and winter (FAO, 1989). For example, the study area receives rain during the summer and spring, while the cold months are almost devoid of rainfall. Winter rains can penetrate the soil to underground storage, while the summer rains in fall on a hot soil surface and are lost by evaporation. Therefore, the effective rainfall available to plants is low.

Wind speed

Compared to similar habitats in Yemen, wind speed in the study area (as measured at Sayun) is low and ranges between 0.8 to1.3 m/sec. (Figure 1.14. The wind speed in the study area is generally high in June and July and low in November and December.

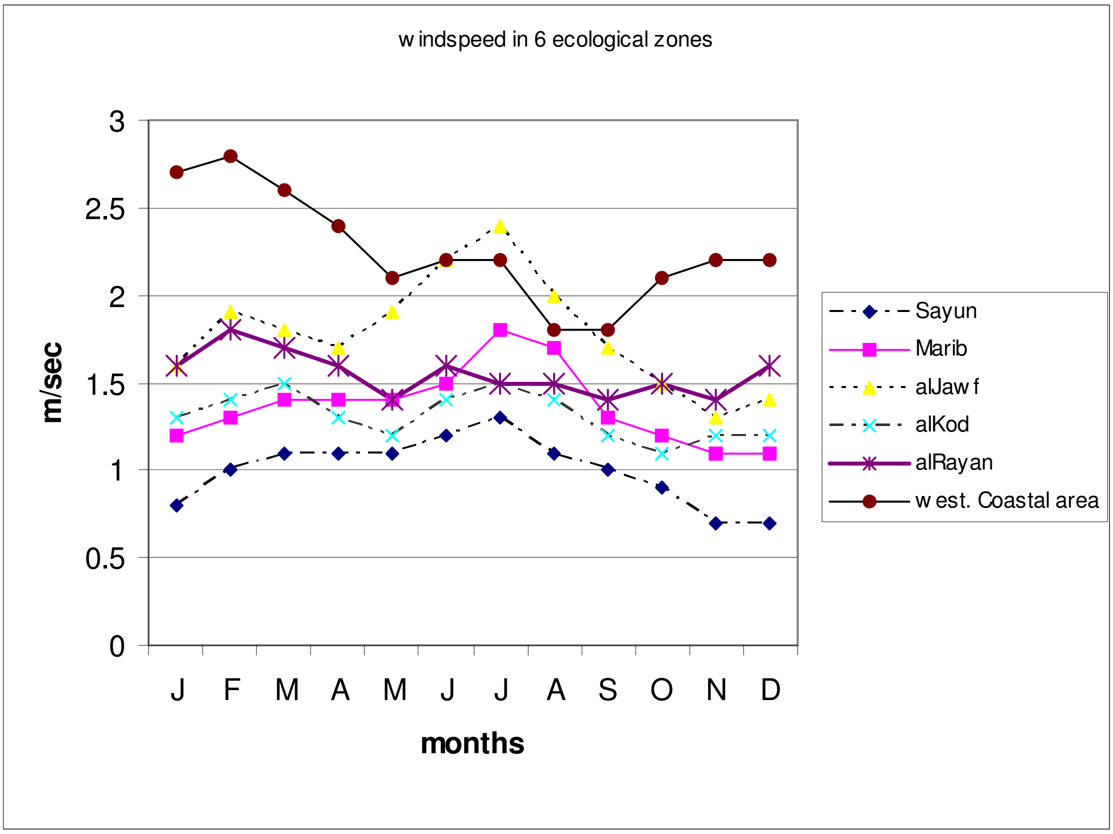


Figure 1.14 Wind speed of 6 dry ecological zones in Yemen. Wind speed at the study areas (Sayun) was the lowest. These ecological sites are located in the arid and semi-arid zones of Yemen. Marib and Al Jawf are located at the desert zone of northern part of Yemen and characterised by having vegetation similar to the study area, while the western coastal area has vegetation similar to the coastal area of Hadhramaut region (AlRayan).

Because of its damaging effects on vegetation and loss of fertile top soil, wind erosion is an important factor in arid and semi-arid areas (Balba, 1995; Bell, 2003). Other climatic variables such as temperature and precipitation have also effects on wind erosion. For example, the presence of soil moisture can reduce the soil's erodibility from wind (Toy et al., 2002). Precipitation can thus be sufficient to keep the soil moist and reduce the wind erosion. Nevertheless, with the high temperatures that characteriz the study area and the easily erodible sandy soil, wind can be a problem

(Toy et al., 2002). Despite this fact, information on the amount of wind on the plateau and the amount of soil removed by wind erosion under the current climate conditions in the study area is not available.

1.7. Geology

1.7.1. Introduction

The present relief of the southern part of Arabia formed as a result of active neotectonic movements of the earth crust that dissected the pre-existing platform into separate structural landforms (SELKHOZPROMEXPORT,1984) and shows that there has been little movement of earth since their deposition some 30 million years ago (Ghazanfar 2004).

The present plateau surface is either of Oligocene-Miocene age, overlying Lower-Eocene deposits (SELKHOZPROMEXPORT, 1984) or an Eocene limestone shelf (Vogt et al 1997). The plateau occupies a vast area to the north and south of Wadi Hadhramaut. The geology of Wadi Hadhramaut and surrounding areas consists of the following formations (Comrie 1992, Komex 1999, MAW, 1996): (see Figure 1.15).

1.7.2. Quaternary units (wadi deposits)

Wadi deposits contain gravels, cobbles, sands, silts and clay-grade materials. Deposition of materials eroded from the plateaus is the main process in the current development of the wadi (Al Mashreki 1999). Coarse materials are laid down in the wadi bed, while finer materials are deposited on top of the wadi terraces when the wadi overflows its banks.

What is visible in site 2 is the lower Jeza formation, the Umm Er Radhuma limestone cliffs, and wadi alluviums with some gravel in the wadi beds (DOVE 2001). There is an outcrop of Mukalla sandstone where Wadi Adim (site 2) opens out into Wadi Hadhramaut (Al-Ghuraf area).

1.7.3. Tertiary units (Hadhramaut group)

These form an extensive and almost continuous cover in the eastern half of Yemen (WRAY 1995, Komex 1999) and consist of the following formations:

Umm er Rahduma formation: Palaeocene carbonate rocks covering the plateau and comprising limestones and dolomites; the thickness ranges between 300-400m. The Wadi systems have been eroded in this formation to a depth of 300m.

Jeza *formations*: Inter-bedded, limestones and shales with poor aquifer properties. The thickness varies from 40 and 110m. The Jeza formation is underlain by the Umm er Radhma aquifer and divided into lower and upper formations:-

Upper Jeza (lower Eocene). Approximately 35 m thick with a limestone or dolomite cap with chert nodules, sometimes underlayen by marl, gypsum, clay and sands.

Lower Jeza (upper Paleocene to lower Eocene). Approximately 40 m thick with a nodular, chalky, well-bedded limestone cap and thin beds of brown and grey shale. The upper and lower members of the Jeza formations are found at lower elevations, along the Wadi escarpment and cover the upper level of the plateau.

1.7.4. Cretaceous units (Tawilah group)

Mukalla formation: Consists of sandstones and continental conglomerates; its thickness varies from 165 m to 520 m with fine to medium grained, white cross bedded sandstones.

Sharwayn formation: A uniform sandstone formation topped by 50 m of thick shale; it forms the uppermost stratigraphic unit of the Tawilah group, and has a thickness of between 11 to 28 m.

1.7.5. Sand dunes

This formation occurs in limited areas to the west of Shibam (site 1) and southwest of site 2.

For the location of the study sites see Figure 1.1 page 6.

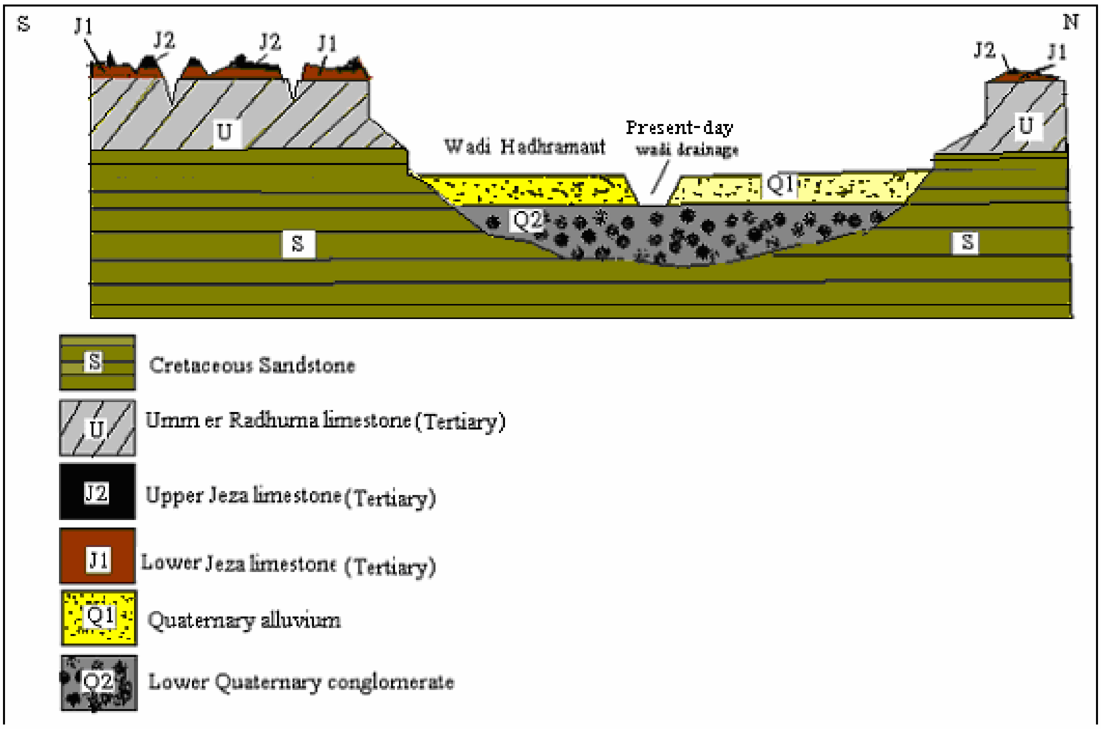


Figure 1.15 Geologic cross-section through W. Hadhramaut and the surrounding plateaus (after SOGREAH 1979). The Quaternary alluvial layer has a favourable for plant growth, it has a good depth, is fine textured, with good nutrient supplies as well as greater soil water availabilities; conversely the limestone plateau is characterised by very thin soils with less water availability for plants.

1.8. Land use

1.8.1. Agriculture

The current land use was determined by interviewing local people and officials from the Agricultural Research and Extension Authority (AREA) at Sayun (see Appendix 5). The eastern part of Yemen at altitudes below 1600 m is characterised by unproductive plateaus with wadis which flood after the heavy but infrequent rainfall in the region. Small oases of date palms are found along the entire Wadi Hadhramaut. Farming, supported by wells and spate irrigation (from the wadis), is all that remains of the large areas formerly irrigated by the large-scale flood control techniques of pre-Islamic times. These date back to the time of the Sabaean kingdom in the first millennium BC (Wissmann, 1968) A recent archaeological survey (Kharaiti, 2000) in Hadhramaut has documented a variety of types of agriculture practised in the distant and recent past. The topographic layout of the valley allowed several, small protected areas to survive on low lying, fluvial terraces along the wadi banks (Komex 1993, Vogt et al., 1997).

Wadi Hadhramaut is one of the most important agricultural regions in the eastern part of Yemen. Most of the wadi bottom is heavily cultivated. Trees such as *Acacia campoptila, Acacia ehrenbergiana, Conocarpus lancifolius, Prosopis juliflora, Ziziphus spina-christi* and others are grown around and in cultivated fields. The irrigated fields are mainly cultivated for palm trees, wheat, sorghum, alfalfa (*Medicago sativa*) and vegetables. Other trees less frequently encountered near or inside the cultivated fields include: *Maerua crassifolia, Ziziphus leucodermis, Tamarix aphylla, Moringa peregrina, Pithecellobium dulce,* and *Anogeissus bentii.* The indigenous trees are used to provide forage, fuel wood and as wind breaks and border markers. According to (Bataher 1998) *Acacia tortilis* (*A. campoptila*) is the most frequent tree in the wadis followed by *Ziziphus spina-christi.*

Another important plant of cultivation is the date. These are grown in date-gardens, which consist of pure stands of *Phoenix dactylifera* or sometimes with annual crops such as alfalfa, and sesame and and various vegetables (e.g. Onion, Potato, Tomato, Garlic, Okra) planted beneath. Alfalfa is considered to be a major fodder crop in Wadi Hadhramaut (Awadelkarem, 1997).

The main crops in the region are:

1. Cereals (wheat, sorghum and sesame),
2. Vegetables (Onion, potato, tomato, garlic),
3. Fodder (alfalfa)
4. Date palms (Phoenix dactylifera).

Anthony et al., (1963) reports the following main crops from Hadhramaut: wheat as a winter crop, sorghum as summer and winter crops, date palms, and lucerne. Sesame and melons are cultivated under flood-irrigation with millet, lucerne and onions as secondary crops under well-irrigation. Most of these crops are currently planted in the study areas.

Some fields are left fallow during the dry seasons and irrigated by spate-irrigation during the seasonal floods which affect the region. In fields, which are irrigated by flood-irrigation, only sorghum, sesame, melons and *Vigna unguiculata* can be cultivated. According to farmers these crops provide harvests even if the fields are flooded only once. Tomatoes used to be widely cultivated, but are now only rarely grown. Irrigation by floods was mainly practiced in sites 2 and 3, no purely rainfed fields were observed in site 1.

The cultivated areas of Hadhramaut region are estimated to be 23050 ha in 2003, about 2% of total cultivated area of Yemen (Table 1.4). SOGREAH estimated the cultivated fields in Wadi Hadhramaut and its tributaries as 23679 ha (Table 1.5).

Years	Floods	Well	Rainfed	Cultivated Area
2003	2996	8529	10373	23050

Table 1.4. Agriculture Area (Hectare) **and no of holdings** (statistical year-book, from 2001 to 2003 respectively).

Wheat	Lucerne	Market garden	Summer sorg	Winter sorgh	Sesame	Palm g only	Cultivated area
11226 47 %	705 3 %	440 2 %	6312 27 %	3261 14 %	243 1 %	1492 6 %	23679 (21.6 %)

Table 1.5. The total cultivated area and percentage cover in W. Hadhramaut in hectares for the period 1977 –1978 (SOGREAH 1979).

Irrigated fields are mainly cultivated for palms, sorghum, wheat, alfalfa (*Medicago sativa*) and other vegetables. Generally sorghum is cultivated in summer and wheat in winter. Alfalfa is grown for about 3 to 5 years and harvested several times every year.

Compared to sites 2 and 3, more cultivated fields are found in site 1. The cultivated areas of the study sites were measured using ArcGIS and found to be as following (see chapter 6):

Site 1: 1877 ha

Site 2: 467 ha

Site 3: 237 ha

Month	J	F	M	A	M	J	J	A	S	O	N	D
Sesame winter						p	P			h	h	
Sesame summer	P						h					
Sorghum winter						P	P			h	h	
Sorghum summer				p			h					
Citrullus	h					p	P			h	h	
Dolichos lablab						p	P			h		

Table 1.6. Cropping calendar for rain fed fields in sites 2 and 3. P= planting, h= harvesting. During the rainy season water is diverted to the fields and left for about week to dry, the following crops are then sown: sesame, sorghum, lablab and citrullus.

Cultivated agriculture is practiced mainly in the wadis. Generally the main crops in the region are: Cereals (wheat sorghum and sesame), Vegetables (Onion, potato, tomato, garlic), Fodder (alfalfa) and Date palms (*Phoenix dactylifera*).

The characteristic annual crops are Alfalfa (*Medicago sativa*) and dense gardens of palm trees (*Phoenix dactylifera*) irrigated mainly by pumping, In spate-irrigation areas, only Sorghum, Sesame, *Citrullus* and *Vigna unguiculata* are cultivated.

In the past the best available estimates of areas under cultivation in Wadi Hadhramaut were from the work of SOGREAH (1979), which relied on the interpretation of arial photographs. However, now, with the availabilty of satellite images and GIS software programs such as ArcView and ERDAS, the cultivated areas can be more accurately calculated and changes in areas under cultivation can be monitored from year to year.

The area of land under irrigation between the west of site 1 (west Shibam) and the point where Wadi Adim falls into the Wadi Hadhramaut was calculated using a satellite image from April 2001 and ArcGIS software. The calculation shows about 73.5 km2 (7350ha) of irrigated fields (Figure1.16).

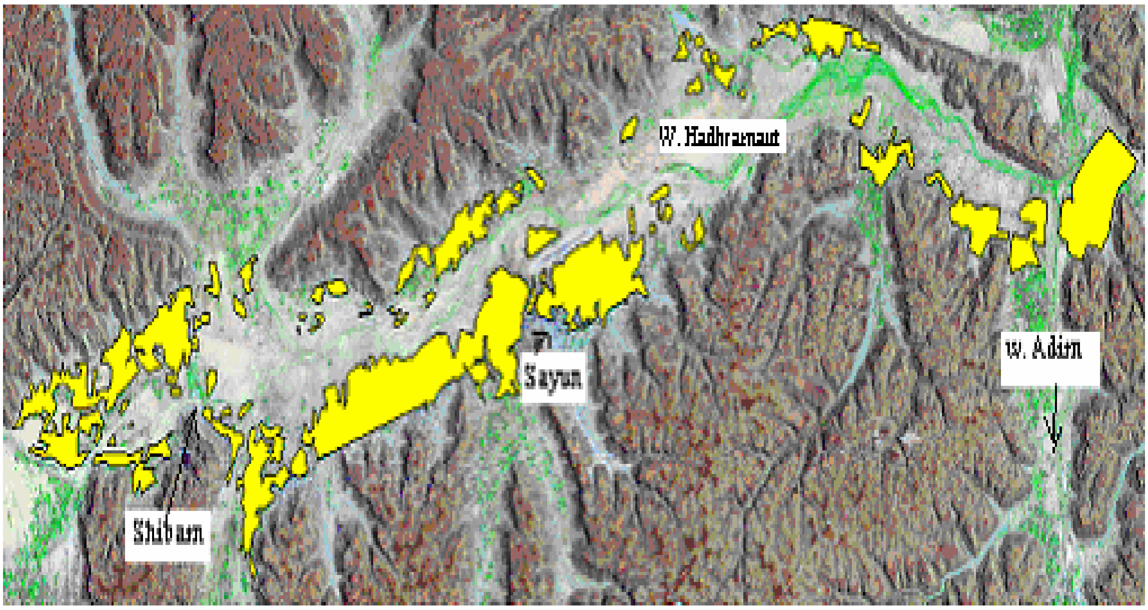


Figure 1.16. The irrigated fields along the Wadi Hadhramaut from site 1 (west Shibam) to the point where Wadi Adim falls into the Wadi Hadhramaut. The cultivated fields are estimated to cover about 73.5 km2 (7350ha). The uncultivated areas are about 68%.

There is no obvious spread of agricultural land onto the rangeland or onto the natural habitats in the Wadi Hadhramaut; in actual fact comparison between the different satellite images shows a decrease in the areas under cultivation in some areas; in particular in areas that have been and, still are affected by floods. For example, the Landsat imageries of 1973 and 1998 of site 1 were classified using ERDAS Imagine (Figure 1.17); the result shows that the cultivated areas decreased dramatically from 1973 to 2001, and, as a result, these areas have reverted to natural vegetation dominated by *Zygophyllum album* (association 2). These areas now provide important grazing for local animals. However, in some areas fields have been created in formerly neglected or marginal areas.

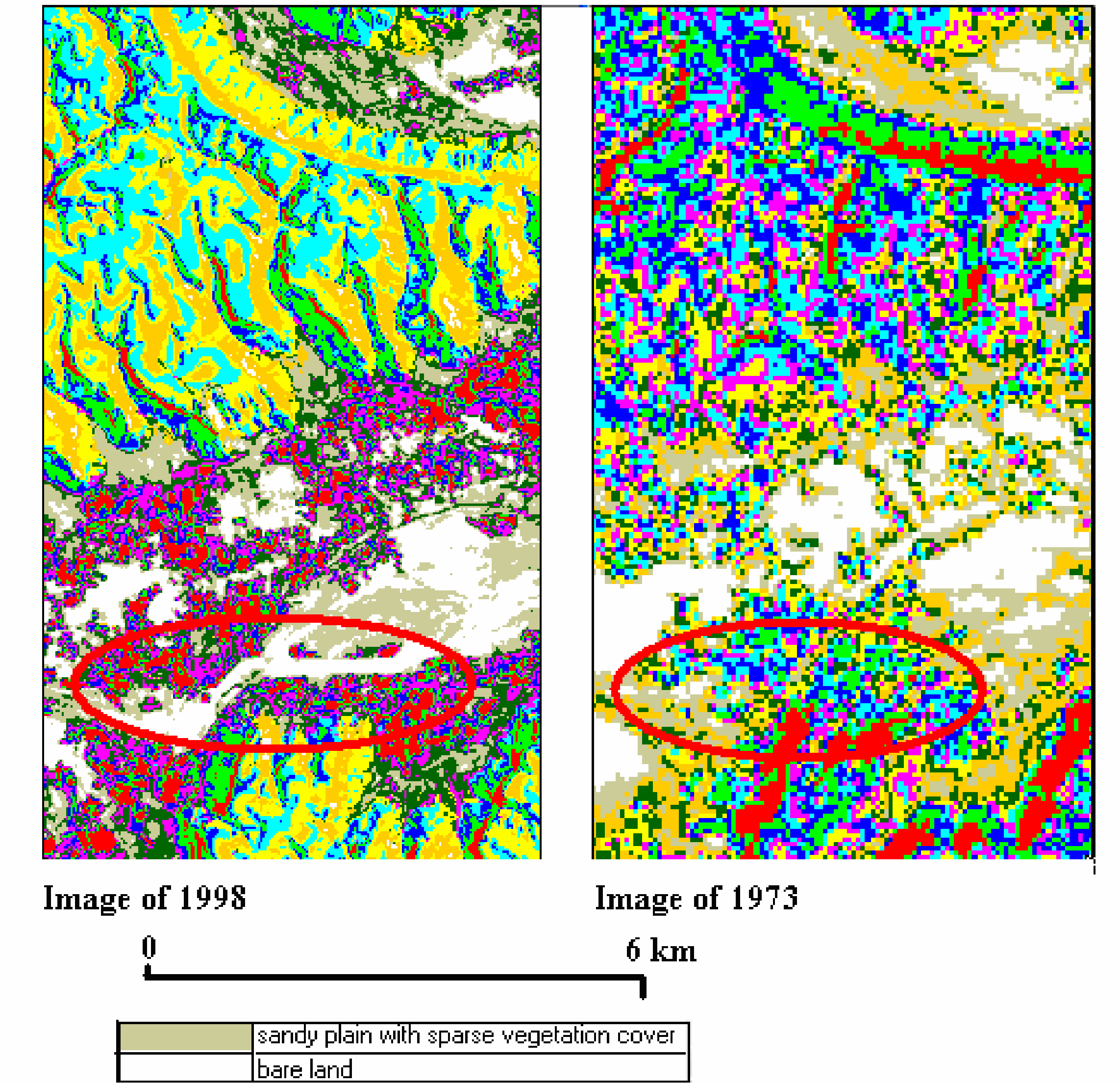


Figure 1.17. Comparison of the changes in land use between 1973 and 1998 in site 1. Due to the extreme floods, some agriculture field areas in 1973 (right) have been washed away and replaced by almost bare sandy areas covered by sparse vegetation (left).

Compared to the cultivated lands of Wadi Hadhramaut (Figure 1.16), uncultivated areas represent about 22961 ha (68%). SOGREAH (1979) estimated the uncultivated areas in Wadi Hadhramaut and its tributaries at more than 78%. According to Alwan (1990) in Wadi Hadhramaut (from Wadi al Khon east to the desert of Ramlat Assaba’tain), only 5.5 % of the land is utilized as agriculture fields and 25.5 % as grazing lands.

From these figures it can be seen that uncultivated areas in the Wadi Hadhramaut and its tributaries range between about 70 and 80%, the figure is higher (about 94%) towards the desert of Ramlat Assaba'tain. These uncultivated areas are distributed as follows:

- Gravely wadi beds and adjacent banks; these are the main grazing lands, as most natural vegetation is concentrated here.
- Bad lands, which are abandoned fields with deep gully erosion; the vegetation here is sparse mainly herbaceous.
- Sand dune areas, covered by sparse vegetation and isolated trees.

1.8.2. Animal husbandry system in the study areas

As the study area is situated in arid and semi-arid areas, the ability to sustain a production system in the study area depends upon the integrated management of cultivated fields and rangelands (Powell et al., 2004; Dixon et al., 2001). Dry lands (Dixon et al., 2001) in the study area comprise 70-80% of the total land area. Local people have developed their own ways of reducing the effect of the harsh environment by using crop and forage plants in agro-pastoral (Figures 1.18 and 1.19) or agro-forestry systems. Livestock are raised mostly on the rangelands near the settlements and on agro-pastoral systems and comprise a major source of income**.** The agro-pastoral systems in the study area are practised widely by almost all farmers. The system involves combining forage crops, such as alfalfa, and annual crops, such as sorghum and wheat, in rotation. Animals usually graze on the sorghum stubble and weeds after harvesting is finished. Agro-forestry, is less widely used. This involves the planting of trees, such as *Ziziphus spina-christa, Ziziphus leucodermis* and date palms, inside or around cultivated fields. Supplementary feeding, using alfalfa leaves of *Prosopis fracta*, seeds of *Acacia spp.* and *Prosopis juliflora* is fairly common in the study area. .

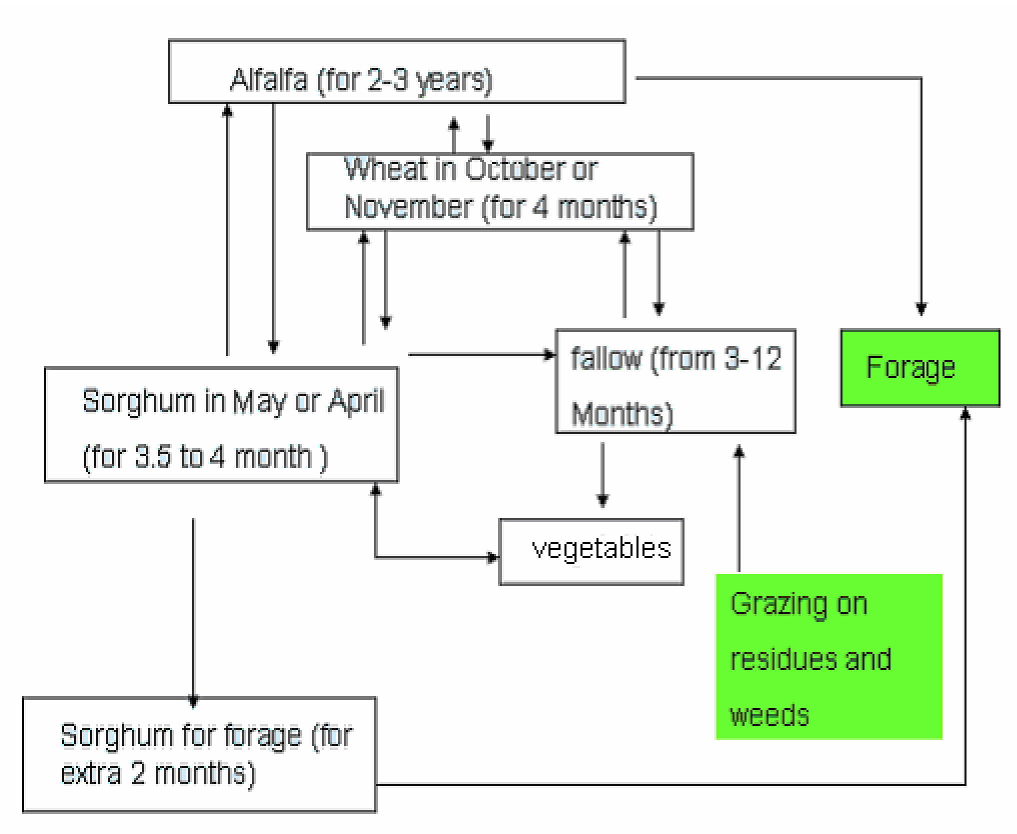


Figure 1.18. Agro-Pastoral system on irrigated fields. Alfalfa is on of the main forage cash crop for livestock, sorghum stubble and weeds are also important sources.

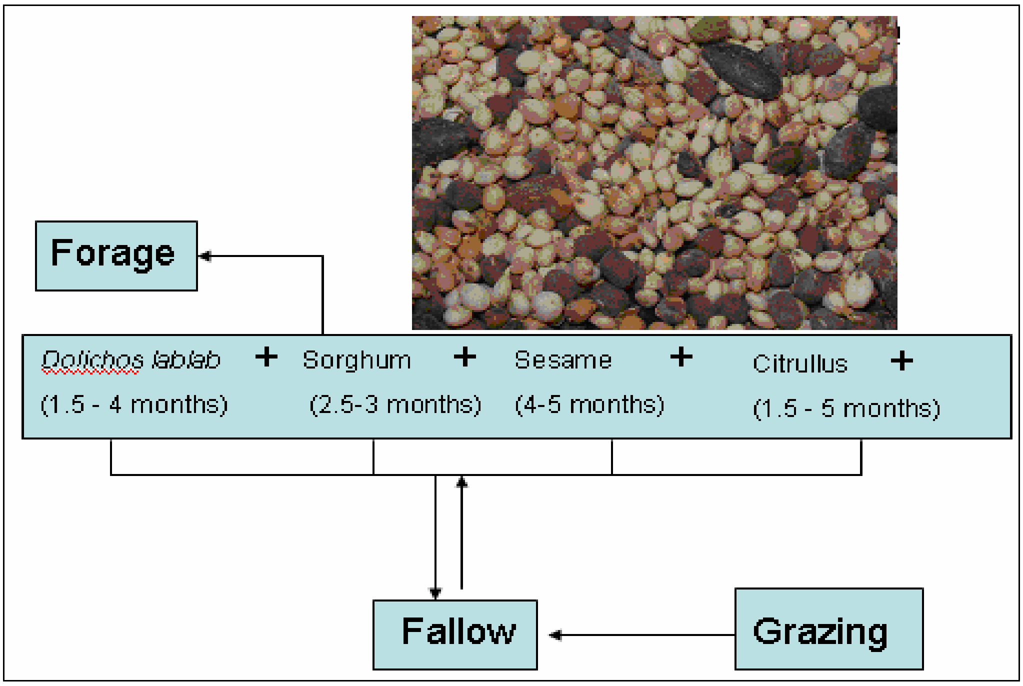


Figure 1.19. Agro-Pastoral system on spate irrigation (floods) fields sites 2 & 3. The floods mainly occur in March and July (summer and spring). Animals graze on the sorghum stubble and weeds. The photo shows a mixture seeds of sorghum, sesame, melons and lablab. A typical mixture includes sesame, sorghum and lablab. Sometimes, in particular in site 2, *Citrullus* spp. are added to this combination.

There are two main forms of animal husbandry in the study areas:

1- Nomadic animal husbandry, in which the herdsmen with their herds of goats, sheep and camels spend the entire year in the Hadhramaut region. The nomads wander constantly from place to place, seeking food and watering places for their herds.

2- Sedentary animal husbandry, in which the goats and sheep graze in the areas surrounding villages throughout the year.

Nomadic animal husbandry

This is practised and still important in the Hadhramaut region. 70 years ago (Stark, 1936), nomads used to move around but generally settled for 4 months in an area between Wadi Amed and near al Ahqaf (in the western part of the study area) searching for fodder, mainly with their camels. Nomadic herders were also noted in the northern and eastern part near Ghayl Bin Yamain (Komex International Ltd, 1999). This type of grazing is no longer practiced; most of the nomads in the study area settled about 5 to 10 years ago. Nevertheless, up to the present time, animal husbandry has been the most productive use of the study area. Due to the low rainfall, the vegetation density of Hadhramaut is generally low, as is the supply of forage and drinking water for animals. These factors force the herdsmen to wander continuously with their herds of camels, goats, and sheep. At the beginning of the rainy season, the herdsmen migrate with their herds towards areas with higher rainfall or with better forage and fewer herders (see Figure 1.20). In the past, particularly during the rainy seasons, nomads used to come to the study area from various parts of the Hadhramaut region (Figure 1.20). These areas are:

- al Mukalla (southern coastal area)
- Ashihr, (southern coastal area)
- Ghayl Bin Yamin (southern coastal area)
- Ghayl ba Wazir (southern plateau)
- Qaf Al Amiri (north of Tarim) and Qaf Al Kuthairi (north of Shibam)
- Thamood (northern part of the study areas)
- Ramlat Assaba'tain desert areas (western part of the study areas)
- Al Masila areas (eastern part of the study areas)

The length of stay in the study areas ranged between one and five years, but some pastoralists have been in the study areas (especially site 3) for more than 10 years.

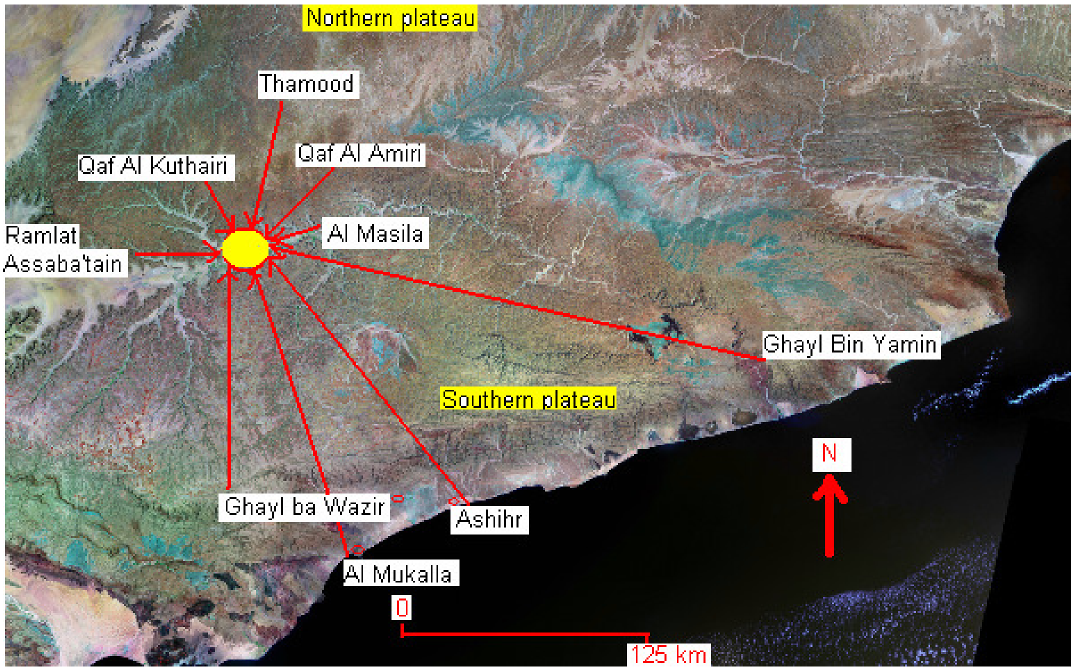


Figure 1.20. The movement of the nomads from surrounding areas and coastal plain to the Wadi Hadhramaut.

Recently, nomads and their herds have started coming to Wadi Hadhramaut, from areas such as Al Masila, in the eastern part of the study area, or from the southern coastal areas, to graze on the pods of *Prosopis juliflora* or even to buy these pods from farmers whose land has been invaded by this tree (plate 1.1).

Plate 1.1. Pods of *Prosopis juliflora* in large sacks, ready to transfer to Al Mukalla and Al Shihr (coastal area). Recently herders have started to come to the study area with their animals to graze on *Prosopis juliflora* or even buy few sacks of pods. For more on *Prosopis juliflora* and its effect on plant ecology see chapter 7.

Sedentary animal husbandry

The development of arable farming encourages sedentary animal husbandry. Village animals graze around the fields in the wadi beds and surrounding slopes. The grazing starts generally in the morning and ends in the evening, some farmers let their livestock graze from the morning to the afternoon and, after a short break, continue to graze from the afternoon until the evening. In the dry season, herders mainlufeed their animals on alfalfa (*Medicago sativa*) and sorghum stalks. Animals also graze on the sorghum stubble remaining in the fields after harvest as well as on weeds. This practice is mainly found in cultivated fields belonging to the government. In some places, especially in Wadi Athahab (site 3), goats and sheep are kept indoors and supplied with forage that has been harvested or bought. This is due to a number of reasons:

1. where the herders were previously young girls who now go to school,
2. where a farmer has few animals
3. where there is an agreement between farmers. This agreement prevents grazing outside, especially during farming period. This law has recently been broken by Bedouins from who have come in from other parts of the Hadhramaut, as a result more pressure has been placed on the rangelands, which may negatively effect the plant ecology in future time.

1.9. Environmental, land unit characteristic and the problems for plant growth

1.9.1. Introduction

According to UNEP & WMO (1996), the effects of climate change may be unimportant compared with the past and present impacts of human activities, including livestock grazing. Human impacts such as roads and other form of infrastructure have a strong impact on plant species distribution and wildlife (Nellemann et al., 2001).

According to the World Resources Institute (WRI, 1992) overgrazing is the most important cause of soil degradation in arid and semi-arid regions. In in semi-arid and arid regions of Africa and Australia, overgrazing causes 49% and 80% respectively of soil degradation (FAD, 2000). In Jabal Bura' (in the western part of Yemen), 42 km2 of woodlands have severely degraded between 1973 and 1987, due to the conversion of woodland to croplands (Herzog, 1993).

1.9.2. The Physical impact of Infrastructural activities

The exploration and production of petroleum has caused major negative impacts to the soil, surface and ground waters of the local ecosystems in the United States of America (Yousif and James, 2003; James and Zielinski, 2003). Current oil exploration and related activities are probably leading to the same problem in the Hadhramaut.

Oil companies have now been present in the region for over 10 years. The impact on the landforms, soil, vegetation, water bodies, habitat, and cultural resources are already obvious in many parts of the study area.

The activities of oil companies in the study area, particularly in Wadi Adim (site 2), have made a considerable impact on the landscape through clearing land for the construction of service tracks, pipeline inspections and access roads. These activities have already heavily eroded the landscape, particularly on the plateau. Many roads on the plateau are new and cover more ground than is necessary. As a result, bulldozers have scraped away the top surface of soil and stones, destroying the vegetation as well as archaeological sites on the plateau. The materials tipped down slopes and over cliffs during the construction of road and pipelines have covered and damaged the vegetation in the wadi beds and adjacent lower slopes.

During the construction of oil wells, the primary emissions are waste water, solid waste, waste oil, chemicals and dust (DOVE, 2001). Most of these waste products have ended up in the adjacent wadis.

1.9.3. Floods

Flooding is a highly dynamic action influencing the plant species of the Wadi Hadhramaut. Information on the effect of flooding on the distribution and richness of plant species is not available. Floods in Wadi Hadhramaut originate exclusively from the northern and southern limestone plateaus (SOGREAH, 1979), although the northern plateau generates fewer floods than southern plateau. The floods of 7th April and 23rd October 1977 devastated areas in both Wadi Adim (site 2) and Qassam (east of Tarim in the eastern part of the study area). Measurements show that Wadi Adim suffer much more frequent flooding than the other wadis (SOGREAH, 1979).

Historically, Wadi Hadhramaut has often suffered from several major floods which caused severe damaged to cities and, in particular, to the historic town of Shibam. Many people and livestock were lost and palm trees destroyed. The strongest and most severe floods were recorded in 1249, 1356, 1493, 1495, 1582, 1590 and 1687 (Lewcock, 1987; INTERCONSULT and MacDonald, 1993). Major floods in recent years occured in 1974, 1977,1987,1989,1992 and 1999. These periods correspond with the patterns of annual rainfall data recorded from Sayun (Appendix 1), which range between 110 mm and 175.6 mm. The floods of March 1989, which lasted for about 9 hours, are considered by far the most severe in Wadi Hadhramaut (INTERCONSULT and MacDonald, 1993). The annual rainfall recorded in 1989 from different stations within W. Hadhramaut (Appendix 2) also shows amounts higher than 100 mm. A strong flood was recorded by SOGREAH (1979) on 2nd March 1978 in Wadi Thibi (site 3) and on 11th July 1978 in Wadi Adim (site 2). Floods occur over the greater part of the wadi systems once or twice a year, with the strongest in the larger wadis usually once a year. The floods are insignificant in small or tributary wadis (SELKHOZPROMEXPORT, 1984).

The vegetation of some parts of the Wadi Hadhramaut is composed of different successional stages reflecting their subjection to annual floods. For example, species richness and distribution along the Wadi Hadhramaut (in particular site 1) has been severely affected by annual flooding and sedimentation. Here the structure of the vegetation has changed from woodland dominated by date palm to grassland dominated by *Zygophyllum album.* Strong floods in Wadi Adim destroyed some important trees, for example *Anogeissus bentii* reported by local people to be abundant in Wadi Adim and Wadi Hikma (site 2). This tree species has been destroyed by floods, in particular the flood of 7 April 1977 (SOGREAH, 1979), and not a single tree of *Anogeissus bentii* was observed during the field work.

1.9.4. Grazing

Grazing can alter the spatial heterogeneity of vegetation, influencing ecosystem processes and biodiversity (Adler et al., 2001). Overgrazing has been indicated as one of the main factors causing range degradation by accelerating erosion, reducing biodiversity, and altering soil properties (Ozgul and Oztas, 1990).

In the study areas, and particularly in Study Site 2, traditional grazing on the plateau has now largely been forbidden because of oil-related activities. Grazing is now mainly confined to the wadis and the adjacent slopes. As a result grazing intensity has increased in the wadis of all Study Sites.. Generally, grazing is continuous; herders going out early every morning and returning in the late afternoon. Very few people now graze animals on the plateau, and then usually only after good rainfall.

According to local people, overgrazing has reduced the abundance of some species notably *Merremia hadramautica, Boerhavia elegans* and *Tribulus arabicus.* The first species is abundant on the wadi beds of site 3 and is found near cultivated and fallow lands at sites 1 and 2. The second species is widespread over in the entire study sites but with low cover.

Goats and sheep dominate the area, with camels and cows limited in number. In addition to grazing, animals are fed with alfalfa, sorghum and crop residues. Grazing time varies but is practiced daily; Herders (mainly women) take their animals (goats and sheep) to the neighbouring area (wadi beds and adjacent slopes) and usually return in the evening. In the dry season, most of the herders feed their animals on alfalfa (*Medicago sativa*) and sorghum. Recently some farmers have started feeding their animals inside their houses most of the year. This is due to a number of reasons, such as a lack of herders and because of the high cost of herders. Also children, who used to herd the animals, have stopped herding any more mainly because farmers prefer to send their children to school. There are also fewer animals and many farmers now have smaller herds and prefer to buy forage rather than to herd them outside. A further factor is that grazing on the plateau is not allowed because of intensive oil activities and the complex security measures that surrounding them.

According to DOVE (2001) herders are allowed to graze on the plateau only if they first obtain permission from the Military commander in Sayun. Other Bedouin say that there is no formal restriction on access to the plateau. In general, military rule since 1994 has restricted the travel patterns of nomadic tribes throughout the plateaus (Komex International Ltd. 1999). Access to grazing in oil company sites on the plateau is not allowed; in addition the pipelines form a physical barrier to their camels. Generally, for most of the Bedouin, the restriction on grazing on the plateau is a small impact on their livelihoods, nevertheless, for some Bedouin, these restrictions create a problem since their traditional routes between grazing areas often cross the plateaus.

1.9.5. Plant collection

Collecting plants for medicinal or other purposes has an impact on certain species. For example the roots of *Rhazya stricta* are crushed, mixed with water and drunk to heal stomach pains. *Boerhavia elegans,* which is reported by local people to have been abundant in the past, has disappeared in some locations or is now rare. The seeds of this plant have been and are still collected extensively by local people to be mixed with traditional food (called As'id).

In the past, people used to protect the areas and slopes bordering their fields from livestock during the period of cultivation. Livestock, mainly belonging to the owner of the fields, was then allowed to graze after harvesting was completed. In addition, people used to harvest the seeds of *Boerhavia elegans* from these protected slopes in large quantities. Now however, this practice has changed and the slopes are no longer protected. Local people believe that the low availability of this plant in recent times is due to this change in the traditional patterns of grazing.

1.10. Soil

A predominance of physical weathering processes in the desert and semi-desert areas keeps soil development at an early stage (Zohary 1962). *Hamadas* are the dominant rock type in the study area, in particular over the plateau. This type of rock occupies large areas of North Africa, Central Asia (Zohary, 1962) and in the Arabian Peninsula (Batanouny, 1981). *Hamada* or *hammada* is Arabic for 'stone desert' and is applied to surfaces covered by stone fragments and pebbles. *Hamada* consists mostly of fine particles and soil produced by weathering. The vegetation of the *hamada* is characterised by very poor cover, and is concentrated mainly in runnels, depressions and other drainage lines (Zohary, 1962 and Batanouny, 1981). Many of the alluvial and colluvial soils formed by erosion and deposition of materials came from the plateau surfaces and small tributaries. (Al Mashreki, 1999; Andrew et al., 2005).

According to Coode Blizard Ltd (1997), SOGREAH (1981) and Al Mashreki (1999), Wadi Hadhramaut and its tributaries lie on alluvium deposits and consist of four alluvial units and one aeolian unit; -

1- Basal gravels and soils of fluvial origin, which form the beds of the main wadis and the lower terraces laying over two metres of hard limestone gravel.

2- Lower silt deposits; with up to 14 m thick of fine alluvial deposition of early Holocene age, the surface of this layer is light reddish brown make up of heavy silt loams to very fine sandy loams.

3- Middle silt (irrigation silts) and laid down during millennia by the activities of early hydraulic civilization in the Hadhramaut giving coarser textured, sandy loam, silt loam soils which dominate the upper horizons of this deposit.

4- Recent flood silts; recent sediments deposited by temporary floods in the main wadis and their tributaries; they form the upper metre of the soil and comprise of loamy sand, silty loam and sandy loam textures.

5- Recent Aeolian deposits. They occur in a number of locations such as Wadi Adim and (site 2) and Wadi Khashamer, Shibam (site 1).

The soil of narrow tributary wadis and the alluvial fans formed at the foot of the limestone cliffs, as defined by SOGREAH (1981) and Al Mashreki (1999) are of alluvial-colluvial origin, formed by recent erosion and deposition of materials from small tributaries flowing from the plateau down into the wadi. An investigation of soil in Wadi Adim, site 2 (Coode Blizard Ltd, 1997) shows that the soils have varied textures but are predominantly sandy loam with sand-filled cracks that cover the entire area, and along which gullying spreads.

Soils in the study area generally are formed from Tertiary and Quaternary material. Parent material consists of sedimentary material brought from elsewhere, mainly gypsum-rich limestone and marl and some sandstone (Al Mashreki, 2005). According to FAO World Soil Resources (FAO, 2003), the soil classification of the study area is Gypsisols, Calcisols (GY).

The plateau has soil less than 10 cm and mountain slopes facing the main wadis have less than 20 cm of soil with the loss of rock material, both are over Umm er Radhuma and Jeza limestone rocks. According to the FAO classification the plateau type of soil may classified as Lithosols and the mountain slope type of soil as Calcaric (Zouzou and Furley, 1975).

Main soil Classification for each land form unit in Wadi Hadhramaut and the surrounding mountain slopes and plateaus is given in Table 1.7 (Al Mashreki, 2005).

Table 1.7: Main soil types. The soil of the study area were classified according to Soil Taxonomy Classification systems (USDA, 1994) and correlated to World Reference Base (WRB, 1998).

Physiographic Unit	Dominant Soil Order	ST classification	FAO classification
Wadi Hadhramaut	Entisols	Typic Torrifluvents	Calcaric Fluvisol
		Typic Torriorthent	Calcaric Regosol
	Aridisols	Typic Calciorthids	Haplic Calcisol
		Typic Campiorthids	Calcaric Campisols
Surrounding mountain slo[	Entisols	Typic Torriopsmments	Calcaric Arenosols
		Typic Torriorthent	Calcaric Regosol
		Typic Torrifluvents	Calcaric Fluvisol
	Aridisols	Typic Haplogypsid	Haplic Gypsisol
		Fluventic Campiorthids	Calcaric Campisols
		Lithic Calciorthids	Eutric Calcisol
Plateaus	Aridisols	Typic Petrogypsid	Petric Gypsisol
		Typic Haplogypsid	Haplic Gypsisol
		Haplic Campiorthids	Haplic Campisols
		Lithic Calciorthids	Eutric Calcisol
	Entisols	Lithic Torriorthent	Eutric Regosol

1.11. Floristics

Largely because of its great variability in elevation, topography, soil and climate, Yemen is one of the most ecologically diverse countries in the Arabian Peninsula. Major vegetation communities include drought-deciduous and evergreen woodland, tropical valley forest, monsoon woodland, coastal and montane grasslands, and some of the most arid deserts on earth. This plant diversity in turn supports a rich biodiversity, including about 3000 plant species (Scholte et al., 1991). Yemen also supports high rates of endemism, large numbers of rare species and many species with restricted distributions. There have been estimated to be about 429 endemic plant species in Yemen (Miller and Nyberg, 1991) this is approximately 14% of the total; of these 307 occur in the Soqotra Archipelago (Miller and Morris, 2004). In

Hadhramaut, the Jol plateau is considered to be a local centre of endemism (Miller & Nyberg, 1991) where endemics such as the following are found: *Pulicaria nivea, P. rauhii, P. lancifolia, Anogeissus bentii, Kissenia arabia* and *Ochradenus* (see chapter 3).

There is no flora covering the whole of Yemen and no list of threatened plants (IUCN, 1986). However, a recent study by Al Khulaidi (2000) estimated the total number of plant species at 2810, belonging to 1006 genera and 173 families, of which 2559 are naturalized, 121 cultivated and 111 introduced.

1.11.1. The geographical distribution of the vegetation in the study area

According to White (1983), the flora of Yemen is, a mixture of paleotropical and holarctic origin with three main three main elements represented: the Somalia-Masai regional centre of endemism and the Afromontane archipelago-like regional centre of endemism are of paleotropical origin and the Saharo-Sindian regional zone is a mixture of both paleotropical and holarctic elements. The Somalia-Masai and the Afromontane dominate in the western mountains, parts of the highland plains and the coastal areas; Saharo-Arabian plants dominate in the eastern mountain and the eastern and northern desert plains.

The map in White & Léonard (1991) shows two of these regional zones occur in Hadhramaut – the Saharo-Sindian and the Somalia-Masai

The following are species occurring in Hadhramaut considered to be of Saharo-Sindian affinity (White, 1983, Zohary, 1973):

Ochradenus baccatus, Rhazya stricta, Panicum turgidum, Aerva javanica. Zygophyllum simplex, Fagonia indica, Salsola spp., Phoenix dactylifera, Hyphaene thebaica, Dipterygium glaucum, Heliotropium rariflorum, Seddera latifolia, Pulicaria undulate, Capparis decidua, Tamarix aphylla, and *Tribulus arabicus.*

A few species of Sahara-Sahel linking element (White, 1983) are found in the region, these are: *Blepharis edulis, Forskohlea tenacissima, Maerua crassifolia, Leptadenia phyrotechnica, Chascanum marrubifolium, Cleome scaposa, Cornulaca monacantha.*

Somalia-Masai species in Hadhramaut include the following (White, 1983): *Acacia spp., Caralluma spp., Aloe spp., Maerua crassifolia, Balanites aegyptiaca, Moringa peregrina, Commiphora gileadensis, Commiphora habessinica, Commiphora kua, Cadaba farinosa, Ficus cordata L. subsp. salicifolia* and *Ziziphus spina –christi.*

1.11.2. The vegetation of the plateau and the Wadi zones

The only recent work in the study area was a brief vegetation survey carried out in Wadi Adim and the surrounding plateau, in the southern part of Wadi Hadhramaut, by the oil company DOVE (2001). The total number of plant species recorded in this study was about 101 species, belonging to 77 genera. The results of this study are summarized in Table 1.8.

No	Vegetation description and type	Sites	Altitude (m)
1	Sparse grassland *Iphiona scabra* & *Zygophyllum simplex*	Flat areas on plateau	907 - 980
2	Woodland, shrubland and open woodland *Rhazya stricta* & *Acacia tortilis*	Floor of main wadis	677 - 718
3	Dense grassland *Schouwia purpurea* & *Pulicaria undulata*	Floor of main wadis: fallow fields	643 - 700
4	Dense woodland to sparse shrubland *Tephrosia sp.* & *Acacia tortilis*	Floor of spur wadis and drainage lines	643 - 940
5	Open woodland and grassland *Seetzenia lanata* & *Bothriochloa insculpta*	Flat to steep slopes, floor of drainage li and small wadis on plateau	850 - 949
6	Shrubland *Grewia villosa* & *Acacia mellifera*	Dry slopes on plateau and facing the ma wadis	940 - 950
7	Shrubland to sparse shrubland *Jatropha spinosa* & *Zygophyllum coccineum*	Shoulders of main wadis and dry slopes plateau	936 - 962
8	Dense woodland *Prosopis juliflora* & *Zygophyllum album*	Wadi floor, *Prosopis* invaded fields or riverbed	680
9	Shrubland *Kanahia laniflora* & *Pluchea dioscoroides*	Oasis stream / river	731
10	Dense woodland *Salvadora persica* & *Phoenix dactylifera*	Wadi floor, cultivated / date palm	680 - 734

Table 1.8. The vegetation types across a hypothetical transect across Wadi Adim and adjacent plateau (DOVE,. 2001). Not: *Acacia campoptila* is incorrectly named as *A. tortilis.*

Three major plant communities from the plateau zone south eastern Hadhramaut have also recorded by Komex International Ltd. (1999). These communities are:

1- *Euphorbia balsamifera - Caesalpinia erianthera* community, with *Euphorbia hadramautica, E. rubriseminalis, Farsetia longisiliqua, Tephrosia heterophylla, Lycium shawii* and others

2- *Grewia erythraea - Jatropha spinosa* community, with *Adenium obesum, Commiphora kua, Acacia mellifera* and *A. hamulosa*.

3- Depression community with *Stipagrostis paradisea, Fagonia paulayana, Cleome brachycarpa, Reseda sphenocleoides and Farsetia linearis*.

This community is similar to the sparse grassland *Iphiona scabra* & *Zygophyllum simplex* vegetation type described by DOVE (2001).

In the Wadi zone the following communities were also recorded by Komex International Ltd (1999):

1-*Typha domingensis* community with *Tamarix nilotica, Juncus acutus, Scirpus corymbosus, Cyperus laevigatus, Eleocharis geniculata* and others; this community is very similar to the *Kanahia laniflora & Pluchea dioscoroides* type that was described on wadi beds by DOVE (2001) and

2- *Acacia ehrenbergiana* community with *Acacia tortilis, Ziziphus leucodermis, Turraea parvifolia and Lycium shawii*.

Several other communities of the main wadis were described by Gabali and Gifri (1991), these are:

1. *Panicum turgidum* community with *Rhazya stricta* and *Tamarix* spp.,
2. *Cassia italica-Tephrosia spp.* community
3. *Anisotes trisulcus -Solanum dubium* community.

1.11.3. The vegetation of the desert Zone

The plant cover is very poor and sparse and is concentrated in depressions and wadis where more moisture is available; on the open plains the vegetation is generally a sparse desert grassland. According to Gabali and Al Gifri, (1991), the main communities in this region are:

1. *Acacia spp.-Tamarix spp*. with an association of *Salvadora persica, Calotropis procera, Balanites aegyptiaca, Leptadenia pyrotechnica* and others in depressions
2. *Panicum turgidum-Lasiurus hirsutus* in relatively deep soil.
3. *Salvadora persica-Tamarix spp*. on the sand dunes.

1.12. Summary

Generally the topography of the 3 detailed study sites is very similar and comprises the following:-

- Steep-sided valleys with flat bottoms cut by deep drainage lines (wadi beds) where most of the vegetation is concentrated,
- steep to moderately steep, rocky mountain slopes facing the main wadis and their tributaries,
- very steep to vertical bare rocky cliffs,
- undulating to almost flat rocky plateaus,
- steep to moderately steep rocky slopes on the plateaus and,
- canyon-like secondary wadis on the plateaus.

As in other arid zones and desert regions (Harris, 1979; Western, 1988), the rainfall distribution in the study area varies from one year to another and from month to another. For example, the Sayun area receives most of the rain during the warm spring and summer months when the temperature is very high. The cold winter periods are almost devoid of rainfall. The rate of evaporation exceeds rainfall throughout the year,

The main crops in the region are:

1. Cereals (wheat, sorghum and sesame),
2. Vegetables (Onion, potato, tomato, garlic),
3. Fodder (alfalfa) and
4. Date palms (*Phoenix dactylifera*).

The area under cultivation in the floor of the wadi Hadhramaut and its tributaries ranges between 20 to 30%; the figure is much lower (about 6%) towards the desert of Ramlat Assaba'tain.

As elsewhere in arid and semi-arid areas, the ability to sustain a production system in the study area depends upon the integrated management of cultivated fields and rangeland. The local people have developed their own systems to reduce the effect of harsh environment by using crop and forage in agro-pastoral combinations.

There are two main forms of animal husbandry in the study areas:

1- Nomadic animal husbandry, in which the herdsmen with their herds of goats, sheep and camels spend the entire year in the Hadhramaut region but wander constantly from place to place, seeking food and watering places for their herds.

2- Daily grazing, in which the goats and sheep graze by local people in the areas surrounding the villages throughout the year.

The intensity of grazing in the main wadi is high, while on the plateau it is low. Sedentary animal husbandry is restricted to the wadis, whilst most Bedouin (nomads) graze on the plateaus. Generally the oil activities have restricted the movement of herders on the plateaus.

Exploration for oil and production of petroleum has caused major negative impacts to the soil, surface and ground waters and the local ecosystems in the study area (in particularly site 2 and currently site 1). The impact of waste water on vegetation seems generally to be beneficial: the release of water in certain wadis has produced vigorous growth of plant species. However, over the long term the vegetation may be intolerant of salts and chemicals in the waste water. This is likely to affect growth and reduce seeds germination.

Flooding is by far the most extreme and active environmental factor influencing the plant species of Wadi Hadhramaut. The structure of vegetation in some areas has been changed from woodland to grassland as a result of floods and this has resulted in the reduction and disappearance of some common species from the study area.

Thus the vegetation of the Hadhramaut appears to the result of the interaction of past and present human activities on a remarkable set of landforms and a set of severe climatic conditions.

Chapter 2. Assessment of previous work on vegetation in the Yemen.

2.1. Introduction

There is little published information on the plants of the Hadhramaut Governorate or indeed of Yemen as a whole. Such paucity is well illustrated by the account in the IUCN publication Plants in Danger (IUCN, 1986). This book provides information about data sources on plants for each country and island group in the world. In the introduction it states that they are "unable to present figures for only a handful of countries" – one of these is Yemen.

In short, the only Floras to cover the area are Flora Arabica (Blatter, 1936), Flora of Aden (Blatter, 1914-1916), Flora Tropischen Arabien (Schwartz, 1939) and the Flora of the Arabian Peninsula and Soqotra (Miller & Cope, 1996). However, the first two, although called "Floras", are little more than annotated checklists and the last is incomplete with only the first of five volumes so far published. An appraisal of the available literature forms the objective of this chapter and it will be seen that this largely follows the history of botanical collectors.

2.2. Botanical Exploration

The botanical exploration of Yemen goes back over two hundred years to the pioneering research of Pehr Forskahl, the botanist on the ill-fated Danish expedition to SW Arabia in 1761-1767, and the posthumous publication in 1775 of his *Flora Aegyptiaco-Arabica* (Miller & Cope 1996, Wood, 1980). Yemen was then known as Arabia Felix - "Happy Arabia" - the fabled land of frankincense and myrrh (Wood, 1997). There is little written about the plants of Yemen in the Early Arab literature. The most important source is the *Kitab al Nabat* (the "book of plants") by the Persian botanist Abu Hanifa al-Dinawari published around 895 AD. This paid particular attention to plant species of medicinal valu but also covered diverse topics such as soils, crops (including cereals and the date palm), astronomy and meteorology. Yusuf Bin Al Rasul al Mudhaffar, the king of Al Rasulya kingdom, who ruled Yemen in the seventeen century, and Al Zabidi in the Taj al Arus (around 1780 A.D.) gave valuable information on plant uses, in particular as medicine.

These early sources dealt principally with the western part of Yemen making little if any reference to the Hadhramaut region (which lies in the eastern part of the country). This situation, with a relative wealth of literature referring to the western part of the country, but more or less none to the eastern part, was little changed until the later part of the 19^{th} century when the first plant collectors ventured into the remote and often inhospitable Wadi Hadhramaut (Gabali and Al Gifri, 1991).

In fact, until this present study, the vegetation of Hadhramaut had never been systematically studied or surveyed by botanists. Previous studies concentrated mainly on compiling floristic checklists or making general descriptions of some of the principal vegetation communities.

As explained above, the account of the botanical exploration of Hadhramaut is essentially a history of botanical collectors and their publications. These, unfortunately, are often of limited scientific value, typically being little more than travelogues.

An excellent summary of these early collectors, together with notes on their publications, is given in Flora Arabica (Blatter, 1936) and a more up to date list, together with notes on where specimens are deposited is given by Wickens in his Guide to Collectors in Arabia (Wickens, 1982). There follows a brief history of the principal collectors and the significance of their collections and publications.

The first recorded collections were made in 1881, by the German Explorer Georg Schweinfurth, famous for his explorations in north east and central Africa, who visited Yemen as a member of the Austrian Riebeck Expedition. He collected plant specimens from the coastal area of Hadhramaut (Wickens, 1982) but did not venture into the interior. His results were published as the Sammlung Arabish-Aethiopischer Pflanzen Ergebnisse von Reisen 1881, 1888, 1889, 1891,1892 in a series of supplements to the *Bulletin de l' Herbier Boissier* (Bulletin of the Boissier Herbarium) These publications contain the names of plants collected by Schweinfurth but no description of the vegetation was given.

In 1894, the German explorer Leo Hirsch collected over 100 specimens from Hadhramaut. He was the first collector to visit the interior, penetrating northwards to Shibam in Wadi Hadhramaut, to some of the main wadis further north and also venturing onto the Jol plateau. His specimens were kept in the Berlin Herbarium but his travels resulted in no scientific description of the area.

In 1893-94 a British expedition headed by the archaeologist and traveller James Theodore Bent, accompanied by the British gardener William Lunt, collected some 150 species of flowering plant including 25 new species and 2 new genera. These were collected on the coastal plain, the southern plateau as well as in the main wadis of Hadhramaut. Their specimens were deposited in the Kew herbarium and the British Museum and a brief notice of their expedition to the Hadhramaut, including a list of plants collected appeared in *Kew Bulletin* in 1894.

In 1917 Philby John was a plant collector visited the region, his plant collection considered some of the earliest data for this region.

The next significant contributions to the botany of Hadhramaut were made by two Austrian explorers, Rathjens and Wissman (1934). They made a series of visits to Hadhramaut in the 1930s. They collected several species from Hadhramaut and their collections written up in the *Flora tropischen arabien* – which as explained above is little more than a annotated checklist with no descriptions of the vegetation.

In 1946 the first collections from the desert interior were made by Wilfred Thesiger and other members of the Desert Locust Survey including Guichard and Tilliland (Thesiger, 1959). Their collections were deposited in the British Museum. Their explorations lead to no scientific descriptions of the vegetation but nevertheless the travelogues of Thesiger make interesting reading and some information on the vegetation can be gleaned from them.

From the 1960s to the present day a series of expeditions by succulent plant enthusiasts have made important contributions to the botanical exploration of Hadhramaut. Principal amongst these collectors was the South African amateur botanist John Lavranos. He first visited the region in 1962, when he travelled from Al-Mukallah to Mawla Mattar (on the escarpment above Al-Mukallah). During this trip he collected herbarium material and live specimens of various succulent plants, some of which proved to be new to science. In April 1964 he visited Al-Mukallah with the late Prof. Werner Rauh, of the University of Heidelberg, Germany. They spent a week travelling up the Wadi Himem to Bayn al-Jibal and then on to the Wadi Hadhramaut via the Wadi Dawa’n. Much material was collected during this trip and several new species described as a result. Between 1996 and 2001 he made several journeys to the Hadhramaut, covering the Jol plateau along both routes from Mukalla via Bayn al-Jibal and also along the main road via Ra's Huweira, including also part of the lower valley of the Wadi Maseilah and the foothills of the Jol between Ash-Shehr and Sayhut. These journeys were in part in the company of a Yemeni botanist Dr. Abdul Nasser Al-Gifri and also with Dr. Bruno Mies of Essen University in Germany, Mr Thomas McCoy and Mr Giuseppe Orlando of UNICEF.

These expeditions resulted in the discovery of several new species and greatly increased our understanding of the distributions of many taxa. The results of these trips are written up in various journals aimed at succulent plant enthusiasts but nevertheless they contain important descriptions of the vegetation (see Lavranos and Al Gifri, 1999; Lavranos, 1966, 1971, 1974 and 1993).

During the last ten years, a series of collectors have visited the region. Important collections have been made but no significant publications have resulted: these are listed below:-

In 1975 an Egyptian UN expert Fathallah collected about 350 specimens from Hadhramaut. His specimens are kept in both Cairo University and al Kod Agricultural Research Station. He made important contributions to the botanical exploration of Hadhramaut.

In 1993 as well as in 2003 and 2004 Tony Miller a botanist working on the Arabian Peninsula vegetation visited the coastal area, Jol plateau and many other places of Hadhramaut. He travelled from the coastal plain to the northern plateau and collected a considerable number of plant species and also live specimens, some of which proved to be new to science. He made important contributions to the botanical exploration of

Hadhramaut. His collections are kept in the Herbarium of Royal Botanic Garden of Edinburgh (RBGE).

In 1992 and 1998 Prof Mats Thulin first visited the region in October 1992 (with Eriksson, Al Gifri and Långström) and the second visit was in November 1998 (with Beier and Mohammed Hussein). In his first visit he collected 412 plant specimens from different parts of Hadhramaut region. In his second visit to the region, he collected over 100 specimens. In his 2 visits, he covered several places from the coastal plains to the northern plateau along such as Al Mukalla, near Riyan and 25 km W of Al Ridah,Tarim, Shibam and finally along Wadi Hajr. His expeditions resulted in the discovery of several new species and greatly increased our understanding of the distributions of many taxa. The results of these trips are written up in various journals and contain important descriptions of the vegetation. (see Thulin, 2001 and 2002; Thulin and Al Gifri, 1993 and 1995).

In 1985, 1992, 1993, 1995 and 2001 a local Taxonomist, Prof. Abdul Nasser Al Gifri, visited Hadhramaut several times, in which he studied the vegetation and flora of Hadhramaut region. On some of his trips he was accompanied by Dr. Lutfi Boulos of Kuwait University (1985) and Prof Mats Tthulin of Uppsala (1992), with Harald Kurschner of Frie Berlin Uni. (1993) and with Lavranous the Arabian succulent expert (1995). The results of these trips are written up in various journals (see Thulin and Al Gifri, 1993 and 1995; AI-Gifri and Kurschner, 1996; Gabali. and AI Gifri, 1990; and Lavranous and Al Gifri, 1999).

From 1996 to 2002 the German botanists Norbert Kilian and Peter Hein (Kilian et al., 2002) have made a series of expeditions to Hadhramaut region, during which they collected a considerable number of plant species and added new records of plant species to the region. Their trips included the southern summit plateau above al Mukala and al Rayan. The specimen collections were deposited in the herbarium of the Botanic Gardens and Botanical Musium Berlin-Dahlem, Germany.

Their work has greatly contributed in understanding the distribution of many endemic, near-endemic and rare species and made a valuable contribution to appreciating the importance of the southern part of the region.

Other local botanists included Al Gabali, Bataher, Bilaidi, Obadi, Bazara'a, and Al Dubaei, who are conducting very limited surveys on vegetation of the Hadhramaut; they mainly joined in the research of other international botanist and explorers.

2.3. Vegetation studies in Hadhramaut

There have been two published descriptions of the vegetation of Hadhramaut:-

1. A study made under the auspices of ACSAD (The Arab Center for the Studies of Arid Zones and Dry Lands). In 1986 a study team from ACSAD, Syria and the Ministry of Agriculture from the former South Yemen made a comprehensive collection of plants. In total 72 sites in 4 governorates (Lahj, Shabwa, Hadhramaut and Al Mahara) were visited and 500 specimens of 280 plant species belong to 50 families and 157 genera were collected. Brief information on location, topography, soil and altitude at each site was collected. The resulting report (Barkuda and Sanadiqi, 1986) contains a map showing the location of the sites visited. However, the location of the sites is not precisely given and in consequence the collections are of limited value for vegetation description or mapping.

Despite the incorrect and incomplete identification of some species, the study has proved valuable, especially in increasing our understanding of the distribution of species in southern and eastern Yemen. Interestingly the invasive plant *Prosopis juliflora* was recorded only from the coastal plain and not from the Wadi Hadhramaut, which show that this species probably was not existence in the study area in 1985. Specimens were deposited in the following places:
Agriculture Research & Extension Authority, Al Kod branch, Yemen
International Central for Genetic resources, Kew, London.
ACSAD Damascus, Syria

2. A survey of the vegetation of Hadhramaut, Yemen (Gabali and Al Gifri, 1991). This study lists dominant and common species and describes some common plant associations. It divides the region into five main ecological zones based on their topography, soil, and climate. It includes a comprehensive review of botanical collecting in Hadhramaut. However, there are significant drawbacks. There is no description of the methodology used, the sites visited are not locally identified and

many species are only identified to genera (e.g. *Ficus spp, Cymbopogon spp., Cassia spp., Barleria spp*. etc).

2.4. Botanical Literature

The above outline of the botanical exploration of Hadhramaut shows how an understanding of the floristic composition of the region was gradually built up by a series of rather unfocussed expeditions spanning some 120 years. However, they did little to improve our understanding of the composition of the vegetation and there is still no comprehensive description of the vegetation. To build up a picture of the vegetation and to place it in a regional context, I have had to rely on publications from surrounding regions. The following proved most useful.

2.4.1. The Vegetation of the Republic of Yemen (Western Part) (Scholte, Al Khulaidi and Kessler, 1991).

This publication is the result of a joint study undertaken by DHV, International consultancy and engineering from the Netherlands and the Yemen Government (Environmental Protection Council and Agricultural Research Authority).
It comprises a vegetation map at a scale of 1:500,000 and a photographic description of the main vegetation types. The map covers most of the western part of Yemen of what was formally called the Yemen Arab Republic.
The study involved both extensive field surveys over most parts of the western part of the country and an analysis of available satellite imagery, in particular SPOT images, The booklet begins with an identification of the eight main vegetation landscapes in Yemen. These are defined as following:

1. Tihama Coastal Plain (< 400 m)
2. Tihama Foothills and Low Altitude Western Mountains (< 1000 m)
3. Medium Altitude Western Mountains (1000-1800 m)
4. High Altitude Western Mountains (1800 m)
5. Highland Plains (2000 m)
6. High Altitude Eastern Mountains and Highlands (> 1800 m)
7. Medium Altitude Eastern Mountains (1200-1800 m)
8. Eastern Desert Plain (< 1400 m).

Each major zone is further subdivided into separate ecological zones. For example, the Tihama coastal plain consists of:
T1 as mangrove Avicenna woodland;
T2 as sabakhas Sueda sparse dwarf-shrub and bare land;
T3 as palm groves, Phoenix-Salvadora as woodland;
T4 as salt-bush lands, Salsola-Odyssea dwarf-shrub land;
T5 as Panicum sparse grassland and bare land;
T6 as Dactyloctenium cultivated land (irrigated);
T7 as Ziziphus-Dobera cultivated land (mainly rainfed);
T8 as Acacia-Commiphora, open woodland and bare land.

Each of these ecological zones is described in general terms, together with information on the importance of the vegetation, for instance, as a resource for forage, timber and firewood together with comments on sustainable management. The vegetation structure of each unit is illustrated by a photograph, from which the main species can be identified by an accompanying black and white sketch of the layout of the photograph. The geography of each ecological zone is described in terms of physiography, geology, climate and the main vegetation types. The problems facing each zone for instance, over-grazing, cutting of trees for firewood and timber and increasing cultivation are identified. These problems are graphically illustrated by a series of pictures showing examples of healthy and problematic sites across the different ecological zones. Recommendations are also given for future management strategies.

The work provides a basic source of material for vegetation studies and a comparative base line for similar studies in the rest of Yemen. Of significant importance is the vegetation map at a scale of 1:500,000. The work has been and is still used as one of basic and important references for biodiversity and forest activities in Yemen.

The work was prepared before the unification of Yemen (May 1990) and the fieldwork has only carried out in the former Yemen Arab Republic. No surveys were undertaken in Hadhramaut, and the eastern part of Yemen is not covered. However, this publication has proved invaluable in helping place the vegetation of Hadhramaut in a regional context.

2.4.2. Flora of Republic of Yemen (Al Khulaidi, 2000).

A comprehensive checklist of the Flora of Republic of Yemen was compiled by EPA (Yemen Environmental Protection Authority) and UNDP (United Nations Development Programme). This work was made possible through financial support of the Sustainable Environmental Management Program, Yemen/97/100.

The work is based on nine main studies on the flora of Yemen carried out between 1975 and 1997 (Boulos, 1988; Diccon, & Miller, 1998; Gabali and Miller, 1992; Gabali, 1998; Hepper, 1975; Mies, 1994; Miller and Cope, 1996; Wood, 1997 and Cope, 1985) and on extensive fieldwork throughout Yemen carried out by the author. In total 2810 species, belonging to 1006 genera and 173 families are listed for Yemen, of which some 415 are endemic, including 236 confined to the Soqotra archipelago.

Under each species entry there are also notes on the distribution of species within Yemen, local names of many species and other references. This is the first checklist to cover the whole of Yemen and is regarded as an important resource for any environmental studies in Yemen.

A similar study was carried out in the former South Yemen, (Boulos, 1988). This publication was the earlier checklist of flora for the former south Yemen followed by a study written by Gabali and Miller (1992). This was a provisional checklist of former South Yemen prepared as a draft. The checklist was based on 10 studies carried out between 1939 and 1990. The former checklists of the Flora of Yemen have contributed greatly to our knowledge of the flora of the Hadhramaut region and have helped to build up understanding of the flora of Hadhramaut.

2.4.3. Flora of the Arabian Peninsula and Socotra Volume 1 (Miller, A.G. & Cope, T.A. 1996).

The Flora of the Arabian Peninsula and Socotra is the first comprehensive study covering the flora of the entire region. It will appear in five volumes; so far only volume 1 has been published (Miller and Cope, 1996). The Flora covers the entire native flowering plants and ferns, as well as major cultivated and economic plants. It includes Yemen, Saudi Arabia, Oman, the United Arab Emirates, Qatar, Bahrain and Kuwait.

Volume 1 contains introductory chapters covering topography, geology, climate, vegetation, floristic, phytogeography, a history of botanical exploration and conservation. The second part of the volume consists of accounts of 63 families. A brief description of families and genera are included, as well as distribution dot maps for all species, the book is comprehensively illustrated and contains keys to genera and species.

It is an organized, excellent and useful study, which is set to become the essential reference source on the Arabian flora.

On the down side, local names of the plant species are not included, there are no colour plates and, so far only volume 1, covering only 63 families, has been published. Unfortunately, the Flora is very expensive and because of this it is not readily available to Yemeni botanists.

2.4.4. Vegetation of the Arabian Peninsula (Ghazanfar and Fisher, 1998)

The Vegetation of the Arabian Peninsula contains the most recent vegetation study, which covers part of Hadhramaut region.

It is the first comprehensive overview of the, phytogeography and vegetation of the Arabian Peninsula. It is written and edited by 15 specialists on the botany and environment of the Peninsula. It covers Yemen, Saudi Arabia, Oman, the United Arab Emirates, Qatar, Bahrain and Kuwait and contains 11 chapters covering climate, geology, phytogeography, vegetation, and ecology of the mountains, wadis, sand deserts, gravel plains, coasts and sabakhas (an Arabic term for a marsh or bare mud). It includes chapters covering the flora and vegetation of all the major habitats and landforms.

The chapters on climate and geology provide important background information for understanding the dynamics and history of the Arabian vegetation.

The book is an important reference source for students, academics and scientists interested in Arabian botany.

On the downside it does not cover the vegetation of Soqotra archipelago. The description of the vegetation of Yemen, in particular the western mountains areas, is based mainly on the studies of Deil and Muller-Hohenstein (Muller-Hohenstein and Rappenhoner, 1991; Muller-Hohenstein, 1984, 1986, 1988, 1989; Deil 1986 and 1991, Deil and Muller-Hohenstein, 1988, 1991; Deil & Rappenhone, 1988, Deil and Al Gifri, 1998) and does not take into account the results of ecological studies carried out by competent bodies in Yemen such as AREA (Agricultural Research and Extension Authority), Land and Water Conservation Project, EPA (Environmental Protection Authority), which contain a wealth of detailed rangeland vegetation studies, based on systematic methodologies such as Braun-Blanquet and supported by land ecological big scale vegetation maps, such as Wistinga and Thalen, 1980; Kessler, 1987 and Al Khulaidi, 1989..

2.4.5. A Handbook of the Yemen Flora
(J.R.I Wood, 1997)

A handbook of Yemen Flora was published in 1997. The book contains an account of all native and naturalized species of fern and flowering plants, found in the former Yemen Arab Republic, In addition, descriptions of all commonly cultivated species are provided. It also contains 40 colour illustrations painted by Hugo Haig-Thomas. The book starts with a chapter on the discovery of the Yemen flora, giving information on how Arab and European scientists and writers became interested in discovering the Yemen flora.

Wood based this work on his extensive collections made during visits to of all parts of the country during his stay in Yemen during the years 1974-1981. The text was finalised in 1982, but unfortunately not published until 1989.

The book is of importance not only to botanists, but also to all those with an interest in the plants of Yemen, including rangeland ecologists, foresters, pharmacists and agriculturalists.

Before the publication of this book, there was no complete Flora covering the Yemen. Even though it is intended to cover only the plants of the former north Yemen, it can also be used to identify a significant proportion of the plants of the former south Yemen.

The identification keys in the book are based mainly on technical characteristics, and so can only be used by those with some basic botanical knowledge. Few illustrations (apart from the colour plates of some 40 species) are included but where they are, for instance line drawings of the leaves of the critical genera such as *Grewia* and *Indigofera*, they are particularly useful. This Flora is most successful used in Yemen today. The Flora also contains an index to genera as well as of Arabic local names. Perhaps its strongest and most useful feature is the very detailed notes given on the distributions of individual species which often proved very helpful in identifying unknown plants.

Unfortunately former South Yemen is not included, making the title of the book, published eight years after the unification, misleading. Many plants are unknown outside southwest Arabia and most of them have never been described before. Generally the accounts are very accurate, however difficulties have been experienced in critical genera such as *Maytenus, Grewia* and *Commiphora*. Unfortunately, the book is very expensive and so not widely available in Yemen.

A flora covering the whole Yemen is urgently recommended. This can be done with the cooperation of Environmental Protection Authority (EPA), Agricultural Research and Extension Authority (AREA) and University of Aden.

2.5. Paleoenvironmental studies

In the past, distributions of plants have shifted dramatically in response to changes in climate (USGS, 2002). Understanding the way plants have responded to past climate change can help predict the way vegetation will respond to future changes.

Paleoenvironmental studies help us understand the causes of climatic change as well as providing information on the present day nature of the plant cover. It does this by looking a range of lines of evidence including offshore deposits, sea level change, cave deposits, palynology, isotopes, geochemistry, sedimentology, paleontology, etc. (Last and Smol, 2005). It helps to reconstruct past environments using fossil materials of plants and animals, or other indicators of past environments (USGS, 2002).

Unfortunately, due to the unsuitable conditions for the preservation of fossils and pollen over most of Arabian Peninsula, there is little direct evidence for reconstructing the past vegetation and climate of the region. However, evidence from a variety of studies from surrounding areas, in particular north and east Africa, helps us to paint a picture of the past climate and vegetation of the Arabian Peninsula. It is believed that Arabia experienced its main floristic invasions during the Tertiary (Ghazanfar & Fisher, 1998). The paleo-African vegetation presumably extended eastwards into the Arabian Peninsula throughout the middle-late Eocene and Oligocene (Mandaville, 1990). Fossil pollen and spore samples from the eastern Rub al Khali, were found to be dominated by the unclassified fern genus, *Psilatricolporites* with pollen showing species of *Myrtaceae* and *Palmae* and spores of the water fern *Ceratopteris* also present indicating a much wetter climate in central Arabia than that of today (Mandaville, 1990).

The palaeoecological atlas of northern and western Africa in the Middle Holocene (8000 BP) (Agwu and Beug, 1982) shows a mosaic of vegetation with the Mediterranean region enlarged to the south and characterized by deciduous and coniferous forests.

The favourable climate in the northern part of Africa and Arabia lasted for about 8000 years (between 14000 and 6000 years ago). According to the maps presented by Adams (2002), the climate in these regions began to become dry again some 5000 years ago. During this period a tropical extremely arid desert expanded and covered almost the whole of the Arabian Peninsula. According to Schroder (2002) and McCorriston, 2000), 10000 to 5000 years ago the Southern Arabia was moister than today. The maps presented by Jallow (2002) showed that about 8000 to 5000 years ago, the Sahara desert receded to small isolated areas in northern Africa and Lake Chad and the forest areas were much larger. About 20000 years ago the Sahara had expanded southward into the current Sahel zone and rivers in this region dried up. The climate began to improve (wetter) about 15000 years ago; this improvement lasted for about 5000 years.

Generally, for most of geological time, the Arabian Peninsula and Africa had a common tropical flora and vegetation, allowing the migration and exchange of the palaeo-African, Indo-Malayan and Mesogean floras across Arabia (BIOLOG, 2004). Then, after the Arabian Peninsula separated from the African continent during the Oligocene (Meister et al., 2002) Arabia was isolated from the Africa. The reconstruction of biomass from pollen and plant macrofossils in Africa and the Arabian Peninsula showed only minor changes, compared to the present day for eastern and central Africa and major changes for the region north of 15º N, with steppe in many low elevation sites that are now desert in the Saharan mountains (Jolly et al, 1998). The investigation of 320 charcoal samples from prehistoric sites in the Eastern Sahara furnishes evidence for a fundamental change of vegetation during the early and middle Holocene (Neuman, 1989).

Pollen records from a crater lake in the Sudanian zone of northeast Nigeria provide evidence for the persistence of woodland savanna throughout the Holocene. Wetter conditions from c. 10000 B.P. to c. 6800 B.P. enabled the establishment of a dense Guinean savanna, though the occurrence and rapid spread of the montane element *Olea hochstetteri* indicates cool climatic conditions prior to c. 8800 B.P. (Salzmann, 2000). The changes in the region have been summarised by Adams (2002).

According to Adams (2002), the climate history of Africa, Asia and Arabia during the last 150,000 years was as follows (see Table 2.1):

The period	The climate
110000-11000 years ago	Drier and cooler than present
43000-40000 years ago	extreme arid with extensive dune & desert
28000-25000 years ago	moister than at present
23000-14500 years ago	aridity and cooling and partly forest
13800-13500 years ago	increase in temperature and moisture
12000-11000 years ago	forest had returned
10000 years ago	moister, more rain than present with pluvial episode
9000-8000 years ago	moister with forest
8000-7000 years ago	moister than at present
7500-6000 years ago	the Sahara was vegetated , rainforest was greater
Since 5000 years ago	similar to the present

Table 2.1. The climate history of Africa, Asia and Arabia during the last 150,000 years Source: Adams (2002).

Paleoenvironmental studies in Hadhramaut

Earlier in this section it was stated that, due to the unsuitable conditions for the preservation of fossils and pollen over most of Arabian Peninsula there is little direct evidence for reconstructing the past vegetation and climate of the region. However, an important piece of research by Dr Kenneth Cole has now revolutionised palaeoenvironmental studies in Hadhramaut (Kenneth et al., 2001). Cole discovered that middens made by packrats in Colorado, USA could be dated back to 50,000 using radiocarbon dating. The fossils contained with the middens preserve a record of the plants and animals that lived within a packrat's range (usually up to 100m) and provided a powerful tool for reproducing past biotic communities. He was able to use a similar technique to age hyrax middens in Hadhramaut.

The background to his research in Arabia is a result of the archaeological importance of Hadhramaut and an active programme to understand the recent vegetation history of the region. This research is coordinated through the Roots of Agriculture in Southern Arabia (RASA) program, headed by Dr. Joy McCorriston, the Yemeni Ministry of Antiquities, and the American Institute for Yemeni Studies (AIYS).

One of the most interesting aspects of this research is the way that fossil hyrax middens have been used to reconstruct paleo-environments in Hadhramaut (Kenneth et al., 2001). The task of this project is to reconstruct the vegetation history through plant macrofossils and pollen contained within hyrax middens in order to understand and to reconstruct the past vegetation and climate and the vegetation and the climatic changes taking place in the area and the possible impacts of domesticated animals (primarily goats and camels) on the vegetation.

The preliminary results of vegetation at their survey site in Wadi Sana (east of the present study area) indicates that the area is currently dominated by *Ziziphus leucodermis, Acacia hamulosa, and A. ehrenbergiana* (Kenneth. et al 2001). Their studies have shown that *Acacia ehrenbergiana*, which today is found throughout Yemen, did not appear in Wadi Sana until 2159 yr B.P. They interpret this as indicating a return to moister climates following an extremely arid period in the late-middle Holocene. The study also suggests that the period of maximum Holocene aridity in the southern Arabian highlands may have been between 5000 and 2500 yr B.P. Archaeological sites from the study area (Kenneth et al., 2001) suggest that in the early mid Holocene (7500 to 6000 years ago) the climate was wetter than at present and that the climate of the entire Middle East would have been more favorable to plant growth from a period beginning 13,000 BP to about 9000 BP. Fieldwork for this remarkable new study began in February-March, 1998, and is still ongoing. Their final results should give valuable information on the past vegetation and climate in the region and act as a baseline for the vegetation and the climatic changes taking place in the study area at present.

Climate change in Arabia

The Intergovernmental Panel on Climate Change (IPCC) project that annual temperatures in the Arabian Peninsula will increase by 1-2°C and precipitation will increase slightly (<0.5 mm/day) throughout the region by 2030-2050 (1PCC, 1996). Furthermore, it predicts that soil moisture will decrease because the insignificant increase in precipitation will be counteracted by the increase in evaporation which will come with rising temperatures - for western Asia, reductions between 2% and 10% are expected (Dai et al 2001). More recent projections (IPCC, 2001) give increases in global mean temperatures in the range of 2 to 4°C by the end of this Century.

Thus, despite uncertainties and a lack of direct evidence, there seems to be agreement on considerable change over the Quaternary in the Hadhramaut region, particularly in the early and middle Holocene. Moister conditions would have encouraged greatly plant growth, species diversity and relict elements of which can be seen today (e.g. *Acacia spp.*) in much drier environment.

2.6. Vegetation maps

Several maps which cover Hadhramaut have been produced. However, all are to a lesser or greater degree inaccurate and none have been based on fieldwork in the region. Most have been apparently based on information collected from Blatter and Schwartz. (described in section 1 above).

- A map scale 1:100 000 showing the woodland types of some areas in Hadhramaut has been produced (Hunting Technical Services Limited, 1992). These types are presented in format of the dominant species, the association species and a general description. A drawing of a vegetation profile and associated species are also described as a characteristic of the class. The report shows also a photograph of this characteristic example.

The following sites have been described:

- Western branch of Wadi Bin Ali near Shibam as Acacia open woodland type,
- Wadi Hadhramaut and tributary wadis (e. g. eastern side of Sayun, wadi Al A'yn, near Tarim as date palm agriculture type,
- South of Tarim, on terrace of wadi Masilah main channel as Tamarix woodland type.

The dominant species, density, canopy cover, height range and thickets of multi-stemmed of each type were mentioned.

The description and illustrations of the woodland types as they appear on the ground were presented, mainly in a format of the dominant trees, the associated species and a general description followed by descriptive statistics of density, stem density, canopy cover, height range, stem diameter and bole length. A drawing of a vegetation profile for the characteristic example of the type was given, with photographs showing the characteristic example and other sites displaying some of variation in the type.

2.6.1. Drawing up a preliminary vegetation map of Arabia (Novikova. N.M. 1970).

The map was based on analysing and studying the publications of botanists and travellers in the Arabian Peninsula. Based on the association of the main plant communities and the habitats, the author divided the Arabian Peninsula into 10 physiogeographic areas.

According to this map the following vegetation communities were described from Hadhramaut:

Ficus sycomorus woodland (15), part of the footslopes near the coastal areas.

Dipterygium glaucum stony-rock Hamada (30) most of the plateau

Leptadenia pyrotechnica stony Hamada (31)

Tribulus longipetalus high ridge sands(32a), the northern desert area

Tamarix spp. Wadi type (37) Wadis cutting the plateaus

Acacia spp. in Wadis (38)

Boswellia carterii woodland (20)

Commiphora opobalsamum woodland (19).

Some of the plant species mentioned in his communities are not common in the Hadhramaut. For example, *Ficus sycomorus* is rare in Hadhramaut but abundant in wadis in Taiz, al Dhalaa, Ibb, Lahg, Hajjah, Abyen, Huf, (on the SW escarpment mountains of Yemen) and in the monsoon woodlands in al Mahara (on the Oman border) where the rainfall is high. *Dipterygium glaucum* is not common on the plateau. This species forms a community on the desert of western part of Hadhramaut and is thinly distributed on most of Wadis in Hadhramaut region (Gabali and Gifri, 1991). The coverage of Hadhramaut is in general very patchy and cannot be relied upon.

2.6.2. Middle East Vegetation Map, scale: 1: 800 0000. (Compiled Tavo, University of Tubingen, 1989).

The map divided the study area into :-

1- mixed formation of herbaceous and semi-woody salt-swamps and coastal dunes (the coastal area)
2- xeromorphic very open scrub (semi-desert shrublands) and open grassland. (the footslope)
3- thorn woodlands (the southern plateau)
4- mixed formation of sclerophyllous-rich extremely xeromorphic woodlands, succulent scrub and xeromorphic open grassland (the middle of the plateau)
5- dry deciduous extremely xeromorphic woodlands (the middle and the northern part of the plateau)
6- mixed formation of xeromorphic very open scrub (semi-desert shrublands), (north Eadi Hadhramaut)
7- mixed formation of xeromorphic very open dwarf shrubland (the desert)
8- Scarce vegetation of sand dunes and desert (al Ruba al Khali).
Scientific name of the plant species were not mentioned.

In general, it is good source of information on the basic vegetation structure of the communities in Hadramaut. The map was not based on field work.

2.6.3. Geobotanical Outline map of the Middle East (Zohary, 1973).

The map divided the Middle East to 8 vegetation types; and classified the Hadhramaut region as Sudanian and sub-Sudanian vegetation (Tropical deserts, savana and forests) in which it is divided to the following subunits:-

- subdivision Acacietea tortilis ssp. sub-sudanica, this covers the study area
- subdivision Savana of Acacietea sudano-arabica (mainly Acacia – Commiphora scrub) and covers south-facing slopes of Hadhramaut region and
- subdivision mosaics of *Haloxylotea salicornici* and Suaedetea desert covering the coastal area of Hadhramaut region.

The map is based on literature review of old travellers to Arabia, such as Deflers (1896), Schwartz (1939) and Wissmann (1968).

According to this map, the region is classified as *Acacietea tortilis* ssp. *sub-sudanica*. This class comprises mainly a Saharo-Arabian with few Sudanian species (Zohary, 1973). This vegetation type is confined to wadis or depressions in several regions such as Egypt, S. Sinai, S. Palestine, the coastal of Arabian Peninsula and S. Eilat, Israel.

In the study area there are few of the leading plant species of this class, namely *Acacia tortilis* (in our case the very similar species *A. campoptila*), *Ziziphus spina-christi, Balanites aegyptiaca, Ochradenus baccatus, Citrullus colocynthis, Cleome droserifolia, Panicum turgidum, Iphiona scabra, Zygophyllum coccineum, Salvadora persica, Moringa peregrina, Capparis cartilaginea, Calotropis procera, Tephrosia apollinea* and *T. nubica.* This type of vegetation was called by Zohary (1973) as pseudo-savana.

Compared to the previous maps, this map gives a more accurate reflection of the composition of the vegetation and the phytogeographical classification of the study area.

2.7. Summary

Most of the mentioned studies are little more than annotated checklists and the botanical exploration of Hadhramaut is essentially a history of botanical collectors and their publications, which has limited scientific value for the study area. Nevertheless, during the last ten years a series of collectors and botanists have visited the region. Important collections have been made and these trips have resulted in the discovery of several new species and greatly increased our understanding of the distributions of many taxa. The results of these trips are written up in various journals (see the references). However these studies, including the previous preliminary flora checklists of the southern Governorate (formally south Yemen), have given incomplete inventories of the plant species of the Hadhramaut region.

The botanical exploration of Hadhramaut shows how an understanding of the floristic composition of the region was gradually built up by a series of rather unfocussed expeditions spanning some 120 years. However, they did little to improve our understanding of the composition of the vegetation and there is still no comprehensive description of the vegetation.

Few vegetation maps which cover the Arabian Peninsula and include the study area have been produced. These maps are not accurate and were based on the information of previous collectors and were not based on field trips to the region.

To build up a precise and accurate picture of the vegetation of the Hadhramaut region, a reconnaissance survey of almost the entire region was conducted fallowed by detailed vegetation surveys of 3 study sites in the next chapters.

Chapter 3: The vegetation of the Hadhramaut

3.1 Introduction

As indicated earlier the Hadhramaut region is too extensive a region (161,749 km²) to allow for a detailed floristic survey within the scope of the present research. Consequently, and in view of the near-absence of previous quantitative work on the topic, it was decided to undertake a preliminary reconnaissance survey, which would provide on overview of the phytogeography and permit the selection of representative study sites for more detailed research.

This chapter presents the results of this reconnaissance survey of the vegetation of the Hadhramaut region. Two transects were chosen, starting from the coastal area in the south and ending towards the west. Sample points were established across transects, one from the south-east (coastal area) to the north-west (up to Wadi Dawa'n) and the other from the east (near to Shibam) towards the west (Ramlat Assaba'tain) (Figure 3.1). A comparison was also made of the vegetation habitats which were similar to those found in the study area.

3.2. Methodology

The two transects were selected to represent the main landscape features and associated vegetation of the Hadhramaut region. The two transects passed along the only accessible roads in the Hadhramaut connecting south with north (transect 2) and west with east (transect 1). Practical considerations, such as access issues, species richness, and travel time were taken into account when the two transects and the sampling points were selected.

Vegetation composition and structure were studied across the two transects along an altitudinal gradient, from the coastal area to the Wadi Dawa'n at altitude of 1000 m asl, then from west of Shibam towards Ramlat Assaba'tain at altitude of about 770 m asl (Figure 3.1).

The areas to be sampled were selected on the basis of altitude and vegetation changes; one 10 X 10 m sample site was selected at approximatley every 100 m asl. Natural vegetation and abundance data were collected using Braun-Banquet's cover scale (See Chapter 4); slope percentage, exposure and stoniness were also recorded.

The sites along the two transects and their relationships to environmental factors were analysed by Canonical Correspondence Analysis (CCA), using the statistical software of MVSP version 3.1 (Figure 3.5). Data were available on: altitude, slope, aspect, stoniness, total vegetation cover % and the total number of species.

The location of the sites and the endemic, near-endemic and rare plant species were plotted using ArcView and Diva-GIS softwares.

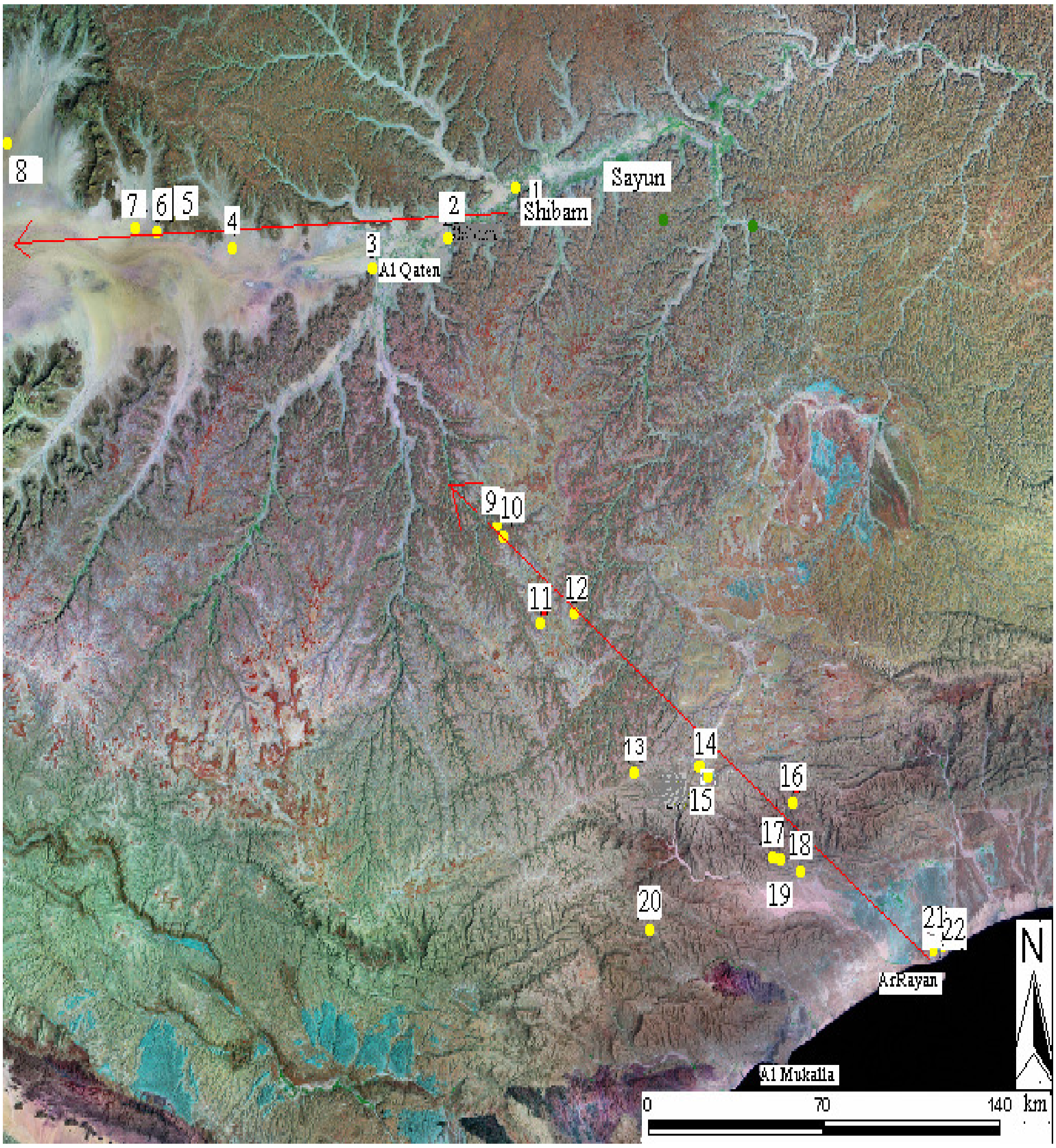


Figure 3.1. An image showing the transects from the coastal region to the plateau in the northern part of the Hadhramaut region and from (Shibam) towards the west (the desert of Ramlat Assaba'tain).

3.3. Climate

The difference in altitude across the different topographical units of the two transects strongly influence climatic conditions. Average temperatures decrease more or less linearly with altitude; temperature was taken to be 1 degree C colder for every 100 m of altitude. The orographic rise of air masses from the onshore wind provides an effective cooling mechanism, which causes rainfall. For example, areas exposed to the sea such as the southern slopes, receive more rainfall than the zones facing the interior plateau. Local topographic features cause similar effects, at correspondingly smaller scales (Ayele and Al Shadily, 2000). A considerable amount of moisture can be added to the ground flora from fog, which affects the escarpment and highest points on the plateau. Some of the richest areas for endemics are found on these escarpments. There is also an important difference in timing of rainfall from the north (Wadi Hadhramaut) to the south (coastal area); the rainfall in the north falls in spring and summer, while in the coastal area it falls mainly in spring and winter. Wadi Hadhramaut is affected by both the Red Sea Convergence zone (RSCZ), which contributes to the first spring rainy period between March and May, and by the Inter-Tropical Convergence Zone (ITCZ) which contributes to the second summer rainy period between July and September, while the coastal area (Al Rayan) is affected mainly by RSCZ (Figure 3.2).

The climate along this transect varies from a mean annual rainfall of about 69 mm at Al Rayan on the coastal area to a mean annual rainfall figure of less than 75 mm at Sayun in the interior. There are no meteorological data over the plateaus; nevertheless the abundance of floods in the secondary wadis flowing across the plateaus suggests that the annual rainfall over these landforms is more than 200 mm (SOGREAH 1979) but highly sporadic. The climate along the second transect varies from a mean annual rainfall of about 74 mm to extreme (hyper-) aridity with a mean annual rainfall of less than 50 mm.

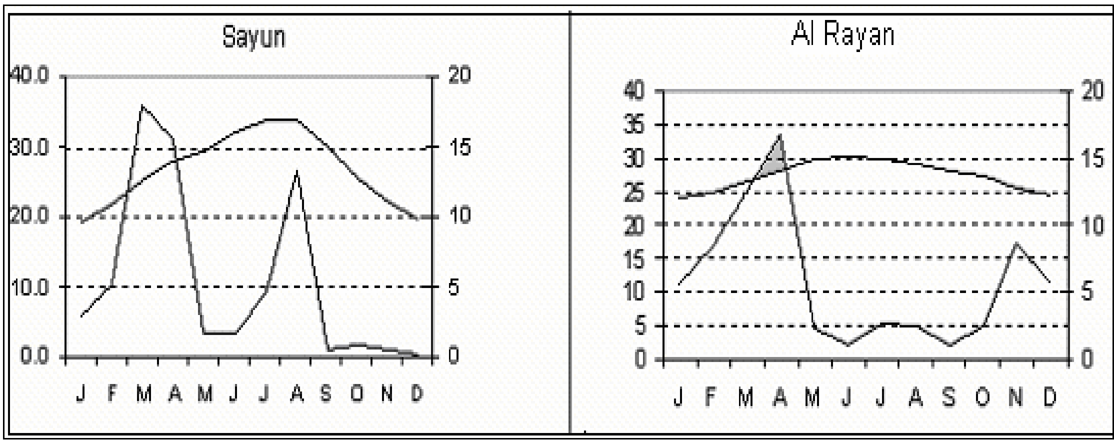


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Figure 3.2. A climate diagram of mean monthly rainfall (the lower line) and mean annual temperature (the upper line) for Sayun (Wadi Hadhramaut, north) and Al Rayan (coastal area, south). The rainfall in the north falls in spring and summer, while in the coastal area falls mainly in spring and winter.

3.4. Topography

The transect from the coastal plain (south) to Wadi Hadhramaut (north), then towards Ramlat Assaba'tain (west Wadi. Hadhramaut) traverses four main topographical units. These units can be broadly described as the coastal plain, the south-facing escarpment, the Jol plateau and the alluvial wadis.

3.4.1. The coastal plain: This is an undulating to almost flat plain, cut by shallow drainage lines. The plain consists of gravels and alluvial deposits with dolomite rocks (Vogt and Sedov 1997).

3.4.2. South-facing slope escarpments: These comprise s-facing mountainous areas which drop from 1500 m to the coastal plain. Cliffs and steep slopes are the dominant features on these mountains.

3.4.3. The plateau (Jol): This plateau consists of rocks of Oligocene-Miocene age (USSR and PDRY, 1984) It is an undulating to almost flat limestone plateau, dissected by numerous deep secondary wadis (gullies and canyon-like secondary wadis). The altitude gradually reduces towards the north and ranges between 900 and 1500 m above sea level. The plateau is dissected by Wadi Hadhramaut and Wadi Masila (MAW, 1996). The altitude of the southern Jol ranges between 860 and 1580 m and is higher than the northern one which rarely exceeds 1200 m.

3.4.4. The wadis: The main wadis are Hadhramaut and Al Masila. Wadi Hadhramaut divides the plateau area into two, northern and southern. Wadi Hadhramaut runs nearly

165 km into Saihout in the al Mahara Governorate, and is located at latitude 16 degrees north and longitude 48 degrees east (Verba et al., 1995). Upstream Wadi Hadhramaut opens westward into a wide desert plain called the Ramlat Assaba'tain. Wadi Hadhramaut is considered to extend between Wadi Saar (west) to west of Tarim (east) (SOGREAH, 1979). The wadi bottom is mostly flat with steep to vertical sidewalls. The valley varies in width, from 1.5 km in the east to 6 km in the west and lies about 300 to 400 m below the level of the plateau.

3.4.5. Sand dune area: An extensive expanse of sandy desert, known as the Ramlat Assaba'tain, is found west of Wadi Hadhramaut. The altitude of the Ramlat Assaba'tain gradually increases from almost 700 m in the east to more than 800 m in the west.

3.5. Results

3.5.1. Vegetation composition of the 2 transects

The following section describes the main vegetation composition of the two transects made across the Hadhramaut region. A comparison of the vegetation types found in Hadhramaut with those of the surrounding regions will be also described. The first transect extends from the east towards the west. Generally the vegetation cover towards the west is poor and sparse and gradually changes from woodland, characterised by *Acacia campoptila* and *Fagonia indica,* to sparse dwarf shrubland or grassland dominated by *Zygophyllum album* and *Dipterygium glaucum.* The second transect extends from the coastal region to the plateau in the northern part of Hadhramaut region. The altitude here varies from sea level in the south to about 1600 m above sea level then to about 600 m above sea level at Wadi Hadhramaut in the northwest of the region. Species richness and species diversity dramatically decrease from east towards the west (transect 1).. The species richness and species diversity of transect 2 increases towards the south, in particular south-facing slopes and drainage lines. The vegetation cover here is very rich especially on slopes or wadis facing south, which are sustained by the regular fogs.

3.5.1a. East west transect (see Figure 3.3)

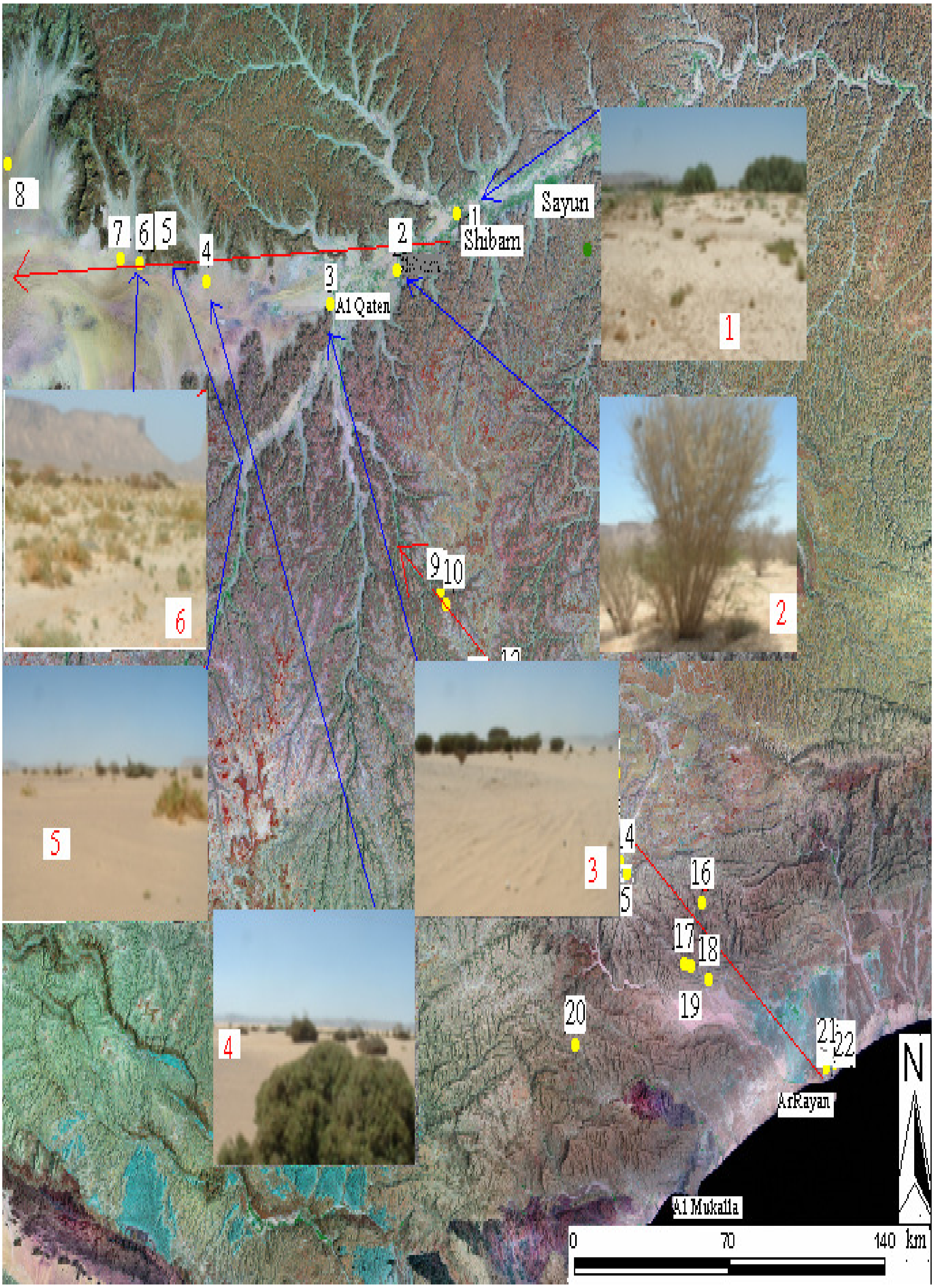


Figure 3.3. A map showing the locations of the sites along the first transect from east to west. Views from 6 locations are also shown.

Key

1- Undulating concave flooded wadi, covered by sand dunes (670 m).

Cover: Trees 1% and dwarf shrubs 30% (40%)

Dwarf shrubland dominated by *Zygophyllum album* and *Dipterygium glaucum,* associated with *Alhagi graecorum, Tribulus arabicus, Cleome scaposa, Panicum turgidum, Calotropis procera, Tephrosia apollinea, Senna italica, Prosopis juliflora* and *Tamarix arabica.*

2- Fallow lands (703 m)

Cover: Trees 55% and dwarf shrubs 2% (57%)

Open woodland dominated by *Acacia campoptila* and *Acacia ehrenbergiana,* associated with *Prosopis juliflora, Zygophyllum album, Capparis spinosa* and *Prosopis farcta.*

3- Undulating to almost flat sand dune area (730 m)

Cover: Trees 3% and dwarf shrubs 1% (4%)

Open woodland dominated by *Acacia campoptila* and *Rhazya stricta* associated with *Acacia ehrenbergiana.*

4- Almost flat sandy plain near cultivated field (740 m)

Cover: Trees 1%, shrubs 3% and herbs 1% (5%).

Sparse shrubland dominated by *Acacia ehrenbergiana* and *Zygophyllum album* with *Acacia campoptila, Rhazya stricta* and *Prosopis juliflora.*

5- Almost flat sand dunes area (750 m)

Cover: Trees <1%, shrubs 2%, dwarf shrubs 20% and herbs 3% (26%)

Dwarf shrubland dominated by *Rhazya stricta* in association with *Acacia ehrenbergiana* and *Acacia campoptila.*

6- Wide sandy wadi bed, almost flat, probably old fallow land (769 m)

Cover: Tree 1%, dwarf shrubs 7% and herbs 15% (23%)

Dwarf shrubland dominated by *Tephrosia apollinea* and *Rhazya stricta* in association with *Acacia campoptila, Panicum turgidum Dipterygium glaucum, Aerva javanica, Tribulus arabicus, Senna italica,* and *Indigofera* sp.

7- Almost flat sandy plain (735 m)

Cover: Shrubs 15% and herbs 5% (15%)

Shrubland dominated by *Rhazya stricta* with *Aerva javanica, Calotropis procera, Prosopis juliflora, Acacia campoptila, Boerhavia* sp., *Tephrosia* sp., *Panicum turgidum, Corchorus depressus* and *Fagonia* sp.

8- Almost flat sandy plain (640 m)

Cover: Herbs 3%.

Sparse shrubland dominated by *Rhazya stricta* with *Acacia campoptila, Aerva javanica* and *Dipterygium glaucum*

3.5.1.b. South-east to north-west transect (Figure 3.4)

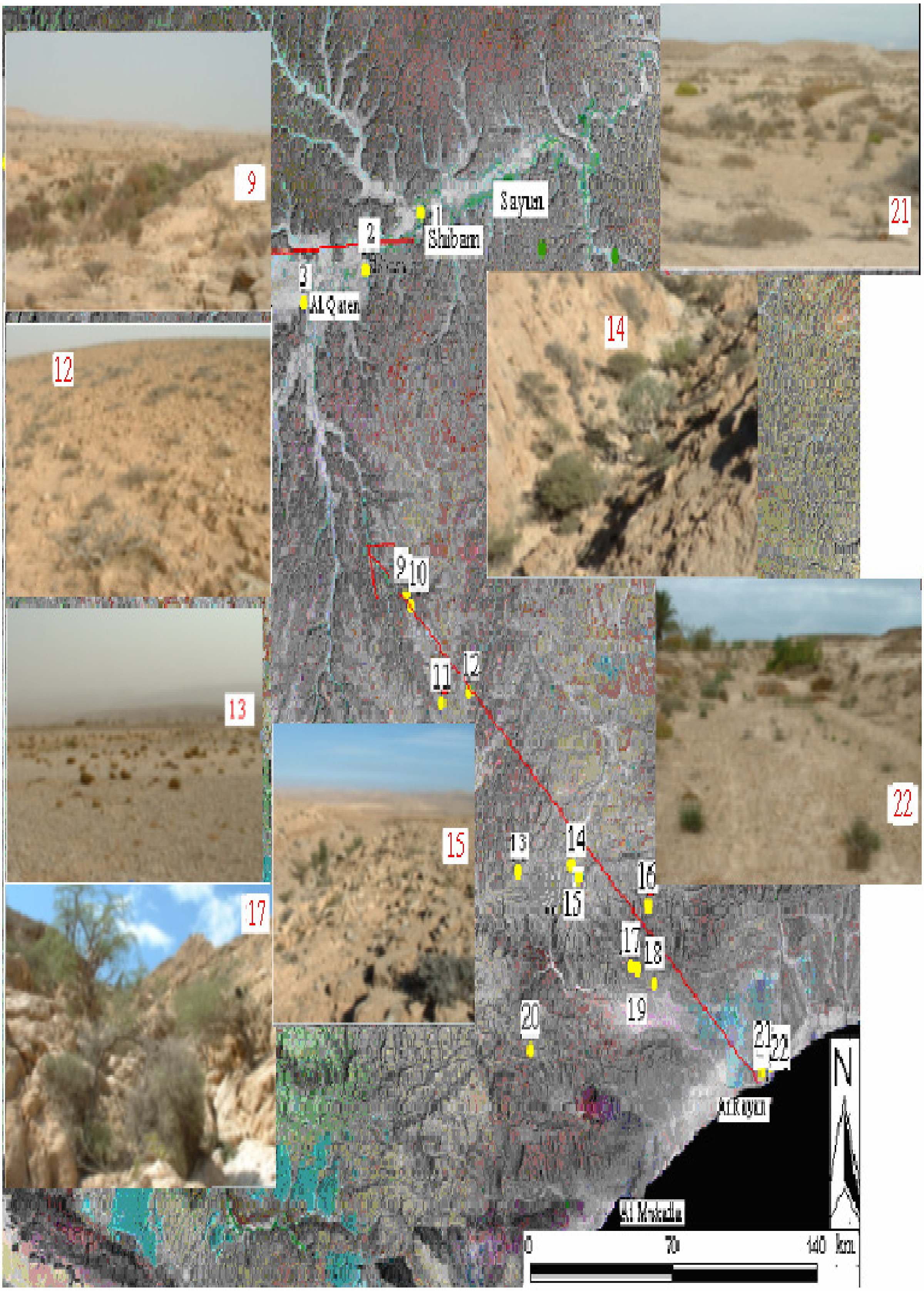


Figure 3.4. A map showing the locations of the sites along the aecond transect from south-east to north-west. Views from 8 locations are also shown

Key:

9. Wadi Daua'n 1000 m. Gully and dissected limestone plateau with trees restricted to gullies.

Cover: Trees 20%, shrubs 5%, herbs 5%, (30%)

Woodland dominated by *Anogeissus bentii* and *Ziziphus leucodermis,* with *Cymbopogon schoenanthus, Cassia* sp., *Indigofera spinosa, Rhazya stricta,* and *Tephrosia* sp.

10. Dissected plateau 1160 m.

Cover: Trees 5%, herbs 15% and dwarf shrubs 7% (27%)

Open woodland dominated by *Acacia hamulosa* and *Pulicaria somalensis* with *Acacia mellifera, Commiphora* sp., *Cymbopogon schoenanthus, Ochradenus arabicus, Barleria bispinosa, Heliotropium* sp., *Pavonia* sp., *Tarenna graveolena, Farsetia* sp., *Aerva javanica, Periploca visciformis, Corallocarpus glomeruliferus, Sarcostemma viminale, Farsetia dhofarica* and *Fagonia* sp.

11 - Sandy wadi bed in plain (1210 m).

Cover: Trees 20%, shrubs 5%, dwarf shrubs 5%, herbs 2% (32%)

Open woodland dominated by *Acacia campoptila* and *Grewia erythraea* with *Acacia hamulosa Solanum schimperianum, Senna italica, S. holosericea, Barleria* sp., *Indigofera spinosa, Pulicaria somalensis, Ceropegia botrys, Zehneria anomala, Pulicaria cylindrica, Balanites aegyptiaca, Convolvulus glomeratus, Gnidia somalensis* var. *sphaerocephala* and *Hibiscus* sp.

12 - Rocky flat plain at summit limestone plateau (1500 m).

Cover: Dwarf shrubs 10% and herbs <1 (11%).

Sparse shrubland dominated by *Jatropha spinosa,* with *Barleria bispinosa Barleria proxima, Barleria* sp., *Hibiscus* sp., *Grewia erythraea, Cymbopogon schoenanthus, Gnidia somalensis* var. *sphaerocephala, Heliotropium strigosum, Ochradenus arabicus, Pulicaria somalensis, Sarcostemma viminale, Tetrapogon villosus, Zygophyllum decumbens* and *Caralluma* sp.

13- Rocky almost flat plateau (1496 m)

Cover: Trees 2%, shrubs 25% and herbs 5% (32 %).

Shrubland dominated by *Dodonaea viscosa* with *Grewia erythraea, Limonium cylindrifolium, Gnidia somalensis var. sphaerocephala, Barleria proxima, Fagonia schweinfurthii, Euphorbia schimperi, Balanites aegyptiaca, Pulicaria somalensis, Euphorbia balsamifera, Aloe* sp., and *Periploca visciformis.*

14 – Rocky secondary wadi on plateau (1344 m)

Cover: Trees 5%, shrubs 20%, dwarf shrubs 5% and herbs 10% (40%)

Open woodland dominated by *Dodonaea viscosa* with *Dracaena serrulata* and *Acacia etbaica, Aloe* sp., *Asparagus* sp., *Balanites aegyptiaca, Barleria proxima, Barleria* sp., *Capparis cartilaginea, Ecbolium* sp., *Euphorbia* sp., *Euphorbia hadramautica, Fagonia schweinfurthii, Gnidia somalensis* var. *sphaerocephala, Grewia erythraea, Indigofera* sp. *Kleinia odora, Launaea* sp., *Launaea spinosa, Limonium cylindrifolium, Lycium shawii, Maerua crassifolia, Ochradenus arabicus, Periploca visciformis, Pulicaria cylindrica, Pulicaria somalensis, Seddera arabica, Tephrosia heterophylla, Ephedra foliata* and *Vernonia arabica.*

15- Plateau near to the previous valley (1300m)

Cover: Trees 1% and shrubs 15%, (16%)

Sparse Shrubland dominated by *Zygophyllum decumbens,* with scattered *Euphorbia balsamifera, Pulicaria somalensis, Acacia etbaica, Heliotropium* sp. and *Acacia oerfota.*

17 – Lip of escarpment overlooking coastal plain (856m)

Cover: Trees 3%, shrubs 5%, dwarf shrubs 5% and herbs 20% (33%)

Open Woodland with *Fagonia* sp., *Aerva javanica, Crotalaria* sp., *Caesalpinia erianthera, Delonix elata, Reseda sphenocleoides, Adenium obesum, Fagonia* sp., *Acacia hamulosa, Heliotropium sp, H. longiflorum, Kleinia odora, Commiphora kua, Cometes abyssinica, Convolvulus glomeratus, Aristida* sp., *Schweinfurthia spinosa, Euphorbia meuliana, Aerva artemisioides, Atractylis kentrophylloides, Blepharis edulis, Crotalaria persica, Convolvulus glomeratus,* and *Kickxia ramosissima*.

18 - Stony slope and drainage line with gully erosion (614m).

Cover: Trees 2%, shrubs 5%, dwarf shrubs 2% and herbs 10% (17%)

Sparse shrubland dominated by *Jatropha spinosa,* with *Fagonia schweinfurthii, Acacia oerfota, Pulicaria somalensis, Sterculia africana, Zehneria anomala, Iphiona anthemidifolia, Solanum schimperianum, Tephrosia heterophylla, Abutilon* sp.*, Aerva javanica, Indigofera spinosa, Acacia mellifera, Commiphora kua, Senna holosericea*, *Cucumis canoxyi, Commelina albescens, Cadaba longifolia, Commicarpus sp, Vernonia* sp.*, Merremia hadramautica., Reseda* sp. and *Cleome brachycarpa*

19 - Rocky slope and depression (235m)

Cover: Trees 1%, shrubs 5% and dwarf shrubs 5% (11%)

Shrubland dominated by *Pulicaria somalensis and Caesalpinia erianthera* with *Cadaba longifolia, Saltia papposa, Aerva javanica, Euphorbia schimperiana, Euphorbia schimperi, Commiphora gileadensis, Cleome droserifolia, Fagonia* sp.*, Acacia tortilis, Senna holosericea, Jatropha spinosa, Acacia oerfota, Rhazya stricta, Reseda* sp.*,* and *Zygophyllum* sp.

20- Stony plateau (1600m)

Cover: Shrubs 2% and dwarf shrubs 5% (7%)

Sparse shrubland dominated by *Euphorbia balsamifera with Jatropha spinosa, Ochradenus arabicus, Psiadia arabica, Pulicaria cylindrica, Ruta amoena, Pulicaria somalensis* and *Kalanchoe caespitosa.*

21 - Undulating sand hummocks and runnels on the coastal area (15m)

Cover: Trees <1%, dwarf shrubs 20% and herbs 1% (22%).

Sparse shrubland dominated by the endemic *Limoniastrum arabicum* with *Cleome macradenia , Odyssea mucronata, Limonium cylindrifolium, Prosopis cineraria, Alhagi graecorum, Aerva javanica, Pulicaria somalensis , Zygophyllum simplex, Jatropha spinosa, Aristolochia rigida, Tribulus* sp.*, Tamarix aphylla, Salvadora persica, Pluchea dioscoroides, Aeluropus lagopoides* and *Halopyrum mucronatum.*

22- Drainage line on the coastal plain (15m)

Cover: **Trees 3%, and shrubs 2% (5%)**

Open woodland dominated by *Tamarix aphylla* associated with *Aerva javanica, Halopyrum mucronatum, Prosopis cineraria, Pluchea dioscoroides, Salvadora persica,* and *Aeluropus lagopoides*.

3.5.2. Environmental data analysis

In Figure 3.5 the main floristic associations and environment variables are presented. The points represent the sites and arrows represent the environmental variables.

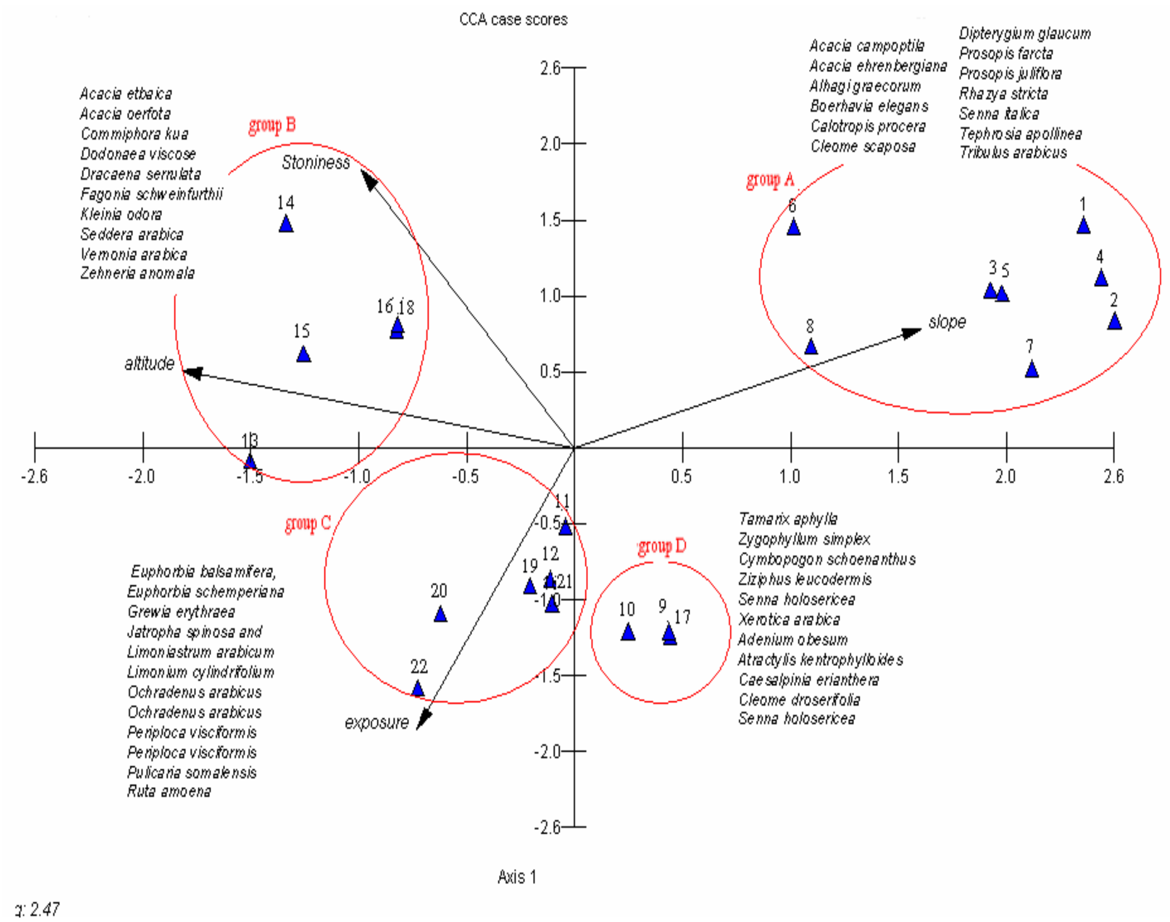


Figure 3.5.Ordination of the location sites along the 2 transects and environment yielded by CCA. The most important variables on axis 1 are altitude and slope percentage; on the second axis the exposure (aspect) and stoniness are important. Group A is found to the right top of the ordination. The species of this group are shown to grow on almost flat surfaces with low altitude and non or very low stoniness, while group (B), top left, is strongly correlated with stoniness and high altitude with relatively flat to slightly steep slopes. Group (C) is found mainly on south-facing, gently sloping plateaus and secondary wadis. Group (D) is found on moderately steep slopes of secondary wadis and adjacent slopes.

The most important variables determining changes in species composition in Figure 3.5 are altitude and stoniness. Group A of the second transect (from west Shibam towards the Ramlat Assaba'tain desert) is found towards the right bottom of the ordination. Species within this group, such as *Rhazya stricta, Acacia campoptila Dipterygium glaucum, Tribulus arabicus* and others, are shown to grow on almost flat sandy surfaces with low altitude and none or very low stoniness, while group (B) top left is strongly correlated with stoniness and altitude with relatively flat to steep slopes; some characteristic species of this group are *Acacia etbaica, A. oerfota, Dodonaea viscosa, Dracaena serrulata* and *Kleinia odora*. Group (C) is mainly found on the south-facing, gently sloping plateaus, coastal plains and secondary wadis from the coast to the high altitude mountains. Some species within this group are widespread along a variety of landforms and altitudes but most of them grow well on relatively flat, stony areas. Some characteristic species of this group are *Limoniastrum arabicum, L. cylindrifolium, Euphorbia balsamifera, Pulicaria somalensis, Ochradenus arabicus, Grewia erythraea, Jatropha spinosa* and *Periploca visciformis* Group (D) is found on moderately steep to almost flat slopes of the secondary wadis and adjacent slopes at moderate altitudes; characteristic species include *Tamarix aphylla, Zygophyllum simplex, Cymbopogon schoenanthus, Ziziphus leucodermis, Senna holosericea, Xerotia arabica, Adenium obesum, Atractylis kentrophylloides* and *Caesalpinia erianthera.* Table 3.1 shows the sample sites with their environmental characteristics and vegetation structure.

Sampling sites	Altitude m	Slope %	exposure	Stoniness %	Trees %	Shrub %	dwarf shrub %	Herb %	total vegetation cover %	total species		Sampling sites	Altitude m	Slope %	exposure	Stoniness %	Trees %	Shrub %	dwarf shrub %	Herb %	total vegetation cover %	total species
1	675	1	e	0	1	0	30	0	31	11		**12**	1530	1	w	50	0	0	10	1	11	15
2	703	1	e	0	5	0	2	0	7	6		**13**	1500	3	ne	80	2	25	0	5	32	12
3	730	1	e	0	3	0	1	0	4	3		**14**	1344	2	sw	80	5	20	5	10	40	30
4	740	2	e	0	1	3	0	1	5	5		**15**	1300	2	sw	95	1	15	0	0	16	6
5	750	2	e	0	1	2	20	3	26	3		**16**	614	3	sw	85	2	5	2	10	19	22
6	769	1	e	0	1	0	7	15	23	9		**17**	856	30	s	80	3	5	5	20	33	23
7	735	15	e	1	0	0	15	5	20	10		**18**	614	25	se	80	2	5	2	10	19	22
8	766	5	e	1	1	0	1	1	3	4		**19**	235	30	sw	70	1	5	5	0	11	18
9	1000	20	ne	85	25	5	0	5	35	7		**20**	1600	2	se	90	0	2	5	0	7	6
10	1160	2	nw	60	5	0	7	15	27	19		**21**	15	2	sw	1	1	0	20	1	22	17
11	1210	2	nw	1	20	5	5	2	32	15		**22**	15	1	sw	1	3	2	0	0	5	7

Table 3.1. The sample plots with their environmental characteristics and vegetation structure.

Figure 3.6 shows the increase of vegetation cover along the altitude gradient. The flat limestone plateau of high altitude areas has a low vegetation cover compared to that of other landforms (e.g. drainage lines and mountain slope) at the same altitude.

Figure 3.7 shows the change of number of species (richness) along the altitudinal gradient. The species richness of the plateau at high altitude areas is low compared to other landforms at the same altitude. The low number of species in the drainage sites 9, 10 and 11 results from slope direction (NW and NE) and low moisture content, as these sites are located further north on altitudes less than 1210 m asl, where the rainfall is lower.

Other environmental conditions such as landform type, soil and moisture should be taken to consideration when there is an attempt to analyse the change in vegetation cover or richness along altitude gradients of Hadhramaut region. These factors are taken into more detailed study is the analysis of the selected study sites (Chapters 4 and 5)

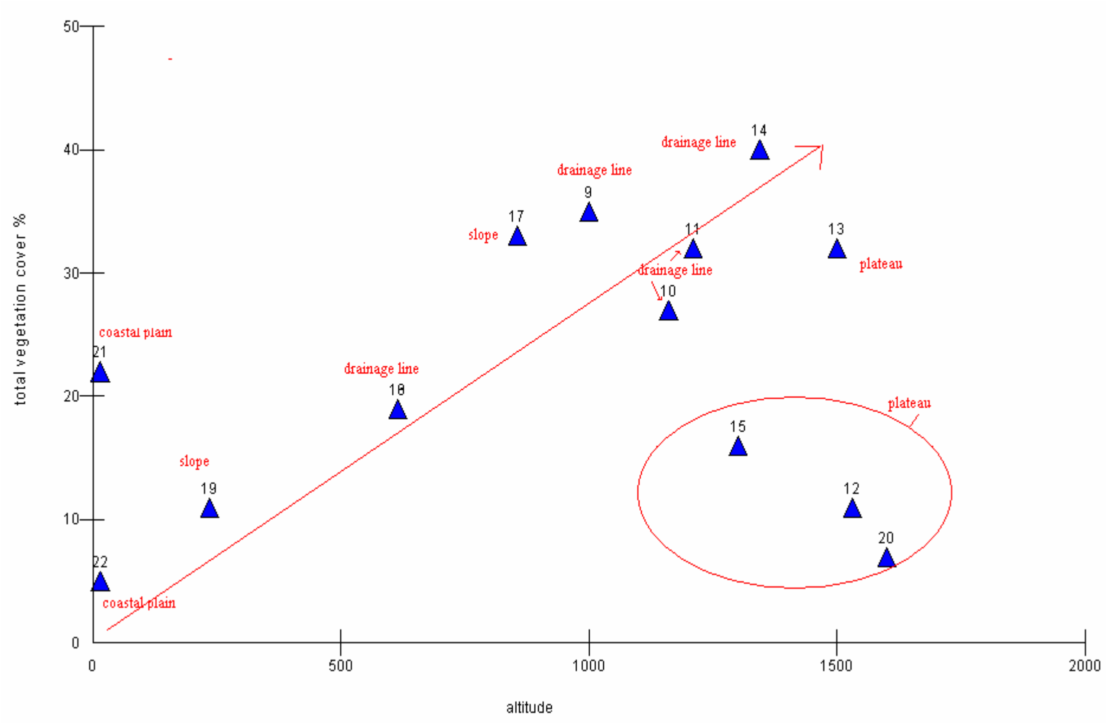


Figure 3.6. The figure shows the increase of vegetation cover percentage along the altitudinal gradient of both transects. Compared to other landforms at the same altitude, the vegetation cover of the plateau at high altitude areas was low. Numbers refer to sampling sites.

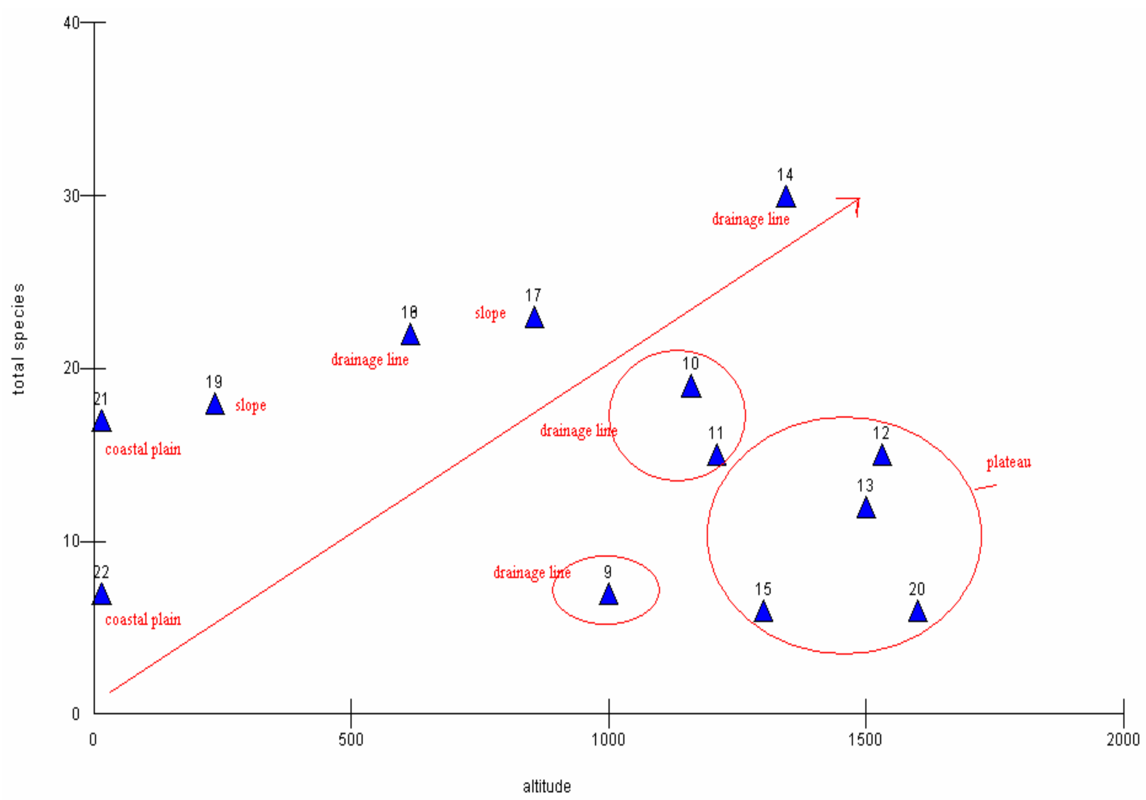


Figure 3.7. The figure shows the change of number of species (richness) along the altitudinal gradient of both transects. Compared to other landforms at the same altitude, the species richness of the plateau at high altitude areas was low. Numbers refer to sampling sites.

3.5.3. Threatened plant species in the region.

Recently the IUCN Red List Categories and Criteria have been promoted as a widely understood system for classifying species at high risk of global extinction. The general aim of the system is to provide a clear framework for the classification of the plant and animal species according to their extinction risk (IUCN, 1994). However, there is inadequate information to make an assessment of the risk of extinction for the plant species in the Hadhramaut region. Extensive information on the distribution, abundance and population of the plant species, in particular endemic and near-endemic plants, needs to be collected to get a clear idea of just how vulnerable to extinction these species are and then to evaluate them according to the IUCN Red List Categories. Nevertheless, a provisional list of Arabian endemic plants and threatened non-endemic plants was published recently by Miller et al (2006). A provisional evaluation of endemic and near-endemic plant species list of Hadhramaut region (Table 3.2) was obtained based on that work and on the available information from field work and other sources (e.g. Lavranos, 2001, Lavranos and Mies, 2001, Lavranos et al., 2004; Thulin, 2001 and 2002, Thulin and Al Gifri, 1993 and 1995; Al-Gifri and Kurschner , 1996; Gabali. and Al Gifri, 1990; and Lavranous and Al Gifri, 1999 and Kilian et al., 2002).

Table 3.2. Provisional list of Hadhramaut Endemic and near Endemic plant species with regional and global assessment (after Miller et al., 2006).

Endemic and near plant endemic plant species	**Family**	**Distribution**				**Assessment**	
		Hadhramaut	**Yemen**	**Arabia**	**Africa**	**Regionally**	**globally**
Acacia campoptila Schweinf. *	Mimosaceae		Y				Provisional NT
Aerva artemisioides Vierh. & Schwartz subsp. artemisioides *	Amaranthaceae	H				NT	
Aloe abyssicola Lavr. & Bilaidi *	Aloeaceae	H					Provisional NT
Aloe doei Lavr. *	Aloeaceae		Y				Provisional NT
Aloe eremophila Lavr. *	Aloeaceae	H					Provisional NT
Aloe fleurentinorum Lavr. & Newton. **	Aloeaceae		Y	S			Provisional NT
Aloe inermis Forssk. *	Aloeaceae		Y				Provisional NT
Aloe luntii Baker *	Aloeaceae	H					Provisional NT
Aloe mahraensis Lavr. & McCoy **	Aloeaceae		Y	O			Provisional NT
Aloe mccoyi Lavr. & Mies *	Aloeaceae	H					Provisional NT
Aloe serriyensis Lavr. *	Aloeaceae	H					Provisional NT
Anogeissus bentii E.G.Baker *	Combretaceae	H				EN	
Anticharis linearis (Benth.) Hochst. ex Asch. **	Sapotaceae		Y			NE	
Aristolochia rigida Duch.	Aristolochiaceae	H		O	Somalia	NE	
Asystasia petalidiodes Defl. *	Acanthaceae		Y			NE	
Atractylis kentrophylloides (Bak.)F.G.Davis **	Asteraceae (Compositae)	H		O		NE	
Barleria farinosa Defl. *	Acanthaceae		Y			NE	
Bauhinia ellenbeckii Harms.	Caesalpiniaceae	H			Ethiopia Somallia	NE	
Boerhavia elegans Choisy *ssp. elegans* **	Nyctaginaceae		Y	S, O		EN	
Boscia arabica Pestalozz. **	Capparaceae (Capparidaceae)		Y	O		VU	
Cadaba baccarinii Chiov.	Capparaceae (Capparidaceae)		Y	O	Somalia		
Calligonum crinitum Boiss. ** *subsp. arabicum*	Polygonaceae		Y	O, U		NE	
Campylanthus pungens Schwartz **	Scrophulariaceae		Y	O		NE	
Caralluma adenensis (Defl.)Burg. **	Apocynaceae (Asclepiadaceae)		Y	O		CR	
Caralluma arabica N.E.Br. **	Apocynaceae (Asclepiadaceae)		Y	O		VU	
Caralluma dolichocarpa Schwartz. *	Apocynaceae (Asclepiadaceae)		Y			NE	
Caralluma flava N.E.Br. **	Apocynaceae (Asclepiadaceae)		Y	O		VU	
Caralluma foulcheri-delboscii var. greenbergiana Lavr.*	Apocynaceae (Asclepiadaceae)	H				NE	

Table 3.2. continue

Endemic and near plant endemic plant species	Family	Distribution				Assessment	
		Hadhramaut	Yemen	Arabia	Africa	Regionally	globally
Caralluma lavrani Rauh & Wertel *	Apocynaceae (Asclepiadaceae)		Y			NE	
Caralluma penicellata (Defl.)N.E.Br. **	Apocynaceae (Asclepiadaceae)		Y	S		VU	
Caralluma quadrrangula (Forssk.)N.E.Br. **	Apocynaceae (Asclepiadaceae)		Y	S, O		LC	
Caralluma shadhabana Lav. & Newton. **	Apocynaceae (Asclepiadaceae)		Y	S		NE	
Caralluma subulata (Forssk.)Decne. **	Apocynaceae (Asclepiadaceae)		Y	S		NE	
Celtis africana Burm.f.	Ulmaceae		Y		Africa	NE	
Ceratonia oreothauma Hillc., Lewis & Verdc. **	Caesalpiniaceae		Y	O		VU	VU
Ceropegia botrys K. Schuhmann	Apocynaceae (Asclepiadaceae)		Y		Somalia	NE	
Ceropegia subaphylla K.Schuhmann	Apocynaceae (Asclepiadaceae)		Y	S, O	N Africa	DD	
Cleome hadramautica Thulin *	Cleomaceae		Y			NE	
Cleome macradenia Schweinf. *	Cleomaceae	H				NE	
Cleome pruinosa T.Anders. **	Cleomaceae		Y			NE	
Conocarpus lancifolius Engl.	Combretaceae		Y		Somalia	NE	LC
Convolvulus sericophyllos T. Anderson. *	Convolvulaceae	H				NE	
Corallocarpus glomeruliforus Schweinf.	Cucurbitaceae		Y	O	N Africa	VU	
Cryptolepis yemenensis Venter & R.L.Verh. *	Apocynaceae (Asclepiadaceae)		Y			NE	
Cucumis canoxyi Thulin & Gifri. *	Cucurbitaceae		Y			VU	
Cystostemon kissenioide (Delf.)A.Miller & H.Riedl. *	Boraginaceae		Y			NE	
Dracaena serrulata Baker.	Agavaceae		Y	S, O	N Africa	EN	EN
Ecbolium strictum Schwartz *	Acanthaceae		Y			NE	
Echidnopsis bentii N.E.Br. *	Apocynaceae (Asclepiadaceae)	H				VU	VU
Echidnopsis globosa Thulin & Hjertson *	Apocynaceae (Asclepiadaceae)		Y			NE	Provisional NT
Echidnopsis seibanica Lavr. *	Apocynaceae (Asclepiadaceae)	H				VU	VU
Echiochilon arabicum (Schwar.)I.M.Johns. *	Boraginaceae	H		O		LC	
Ephedra milleri Freitag & Mairer-Stolte. **	Ephedraceae (Gnetaceae)		Y	O		NE	Provisional LC
Euphorbia applanata Thulin & Gifrii. *	Euphorbiaceae	H				NE	
Euphorbia fodhliana Defl. *	Euphorbiaceae	H				NE	Provisional NT
Euphorbia meuleniana O. Schwartz *	Euphorbiaceae	H				NE	Provisional NT
Euphorbia quaitensis S.Carter *	Euphorbiaceae	H				NE	Provisional NT

Table 3.2. continue

Endemic and near plant endemic plant species	Family	Distribution				Assessment	
		Hadhramaut	Yemen	Arabia	Africa	Regionally	globally
Euphorbia riebeckii Pax. **	Euphorbiaceae		Y	O		NE	LC
Euphorbia rubriseminalis S.Carter *	Euphorbiaceae		Y			NE	Provisional NT
Euphorbia seibanica Lavr. & Gifri. *	Euphorbiaceae	H				NT	Provisional NT
Fagonia hadramautica Beier & Thulin *	Zygophyllaceae	H				NT	VU
Farsetia linearis Dene ex Boiss **	Brassicaceae (Cruciferae)		Y	S, O, U		LC	
Farsetia dhofarica Jonsell & Miller. **	Brassicaceae (Cruciferae)		Y	O		NE	
Gaillonia jolana Thulin *	Rubiaceae	H					
Gymnocarpos rotindifolius Petruss & Thulin. **	Caryophyllaceae (Illecebraceae)	H		O		VU	
Halothamnus bottae Jaub. & Spack **	Chinopodiaceae		Y	S, O, U		NE	
Heliotropium bottae Deflers. *	Boraginaceae		Y			NE	
Heliotropium fartakense Schwartz **	Boraginaceae		Y	O		LC	
Heliotropium makallense Schart. *	Boraginaceae	H				NE	
Heliotropium paradoxum Vatke. *	Boraginaceae	H				NE	
Heliotropium wagneri Vierh. *	Boraginaceae	H				VU	VU
Heliotropium wissmannii Schwartz *	Boraginaceae	H				NE	
Huernia hadhramautica Lavr. *	Apocynaceae (Asclepiadaceae)	H					Provisional NT
Indigofera nephrocarpoides J.B.Gillett *	papilionoideae (Fabaceae)		Y			NE	
Indigofera rubromarginata Thulin **	Asteraceae (Compositae)		Y	O			
Iphiona anthemidifolia (Bak.)A.Anderb. *	Asteraceae (Compositae)	H				NE	
Iphiona senecionoides (Bak.)A. Anderb. **	Asteraceae (Compositae)		Y	O		LC	
Iphiona teretefolia A.Anderb. *	Asteraceae (Compositae)	H				NE	
Justicia areysiana Defl. **	Acacnthaceae		Y	O		LC	Provisional DD
Kleinia deflersii Defl. *	Asteraceae (Compositae)		Y				Provisional CR
Kleinia odora (Forssk.)A.Berger **	Asteraceae (Compositae)		Y	S, O		VU	
Launaea castanosperma F.G.Davies. **	Asteraceae (Compositae)	H		O		NE	
Lavandula subnuda Benth. **	Lamiaceae (Labiatae)	H		O		NE	
Limoniastrum aramicum J. Edmondson *	Plumbaginaceae	H				CR	
Merremia hadramautica (Baker) R.R. Mill *	Convolvulaceae	H				NE	
Ochradenus arabicus Chaudhary, Hillc. & A.G. Mill.**	Resedaceae		Y	S.O, UAE		NE	
Ochradenus gifrii Thulin. **	Resedaceae		Y	S. O		NE	
Ochradenus spartioides (Schwartz)Abdulla. *	Resedaceae	H				NE	
Orbea luntii (N.E. Brown) Bruyns = (Caralluma luntii N.E.Br.) **	Apocynaceae (Asclepiadaceae)	H		O		NT	
Pavonia subaphylla Schwartz *	Malvaceae	H				NE	

Table 3.2. continue

Endemic and near plant endemic plant species	Family	Distribution				Asessment	
		Hadhramaut	Yemen	Arabia	Africa	Region	globally
Pentzia arabica Thulin *	Asteraceae (Compositae)	H				NE	
Pluchea arabica (Boiss.)Qaiser & Lack. **	Asteraceae (Compositae)	H		O		NE	
Pulicaria cylindrica (Bak.)O. Schwartz **	Asteraceae (Compositae)	H		O		NE	
Pulicaria lancifolia Schwartz. *	Asteraceae (Compositae)	H				NE	
Pulicaria nivea Schwartz *	Asteraceae (Compositae)	H				NE	
Pulicaria rauhii Gamal-Eldin. *	Asteraceae (Compositae)	H				NE	
Reseda sphenocleoides Defl. **	Resedaceae		Y	O		NE	
Rhus flexicaulis Baker *	Anacardiaceae		Y			VU	
Rhus glutinosa A. Rich *subsp neoglutinosa* Gilbert	Anacardiaceae	H			Ethiopia	NE	
Rhytidocaulon mccoyi Lavr. & Mies *	Apocynaceae (Asclepiadaceae)	H				NE	
*Saltia papposa (*Forssk.) Moq. *	Amaranthaceae		Y			NE	
*Schweinfurthia latifolia (*Baker. Ex) Oliver *	Scrophulariaceae		Y			NE	
Schweinfurthia spinosa Miller, Sutton & Short **	Scrophulariaceae	H	O			NE	
Seddera hadramautica R.R.Mill *	Convolvulaceae	H				NE	
*Sideroxylon mascatense (*A. DC.) T.D. Penn. *	Sapotaceae	H				NE	
Stachys yemenensis Hedge. *	Lamiaceae (Labiatae)		Y			NE	
Stultitia araysiana Lavr. & Bilaidi *	Apocynaceae (Asclepiadaceae)		Y			NE	
Taverniera glauca Edgeworth *	Papilionoideae (Fabaceae)		Y			NE	
*Taverniera multinoda T*hulin *	Papilionoideae (Fabaceae)		Y			NE	
Taverniera schimperi Jaub. & Spach. *	Papilionoideae (Fabaceae))		Y			NE	
Tephrosia dura Baker	Papilionoideae (Fabaceae))	H			Somalia	NE	
Tephrosia hadramautica M.Thulin *	Papilionoideae (Fabaceae)	H				NE	
Teucrium eximium Schwartz. *	Lamiaceae (Labiatae)	H				NE	
Teucrium rhodocalyx Schwartz. *	Lamiaceae (Labiatae)	H				NE	
Verbascum luntii E.G.Baker. *	Scrophulariaceae	H				NE	
Vernonia areysiana Defl. *	Asteraceae (Compositae)		Y			NE	
Xerotia arabica Oliver **	Caryophyllaceae (Illecebraceae)	H		S		NE	
Ziziphus leucodermis (E.G.Baker) Schwartz **	Rhamnaceae	H		O		NE	

Key:

IUCN categories	LEAST CONCERN (LC)	**Country**	
NOT EVALUATED (NE)	NEAR THREATENED (NT)	Y= Yemen, H= Hadhramaut region	O= Oman
DATA DEFICIENT (DD)	ENDANGERED (EN)	S= Saudi Arabia	U= Unite Arab Emirate
VULNERABLE (VU)	CRITICALLY ENDANGERED (CR)		UAE= united Arab Emirate

Note: Some species in the list are found outside Arabia only in Somalia, Ethiopia and North Africa.

3.5.4. Comparison with previous vegetation studies

As discussed in Chapter 2, many vegetation studies have been conducted in different parts of Yemen. Some of these studies were carried out in habitats that are similar to those found in the study area, such as at Marib and the southern and western coastal areas. A resemblance in vegetation composition was found between these areas and the Hadhramaut study area, and the following account indicates some of the similarities.

3.5.4. a. Comparison with previous vegetation studies in Yemen

Indigofera spinosa, Jatropha spinosa and *Maerua crassifolia* form an open woodland and grassland on some isolated foothills of southern and western mountains and on the coastal plains of Yemen (e.g. on wadis, drainage lines, along the edges of the wadi and sand dunes) between 500 and 1900 m (Al Khulaidi, 2000); these areas have a relatively higher annual rainfall than Wadi Hadhramaut (Figure 3.8). *Rhazya stricta* is restricted to wadi beds and sands of northern east and eastern desert areas of Yemen (e.g. Marib and Rada') and the desert of Oman (Ghazanfar, 2004). In lower altitudes of the Hormozgan province in Iran there is a savanna-like community of *Acacia tortilis* and *A. ehrenbergiana,* and *Rhazya stricta* is frequent along seasonal rivers and shallow valleys (Zohary, 1973).

The Acacia campoptila community association with *Panicum turgidum*, *Aerva javanica, Indigofera spinosa, Fagonia indica, Ochradenus baccatus, Dipterygium glaucum Calotropis procera* and *Rhazya stricta* is widespread in the wadi beds at Marib, Harib, Ataq and Rada' in Yemen (Al Khulaidi, 1989; Wistinga and Thalen 1980; Al Hubaishi and Muller-Hohenstein, 1979; Barkuda and Sanadiqi, 1986). These areas are characterised by having more rainfall than the Hadhramaut region. Some characteristic species of wadi beds in these areas, such as *Leptadenia pyrotechnica*, *Lycium shawii*, *Jatropha spinosa* and *Acacia oerfota,* were absent at similar habitats in Hadhramaut. The last two species were confined to slopes of the plateaus and were absent on the wadi beds in Hadhramaut. Some characteristic species of the Hadhramaut region, such as *Tephrosia apollinea* subsp. *longistipulata, Ziziphus leucodermis,* and *Merremia hadramautica* were not recorded at either Marib or Rada'.

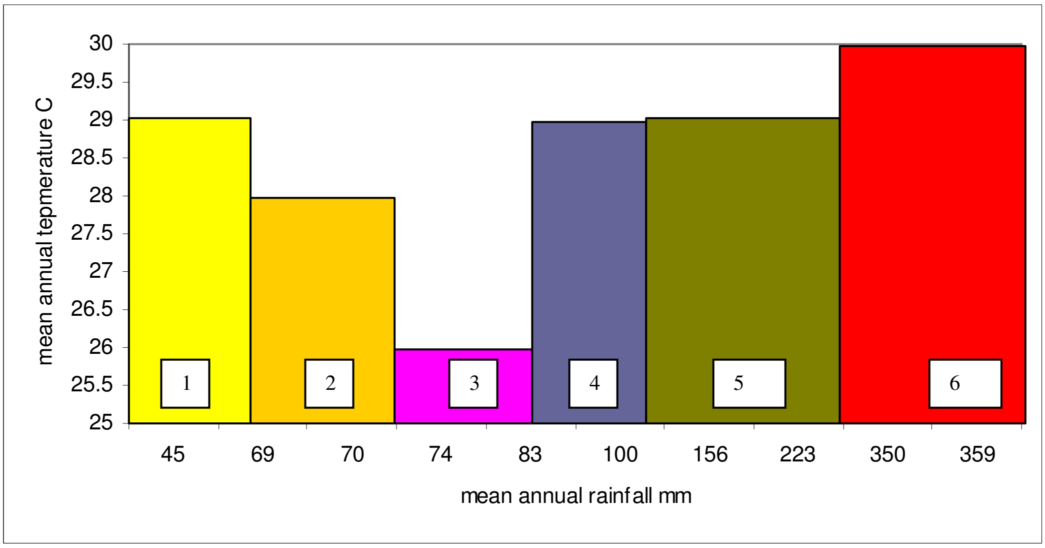


Figure 3.8. The main vegetation associations of 6 ecological areas in Yemen:
1- Al Mokha (western coastal area),
2- Al Kod (southern coastal area),
3- Marib (northern arid area),
4- Al Hudaydah,
5- Zabid and
6- Al Jaruba (western coastal area).
The ap (left) shows the location of these areas.

The main vegetation associations:
1- *Salsola spinescens - Suaeda fruticosa*: is dwarf shrubland; sassociated species include *Salvadora persica.* **2- *Dipterygium glaucum - Panicum turgidum*** forms a grassland on sand dunes plain; associated species include: *Fagonia indica, Aerva javanica* and *Indigofera spinosa.* **3- *Acacia campoptila – Aerva javanica*** forms grassland and woodland on drainage lines; associated species include: *Fagonia indica, Panicum turgidum, Indigofera spinosa, Dipterygium glaucum, Rhazya stricta, Ochradenus baccatus* and *Acacia oerfota*. ***4- Odyssea mucronata - Panicum turgidum*** forms a shrubland; associated species include: *Dipterygium glaucum* and *Cadaba rotundifolia.* **5- *Salvadora persica – Tamarix aphylla*** forms a woodland along Wadis; associated species include: *Calotropis procera*, *Cadaba rotundifolia and Cissus quadrangularis.* ***Leptadenia pyrotechnica – Panicum turgidum*.** forms a grassland or shrubland found on sand dunes; associated species include: *Aerva javanica* and *Odyssea mucronata*. **6- *Acacia tortilis – Lasiurus scindicus* forms a** grassland or open woodland; associated species include: *Jatropha glauca*, *Acacia ehrenbergiana, Indigofera spinosa, Leptadenia pyrotechnica, Cassia senna,* and *Indigofera oblongifolia.*

3.5.4.b. Comparison with the vegetation of the region and East Africa

The vegetation of the Hadhramaut region is very similar to the vegetation of wadis, in Sudan, Palestine and Arabia (White, 1983; Zohary 1973). Species of *Acacia* (e.g. *Acacia tortilis* and *A. hamulosa*) are accompanied by other typical species such as *Panicum turgidum, Leptadenia pyrotechnica.* On a sand wadi between Thaif and Bisha (Saudi Arabia) *Rhazya stricta, Aerva javanica, Pennisetum divisum* and others form a savanna-like vegetation (Zohary, 1973) and similar vegetation is also found in Wadi Bike, Egypt (Abdul El-Ghani, 2000). The *Acacia tortilis-Panicum turgidum* community is widespread throughout the tropical Sahara and the Sahel regions (White, 1983). The vegetation of the Tihama Plain (along the Red Sea coast of Yemen) is very similar to the vegetation of coastal area of Hadhramaut and the semi-arid grasslands of East Africa found in Kenya, Somalia and to a small extent in NE Uganda (Lind and Morrison, 1974).

Acacia tortilis and *A. hamulosa* form savanna-like communities in association with *Panicum turgidum, Leptadenia pyrotechnica, Aerva javanica, Calotropis procera* and *Ziziphus spina-christi* which are widespread throughout tropical regions along the south of the Sahara desert and in wadis in Sudan, Egypt, Palestine and Arabia (Zohary 1973; White, 1983).

A similar habitat to the open woodland dominated by *Dracaena serrulata* is found on Jebel Samhan, a south-facing escarpment in southern Oman, at altitudes between 600-1100 m asl (Al-Zdjali, 1995; Michael, et al., 2001).

3.6. Conservation and management of plant species and biodiversity

3.6.1. Introduction

Plant biodiversity is an important natural resource for humans and wildlife. Human activities have dramatically affected natural resources caused great damage to the environment resulting in a great loss of biodiversity in many parts of the world. Because of the industrial revolution, the impact has become global rather than regional. This global impact is taking place through 4 primary processes (Otten, 2001):- over-harvesting, unknown species introduction, pollution, and habitat destruction. Plant species that have taken millions years to develop, are now rapidly destroyed by human activities and climate change (Bryant, 2004). Plant species in Hadhramaut are being threatened by a rapidly growing human population, increasing climatic hazards, economic development and, in by particular, oil-related activities and devastating seasonal floods in the main wadis. Currently, many plant species are rare, threatened, or endangered in the region; however, further studies are needed to ascertain the number of species under threat: this will form the basics for a conservation and management strategy.

3.6.2. Important sites of Hadhramaut region

A working list of known plant species is considered to be a fundamental requirement for plant conservation. At present we do not have a complete inventory of the plants of the Yemen. With the continuing discovery of new endemic plant species every year from all parts of Yemen: for example, over the last 11 years new endemic plant species for Yemen include: *Acacia harala* Thulin & Gifri. (2000), *Acacia mahrana* Thulin & Gifri (2000)*, Aloe irafensis* Lavr. McCoy & Gifri (2004), *Aloe luntii Baker* (2002), *Campylanthus antonii* Thulin (1995), *Cleome hadramautica Thulin* (2002), *Cleome socotrana* Balf. (2002), *Cucumis canoxyi* Thulin & Gifri (1994), *Echidnopsis globosa* Thulin & Hjertson (1995), *Euphorbia applanata* Thulin & Gifrii. (1995), *Euphorbia quaitensis* S.Carter (1995), *Fagonia hadramautica* Beier & Thulin (2005), *Gaillonia jolana* Thulin (1998), *Gaillonia yemenensis* Thulin (1998), *Indigofera rubromarginata* Thulin (1995), *Nesocrambe socotrana* AG Mill. (2002), *Ochradenus gifrii* Thulin (1994), *Pentzia arabica* Thulin (2001), *Rhytidocaulon mccoyi* Lavr. & Mies (2001), *Tephrosia hadramautica* Thulin (1994) and many others in particular, many new species continue to be found in previously unexplored areas in the Soqotra Archipelago, Hadhramaut and Al Mahara Governorates. The total number of known species in Yemen is currently estimated to be around 2900. The number of known plant species recorded by myself (Al Khulaidi, 2000) was 2810 species. Further fieldwork remains essential in some presently unexplored areas of Yemen to enable more comprehensive assessments to be undertaken. Of particular concern is that much work has still to be done to achieve the year 2010 Global strategy of plant conservation (CBD and UNEP, 2002) which aims to achieve the following goals:

(a) Understanding and documenting plant diversity (b) Conserving plant diversity.
(c) Using plant diversity sustainably (d) Promoting education and awareness about plant diversity (e) Building capacity for the conservation of plant diversity.

Important areas to be protected are identified using criteria which include endemism, rarity, near-endemism, species richness, and threat to and richness of habitats.

469 plant species have been identified from the Hadhramaut region (Appendix 4). There are 107 taxa which are endemic and near-endemic (Table 3.2); 67 of these are endemic to Yemen, of these about 40 are confined to Hadhramaut region. Apart from work recently carried out by Miller and Al Khulaidi (2004), there have not been attempts to apply the IUCN threatened categories to plant species in Yemen. However, the categories for Soqotra Island have been completed (Miller and Morris, 2004).

The vegetation of the Hadhramaut plateau (Jol), on the south-facing mountains or monsoon-affected coastal mountains of the southern part of Hadhramaut region is sustained by the regular fogs that envelop the region. The summits of these mountains, which just below 2000 m asl (Figure 3.9), are considered to have the the richest flora in the region; particularly as regards endemic and near-endemic and newly recorded plant species. The summits have a unique vegetation notably in around Kor Seiban (14°82’N 48°81’E, 1850 m), Sharj al Alif (14° 48' N 48° 46' E, 1840 m), Al Qumra (14° 48' 29N 8° 44' 58E, 1968 m) and Maula Matar (14° 46' 6N 48° 47' 52E, 1651 m), and in the coastal area east of Al Mukalla (14° 42 ‘83’’N, 49° 29’ 91”E, 15 m). Generally, the escarpments south of Maula Mattar to around Bain al-Jibal are recorded as the richest, probably because they are relatively easy to reach (Lavranos ,1966; Lavranos and Mies, 2001; Thulin, and Al Gifri, 1993). However, there are other areas along the escarpment which are hard to get to and which are much less exposed to human pressures. It is argued that these sites should be included in the list of the proposed protected areas in Yemen in future strategies. Other Interesting sites are found in the coastal area between Al Mukalla and Al Hami, where there are further endemic and near-endemic plant species. Examples of remarkable species in these sites include:
Euphorbia seibanica, Rhytidocaulon mccoyi, Aloe eremophila, Huernia hadhramautica, Echidnopsis seibanica, Anogeissus bentii, Justicia areysiana, Schweinfurthia latifolia, Cucumis canoxyi, Caralluma lavrani, Euphorbia applanata, Cryptolepis yemenensis, Launaea castanosperma, Ochradenus arabicus, Echidnopsis

globosa, *Limoniastrum arabicum* and *Enicostema axillare* (Al Gifri and Gabali 1999; Lavranos and Mies, 2001; Meister et al., 2005, and Kilian et al., 2002):

(For more see the list of plant species, Table 3.2).

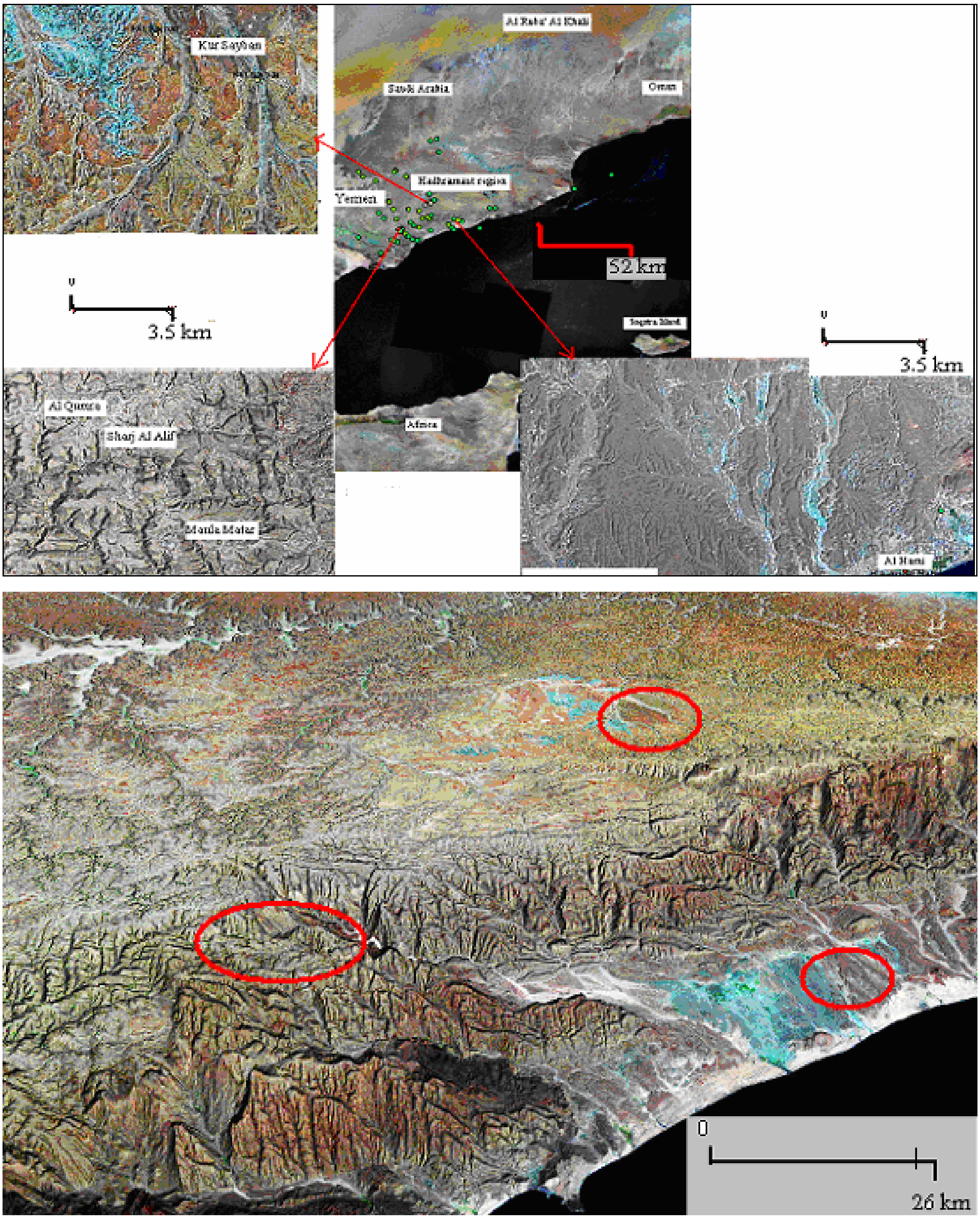


Figure 3.9. The important areas for conservation in Hadhramaut region, Kor Seiban, Sharj al Alif, Al Qumra), Maula Matar and coastal area. The green dots show the distribution of rare, endemic and near-endemic plant species in the Hadhramaut based on field work records as well as on the records of Kilian et al (2002), Thulin et al (2001), Thulin and Al Gifri (1995), Miller and Al Khulaidi, 2004 and Lavaranos (2001).

3.7. Currently existing protected areas in Yemen

At present there are no government protected areas in Yemen. Actively protected areas in Yemen are normally managed by the local communities and fall into the following categories: (Al Khulaidi and El-Ghouri, 1996):- At present there are no fully protected areas by legislation although three are at present being proposed (see below and Chapter 7)

- woodlands and/or shrublands that are formed and protected naturally and mostly situated in remote areas,
- woodlands that are situated around agricultural fields and surrounding areas,
- National parks artificially afforested small sites and areas run by the public sector, these are planted mainly by introduced trees and shrubs.

In many parts of the country, traditional small protected areas can be found. These areas are mainly situated around or near villages and are privately or communally owned. These kinds of protected areas are known in Islamic history as (*hima*) and almost every village in the Arabian Peninsula was associated with one or more *himas.* Management of the *himas* was highly adaptive to the particular requirements of a given village and the potential of a given area. For example, himas in the Arabian Peninsula were managed to protect and conserve plants by limiting animal grazing but allowing the cutting of fodder; permitting seasonal grazing and fodder cutting after plants had flowered, limiting grazing to certain types of animals, or protecting trees (Draz, 1969; Sulayem and Joubert; 1994, Llewellyn, 2000)

Traditional rules are used to protect these areas, which are mainly used for grazing. The implementation of these rules differs from one place to another; the common rules are formed by agreement with a fine between 1000 and 10 000 Yemeni Reyal for cutting trees from the protected areas. These protected areas represent the better managed sites of the Yemen, and are normally managed by local communities, village leaders or Sheikhs. Different types of protected areas exist in Yemen called locally *Mahajer* in Arabic (*hima*). This type of protected area can be divided into the following categories (Kessler, 1988a):

- **Temporary protected areas**: located adjacent or around cultivated fields, the main reasons to set up these areas are

a) to protect the crops from grazing

b) to reserve forage for dry season

This type used to be common in the past in different parts of the Hadhramaut region.

- **Permanent protected areas**: located on rocky slopes, and set up for the following reasons:

  a) to harvest rain from the slopes

  c) to be used as personal grazing and firewood collecting

  d) as a result of a dispute about the ownership of areas.

- **Temporary village protected areas**: mountain slopes declared as protected areas for a certain period (mostly rainy season and mainly used for grazing).

Currently the Yemeni government is carrying out biodiversity assessment activities on proposed protected areas. Two of these areas will be declared as protected areas shortly (UNEP, 2004); these area are Jabal Bura' (western mountain area) and Huf, Al Mahara (eastern part of the country). The protected areas will be under the IUCN Category definition II, which aims for the area to be managed mainly for ecosystem protection and recreation (IUCN, 2004**,** Anon, 1994).

3.8. Conservation of plants

Most of the conservation carried out in Yemen is based on traditional protected areas that are mainly made for traditional grazing activities. In these protected areas, conservation of a particular habitat or plant species was not the aim of the preservers.
Over 600 endemic, near-endemic and non-endemic plant species from Yemen have been evaluated recently for conservation status to CITES 1 and 2. (Miller and Al Khulaidi, 2004), but still a lot of work remains to be done in the future to cover the unexplored areas. However, assessments of the endemic plants of the Soqotra Archipelago have been completed in line with the IUCN categories (Miller and Morris, 2004).

The Hadhramaut is an important area of biodiversity, especially the southern plateau which has a considerable number of endemic and near-endemic plant species.

All endemics from the Hadhramaut region must ultimately be included in the IUCN Red Data world list, but to achieve this further studies are required. Examples of endemics and near-endemics species are: *Cucumis canoxyi, Cleome macradenia, Cleome pruinosa, Commicarpus stenocarpus, Commiphora foliacea, Cystostemon kissenioide, Ecbolium strictum, Echidnopsis bentii, Echidnopsis globosa, Echidnopsis seibanica, Echiochilon arabicum, Echiochilon colona, Echiochilon strigosum,, Ephedra milleri, Eragrostis maharana, Eriochloa fatmensis, Eruca sativa, Erucastrum arabicum, Euphorbia applanata, Euphorbia arabica, Euphorbia balsamifera, Euphorbia fodhliana, Euphorbia meuleniana, Euphorbia quaitensis, Euphorbia rubriseminalis, Euphorbia seibanica, Fagonia hadramautica* and others (see Table 3.2). Only a few species from the Hadhramaut are already included in the IUCN Red Data list as Vulnerable (VU); (Miller and Al Khulaidi, 2004; Beier, 2005; Ghazanfar and Al Kiyumi, 1999), these species are *Caralluma adenensis, Echidnopsis bentii, E. seibanica Heliotropium wagneri* and *Fagonia hadramautica.*

3.8.1. National policy on protected areas

Natural protected areas are the in-situ method for the conservation of biological diversity and special entities with unique or endemic or rare flora and fauna. Protected areas offer protection for all the plant species from over-use and degradation and they provide suitable sites for field studies and research on biodiversity and natural resources, and provide suitable sites for training and monitoring environmental change. It is therefore, an ancillary objective of this research to propose clearly defined areas which deserve protected status.

3.8.2. Future Activities

Research activities would ideally be carried out by the Environmental Protection Authority (EPA) and Agricultural research and extension Authority (AREA). Activities are needed to provide data for planning and formulating programs of applied projects, selecting suitable sites for protection as nature reserves and assessing the current status of plants and habitats. This will provide a baseline for monitoring change in the natural environment and should provide information for the evaluation and protection of natural resources.

The research should include the following:

- Inventories and collections of plant species from the southern coastal area to the northern plateau bordering the Empty Quarter.
- Surveys of the biodiversity and natural resources in selected areas
- Mapping of land vegetation, land use and topography of selected areas
- Identification of the vegetation associations and the vegetation structures
- Compilation of a check list of plant species
- Plant taxonomic studies
- Identification and assessment of rare, endemic, near-endemic and endangered species
- Social economic studies related to biodiversity
- Consideration of possible legislative measures to prevent pollution and landscape damage

3.9. Conclusions

Due to the sharp climate gradient from east to west, the changes in the structure and composition of the vegetation E-W (transect 1) are more marked than those from south (coastal plain) to the north (transect 2). Transect 2 extends from Al Rayan on the coastal region east of al Mukalla in the south across the central plateau to Sayun in Wadi Hadhramaut north. The altitude varies from see level south then rises to about 1600 m on the escarpment above al Mukalla and then falls to about 1000 m above sea level in Wadi Hadhramaut in the north. The rainfall along this transect varies from a annual mean of about 69 mm at Al Rayan on the coastal plain in the south to a mean annual less than 75 mm in Sayun in Wadi Hadhramaut in the north. There is no rainfall data from the limestone plateau across the middle part of the transect, nevertheless, the abundance of floods on the wadis running off from the plateaus and the landforms suggests an annual rainfall of more than 200 mm (SOGREAH, 1979). The climate along the first transects decreases from a mean annual rainfall of about 74 mm in the east to an extreme arid climate with a mean annual less than 50 mm in the west. The altitude varies from 670 m above sea level in the east to about 770 m above sea level in the west. Generally species richness and diversity decrease from east to west. In the west the vegetation cover is sparse but moving eastwards it gradually increases until in the far east it is transformed into woodland characterised by *Acacia campoptila* and

Fagonia indica, sparse dwarf shrubland or grassland dominated by *Zygophyllum album* and *Dipterygium glaucum* in the west

Despite similar parent rock and landscape, the plant composition along the second transect differed in both vegetation structure and plant associations. This may be ascribed to difference in moisture availability along the altitudinal gradient from south to north. The floristically richest part of the transect was on the south-facing escarpments and the high ridges above al Mukala. These areas are regularly blanketed in cloud which significantly supplements the moisture available for plant growth. This is a widespread phenomenon across southern Arabia where fogs play an important role in sustaining vegetation. For instance, in the monsoon woodland of Hauf and Dhofar on the Yemen-Oman border and on the low limestone plateau of the Jiddat al Harasis in the deserts of central Oman and Dhufar (Oman) (Ghazanfer, 2004; Kurschner et al.,1998). The vegetation of the drier parts of the transect comprises open shrubland dominated by *Acacia tortilis, A. ehrenbergiana* and *Ziziphus leucodermis* associated with *Prosopis cineraria, Zygophyllum* spp*., Rhazya stricta, Iphiona scabra, Tephrosia apollinea, Panicum turgidum* and *Pulicaria glutinosa*. Similar vegetation has been reported in similar habitats with an annual rainfall of less than 50 mm in the eastern parts of the Oman desert (Ghazanfer, 2004).

Rhazya stricta is a Saharo-Sindian characteristic plant species of the desert dry wadis that have spring and summer rainfall. This species was not seen in the coastal areas of al Mukalla, which is much more humid that the interior and has rainfall mainly in spring rainfall with little in winter. The limit of distribution of this species towards the south seems to be at about 1000 m asl (Figure 3.10). This Sahro-Sindian species is widely distributed from north Jeddah (Saudi Arabia) to the northern part of the United Arab Emirates (Ghazanfar and Fisher, 1998; Western, 1985).

Pulicaria somalensis, Ochradenus arabicus and *Ochradenus baccatus* are other interesting species that show well-defined distributions (Figure 3.10). The first species is widespread between the southern coastal areas to a limit distribution at about 1200 m towards the north; the second is widespread from the foothills of the coastal escarpment to almost the same one point in the north as *P. somalensis*; the third species has a distribution from the eastern part of W. Hadhramaut towards the north. *Pulicaria* *somalensis* is widespread on the stony gravel coastal plains of some Gulf countries (Ghazanfar and Fisher, 1998), while O*chradenus arabicus* is only known from northern Oman, Saudi Arabia united Arab Emirate and the Hadhramaut region.

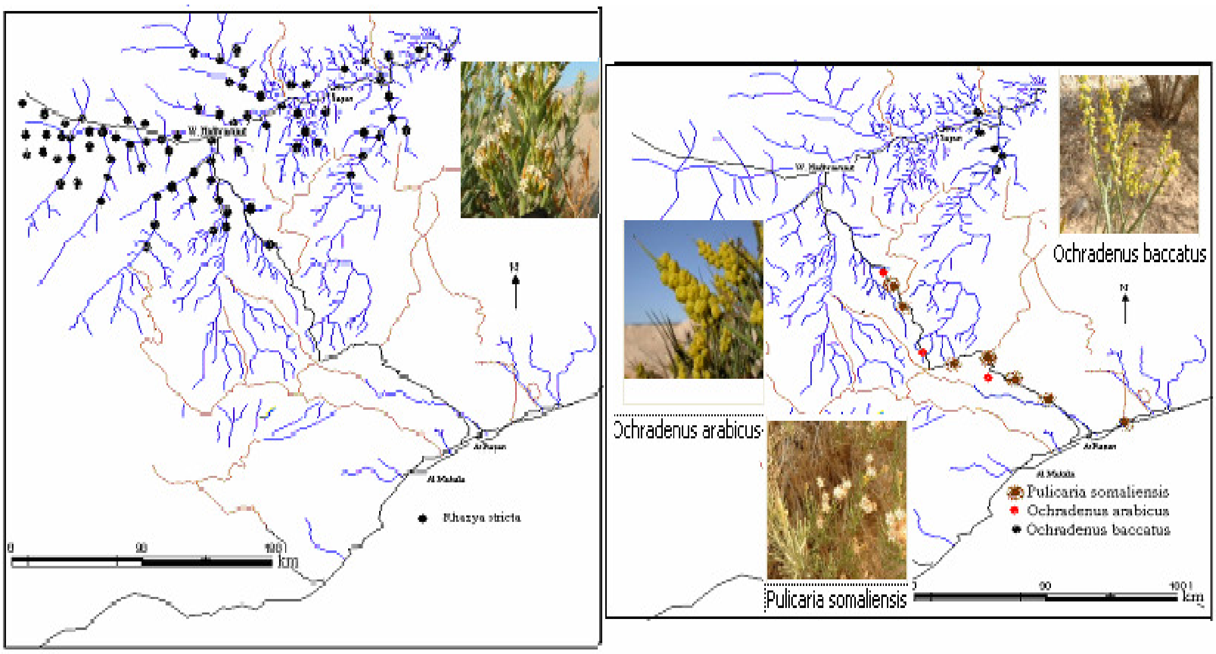


Figure 3.10. Examples of distributions of characteristic plant of the region from the reconnaissance vegetation survey:. *Pulicaria somaliensis, Ochradenus arabicus* and *Ochradenus baccatus* (right*)* and *Rhazya stricta* (left)

Several changes in the appearance of the vegetative with increase in altitude were noticed. In the southern transect, there was a clear succession of plant species from the low coastal area to high elevation sites; only 4 plant species (e.g. *Pulicaria somaliensis, Jatropha spinosa, Fagonia schweinfurthii* and *Indigofera spinosa)* were found at almost all elevations and the plant species of the highest elevation are almost completely distinct from those at the lowest elevation. Examples of high altitude species (over 1150 m) include *Euphorbia balsamifera, Gnidia somalensis* var. *sphaerocephala*, *Ochradenus arabicus, Barleria bispinosa, Barleria proxima, Aloe* sp., *Acacia etbaica, Dodonaea viscose, Dracaena serrulata* and *Ephedra foliata.* Some of these species are restricted to specific landform types, for example *Euphorbia balsamifera* grows only on almost flat limestone plateau summits while others, like *Dracaena serrulata* and *Ephedra foliata,* prefer the rocky slopes above secondary wadis. On the other hand there was no clear succession of plant species from the east towards Ramlat Assaba'tain (transect 1). The following are widespread on this habitat: *Acacia campoptila, Acacia ehrenbergiana, Dipterygium glaucum, Panicum turgidum Tephrosia apollinea* and *Prosopis juliflora.*

Other species are confined to specific landform and altitude. For example, *Aeluropus lagopoides, Halopyrum mucronatum, Odyssea mucronata, Limoniastrum arabicum, Aristolochia rigida* are only seen on the sandy areas along the coast. Whilst *Salvadora persica, Tamarix aphylla, Prosopis cineraria* and *Pluchea dioscoroides* grow are typically found on almost flat wadi beds at moderate altitudes in the study area further north.

The greatest vegetation cover percentage and species richness were observed in the south and south-east facing mountain rocky slopes and drainage lines and also in the north-east and north-west facing transition sites, where species from both high and low altitudes were recorded. Shrubland is the dominant structural form in transect 1; trees percentages were high at the middle altitude (1000-1200 m) of the north-west and north-east facing secondary wadi beds. Generally as in other areas of the world (Hopper and Maslin, 1978), the geographical isolation of this region has played and still is playing an important role in isolating the area and therefore protecting the plant species from human activities.

About 469 plants are found in Hadhramaut region, of which about 23% (107 taxa) are endemic and near-endemic, and many have their origin in the African zone (see Appendix 4). Adaptive radiation and speciation by geographical separation has occurred in many genera and each mountain range in the western escarpment of Arabian Peninsula has its own endemic species (Ghazanfar and Fisher, 1998), the most endemic-rich family in the Hadhramaut region is Apocynaceae (19) , and the genera with most endemics are *Caralluma* (11 taxa), and *Aloe* (9 taxa).

In this Chapter, a general description of the vegetation composition across the Hadhramaut region has been presented. Several changes in vegetative characteristics due to altitude gradients and climate change were noticed. The Hadhramaut region which is not explored very well is very rich in endemics and near-endemics, in particular the southern summit. Further surveys covering the descriptions of soil, land use, moisture content and landform should be carried out in this extraordinary region so that a more accurate assessment can be made of the distribution, abundance and composition of its plants and, in particular, of its rare, endemic and near-endemic species. The distribution maps of some important plant species in Hadhramaut region can be seen in chapter 6.

The data that are presented in this chapter have been valuable in providing a general assessment of the main vegetation types in the Hadhramaut and have supported the selection of sites for further detailed studies. They have also been useful for framing recommendations for future management and conservation activities. The next two chapters will illustrate in detail the biodiversity and the main vegetation associations of the three selected study sites within Wadi Hadhramaut.

Chapter 4. Floristic analysis and plant biodiversity

4. 1. Introduction

Studies on the vegetation of Hadhramaut go back to the last two decades of the nineteenth century (Gabali and Al Gifri, 1991) but the present work is the first systematic survey of the vegetation of the region. As indicated earlier, previous studies concentrated on compiling flora checklists or on general descriptions of the vegetation communities of certain habitats without following any consistent scientific methodology. The study area is still the least known part of the whole of Yemen. It is intended that the present research should form the basis for any future management plan for the region. The aims of this chapter are to answer the following research questions:

- What are the principal plant associations?
- Which sites contain the greatest species diversity?
- What are the principal physical and anthropogenic factors affecting contemporary plant patterns?. The structure of the presentation is illustrated in Figure 4.1.

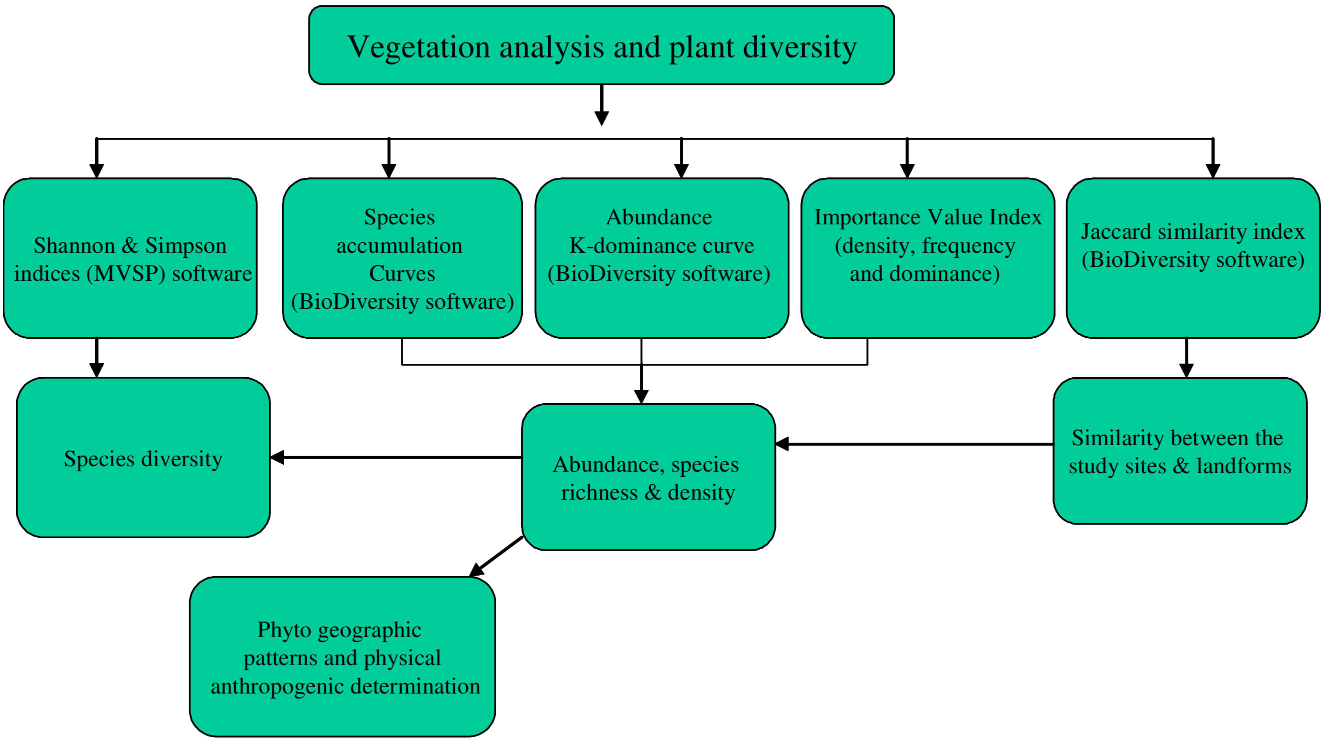


Figure 4.1. Diagram showing the structure of this chapter.

4.2- Methodology

A large number of techniques have been employed to describe and assess the plant associations of an area and to understand plant diversity. The study area (Wadi Hadhramaut) was subdivided into 3 representative study sites for detailed survey and vegetation analysis. This chapter deals with a relation of the most appropriate methods that serve to explain the research questions outlined in the introduction.

Number of individuals per hectare

Number of individuals refers to the density of each species that has been recorded in the sample sites during the vegetation survey. The numbers of individuals in each site were calculated per hectare. This is achieved by dividing the total number of individuals by the total areas surveyed in the different land forms.

Frequency

Frequency is defined as the number of times a plant species is present within a given number of sample quadrats of uniform size placed repeatedly across a stand of vegetation (Mueller-Dombois and Ellenberg 1974; and Daubenmire, 1968). Plant frequency, by itself, is useful for monitoring vegetation changes over time at the same locations or for comparisons of different locations. Frequency was calculated by dividing the number of plots in which a species occurs into the total number of plots sampled.

Plant species diversity

Diversity is a measure of the number of species within a unit area and has been used by different plant ecologists to evaluate plant species in different ecosystems of the world. Diversity has two components: species richness (S), and species evenness (equitability), or how well distributed is abundance among species within a community (Wilsey et al., 2000).

Diversity can be considered as a factor alongside species composition, disturbance, soil type and climate that influences ecosystem functioning (Tilman, 2000). Human activity is obviously reducing the diversity of species within many habitats worldwide, and is speeding up extinction (Tilman, 2000; Vitousek et al., 1997).

Diversity increases when

1- The number of species increases (species richness) or
2- The species abundance become more equal (evenness)

Many species diversity indices have been developed. The most popular diversity index is the Shannon index (Shannon-Wiener index). It is the most widely used diversity index in plant ecology because it includes both species richness and abundance (Krebs, 1999). Richness refers to the number of species present; evenness refers to the distribution of species among different habitats. The Simpson diversity index is another diversity measure used by plant ecologists. Like Shannon’s index, Simpson's index accounts for both abundance and evenness of species. These indices are closely related (Hill, 1973).

The values of the Simpson index are between 0 in a community of one species, to 7 in a more diverse community (Kutiel et al., 2000). The more the area is dominated by one of the components, the closer the value is to 1. The Simpson’s index is more sensitive to more abundant species and less sensitive to species richness and therefore weighs abundant species more than rare species (Gage, 2002). The Shannon index takes into consideration the relative contribution of all species. The more the abundance is equitably distributed among species, the higher the value of diversity (Kutiel et al., 2000). The total number of individuals and both the Shannon and Simpson indices were used to illustrate the plant diversity of the study sites. The plant diversity of the study sites over different landforms was calculated using the Shannon index (Table 4.11 and Figure 4.9a). This plot provides a measure of species diversity, allowing comparison between the different habitats. Since each surveyed habitat has a different area, individuals were standardised per hectare (Koellner et al., 2004).

Percentage cumulative abundance was plotted against log species rank, using BioDiversity Professional Beta (McAleece, 1997), It was also used for comparing diversity between the 3 study sites (Figures 4.7) and between the different landforms (Figure 4.9).

Abundance and density

Numbers of individuals and frequency were recorded. Further, importance value indices (IVI) of each plant species were calculated in all study sites by summing the relative density value, the relative dominance value, and the relative frequency value.

Importance Value and Species Richness

Importance values refer to how important a species is in terms of the structure of a community or species composition. To determine the importance of each species sampled, the importance value index (IVI) of each plant species was calculated in all study sites by summing the relative density value, the relative dominance value, and the relative frequency value (Mahdi & Al Khulaidi, 1999; Nautiyal et al., 2003) (see Table 4.6). Importance value curves were obtained using BioDiversity software by plotting abundance against species rank for the three study sites (Figure 4.6) and for the different landforms (Figure 4.5).

These values are expressed in an absolute form and as relative density, relative dominance, and relative frequency, which shows the percentage of an individual species with respect to the total species. These values are calculated by the following equations:-

- Absolute density = Number of individuals of a species per hectare
- Relative density = Density (number of individuals) of a species/ total density for all species x 100
- Absolute dominance = Total basal cover of a species per hectare
- Relative dominance = Dominance for a species/ total dominance for all species x 100

- Absolute Frequency = Number of sample sites in which a species occurs/ total number of sample sites

- Relative Frequency = Frequency value for a species/ total of frequency values for all species x 100

- Importance Value Index (IVI) = relative density + relative dominance + relative frequency

Species richness was determined as the total number of species distinguished at each habitat. The number of individuals was determined at each sample site, and then the numbers were averaged and weighed per hectare.

Species accumulation curves

This is a method for determining whether the sampling is sufficient to have collected all the plant species from a region or for comparing species richness between different communities (Moreno and Halffer, 2000; Willott, 2001).
The expected species richness in each study area was estimated by species accumulation curves. The analysis used software developed by the BioDiversity Professional Beta (McAleece, 1997). Species richness, diversity and the proportion of rare species in a community influenced the shape of species accumulation curves (Thompson, et al., 2003).
Species accumulation curves can provide three basic pieces of information:
1) How many species there are,
2) How species are distributed,
3) How adequately the habitat was sampled.

The level at which a curve levels off indicates the number of species in the habitat. The rate at which the curve begins to level off indicates how species are distributed. For example, if a curve rises quickly and levels off it means that most of the species are found in just the first few sampling plots. The curve for species versus the number of sample sites was plotted for each site and for each land form in the 3 study sites in order to calculate the minimum number of samples that should be taken to be truly representative of the habitats in the study area.

Similarity between study sites

Data of presence and absence using the BioDiversity Program software was analysed by the Jaccard distance similarity index in order to assess the similarity between the 3 study sites and between the different habitats within these areas. According to Chao et al., (2005), the Jaccard distance measure gives reasonable similarity clusters result if presence/absence data are used.

4.3. Results

4.3.1. Flora

A total of 134 species belonging to 42 families (about 30% of flora of Hadhramaut region) were recorded in the study area and, of these, seven species are endemic to Yemen (five of them endemic to Hadhramaut region).

A total of 117 plant species were collected in the whole sample plots of which 4 have not yet been identified. There are 74 species in site 1, 83 species in site 2 and 61 species in site 3, with 39 plant species recorded in all 3 study sites. The areas surveyed was estimated as 0.46 ha, 0.53 ha and 0.34 ha respectively, which correspond to 46, 53 and 34 X 100 m² sample plots.

Two voucher specimens were collected from each plant species, one set is deposited in the herbarium of Royal Botanic Garden of Edinburgh, UK (E) and the other is deposited in the herbarium of the Agricultural Research and Extension Authority (AREA), regional station, Taiz, Yemen.

The species records from the study area were classified using both Braun-Blanquet and Twinspan into: (1) groups that show a similar distribution across the sample plots, these were termed <u>sociological species groups</u> and (2) into groups of sample plots with a large similarity termed <u>vegetation associations</u> (see chapter 5).

The following plant species were considered rare, because they were only recorded once: *Cadaba heterotricha, Cadaba farinosa, Aerva artemisioides, Euphorbia rubriseminalis, Glossonema varians, Trichodesma calathiforme, Salvadora persica,* *Leptadenia arborea, Withania somnifera,* and *Portulaca oleracea*. All species were found in site 2 except the endemic *Aerva artemisioides,* which was only found in site 3. However this species was recorded by DOVE (2001) on the plateau at site 2. The last three species are weedy species and are found in large quantities in wetter areas, especially in or near cultivated and fallow lands.

The largest families in terms of species in the study sites are:

- Poaceae (Gramineae) with 13 species
- Fabaceae with 12 species
- Zygophyllaceae with 11 species
- Capparaceae with 9 species
- Mimosaceae with 8 species
- Asteraceae with 7 species

Poaceae (Gramineae) is the family with highest number of individuals; 17 families were recorded with one single species (Table 4.1).

Table 4.1. List of families and number of species in alphabetical order of families for the 3 study sites

	Family	*Scientific name*		Area
	Acanthaceae (3)	*1.*	*Barleria aff. bispinosa* (Forssk.)Vahl.	1,2,3
		2.	*Blepharis edulis* Forssk.	1,2,3
		3.	***Peristrophe paniculata*** (Forssk.)Brummitt	3"
	Amaranthaceae (2)	*4.*	*Aerva artemisioides* Vierh. & Schwartz *subsp. artemisioides.* *	3
		5.	*Aerva javanica* (Borm.f.)Juss. ex Schult.	1,2,3
	Apocynaceae (5)	*6.*	*Calotropis procera* (Ait.)Ait.f.	1,2
		7.	*Glossonema varians* (Stocks)Benth. ex Hook.	3
		8.	*Leptadenia arborea (*Forssk.)Schweinf.	2
		9.	*Rhazya stricta* Decne	1,2,3
		10.	***Periploca visciformis*** (Vatke)K.Schum.	**2"**
	Arecaceae (Palmae) (1)	*11.*	*Phoenix dactylifera* L.	1,2,3
	Asteraceae (Compositae) (7)	*12.*	*Helichrysum pumilum* (Klatt.)Moes.	2
		13.	*Hochstetteri schimperi* DC.	2
		14.	*Iphiona anthemidifolia (*Bak.)A.Anderb. *	1
		15.	*Iphiona scabra* DC.	1
		16.	*Launaea sp.*	2
		17.	*Pluchea dioscorides* (L.)DC.	2
		18.	*Pulicaria undulata* (L.)C.A.Mey.	2
	Balanitaceae (1)	*19.*	***Balanites aegyptiaca*** Del.	2"
	Boraginaceae (5)	*20.*	*Arnebia hispidissima* (Lehm.)DC.	2
		21.	*Heliotropium ramosissimum* (Lehm.)Sieb. ex DC.	1,2,3
		22.	***Heliotropium longiflorum*** Steud. & Hochst. ex Bunge	**3"**
		23.	*Heliotropium rariflorum* Stocks	1,3
		24.	*Moltkiopsis ciliata (*Forssk.)I.M.Johnston.	1
		25.	*Trichodesma calathiforme* Hochst.	2
	Brassicaceae (Cruciferae) (3)	*26.*	***Erucastrum arabicum*** Fisch. & Mey.	1"
		27.	*Farsetia linearis* Dene	1,2,3
		28.	***Farsetia longisiliqua*** Decne**.**	**3"**
	Burseraceae (2)	*29.*	*Commiphora foliacea* Sprague. ***	1,2,3
		30.	*Commiphora kua* (J.F.Royale) Vollesen .	2,3
	Caesalpiniaceae (3)	*31.*	*Cassia senna* L.	3
		32.	*Senna holosericea* (Fres.)Greuter	1
		33.	*Senna italica* Miller	1,2,3
	Capparaceae (6)	*34.*	*Cadaba heterotricha* Stocks ex Hook.	2
		35.	*Cadaba farinosa* Forssk.	2
		36.	*Capparis cartilaginea* Decne.	1,2
		37.	*Capparis spinosa* L.	1,.2
		38.	*Dipterygium glaucum* Decne.	1,2,3
		39.	*Maerua crassifolia* Forssk.	1.2.3
	Caryophyllaceae (1)	*40.*	*Cometes abyssinica* (R.Br.) Wallich.	1,2
	Chenopodiaceae (3)	*41.*	*Cornulaca amblyacantha* Bunge.	2,3
		42.	*Halothamnus bottae* Jaub. & Spach	1,2,3
		43.	*Salsola imbricata* Forssk.	2
	Cleomaceae (3)	44.	*Cleome brachycarpa* Vahl. ex DC.	1,2,3
		45.	*Cleome droserifolia* Del.	1,2,3
		46.	*Cleome scaposa* DC.	1,2,3
	Convolvulaceae (5)	*47.*	*Convolvulus arvensis* L.	1
		48.	*Convolvulus glomeratus* Choisy	2,3

Table 4.1. Continue

		49.	*Cressa cretica* L.	1
		50.	*Merremia hadramautica* Hall.f. *	1,2,3
		51.	*Seddera latifolia* Hochst. & Steud.	2
	Cucurbitaceae (3)	*52.*	*Corallocarpus glomeruliflorus* Schweinf.	2,3
		53.	*Citrullus colocynthis* (L.)Schrad.	1,2
		54.	***Cucumis canoxyi*** Thulin & Gifri. *	**2”**
	Cuscutaceae (Convolvulaceae) (1)	*55.*	***Cuscuta campestris*** Yunker.	**3”**
	Cyperaceae (1)	*56.*	*Cyperus conglomeratus* Rottb.	2,3
	Euphorbiaceae (4)	*57.*	*Chrozophora tinctoria* A.Jjuss.	1,2,3
		58.	*Euphorbia granulata* Forssk.	1
		59.	*Euphorbia rubriseminalis* S.Carter. **	2
		60.	*Jatropha spinosa* (Forssk.)Vahl	2,3,
	Fabaceae (Papilionoideae) (12)	*61.*	*Alhagi graecorum* Boiss.	1
		62.	*Crotalaria persica* (Burm.f.)Merr	1,2
		63.	*Crotalaria saltiana* Andr.	1,3
		64.	*Indigofera oblongifolia* Forssk.	3
		65.	*Indigofera spinosa* Forssk.	1,2,3
		66.	*Indigofera spiniflora* Hochst. & Steud. ex Boiss.	2
		67.	***Medicago sativa*** L.	**1,2,3”**
		68.	*Rhynchosia memnonia* (Del.)DC.	2,3
		69.	*Tephrosia apollinea* (Del.)DC. subsp. *longistipulata*	1,2,3
		70.	*Tephrosia dura* Baker	1,3
		71.	*Tephrosia nubica* (Boiss.)Baker *subsp. arabica* (Boiss.)Gillett	1,3
		72.	***Tephrosia subtriflora*** Hochst. ex Baker.	3
	Loranthaceae (1)	*73.*	*Plicosepalus curviflorus* (Benth. ex Oliv.)Tiegh.	1,2
	Malvaceae (4)	*74.*	*Abutilon bidentatum* Hochst. ex A.Rich	2
		75.	***Abutilon fruticosum*** Guill. & Perr.	2”
		76.	***Abutilon pannosum*** (Forrsk.) Schlechl.	2”
		77.	*Senra incana* (Cav.)DC.	1,2
	Mimosacea (8)	*78.*	*Acacia campoptila* Schweinf. **	1,2,3
		79.	*Acacia ehrenbergiana* Hayne.	1,2,3
		80.	*Acacia hamulosa* Benth.	1,2,3
		81.	*Acacia mellifera* (Vahl)Benth.	1,2,3
		82.	*Acacia oerfota* (Forssk.)Schweinf	1,2
		83.	*Prosopis cineraria* (L.)Druce	**1,2”**
		84.	*Prosopis farcta* (Banks. & Sol.)Mc Bride.	1
		85.	*Prosopis juliflora* (Sw..)DC.	1
	Moraceae (1)	*86.*	***Ficus cordata*** L subsp. ***salicifolia***	**2”**
	Moringaceae (1)	*87.*	***Moringa peregrina*** (Forssk.)Fiori	**1”**
	Nyctaginaceae (1)	*88.*	*Boerhavia elegans* Choisy subsp. *elegans.* ***	1,2,3
	Pedaliaceae (1)	*89.*	***Sesamum indicum*** L.	**1,2,3”**

Table 4.1. Continue

	Poaceae (Gramineae) (13)	*90.*	*Aristida triticoides* Henrard.	1,2,3
		91.	*Chloris barbata* Sw.	1
		92.	*Chrysopogon aucheri* (Boiss.)Stapf var. *quinqueplumis*	2,3
		93.	*Cymbopogon schoenanthus* (L.) Spreng subsp. *schoenanthus*	1,2,3
		94.	*Cynodon dactylon* (L.)Pers.	1,2
		95.	***Dactyloctenium aegyptium*** **(L.)P.Willd.**	**3”**
		96.	*Dichanthium insculptum* (A.Rich.)Clayton	1,2,3
		97.	*Enneapogon desvauxii* J.E.Smith	1,2,3
		98.	*Eragrostis sp.*	2,3
		99.	*Lasiurus scindicus* Henrard	1,3
		100.	*Panicum turgidum* Forssk.	1,3
		101.	*Setaria verticillata* (L.)P. Beauv.	1
		102.	*Stipagrostis hirtigluma* (Steud. ex Trin. & Rupr.)De Winter	1,2,3
28	Portulacaceae (1)	*103.*	*Portulaca oleracea* L.	2
	Ranunculaceae (1)	*104.*	***Nigella sativa*** **L.**	**3”**
	Resedaceae (2)	*105.*	*Ochradenus baccatus* Del.	2,3
		106.	*Reseda sphenocleoides* Defl. ***	1
31	Rhamnaceae (3)	*107.*	*Ziziphus leucodermis* (E.G.Baker) Schwartz ***	1,2,3
		108.	*Ziziphus spina-christi* (L.)Willd.	1,2,3
	Rubiaceae (2)	*109.*	*Kohautia retrorsa* (Boiss.)Bremek.	1,2,3
		110.	*Tarenna graveolens* (S.Moore)Bremek. subsp. *arabica*	2
	Salvadoraceae (1)	*111.*	*Salvadora persica* L.	2
	Scrophulariaceae (3)	*112.*	*Anticharis glandulosa* (Ehrenb. & Hempr.)Aschers.	2,3
		113.	*Lindenbergia indica* (L.)Kuntze	1
		114.	***Striga asiatica*** (L.)Kuntze	3”
	Solanaceae (2)	*115.*	*Datura innoxia* Mill.	1
		116.	*Withania somnifera* (L.)Dun	1
	Sterculiaceae (1)	*117.*	*Hermannia paniculata* Franch.	3
	Tamaricaceae (2)	*118.*	*Tamarix aphylla* (L.)Karst.	1,2
		119.	*Tamarix arabica* Bunge	2
	Tiliaceae (2)	*120.*	*Corchorus depressus* (L.)Christ	1,2,3
		121.	*Grewia erythraea* Schweinf.	2
	Urticaceae (1)	*122.*	*Forskohlea tenacissima* L.	1
	Verbenaceae (1)	*123.*	*Chascanum marrubifolium* Fenzl ex Walp.	2
	Zygophyllaceae (11)	*124.*	***Fagonia bruguieri*** DC.	**1”**
		125.	***Fagonia hadramautica*** Beier & Thulin *	**2”**
		126.	*Fagonia indica* Burm.f.	1,2,3
		127.	*Fagonia paulayana* Wagner & Vierh.	1,2,3
		128.	*Seetzenia lanata* (Willd.) Bullock	1,2
		129.	*Tribulus arabicus* H.Hosnlined.	1,2,3
		130.	***Tribulus terrestris*** L.	**2 ”**
		131.	*Zygophyllum album* L. var. *amblyocarpum*	1
		132.	*Zygophyllum coccineum* L.	1,3
		133.	*Zygophyllum decumbens* Del .	2
		134.	*Zygophyllum simplex* L.	1,2

key:

bold Species found outside of the sample sites
* Endemic to Hadhramaut
** Endemic to Yemen
*** Endemic to Arabian Peninsula

A total of 134 species belonging to 42 families (about 30% of the known flora of Hadhramaut region) were recorded in the study area. A total of 117 plant species were recorded in the 3 sites of the study area, of which 5 are endemic to Hadhramaut. The density and the distribution of these species were different from one study site to another, as well as from one landform to another.

The following endemic taxa for the Hadhramaut were found in the study sites: *Aerva artemisioides* subsp *artemisioides, Iphiona anthemidifolia, Cucumis canoxyi, Merremia hadramautica* and *Fagonia hadramautica.*

Observations outside the cross sections but within the study sites revealed the following 22 plant species: -

1. *Abutilon fruticosum*
2. *Abutilon pannosum*
3. *Balanites aegyptiaca*
4. *Cucumis canoxyi* *
5. *Cuscuta campestris*
6. *Dactyloctenium aegyptium*
7. *Erucastrum arabicum*
8. *Fagonia bruguieri*
9. *Fagonia hadramautica* *
10. *Farsetia longisiliqua*
11. *Ficus cordata L subsp. salicifolia*
12. *Heliotropium longiflorum*
13. *Medicago sativa*
14. *Moringa peregrina*
15. *Nigella sativa*
16. *Periploca visciformis*
17. *Peristrophe paniculata*
18. *Prosopis cineraria*
19. *Sesamum indicum*
20. *Striga asiatica*
21. *Tephrosia subtriflora*
22. *Tribulus terrestris*

*= taxa endemic to the Hadhramaut.

Most of these species are weeds found near or in the cultivation. Two of the species (*Medicago sativa* and *Nigella sativa)* are cultivated by local people.

The species *Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus, Dichanthium insculptum* and *Boerhavia elegans* subsp. *elegans,* occur throughout the entire area, in particular on the mountain slopes facing the main wadis, the plateaus and their slopes and the secondary wadis, while *Acacia campoptila*, *Panicum turgidum,* *Aerva javanica, Indigofera spinosa, Fagonia indica, Ochradenus baccatus, Dipterygium glaucum* and *Rhazya stricta* are widespread species of wadi beds.

Phytogeography attempts to divide the globe into natural floristic units (Miller and Cope, 1996). According to Zohary (1973), the Hadhramaut region falls within Saharo-Arabian (covering the northern part) and Nubo-Sindian province of Sudanian-region (covering the southern part). Most of the Sahro-Arabian elements are found in the main wadis, while most of the Sudanian-region elements are found on the plateau. The northern limit of the Sudanian-region in the Hadhramaut region can be drawn with latitude ranging from 15° 22' in Wadi Daua'n west to 15°35' in Wadi Sah east but considerable numbers of African are found further north between 15° 49' to 15° 50' on the plateau of site 2 (see Figure 7.1).

About 28% (42) of species recorded from the SW of the Egyptian desert (Shede, 2002) are found in the study area and most of them are Saharo-Sindian + Saharo-Zambezian (White, 1983). Among the Saharo-Sindian elements in the study area that extends to Egypt, Palestine, Arabia, southern Iraq and south western Syria and Iran (Zohary, 1973) are:-

Panicum turgidum, Aerva javanica. Phoenix dactylifera, Capparis cartilaginea, Cassia italica, Forskohlea tenacissima, Dipterygium glaucum, Leptadenia arborea, Periploca visciformis, Rhazya stricta, Fagonia indica, F. paulayana, F. bruguieri, Tribulus arabicus, Withania somnifera, Zygophyllum simplex, Z. album, Z decumbens, Z. coccineum, Lasiurus scindicus, Cyperus conglomeratus, Cymbopogon schoenanthus, Blepharis edulis, Pulicaria undulata, Heliotropium rariflorum, Chrozophora oblongifolia. These species are well represented in the main wadis.

The Sudanian element is concentrated on the plateau. According to Zohary (1973), this element is confined partly to families and genera that are absent elsewhere in the Asian part of the Middle East. The Sudanian elements in the study area can be as a result of immigration; this may have happened in the period about 4,000 to 8,000 years ago when Sudanian plants started penetrating to the deserts of Palestine and Israel (Shmida and Aronson, 1986). Examples are *Acacia mellifera, A. hamulosa, A. ehrenbergiana Calotropis procera, Salvadora persica, Tamarix aphylla, Tephrosia* *apollinea, Calotropis procera, Capparis spinosa, Ziziphus leucodermis, Ziziphus spina-christi, Moringa peregrina,* and *Ochradenus baccatus.*

The following are endemic or near-endemic species recorded in the study sites: *Acacia campoptila, Boerhavia elegans* subsp. *elegans, Aerva artemisioides* subsp *artemisioides, Euphorbia rubriseminalis, Farsetia linearis, Iphiona anthemidifolia, Reseda sphenocleoides, Ziziphus leucodermis.*, *Merremia hadramautica, Cucumis canoxyi* and *Fagonia hadramautica*; the last two species are found only on the plateau of site 2.

Other elements are the Central American and Caribbean native species, such as the exotic *Prosopis juliflora,* or the Hadhramaut-Somalia connection such as *Tephrosia dura* and a Hadhramaut-Dhofar (Oman) connection such as *Ziziphus leucodermis* and *Reseda sphenocleoides.*

4.3.2. Number of individuals per hectare

Site	1						2					3				
Landform	w	f	ms	pla	wp	sp	w	ms	pla	wp	sp	w	ms	pla	wp	sp
Acacia campoptila	186	0	23	0	20	0	400	20	0	33	0	217	0	0	0	0
Aristida triticoides	7	0	115	33	0	100	14	0	0	1033	238	50	50	0	0	0
Blepharis edulis	7	0	8	0	0	0	1307	0	0	0	48	633	0	0	0	0
Boerhavia elegans	36	0	154	333	80	100	57	20	0	33	62	75	150	0	250	100
Dichanthium insculptum	79	0	138	417	360	50	0	200	0	433	743	50	80	0	800	957
Fagonia indica	171	67	200	200	0	0	250	0	0	83	19	342	0	0	0	0
Farsetia linearis	7	0	115	350	80	0	0	60	25	267	214	0	30	0	0	14
Indigofera spinosa	14	0	0	0	0	0	393	60	0	0	271	608	0	0	0	0
Stipagrostis hirtigluma	0	0	215	1433	120	250	129	140	250	350	376	0	640	100	1500	571
Tephrosia apollinea	836	33	192	0	60	71	300	0	33	14	71	92	200	0	0	0
No of sample plots	14	6	13	6	5	2	14	5	4	6	21	12	10	3	2	7

Table 4.2. Number of individuals per hectare for the most dominant species over the different landforms. w= main wadi, f= field or fallow lands, ms= slope facing main wadis, pla= plateau, wp= secondary wadi, sp= slope on plateau.

The species *Stipagrostis hirtigluma* and *Dichanthium insculptum* are well represented in the 3 study sites, particularly on plateaus and mountain slopes facing the main wadis (Table 4.2). *Aristida triticoides, Blepharis edulis, Dichanthium insculptum, Farsetia linearis* and *Indigofera spinosa* are well represented in site 2, with *Stipagrostis hirtigluma* in site 3 and *Boerhavia elegans* and *Tephrosia apollinea* in site 1. *Acacia campoptila, Tephrosia apollinea, Fagonia indica, Indigofera spinosa* and *Blepharis edulis* are highly represented on wadi beds while *Dichanthium insculptum* and *Stipagrostis hirtigluma* are well represented on the slopes of plateaus. Table 4.3 shows number of individuals per hectare of each plant species in the 3 study sites:-

Table 4.3. Number of individuals per hectare (density) of each species in the three study sites.

	Site				Site		
Plant species	**1**	**2**	**3**	**Plant species**	**1**	**2**	**3**
Abutilon bidentatum	0	4	0	*Grewia erythraea*	0	15	0
Acacia campoptila	65	115	70	*Halothamnus bottae*	2	9	32
Acacia ehrenbergiana	33	17	3	*Helichrysum pumilum*	0	25	0
Acacia hamulosa	26	6	3	*Heliotropium ramosissimum*	11	49	22
Acacia mellifera	11	8	3	*Hermannia paniculata*	0	0	11
Acacia oerfota	11	9	0	*Hochstetteri schimperi*	0	25	0
Aerva artemisioides	0	0	3	*Indigofera oblongifolia*	0	0	5
Aerva javanica	63	19	41	*Indigofera spinifolia*	0	38	0
Compositae aff Flaveria	0	8	0	*Indigofera spinosa*	4	217	197
Heliotropium rariflorum	13	0	3	*Iphiona anthemidifolia*	2	0	0
Alhagi graecorum	85	0	0	*Iphiona scabra*	33	9	16
Anticharis glandulosa	0	4	5	*Jatropha spinosa*	0	55	30
Aristida triticoides	43	215	43	*Kohautia retrorsa*	22	21	43
Arnebia hispidissima	0	6	0	*Launaea sp.*	0	4	0
Barleria aff bispinosa	11	36	5	*Leptadenia arborea*	0	2	0
Blepharis edulis	4	364	205	*Lindenbergia indica*	4	0	0
Boerhavia elegans	111	45	97	*Maerua crassifolia*	2	21	5
Cadaba farinosa	0	2	0	*Merremia hadramautica*	2	30	105
Cadaba heterotricha	0	2	0	*Moltkiopsis ciliata*	4	0	0
Calotropis procera	13	8	0	*Ochradenus baccatus*	0	36	5
Capparis cartilaginea	7	2	0	*Panicum turgidum*	7	0	89
Capparis spinosa	9	2	0	*Peristrophe paniculata*	0	0	3
Cassia senna	4	0	0	*Phoenix dactylifera*	41	0	0
Chascanum marrubifolium	0	6	0	*Plicosepalus curviflorus*	4	9	0
Chloris barbata	30	0	0	*Pluchea dioscorides*	0	4	0
Chrozophora tinctoria	39	23	3	*Portulaca oleracea*	0	2	0
Chrysopogon aucheri	0	43	8	*Prosopis farcta*	72	0	0
Citrullus colocynthis	7	4	0	*Prosopis juliflora*	15	0	0
Cleome brachycarpa	48	17	46	*Pulicaria undulata.*	0	23	0
Cleome droserifolia	11	8	14	*Reseda sphenocleoides*	9	0	0
Cleome scaposa	4	32	165	*Rhazya stricta*	9	30	59
Cometes abyssinica	7	4	0	*Rhynchosia memnonia*	0	2	8
Commiphora foliacea	9	30	3	*Salsola imbricata*	0	17	0
Commiphora kua	0	21	5	*Salvadora persica*	0	2	0
Convolvulus arvensis	4	0	0	*Seddera latifolia*	0	6	0
Convolvulus glomeratus	0	11	3	*Seetzenia lanata*	15	2	0
Corallocarpus glomeruliflorus	0	8	14	*Senna holosericea*	0	28	16
Corchorus depressus	13	9	5	*Senna italica*	20	21	51
Cornulaca amblyacantha	0	15	16	*Senra incana*	57	2	0
Cressa cretica	28	0	0	*Setaria verticillata*	39	0	0
Crotalaria persica	7	32	0	*Stipagrostis hirtigluma*	272	255	370
Crotalaria saltiana	2	0	27	*Striga asiatica*	0	0	3
Cymbopogon schoenanthus	87	17	27	*Tamarix aphylla*	4	6	0
Cynodon dactylon	65	2	0	*Tamarix arabica.*	0	8	0
Cyperus conglomeratus	0	9	5	*Tarenna graveolens*	0	9	0
Datura innoxia	2	0	0	*Tephrosia apollinea*	320	45	114
Dichanthium insculptum	159	362	262	*Tephrosia dura*	107	0	3
Dipterygium glaucum	20	8	8	*Tephrosia nubica*	9	0	332
Enneapogon desvauxii	24	4	165	*Tephrosia subtriflora*	0	0	8
Eragrostis sp.	0	8	8	*Tribulus arabicus*	2	26	30
Erucastrum arabicum	65	0	0	*Trichodesma calathiforme*	0	2	0
Euphorbia granulata	4	0	0	*Withania somnifera*	2	0	0
Euphorbia rubriseminalis	0	2	0	*Ziziphus leucodermis*	2	6	14
Fagonia indica	143	83	138	*Ziziphus spina-christi*	13	2	5
Fagonia paulayana	28	9	124	*Zygophyllum album*	170	0	0
Farsetia linearis	89	123	11	*Zygophyllum* coccineum	65	0	5
Forskohlea tenacissima	7	0	0	*Zygophyllum decumbens*	0	115	0
Glossonema varians	0	0	3	*Zygophyllum simplex*	22	0	0

The number of individuals per hectare (Table 4.3) is calculated by dividing the total number of individuals into the total areas for each site as surveyed over the different landforms. 38 plant species are common to all 3 study sites. Variations in number can also be observed. Some species occur at high numbers in one site and at low numbers or are absent in other sites. *Stipagrostis hirtigluma* and *Dichanthium insculptum* are common in the 3 sites while *Blepharis edulis and Indigofera spinosa* are common in site 2 and 3 especially on wadi beds (Figure 4.2). Compared to sites 1 and 2, *Cleome scaposa*, *Enneapogon desvauxii, Fagonia paulayana*, *Tephrosia nubica* and *Merremia hadramautica* are common in site 3.

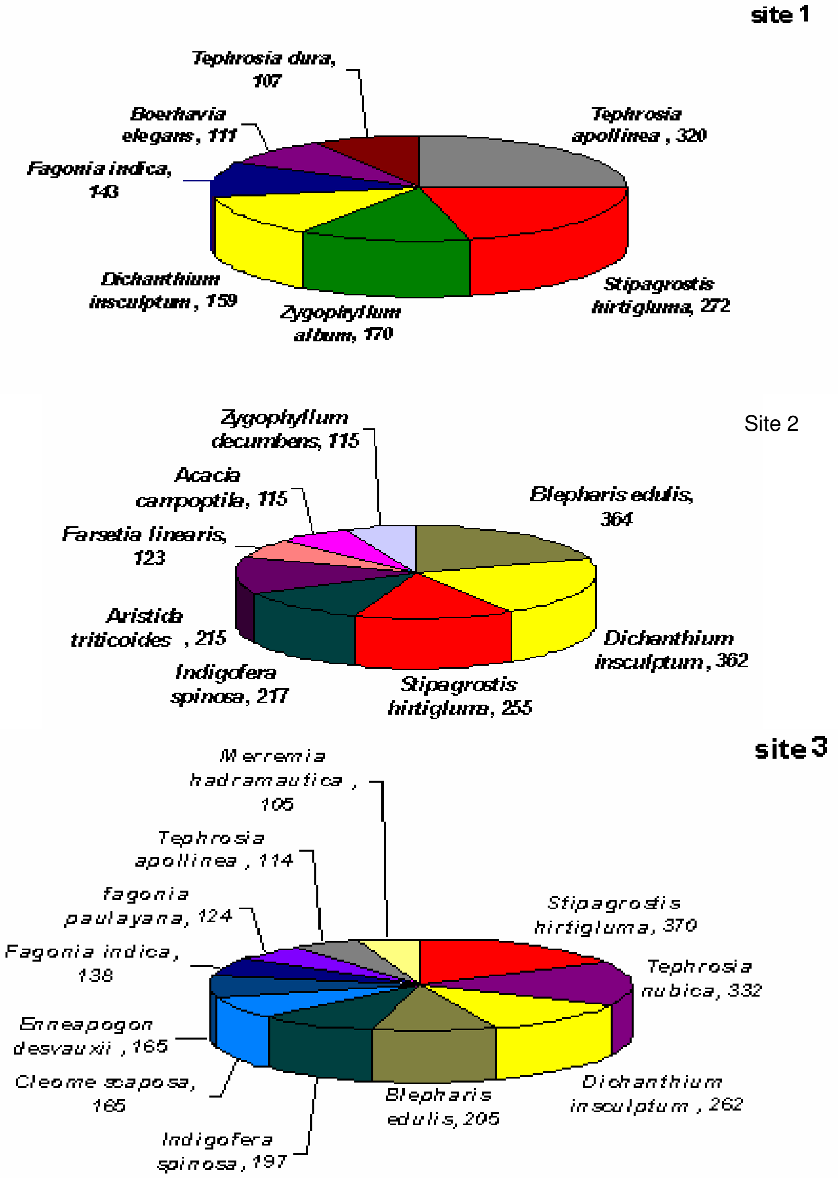


Figure 4.2. Number of individuals per hectare for the most dominant species across the 3 study sites.

Variations in number of individuals are observed in the three study sites. Also some species occur at high numbers in one landform and at low numbers or are absent in other landforms. For example, the number of individuals of *Acacia campoptila, Acacia ehrenbergiana and Tephrosia apollinea* were high in relatively flat wadi beds and favourable moisture sites, while *Dichanthium insculptum* was high on the slopes of the rocky slopes of the plateau. Also, the low density of *Enneapogon desvauxii, Merremia hadramautica, Stipagrostis hirtigluma* and *Rhazya stricta* in sites 1 and 2 may be due to high human activities in these sites. Plant density is affected not only by the availability of the main limiting factors, namely water and minerals, but is also determined by the species composition of the annual vegetation (Kigel, et al., 2004).

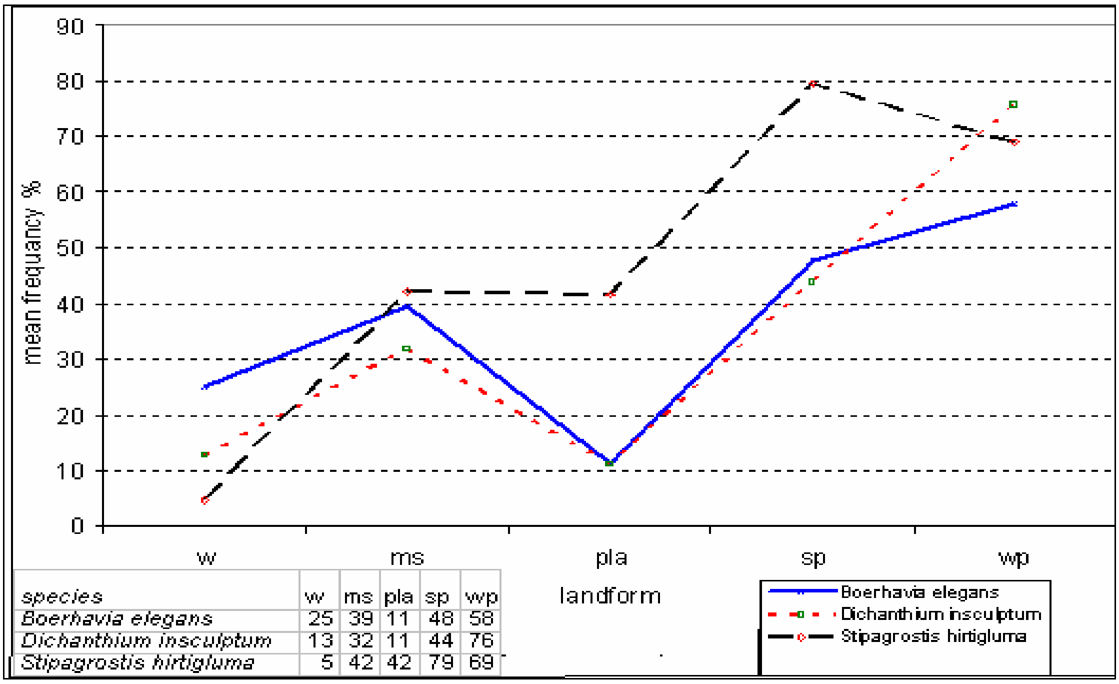
Variation in the density of plant species is observed during the field work; this can be due to timing of rainfall distribution or over-grazing. For example the density of *Blepharis edulis, Boerhavia elegans, Tephrosia apollinea* and *Tribulus arabicus* was high after the rain or flooding and the high density of *Boerhavia elegans* in site 1 can be due to low grazing pressure. Generally, many factors such as climatic conditions, grazing and topographic conditions have determined the density of the plant species and total seed bank under the soil surface. The long-term study of the effect of climate change and human activities such as grazing on the plant density and on the seed bank changes is needed. This can lead to better understanding of the dynamics of the seed bank and of the density of plant species. (For more see chapter 7)

4.3.3. Frequency and Importance values:

Table 4.4 shows the frequency of each plant species in the different ecological zones across the 3 study sites.

The number of individuals per hectare (density) explains how many plants there are in a unit of area but cannot tell us about how these plants are distributed; to know that, the frequency of each plant species per hectare was calculated (Table 4.4).

Variations in abundance can also be observed. Some species occur at high frequencies in one landform and at low frequencies or absent in other landforms. For many of them, differences in mean abundance were obvious.



species	w	ms	pla	sp	wp
Boerhavia elegans	25	39	11	48	58
Dichanthium insculptum	13	32	11	44	76
Stipagrostis hirtigluma	5	42	42	79	69

Figure 4.3. The mean frequency in each landform for the three most abundant species in the study sites. Variations in abundance can be observed. The frequency was high for *Stipagrostis hirtigluma* (79%) on the slope of the plateaus (sp) and for *Dichanthium insculptum* (76%) and *Boerhavia elegans* (58%) in the secondary wadis of the plateaus (wp).

Acacia campoptila was one of the most abundant species recorded in the wadis, where it had a mean frequency of 81%, but it occurred at less than 20% on the mountain slopes facing the main wadis and on the secondary wadis of the plateaus. The frequency of this species was the highest in site 3. Studies conducted in two tributary wadis in Hadhramaut by Bataher (2004), found that the frequency of *Acacia campoptila* was the highest. Other important species of the wadis are *Fagonia indica* with mean frequency of 67%, and *Tephrosia apollinea* with mean frequency of 46%.

Stipagrostis hirtigluma, Dichanthium insculptum and *Boerhavia elegans* were widespread species, with a considerable variation in abundance from one landform to another. The mean frequency of these three species significantly increased from the main wadis to the adjacent slopes, then decreased on the plateaus and increased again to reach a peak over the slope of the plateaus in the case of the first species, and at the secondary wadis of the plateaus in the case of the last two species (see Figure 4.3). The low frequency of these species on the main wadis and adjacent slopes can be due to overgrazing by herders from local areas, who mainly herd their animals not far from their villages. Generally, the frequency of these species was low in the main wadis and over the plateaus. *Dichanthium insculptum* and *Boerhavia elegans* were missing on the plateaus of sites 2 and 3, while *Stipagrostis hirtigluma* was missing on the main wadis of sites 1 and 3.

Table 4.4. The frequency per hectare for each plant species. Variations in frequency can be observed. Some species occur at high frequencies in one site and at low frequencies or absent in other site.

plant species / study site	1	2	3	plant species / study site	1	2	3
Abutilon bidentatum	0	2	0	*Grewia erythraea*	0	6	0
Acacia campoptila	26	30	35	*Halothamnus bottae*	2	6	15
Acacia ehrenbergiana	9	9	3	*Helichrysum pumilum*	0	4	0
Acacia hamulosa	11	2	3	*Heliotropium ramosissimum*	11	17	12
Acacia mellifera	7	6	3	*Heliotropium rariflorum*	7	0	3
Acacia oerfota	4	6	0	*Hermannia paniculata*	0	0	5
Aerva artemisioides	0	0	3	*Hochstetteri schimperi*	0	9	0
Aerva javanica	20	11	32	*Indigofera oblongifolia*	0	0	3
Alhagi graecorum	11	0	0	*Indigofera spinifolia*	0	9	0
Anticharis glandulosa	0	2	3	*Indigofera spinosa*	2	28	26
Aristida triticoides	15	15	9	*Iphiona anthemidifolia*	2	0	0
Arnebia hispidissima	0	4	0	*Iphiona scabra*	15	6	3
Barleria aff bispinosa	4	6	3	*Jatropha spinosa*	0	17	12
Blepharis edulis	4	13	15	*Kohautia retrorsa*	9	11	15
Boerhavia elegans	30	19	38	*Launaea sp.*	0	2	0
Cadaba farinosa	0	2	0	*Leptadenia arborea*	0	2	0
Cadaba heterotricha	0	2	0	*Lindenbergia indica*	4	0	0
Calotropis procera	13	6	0	*Maerua crassifolia*	2	11	3
Capparis cartilaginea	7	2	0	*Merremia somalensis*	2	4	32
Capparis spinosa	4	2	0	*Moltkiopsis ciliata*	4	0	0
Cassia senna	2	0	0	*Ochradenus baccatus*	0	15	3
Chascanum marrubifolium	0	2	0	*Panicum turgidum*	4	0	18
Chloris barbata	4	0	0	*Phoenix dactylifera*	9	0	0
Chrozophora tinctoria	11	6	0	*Plicosepalus curviflorus*	2	6	0
Chrysopogon aucheri	0	9	3	*Pluchea dioscoroides*	0	2	0
Citrullus colocynthis	7	2	0	*Portulaca oleracea*	0	2	0
Cleome brachycarpa	17	4	32	*Prosopis farcta*	15	0	0
Cleome droserifolia	9	6	15	*Prosopis juliflora*	9	0	0
Cleome scaposa	4	6	24	*Pulicaria undulata.*	0	6	0
Cometes abyssinica	7	2	0	*Reseda sphenocleoides*	2	0	0
Commiphora foliacea	7	17	3	*Rhazya stricta*	4	13	12
Commiphora kua	0	8	3	*Rhynchosia memnonia*	0	2	3
Convolvulus arvensis	4	0	0	*Salsola imbricata*	0	11	0
Convolvulus glomeratus	0	4	0	*Salvadora persica*	0	2	0
Corallocarpus glomeruliflorus	0	4	9	*Seddera latifolia*	0	4	0
Corchorus depressus	2	2	3	*Seetzenia lanata*	4	2	0
Cornulaca amblyacantha	0	2	6	*Senna holosericea*	0	8	12
Cressa cretica	7	0	0	*Senna italica*	9	6	15
Crotalaria persica	2	4	0	*Senra incana*	7	2	0
Crotalaria saltiana	2	0	3	*Setaria verticillata*	7	0	0
Cymbopogon schoenanthus	26	4	18	*Stipagrostis hirtigluma*	30	32	41
Cynodon dactylon	4	2	0	*Tamarix aphylla*	4	2	0
Cyperus conglomeratus	0	6	3	*Tamarix arabica.*	0	4	0
Datura innoxia	2	0	0	*Tarenna graveolens*	0	2	0
Dichanthium insculptum	24	28	26	*Tephrosia apollinea*	37	15	12
Dipterygium glaucum	11	8	3	*Tephrosia dura*	15	0	3
Enneapogon desvauxii	4	2	24	*Tephrosia nubica*	4	0	32
Eragrostis sp.	0	2	0	*Tribulus arabicus*	2	8	14
Erucastrum arabicum	2	0	0	*Trichodesma calathiforme*	0	2	0
Euphorbia granulata	2	0	0	*Withania somnifera*	2	0	0
Euphorbia rubriseminalis	0	2	0	*Ziziphus leucodermis*	2	6	12
Fagonia indica	41	26	21	*Ziziphus spina-christi*	11	2	0
Fagonia paulayana	9	6	24	*Zygophyllum album*	11	0	0
Farsetia linearis	30	25	9	*Zygophyllum coccineum*	11	0	3
Forskohlea tenacissima	4	0	0	*Zygophyllum decumbens*	0	25	0
Glossonema varians	0	0	3	*Zygophyllum simplex*	11	0	0

Variations in frequency are characteristic. Some species occur at high frequencies in one site and at low frequencies or absent in other sites. For example the frequency of *Stipagrostis hirtigluma, Dichanthium insculptum* and *Boerhavia elegans* was high across the 3 study sites. *Boerhavia elegans, Seetzenia lanata* and *Aristida triticoides* was high in site 1, *Farsetia linearis, Ochradenus baccatus and Indigofera spinosa* were high in site 2 and *Cleome scaposa, Enneapogon desvauxii, Fagonia paulayana* and *Merremia hadramautica* were high in site 3 (Table 4.5a).

plant species	site 1	plant species	site 2	plant species	site 3
Fagonia indica	41	*Stipagrostis hirtigluma*	32	*Stipagrostis hirtigluma*	41
Tephrosia apollinea	37	*Acacia campoptila*	30	*Boerhavia elegans*	38
Boerhavia elegans	30	*Dichanthium insculptum*	28	*Acacia campoptila*	35
Farsetia linearis	30	*Indigofera spinosa*	28	*Aerva javanica*	32
Stipagrostis hirtigluma	30	*Fagonia indica*	26	*Cleome brachycarpa*	32
Acacia campoptila	26	*Farsetia linearis*	25	*Merremia somalensis*	32
Cymbopogon schoenanthus	26	*Zygophyllum decumbens*	25	*Tephrosia nubica*	32
Dichanthium insculptum	24	*Boerhavia elegans*	19	*Dichanthium insculptum*	26
Aerva javanica	20	*Commiphora foliacea*	17	*Indigofera spinosa*	26
Cleome brachycarpa	17	*Heliotropium ramosissimum*	17	*Cleome scaposa*	24
Aristida triticoides	15	*Jatropha spinosa*	17	*Enneapogon desvauxii*	24
Iphiona scabra	15	*Aristida triticoides*	15	*Fagonia paulayana*	24
Prosopis farcta	15	*Ochradenus baccatus*	15	*Fagonia indica*	21
Tephrosia dura	15	*Tephrosia apollinea*	15	*Cymbopogon schoenanthus*	18
Calotropis procera	13	*Blepharis edulis*	13	*Panicum turgidum*	18
Acacia hamulosa	11	*Rhazya stricta*	13	*Blepharis edulis*	15
Alhagi graecorum	11	*Aerva javanica*	11	*Cleome droserifolia*	15
Chrozophora tinctoria	11	*Kohautia retrorsa*	11	*Halothamnus bottae*	15
Dipterygium glaucum	11	*Maerua crassifolia*	11	*Kohautia retrorsa*	15
Heliotropium ramosissimum	11	*Salsola imbricata*	11	*Senna italica*	15
Ziziphus spina-christi	11	*Acacia ehrenbergiana*	9	*Tribulus arabicus*	14
Zygophyllum album	11	*Chrysopogon aucheri*	9	*Heliotropium ramosissimum*	12
Zygophyllum coccineum	11	*Hochstetteri schimperi*	9	*Jatropha spinosa*	12
Zygophyllum simplex	11	*Indigofera spinifolia*	9	*Rhazya stricta*	12
Acacia ehrenbergiana	9	*Commiphora kua*	8	*Senna holosericea*	12
Cleome droserifolia	9	*Dipterygium glaucum*	8	*Tephrosia apollinea*	12
Fagonia paulayana	9	*Senna holosericea*	8	*Ziziphus leucodermis*	12

Table 4.5a. The most high requency species over the 3 study sites.

Stipagrostis hirtigluma and *Dichanthium insculptum* are the most important plant species in the study sites (Table 4.5b).

Table 4.5b. Most important plant species in the study areas with their total importance values.

plant species	site 1	plant species	Site 2	plant species	Site 3
Stipagrostis hirtigluma	193	*Stipagrostis hirtigluma*	306	*Stipagrostis hirtigluma*	346
Dichanthium insculptum	112	*Farsetia linearis*	132	*Dichanthium insculptum*	209
Cleome brachycarpa	111	*Dichanthium insculptum*	129		

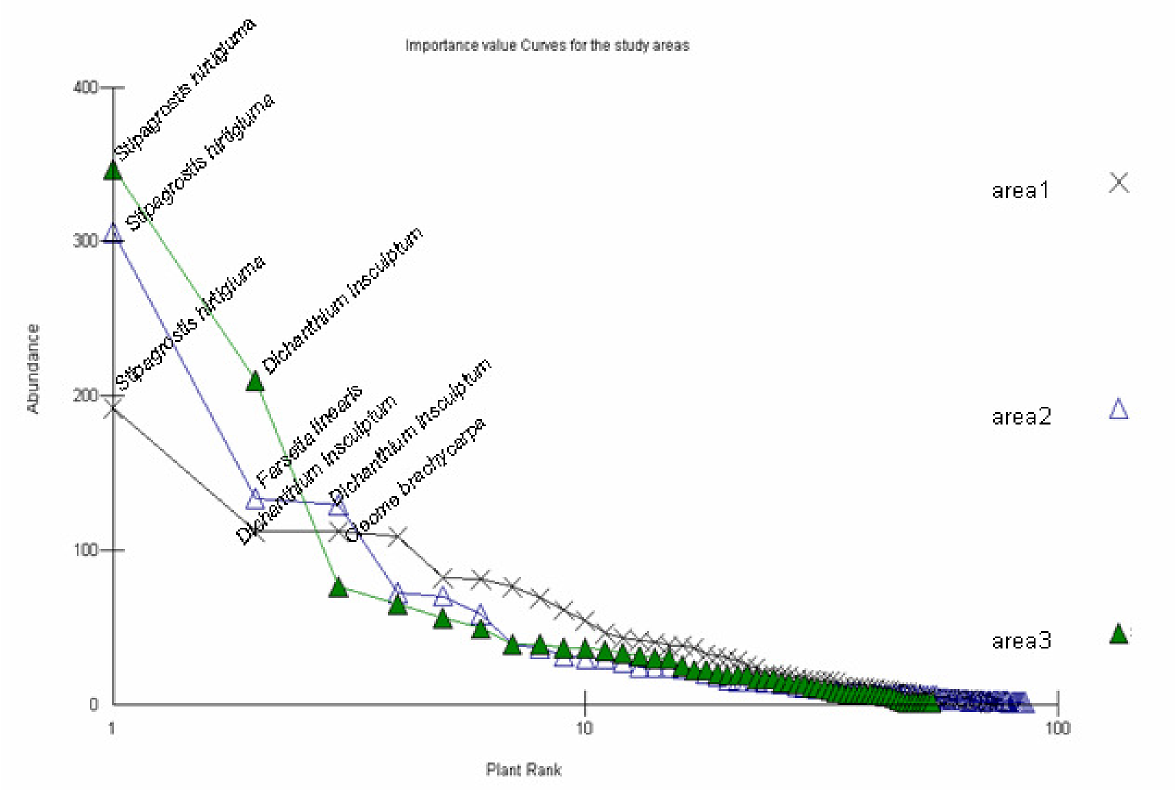


Figure 4.4. Importance Value Curves for the three study sites. The curves have steep slopes because most of the percentage importance values in the study sites are distributed among just a few species (see table 4.10). For example, site 3 has a steep curve because most of the percentage importance values are distributed among just *Stipagrostis hirtigluma* and *Dichanthium insculptum.*

Steeper curves in Figure 4.4 show that the site is only dominated by a few species, while straight curves show that the site is dominated by more species. The Importance value curves of the three study sites have steep slopes because most of the percentage importance values are distributed among just a few species. Site 1 is dominated by only three species, notably *Stipagrostis hirtigluma, Dichanthium insculptum* and *Cleome brachycarpa;* site 2 is dominated by three species notably, *Stipagrostis hirtigluma, Farsetia linearis, Dichanthium insculptum*, and site 3 is dominated by two species, notably *Stipagrostis hirtigluma* and *Dichanthium insculptum. Stipagrostis hirtigluma* and *Dichanthium insculptum* are widely distributed over the entire study sites in particular on the plateau zone. Table 4.6 shows the importance value of each species in different landforms of the three study sites.

Table 4.6. Importance Value Index for each plant species over different landforms of the three study sites. w= main wadi, fal= field or fallow land, ms= mountain slope facing main wadi, pla= plateau, wp= secondary wadi, sp= slope on plateau.

The study site	**1**						**2**					**3**				
Plant species / landform	w	fal	ms	pla	wp	sp	w	ms	pla	wp	sp	w	ms	pla	wp	sp
Abutilon bidentatum	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Acacia campoptila	19	0	8	0	5	0	52	20	0	5	0	27	0	0	0	0
Acacia ehrenbergiana	9	0	0	0	0	0	7	0	0	0	1	0	0	0	6	0
Acacia hamulosa	7	0	0	0	9	0	0	0	0	4	0	0	0	0	6	0
Acacia mellifera	0	0	0	0	19	0	0	0	0	4	3	0	0	0	6	0
Acacia oerfota	0	0	0	0	15	0	0	0	0	4	3	0	0	0	0	0
Aerva artemisioides	0	0	0	0	0	0	0	0	0	0	0	0	0	53	0	0
Aerva javanica	1	0	31	10	0	0	4	0	0	5	2	11	12	0	13	0
Alhagi graecorum	1	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anticharis glandulosa	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4
Aristida triticoides	1	0	19	7	0	27	2	0	0	39	16	4	7	0	0	0
Arnebia hispidissima	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Barleria aff bispinosa	4	0	0	0	0	0	1	0	0	14	0	2	0	0	0	0
Blepharis edulis	1	0	3	0	0	0	55	0	0	0	4	23	0	0	0	0
Boerhavia elegans	5	0	25	29	13	37	7	14	0	5	7	6	30	0	19	14
Cadaba farinosa	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Cadaba heterotricha	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Calotropis procera	7	0	0	5	0	0	3	0	0	0	1	0	0	0	0	0
Capparis cartilaginea	1	0	0	0	9	0	0	0	0	2	0	0	0	0	0	0
Capparis spinosa	0	9	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Cassia senna	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chascanum marrubifolium	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Chloris barbata	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrozophora tinctoria	0	0	1	13	23	0	0	0	0	1	0	0	0	0	0	0
Chrysopogon aucheri	0	0	0	0	0	0	0	0	0	30	0	0	0	0	10	0
Citrullus colocynthis	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cleome brachycarpa	0	0	16	5	0	90	1	42	0	0	0	9	23	0	0	0
Cleome droserifolia	0	0	8	7	0	0	1	0	0	6	0	3	7	0	6	0
Cleome scaposa	1	0	3	0	0	0	8	0	0	0	0	5	45	0	0	0
Cometes abyssinica	0	0	5	5	0	0	0	0	0	0	2	0	0	0	0	0
Commiphora foliacea	0	0	0	0	12	18	0	0	0	3	13	0	0	0	0	4
Commiphora kua	0	0	0	0	0	0	0	0	0	2	5	0	0	0	0	7
Convolvulus arvensis	0	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Convolvulus glomeratus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Table 4.6 Continued

The study site	**1**						**2**					**3**				
Plant species / landform	w	fal	ms	pla	wp	sp	w	ms	pla	wp	sp	w	ms	pla	wp	sp
Corallocarpus glomeruliflorus	0	0	0	0	0	0	0	0	0	3	2	0	0	0	15	6
Corchorus depressus	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Cornulaca amblyacantha	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	13
Cressa cretica	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crotalaria persica	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crotalaria saltiana	0	0	0	0	5	0	0	0	0	0	0	0	0	0	20	0
Cymbopogon schoenanthus	14	0	0	0	47	0	2	0	0	6	0	8	0	0	0	4
Cynodon dactylon	0	28	0	0	0	0	0	14	0	0	0	0	0	0	0	0
Cyperus conglomeratus	0	0	0	0	0	0	0	23	0	7	0	0	0	73	0	0
Datura innoxia	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dichanthium insculptum	7	0	17	24	36	28	0	76	0	30	50	4	14	0	34	101
Dipterygium glaucum	8	0	0	0	0	0	3	0	0	0	0	2	0	0	0	0
Enneapogon desvauxii	0	0	5	6	0	0	2	0	0	0	0	1	29	0	6	15
Eragrostis sp.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Erucastrum arabicum	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbia granulata	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbia rubriseminalis	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Fagonia indica	19	8	29	20	0	0	24	0	0	3	3	19	0	0	0	0
Fagonia paulayana	0	0	3	0	27	0	0	0	0	1	4	0	40	0	10	9
Farsetia linearis	1	0	24	38	18	0	0	25	79	13	23	0	8	0	0	4
Forskohlea tenacissima	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
Glossonema varians	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
Grewia erythraea	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
Halothamnus bottae	0	0	3	0	0	0	1	0	0	7	0	1	0	0	10	20
Helichrysum pumilum	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
Heliotropium ramosissimum	2	0	7	0	0	0	3	0	0	2	5	3	3	0	0	6
Heliotropium rariflorum	5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hermannia paniculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0
Hochstetteri schimperi	0	0	0	0	1	0	0	0	0	3	7	0	0	0	0	0
Indigofera oblongifolia	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Indigofera spinifolia	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0
Indigofera spinosa	2	0	0	0	0	0	24	33	0	0	21	30	0	0	0	0
Iphiona anthemidifolia	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Iphiona scabra	0	0	5	20	16	0	0	0	0	2	3	0	0	0	14	0
Jatropha spinosa	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	26
Kohautia retrorsa	5	0	0	0	9	0	0	0	0	8	4	6	0	0	23	0
Launaea sp.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Leptadenia arborea	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Lindenbergia indica	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.6 Continued

The study site	**1**						**2**					**3**				
Plant species / landform	w	fal	ms	pla	wp	sp	w	ms	pla	wp	sp	w	ms	pla	wp	sp
Maerua crassifolia	1	0	0	0	0	0	0	0	0	0	10	0	0	0	0	4
Merremia hadramautica	1	0	0	0	0	0	0	0	0	0	0	21	0	0	6	0
Moltkiopsis ciliata	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
Ochradenus baccatus	0	0	0	0	0	0	16	0	0	0	0	2	0	0	0	0
Panicum turgidum	3	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0
Peristrophe paniculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phoenix dactylifera	0	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plicosepalus curviflorus	2	0	0	0	0	0	4	0	0	2	0	0	0	0	0	0
Pluchea dioscorides	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Portulaca oleracea	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Prosopis farcta	6	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prosopis juliflora	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pulicaria undulata.	0	0	0	0	0	0	1	0	0	17	2	0	0	0	0	0
Reseda sphenocleoides	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhazya stricta	4	0	0	0	0	0	14	0	0	0	0	11	0	0	0	0
Rhynchosia memnonia	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Salsola imbricata	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0
Salvadora persica	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Seddera latifolia	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0
Seetzenia lanata	0	0	0	8	0	39	0	0	0	0	1	0	0	0	0	0
Senna holosericea	0	0	0	0	0	0	6	0	0	0	0	5	3	0	0	0
Senna italica	4	3	3	0	0	0	8	0	0	0	0	9	0	0	10	0
Senra incana	1	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Setaria verticillata	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stipagrostis hirtigluma	0	0	32	89	15	57	8	50	221	23	27	0	47	174	59	62
Striga asiatica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamarix aphylla	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Tamarix arabica.	0	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0
Tarenna graveolens	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Tephrosia apollinea	48	4	22	0	7	0	10	0	0	3	3	7	14	0	0	0
Tephrosia dura	25	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Tephrosia nubica	3	0	0	0	0	0	0	0	0	0	0	53	0	0	0	0
Tephrosia subtriflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tribulus arabicus	1	0	0	0	0	0	9	0	0	0	0	5	10	0	0	0
Trichodesma calathiforme	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Withania somnifera	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ziziphus leucodermis	0	0	0	0	3	5	2	0	0	2	0	4	0	0	0	0
Ziziphus spina-christi	4	7	0	0	0	0	0	3	0	0	0	0	2	0	0	0
Zygophyllum album	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zygophyllum coccineum	13	0	4	0	0	0	0	0	0	0	0	0	5	0	0	0
Zygophyllum decumbens	0	0	0	0	0	0	0	0	0	16	23	0	0	0	0	0
Zygophyllum simplex	3	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0

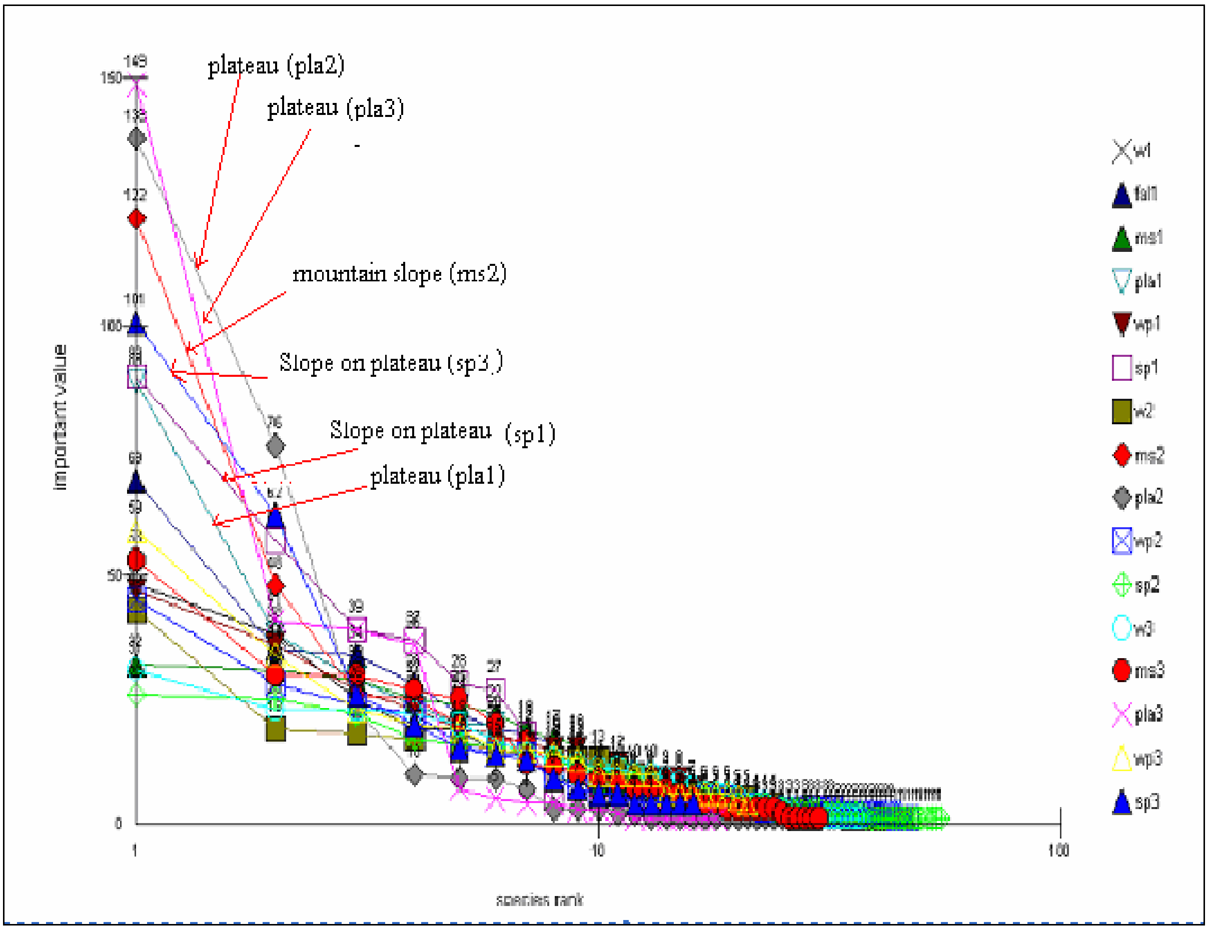


Figure 4.5 The distribution of total Importance Values over each landform in the study sites. w= main wadi, fal= field or fallow land, ms= mountain slope facing main wadi, pla= plateau, wp= secondary wadi, sp= slope on plateau. Numbers refer to the study site. pla2 has steep curves because it is dominated by only two species *Stipagrostis hirtigluma* and *Farsetia linearis.*

Table 4.6 and Figure 4.5 show the importance values for each plant species over different landforms for the three study sites. The Importance Values can be seen to vary distinctly between the different landforms. As can be observed, there are a few species in these habitats that have more important value than any other species. Steeper curves show that the landform is dominated by only a few species or that most of the percentages Importance Values are distributed among just a few species; while straight curves show that the landform is dominated by more species or that most plants species within this landform have similar percentage importance values. For example, the (pla2), (pla3), (ms2) and (sp3) curves (Figure 4.5) have a steep slope because most of the percentages Importance Values in these habitats are distributed among just a few species. The first habitat was dominated by *Stipagrostis hirtigluma* and *Farsetia linearis,* the remaining three habitats were dominated by *Stipagrostis hirtigluma* and *Dichanthium insculptum* (Table 4.6).

4.3.5. Floristic diversity

In total 117 plant species were found in the study area (about 10 taxa per hectare).The mean number of species per sample plots was 7.6. The maximum number of species at any one sample plot was 20 and the minimum was two. Many species were present only in one or very few sample plots. Out of 117 plant species, only 7 (6%) were present in more than 30% of the sample plots. These species are:
Acacia campoptila, Fagonia indica, Tephrosia apollinea, Boerhavia elegans, Dichanthium insculptum, Farsetia linearis and *Stipagrostis hirtigluma*. The first 3 species are mainly found on wadi beds, the rest of the species are widely distributed throughout the landforms, with a high frequency on the plateau and on the rocky slopes facing the main wadis.

The calculation of plant diversity using numbers of individuals for each plant species was achieved by using Shannon and Simpson indices. The use of presence and absence data failed to give logical results, for example the evenness values for all areas were 1.

The Simpson index was calculated as 0.96 for site 1, and 0.94 for sites 2 and 3, while the Shannon index is calculated as 3.55 for site 1, 3.41 for site 2 and 4.24 for site 3. The three study sites (Table 4.7) have different numbers of plant richness (74 in 1, 83 in 2 and 61 in 3) with different total numbers of individuals (1275 in 1, 1555 in 2 and 1156 in 3). As can be seen, site 2 has more species and individuals. However, both Shannon's and Simpson's diversity indices show that the study site 1 was more diverse than sites 2 and 3. This is because the total number of individuals in site 1 is almost equally distributed between the most plant species (Figure 4.6), in other word has more evenness (Wilsey et al., 2000) than sites 2 and 3 (Table 4.7). For example In site 2, 50 % of the individuals belong to only 5 species (Table 4.3 and Figure 4.6), namely *Aristida triticoides, Blepharis edulis, Indigofera spinosa, Dichanthium insculptum* and *Stipagrostis hirtigluma,* while in site 3, 50% of the individuals belong to only 4 species, namely *Blepharis edulis, Dichanthium insculptum, Stipagrostis hirtigluma Tephrosia nubica, Indigofera spinosa, Cleome scaposa* and *Enneapogon desvauxii,* while the distribution was among 8 plant species in site 1.

	Simpson's index		Shannon's index		No of	No of
Area	Index	Evenness	Index	Evenness	Species	individuals
1	0.96	0.968	3.55	0.824	74	1275
2	0.94	0.953	3.41	0.773	83	1555
3	0.94	0.959	4.24	0.789	61	1156

Table 4.7. Simpson's and Shannon's indices of the 3 study sites. Both Simpson and Shannon indices show that site 1 is more diverse than site 2 and 3. The number of species of site 2, is high, but the evenness is low, as a result the diversity was low.

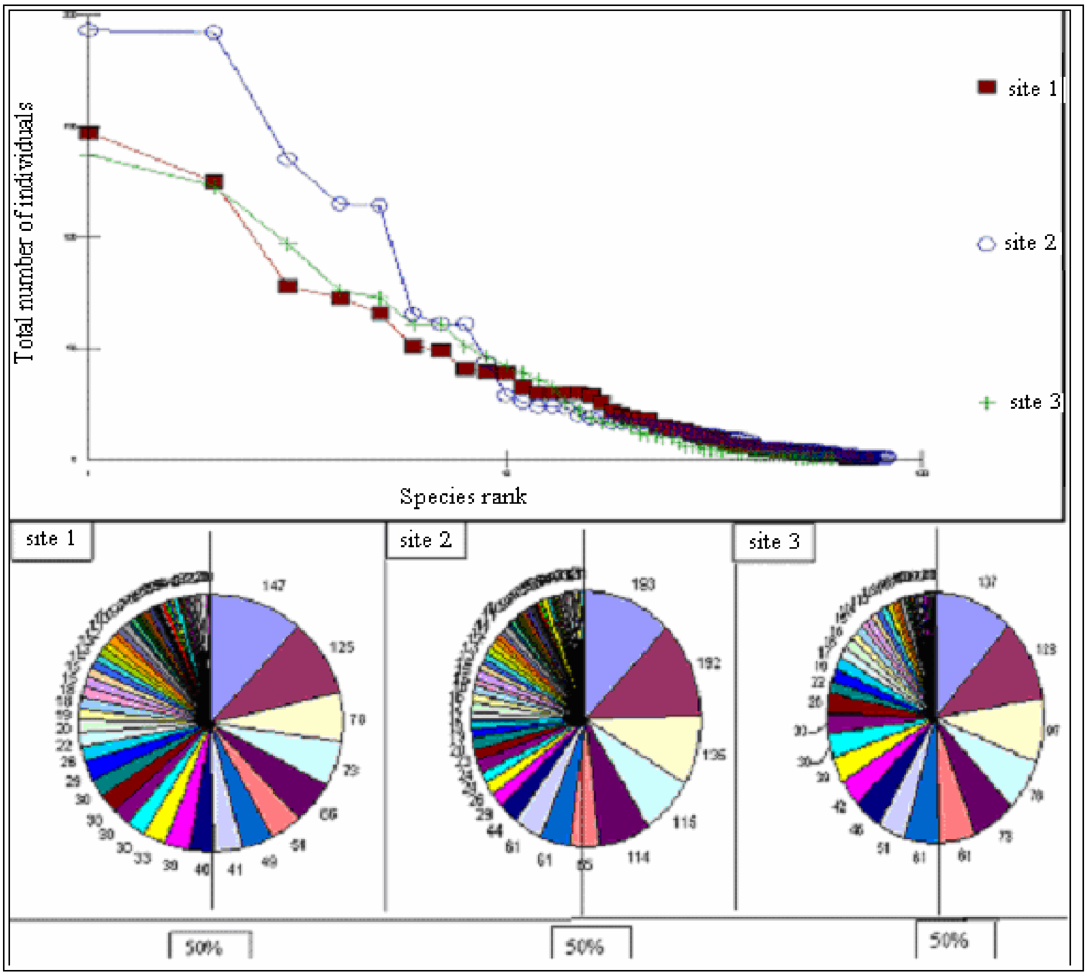


Figure 4.6. The distribution patterns of number of individuals between the plant species in the three study sites. The total number of individuals in site 1 is more evenly distributed. 50% of individuals were distributed among 5 plant species in site 2 and among almost 6 plant species in site 3, while the distribution was among 8 plant species in site 1.

The comparison in diversity between the 3 study sites can be further illustrated by plotting percentage cumulative abundance against log species rank over the different landforms (Figure 4.7). In this case, the lower line has the higher diversity (Shaw et al., 1983). The output (Figure 4.7) shows that site 1 has higher diversity than the other two sites, and this result supports the Shannon and Simpson indices result shown earlier in Table 4.7.

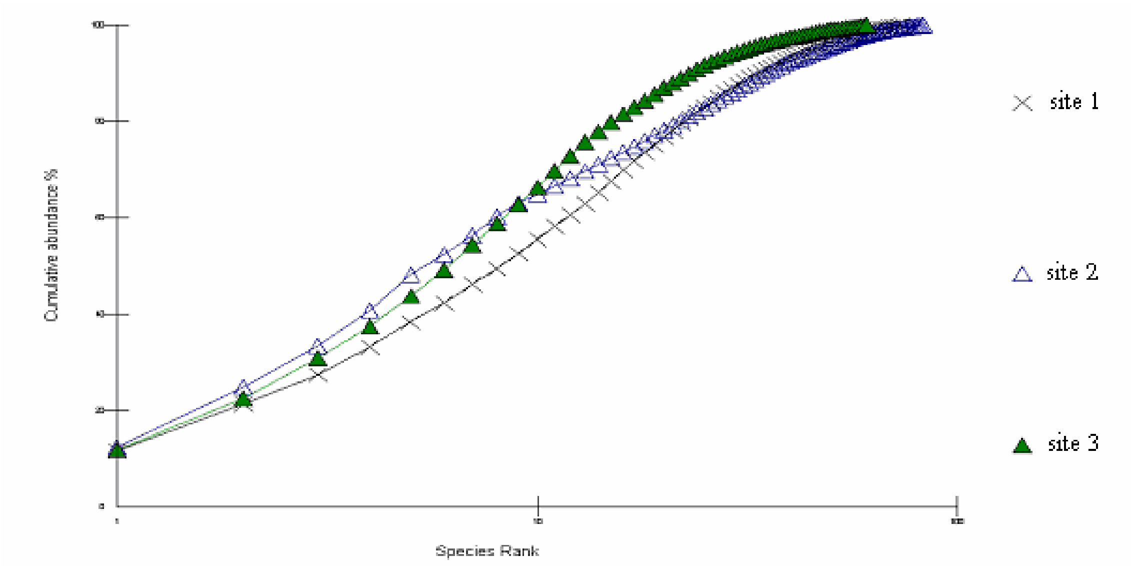
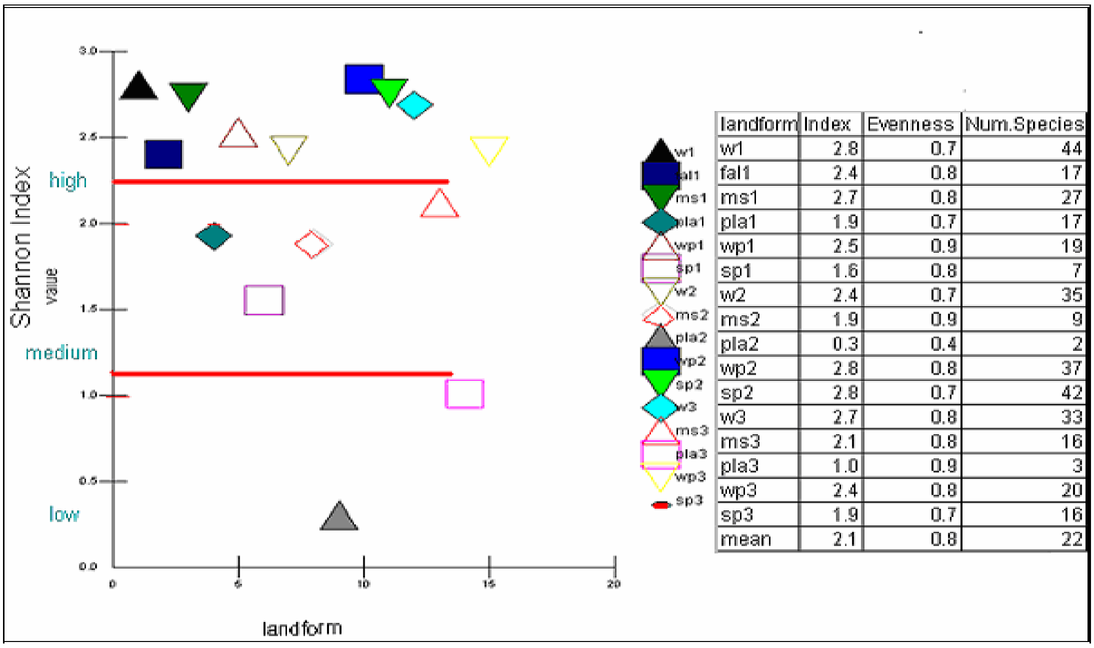


Figure 4.7. Cumulative abundance curves, known also as k-dominance curves (John and Gallegos, 2001) for the three study sites showing cumulative ranked abundances plotted against log species rank. The lower line, which in this case represents site 1, has the higher diversity.

The biodiversity of different landforms was also calculated using the Shannon index (Figure 4.8).



landform	Index	Evenness	Num.Species
w1	2.8	0.7	44
fal1	2.4	0.8	17
ms1	2.7	0.8	27
pla1	1.9	0.7	17
wp1	2.5	0.9	19
sp1	1.6	0.8	7
w2	2.4	0.7	35
ms2	1.9	0.9	9
pla2	0.3	0.4	2
wp2	2.8	0.8	37
sp2	2.8	0.7	42
w3	2.7	0.8	33
ms3	2.1	0.8	16
pla3	1.0	0.9	3
wp3	2.4	0.8	20
sp3	1.9	0.7	16
mean	2.1	0.8	22

Figure 4.8. Diversity of the different landforms using Shannon index. w= main wadi, fal= field or fallow lands, ms= slope facing main wad, pla= plateau, wp= secondary wadi, sp= slope on plateau. Numbers refer to the study site. w1, wp2 and sp2 have the highest diversity values, while pla2 and pla3 have the lowest. A habitat with high evenness has a larger diversity index than a habitat of higher or the same number of species with lower evenness (e.g. fal 1 & pla 1 and w2 & w3).

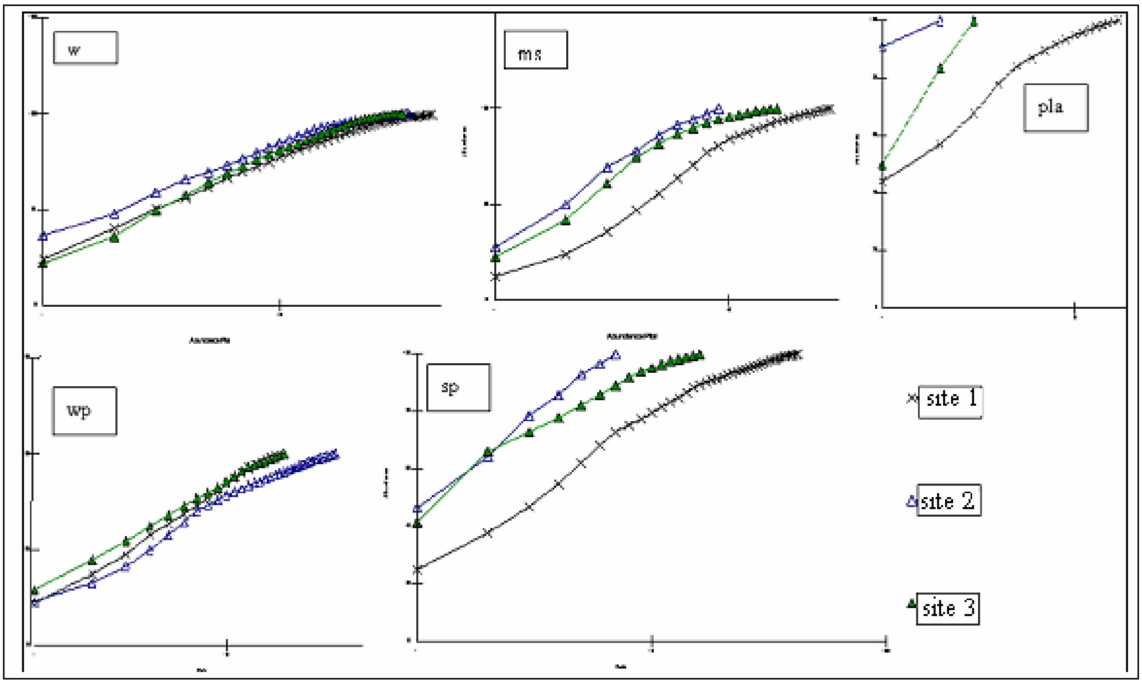


Figure 4.9. Cumulative abundance curves, known also as k-dominance curves (John and Gallegos, 2001) for the different landforms in the study sites showing cumulative ranked abundances plotted against log species rank. Almost all landforms of site 1 have higher diversity and all landforms of site 2 have low diversity, except the secondary wadi of site 2 (wp2). This due to high number of species found over this landform.

The Shannon diversity index of main landforms varied from 0.3 to 2.8, the mean was 2.1. Figure 4.8 and 4.9 show that main wadis, wp2, sp2 and ms1 are the most diverse habitats. These index values correspond to the high number of plant species at each habitat, while the landforms pla2, pla3 and sp1, which are characterized by a low number of species (from 2 to 7), have lower diversity. In addition, a habitat with high evenness has a larger diversity index than a habitat of higher or the same richness with lower evenness. For example fal1 has the same species of pla1, but fal1 is more diverse than pla1, and w3 has less species than w2, but w3 is more diverse than w2 because both fal1 and w3 have more evenness than pla1and w2 (Figure. 4.8).

The diversity indices calculated for the main wadis are generally high and range between 2.4 and 2.8. There are no significant differences between the diversity of these wadis. The relatively high diversity of the wadi in site 1 is due to the fact that 12 species in this landform are confined to cultivated and palm field areas, with species composed of weeds such as *Alhagi graecorum, Phoenix dactylifera, Cressa cretica, Capparis spinosa, Cynodon dactylon, Chloris barbata, Convolvulus arvensis, Datura innoxia* and *Withania somnifera.* (see vegetation association 1, chapter 5).

Site 1 was the most diverse, while site 2 was the richest in plant species. Plant species of some locations on slopes (sp) and secondary wadis of plateaus (wp) have been found to be more diverse with a very dense cover when surface soil is irrigated by contaminated water as in case of site 2 (plate 4.1*).* In these sites*,* species that require high moisture such as *Abutilon bidentatum, Pluchea dioscoroides, Leptadenia arborea, Pulicaria undulata* and *Tamarix arabica* are abundant. On the other hand, common species of slopes and wadis of plateaus such as *Stipagrostis hirtigluma, Indigofera spinosa and Maerua crassifolia* are absent here.

Plate 4.1. Dense vegetation cover dominated by *Dichanthium insculptum* and *Farsetia linearis* on the slope of plateau, site 2. Bare ground surface (foreground) is due to intolerance of the vegetation to salts and chemicals in the waste water.

All plant species of the mountain slopes facing the main wadis (ms) are herbaceous, except for trees of *Acacia campoptila*, which are found as individuals in favoured locations (in particular in gullies at the foot of these slopes). Due to the steep slopes, the soil is probably affected by runoff and exposed to direct evaporation as a result the lower moisture (Danin et al., 1997), and the shallow soil cover is not sufficient to support woody or shrubby vegetation. The dominant species here are *Dichanthium insculptum, Boerhavia elegans, Cleome brachycarpa Stipagrostis hirtigluma* and *Farsetia linearis* and they are very well developed on such dry habitats (see Associations 8 and 9, chapter 5).The frequency of these species range between 15% and 60%.

Almost half of plant species on mountain slopes facing the main wadis at site 1 are annual herbs and only 15 plant species are found here. Compared to the rest of the slopes, the slopes of site 1 have high diversity (Figures 4.8 and 4.9). The mountain slope is subjected to overgrazing by local herders and Bedouins. The structure of vegetation of this habitat cannot resist overgrazing, and consequently the vegetation cover has been reduced dramatically.
The diversity of the slopes on the plateaus (sp) is medium to high and ranges between 1.6 and 1.8 (Figure 4.8). Here the diversity on slopes of site 1 is the lowest. The diversity of slopes of site 2 was high due to the increase of moisture content in one sample plot. This plot is regularly irrigated by contaminated water from the oil workings (plate 1); 23% of plant species that occur on this habitat are confined to this location.

The plateaus generally have the lowest diversity. This could be due to physical factors, which are characterised by high proportion of exposed hard jagged limestone, dolomite and chert fragments (Komex International Ltd 1999), and a high proportion of sand and stones (Plate 4.2). Similar landscapes with almost bare vegetation are found in the desert areas throughout the world (Danin, 1983). The plateau of site 2 contained the lowest diversity; this could be (in addition to the physical factors), due to the intensive activities of oil workings.

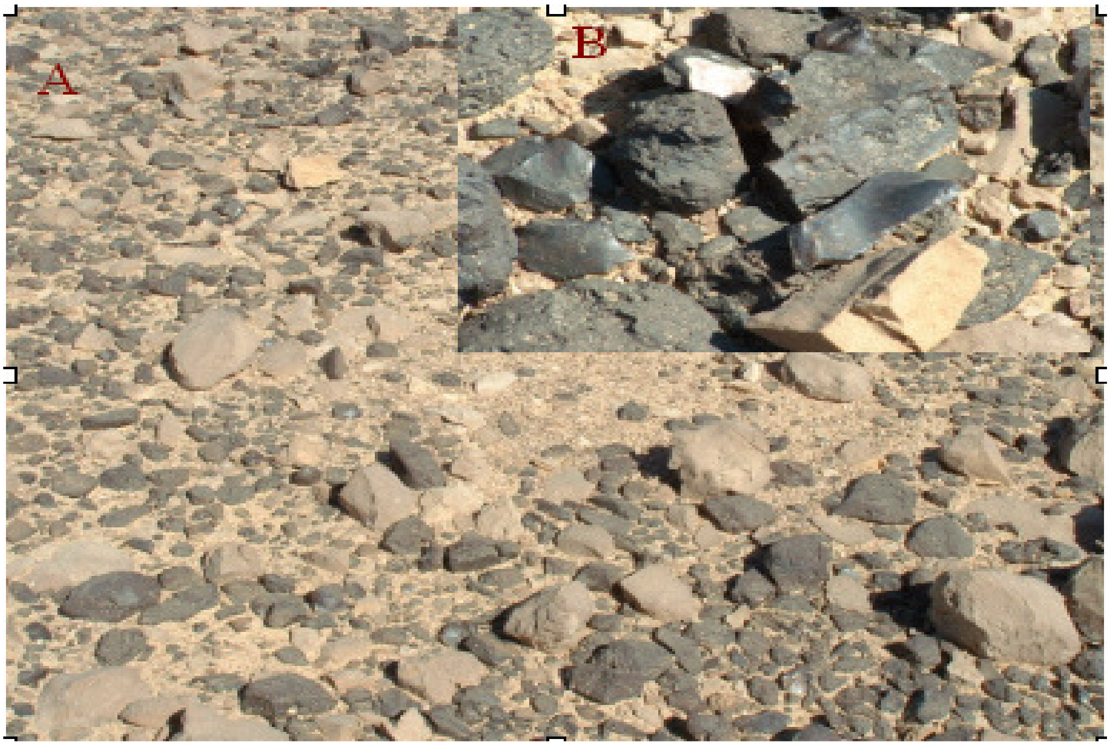


Plate 4.2. Bare dolomite and chert fragments surface with sandy loam textured on the plateau of area 1. (A) General view, (B) a close view.

Generally most of surfaces on the plateau of sites 2 and 3 are almost devoid of vegetation. The diversity calculated for the plateaus (pla) of site 1 is higher than sites 2 and 3.

The higher diversity of plateau in site 1 may be due to one or more of the following reasons:

1- The moisture content and clay content of the soil samples collected is higher (see soil data table chapter 5).

2- The landform of the plateau in site 1 consists of small hills with alluvial fans and drainage lines formed at the foot of these hills, which support a habitats characterise by relatively deep, moist soil. The E.C of the alluvial deposits in these drainage lines is relatively high (3 %). This salt probably built up as water is evaporated very rapidly from the surface. Halophyte plants that have adapted to tolerate a high salt regime, such as *Zygophyllum simplex, Fagonia indica Dichanthium insculptum* aand *Tamarix arabica* re confined here.

3- Plant species of some locations have been found to be more diverse due to the removal of the surface layer by local people to make protection barriers to guard the road. The exposed soil below the surface layer is able to support greater plant life (i.e. the subsurface horizons are the most favourable).

4- Disturbed areas can be invaded easily by new species, which increase species richness. (Focht and Pillar, 2003). Species of disturbed areas such as *Calotropis procera, Farsetia linearis* and *Chrozophora oblongifolia*, were only found here.

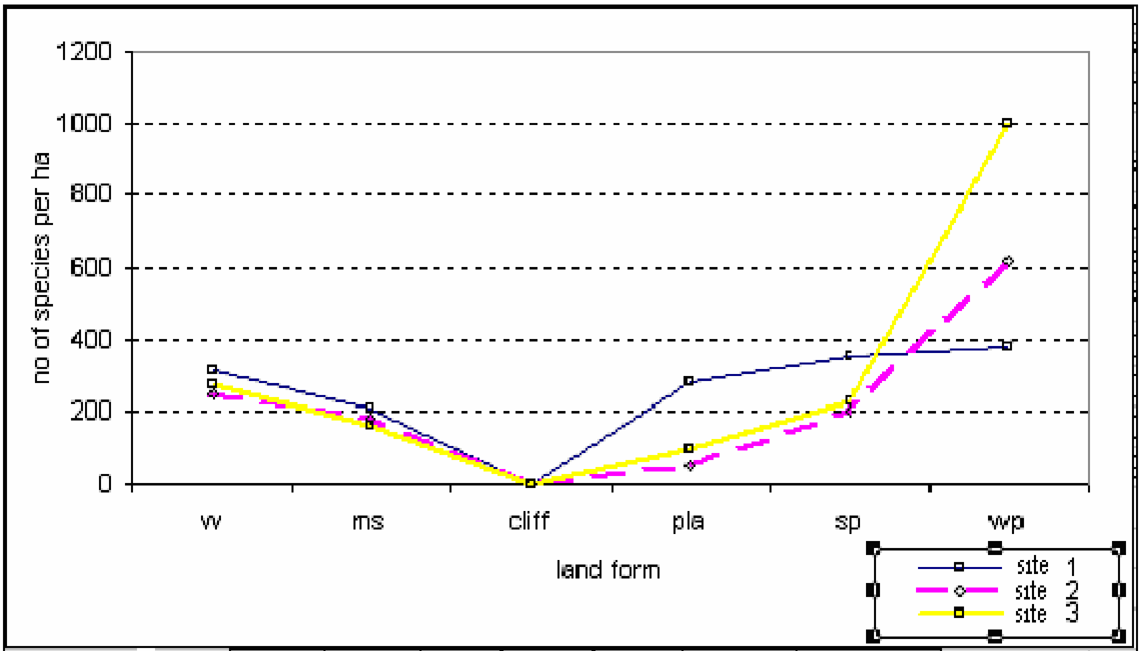
In addition to high organic matter, soil fertility and high moisture content (Furley and Newey, 1983; Krishnaswamy and Richterb, 2002; Norton et al., 2003; Walker and William, 2002), the increase of plant species on the alluvial fans that are located at the bottom of the plateaus, can be also due to immigration of some species from the plateaus down to the wadis. For example, species such as *Maerua crassifolia*, which is usually confined to the plateau, is found at the foot of the wadi bed in site 1.

It is understood from the previous section that study site 1 was more diverse than sites 2 and 3, while site 2 was the richest in plant species. This is because the total number of individuals in site 1 is almost equally distributed between the most plant species. The diversity of the slopes on the plateaus (sp) is medium to high. The plateaus generally have the lowest diversity. The main wadis, secondary wadis of site 2, the slope of plateaus of site 2 and the mountain slopes of site 1 are the most diverse habitats. The index values of these landforms correspond to the high number of plant species at each habitat, while the plateaus of site 2 and 3 and the slopes of plateau of site 1, have lower diversity, these landforms are characterized by a low number of species. Plant species of some locations have been found to be more diverse with a very dense cover when surface soil is irrigated or when rocky surface layer is removed. Generally, abiotic and biotic factors account for variation in species composition and diversity.

4.3.6. Species richness and density over the landform gradient

Figure 4.10 shows that number of species per hectare varies across the different landforms. The number of species over the plateaus increases steadily from exposed flat surfaces, to the slopes, then to the bottom of the secondary wadis. In the main wadis, the number of species for the three study sites increases from zero on the cliffs, to the slopes that face the main wadis, then to the main wadi beds. The peak in the number of species (1000 species/ha) is found at the bottom of the secondary wadis that cut the plateaus of site 3 (wp3). The lowest is found at the plateaus of sites 2 and 3.

Species richness was high on the valley floor on both the main wadis and the secondary wadis and was low on the mountain slopes, plateaus and slopes of the plateaus. This is possibly due to the movement of large volumes of water and sediments down the slopes during the rainy season (Robert & Thomas 1997); as a result, the amount of moisture is increased at the subsurface store.

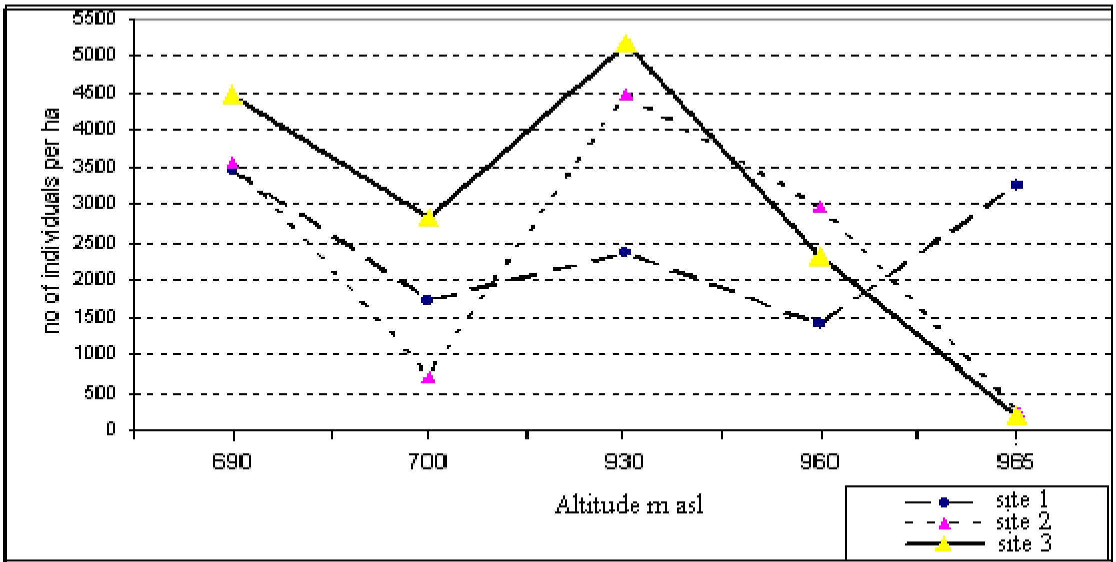


land fo	w	ms	cliff	pla	sp	wp
site 1	314	208	0	283	350	380
site 2	250	180	0	50	200	617
site 3	275	160	0	100	229	1000

Figure 4.10. Number of species per hectare over the landform gradient. w = wadi, ms = mountain slopes facing main wadis, cliff = very steep cliffs facing the main wadis, wp = secondary wadi, sp = slope on plateaus, pla = plateau. The number of species decreases from main wadi to the cliff and on the plateau it increases from exposed flat surfaces to the bottom of the secondary wadis.

The continuous deposition over the foot slopes also increases the depth of the soil over the wadi bottom as well as the amount of organic matter and moisture. Conversely, increases in erosion over the slopes decreases the depth of the soil of these lower slopes (Furley & Newey, 1983). The low number of species at wp1 is due to the landform characteristics of relatively narrow shallow wadis with steep short sides; in addition, the surface of this wadi has solid pavement with a soil cover of less than 2%.

Figure 4.11 shows the fluctuation in number of individuals over the altitude gradient. Elevation has no obvious effect on the distribution of numbers of individual species. The high number of individuals at 690 and 930 m and low number of individuals at 965 m are due to landforms characteristics; in the first two, the landform is a deep valley bottom and in the second, the landform is an exposed surface of the plateaus. A sharp decline in numbers of individuals from 930m to 965m of the plateau areas in sites 2 and 3 is due to landform changes from relatively wet wadi bottom to the slope and then to the exposed dry surface of the plateaus. The high number of individuals at the plateau of site 1 is due to human disturbance (see the previous section). Elevation has an effect on the distribution of some individual species. For example some species such as *Acacia mellifera*, *Corallocarpus glomeruliflorus, Jatropha spinosa* and *Chrysopogon aucheri* are confined to high altitude areas (over 900m), while others like *Acacia ehrenbergiana, Zygophyllum album, Rhazya stricta* and *Alhagi graecorum* are confined to low altitude areas (less than 700m).



altitude	690	700	930	960	965
site 1	3457	1723	2360	1400	3250
site 2	3571	720	4483	2962	275
site 3	4475	2820	5150	2314	200

Figure 4.11. Species density per hectare along the landform gradient. w = wadi, ms = mountain slopes facing main wadis, cliff = very steep cliffs facing the main wadis, wp = secondary wadi, sp = slope on plateaus, pla = plateau. The high number of individuals at 690 and 930 m and low number of individuals at 965 are due to landforms characteristics; in the first two, the landform is a deep valley bottom and in the second, the landform is an exposed surface of the plateaus. A sharp decline in numbers of individuals from 930m to 965m of the plateau areas in site 2 and 3 is due to landform changes from relatively wet wadi bottom to the slope and then to the exposed dry surface of the plateaus. The high number of individuals at the plateau of site 1 is due to human disturbance.

The previous section showed that the number of species per hectare varies across the different landforms. Species richness was high on the valley floor on both the main wadis and the secondary wadis and was low on the mountain slopes, plateaus and slopes of the plateaus. This is due to the movement of large volumes of water and sediments down the slopes during the rainy season, as well as the depth of the soil over the wadi bottom and the amount of organic matter and moisture were high. The low number of species is due to the landform characteristic of relatively narrow shallow wadis with steep short sides. Generally the density and the distribution of plant species were different from one study site to another, as well as from one landform to another. The landforms, with their component, such as moisture, were the main factors affecting the distribution and the density of plant species. Human activities play an important role in some sites.

4.3.7. Species accumulation curves

Curves for species versus the number of sample plots were plotted for each area in order to ascertain the minimum number of samples that should be taken to be representative of the habitats in the study areas (Willott, 2001). The total number of species increases with area, leading to an increased probability of finding more species with larger areas. At some spatial scale, all or most of species will be counted before the entire area is sampled.

The curves of species versus number of sample plots for the three study sites tend to flatten, indicating that the number sample sites was sufficient to record their floristic composition (Mueller-Dombois and Ellenberg, 1974; Thompson et al., 2003). The curves rise quickly at the early stage, meaning that most of the species are recorded in just the first few sampling plots, and subsequently they almost level out.
The total numbers of samples that have been taken in the 3 study sites were as following: site 1 (49), site 2 (54) and site 3 (37). Figures 4.12 to 4.14 show that 20 sample plots (totalling 0.2 hectares) would be satisfactory to cover almost 74%, 69% and 84% of plant species recorded for site 1, site 2 and site 3 respectively. The curves increase very slowly with continued sampling; for example conducting a further 20 sample sites would add 19 (26%), 26 (31%) and 10 (16%) new species respectively to the three study sites.

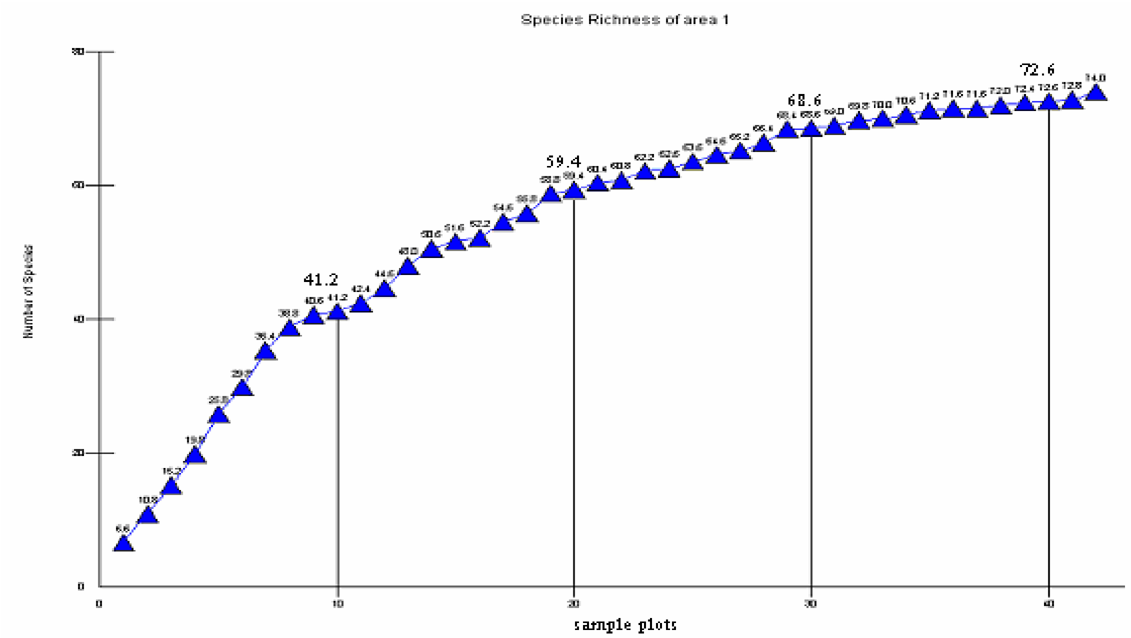


Figure 4.12. Curve of species versus number of sample sites for site 1. At the beginning, 41 plant species (55.4%) were counted in the first 10 sample plots (totalling 0.10 ha), at a rate of almost 4 new species per sample site. 20 sample plots was satisfactory to account for 80% (almost 60 plant species). By the time 60 species are counted, new species are being recorded at a rate of one new species per sample plot. After 65 species had been recorded, the rate of new species recording drops sharply.

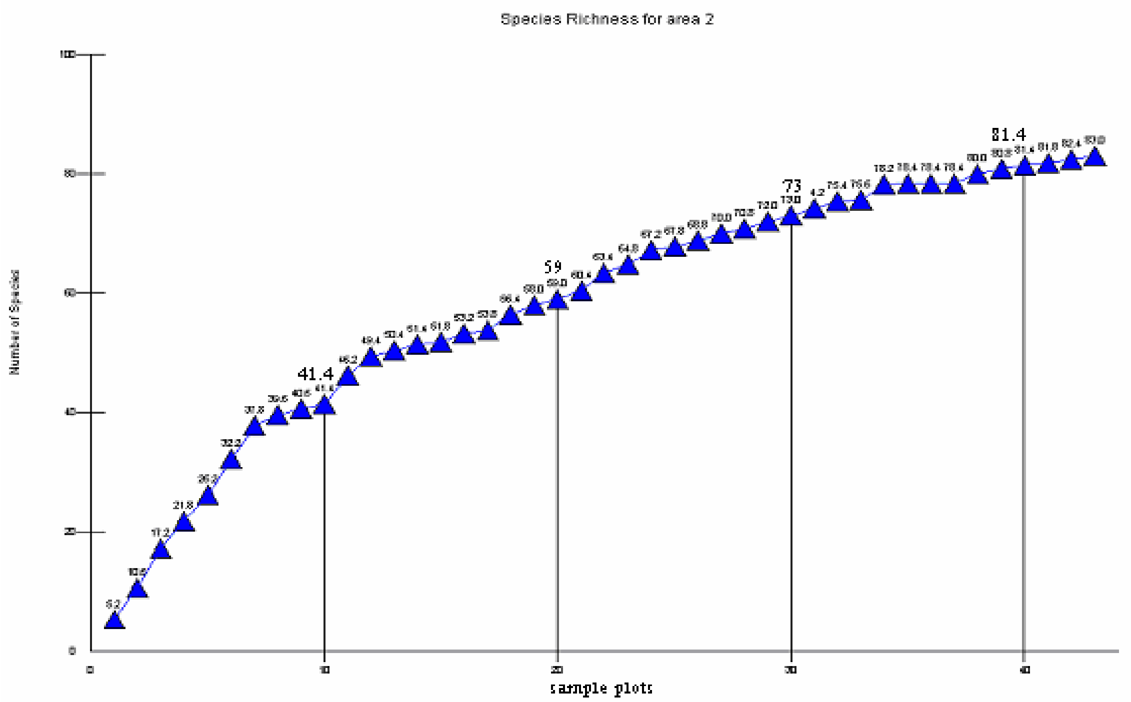


Figure 4.13. Curve of species versus number of sample plots for site 2. At the beginning, 41 plant species (49.4%) were counted in the first 10 sample sites (0.10 ha), at a rate of almost 5 new species per sample sites. 20 sample plots were satisfactory to account 71% (almost 59 plant species). After 68 species had been recorded, the rate of new species recording drops sharply, almost 1 new species every sample plots, then the rate slightly drop again to about 1 new species every 2 to 3 sample plots.

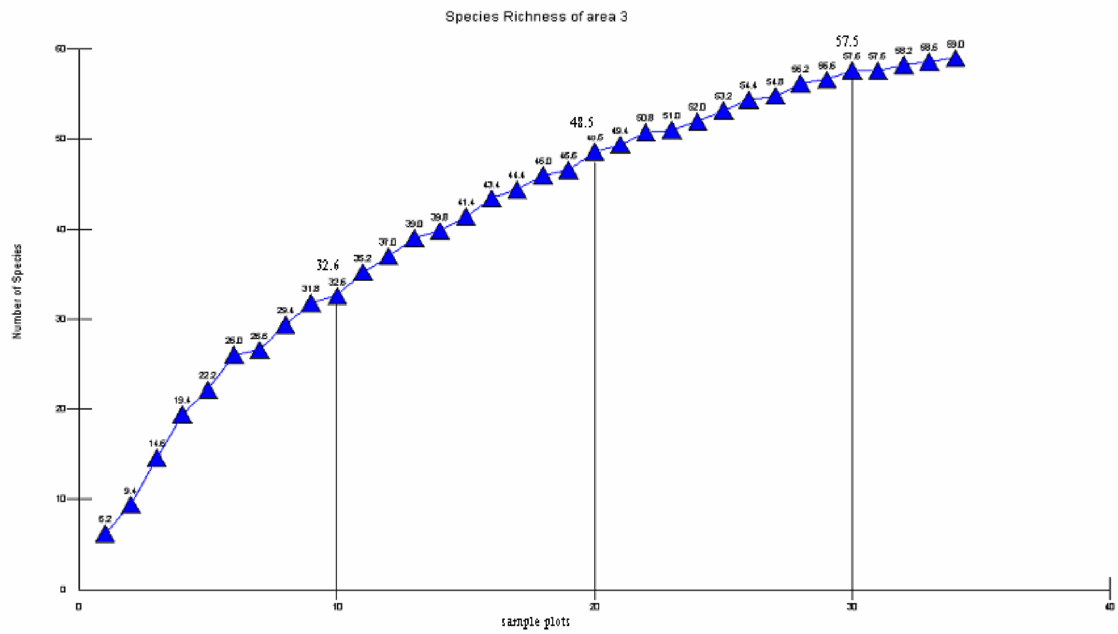


Figure 4.14. Curve of species versus number of sample plots for site 3. At the beginning, 33 plant species (56%) were counted in the first 10 sample plots (0.10 ha), at a rate of almost 4 new species per sample sites. 20 sample plots were satisfactory to account 83% (almost 49 plant species). After 57 species were recorded, the rate of new species recording drops sharply, to almost 1 new species every 2 sample plots.

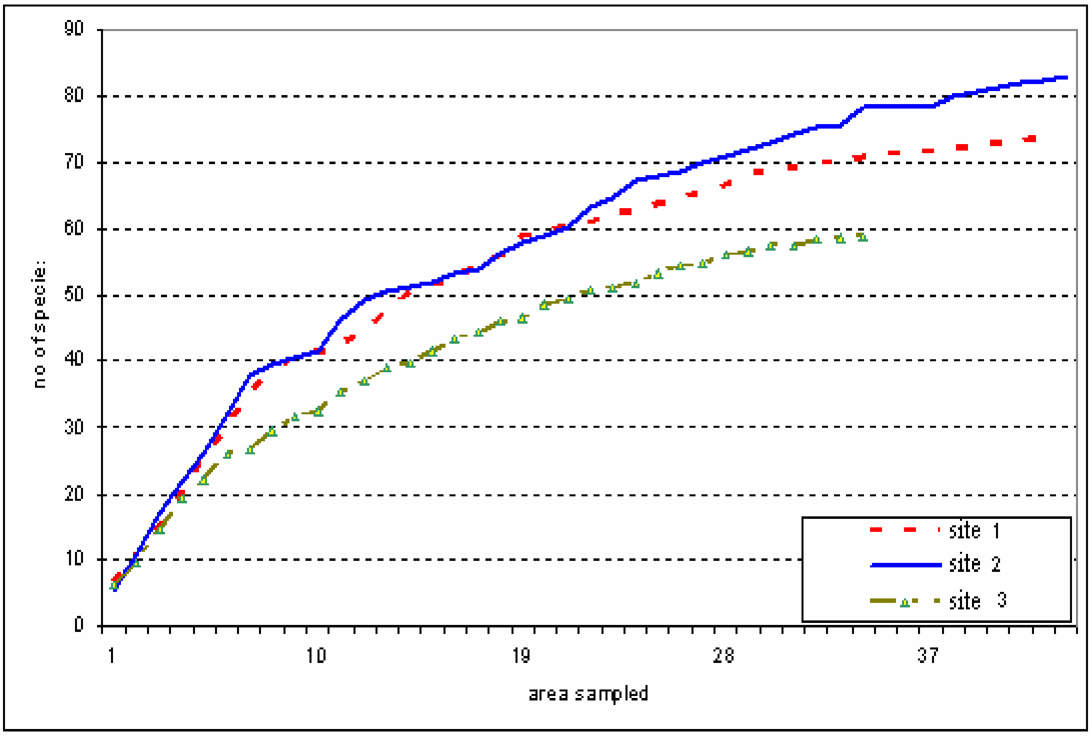


Figure 4.15 Curve of species versus number of sample plots for the three study sites. Site 2 was the most species rich and site 3 the least.

From above figure it can be seen that site 2 is the richest in terms of plant species and site 3 the least.

Most of the species of the study sites have been recorded in just the first few sampling plots, and the survey has captured the vast majority of plant species presented in the study sites. The number of species encountered did not increase with area, signifying that most species were counted before the total area was sampled. This suggests that most of plant species in the study areas are uniformly dispersed throughout the habitats (Scheiner et al., 2000). The great numbers of species were encountered at 30 sample plots. Thus, optimal number of 10 X 10m samples, which should be taken to be truly representative of each study site, is concluded to be 30.

4.3.8. Similarity between the three study sites and between the different landforms

From Figure 4.16, it can be observed that sites 2 and 3 are very similar to each other, with similarity of 50%. Site 1 showed a similarity of less than 46% with sites 2 and 3. The result is also shown in Table 4.8.

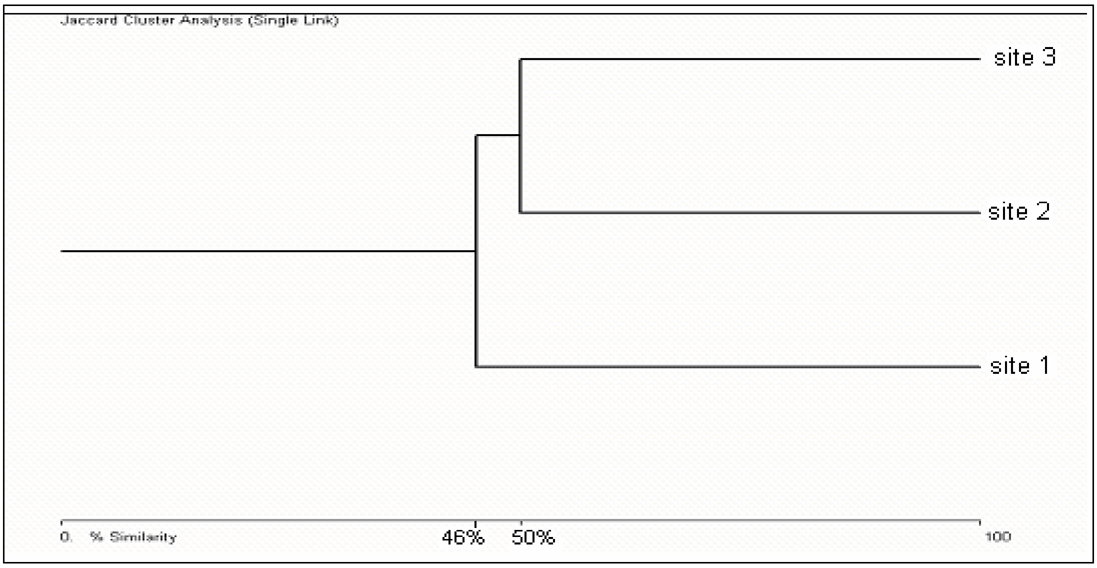


Figure 4.16. Cluster analysis based on the Jaccard distance analysis of the 3 study sites.

Step	Clusters	Distance	Similarity	Joined 1
1	2	50	50	2
2	1	54.8	45.2	1
Similarity Matrix				
	site 1	site 2	site 3	
site 1	*	44.0	45.2	
site 2	*	*	50	
site 3	*	*	*	

Table 4.8. Jaccard distance Index between the 3 study areas. A decline of similarity with increasing distance between areas is obvious. High similarity (50%) between area 2 and 3 and low similarity (44%) between area 1 and 2 can be seen.

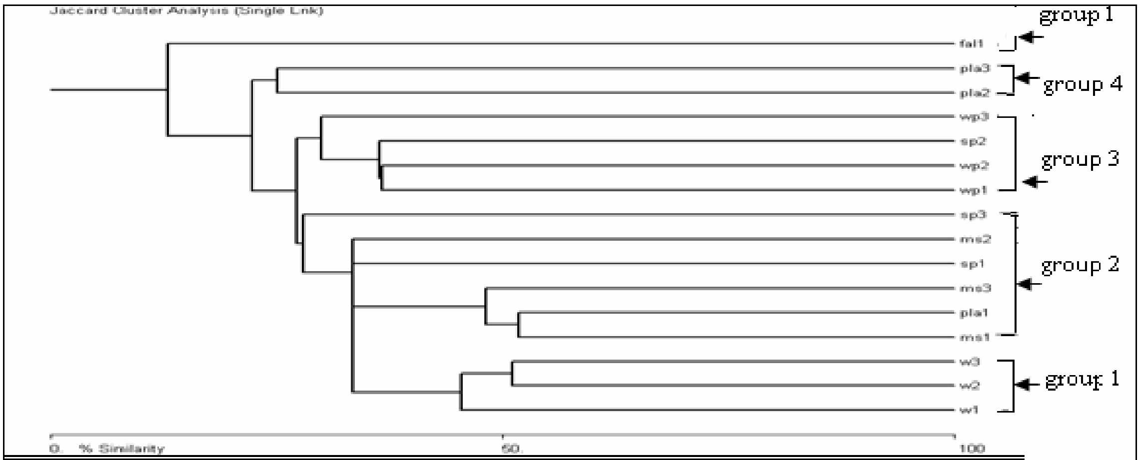
From Figure 4.17 we can see that there are 4 groups of similarities between the different landforms. These groups can be summarised as follow:

Group 1 comprises the main wadis of the 3 study sites (w1, w2, &w3) and cultivated fields of site 1(fal1) with a similarity between 45% and 51%,

Group 2 comprises mountain slopes of the 3 study sites (ms1, ms2 & ms3), plateau of site 1 (pla1) and slopes on the plateaus of site 1 and 3 (sp1 & sp3) with similarity between 33% and 52%,

Group 3 comprises secondary wadis of the three study sites (wp1, wp2 & wp3) and slopes on the plateau of site 2 (sp2) with similarity between 30% and 36% and

group 4 comprises plateaus of site 2 and 3 (pla2 & pla3) with similarity of 25%.



Step	Clusters	Distance	Similarity	Joined 1	Joined 2
1	15	48.28	51.72	ms1	pla1
2	14	48.89	51.11	w2	w3
3	13	51.72	48.28	ms1	ms3
4	12	54.72	45.28	w1	w2
5	11	63.41	36.59	wp1	wp2
6	10	63.79	36.21	wp1	sp2
7	9	66.67	33.33	w1	ms1
8	8	66.67	33.33	w1	sp1
9	7	66.67	33.33	w1	ms2
10	6	70.00	30.00	wp1	wp3
11	5	72.00	28.00	w1	sp3
12	4	72.97	27.03	w1	wp1
13	3	75.00	25.00	pla2	pla3
14	2	77.78	22.22	w1	pla2

Figure 4.17. Cluster analysis based on the Jaccard Analysis for the different landforms in the study sites. w = main wadi, fal 1 = palm groves and fields of area 1, ms = slope facing main wadi, pla = plateau, sp = slope on plateau, wp = secondary wadi. The number in front of each landform symbol refers to the study site. A decline of similarity with increasing distance between areas is obvious. The cluster above shows 4 landform groups of similarities, ms1 and pla1 and w2 and w3 are the most similar habitats, with similarity ranges between 51% to 52% and distance ranges between 48.3 and 48.9

The cluster above shows 4 landform groups of similarities in which ms1 and pla1 and w2 and w3 are considered as the most similar habitats over the study sites. The formers (ms1 & pla1) are characterised by low number of species ranging from 17 to 27 and the latter (w2 & w3) by high number of species ranging between 33 and 35 (Figure 4.9a). The least rich habitats are pla2 and pla3 with a number of species less than 3. Groups 1 and 3 are characterised by high number of individuals and richness.

As mentioned in previous floristic diversity section, site 1 was more diverse than sites 2 and 3; this is because the total number of individuals in site 1 is almost equally distributed between the most plant species (see section 4.3.5). The similarity between the different landforms has also close link with the number of plant species, for example the main wadis which are characterised by high diversity, high richness and relatively high evenness were grouped together (group 1), and the secondary wadis of the plateau, which characterised by high evenness, relatively high diversity and richness were grouped together (group 3), because of their high diversity index, the slopes of the plateau of site 2 were put with this group. The plateaus of sites 2 and 3 (group 4), characterised by low diversity and richness (see Figures 4.8 and 4.18).

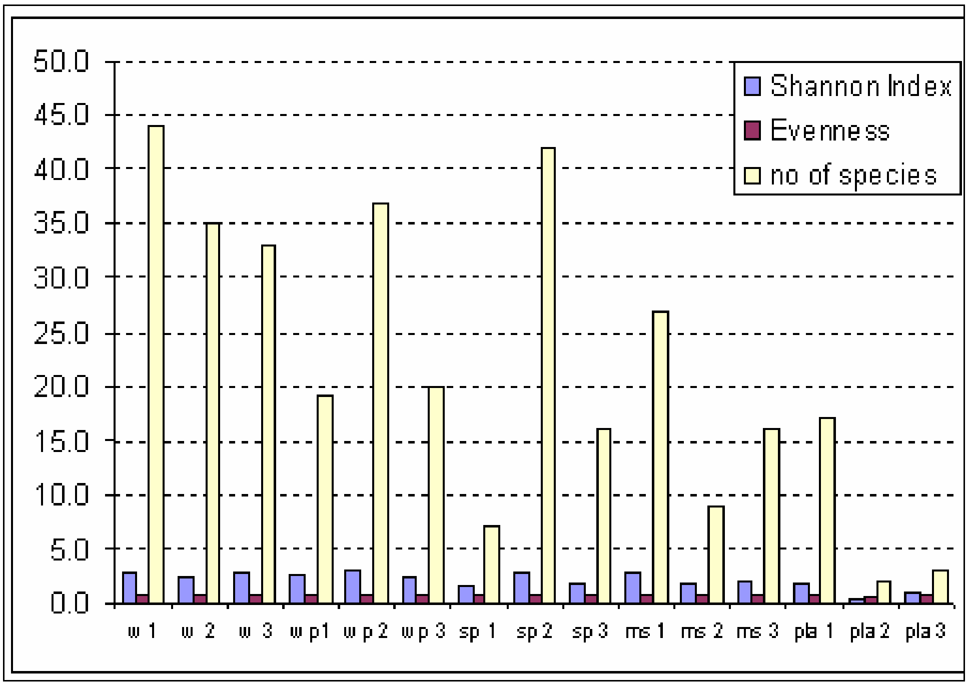


Figure 4.18. Diversity, evenness and number of species (richness) of the different landforms using Shannon index. w= main wadi, ms= slope facing main wad, pla= plateau, wp= secondary wadi, sp= slope on plateau. Main wadis and secondary wadis characterized by high diversity and richness, while the plateaus by low diversity and richness.

4.4. Summary

A total of 117 plant species were recorded in the 3 sites of the study area, of which 5 are endemic to Hadhramaut. The density and the distribution of these species were different from one study site to another, as well as from landform to another. The landforms with their component such as moisture were the main factors affecting the distribution and the density of plant species. Human activities play an important role in some sites.

Most of the plant species of the study sites are desert-adapted species which botanists have classified as Saharo-Sindian, or Saharo-Arabian (Zohary, 1973). Some of these species are of African origin. These species have adapted to the current harsh climate. As a result, many of these plants are now so adapted that they cannot live outside of the arid and semi-arid region that characterises the study area. On the other hand, some of these species do not exist in other parts of the world and these are considered as endemic. The following are endemic and near-endemic species of the study area:
Acacia campoptila, Boerhavia elegans subsp *elegans, Anogeissus bentii, Aerva artemisioides subsp artemisioides, Cucumis canoxyi Euphorbia rubriseminalis, Farsetia linearis, Iphiona anthemidifolia, Reseda sphenocleoides, Ziziphus leucodermis. Merremia hadramautica* and *Fagonia hadramautica.*

The plant species composition varies according to topography and drainage, soil nutrient status and environmental hazards (Furley, 1999). Variation in plant species from one landform to another and within one landform is obvious in the study sites. For example, the following 2 species are well represented in the 3 study sites: *Stipagrostis hirtigluma* and *Dichanthium insculptum;* they are particularly on plateaus and mountain slopes facing the main wadis, with a considerable variation in abundance from landform to another (see table 4.9). Both species are considered to be the most important plants in the study sites. *Acacia campoptila* is one of the most abundant species recorded in the wadis, where it has a mean frequency of 81%. The Importance Value Index of each plant species was calculated to determine the importance of each plant species in the study sites; this indicated that *Stipagrostis hirtigluma, Dichanthium insculptum, Cleome* *brachycarpa* and *Farsetia linearis* are the most important plant species in the study sites.

Species richness is higher on the valley floor in both the main wadis and the secondary wadis and was low on mountain slopes, plateaus and slopes of the plateaus.

	w1		ms1		pla1
Tephrosia apollinea	48	Stipagrostis hirtigluma	32	Stipagrostis hirtigluma	89
Zygophyllum album	38	Aerva javanica	31	Farsetia linearis	38
Tephrosia dura	25	Fagonia indica	29	Boerhavia elegans	29
Acacia campoptila	19	Boerhavia elegans	25	Dichanthium insculptum	24
Fagonia indica	19	Farsetia linearis	24	Fagonia indica	20
	wp1		sp1		field
Cymbopogon schoenanthus	47	Cleome brachycarpa	90	Phoenix dactylifera	69
Dichanthium insculptum	36	Stipagrostis hirtigluma	57	Prosopis farcta	35
Fagonia paulayana	27	Seetzenia lanata	39	Alhagi graecorum	34
Chrozophora tinctoria	23	Boerhavia elegans	37	Cynodon dactylon	28
Acacia mellifera	19	Dichanthium insculptum	28	Senra incana	22
	w2		ms2		pla2
Blepharis edulis	55	Dichanthium insculptum	76	Stipagrostis hirtigluma	221
Acacia campoptila	52	Stipagrostis hirtigluma	50	Farsetia linearis	79
Fagonia indica	24	Cleome brachycarpa	42		
Indigofera spinosa	24	Indigofera spinosa	33		
Ochradenus baccatus	16	Farsetia linearis	25		
	wp2		sp2		
Aristida triticoides	39	Dichanthium insculptum	50		
Chrysopogon aucheri	30	Stipagrostis hirtigluma	27		
Dichanthium insculptum	30	Farsetia linearis	23		
Stipagrostis hirtigluma	23	Zygophyllum decumbens	23		
Pulicaria undulata.	17	Indigofera spinosa	21		
	w3		ms3		pla3
Tephrosia nubica	53	Stipagrostis hirtigluma	47	Stipagrostis hirtigluma	174
Indigofera spinosa	30	Cleome scaposa	45	Cyperus conglomeratus	73
Acacia campoptila	27	Fagonia paulayana	40	Aerva artemisioides	53
Blepharis edulis	23	Boerhavia elegans	30		
Merremia somalensis	21	Enneapogon desvauxii	29		
	wp3		sp3		
Stipagrostis hirtigluma	59	Dichanthium insculptum	101		
Dichanthium insculptum	34	Stipagrostis hirtigluma	62		
Kohautia retrorsa	23	Jatropha spinosa	26		
Crotalaria saltiana	20	Halothamnus bottae	20		
Boerhavia elegans	19	Enneapogon desvauxii	15		

Table 4.9. Most important plant species in the 3 study sites with their importance values per hectare. *Stipagrostis hirtigluma* and *Dichanthium insculptum* are well represented in the 3 study sites. *Acacia campoptila* was one of the most abundant species recorded in the wadis.

The diversity of main wadis and the secondary wadis is high. In these landform systems, the complex micro-landforms such as minor depressions, terraces, colluvial and alluvial deposits and levees which lead to accumulate moisture and nutrients or salinity, can help in creating significantly higher species richness than the adjacent slopes (Furley, 1974; Goebel et al., 2003). Compared to the rest of the mountain slopes, the slopes of site 1 have high diversity. The mountain slope of sites 2 and 3 are more subjected to overgrazing by local herders and nomadic Bedouins. The structure of vegetation of this habitat cannot resist overgrazing, and consequently the vegetation cover has been reduced dramatically. The diversity of the slopes on the plateaus (sp) is medium to high and ranges between 1.6 and 1.8. Here the diversity on slopes of site 1 is the lowest. The diversity of slopes of site 2 is high. The plateaus generally have the lowest diversity. The diversity calculated for the plateaus (pla) of site 1 is higher than for sites 2 and 3. Generally, most of the surfaces on the plateau of sites 2 and 3 are almost devoid of vegetation. The diversity of slopes of site 2 was high due to the increase of moisture content in one sample plot. This plot is regularly irrigated by contaminated water from the oil workings (plate 4.1). The plateaus generally have the lowest diversity. This could be due to physical factors, which are characterised by high proportion of exposed hard jagged limestone, dolomite and chert fragments with thin soil and a high proportion of sand and stones (plate 4.2). The plateau of site 2 contained the lowest diversity; this could be (in addition to the physical factors), due to the intensive activities of oil workings, (see section 4.3.5).

Phytogeography attempts to divide the globe into natural floristic units (Miller and Cope, 1996). According to Zohary (1973), the Hadhramaut region falls within Saharo-Arabian (covering the northern plateau) and Nubo-Sindian province of Sudanian-region (covering the southern plateau). Most of the Sahro-Arabian elements (Holarctic origin) are found in the main wadis, while most of the Sudanian-region (Paleotropical origin) elements are found on the plateau. The northern limit of the Sudanian-region can be drawn with latitude ranging from 15° 49’ to 15° 50’ on the plateau of site 2.

The flora of the study area has strong links with adjacent parts of Africa and Arabia but some species and genera have interesting distributions for example, *Ochradenus baccatus* which is restricted to the main wadis of sites 2 and 3 has a typical Saharo-Sindian distribution (Miller, 1984) being found in the deserts of eastern north Africa, Somalia, Sudan, Egypt, the Gulf countries, Iran and Pakistan (Miller, 1984). The related species is the near-endemic *Ochradenus arabicus*, and is found in the southern part of the Hadhramaut region and in Oman, Saudi Arabia and UAE, the distribution patterns of this species is associated with fog-affected areas. There are several local endemics of Ochradenus in southern Arabia including *O. aucheri* subsp. *aucheri* from

UAE and Oman, *O. harsusiticus* and *O. gifrii* from Oman (Ghazanfar, 2004; Miller, 1984) and al Mahara, Yemen (Thulin, et al., 2001). The endemic *Aerva artemisioides* subsp *artemisioides* has wide range distribution, but with very low frequency, for example in the study area it was only found in 2 locations. There are 2 sub species of *Aerva artemisioides*: subsp. *artemisioides*, which is endemic to Hadhramaut and subsp. *batharitica*, which is endemic to central Oman. *Cucumis canoxyi* is an endemic. It has a wide distribution from the southern mountains at 615 m asl to study site 2 at 950 m.

It has previously been noticed that some plant species have relatively high values for density and a low frequency. Low frequency of plants means unequal distribution over the study areas. For example *Blepharis edulis* has high density values in sites 2 and 3 but is not well distributed (low frequency). This plant is only abundant in rocky habitats in the main wadis and less common or absent from other habitats. This also can be seen in other species such as *Indigofera spinosa* and *Tephrosia apollinea,* which are found mainly on wadi beds and on relatively moist sites.

In this chapter the floristic composition of the study sites, their important values and the abundance have been described and analysed, as well as the plant diversity, and the vegetation fond over each landform in the 3 study sites have been assessed. In the next chapter the plant species that been identified in chapter 4 will be further explored in terms of association and structure, in order to recognize the types of vegetation and the structure of plant communities of the study sites.

Chapter 5. Vegetation associations: structure and environment analysis

5.1. Introduction

This chapter presents the results of the study of floristic vegetation associations and structure in the three study sites located at Wadi Hadhramaut, namely Shibam (site 1), Wadi Adim (site 2) and Wadi Athahab (site 3). The aims of this chapter are to answer the following research questions:

- What are the types of vegetation and the structure of plant communities?
- What are the factors and processes affecting vegetation change?
- What has been the nature of land use change and how has it affected plant composition and distribution?

The structure of the presentation is illustrated in Figure 5.1.

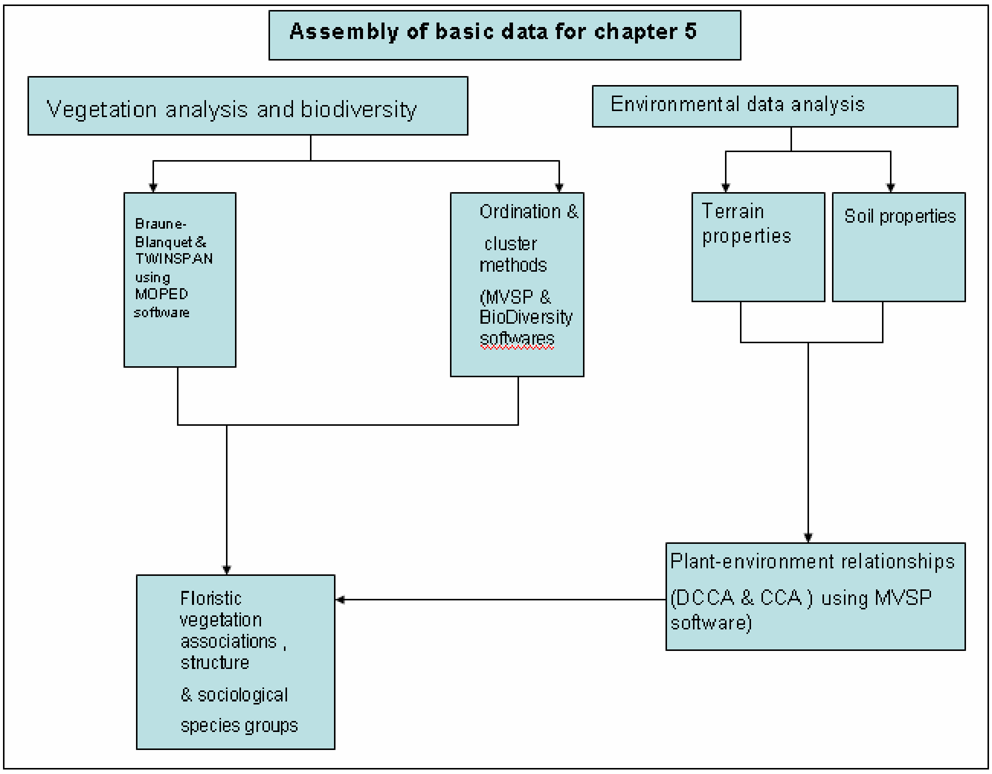


Fig. 5.1 Diagram showing the structure of this chapter

The main aims of vegetation sampling were to identify plant species and their density cover, and to explain the locality of these plant species.

There are many sampling techniques that study the vegetation and its relationship to environment; each method has its strengths and limitations but the most important are:

1. quadrat methods,
2. transect methods,
3. point-intercept methods,
4. line-intercept methods,
5. plotless methods.

Quadrat methods have been the most widely used by plant ecologists (Lisa and Susan, 2001). The size of the quadrat varies from one habitat to another and there is considerable discussion as to the most appropriate quadrat size for local type of vegetation. For example, sparse vegetation required small quadrats (10x10 m) and dense vegetation required larger quadrats (50x50 m) in the work reported by Van Gils et al., (1985) in order to cover the area studied and include significant numbers of plant species. Mueller-Dombois and Spatz, (1975) suggested a size of 400 m2 for shrubland, 200 m2 for grassland and 100 m2 for savanna, While Kent & Coker, (1992) suggested 1mX1m-4mX4m for grassland and 10mX10m for scrub and shrubland, but there can be significant differences in the tree-shrub-herbaceous plant cover in these biomes which would affect the size of sample plot. Species-area curve method (Kent & Coker, 1992, see Appendix 6 was applied to estimate the optimum size of quadrat for the vegetation of the study area, the method showed that 10X10m quadrat was adequate for sampling about 50 to 60% of the plant specie recorded in the study area.

Transect methods have been used to measure the vegetation across sites where there are rapid changes in landforms and vegetation and are recommended as being less time-consuming than using quadrats.

The point-intercept method is objective and rapid but more time- consuming than quadrat or transect methods. It is not recommended for cover less than 5% or greater than 35% (Diersing et al., 1992).

Line-intercept methods are suitable in sparse vegetation and for species with a relatively large basal area. It is considered suitable for dense herbaceous species. (Canfield, 1941).

Plotless sampling is appropriate for the inventory of trees and woody shrubs in sites of forest and savannah woodland ecosystems (Cottam and Curtis, 1956; Kent and Coker, 1992) or for measuring species abundances (Eldridge et al., 2003), and is used if the delineation of a sample plot is not possible (Van der, 2004).

A combination of transect and quadrat methods were selected in this study because they are consistent with the Braun-Blanquet approach, which can include information on topography such as slope, aspect, soil and meso-climate.

5.2. Methodology

5.2.1. Transect approach

Transect surveys has been shown to be extremely successful in studies of vegetation, especially across sloping terrain and other vegetation gradient (Kent & Coker, 1992). In the present study sites, the sharply defined topographic units lend themselves to a cross sectional transect approach. The methodology used for the vegetation transects in the present study has been adapted from that used by the Forest Planning and Management Project in Belize (Furley, 1974; Goldsmith et al., 1986). After preliminary reconnaissance, transects were located over the plateau and the main wadi. Each transect was 10 m in width. Transects were chosen to cross the region and identify major vegetation communities in the different landforms (Figure 5.2b).

Because of the sparse cover of vegetation, the transects were 5700 to 9600 m long in almost straight lines over the plateau (pla) and the drainage lines (wp), with an additional 2000 to 3500 m cutting the width of the main wadi and adjacent slopes (ms). In places with insufficient land for a given topographic unit, additional horizontal lines orthogonal to the main lines were made or additional sites were added (Figures 5.2 b and c).

Figure 5.2a. General 3D view, showing the different landscape units over the plateau and the main wadi (Source NASA world wind.com).

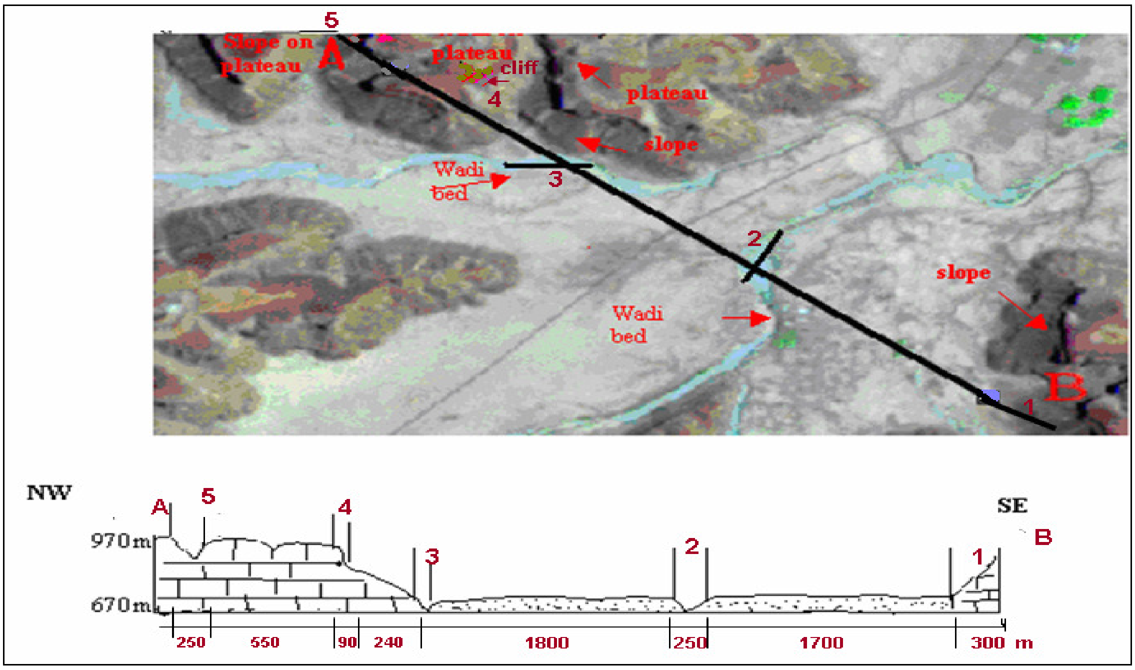


Figure 5.2b. Idealized representative transect illustrating the main landform units in the study sites. The transect line is shown cutting the same topographic units as depicted in Figure 5.2a. 1= mountain slope, 2= wadi bed, 3= wadi bed, 4= cliff, secondary wadi on plateau and adjacent slope.

A total of 3 transects, 10 m wide, were selected. At each transect, sampling points were established at 100 m intervals. The locations of the transects were selected according to accessibility to the plateau and to reflect the characteristic vegetation zones. This was considered sufficient to represent the region in an area of relatively uniform physiographic relief and vegetation distribution (Fig. 5.2 a & b). The selected transects represent the vegetation of the entire study area (Wadi Hadhramaut), reflecting the different geological and topographical zones. The sample points were approximately 10x10 m.

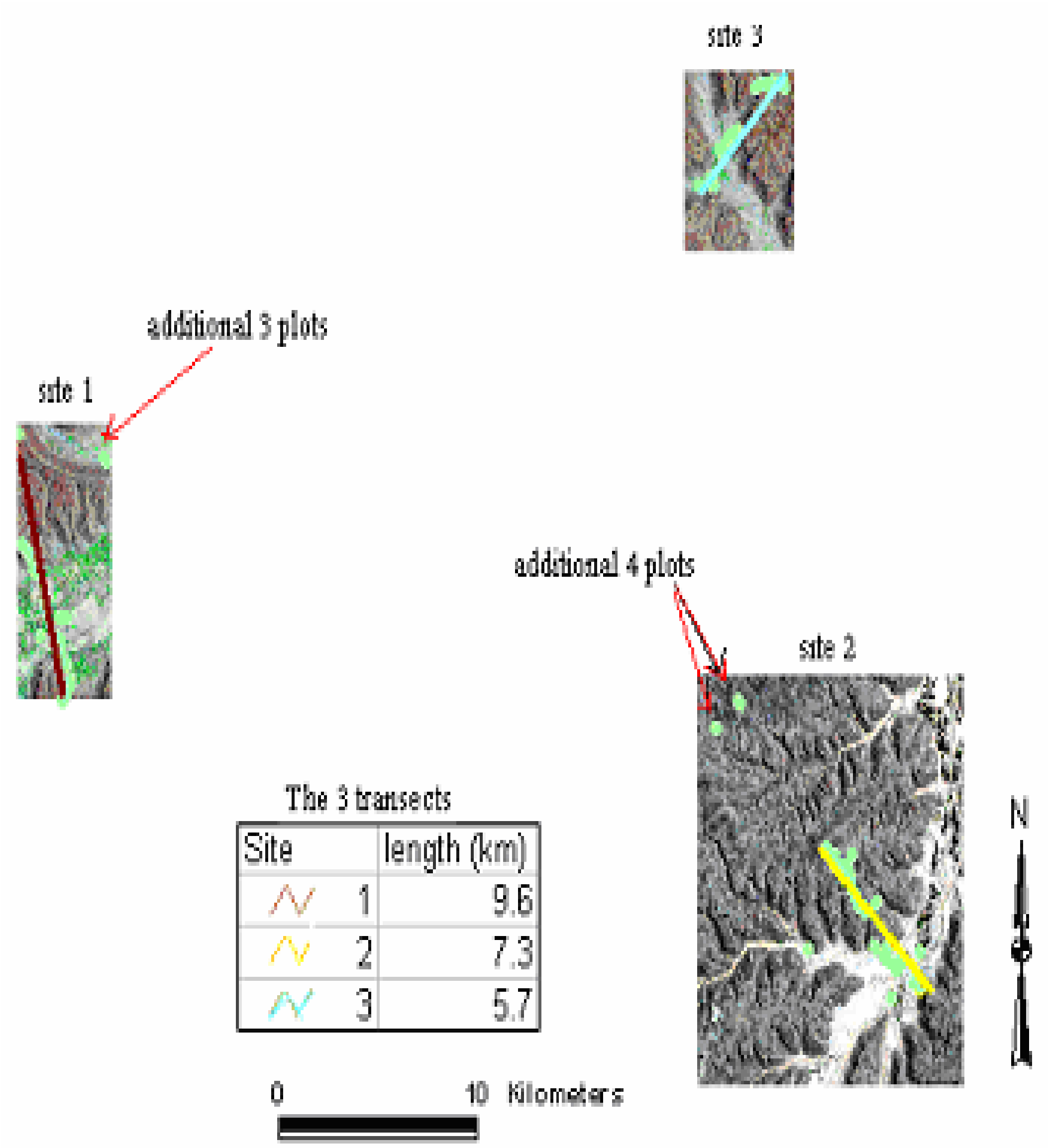


Figure 5.2c. The length of the 3 transects across the study sites. The transects were 5700 to 9600 m long in almost straight lines over the plateau (pla) and the drainage lines (wp). In places with insufficient land for a given topographic unit, additional horizontal lines cutting the main lines were made or additional plots were added. For example, 4 sample plots were added in sites where oil activities are going on (site 2) and 3 sample plots where there is insufficient natural wadi along selected transect (site 1). The site 1 transect mostly passes through the agricultural fields of the main wadi.

5.2.2. Braun-Blanquet approach

The Braun-Blanquet approach (1932) for classification and data collection of vegetation has been used recently in Yemen by Westinga and Thalen, (1980), Kessler, (1987) and Al Khulaidi, (1989, 1992, 1993, 1996 and 1996). Many vegetation studies in the world have been conducted using this approach and have been accepted as being suitable for illustrating vegetation communities. The Braun-Blanquet approach includes information on topography such as slope, aspect, soil and climate and was and is still very useful for classification of plant communities and can be used to estimate abundance and species composition.

5.2.3. Data collection

With the aid of a vegetation data sheet the following variables were measured and recorded in the field:

- Terrain (land form by field observation according to the categories, slope percentage using Suunto Clinometer; exposure using compass and altitude; latitude and longitude using Geographical Positioning System (GPS).
- Soil (texture, depth, type of erosion, surface stoniness).
- Vegetation cover, expressed as a percentage of each plant species estimated by using the ITC modified Braun - Blanquet cover/density scale (Van Gils et al., 1985 and Zonneveld, 1986) (Table 5.1).

To facilitate the identification of the maximum number of species, four visits were made to these sample sites, July and December (2003) and January and April (2004).

1- density if cover more than 5%	
Cover sample	Cover %
1	10 (5 -15)
2	20 (15 - 25)
3	30 (25 - 35)
4	40 (30 - 35)
5	50 (45 -55)
6	60 (55 - 65)
7	70 (65 -75)
8	80 (75 - 85)
9	90 (85 - 95)
10	100 (95 - 105)
2- density if cover less than 5%, m = many, a = abundant, p = poor, r = rare	

Table 5.1. ITC modified Braun - Blanquet Scale cover/density (Van Gils et al., 1985 and Zonneveld, 1986). Cover density was assessed for each plant species encountered.

Soils from 37 sample plots representing the different landforms were collected at depth of 10 to 20 cm and analysed by the soil laboratory of Agricultural and Extension Authority, regional station, Taiz (Yemen). The following analyses were under taken and were considered to give a preliminary over view of the soil conditions.

Texture, pH, Ec, CaCO3 %, O.C % and CeC.

5.2.4. Methods of soil Analysis

Textural analysis, by hydrometer method.

pH- determination: by pH meter using 1: 1soil water ratio suspension.

Electric conductivity (Ec in ms /cm): by conductivity meter using 1:1 soil-water ratio suspension.

Calcium carbonate: by acid- neutralization using hydrochloric acid.

Organic carbon: by the Walkley-Black method.

Soil moisture content: oven drying at 105°c for 24 hours.

Cation Exchange Capacity by barium acetate saturation and calcium replacement.

5.2.5. Vegetation analysis

The first stage was the grouping together of a set of observational units (in this case, quadrats or sample plots) on the basis of their common floristic composition (Kent & Coker, 1992).
There are many and varied methods for carrying out vegetation classification based on floristic characteristics, and the results were initially drawn up as a raw-data matrix.

Braun-Blanquet

The Braun-Blanquet classification method shows relatively clear vegetation associations and sociological group structures, with dominant species and with species that are confined to specific associations, facilitating the labelling of associations with appropriate names.
The following method was used to survey the plant cover based on the Zurich-Montpellier (Kent & Coker, 1992) or Braun-Blanquet school (Zonneveld, 1989):-

1. plant species were identified and entered in rows and sample plots were entered in columns of an initial matrix (Table 5.2).
2. density/cover symbols for each plant species and environmental data such as altitude, aspect, exposure, stoniness and rock outcrops for each sample plot were added.
3. sample plots with a high similarity of plant species composition were placed side by side.
4. Plant species with similar patterns in quadrat plots were aggregated.

Rearrangement of plots and plants species in the matrix was continued until a diagonal matrix of mutually discriminate clusters of both plots (called vegetation types or associations or plant communities as defined by Kent & Coker, (1992) and a group of plant species (taxa) that are more or less similar in behaviour and called sociological species groups (Zonneveld, 1989) were derived (Table 5.3). Floristic vegetation associations are labelled by the dominant species (the second name) and by the species almost exclusively occurring in the association (the first name).

Even though the tabular rearrangement of association groups was based on the basis of floristic composition data, the associations which resulted reflect certain environmental conditions such as moisture, landform, altitude and soil.

Sample plots

Plant species	1	2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Prosopis farcta																										m	r	c		2		r							m							c
Phoenix dactylifera																												3	c			c							9							
Convolvulus arvensis																													r										r							
Cressa cretica																												c	r	c																
Withania somnifera																																							r							
Rhazya stricta	c	c						r					r	c	r	c	c	c	r																			c				c	r		c	
Datura innoxia																																							r							
Senna incana																							r				a	c				c														
Alhagi graecorum																										r	1		r	c									a							
Citrullus colocynthis																										r														r						r
Ziziphus spina-christi																										r						r		r												
Dipterygium glaucum		c														r			r							c					c									r		r				r
Acacia campoptila	r	r	c	c	r	c		c	a	c	2	r	a	c	c	r	a	c	c			c	c	c									c	c	5		c	c			c	1	c	c	c	
Tephrosia apollinea	c		r						m	c							a	c	c		1	a	a	a		r			r		c		a	m						r	a		c		a	
Tephrosia dura			r																		c	1	a	a									a	c							r					
Dichanthium insculptum	c			c																				c										c							c					
Kohautia retrorsa					r																r													c							c			c	c	
Barleria aff bispinosa											c											c																			c		r			
Cynodon dactylon																													a										2							
Zygophyllum album																						a	c		a	c														1	r					3
Calotropis procera									c																r	r									r					r						
Cymbopogon schoenanthus	r		c									r					c		r		r	c	r	r									c	c			c					c			r	
Acacia hamulosa																						a												c							r					
Senna holosericea					r						r					r		c		c															c											
Tribulus arabicus		c					c				c			c					r																	c										
Salsola imbricata						r	r	c																												r						r	r			
Blepharis edulis	c	m			c		a	1		1												r														1							c	a		
Aerva javanica	c	r	c			c						r				r				c	r																	r						r	c	
Aristida triticoides				c			c																			r?																		c		
Heliotropium ramosissimum						r																															r				r		c	c		
Panicum turgidum											c	r								r					r	c											a								c	
Merremia somalensis	r			c	r							c																									a	c						c	c	
Cassia italica	c												c						c			c							r									r				c	c	a	c	
Halothamnus bottae											r																																r			
Cleome brachycarpa	c	r			c						c									c																							r			
Ochradenus baccatus									c				c	c				c																	c							c	c		r	
Boerhavia elegans	c							r			r								c			c														c					r		c	c		
Zygophyllum coccineum																						a	c	c									c													
Heliotropium rariflorum																										r					r									r						
Prosopis juliflora																	c								r	r																				
Capparis spinosa																												c											c							
Tamarix aphylla									c																r	r														`						
Fagonia paulayana	c	c			c	r	r	c			c		c		a	r	c		c	r	r	c	r	c			r		c		r		c	c	c	r	r				c	a	c	m		
Acacia ehrenbergiana														c	r		a	r	r		a					r									c											
Cleome scaposa	c	c				r					r			a		r			r																											
Plicosepalus curviflorus									c										c																r											
Indigofera spinosa	a	c			c	c			a	1	a	r							c	c																	a	c				m			m	
Tephrosia nubica	c		m	1	a						c	c								c																	2	1			c			c	a	
Cleome droserifolia				r		r																															r									
Ziziphus leucodermis	r			r									r																									r				r			c	

Table 5.2. An initial matrix of plant species and samples in order to demonstrate the methodology employed. key: density if cover less than 5%, m = many, a = abundant, c = occasional (= poor), r = rare; density if cover more than 5%, 1= 10(5-15%), 2= 20(15-25%) etc. (see table 5.1).

		vegetation association																																													
	sample plot	30	40	29	31	28	33	27	47	26	32	41	25	34	24	23	42	35	22	20	18	16	19	15	36	14	43	10	17	9	11	37	8	44	7	2	12	21	6	13	3	38	45	5	46	39	1
	altitude	670	690	722	720	707	703	680	700	671	700	670	733	729	723	705	686	683	683	673	673	643	679	686	624	645	650	654	681	632	692	668	668	640	644	644	657	651	579	646	655	620	662	626	620	583	668
	Aspect	e	e	e	e	e	e	n	e	ne	e	ne	ne	ne	ne	n	ne	ne	n	e	n	ne	ne	n	ne	se	e	nw	e	sw	w	s	s	se	se	se	s	sw	e	sw	sw	sw	w	nw	sw	e	se
	slope %	0	0	0	0	0	0	2	3	1	1	1	10	3	3	2	2	3	1	2	2	1	3	3	1	3	2	3	2	2	2	1	1	5	3	1	1	2	2	1	2	5	2	5	2	1	2
	surface stoniness	1	1	0	0	0	0	0	0	3	0	5	85	90	70	60	90	80		95	80	55	15	3	10	0	70	30	95	70	80	90	75	70	0	80	80	70	85	60	95	70	70	95	80	50	90
	rock outcrops	0	0	0	0	0	0	0	0	0	0	0	6	7	5	0	0	0		0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	2	0	0	0	9	0	0	0
	erosion	r	r	r	r	r	r	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f
	trees	<1	90	30	0	0	0	<1	0	<1	0	0	1	1	5	7	1	2	3	1	10	1	3	7	7	20	30	2	1	1	3	0	0	1	1	<1	2	0	<1	<1	<1	2	1	<1	7	1	<1
	shrub	0	0	0	0	0	0	0	0	1	0	0	15	30	20	10	0	7	1	0	0	0	1	0	3	10	5	3	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	2	0	2
	dwarf shrub	0	1	15	30	25	0	0	0	0	0	0	0	0	0	5	2	0	0	2	0	1	0	3	0	1	5	0	2	0	30	0	0	1	1	0	5	2	3	3	15	30	1	10	7	30	2
	herb	5	1	1	<1	5	2	5	50	3	2	8	3	10	15	5	2	5	10	5	3	2	1	<1	1	0	1	5	<1	4	5	<1	<1	2	3	3	<1	<1	<1	<1	0	<1	1	<1	1	1	3
	Prosopis farcta		m	c	2	r	r	m	c																																						
	Phoenix dactylifera □	c	9	3			c																																								
	Alhagi graecorum	r	a		c	1		r																																							
	Senna incana			c		a	c								r																																
	Cressa cretica	r		c	c																																										
a	Cynodon dactylon	a	2																																												
	Capparis spinosa		c	c																																											
	Convolvulus arvensis	r	r																																												
	Datura innoxia		r																																												
	Withania somnifera		r																																												
	Zygophyllum album							c	3	a		1			c	a	r																														
	Prosopis juliflora							r		r											c																										
	Citrulus colocynthis							r	r			r																																			
b	aff Heliotropium sp. Tiny							r			r	r																																			
	Tamarix aphylla							r		r		`																c																			
	ziziphus spina-christi						r	r										r																													
	Dipteregium glaucum							c	r		c	r								r							r		r							c											
c	Calotropes procera							r		r		r													r			c																			
	Acacia campoptila												c	c	c	c	c	c		c	a	c	c	c	5	a	1	a	r	c	c			c	c	r	2		r	r	c	c	c	c	c	c	r
	Fagonia ovalifolia	c				r					r		c	c	r	c	c	c	r	c	c	a			c	c	a		r	c		r	r	c	r	c	c	r	c			r	m				c
d	Tephrosia apollinea	r						r			c	r	a	a	a	a	a	m	1	c	a		c					m			c			c							r				a		c
	Zygophyllum coccineua												c	c	c	a																															
e	Tephrosia dura												a	a	a	1	r	c	c																						r						
f	Cymbopogon schoenanthus												r	c	r	c		c	r	r	c						c													r	c	c			r		r
	Dichanthium insculptum												c				c	c																										c			c
g	Boerhavia elegana															c	r			c										r		c		c			r						c				c
	Kohautia retrorsa																c	c	r																				r				c?		c		
	Acacia hamulosa															a	r	c																													
h	Barleria aff bispinosa															c	c																	r			c										
i	Acacia ehrenbergiana							r											a	r	a	r	r	c	c																						
	Rhazia stricta																			r	c	r	c	c		r	c		c	r				r		c									c	c	c
	Ochradenus baccatus																						c	c	c	c	c	c						c											r		
g	Cassia adenensis																						c		c				r								r	c	r								
	Cleome scaposa																			r				a					r						r	c	r										c
k	Tribulus arabicus																			r				c								c	c			c	c										
l	Plicosepalus curviflorus																			c					r			c																			
m	Salsola imbricata																										r			c		r	r	r	r												
	Indigofera spinosa																			c							m	a			1				c	c	a	c	c	r		a			m	c	a
	Blepharis edulis															r														1	1	1	a	c		m			c				a				c
n	Cassia italica	r														c				c						c	c							c									a		c	r	c
	Aerva javanica																		r										r						c	r		c		r	c		r		c	r	c
	Cleome brachycarpa																																	r		r	c	c	c								c
	Aristida tritioides							r																									c										c	c			
	Cleome droserifolia																																		r							r		r			
	Halothamnus bottae																																	r			r										
o	Heliotropium ramosissimum																r																	c	r							r	c				
	Tephrosia nubica																c																				c	c	a	c	m	2	c	1	a	1	c
	Merremia somalensis																																						r	c		a	c	c	c	c	r
	Panicum turgidum							c		r																											c	r		r		a			c		
p	Ziziphus leucodermis																									r	r																	r	c	r	r

Table 5.3. The final matrix of vegetation based on plant species and sample plots as derived from Table 5.2 to demonistrate the methodology. vegetation associations (1 - 7) in the columns versus sociological species groups (a to p) in the rows. key: density if cover less than 5%, m = many, a = abundant, c = occasional (= poor), r = rare; density if cover more than 5%, 1= 10(5-15%), 2= 20(15-25%) etc. (see Table 5.1).

Twinspan

Traditional approaches to plant classification often use ordination (e.g. Twinspan) analysis to investigate plant communities and the environmental gradients influencing species composition. Twinspan produces good results if rare species are removed (Kent & Coker, 1992). For example, study of the vegetation of Egyptian salt marshes (Abd El-Ghani, 2000) using Twinspan performed well by excluding species that covered less than 5%. The Twinspan method proved to be very sensitive to changes in the parameters defined (Pitkänen, 2000) for the classification. So running Twinspan with different optional settings such as different number of species, different level of divisions or group size produced data with different groups. In Twinspan analysis, the first two or three higher levels tend to be valid with relevant ecological meaning, but the lower levels can sometimes seem quite illogical (Dr. Colin Legg, personal contact).

Cluster and Ordination analysis

These are exploratory data analysis tools for solving classification problems. Their object is to sort plant species into groups, or clusters, so that the degree of association is strong between members of the same cluster and weak between members of different clusters (Kent & Coker, 1992).

Modern computer programs can cope with large databases for classification of vegetation, with methods based on mathematics and statistical analysis (Kent & Coker, 1992), and the results of this classification strongly depend on the structure of the data (Lubomir, 2002).

Cluster classification was conducted by means of Cluster Minimum Variance analysis and Square Euclidean Dissimilarity Criterion, using the statistical software of the Multi-Variate Statistical Package (MVSP) version. 4.2, and by Bray-Curtis Similarity using BioDiversity Professional Beta (McAleece, 1997; Kovach, 1985). Kent & Coker, (1992) found that the Minimum Variance analysis method is the optimal for similarity analysis and makes most ecological logic. BioDiversity Professional Beta software using Bray-Curtis similarity Group-Average clustering was applied to compare the main floristic associations. Bray-Curtis was used because it is offers an acceptable coefficient for biological data on community structure (Cheng, 2004).

Detrended Correspondence Analysis (DCA) is an ordination method and was conducted using statistical software of MVSP version 5.2. The DCA analysis is intended to avoid what is called the arch effect, in which the points are arranged in an arched pattern along the first two axes, rather than a linear pattern (Kent & Coker, 1992).

Environmental data analysis

Canonical Correspondence Analysis (CCA) is a package of relatively recent ordination techniques developed by ter Braak (1986). It is a multivariate direct gradient analysis method that has become very widely used in ecology (Kent & Coker, 1992; ter Braak and Smilauer, 1998). This method is derived from correspondence analysis (CA), but has been modified to allow environmental data to be incorporated into the analysis. These comparisons are achieved by performing statistical package of MVSP version 5.2.

The results of CCA can be presented in a diagram containing the environmental variables plotted as arrows originating from the centre of the graph, along with points for the sample plots and plant species. The relationships between the samples and species are as in CA; each sample point lies at the centroid of the points for species that occur in those samples. The arrows representing the environmental variables indicate the direction of maximum change of that variable across the diagram. For example in Figure 5.3 there is clear arrow for altitude to the left of the diagram; this indicates that altitude is increasing along a gradient from the right to the left.

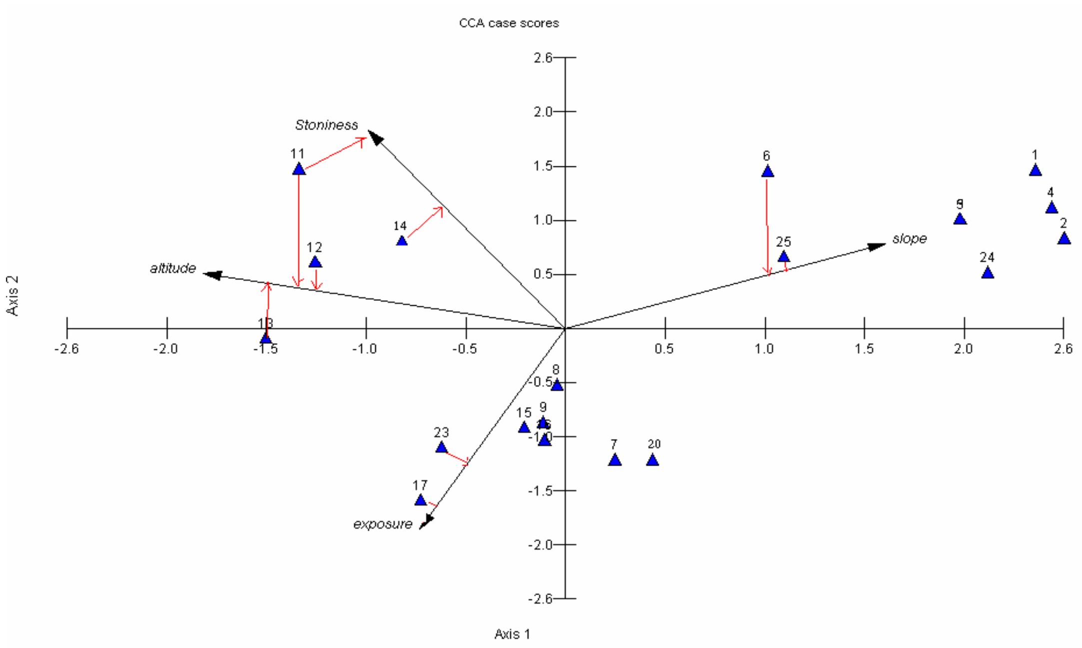


Figure 5.3. Example of CCA ordination diagram. The arrows represent the environmental variables with the direction of maximum change of that variable across the diagram. In this example the arrow for altitude is increasing along a gradient from the right to the left and a long altitude arrow indicates a large change and indicates also that the change is strongly correlated with axis 1 and therefore with the plots 12 and 13. Slope percentage is strongly correlated with ordination axis 1 and increasing along a gradient from the left to the right.

The length of the arrow is proportional to the rate of change, so a long altitude arrow indicates a large change and indicates that change in altitude is strongly correlated with the ordination axes and thus with the association variation shown by the diagram. Points with their vertical projections near to or beyond the tip of the arrow will be strongly associated with the environment that is represented by this arrow. Those at the opposite end will be less strongly associated (Kent & Coker, 1992).

The sample sites of the study sites and environmental factors have been analysed by Detrended Canonical Correspondence Analysis (DCCA) using statistical software of MVSP version 5.1. Environmental data were available on altitude, average annual rainfall, surface stoniness, rock outcrops, and slope percentage. The detrended canonical correspondence analysis (DCCA) was applied to avoid the arch effect and to assess the plant species-environment correlation more accurately. Also the main floristic associations of the study sites and environmental factors have been analysed by Canonical Correspondence Analysis (CCA) using statistical software of MVSP version 5.1. Environmental data were available on:
Altitude, surface stoniness, $CaCO_3$ %, slope %, pH, CeC, rock outcrops, erosion, moisture %, EC % and O.C. %.

5.2.6. Vegetation structure

Vegetation structure was classified according to the diagram given in van Gils et al. (1985) see Figure 5.4.

In the study sites woody plants greater than 1 m in height were considered as trees; woody plants under 1 m were considered as shrubs, while woody plants under 0.5 m were considered as sub-shrubs or dwarf shrubs. Non-woody plants (grasses and ground cover herbs) were grouped as the herbaceous stratum. To analyse the relationship between different landforms and vegetation cover, data for percentage cover of each species was entered into a Multi-Variate Statistical Package (MVSP) and analysed using Canonical Correspondence Analysis (CCA).
Data of vegetation cover percentage per 100 m² was entered into the BioDiversity Professional Beta software to analyse the abundance of each species in different landforms. The data for cultivated lands was not included into analysis and is treated separately, because it was

obviously dominated by cultivated palm trees and weeds, namely: *Phoenix dactylifera, Prosopis farcta, Cynodon dactylon* and *Alhagi graecorum.*

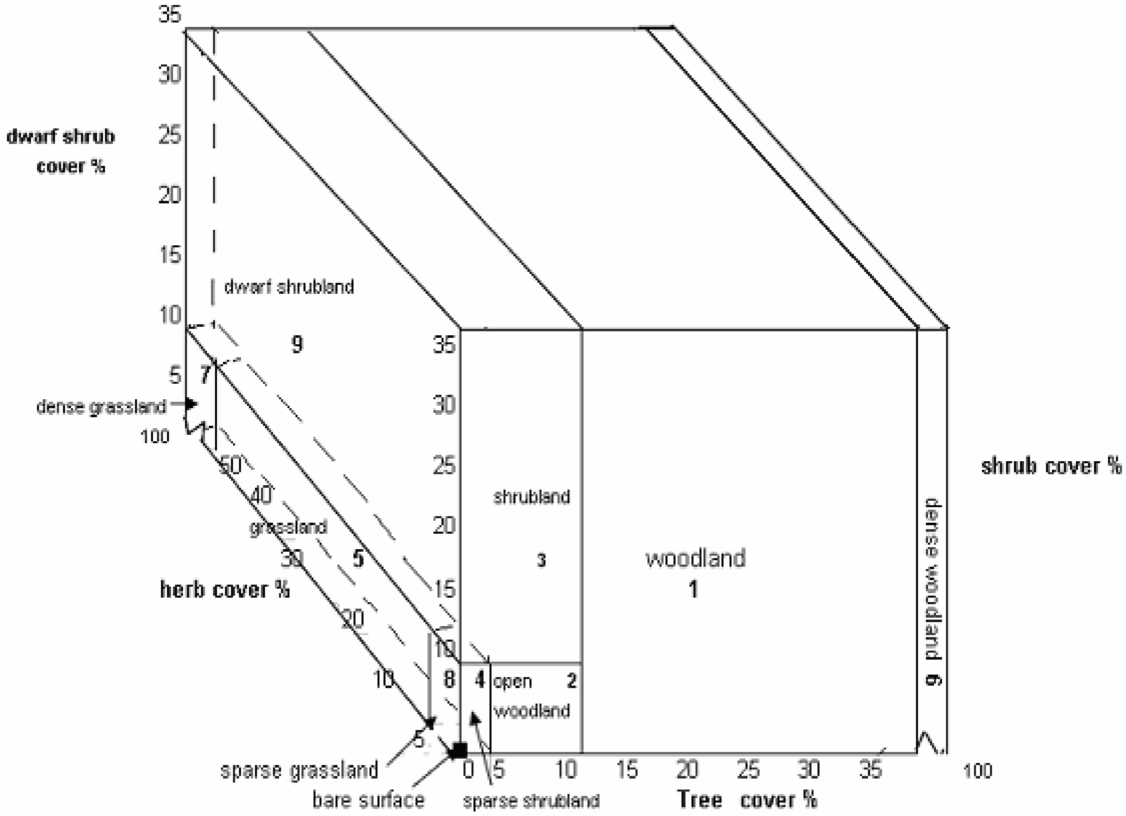


Figure 5.4. Three dimensional diagram representing of structure vegetation types (after van Gils et al., 1985). 1- woodland 2- open woodland 3- shrubland 4- sparse shrubland 5- grassland 6- dense woodland 7- dense grassland 8- sparse grassland 9--dwarf shrubland.

5.3. Results

5.3.1. Vegetation associations and Socio-Ecological species groups

A total of 116 sample plots in different landforms and ecologies throughout the study sites were combined according to the similarity in their species composition by following the classification methods mentioned above, to form groups of floristic vegetation associations. These floristic vegetation associations groups were made of selected sample plots throughout the study sites. A total of 42 sample plots were analaysed from Shibam (site 1), 43 sample plots from Wadi Adim (site 2), and 31 sample plots from Wadi Athahab (site 3) (Table 5.4). Table 5.4b shows the number of bare sample plots for each landform. Table 5.4c shows the GPS coordinates of the sample plots

Site / Landform	w	ms	f	pla	wp	sp	Total sample plots
Site 1	14	11	6	4	5	2	42
Site 2	17	3	0	1	6	16	43
Site 3	12	9	0	1	2	7	31

Table 5.4a. Number of sample plots for each landform in the study sites. Key: w= wadi, ms = slopes facing the main wadis, pla = plateau, sp = slopes on plateau, wp = secondary wadi on plateau, f = fields or fallow lands.

Site / Landform	w	ms	f	pla	wp	sp	Total sample plots
Site 1	0	2	0	2	0	0	4
Site 2	0	2	0	3	0	5	10
Site 3	0	1	0	2	0	0	3

Table 5.4b. Number of bare sample plots for each landform in the study sites Key: w= wadi, ms = slopes facing the main wadis, pla = plateau, sp = slopes on plateau, wp = secondary wadi on plateau, f = fields or fallow lands.

Sample plots	142	116	115	114	113	144	110	134	135	111	212	211	132	131	133	109	106	107	108	138
coordinate	15 54 48 35	15 54 487 48 35 420	15 54 543 48 35 414	15 54 608 48 35 414	15 54 715 48 35 440	15 54 891 48 35 217	15 54 768 48 35 444	15 55 173 48 35 574	15 55 196 48 35 626	15 54 716 48 35 443	15 48.364 48 59.646	15 48 324 48 59 615	15 54 004 48 35 794	15 53 924 48 35 769	15 54 032 48 35 821	15 54 - 48 35 -	15 53 617 48 35 607	15 50 617 48 35 640	15 53 740 48 35 670	15 58 295 49 36 659
Sample plots	137	244	247	247	244b	243	203	203b	207	204	201	202	216	210	208	209	314	315	302	301
coordinate	15 58 322 48 36 736	15 48 935 48 58 836	15 48 058 48 58 984	15 48 058 48 58 984	15 48 934 48 59 797	15 48 924 48 58 791	15 49 901 48 58 498	15 49 030 48 58 419	15 48 740 48 59 122	15 49 041 48 58 455	15 48 958 48 58 610	15 48 980 48 58 546	15 48 376 48 59 827	15 48 614 48 59 081	15 48 698 48 59 154	15 48 738 48 59 192	16 03 868 48 53 750	16 03 924 48 53 697	16 04 525 48 54 084	16 04 473 48 54 066
Sample plots	306	305	304	303	320	307	118	123	104	119	139	138b	334	317	309	312	310	313	319	311
coordinate	16 04 682 48 54 150	16 04 682 48 54 150	16 04 628 48 54 137	16 04 571 48 54 108	16 04 909 48 54 460	16 04 790 48 54 227	15 56 121 48 34 841	15 56 319 48 34 685	15 54 417 48 35 479	15 56 162 48 34 874	15 56 - 48 34 -	15 58 737 48 36 498	16 03 474 48 54 349	16 04 868 48 54 359	16 04 839 48 54 340	16 03 827 48 53 814	16 04 792 48 54 349	16 03 833 48 53 770	16 04 920 48 54 450	16 03 811 48 53 368

Table 5.4c. The GPS coordinates in degree, minute, second format of the sample plots.

The aim of vegetation classification is to group the plant species together on the basis of their floristic composition into plant associations (communities) generally known as plant phytosociological units (Kent & Coker, 1992). Following the method of Braun-Branquet, Twinspan and ordination methods, the sample plots were arranged to similarities and then combined in 15 vegetation associations and 29 socio-ecological groups (Table 5.6). The matrix (Table 5.7) shows a diagonal clusters where the boundaries of association and sociological species groups can be detected visually through absence or presence of different plant species. Detailed description of socio-ecological groups is presented in Table 5.6.

Sample plot distributions obtained by following Twinspan and ordination methods were not formed to be located exactly in homogeneous patterns as indicated by following the school of Braun-Blanquet. They were therefore re-arranged, combined or merged according to their floristic composition and landform similarities. The 6 group of communities that been found following Twinspan, were re-arranged and combined to five group of communities and some of these groups were further divided to a final grouping of 15 vegetation associations (see the methodology 5.3).

Applying lower level of divisions for the vegetation classification using Twinspan produces similar results to those obtained by using Braun-Blanquet and matches the ecological variables of the study sites. However, at the higher level of division the results were not logical but subjective. For example, the high level of division produced a high number of groups (14 groups when 5 level was selected and 9 groups when 4 level was selected), but the classification results are acceptable and similar to those obtained by using Braun-Blanquet. By applying 4 levels of division, this classification revealed 6 groups.

Further division to sample plots resulted in several unacceptable and un-meaningfully small groups of associations. For example, a few sample sites were misclassified or in unsuitable locations, these samples ended up in different parts of the tree and gave new groupings that did not fit with the classification of Braun-Blanquet analyses. However applying the lower level of division gave acceptable results with a few exceptions, for example sample plots 208, 209 & 219 of main wadi association 6 as defined by Braun-Blanquet, were classified by Twinspan as group 2 of the plateau and mountain slopes. These sample plots had to be rearranged and put in the most suitable site taking into consideration the species composition of the sample site, the habitat and the appearance of annual species that may be found in the sample plot during the field work.

The DCA and Decorana (Hill, 1979) ordination analysis methods have revealed some associations and groups in which, although dissimilar to the data obtained by Braun-Blanquet school, failed to generate reasonable and acceptable vegetation associations. Nevertheless they were useful to rearrange some sample plots and plant species of Braun-Blanquet data.

Some similarity was found, when comparing the classification results of Twinspan with the distribution of sample sites according to DCA and Decorana ordination (figures 5.6 & 5.7). Some sample plots from the same groups were plotted close to each other; however several sample plots plotted in different locations. As for the Braun-Blanquet method, in DCA ordination analysis and Decorana, groups 5 and 6 were plotted close to each other forming only one group rather than 2 groups as in the case of the Twinspan analysis. There are nearly clear segregations between sample plots of some groups, such as groups 2, 3 and 4, but still with some exceptions. Some sample plots belong to particular group with others belonging obviously to different groups. For example, some sample plots of group 1 were put with group 2 or some sample plots of group 2 were put with group 3 (Figures 5.6 and 5.7).

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The classification of Twinspan using level of division 4 and minimum group size 5 generated 6 groups. Similar groups in their plant composition were combined to one group, for example 5 and 6 to group 5 (Table 5.4).

The classification of Twinspan was taken to 3 levels (Figure 5.5). At the higher level (level 1), the first division separated cultivated sites (6 sample plots) from all others (109 sample plots). At level 2, the cultivated sites were further divided into two divisions comprising palm grove sites (2 sample plots) and a combination of palm grove and fallow lands (4 sample plots); these 2 groups were not further divided. The remaining plots were divided into two divisions comprising the main wadis (38 sample plots) and the rest of the landforms (71 sample plots). At the lower level (level 3) the main wadis were divided further into two groups; flooded sandy wadi beds (5 sample plots) and rocky wadi beds (33 sample plots). The rest of the landforms were divided into further two groups comprising 4 different landform units- mountain slopes facing main wadis together with plateaus, and some slopes of plateaus and secondary wadis (51 sample plots) and secondly, the remainder of the slopes of plateaus (20 sample plots).

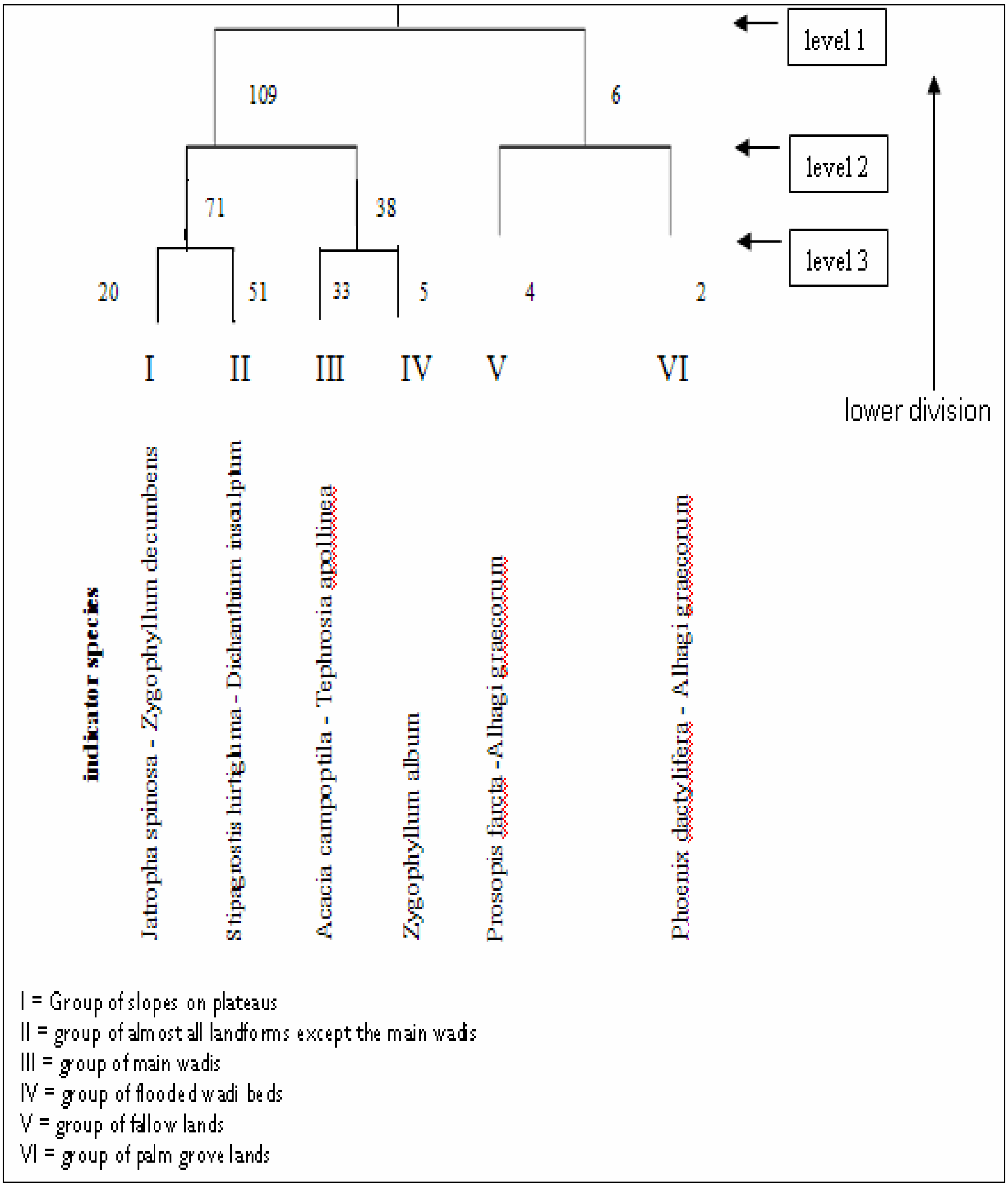


Figure 5.5 Twinspan classification based on presence and absence data for 113 species and 115 sample plots. The classification generated 6 group of communities. At level 1: 2 groups, at level 2: 4 groups, then at level 3: 6 groups. Indicator species are used to name these groups.

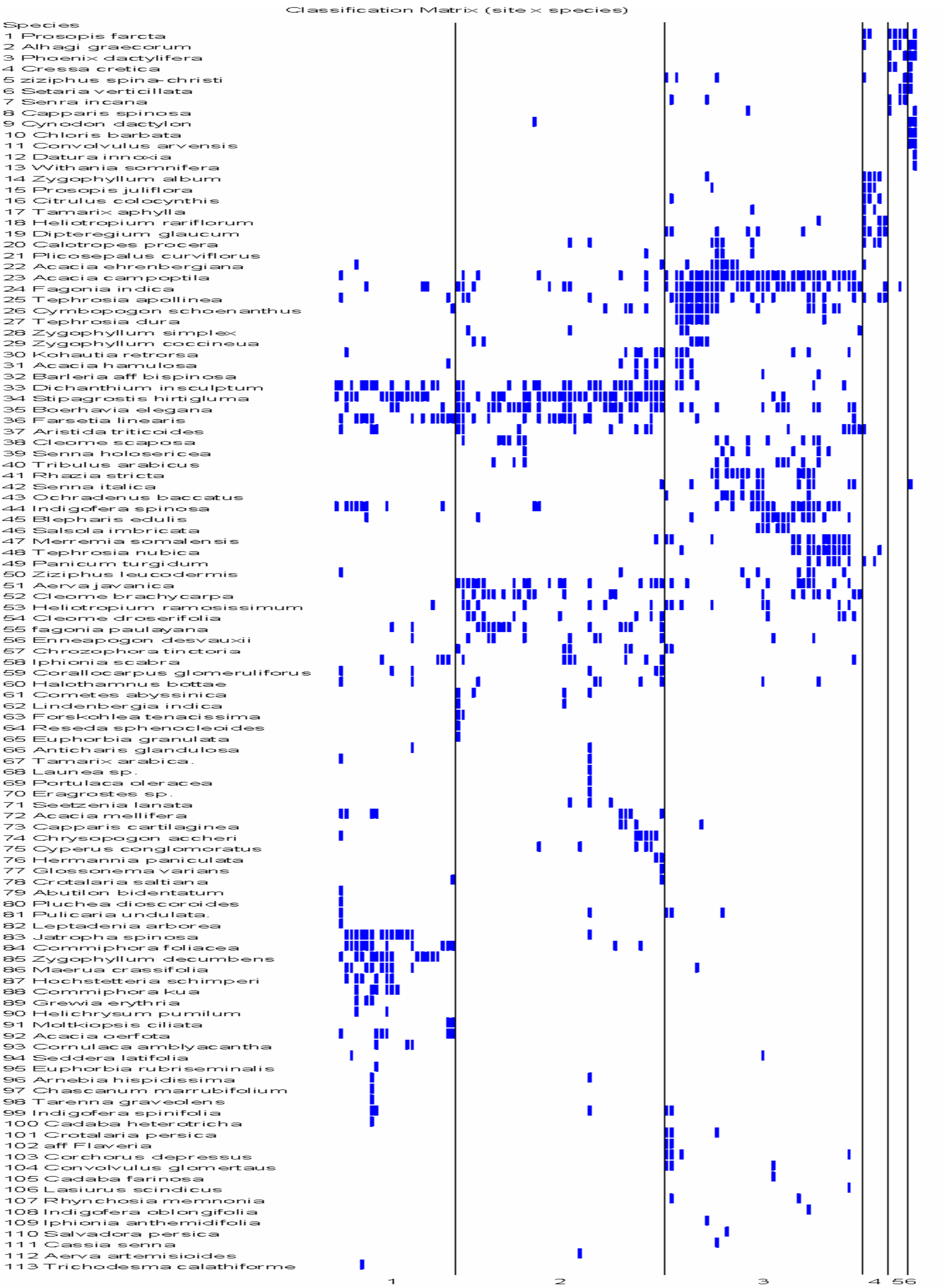


Table 5.5. The classification matrix result according to Twinspan. In Braun-Blanquet classification method groups 5 and 6 have been combined because of their species composition similarities (See Table 5.7).

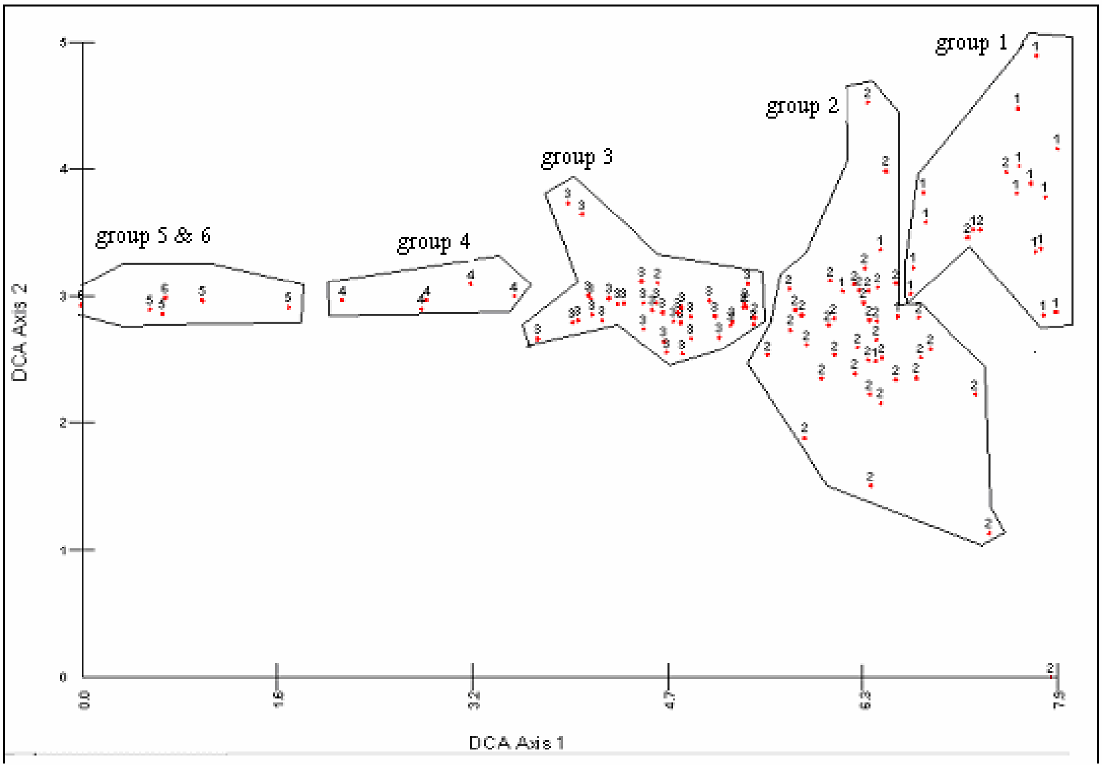


Figure 5.6. The result of DCA ordination analysis of numbers that represent the main groups according to a Twinspan classification. As in the Braun-Blanquet method, DCA analysis groups 5 and 6 close to each other forming only one group rather than 2 groups as in case in Twinspan. However there is still a mix between the sample plots from group1 and 2.

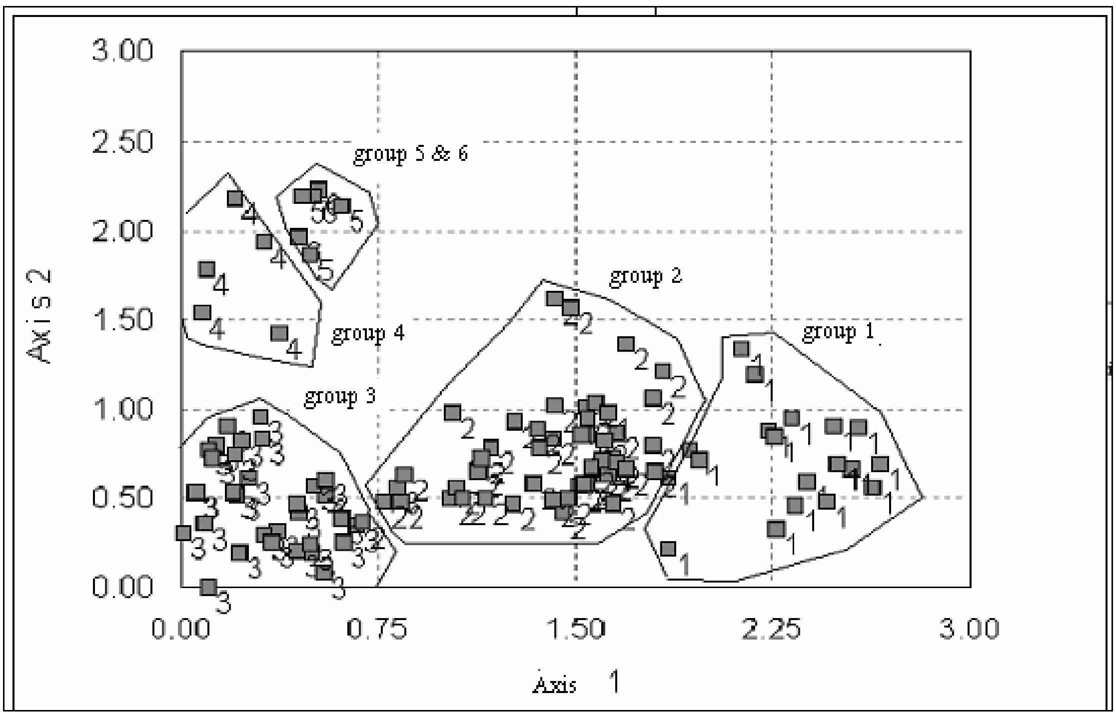


Figure 5.7. The result of Decorana ordination analysis of the numbers that represent the main groups according to a Twinspan classification. As the Braun-Blanquet method, Decorana analysis groups 5 and 6 close to each other forming only one group rather than 2 groups as in case in Twinspan.

Table 5.6. Description of the main Socio-Ecological groups of plant species. The plant species were clustered to similar groups implementing the Braun-Blanquet method and the Neighbour-Joining method by using Modelling Patterns in Environmental Data (MOPED) software.

Most indicative species	Common species	Poor species	Rare species

A. **Species of the flat to almost flat fertile wadis and as invaders at moist** sites (roadsides, fallow fields and near cultivated fields), between 670 and 750 m above sea level.

Phoenix dactylifera	*Alhagi graecorum* *Cressa cretica* *Prosopis farcta*	*Capparis spinosa* *Convolvulus arvensis* *Setaria verticillata* *Senna incana* *Cynodon dactylon* *Ziziphus spina-christi*	*Datura innoxia* *Chloris barbata* *Withania somnifera*

B. **Species of the temporary flooded streambeds, subjected to severe flooding,** consisting predominantly of sandy wadi beds between 670-725 m above sea level, mainly in site 1, some of them also occur on fallow lands and cultivated fields. This group confined to association 2.

Zygophyllum album	*Prosopis juliflora* *Heliotropium rariflorum* *Citrullus colocynthis*	*Tamarix aphylla*	none

C. **As the group B. but extending to rocky, almost flat wadi beds and disturbed sites,** cultivated fields and fallow lands. (between 640 and 750 m above sea level).

Dipterygium glaucum	*Calotropis procera*	none	none

D. **Species mainly found on the relatively narrow, almost flat, wet drainage lines of site 2,** which is cultivated during the rainy season and left fallow during the dry season. Some of these species are found also on moisture sites. Some species have spread to the moist sites of plateaus and their slopes.

Crotalaria persica	*Pulicaria undulata* *Compositae aff. Flaveria* *Corchorus depressus* *Chrozophora tinctoria* *Indigofera spinifolia*	*Convolvulus glomeratus*	none

E. **Species found mainly on rocky wadi beds**, almost throughout the study sites; also found on relatively moist sites of rocky mountain slopes facing the main wadis, plateaus, and drainage lines that cut these plateaus, as well as on fallow lands. These species show adaptations to extreme floods.

Acacia campoptila	*Fagonia indica* *Tephrosia apollinea*	*Cymbopogon schoenanthus*	none

F. **Species mainly of the relatively moist wadi bed**, and alluvial fans or drainage lines that cut the plateaus, almost throughout the study sites.

Kohautia retrorsa	*Acacia hamulosa*	*Barleria aff bispinosa*	none

G. **Species of north and northeast facing slopes and undulating to slightly sloping very rocky wadi bed**, of site 1 (between 983 and 733 m above sea level). *Zygophyllum coccineum* penetrates the adjacent north and south west facing mountain slopes. (between 667 and 690 m above sea level).

Tephrosia dura	*Zygophyllum coccineum*	none	none

H. **Species occurring throughout the entire site**, in particular on mountain slopes facing the main wadis, the plateaus and their slopes and secondary wadis, not seen on the sandy strong flooded wadi beds and cultivated sites.

Dichanthium insculptum	*Boerhavia elegans*	none	none

I. **Species are mainly found on relatively rocky, almost flat, moist wadi beds**, along river banks and on depressions near cultivated fields (between 680 and 750 m above sea level). *Plicosepalus curviflorus* is a parasitic on both *Acacia ehrenbergiana* and *Acacia campoptila.*

Acacia ehrenbergiana	none	*Plicosepalus curviflorus*	none

J. **Species confined to rocky almost flat wadi beds**, especially of sites 2 and 3. *Senna italica* spreads to the cultivated fields, moisture sites of southeast moderately steep adjacent rocky slopes and almost flat rocky secondary wadis of plateaus (between 754 and 926 m above sea level).

Rhazya stricta	*Ochradenus baccatus* *Senna italica* *Senna holosericea*	none	none

K. **As in group J, found on rocky almost flat moist wadi beds of sites 2 and 3**, but have spread to adjacent relatively moist very rocky mountain slopes of site 3. (between 590 and 677 m above sea level). *Tribulus arabicus* is also found near cultivated fields.

Cleome scaposa	*Tribulus arabicus*	none	none

L. **Species occurring mainly on very rocky wide wadis** (between 579 and 690 m above sea level), with low distribution extending to adjacent rocky mountain slopes or on slopes of plateau (over 700m above sea level.).

Indigofera spinosa	*Blepharis edulis*	none	none

M. **One rare species occurring on almost flat to undulating rocky wadi beds**, river banks, and rarely on drainage lines or narrow wadis that cut the plateaus.

Ziziphus leucodermis	none	none	none

N. One species found only on rocky saline wadi beds of site 2.

Salsola imbricata	none	none	none

O. **Species confined mainly to relatively moist almost flat very rocky wadi beds** of site 3 (between 570 and 668 m above sea level), some species of this group are found in low quantities on cultivated, and fallow lands. The species of this group are very palatable and have been negatively effected by over grazing in sites 1 and 2.

Merremia hadramautica *Tephrosia nubica*	none	*Panicum turgidum*	none

P. **Widespread annual species, occurring in almost all ecological zones**, in particular rocky disturbed mountain slopes. Less common or absent on the slopes of the plateaus and on sandy flooded streambeds.

Aerva javanica	*Cleome brachycarpa*	*Heliotropium ramosissimum*	none

Q. **Species of stony moderately steep, mountain slopes facing the main wadis, plateaus, and narrow rocky secondary wadis and alluvial fans of the plateaus**. Rarely found on the main wadis and on the slopes of the plateaus.

Cleome droserifolia	*Iphiona scabra*	*Zygophyllum simplex*	none

R. **Species of stony mountain slopes facing main wadis, plateaus**, as well as slopes and narrow rocky secondary wadis of the plateaus. Rarely found on the main wadi beds.

Stipagrostis hirtigluma	*Farsetia linearis* *Aristida triticoides* *Fagonia paulayana*	*Enneapogon desvauxii*	*Halothamnus bottae*

S. **Rare species prefer moist sites** of very rocky alluvial fans and moister slopes as well as eroded surface sites of the plateaus.

Cometes abyssinica	*Forskohlea tenacissima*	none	*Lindenbergia indica* *Reseda sphenocleoides* *Euphorbia granulata*

T. **One rare species found only on moist sites** such as eroded surface on the plateaus and very rocky slopes of the plateaus.

Seetzenia lanata	none	none	none

U. **One rare species occurring as individuals on very steep rocky slopes** of narrow secondary wadis and drainage lines of the plateaus (between 858 and 920 m above sea level.) and spreads to the very steep slopes ridges that facing the main wadis (at 730 m above sea level.).

Capparis cartilaginea	none	none	none

V. **Species occurring on moist almost flat to slightly steep slope narrow rocky secondary wadis of the plateaus** (between 855 and 950 m above sea level). *Cyperus conglomoratus* is found also on almost flat rocky plateaus and north east facing, very rocky mountain slopes facing the main wadis of site 2.

Chrysopogon accheri	*Cyperus conglomeratus*	none	none

W. **Rare species occurring on wet almost flat and slightly steep rocky narrow secondary wadis of the plateaus** (between 914 and 977 m above sea level). *Leptadenia arborea* is also found as invasive plant near cultivated fields of main wadis of site 1.

Hermannia paniculata	none	none	*Glossonema varians* *Abutilon bidentatum* *Pluchea dioscoroides* *Leptadenia arborea*

X. **Very rare species occurring on the moderately steep slope** shallow drainage lines that cut the plateau of site 1 (between 977-980 m above sea level.).

Crotalaria saltiana	none	none	*Moltkiopsis ciliata*

Y. **Species of moderately steep slope secondary wadis and rocky dry steep slopes** of the plateaus (between 865 and 995 m above sea level).

Commiphora foliacea	*Acacia mellifera* *Acacia oerfota* *Zygophyllum decumbens*	none	*Corallocarpus glomeruliflorus*

Z. **Species mainly of dry rocky slopes of the plateaus**, *Maerua crassifolia* penetrates the adjacent narrow secondary wadis and farther towards the main wadis and adjacent cultivated fields.

Jatropha spinosa	*Maerua crassifolia* *Commiphora kua Hochste schimperi*	*Grewia erythraea*	*Helichrysum pumilum* *Cornulaca amblyacantha*

AA. **Rare species found on moister sites of moderately rocky slopes** of the plateaus (between 946 and 953 m above sea level.).

Anticharis glandulosa	none	*Tamarix arabica* *Eragrostes sp. Laune sp.*	*Portulaca oleracea*

BB. **Rare species, only found in site 2 on northeast facing relatively wet rocky slopes** of plateaus at 950 m asl and adjacent secondary wadi.

Arnebia hispidissima	none	none	*Chascanum marrubifolium* *Tarenna graveolens* *Cadaba heterotricha*

CC. **Very rare species occurring as individuals on rocky wadi beds**

Iphiona anthemidifolia, Cassia senna, Salvadora persica, Seddera latifolia, Cadaba farinose, Rhynchosia memnonia, Indigofera oblongifolia and *Lasiurus scindicus*

DD. **Very rare species found on slightly steep slopes**, rocky narrow secondary wadis of plateau and rocky surface of plateau of site 2 and 3.

Aerva artemisioides, Trichodesma calathiforme and *Euphorbia rubriseminalis*

Table 5.7

Table 5.7. A matrix of floristic vegetation associations (1-15) in the columns versus sociological species groups (A-CC) in the rows. numbers refer to the individuals of each species.

	Twinspan classification	6	6	5	5	5	5	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	2	2	3	3	3	3	3	3	3	3	3	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Association	1						2					3		4							5											6						7												8							9								
	Scientific name	141	142	116	115	114	113	144	110	134	135	111	212	211	132	131	133	109	106	107	108	138	137	244	247	247	244b	243	203	203b	207	204	201	202	216	210	208	209	314	315	302	335	301	306	305	304	303	336	320	307	118	123	104	119	139	140	138b	334	317	309	312	310	313	337	319	311
	Prosopis farcta		7	6	7	1	1	10	1																																																										
	Alhagi graecorum	1	8		4	25		1																																																											
A	Phoenix dactylifera □	3	8	6			2																																																												
	Cressa cretica	2		6	5																																																														
	Ziziphus spina-christi	2					1	1					1																																																						
	Senra incana			5		17	2							1							2																																												
	Setaria verticillata	7				1	10																																																											
	Convolvulus arvensis	1	1																																																															
	Capparis spinosa		2	2																										1																																				
	Cynodon dactylon	10	20																																																															
	Chloris barbata	4	10																																																															
	Datura innoxia		1																																																															
	Withania somnifera		1																																																															
	Zygophyllum album							4	40	12	17										5																																												
	Prosopis juliflora							1	3	1												2																																											
B	Tamarix aphylla							1		1																					3																																		
	Citrulus colocynthis							1	1		1			2																																																			
	Heliotropium rariflorum							3			1	2																															1																						
	Dipteregium glaucum							3	1		1	3	1	1									1							1		1									3																									
C	Calotropes procera							1		1	1											1	1	1							2																																			
	Pulicaria undulata												2	3										1																																											
	Crotalaria persica												11	6									3																																											
	Compositae aff. Flaveria												2	2																																																				
D	Corchorus depressus												1	5		6																																		2																
	Convolvulus glomertaus												1	5																					1																															
	Chrozophora tinctoria												3	1																																						1														
	Indigofera spinifolia												1	1																																																				
	Acacia campoptila												2		3	3		4	3	2	5	4	2	4	5	5	7	2	10	1	5	10	4	2	3	3	1		1	2	1	5	1	6	3		1	2	2	2	1		1				1									
E	Fagonia indica	3				1						1	1		5	2	1	3	5	2	1	2	2	6				11	1	1		8	2	1		3	1	1	3		3	5		3		1		1		25	9	3	5	6		3										
	Tephrosia apollinea	2						1			1	3		1	25	7	10	10	10	30	12	7	1				2				2		3		3							8	2		1						20		2		3			20								
	Cymbopogon schoenanthus														2	1	1	2	1	3	1	2	1									2										1	1		3		1	3																		
	Kohautia retrorsa														3	2	1		1																				1			3								4																
F	Acacia hamulosa														2	1		7																																																
	Barleria aff bispinosa															3		2															1											2																						
	Tephrosia dura														5	1	2	15	7	11	8																								1																					
	Zygophyllum coccineua																	10	6	4	8																																			2		2								
	Boerhavia elegans															1		2					2										2			1	4	1					5	1						3	1	10	2		4				1	3	2		2	1	5	2
H	Dichanthium insculptum														3	4			4																								3						3		5	10	8										3			5
	Plicosepalus curviflorus																						2	1							3																																			
I	Acacia ehrenbergiana																6					7	1	1	4	4	2	1																																						
	Rhazya stricta																					3	1		3	3	3	1	1	5		2	1							2	5	5	8																							
J	Senna italica	1																4					3						4			2	5							1		3	2							10	1															
	Senna holosericea																							2			2			1									1					1		3																				1
	Ochradenus baccatus												1											5	3	3	2		1		3	2	2									2																								
	Cleome scaposa																						1		15	15				1				1							3		3	1									1								1	1	7		10	35
K	Tribulus arabicus																						1		7	7										1	3	3			5			2																1				1		1
	Indigofera spinosa																						2				5				7	10	1	2	30				5	4	3	10	27	12		3	1	8																		
L	Blepharis edulis																	1															2	1	40	50	60	30	3		55	1	2							15							1									
M	Ziziphus leucodermis																												1			1								1		2	1						1																	
N	Salsola imbricata																															1	1	1		4	1	1																												
	Merremia somalensis												10	6								1																	1	4		5	1		5	2	3	8	5	2																
O	Tephrosia nubica															3																							10	25		8	4	5	14	3	5	25	15	4																
	Panicum turgidum							2		1																																3		2		1	1	10		1																
	Aerva javanica													2			1													1				3						1	1	3	2				1			1		8	10		3	3	1	2						1		1
P	Cleome brachycarpa																																1						2		1		1	3		2					1		3	1		2		1	2	1		2		1	1	
	Heliotropium ramosissimum												6	11		1						1											2	1														1		3			1		1		1									1
	Cleome droserifolia																																	1														1	1		1				1	1		1						1		
Q	Iphionia scabra																																																		1		1													
	Zygophyllum simplex															1	1																																					1	3											
	Stipagrostis hirtigluma																																		15		3															10	8				1			55	3	3				3
	Farsetia linearis																																																		1	3	5			2			1							2
R	Aristida triticoides																																					2											2	4	3	8	2	2											5	
	Fagonia paulayana																																																								1	1	1	1	7	2	25			2
	Enneapogon desvauxii																																		2								1												8				2	50						2
	Halothamnus bottae																																1											1													1									
	Cometes abyssinica																																																			1				1										
	Forskohlea tenacissima																																																			2	1													
S	Lindenbergia indica																																																			1														
	Reseda sphenocleoides																																																			4														
	Euphorbia granulata																																																			2														
T	Seetzenia lanata																																																																		
U	Capparis cartilaginea																			1																																														
	Chrysopogon aucheri																																																																		
V	Cyperus conglomoratus																																																																		
	Hermannia paniculata																																																																		
	Glossonema varians																																																																		
W	Abutilon bidentatum																																																																		
	Pluchea dioscoroides																																																																		
	Leptadenia arborea																																																																		
X	Crotalaria saltiana																																																																	
	Moltkiopsis ciliata																																																																		
	Acacia mellifera																																																																		
	Zygophyllum decumbens																																																																		
Y	Commiphora foliacea																																																																		
	Acacia oerfota																																																																	
	Coralliocarpus glomeruliflorus																																																																		
	Jatropha spinosa																																																																		
	Maerua crassifolia																		1																																															
	Hochstetteri schimperi																																																																		
Z	Commiphora kua																																																																		
	Grewia erythraea																																																																		
	Helichrysum pumilum																																																																		
	Cornulaca amblyacantha																																																																		
	Anticharis glandulosa																																																																		
	Tamarix arabica.																																																																		
AA	Launea sp.																																																																		
	Portulaca oleracea																																																																		
	Eragrostes sp.																																																																		
	Arnebia hispidissima																																																																		
BB	Chascanum marrubifolium																																																																		
	Cadaba heterotricha																																																																		

Table 5.7.

Table 5.7. A matrix of floristic vegetation associations (1-15) in the columns versus sociological species groups (A-CC) in the rows. numbers refer to the individuals of each species.

Twinspan classification	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Association	10							11												12													13										14				15				
Scientific name	121	213	217	215	122	101	102	128b	124	143	125	322	241	237	328	327	323	136	136b	129b	128	129	246	246/b	236	230	333	332	237c	220	130a	130b	239	248	234	218	245	231	238	229	233	240	330	324	326	331	223	227	235	224	223b
Prosopis farcta																																																			
Alhagi graecorum																																																			
Phoenix dactylifera																																																			
Cressa cretica																																																			
ziziphus spina-christi																																																			
Senra incana																																																			
Setaria verticillata																																																			
Convolvulus arvensis																																																			
Capparis spinosa																																																			
Cynodon dactylon		1																																																	
Chloris barbata																																																			
Datura innoxia																																																			
Withania somnifera																																																			
Zygophyllum album																																																			
Prosopis juliflora																																																			
Tamarix aphylla																																																			
Citrulus colocynthis																																																			
Heliotropium rariflorum																																																			
Dipteregium glaucum																																																			
Calotropes procera										1				1																																					
Pulicaria undulata														3															3																						
Crotalaria persica																																																			
aff Flaveria																																																			
Corchorus depressus																																																			
Convolvulus glomertaus																																																			
Chrozophora tinctoria									1	4											4	8																													
Indigofera spinifolia														4																			5						9												
Acacia campoptila				1																1					1				1																						
Fagonia indica						1			9	3															5						3							2										1	1		
Tephrosia apollinea														3															2		5	1																			
Cymbopogon schoenanthus																	1				4	20			7							2																			
Kohautia retrorsa																					4		6	1			7	1						4																	
Acacia hamulosa																				1			3		1		1				1	1																			
Barleria aff bispinosa																							8		10																										
Tephrosia dura																																																			
Zygophyllum coccineua																																																			
Boerhavia elegans	3			1					10	10				8			1	1	1	2		2	1			1	2	3		1	3			2								3	6								
Dichanthium insculptum		2	4	4					10	15				50	33	30			1	8	3	7			10	2	10	6	4				10		5		7	30	3			10			4			1		15	35
Plicosepalus curviflorus																									1																										
Acacia ehrenbergiana																												1								1															
Rhazia stricta																																																			
Senna italica																												3			1																				
Senna holosericea																																																			
Ochradenus baccatus																																																			
Cleome scaposa																																																			
Tribulus arabicus																																																			
Indigofera spinosa		2	1	1																										2				8	2	23	1	20			1										
Blepharis edulis																																						10													
Ziziphus leucodermis																				1									1																						
Salsola imbricata																																																			
Merremia somalensis																											1																								
Tephrosia nubica																																																			
Panicum turgidum																																																			
Aerva javanica	1					1		1	1					2										1		1	1	1																							
Cleome brachycarpa	1	8							1									12	1												1																				
Heliotropium ramosissimum														1			3									1																								1	
Cleome droserifolia								2															1			2		1			1																				
Iphionia scabra									3	2	1										1				1			6		3	6	6								1											1
Zygophyllum simplex										4																					1																				
Stipagrostis hirtigluma	1		3	4	1	3	5	10	40	30	6	3	10		2	5	5	4	1		3	3	1	3	7	10	8	22			3			20	30	2				5	5	9	6	2	15	5	7	1	1		
Farsetia linearis				3		1	3	8	11	1	1		1	10						2						6			10	2	1	1				10	2	4	7							1		1		7	2
Aristida triticoides											2							2					2		50	2			3				5						30												
Fagonia paulayana														1						2	2	8						3														3				5					
Enneapogon desvauxii										3					1	1												1																		3					
Halothamnus bottae															2	3								2				3	2																	3					
Cometes abyssinica									1					2																																					
Forskohlea tenacissima																																																			
Lindenbergia indica									1																																										
Reseda sphenocleoides																																																			
Euphorbia granulata																																																			
Seetzenia lanata										3				1				4																																	
Capparis cartilaginea																				1	1		1																												
Chrysopogon aucheri																							10	4	2	5	3		2																						
Cyperus conglomoratus				2								2											1		1	2																									
Hermannia paniculata																											2	2																							
Glossonema varians																												1																							
Abutilon bidentatum																													2																						
Pluchea dioscoroides																													2																						
Leptadenia arborea																													1																						
Crotalaria saltiana																												10			1	1																			
Moltkiopsis ciliata																															1	1																			
Acacia mellifera																				2	2	1						1	2				1	1					1												
Zygophyllum decumbens																													8				15			1	1		4	1	4	8					4	1	5	4	5
Commiphora foliacea																			1					1						1	2	1		2	2	3	1	1	1		4					1					
Acacia oerfota																													2		3	2	1							2	1										
Corallocarpus glomeruliflorus														1													1	2	2													1				2					
Jatropha spinosa														1																				4	6	2	2	2	1	3	2	6	2	2	4	3					
Maerua crassifolia																																		1	2			1	4	1	2	1				1					
Hochstetteri schimperi																																	3	4		2	1				3	1									
Commiphora kua																																	1			3			5		1	1	2								
Grewia erythraea																																				2		3	3												
Helichrysum pumilum																																				10					3										
Cornulaca amblyacantha																																	8												1	5					
Anticharis glandulosa														2																																2					
Tamarix arabica.														2															2																						
Launea sp.														2																																					
Portulaca oleracea														1																																					
Eragrostes sp.														4																																					
Arnebia hispidissima														2																									1												
Chascanum marrubifolium																																							3												
Cadaba heterotricha																																							1												

5.3.2. Soil laboratory analysis results

Soil samples from the surface layer (0 - 10 cm) and from 10 to 20 cm were taken from 48 plots in the three study sites representing the different landforms (Table 11). The analysis was undertaken by the soil and water department laboratory in the Agriculture Research and Extension Authority, Taiz, Yemen.

Generally there is limited or no soil cover on the rocky slopes and plateau areas. Most of the landscapes are covered by accumulations of hard course textured limestone, dolomite and chert fragments left after millions of years of weathering (Komex International Ltd,. 1999). The depth of the soil in the rocky slopes and plateaus is very shallow and does not exceed 50cm, and is usually much less while the depth in the farmable area is more than 50cm.

Interpretation

The results show that the soils have varied textures being predominantly sandy loam with high proportion of sand and stones**.** The average pH values range between 7.4 and 8.7 with average of 7.98. There is no significant variation from one horizon to another (Table 5.8). Silty soils are observed in wadis at Wadi Adim (site 2) and Wadi Athahab (site 3). Sand filled cracks with deep gullies are common in site 1 (plate 5.1). The percentage of $CaCO_3$ is generally high and ranges from 36 to 37.4. In cultivated fields and fallow lands the percentage is low and ranges between 29.7 and 37.4 (see the soil cross section Figure 5.8a).

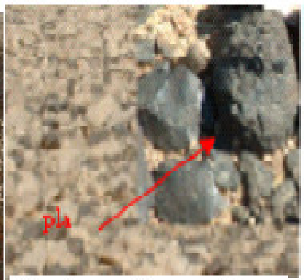
Table 5.8. Laboratory analysis results of the soil collected from 37 sites in the three study areas. w= main wadi, ms= slope facing main wadi, fal= fallow land, f= field, pla= plateau, ps= slope on plateau. SL= sandy loam, L= loam, LS= loamy sand, S= sand, SiL= silty loam. - = no data.

Sample plot	Land form	Depth (cm)	Sand % 2-0.05	Silt% 0.002 (mm)	Clay% (mm)	Textural class	pH (1:1)	Ec (1:1) ms/cm	CaCO3 %	O.C %	C.eC cmol/kg	Moisture %	Stoniness %
Site 1													
1	ms	0-10	52	42	6	Sl	8.2	0.34	37.2	0.46	4.7	3.4	56
1	ms	10-20c	54	40	6	Sl	8.3	0.45	37.2	-	4.7	12.9	44
		average		41	6	SL	8.25	0.395	37.2	0.46	4.7	8.15	50
3	ms	0-10	66	24	10	Sl	8	2.7	34.7	0.35	9.2	7.3	61
3	ms	10-20c	64	26	10	Sl	8	2.5	36	-	6.4	4.4	38
		average	65	25	10	SL	8	2.6	35.35	0.35	7.8	5.85	49.5
18	ms	0-10	50	40	10	SL	8.2	1	35.7	-	5.2	1.6	58
21	ms	0-10	50	38	12	L	8.2	0.54	36.5	-	5.7	1.1	50
6	w	0-10	60	34	6	Sl	8.2	0.45	37.2	0.56	4.7	2.8	50
8	w	0-10	48	44	8	Sl	8.2	18.2	37	0.23	5	1.8	44
8	w	10-20c	56	34	10	Sl	8.3	10.4	37	-	5.7	1.1	45
		average	52	39	9	SL	8.25	14.3	37	0.23	5.35	1.45	44.5
10	w	0-10	86	4	10	L	8.6	0.36	37	-	2.1	1.2	0.8
10	w	10-20c	88	6	6	LS	8.7	0.23	37..2	0.15	1.4	1.4	0.4
		average	87	5	8	L, LS	8.65	0.295	37	0.15	1.75	1.3	0.6
12	f	0-10	44	46	10	L	8.3	3.1	37.2	0.21	5.2	2.1	32
12	f	10-20c	36	42	16	L	8.2	3.4	35.2	-	5.2	1.3	26
		average	40	44	13	L	8.25	3.25	36.2	0.21	5.2	1.7	29
14	f	0-10	36	50	14	L	8	5.3	35.7	0.32	7.6	1.3	41
14	f	10-20c	50	40	10	SL	8	7.2	36	-	7.6	2.3	47
		average	43	45	12	L, SL	8	6.25	35.85	0.32	7.6	1.8	44
24	pla	0-10	48	32	20	L	7.9	2.9	37	0.34	8	4.1	56
27	pla	0-10	72	24	4	SL	8.1	0.37	34..2	0.52	11	2.3	33

Table5.8 cont.

Site 2													
1	w	0-10	64	30	6	SL	7.8	0.23	36.7	0.41	3.8	6.5	41
1	w	10-20c	80	16	4	LS	8	0.22	37.4	-	4.7	5.2	93.1
		average	72	23	5	SL, LS	7.9	0.225	37.05	0.41	4.25	5.85	67.05
7	w	0-10	60	36	4	SL	7.9	0.39	37	-	5.4	1.2	6
7	w	10-20c	58	36	6	SL	7.9	0.36	36..5	-	5.7	0.8	3
		average	59	36	5	SL	7.9	0.375	37	-	5.55	1	4.5
8	w	0-10	30	56	14	SiL	7.9	0.02	37.2	0.52	9.2	0.9	48
9	w	0-10	56	38	6	SL	8.1	0.28	37.2	-	5.6	0.9	53
11	fal	0-10	60	32	8	SL	8.1	0.45	29.7	0.49	6.1	5.5	48
5	fal	0-10	58	36	6	SL	7.6	0.54	37..2	-	5.2	0.9	59
13	ms	0-10	46	48	6	SL	7.9	0.33	37..2	-	6.6	0.5	67
22	pla	0-10	60	32	8	SL	8	0.67	37	0.43	5.6	3.1	43
32	pla	0-10	68	26	6	SL	7.8	0.89	37	-	8.5	0.5	36
18	ps	0-10	52	38	10	SL	8.2	0.2	36..5	-	6.4	2.4	55
24	ps	0-10	56	38	6	SL	8	0.52	37.2	-	5.2	14.2	58
31	ps	0-10	44	48	8	SL	8.1	0.32	37	0.53	3.3	2.4	59
33	ps	0-10	86	8	6	LS	8.1	0.27	37	0.17	3.3	0.7	49
37	ps	0-10	60	36	4	SL	7.4	6.94	37.4	0.2	6.1	3	37.8
37c	wp	0-10	59	32	9	SL	8	0.34	37	0.45	4.6	3.7	60
Site 3													
1	w	0-10	50	40	10	SL	7.7	3.1	37	-	10.8	2.1	61
1	w	10-20c	82	14	4	LS	8	0.17	37.4	-	3.3	2.3	57.9
		average	66	27	7	SL, LS	7.85	1.635	37.2	-	7.05	2.2	59.45
3	w	0-10	44	44	12	L	7.8	0.63	37.4	-	-	4.9	75
3	w	10-20c	88	8	4	S	7.5	0.39	37.4	0.3	3.8	2.2	54.7
		average	66	26	8	L, S	7.65	0.51	37.4	0.3	3.8	3.55	64.85
5	w	0-10	24	60	10	SiL	7.2	0.65	37.3	0.58	-	3.4	39
5	w	10-20c	36	52	12	SiL	7.5	0.53	37.3	0.64	9.6	14	29
		average	30	56	11	SiL	7.35	0.59	37.3	0.61	9.6	8.7	34
16	fal	0-10	60	34	6	SL	7.4	1.3	37.4	0.49	-	6.7	59
10	ms	0-10	46	46	8	SL	7.6	0.52	37.3	-	8.5	7.9	33
11	ms	0-10	48	42	10	L	7.8	0.6	37.4	-	8.2	7.3	18
13	ms	0-10	54	36	10	SL	7.9	0.58	37.4	-	6.1	8.3	57
18	ms	0-10	42	48	10	L	7.7	1.1	37.4	0.46	-	0.9	62
19	ms	0-10	40	40	20	L	8.1	0.59	37.2	-	-	6.1	56
24	ps	0-10	56	32	12	SL	8.2	0.41	37.4	-	-	1.1	53
28	ps	0-10	48	36	16	L	8.3	0.36	37.4	-	-	2.4	43
30	ps	0-10	58	30	12	SL	8.3	0.33	37.4	0.64	-	1.2	57

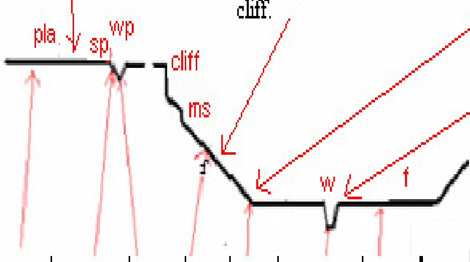
Narrow drainage line on the plateau, with predominantly pavement rock covering 80 to 99% of the surface



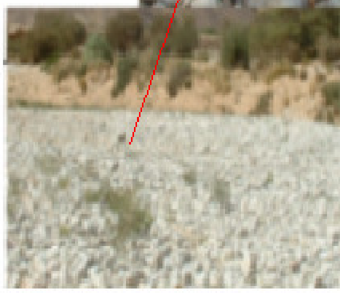
The plateau surface, very shallow with Cher gravels covered by thin soil.

Very eroded shallow steep slope facing the main wadi, with rocky loss materials, background the very steep cliff.

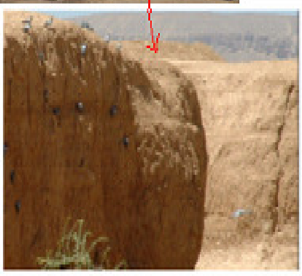
Colluvial, formed by recent erosion and deposition fro the plateau



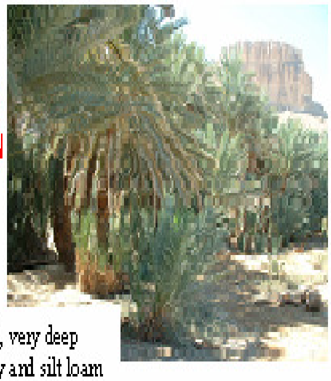
landform	pla	sp	wp	ms	tributer	w	fields
depth (cm)	10	10	10	20	20	20	50
sand %	62	57.5	59	51.0	61.6	58.5	49
silt %	28.5	33.3	32.3	39.2	31.6	32.8	40
clay %	9.5	9.25	9	9.8	6.8	8.2	10
textural	sl	sl,ls,l	sl	sl, l	sl	l,sl,ls,sil,s	sl, l
pH	8.0	8.1	8	8.0	8.1	7.9	7.9
Ec	1.2	1.2	0.3	0.94	5.9	0.59	3.0
CaCO3 %	36.3	37.2	37.1	36.8	37.1	37.2	35.5
O.C %	0.43	0.39	0.4	0.42	0.40	0.44	0.4
C.e.C %	8.3	4.86	4.6	6.5	4.8	5.7	6.2
moisture %	2.5	3.43	4	5.1	3.5	2.9	2.9
stoniness %	42	64	60	50	75	52	44.6



Wadi bed, covered by alluvium deposits of rounded white limestone gravels.



Bare sand tilled cracks with deep gullies are common in the main wadi of sites 1 and 3
.



Cultivated field, very deep alluvium, loamy and silt loam texture.

Figure 5.8a. Soil cross section of the study area. The soil depths of the plateau surface and the rocky slopes are very shallow and range between 10-20cm, while the soil depth of the main wadi beds is more deeper and ranges from 30 to 50cm. The soil of the plateau surface is shallow, mixed with gravel and stones materials. The soil type of the plateau can be classified as: Entisols (Almashreki, 2005). The wadi beds are covered by alluvium deposits of rounded lime-stone gravels, stones and boulders. Most of the land of the main wadis in sites 2 and 3 are covered by bare soil dissected by landslides and deep gullies. Generally the soil of the agricultural fields is very deep alluvium soils, loam and silt loam texture. Most of this soil can be classified as Entisols (see Table 1.7).

There is little variation in most chemical soil properties over the different land forms, especially in CaCa3%, O.C%, and pH. Despite these similarities, there are important variations in soil depth, soil texture, moisture content and Ec (Figure 5.8b). This is probably complemented by different plant species composition and associations along the cross section. The variation of vegetation associations in the main wadis and adjacent mountain slopes is probably due to significant variation in soil texture in these landforms. High vegetation cover, in particular of palm trees, is seen on the foothills of the mountain slopes. These sites are characterised by deeper soil, high level of water availability and weathering of colluvial deposits from the plateau above which lead to increased plant variety and greater biomass (Furley, 1974). The sparse cover and bare surfaces of the plateau reflect the chert gravels covered by thin soil. This has resulted in one vegetation association with almost uniform vegetation structure.

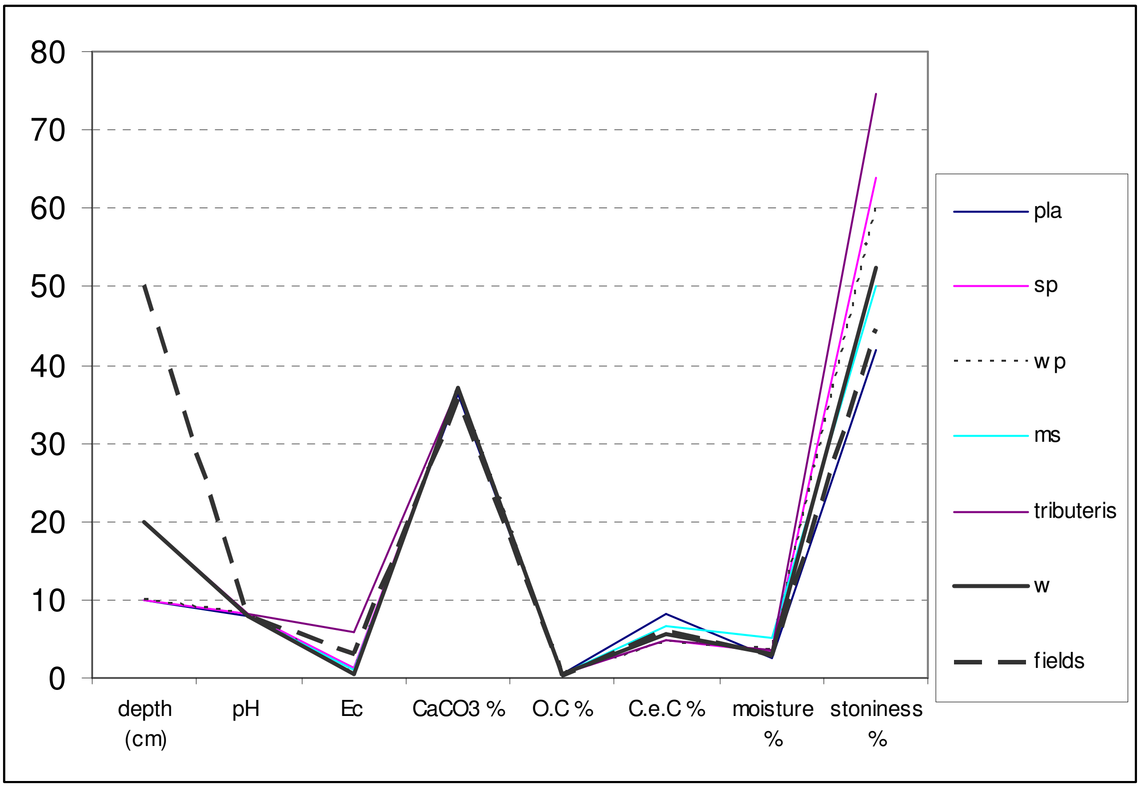


Figure 5.8b. The variation in soil properties over the different landforms. There is little variations in most chemical soil properties over the different land forms, especially in CaCa3%, O.C%, and pH.

5.4. The vegetation of the different land forms

5.4.1. The vegetation of the main wadis (w)

The total vegetation cover of the main wadis ranges between 2% and 50%, with an average of 17.8%, while the cover in the palm grove localities reaches almost 95%. The average tree cover is 6.7%, and this occurs mainly as scattered individuals dominated by *Acacia campoptila;* the shrub cover is almost 3%; the dwarf shrub cover is nearly 4%, and herbaceous cover is 6.4 %). (Table 5.9)

The total number of plant species collected is 61 (about 52% of the total number of species recorded in all the study sites), with 44 (63%) in Shibam, (site 1) 35 (50%) in W. Adem (site 2) and 33 (47%) in W**.** Athahab (site 3). Of these, 17 plant species are distributed throughout the study sites, with *Acacia campoptila, Fagonia indica* and *Tephrosia apollinea* occurring at a high frequency. The vegetation is generally concentrated at the edges of wadi beds. About 10 plant species are only recorded near or in cultivated or fallow lands of site 1.

The soil of the wadis is characterized by:

- High calcium carbonate levels in all horizons, which range between 36.5% and 37.4%, with an average of 37.2% in the upper sections and 37% at lower depths.
- High average pH values of 8 with extreme values of 7.8 and 8.7.
- Low organic matter contents ranging between 0.15% and 0.64%, with an average of 0.42%.
- Heterogeneous soil texture, predominantly sandy loam and silty loam.
- Low to high salinity, generally from 1 to 14.3 ms/cm.

Site 1																					
Plot no	116	141	142	114	115	113	144	134	111	135	110	106	107	118	109	131	132	133	137	138	average
trees	30	<1	90	0	0	0	<1	<1	0	0	0	1	1	5	7	1	2	3	1	10	8.9
shrub	15	0	0	0	0	0	0	1	0	0	0	15	30	20	10	0	7	1	0	0	5
dwarf shru	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0	2	0	0.5
herb	1	7	4	30	30	0	5	4	2	8	50	4	11	16	5	3	6	11	5	3	10
total	46	7	95	30	30	0	5	5	2	8	50	20	42	41	27	6	15	15	8	13	23

Site 2															
Plot no	203	204	203b	201	202	207	243	244b	247	244	210	216	208	209	average
trees	20	30	1	1	1	2	1	3	7	7	1	3	0	0	5.5
shrub	10	5	0	2	0	3	0	1	0	3	0	0	0	0	1.7
dwarf shru	1	5	2	1	1	0	1	0	3	0	0	30	0	0	3.1
herb	4	2	<1	2	3	5	2	1	<1	1	4	8	3	<1	3.2
total	35	42	3	6	5	10	4	5	10	11	5	41	8	8	14

Site 3														
Plot no	307	320	301	315	301	302	306	304	314	303	305	302	average	overall average
trees	1	<1	7	1	<1	<1	2	0	<1	<1	<1	2	2	
shrub	0	0	2	0	2	0	0	0	0	0	0	1	0	
dwarf shru	1	10	7	30	2	0	5	2	3	3	15	30	9	
herb	2	1	3	1	3	3	1	1	1	1	1	11	2	
total	4	11	19	32	7	3	8	3	4	4	16	44	13	

Table 5.9. Average vegetation cover for each sample plots in the main wadis of the three study sites. The average vegetation cover ranges between 13 % in site 3 and 23% in site 1. Trees and herbaceous plants are the dominant strata. The cover in some favoured locations is high, for example the palm grove localities range from 46 to 95%, the abundance of *Zygophyllum album* on previously cultivated areas has raised the vegetation cover to 50%.

5.4.2. The vegetation of the mountain slopes facing the main wadis (ms)

Compared to other ecological zones, the vegetation of the mountain slopes is generally sparse. The total vegetation cover ranges between 1% and 8%, The high percentage (12%) of herbaceous plant in plot 123 is due to the micro climate differences, for example, slight changes in landform characteristics, such as the bottom of the slopes, drainage lines or small gullies, where moisture and soil are accumulated and as a result become favourable for annual grasses such as *Dichanthium insculptum* and *Stipagrostis hirtigluma* in the case of site 1 (see association 8 and plate 5.7). The total vegetation cover ranges between 1% and 12%, with an average of 2%. Generally trees, shrubs and dwarf shrubs are not found in this zone. Rarely, individual trees are found in some locations. The average tree cover is less than 1 %, and the herbaceous cover is 3%. (Table 5.10). The vegetation is mainly concentrated on furrows, rills or gullies that cut the slopes.

There are 32 plant species collected in total in this zone. (27% of the total plant species collected over the study sites), with 27(84%) in Shibam, (site 1) 9 (28%) in Wadi Adem (site 2) and 16 (50%) in Wadi Athahab (site 3). Of these, 5 plant species occur with high frequency and are distributed throughout the study sites, these species are: *Dichanthium insculptum, Boerhavia elegans, Cleome brachycarpa, Stipagrostis hirtigluma* and *Farsetia linearis*.

The soil of this zone are characterized by:

- ➢ High calcium carbonate levels in all horizons, which range between 34.7% and 37.4%, with an average of 36.7% in the upper depth and 36% in the lower depth. .
- ➢ High average pH values of 8 with extreme values of 7.8 and 8.3.
- ➢ Low organic matter, less than 0.35%, with an average of 0.42%.
- ➢ Heterogeneous soil texture, loamy and sandy loam, with stoniness more than 80%.
- ➢ Very low to moderate salinity, generally between 0.34 and 2.7ms/cm.

Site	1													average	2					average	3										average	overall avera
plot no	104	123	118	140/2	119	121	136b	133/1	102	101	122	103	105		215	217	213	214	242		309	311	317	312	313	310	319	334	303/7	316		
trees	<1	0	<1	0	0	0	<1	0	0	0	0	0	0	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
shrub	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dwarf shrub	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
herb	2	12	2	2	1	1	1	5	2	1	0	0	0	2	4	8	2	0	0	3	3	3	1	0	2	0	1	2	0	0	1	2
total	**2**	**12**	**2**	**2**	**1**	**1**	**1**	**5**	**2**	**1**	**0**	**0**	**0**	2	4	8	2	0	0	3	3	3	1	1	2	1	1	2	<1	0	2	**2**

Table 5.10. Average vegetation cover for each sample plots in the mountain slopes facing the main wadis of the three study sites. The average vegetation cover ranges between 2% in sites 1 & 3 and 3 % in site 2. Herbaceous plants are dominant. The high percentage of herbaceous plant in plot 123 is due to the micro climate such as slight change in landform characteristics, such as the bottom of the slopes, drainage lines or small gullies where moisture and soil are accumulated and as a result become favourable for annual grasses such as *Dichanthium insculptum* and *Stipagrostis hirtigluma* in the case of site 1 (see association 8 and plate5.7).

5.4.3. The vegetation of the plateaus (pla)

The vegetation of the plateaus is generally very low. The total vegetation cover ranges between 2% and 9%, with an average of 4%. Generally trees, shrubs and dwarf shrubs are not found in this zone (Table 5.11); the vegetation, which is mainly herbaceous, is concentrated in furrows, depressions, rills or gullies that cut the plateaus.

The total number of plant species found in this zone was 19 (16% of plant species collected over the study sites), with 17(89.5%) in Shibam (site 1), 2 (10.5%) in Wadi Adem (site 2) and 3 (15.8%) in Wadi Athahab (site 3). *Stipagrostis hirtigluma* and *Farsetia linearis* are widespread in this zone. The high percentage of total and vegetation cover of site 1 is due to the removal of the surface layer in plot 124 by the local people to make protection barriers to prevent the road from water erosion. The exposed soil below the surface layer was able to support greater plant life.

The vegetation in this zone is very poor in species, with no significant or specific species to build a clear definition of associations. Almost all species in this zone occur elsewhere in the study sites, except the endemic species *Aerva artemisioides*, which is confined to the plateaus and adjacent narrow wadis or drainage lines.

The soils of this zone are characterized by:

- High calcium carbonate levels in all horizons, which range between 34.2% and 37.4%, with an average of 37 % in the upper horizon and 35.6 % in the lower horizon.
- High average pH values of 7.9 with extreme values of 7.5 and 8.1.
- Low organic matter levels of less than 0.3%, with an average of 0.4 %.
- Heterogeneous soil textures, mainly loamy, sandy and sandy loam, with a high percentage of stoniness.
- Very low to moderate salinity, generally between 0.17 and 2.9ms/cm.

site	1							2					3				
plot no	124	143/6	128b	125	126	127	average	241/6	232	222	228	average	322	325	329	average	overall average
trees	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
shrub	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dwarf shru	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
herb	40	9	2	1	0	0	9	6	0	0	0	2	3	0	0	1	4
total	40	9	2	1	0	0	9	6	0	0	0	2	3	0	0	1	4

Table 5.11. Average vegetation cover for each sample plots in the plateaus of the three study sites. The average vegetation cover, which is only herbaceous, ranges between 1% in site 3 and 9 % in site 1. The high percentage of herbaceous plants in plot 124 of site 1 is due to the removal of the surface layer by the local people to make protection barriers to prevent the road from water erosion. The exposed soil below the surface layer was able to support greater plant life (see Association 11).

5.4.4. The vegetation in narrow secondary wadis of the plateaus (wp)

The total vegetation cover in narrow secondary wadis and drainage lines in the plateaus ranges between 4% and 37%, with an average of about 19%. In moist sites the cover increases to 86%. The average tree cover is 2.5%, the shrub cover is less than 1%; the dwarf shrub cover is nearly 1.1%, and herbaceous cover is 16`% (Table 5.12). The total number of plant species found in this zone was 47 (40% of the total species collected from the study sites), with 19(40%) in Shibam (site 1), 37 (79%) in Wadi Adem (site 2) and 20 (43%) in Wadi Athahab (site 3). *Dichanthium insculptum, Boerhavia elegans, and Stipagrostis hirtigluma* are widespread plant species in this zone. The following species are only found in this zone: *Hermannia paniculata, Crotalaria saltiana, Glossonema varians, Euphorbia rubriseminalis. Abutilon bidentatum, Pluchea dioscoroides* and *Leptadenia arborea.* The last two species are seen in other ecological zones outside the sample sites, such as moisture adjacent slopes or main wadis. *Leptadenia arborea* is considered by local people as an aggressive weed.

site	1						2							3			overall average
Plot no	130a	130b	128	129b	129	average	246	237c	230	236	239/3	246/b	average	332	333	average	
trees	5	5	<1	2	<1	4	1	5	0	1	1	<1	1.6	<1	<1	1	
shrub	0	2	0	0	0	0	0	1	0	0	0	0	0.2	0	0	0	
dwarf shrul	0	0	0	0	0	0	2	10	0	1	1	0	2.3	0	0	0	
herb	7	1	7	11	20	9	20	70	9	35	2	15	25	12	4	8	
total cover	12	8	7	13	20	12	23	86	9	37	4	15	29	12	4	8	

Table 5.12. Average vegetation cover for each sampling plots of the secondary wadis in the plateaus of the three study sites. The average vegetation cover ranges between 12% in site 1 and 29 % in site 2. The high percentage of herbaceous plants in site 2 is due to the influence of oil exploration work near to the sample plot, that increases the moisture in the soil at the bottom of the secondary wadi and adjacent slope (see association 12 chapter 5 and plate 5.14).

5.4.5. The vegetation of slopes in plateaus (sp).

The total vegetation cover of slopes in plateaus ranges between 1% and 57%, with an average of 14%, the cover on wet slopes that are irrigated by contaminated water from oil exploration work (plate 5.13), reaches almost 86%. The average tree cover is 0.9%, the shrub cover is 0.7%, the dwarf shrub cover is less than 0.2 %, and the herbaceous cover is 12%). (Table 5.13). The total number of plant species of this region is 47 (40% of the total species collected from the three study sites), with 7(15%) in Shibam, (site 1) 42 (89%) in Wadi Adem (site 2) and 16 (34%) in Wadi Athahab (site 3). Of these, the following three species are distributed with relatively high frequency throughout the study sites: *Dichanthium insculptum, Boerhavia elegans* and *Stipagrostis hirtigluma* (Table 4.4, chapter 4).

The soil of this zone is characterized by:

- High calcium carbonate in all horizons, which ranges between 36.5% and 37.4%, with average of 37.2% in the upper horizon and 37.4 in the lower horizon. .
- High average pH values of 8 with extreme values of 7.5 and 8.3.
- Low organic matter contents ranging between 0.17% and 0.64%, with an average of 0.41%.
- Heterogeneous soil texture, predominantly sandy loam and loamy sand.
- Very low salinity, generally less than 1ms/cm.

site	1				2																							3								
plot no	136	136b	23	average	220	223b	224	223	227	235	237/2	237/1	233	231	234	248	236/2	245	229	240/4	218/5	219	221	225	226	234/b	average	328	327	331	324	330	326	323	average	overall average
trees	0	<1	1	1	1	0	0	0	0	0	0	o	1	1	1	2	15	<1	1	1	1	0	0	0	0	0	1	0	0	<1	0	1	0	0	0.2	0.9
shrub	0	0	0	0	0	0	0	0	0	0	1	1	1	5	3	5	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	<1	0	0	0.2	0.7
dwarf shrub	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	<1	<1	0	2	0	0.4	0.2
herb	4	3	31	13	3	2	12	2	2	2	85	80	2	51	6	3	45	2	1	6	22	0	0	0	0	0	15	3	6	3	0	0	1	2	2.1	12
total cover	**4**	**3**	**32**	13	4	2	12	2	2	2	86	81	4	57	12	10	61	3	3	9	24	0	0	0	0	0	17	3	6	5	1	1	3	2	3	**14**

Table 5.13. Average vegetation cover for each sample plots of the slopes in the plateaus of the three study sites. The average vegetation cover is dominated by herbaceous plant and ranges between 3% in site 3 and 17 % in site 2. The high percentage of vegetation in site 2 is due to the influence of oil exploration work near to the sample plot, that increases the moisture in the soil at the bottom of the secondary wadi and adjacent slope (see association 12 and plate 5.14) as well as due to the accumulation of sediments, moisture and soil through the drainage lines and rills that cut the slopes (see plate 5.16).

5.5. Main vegetation associations

5.5.1. *Alhagi graecorum* - *Phoenix dactylifera* cultivated association

This association densely planted and forms woodland with sparse grassland and is restricted to cultivated sites and on sites of date gardens (with the palm *Phoenix dactylifera*) and fallow fields in Shibam (site 1).
The vegetation cover ranges between 2% and 46%. In date garden sites, the cover can reach 95%. The average tree cover is 24%, the average dwarf shrub cover is 14%, and the average herbaceous cover is about 3 %.

The topography is composed of flat wadis, The soil is loamy and sandy loam with high salinity (between 3.1 and 7.2 ms/cm, the figure is less than 1 in fallow lands), low $CaCO_3$ (between 35 and 37.4%), pH ranges between 7.4 and 8.3, O.C ranges between 0.21 and 0.49 and C.E.C ranges between 5.2 and 7.6 meq/100g . The soil is alluvial-colluvial in origin; the raw mineral soils are Entisols (SOGREAH, 1981) and probably equivalent to Inceptisoil. The altitude ranges from 670 to 722 m above sea level.
Weeds are the dominant and most common species of this association. This association is reflected the next association in that it used to be covered by dense palm trees before being degraded by continuous severe floods.

The dominant species is the date palm *Phoenix dactylifera*. The following species are only found in this association: *Alhagi graecorum, Cressa cretica, Chloris* sp.*, Capparis spinosa, Datura innoxia,* and *Withania somnifera.*


Plate 5.1. Association 5.5.1 A date garden. Widespread along the Wadi Hadhramaut.


Plate 5.2. Association 5.5.1. In the foreground fallow land with *Alhagi graecorum* and *Senna incana* with cultivated fields, scattered date palms in the background

5.5.2- *Citrullus colocynthis - Zygophyllum album* association

This association forms grassland, sparse grassland and sparse shrubland in Wadi Khashamr, Shibam (site 1).

The vegetation cover is very poor ranging between 2% and 8%, but in some favourable locations reaches 50%. The average tree cover is less than 1 %, the average shrub cover is less than 1 %, and the average herbaceous cover is 16 %.

The topography is undulating to almost flat, subjected to severe flooding, consisting predominantly of sandy wadi beds, with 3-5% cover of small rocks. The soil is loam to loamy sand with a high sand proportion (86-88%), CeC is 1.7, $CaCO_3$ is 37.1, EC is 0.3 and pH is 8.7. The altitude ranges from 670 m to 700 m above sea level.

This association is probably a degraded site of wadi beds that used to be covered by dense palm trees with association of *Ziziphus spina-christi*. The highly invasive tree *Prosopis juliflora* is found in many locations. The dominant species is *Zygophyllum album*. The following species are found only in this association: *Citrullus colocynthis* and *Calotropis procera.*

Plate 5.3. Association 5.5.2. in the foreground scattered *Zygophyllum album* and *Prosopis farcta;* in the background palm trees , with *Acacia ehrenbergiana. Prosopis juliflora* was once planted widely for sand dune stabilization and easily occupies this type of habitat. As for many desert plants (Batanouny, 2000), the exposed roots of these plants adapt to tolerate floods for long time.

5.5.3. *Convolvulus glomertaus - Merremia hadramautica - Crotalaria persica* association

This association forms a dwarf shrubland, found on fallow lands located at site 2 (between 675 and 676 above sea level).

The terrain consists of almost flat, narrow, relatively rocky wadi beds. The soil is sandy loam, with low CaCO3 (30%), high CeC (6.1%) and high moisture content (5.5%) with pH 8.1 and O.C 0.5%.

The vegetation cover is high and ranges between 65 to 75%, dominated by a dwarf shrub cover. The average dwarf shrub cover is 60%, and average herbaceous cover is 9 %. The association is dominated by *Crotalaria persica* and *Merremia hadramautica*.

The following species are abundant in this association and always occur:

Pulicaria undulata, Crotalaria persica, Compositae *aff. Flaveria, Corchorus depressus, Chrozophora tinctoria, Heliotropium ramosissimum* and *Convolvulus glomeratus.*

Plate 5.4. Association 5.5.3. Fallow land on relatively stony wadi bed, dominated by dwarf shrubland of *Merremia hadramautica* and *Crotalaria persica*.

5.5.4 -*Tephrosia dura - Tephrosia apollinea- Fagonia indica* association

This is a mixture of open woodland with sparse shrubland, and grassland, occurring on Wadi Khumur and Shie'b Sultan of site 1 (between 638-733 m above sea level).

This association is found on slightly undulating or almost flat rocky wad beds and depressions, often with extensive rocky outcrops. The soil is sandy loam, with stone proportions ranging between 60 to 95% and low moisture content. CeC is 5, O.C. is 0.4%, $CaCO_3$ is 37.1%, EC is 7.4% and pH is 8.3.

The vegetation cover ranges between 6 to 42%. The average tree cover is 3%, the average shrub cover is 12%, the average dwarf shrub is 1% and the average herbaceous cover is about 8 %.

The leading species are *Fagonia indica,* and *Tephrosia apollinea,* in association with *Acacia campoptila.* The former species, as well as *Cymbopogon schoenanthus* and *Tephrosia dura,* are always present. Trees are dominated by *Acacia campoptila* and are found over large areas with a sparse and scattered distribution but, in some locations, they form open woodland. In areas where water is significant, such as in depressions and near cultivated fields, the vegetation is relatively rich with species such as:

Acacia ehrenbergiana, Acacia hamulosa, Barleria aff. bispinosa, Boerhavia elegans, Dichanthium insculptum, Kohautia retrorsa, and *Zygophyllum simplex. Zygophyllum album* and *Senra incana* are only seen in high saline sites; on the other hand *Kohautia retrorsa* and *Acacia hamulosa* were absent in these sites.

Plate 5.5. Association 5.5.4. Scattered species of *Tephrosia apollinea.* with *Acacia campoptila* (a tree to the right).

5.5.5- *Acacia ehrenbergiana - Rhazya stricta - Acacia campoptila* association

This association is a mixture of open woodland, sparse shrubland, and sparse grassland, found mainly on wadi beds and adjacent banks of wadi beds in Wadi Adem and its tributaries Wadi Bayut and Wadi Hikma of site 2 and in a small location at Wadi Nia'm, Shibam north east of site 1.

The topography is undulating to almost flat stony over wide wadi beds and banks; subject to strong flooding, the soil is yellowish with pale brown loamy to sandy loam texture, with high CeC (5.5%), low EC (3.8%), low moisture (1%), high clay content (10%) and with pH of 7.9%; no rock outcrops. The altitude ranges between 624 and 686 m above sea level. The vegetation cover varies between 3 and 41%, (the average tree cover is 8 %, the average shrub cover is 2.2, the average dwarf shrub is 1.4% and the average herbaceous cover is about 3 %).

Acacia campoptila is the dominant species. *Cassia senna, Crotalaria persica* and *Salvadora persica* are rare and only found in this association. *Acacia campoptila* and *A. ehrenbergiana* form open woodland in varies locations. In places characterized by non-stony compacted soil with pale brown sandy loam texture, only a few species (about 6) are found, (plate 5.6). *Rhazya stricta, Fagonia indica* and *Ochradenus baccatus* occur at a high frequency.

Plate 5.6. Association 5.4.5 Foreground, almost bare compacted hard soil with very poor cover of *Fagonia indica* and *Cassia italica*. In the background open woodland of *Acacia campoptila* with very few *Ochradenus baccatus*. (Wadi Bayut, site 2).

5.5.6- Salsola imbricata - Blepharis edulis association

This association is a mixture of sparse shrubland, dwarf shrubland and sparse grassland, on wadi beds and adjacent banks in site 2.

The terrain is almost flat to undulating rocky wadi beds and banks, with sandy loam and silty soil, almost no rock outcrops. The CeC is 6.2, O.C. is 0.5%, CaCO3 is 37%, EC is 3.8%, pH is 7.9 and moisture content is 2.8%. The altitude ranges between 632 and 692m.

The vegetation cover is very poor, ranging between 2% and 41%. The average tree cover is 4%, the average shrub cover is 1%, the average dwarf shrub cover is 4% and the average herbaceous cover is 3%. The vegetation cover in some more favourable sites, such as wadi banks (plate 6.7) or at the foot of the limestone slopes where alluvium has been deposited by a small tributaries flowing from the plateau down to the main wadi (alluvial fan), reaches 41%. (plate 5.8).

Blepharis edulis is the dominant species especially on the rocky, almost flat open sites (Hamada) with little sediment cover, which are exposed to high winds and sun. This habitat also has very limited plant growth (plate 5.10). Here *Acacia campoptila* becomes rare or absent. *Salsola imbricata* is only found in this association. The following occur with high frequency in the association: *Acacia campoptila, Salsola imbricata, Boerhavia elegans* and *Fagonia indica.*

Plate 5.7. Association 5.5.6 Foreground woodland of *Acacia campoptila* with dwarf shrub *Salsola imbricata, Indigofera spinosa* and *Fagonia indica.*

Plate 5.8. Association 5.5.6. Foreground *Acacia campoptila*. Background herbaceous cover of *Indigofera spinosa, Blepharis edulis* and *Stipagrostis hirtigluma*. (Shie'b Al Salaq, sample plot 216, site 2). Fallen rocks and finer particles accumulate at the base of the mountain slope and make it appropriate for plants.

Plate 5.9. Association 5.5.6. Foreground almost flat, wide, very shallow rocky, open wadi bed (Hamada) dominated by *Blepharis edulis*. Background single tree of *Acacia campoptila*.

5.5.7- Tephrosia nubica - Acacia campoptila - Merremia hadramautica association

This is a widespread rich association that contains about 37% of total species of the wadi associations and is considered as the second richest association. This association is confined to wadi beds and adjacent banks of Wadi Athahab and its tributaries (site 3). However, the vegetation cover is poor (mainly sparse grassland with dwarf shrubland) and ranges between 3% and 43%. The average tree cover is 2%, the average shrub cover is less than 1 %, the average dwarf shrub cover is 9% and the average herbaceous cover is 3%.

The terrain varies from undulating to almost flat rocky wadi beds and banks with soil of sandy loam, silty and loamy texture. The CeC is 10, O.C% is 7, $CaCO_3$ is 37.2%, EC is 1.4%, pH is 7.6% and moisture content is 3.1%. The altitude ranges between 579 and 668 m above sea level.

Merremia hadramautica, and *Acacia campoptila* are the dominant species. In addition *Tephrosia nubica, Indigofera spinosa* and *Fagonia indica* occur at a high frequency. In areas that are subjected to severe flooding (see plate 5.10), the number of plant species does not exceed 7. *Merremia hadramautica* only occurs in this association.

Plate 5.10. Association 5.5.7. Foreground *Tephrosia nubica* and *Merremia hadramautica*. Background trees of *Acacia campoptila*. Very few species are found in sites that are subjected to severe flooding, the number of plant species here does not exceed 7, while dense cover is found at the edge of the wadi bed.

5.5.8. *Forsskaolea tenacissima - Boerhavia elegans* association

The structure of this association is grassland and includes sparse grassland found on mountain slopes facing the main wadis of site 1.

Stipagrostis hirtigluma is the dominant species. In addition, the following species also occur at a high frequency: *Aerva javanica, Farsetia linearis* and *Fagonia indica.*

The terrain is eroded, moderate to steep very rocky shallow slopes, with rill and gully erosion, and soil of loam and sandy loam texture. The CeC is 5.2, O.C% is 0.2, $CaCO_3$ is 35.7%, EC is 1%, pH is 8.2% and moisture content is 1.6%.The altitude ranges between 690 and 827 m above sea level.

The vegetation cover is very poor and ranges between 1% and 5%, the average tree cover is less than 1% and the average herbaceous cover is about 4%. The vegetation cover reaches 12% in more favourable sites where moisture and soil accumulate, such as drainage lines or depressions. (Plate 5.7). The smaller particles that accumulate in these sites with a cover of gravels, sands and silts are able to support quite good plant growth.

Plate 5.11 . Association 5.5.8. Very eroded slope with vegetation concentrated on the drainage lines and depressions. Foreground plants are *Reseda sphenocleoides*; and background plants are *Stipagrostis hirtigluma, Aerva javanica* and *Dichanthium insculptum.* This slope presents a good barrier against the loss of a lot of particles such as gravels, sands and silts and in consequence supports quite good plant growth.

5.5.9. *Fagonia paulayana - Boerhavia elegans - Cleome scaposa* association

An association predominantly made up of sparse grassland and is confined to mountain slopes facing the main wadis of site 3.

Fagonia paulayana and *Cleome scaposa* are the dominant species. In addition the following species also occur with a high frequency: *Boerhavia elegans,* and *Cleome brachycarpa.*

The vegetation cover is very poor and mainly consists of herbaceous plants, and ranges between less than 1 % and 3%, with an average herbaceous cover of 3%.

The terrain consists of very eroded, moderate to steep slopes, rocky with high soil loss, and soil of pale brown colour, loam and sandy loam texture. The CeC is 7.6, O.C% is 0.2, $CaCO_3$ is 37.3%, EC is 0.57%, pH is 7.9% and moisture content is 7.4%. Rill and gully erosion are very obvious. The altitude ranges between 590 m and 685 m above sea level.

Plate 5.12. Association 5.5.9. (sample plot 310). Very eroded rocky slope with high soil loss. The vegetation cover is less than 1%.

Plate 5.13. Association 5.5.9. Eroded rocky steep slope with vegetation cover less than 2% in stone pavement.

5.5.10. *Indigofera spinosa - Stipagrostis hirtigluma* association

This association is predominantly sparse grassland found on mountain slopes facing the main wadis of sites 1 and 2. Very similar to the previous association but different in having fewer species. The common species in the previous association such as *Fagonia paulayana, Enneapogon desvauxii, Cleome scaposa* and *Tribulus arabicus* are absent here. *Indigofera spinosa,* which is common here, was not found in the previous association.

The terrain is much eroded, moderate to very steep, rocky, shallow dry slopes; with soil of sandy loam and loam texture; rill and gully erosion are seen in some locations. The CeC is 5.7, $CaCO3$ is 37%, O.C% is 0.2, EC is 0.42%, pH is 8.1% and moisture content is 3.2%. The altitude ranges between 692 and 763 m above sea level.

Stipagrostis hirtigluma is the dominant species. The vegetation cover is very poor and mainly consists of herbaceous plants, ranging between 2% and 8%; the average herbaceous cover is about 3 %. The number of species in this habitat is very low and does not exceed 10.

Plate 5.14. Association 5.5.10. Very eroded and unstable steep slopes with vegetation cover less than 2%. The vegetation is mainly found in runnels and rills.

5.5.11. *Seetzenia lanata - Dichanthium insculptum* association

This association is widespread and forms a grassland and sparse grassland, and is found on plateaus and their slopes over different parts of the study sites.

The terrain varies from almost flat to moderate steep slopes, and is very rocky, with shallow loamy soils. The CeC is 8, $CaCO_3$ is 37%, O.C% is 0.34, EC is 1.6%, pH is 8.1% and moisture content is 3.3%. The altitude ranges between 910 and 995 m above sea level.

Stipagrostis hirtigluma is the dominant species. Other important species of this association are *Farsetia linearis* and *Dichanthium insculptum*. *Arnebia hispidissima, Portulaca oleracea, Seetzenia lanata* and *Launaea* sp. are only seen on the slopes of this habitat. The vegetation cover is generally very poor and ranges between 1% and 9%. The average tree cover is less than 1%, the average shrub cover is less than 1%, and the average herbaceous cover is 13.2 %. However, the cover rises to 40% in places where surface stony sites have been cleared and soils been exposed (plate 5.15); the average herbaceous cover is about 14%. On wet slopes that are contaminated water from oil exploration work (plate 5.16); the cover can reach almost 91%.

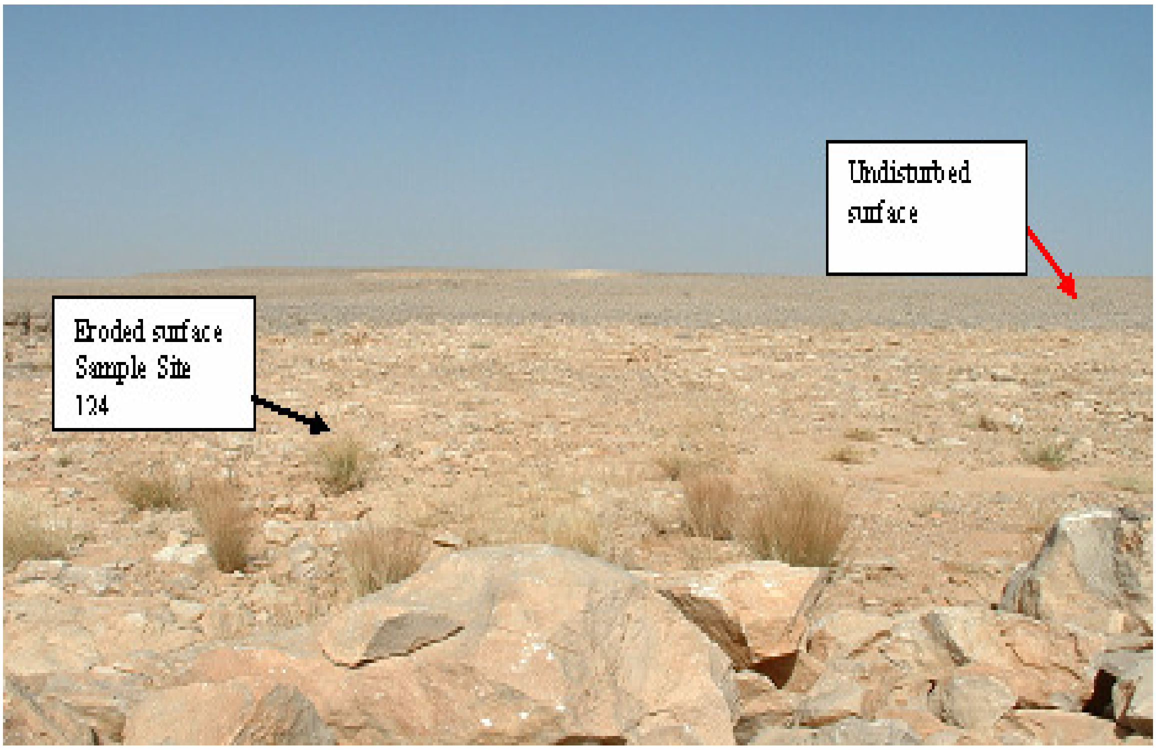


Plate 5.15. Association 5.5.11. Foreground, eroded surface with *Stipagrostis hirtigluma* and *Farsetia linearis* (sample plot 124), background undisturbed surface with very poor or no vegetation cover. With the removal of the surface stone layer, the exposed soil is able to support a high vegetation cover and reaches 40%. This new composition of plant species can be considered as a primary succession habitat.

Plate 5.16. Association 5.5.11 (sample site 237) dominated by *Dichanthium insculptum* and *Farsetia linearis.* Compared with the surrounding dry gentle slopes, very dense vegetation cover can be seen in the foreground and the adjacent wadi. This is due to seepage of contaminated water from oil exploration work.

5.5.12. *Chrysopogon aucheri- Stipagrostis hirtigluma* association

This is a widespread association, predominantly grassland, with a few sites covered by sparse shrubland, sparse grassland and dense grassland. This association is the richest with a number of plant species and is found on narrow secondary wadis and drainage lines over the plateaus, across all the study sites and on alluvial fans on the plateau of site 1.

The vegetation cover ranges between 4 and 37%; in favourable moisture soil sites the cover reaches 86%. The average tree cover is 2.7%, the average shrub cover is less than 1%, the average dwarf shrub cover is 1.1% and the average herbaceous cover is 17.6 %.

The characteristic landform consists of slightly steep slopes to almost flat, narrow secondary wadi drainage lines that cut the plateaus and alluvial fans. The predominant pavement rock covers 80 to 99 % of the site. The CeC is 6.1, O.C. is 0.2%, CaCO3 is 37%, EC is 6.9%, pH is 7.4% and moisture content is 3%. The altitude ranges from 858 to 979m.

The dominant species are *Dichanthium insculptum* and *Stipagrostis hirtigluma.* The following species are found only in the wettest, highly saline (about 7 ms/cm) sites of this association: *Abutilon bidentatum, Pluchea dioscoroides, Leptadenia arborea, Pulicaria undulata* and *Tamarix arabica.* Other species that occur only in this association are: *Moltkiopsis ciliate, Chrysopogon aucheri, Hermannia paniculata, Glossonema varians,* and *Abutilon bidentatum*.

Plate 5.17. Association 5.5.12 (sample site 130). Alluvial fan with good cover on the plateau of site 1. Foreground *Cymbopogon schoenanthus* and *Acacia oerfota*. Background *Commiphora foliacea.*

Plate 5.18 Association 5.5.12. Narrow drainage line on the plateau, with predominantly pavement rock covering 80 to 99 % of the site. Foreground *Dichanthium insculptum, Stipagrostis hirtigluma* and *Barleria aff bispinosa*. Background *Acacia hamulosa.*

Plate 5.19. Association 5.5.12. Very wet site with dense vegetation cover reaching 86%. Foreground, *Chrysopogon aucheri, Dichanthium insculptum, Farsetia linearis, Aerva javanica* and others. Background trees of *Acacia oerfota*, *Acacia mellifera* and *Commiphora foliacea.* Very dense vegetation cover can be seen due to ?seepage/watering of/by contaminated water from oil exploration work.

5.5.13. *Maerua crassifolia - Jatropha spinosa - Stipagrostis hirtigluma* association

The structure of this association is predominantly sparse shrubland with a few locations covered by sparse grassland, woodland, dense grassland and grassland found in site 2.

The terrain is moderate to steep rocky slopes (30-50%) and alluvial fans with rill erosion, and soils of sandy loam and loamy sand texture. The CeC is 4.3, O.C.% is 0.35%, CaCO3 is 36.8%, EC is 0.26%, pH is 8.1% and moisture content is 1.8%. The altitude ranges between 899 and 977 m.

The vegetation of this association is quite rich predominantly herbaceous and the cover ranges between 3% and 61%. The average tree cover is 3%, the average shrub cover is 2%, the average dwarf shrub cover is 1% and the average herbaceous cover is 14%.

Jatropha spinosa is the dominant species. In addition to the dominant species, the following species also occur in high frequency: *Dichanthium insculptum, Stipagrostis hirtigluma, Zygophyllum decumbens* and *Commiphora foliacea.* The following are only species that almost occur in this association: *Maerua crassifolia, Grewia erythraea, Helichrysum pumilum, Seddera latifolia, Chascanum marrubifolium, Tarenna graveolens, Cadaba heterotricha, Arnebia hispidissima, Trichodesma calathiforme* and *Euphorbia rubriseminalis.* The latter species was only seen once on a rocky, narrow wadi bed and adjacent foot slopes (alluvial fan).

Plate 5.20. Association 5.5.13 (sample site 245). Dry, shallow, very eroded slope with vegetation cover less than 5%. Background sparse cover of *Jatropha spinosa* with *Dichanthium insculptum* and *Farsetia linearis*

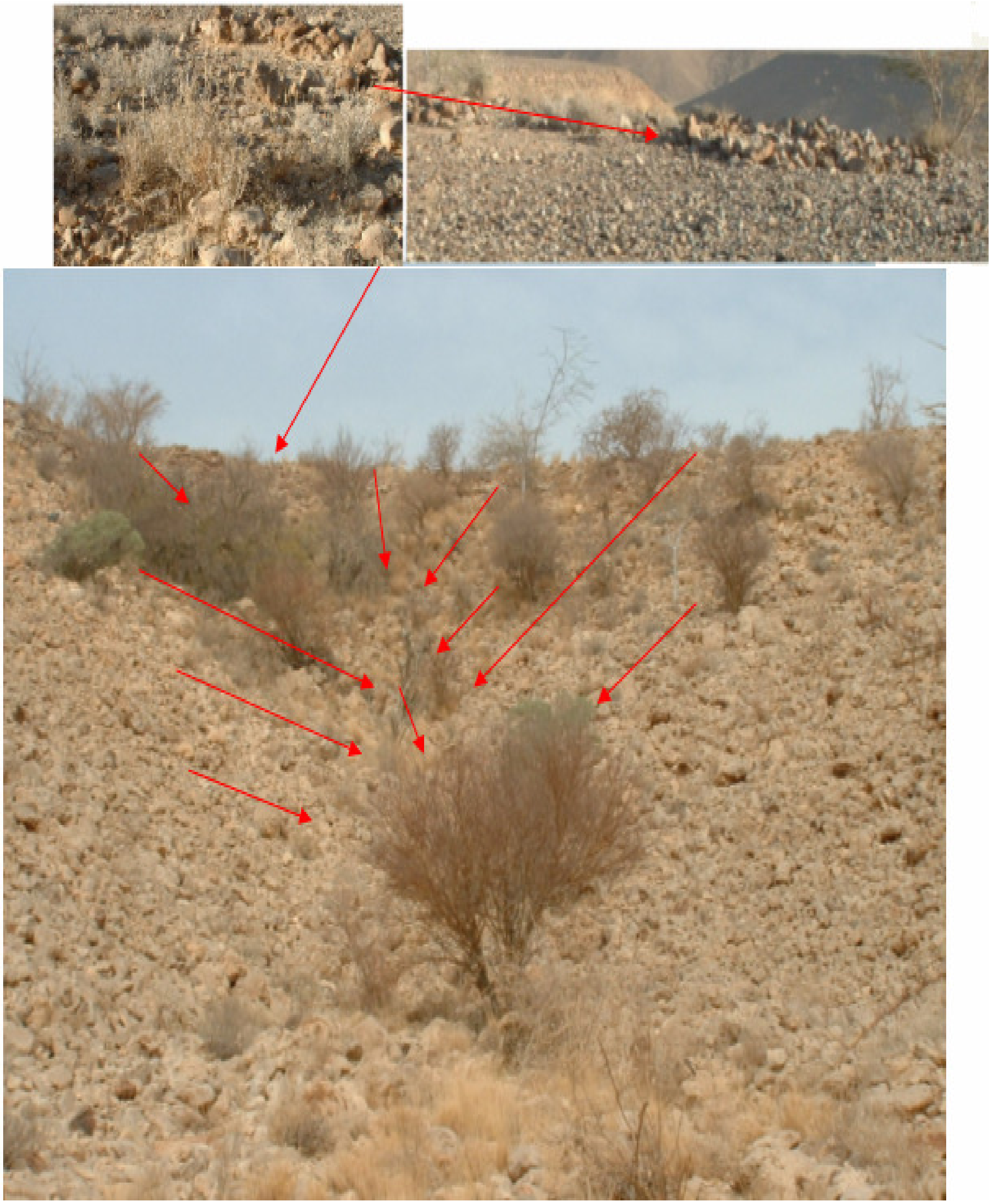


Plate 5.21. Association 5.5.13 (sample site 238). Runnels on slope, influencing vegetation cover. Foreground herbs dominated by *Indigofera spinosa.* Background trees mainly *Acacia mellifera, Maerua crassifolia,* and *Jatropha spinosa.* The richness of this slope is due to stone ring shape foundation on the plateau which diverts more water during the rainy season towards this slope (top picture) and also the v shape type of slope which directs the flow of the water towards the dense cover. (The arrows show the direction of water flow).

5.5.14- *Cornulaca amblyacantha - Stipagrostis hirtigluma* association

This association is confined to site 3 and is predominantly sparse grassland with a few locations covered by sparse shrubland.

The terrain is a moderately steep very rocky slope, with rill and gully erosion, and soils of a sandy loam texture. The CeC is 5%, O.C%. is 0.64%, $CaCO_3$ is 37.4%, EC is 0.37%, pH is 8% and moisture content is 1%. The altitude ranges between 932m and 955 m above sea level.

Stipagrostis hirtigluma is the dominant species. In addition to the dominant species, the species *Jatropha spinosa* also occur at a high frequency. The species *Cornulaca amblyacantha* only occurs in this association.

The vegetation cover is very poor with only 13 plant species, and ranges between less than 1 % and 4%. The average tree cover is < 1, the average shrub cover is less than 1 %, the average dwarf shrub is 1% and the average herbaceous cover is 1%.

Plate 5.22. Association 5.5.14 (sample site 326). Very eroded rocky slopes with vegetation cover <4%. Background *Jatropha spinosa* with *Stipagrostis hirtigluma.*

5.5.15. *Zygophyllum decumbens - Dichanthium insculptum* association

The structure of this association is confined to site 2 and is predominantly sparse grassland with few locations covered by grassland. This association is very similar to association 10 but different in having fewer species. Some species that are found in association 10, such as *Boerhavia elegans*, *Cleome brachycarpa* and *Indigofera spinosa,* were absent here. On the other hand, the common species of this association (*Zygophyllum decumbens)* was not found in association 10.

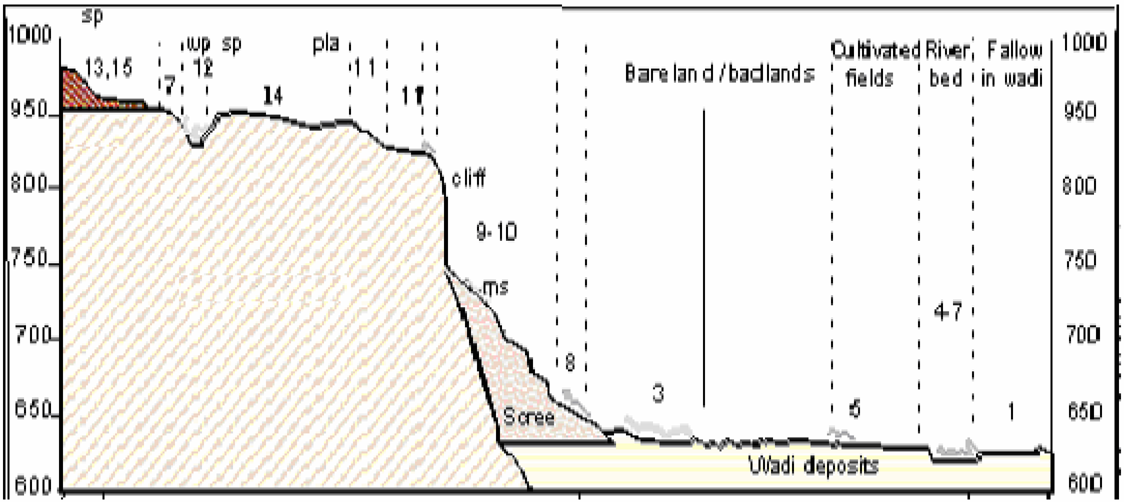
The terrain is a moderately steep slope (30-40%) very rocky, with rill erosion, high soil loss, and soil with a sandy loam texture. The CeC is 5.2%, O.C%. is 0.5 %, $CaCO_3$ is 37%, EC is 0.5%, pH is 8% and moisture content is 14%. The altitude ranges between 922 and 949m.

Dichanthium insculptum is the dominant species, the species *Zygophyllum decumbens* always occurs in this association. This association represents the degraded sites of association 13 that occur in the same study site and in the same type of land formation.

The vegetation cover is very poor, with only 8 plant species that are mainly herbaceous, ranging between 2% and 12%, , with an average of 4% cover.

Plate 5.23. Association 5.5.15 (sample site 224), very rocky slope with sparse vegetation cover dominated by *Dichanthium insculptum* and *Zygophyllum decumbens.*

5.6. Summary of the vegetation associations.



No	The vegetation association	Sites	Altitude a.s.l. (m)
1	*Alhagi graecorum - Phoenix dactylifera*	Flat fallow and cultivated lands,site1	*670-722*
2	*Citrullus colocynthis - Zygophyllum album*	Flooded wadi bed, site 1	*670 - 700*
3	*Convolvulus glomeratus – Merremia hadramautica – Crotalaria persica*	Old fallow land, site 2	*675-677*
4	*Tephrosia dura - Tephrosia apollinea- Fagonia indica*	wadi beds and depressions, site 1	*683-733*
5	*Acacia ehrenbergiana – Rhazia stricta – Acacia campoptila*	almost flat to undulating rocky, wadi beds and banks, site 1 & 2	*624-686*
6	*Salsola imbricate - Blepharis edulis*	Wadi beds and adjacent banks, site 2.	*632-692*
7	*Tephrosia nubica - Acacia campoptila - Merremia somalensis*	Wadi beds and adjacent banks, site 3	*579-668*
8	*Forskohlea tenacissima - Boerhavia elegans*	moderate to steep rocky slopes and alluvial fans facing the main wadis of site 1.	*690-827*
9	*Fagonia paulayana - Boerhavia elegans – Cleome scaposa*	very eroded moderate to steep rocky slope facing the main wadis of sites 3.	*590-685*
10	*Indigofera spinosa - Stipagrostis hirtigluma*	eroded moderate to steep rocky slope, facing the main wadis of sites 1 & 2	*692- 763*
11	*Seetzenia lanata - Dichanthium insculptum*	plateaus and their slopes, all sites	*910-995*
12	*Chrysopogon aucheri - Stipagrostis hirtigluma*	narrow wadis and drainage lines of the plateaus in all study sites	*858-979*
13	*Maerua crassifolia - Jatropha spinosa – Stipagrostis hirtigluma*	slope of plateau, site 2	*899-977*
14	*Cornulaca amblyacantha - Stipagrostis hirtigluma*	Slope of plateau, site 3	*932-955*
15	*Zygophyllum decumbens - Dichanthium insculptum*	Slope of plateau, site 2	*922-949*

Figure 5.9. Summary diagram of floristic vegetation associations across the main topographical units.

Most of the vegetation associations are dominated by herbaceous plants Vegetation associations 1, 2, 4, 8 and 13 are confined to site 1; vegetation associations 3, 6, 13 and 15 are confined to site 2, while vegetation associations 7, 9 and 14 are confined to site 3. The vegetation associations of the main wadis are dominated by *Acacia campoptila, Fagonia indica, Tephrosia apollinea and Cymbopogon schoenanthus*. Trees on the main wadis are dominated by *Acacia campoptila* and are found over large areas with a sparse and scattered distribution, but in some locations, they form open woodland. Associations 8, 9 and 10 are confined to mountain slopes facing the main wadis and are dominated by *Dichanthium insculptum, Boerhavia elegans, Cleome brachycarpa, Stipagrostis hirtigluma* and *Farsetia linearis*. Associations 13, 14 and 15 are confined to the slopes of the plateau and dominated by *Dichanthium insculptum Zygophyllum decumbens, Jatropha spinosa* and *Stipagrostis hirtigluma.*

Association 7 is considered to be the second richest association. This association is confined to wadi beds and adjacent banks of Wadi Athahab and its tributaries (site 3). Association 12 is the richest association and is found on narrow secondary wadis and drainage lines over the plateaus across all the study sites and on alluvial fans on the plateau of site 1. Associations 1 and 3 have the highest vegetation cover percentages. Association 1 is dominated by trees and shrubs namely *Phoenix dactylifera, Prosopis farcta* and *Alhagi graecorum*, while association 3 is dominated by dwarf shrub and herbaceous cover namely *Merremia hadramautica, Crotalaria persica,* and *Heliotropium ramosissimum.*

The following Figures (5.10 to 5.12) illustrate the different land uses and topographical features of each study site.

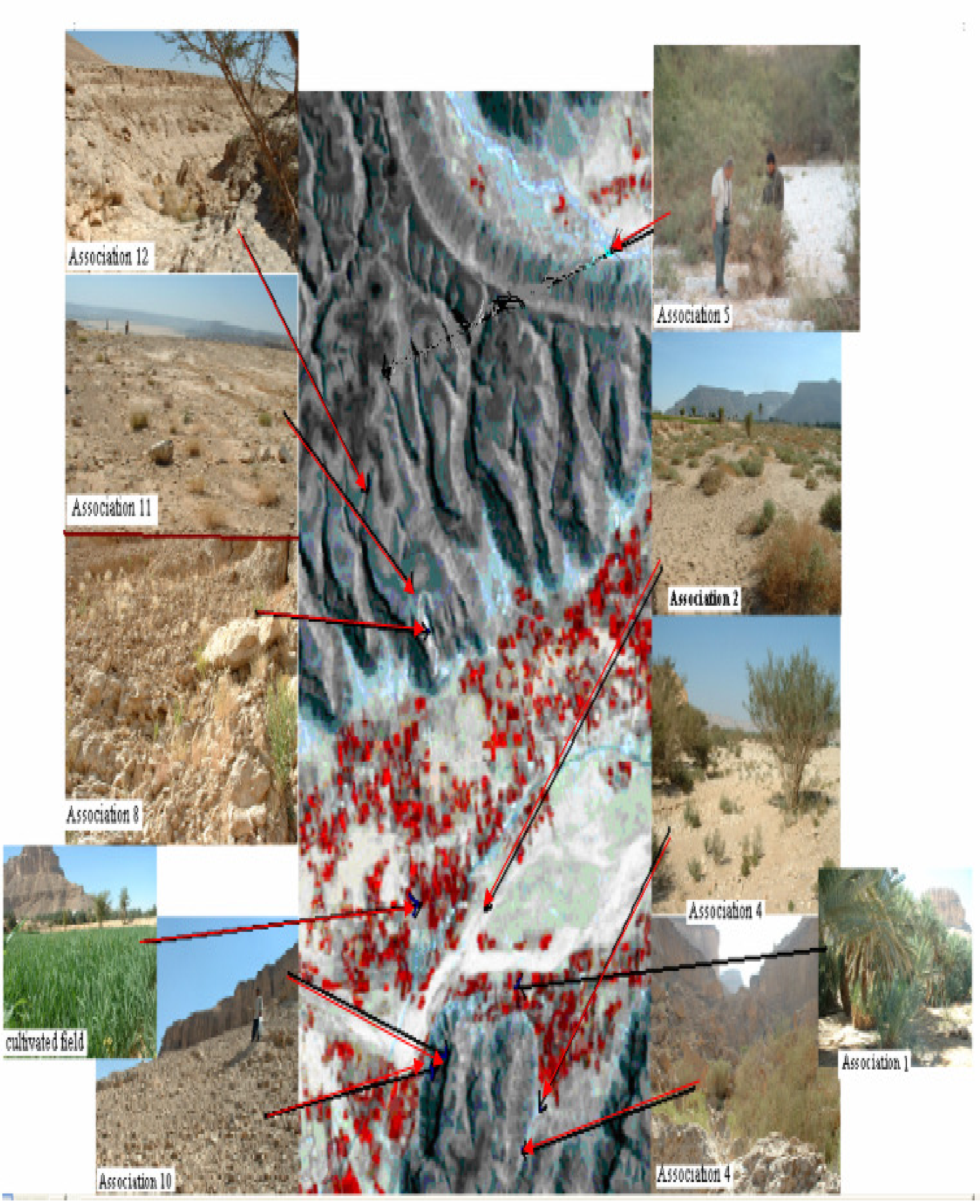


Figure 5.10. Main vegetation associations of site 1

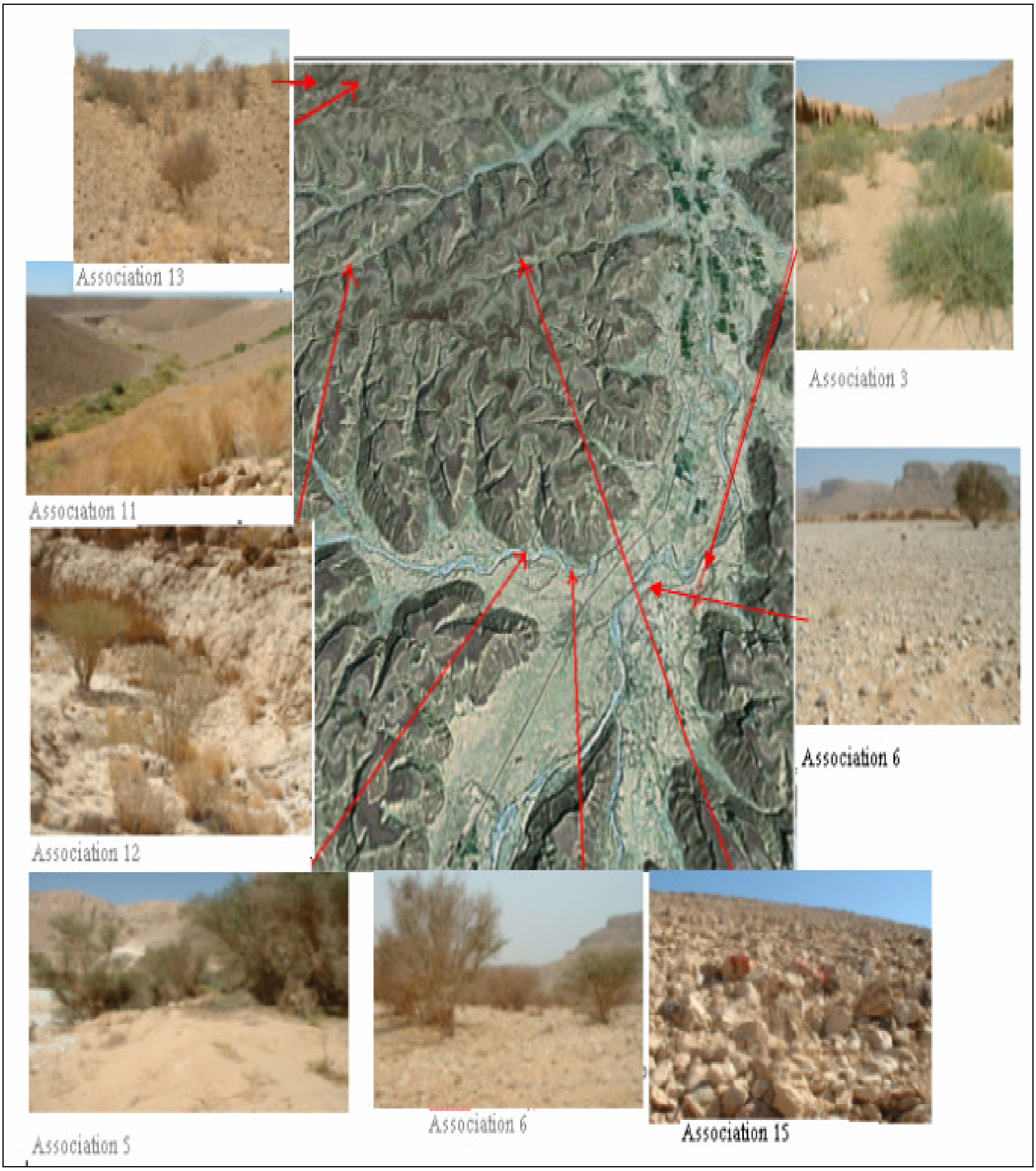


Figure 5.11. Main vegetation associations of site 2

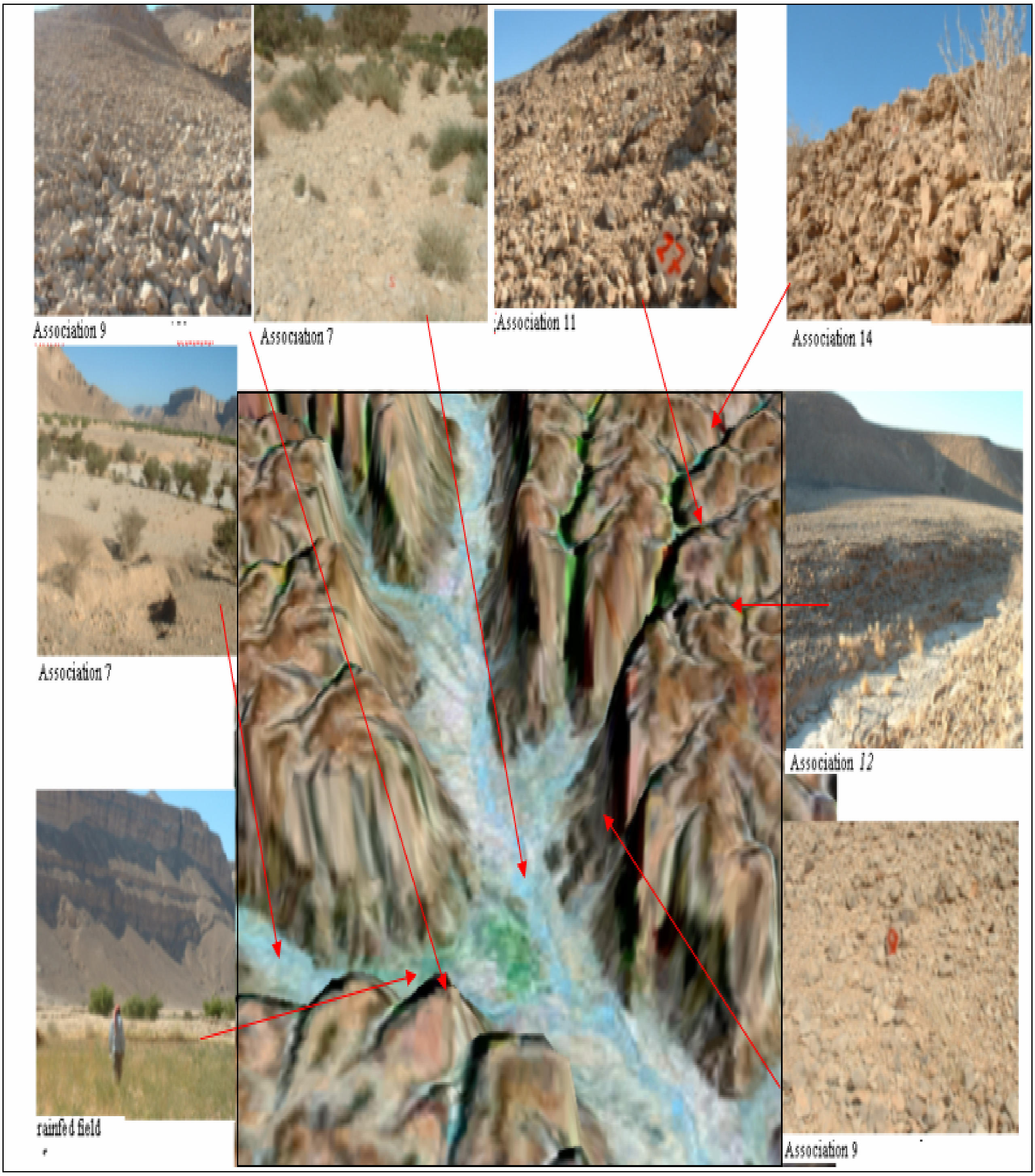


Figure 5.12. Main vegetation associations of site 3.

5.7. Similarity between the main vegetation associations

In the previous sections, the main floristic associations were described in terms of vegetation composition, structure, locality and dominant plant species. The next stage has been the analysis of similarities between the various vegetation associations using Bray-Curtis similarity method with Group-Average clustering and presence and absence data.

This method appears to give a reasonable grouping of clusters, which shows two main groups (Figure 5.13):-
Group A. Comprises the associations of main wadis and
Group B. Comprises the associations of slopes facing the main wadis and the plateau zones.

Associations 6 and 7 as identified in Figure 5.13 and Table 5.14 are considered as the most similar habitats within the study sites, with similarities of 66%, followed by associations 8 and 9 with a similarity of 62% (Table 5.14). The former two associations are found on the main wadi beds of sites 1 and 3 and the latter two are found on the mountain slopes that face the main wadis of sites 1 and 3.

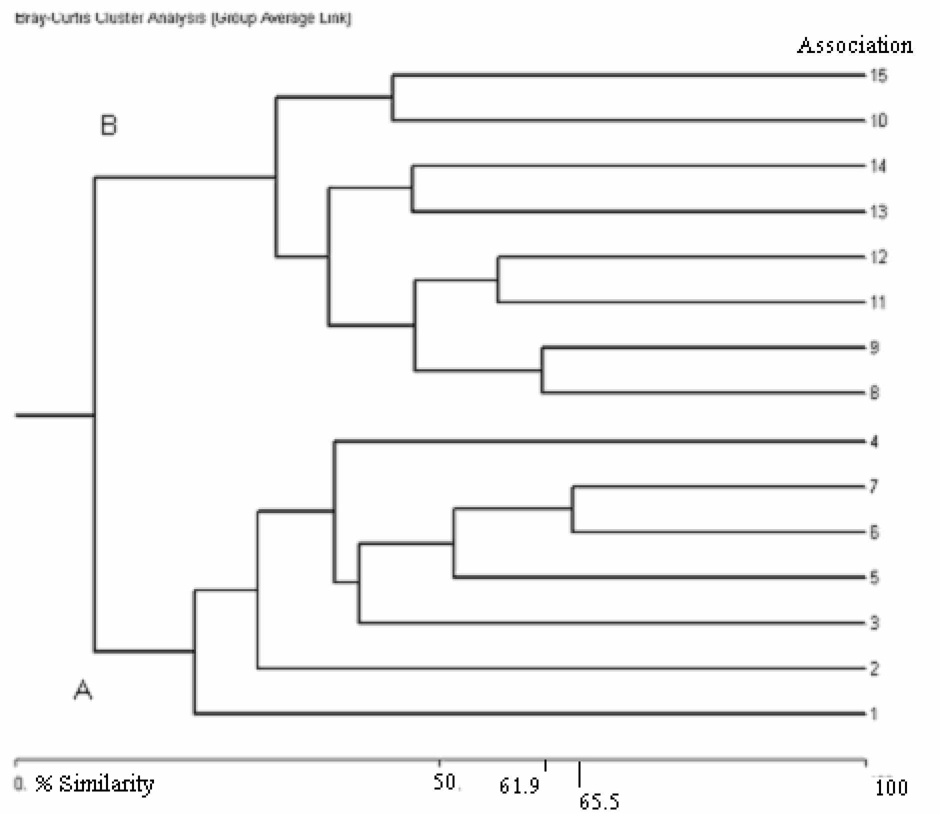


Figure 5.13. Similarity dendrogram produced by the Bray-Curtis similarity method using Group-Average clustering, showing the similarity between the main floristic associations in the 3 study sites. Associations 6 and 7 are the most similar habitats in the study sites with a similarity of almost 66%, then associations 8 and 9 with a similarity of almost 62% (Table 5.8). Associations 1 to 7 (group A) are confined to the main wadis, while the remaining associations (group B) are distributed over the slopes facing the main wadis (8-10) and the plateau zones (11-15).

Similarity Matrix

association	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*	25.8	17.6	19.5	18.2	10.3	8.2	9.5	0.0	15.4	3.9	6.7	4.2	0.0	9.1
2	*	*	28.6	28.6	36.6	16.0	28.0	14.0	6.5	7.4	16.4	13.1	12.2	0.0	8.7
3	*	*	*	35.6	45.8	32.6	37.7	26.1	11.8	20.0	25.5	25.0	7.7	0.0	15.4
4	*	*	*	*	36.4	36.0	50.0	45.3	29.3	32.4	29.0	45.1	27.1	20.0	24.2
5	*	*	*	*	*	49.1	54.0	28.6	27.3	25.0	24.6	37.8	12.9	4.7	11.1
6	*	*	*	*	*	*	65.5	58.8	51.3	40.0	36.7	43.5	24.6	21.1	19.4
7	*	*	*	*	*	*	*	49.2	44.9	31.1	34.3	48.1	20.9	16.7	14.6
8	*	*	*	*	*	*	*	*	61.9	42.1	60.3	52.8	30.0	34.1	35.3
9	*	*	*	*	*	*	*	*	*	46.2	43.1	36.7	25.0	41.4	36.4
10	*	*	*	*	*	*	*	*	*	*	34.0	35.7	27.3	32.0	44.4
11	*	*	*	*	*	*	*	*	*	*	*	56.8	37.7	44.0	27.9
12	*	*	*	*	*	*	*	*	*	*	*	*	41.0	30.5	26.9
13	*	*	*	*	*	*	*	*	*	*	*	*	*	47	30
14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	29
15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 5.14. Similarity matrix between the main floristic associations. This matrix contains numbers which represent the percentage of similarity between the main floristic associations . Associations 6 and 7 are the most similar habitats, with a similarity of nearly 66%. There are also high similarities between associations 8 and 9 (about 62%) and between associations 11 and 12 (about 57%).

The similarity between the vegetation associations produced using Bray-Curtis was based on the number of plant species occurring in these vegetation associations. For example, out of 41 plant species in associations 6 and 7, 20 were occurring in both associations and out of 29 plant species in associations 8 and 9, 15 are found in both associations. The similarity percentage between 2 associations increases with the increase of similar plant species in both associations. The cluster method also separated the associations of main wadis from the rest of the associations, this also based on the previous reasons.

5.8. The distribution of vegetation associations throughout the study sites

As described earlier, 15 floristic vegetation associations have been distinguished according to their floristic composition using Braun-Blanquet and Twinspan classification methods (section 5.3). Table 5.15 shows the distribution of these vegetation associations throughout the study sites.

Association site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	+	+		+	+			+		+	+	+			
2			+		+	+				+	+	+	+		+
3							+		+		+	+		+	

Table 5.15. The distribution of the floristic associations throughout the study sites. Associations 11 and 12 are distributed throughout the study sites.

As we notice from Table 5.9, most floristic associations are confined to specific sites except associations 5 and 10, which occur in sites 1 and 2 and associations 11 and 12, which are distributed throughout all the study sites.

Association 11 is predominantly grassland, found mainly on the plateaus and surrounding slopes and dominated by *Stipagrostis hirtigluma* and *Dichanthium insculptum*. This association is characteristic of the vegetation that covers all the plateaus and surrounding degraded slopes. Association 13, which confined to site 2 is predominantly sparse shrubland and dominated by *Jatropha spinosa* with high frequency of *Dichanthium insculptum* and *Stipagrostis hirtigluma.* This association can be a climax vegetation before being disturbed and degraded to secondary succession

(Kent & Coker, 1992); this succession represented by association 15, which is characterised by very few species, not more than 8, of mainly herbaceous plants.

In order to use vegetation as an environmental indicator, the plant species were subdivided into sociological groups, or groups of plant species that behave similarly (Zonneveld, 1989) or have the most similar distribution across the sample plots (Martin et al., 2003).

Figure 5.14 shows the vegetation associations (in the columns) versus sociological species groups (in the rows), illustrating the distribution patterns of the sociological species groups across the different landforms. The bar diagram shows that each floristic vegetation association is characterised by a specific combination of plant-sociological groups, except for association 1 which has only sociological species group A. This association is confined to the cultivated fields, and has specific plant species which are absent in other environments.

Some sociological species groups are confined to a particular association, for example groups A, B, G, I, N, T and V are found only in associations 1, 2, 4, 5, 6, 11, and 12 respectively. Most of the sociological species groups are present in more than one association, while sociological species group H occurs in almost all of the floristic vegetation associations. Some sociological species are represented at very low frequencies, as for example, groups S, W, X, AA, BB and CC; these groups are characterised mainly by very rare plant species. For more detail see Table 5.6 which describes the sociological species groups.

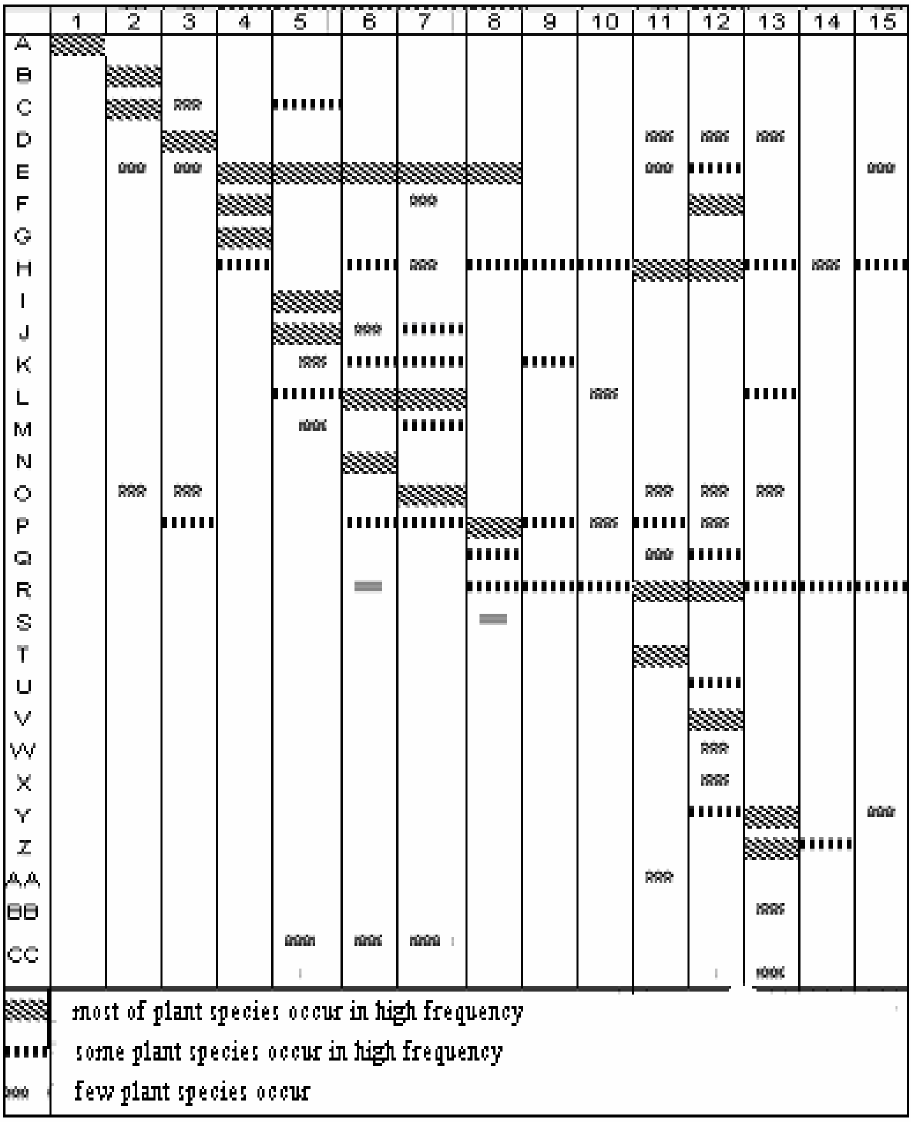


Figure 5.14. A bar diagram of floristic vegetation associations 1-15 (in the columns) versus sociological species groups A-CC (in the rows). It can be seen that there are very clear separations between 3 groups that grow on main wadis (1 to 7), on mountain slopes facing main wadis (8 to 10) and on the plateau zones (11 to 15). Some sociological species groups, such as groups A and B, have very limited distributions; the first is confined to cultivated fields and the latter is confined to flooded sandy wadi beds of site 1; whereas other groups such as group H have variable distribution across a wide range of landforms, with high frequency on the plateaus and group E with high frequency in the wadi beds. Also distributions limited to particular landforms can be seen, for example plant species of groups U, V, W and X are mainly confined to secondary wadis of plateaus, while group Z is confined to slopes of plateaus of site 2 and 3. Group Z, Groups AA, BB and CC are rarely represented species. The distribution of vegetation associations (in the columns) varies from one site to another. For example, associations 1, 2 and 3, have limited distribution while associations 11 and 12 are distributed throughout the 3 study sites.

Main floristic vegetation associations are:

1. Alhagi graecorum - Phoenix dactylifera, 2. Citrullus colocynthis - Zygophyllum album,
3. Convolvulus glomertaus - Merremia hadramautica - Crotalaria persica, 4. Tephrosia dura - Tephrosia apollinea- Fagonia indica, 5. Acacia ehrenbergiana - Rhazya stricta - Acacia campoptila, 6.Salsola imbricata - Blepharis edulis, 7. Tephrosia nubica - Acacia campoptila - Merremia hadramautica,
8. Forskohlea tenacissima - Boerhavia elegans, 9. Fagonia paulayana - Boerhavia elegans - Cleome scaposa, 10. Indigofera spinosa - Stipagrostis hirtigluma, 11. Seetzenia lanata - Dichanthium insculptum, 12. Chrysopogon aucheri- Stipagrostis hirtigluma, 13. Maerua crassifolia - Jatropha spinosa - Stipagrostis hirtigluma, 14. Cornulaca amblyacantha - Stipagrostis hirtigluma, 15. Zygophyllum decumbens - Dichanthium insculptum

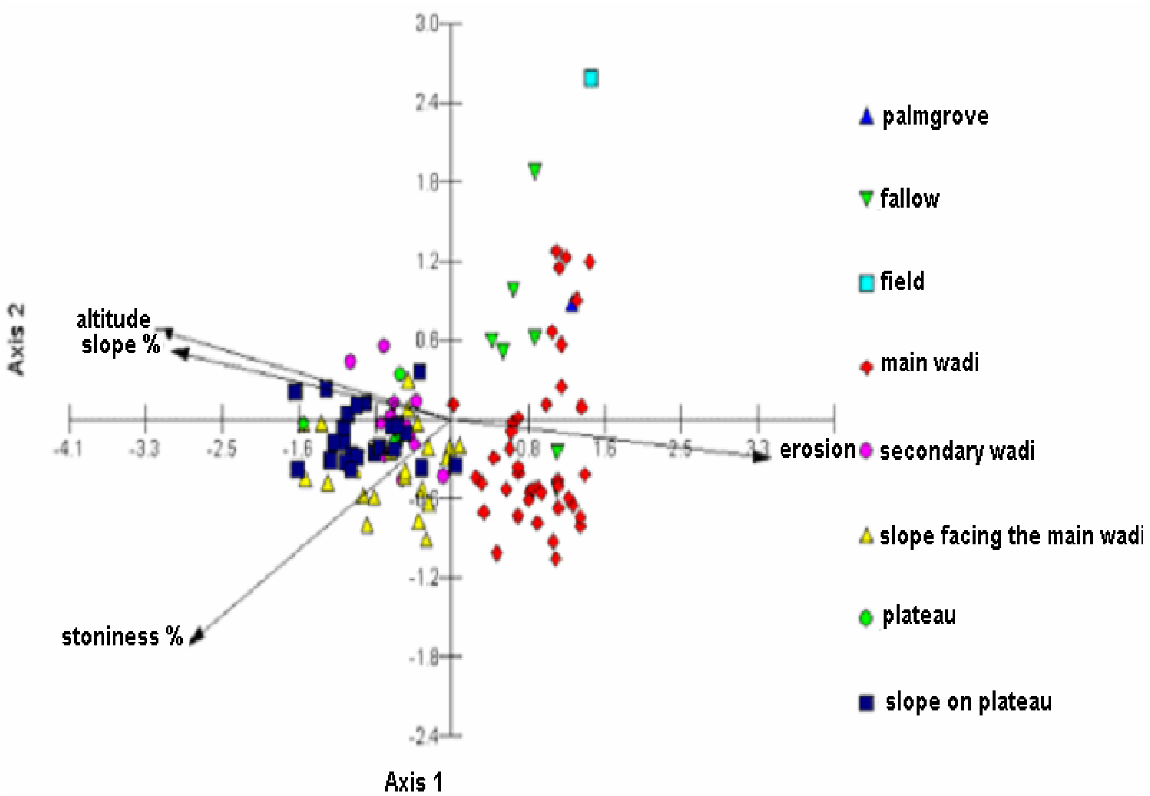
The plant species were subdivided into groups of species that behave similarly or are distributed similarly across the sample plots (i.e. sociological species groups). These groups were distributed characteristically across the different habitats. The distributions of the sociological groups depend on the environmental nature of the landforms. Some associations have limited distribution to specific habitats such as agricultural fields, wadi beds, rocky slopes or plateau sites and others have a wide range of distribution. For example, associations 1, 2 and 3, have limited distribution while associations 11 and 12 are distributed throughout the 3 study sites. Also plant species of groups U, V, W and X are mainly confined to secondary wadis of plateaus, while group Z is confined to slopes of plateaus of site 2 and 3. Group Z, Groups AA, BB and CC are rarely represented species. The distribution of vegetation associations (in the columns) varies from one site to another. Each vegetation association has its own sociological species group, some have one group and others have more than one group

5.9. Environmental data analysis

5.9.1. The sampling plots

The sample plots of the study sites and environmental factors (Figure 5.15) have been analysed by Canonical Correspondence Analysis (CCA) using the software of the Multi-Variate Statistical Package (MVSP) version 3.1. Environmental data were available on altitude, surface stoniness, erosion and slope percentage.

The points represent sample plots and arrows represent the environmental variables. The arrows point in the direction of maximum change of the environmental variable across the diagram.



		Axis 1	Axis 2
altitude		-0.364	0.079
slope %		-0.344	0.06
stoniness %		-0.324	-0.195
erosion		0.391	-0.034

Figure 5.15. Canonical Correspondence Analysis (CCA) ordination biplot of sampling points on main landforms and environmental variables. Arrows represent the environmental data and point in the direction of maximum change of the environmental variable across the diagram. Altitude and stoniness are the most important environmental variables. All environmental variables in particular altitude and erosion are strongly correlated with ordination axis 1. There is a very clear segregation between two groups, the sample plots of the main wadis and cultivated areas (right) and the sample plots of the other landforms (left). The first group is strongly correlated with erosion from flooding, and the second group is strongly correlated with the remaining environmental variables.

Altitude and surface stoniness are the most important environmental variables and increase along a gradient from the right to the left. The landform groups are clearly distinguished by the environmental variables. There is a strong relationship between the distribution of sample plots on the main wadis (right) and erosion from flooding, and between the distribution of sample plots of the mountain slopes and plateau zones (left) and the remaining variables. The sample plots of cultivated and fallow lands are negatively correlated with stoniness, while the sample plots of the main wadi beds are located at the low altitude and negatively correlated with slope percentage.

5.9.2. Plant species

The CCA axis (Figure 5.16) shows that slope %, altitude and stoniness increase along a gradient from the right to left and are strongly correlated with ordination axis 1. The CCA axis represents the following orders:

1. Species more commonly associated with cultivated fields (top right, *e.g. Prosopis farcta, Alhagi graecorum, Phoenix dactylifera, Cressa cretica, Ziziphus spina-christi* and *Senra incana*), that are negatively correlated with increasing altitude, slope % and stoniness.
2. Species commonly associated with severely flooded wadi beds (middle right), e.g. *Zygophyllum album, Prosopis juliflora, Tamarix aphylla, Citrullus colocynthis, Heliotropium rariflorum, Dipterygium glaucum, Calotropis procera, Merremia hadramautica, Tephrosia nubica* and *Panicum turgidum;* these species consist of sociological groups B, C, N and O.
3. Species commonly associated with rocky wadi beds (bottom right), e.g. *Cymbopogon schoenanthus, Ziziphus leucodermis, Zygophyllum coccineum, Tephrosia dura* and *Barleria aff bispinosa;,* these species are positively correlated with stoniness and flood erosion and negatively correlated with increasing altitude and slope%, they were not found in the wadi beds where the floods are severe.
4. The species *Glossonema varians, Euphorbia rubriseminalis, Cornulaca amblyacantha, Arnebia hispidissina, Hermannia paniculata, Moltkiopsis ciliate, Forskahlea tenacissima, Hermania paniculata, Moltkiopis ciliate, Tamarix arabica* and *Chascanum marrubifolium top left* are strongly correlated with high altitude and moderately steep slope, secondary wadi and alluvial fans of the plateau in site 2, most of these species are found in association 12, chapter 5). These species are characterised as being rare. Also species of rocky slopes of the plateau e.g. *Enneapogon desvauxii, Fagonia paulayana, Commiphora foliacea* and *Corallocarpus glomeruliflorus* are positively correlated with moderately steep slope and high altitude.
5. The species bottom left e.g. *Maerua crassifolia, Zygophyllum decumbens, Jatropha spinosa, Grewia erythraea, Helichrysum pumilum, Cornulaca amblyacantha* and *Hochstetteri schimperi, Commiphora kua* are strongly

correlated with high altitude rocky steep slopes of association 13, sociological species groups Z and AA.

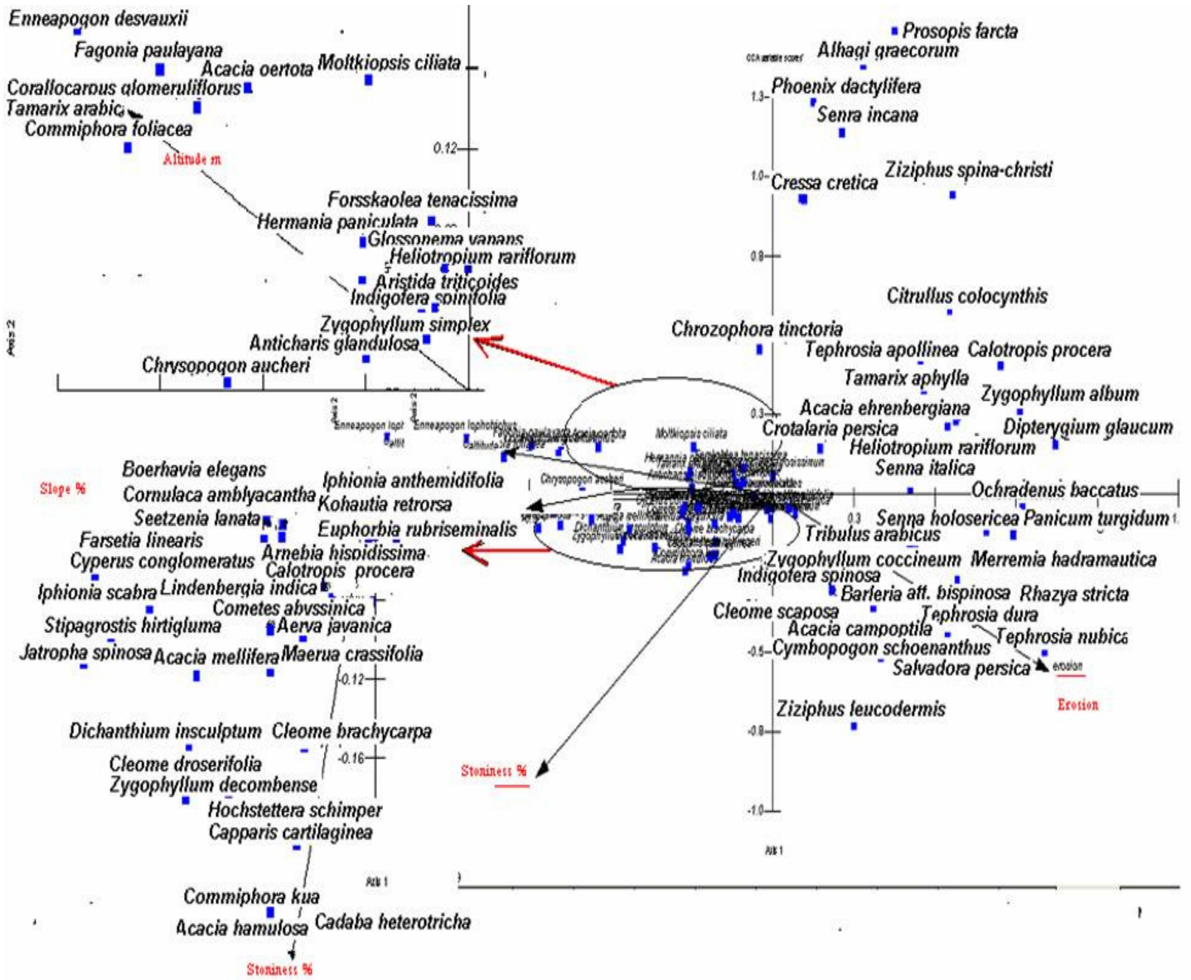


Figure 5.16. Canonical Correspondence Analysis (CCA) ordination biplot of plant species and landform environmental variables. Arrows represent the environmental data. Altitude and stoniness are the most important environmental variables. All environmental variables except stoniness are strongly correlated with ordination axis 1. Species of cultivated fields (top right) are negatively correlated with increasing altitude, the species of rocky wadi beds (bottom right) are strongly correlated with flood erosion. The species top left are correlated with moderately steep slope, while the species bottom left are strongly correlated with slope % and stoniness.

Erosion and in particular flooding plays an important part in changing and destroying the vegetation structure in many areas and even in causing the disappearance of some individual species that cannot stand the extreme floods characteristic of the main wadis. To get a broader understanding of the effect of erosion, the data were analysed taking only erosion as a variable, but the result was not satisfactory to interpret, therefore taking to consideration of almost uniformly altitude over the see level of wadis, altitude variable was added to erosion variable (Figure 5.17). The results show that the species such as *Zygophyllum album, Dipterygium glaucum, Ochradenus* *baccatus, Prosopis juliflora, Tamarix aphylla, Rhazya stricta, Tephrosia nubica, Calotropis procera,* and *Panicum turgidum* are strongly negatively correlated with flood erosion, while species such as, *Kohautia retrorsa, Acacia hamulosa, A. ehrenbergiana, Ziziphus leucodermis* and *Zygophyllum coccineum* are sensitive to extreme flood erosion.

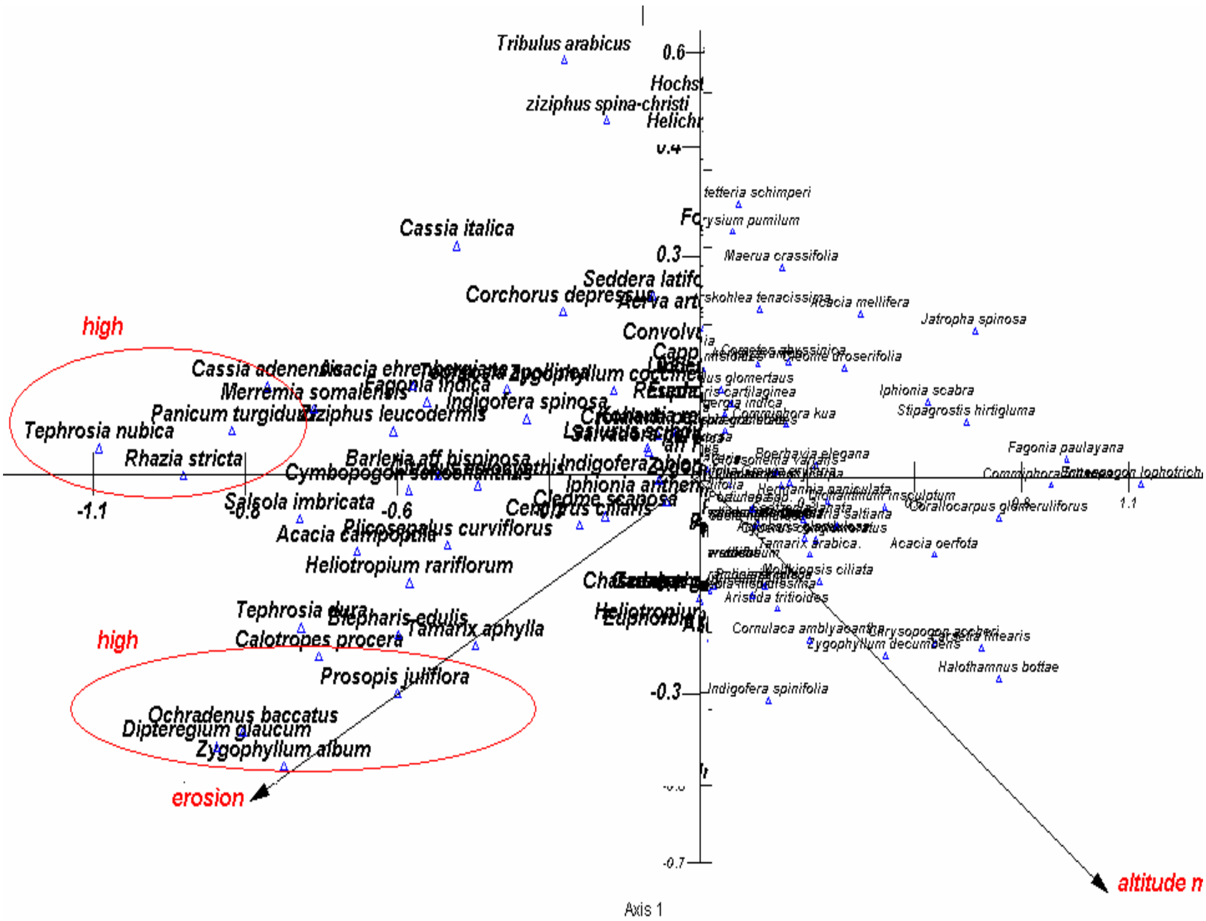
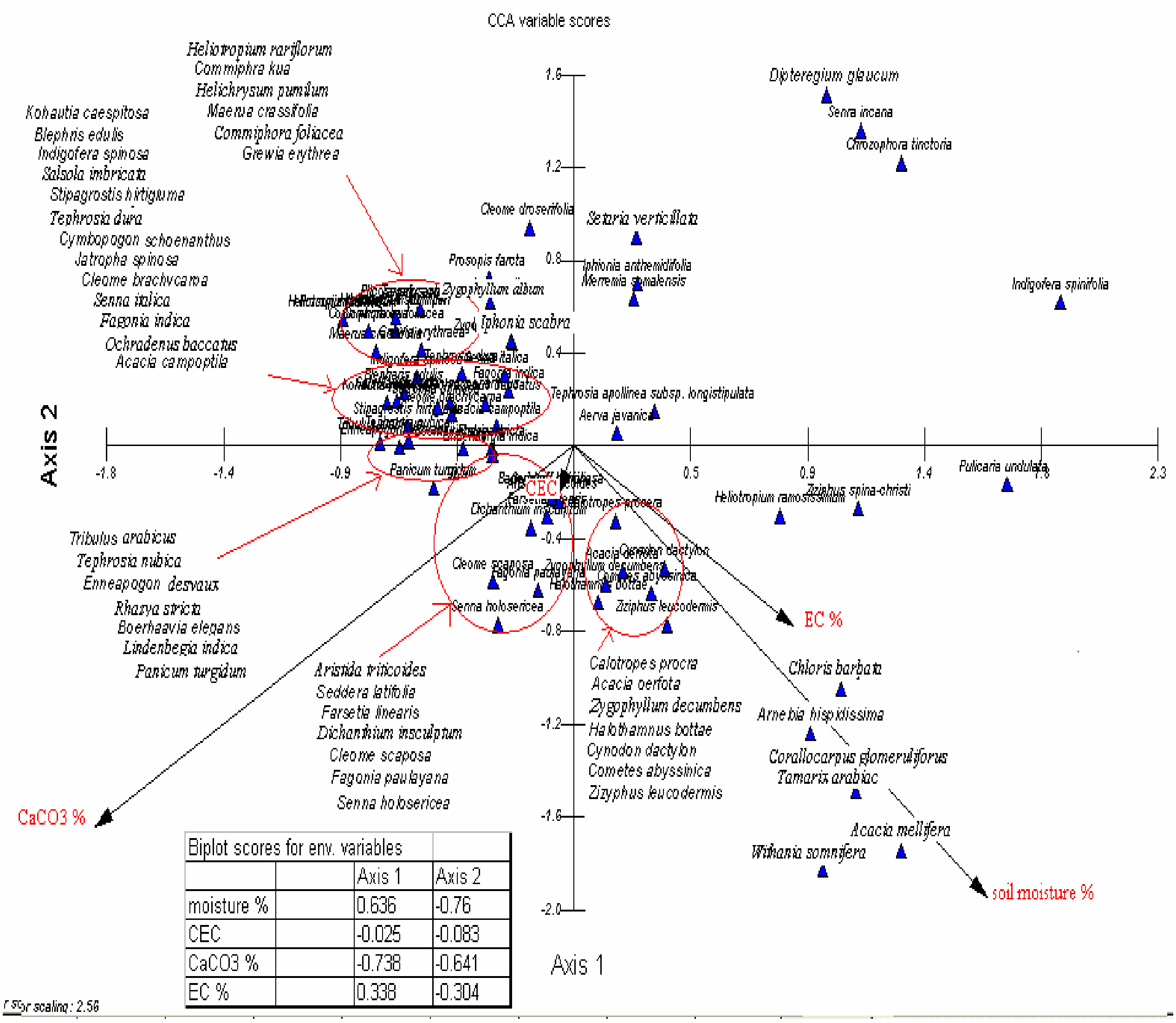


Figure 5.17. Interpretation of the effect of erosion on the species using 2 variables (erosion and altitude). The species (bottom left e.g. *Zygophyllum album, Dipterygium glaucum, Ochradenus baccatus, Prosopis juliflora, Tamarix aphylla, Rhazya strica, Tephrosia nubica, Calotropis procera* and *Blepharis edulis* are strongly negatively correlated with flood erosion. The species *Cymbopogon schoenanthus, Kohautia retrorsa, Acacia hamulosa, Barleria aff. bispinosa, Tephrosia dura, Ziziphus leucodermis* and *Zygophyllum coccineum* are quite sensitive to extreme flood erosion.

The plant species were further analysed using 4 soil variables (soil moisture, $CaCO_3$, EC% and CeC).

Figure 5.18a shows that weed species of agricultural fields (bottom right) such as *Chloris barbata, Convolvulus arvensis, Cynodon dactylon, Ziziphus spina-christi* and *Withania somnifera* and some species of secondary wadis and slopes on the plateau such as *Acacia mellifera, Acacia oerfota, Tamarix arabica, Cometes abyssinica,* *Corallocarpus glomeruliflorus, Arnebia hispidissima, Pulicaria undulata, Zygophyllum decumbens* and *Halothamnus bottae* are strongly correlated with moisture content and EC. Species such as *Jatropha spinosa, Grewia erythraea, Helichrysum pumilum, Maerua crassifolia, Commiphora kua* (top left) are negatively correlated with EC% and soil moisture, while species such as *Indigofera spinifolia,, Chrozophora tinctoria, Dipterygium glaucum, Tephrosia apollinea, Aerva javanica* and *Iphiona anthemidifolia* (top right) are positively correlated with EC% and negatively correlated with CaCO3.



Biplot scores for env. variables		
	Axis 1	Axis 2
moisture %	0.636	-0.76
CEC	-0.025	-0.083
CaCO3 %	-0.738	-0.641
EC %	0.338	-0.304

Figure 5.18a. Canonical Correspondence Analysis (CCA) ordination biplot of plant species and 4 environmental variables. Soil moisture and CaCO3 are the most important environmental variables. All environmental variables except CeC are strongly correlated with ordination axis 1. Weedy species of agricultural fields (bottom right) such as *Chloris barbata, Convolvulus arvensis, Cynodon dactylon, Ziziphus spina-christi and Withania somnifera* and some species of secondary wadis and slopes on the plateau such as *Acacia mellifera, Acacia oerfota, Tamarix arabica, Cometes abyssinica, Corallocarpus glomeruliflorus, Arnebia hispidissima, Pulicaria undulata, Zygophyllum decumbens* and *Halothamnus bottae* are strongly correlated with moisture content and EC. Species such as *Jatropha spinosa, Grewia erythraea, Helichrysum pumilum, Maerua crassifolia, Commiphora kua* (top left) are negatively correlated with EC% and soil moisture, while species such as *Indigofera spinifolia,, Chrozophora tinctoria, Dipterygium glaucum, Tephrosia apollinea, Aerva javanica* and *Iphiona anthemidifolia* (top right) are positively correlated with EC% and negatively correlated with CaCO3.

Because no soil data from all sample points has been taken, the above result can be considered as first attempt to discuss the relationship between the plant species and the main environmental factors. Generally the plant species of the cultivated fields are negatively correlated with CaCO3, while the species of the main wadi bed, the plateau and the slope of the plateau are positively correlated with CaCO3 and negatively correlated with EC% and soil moisture (Figure 5.18b).

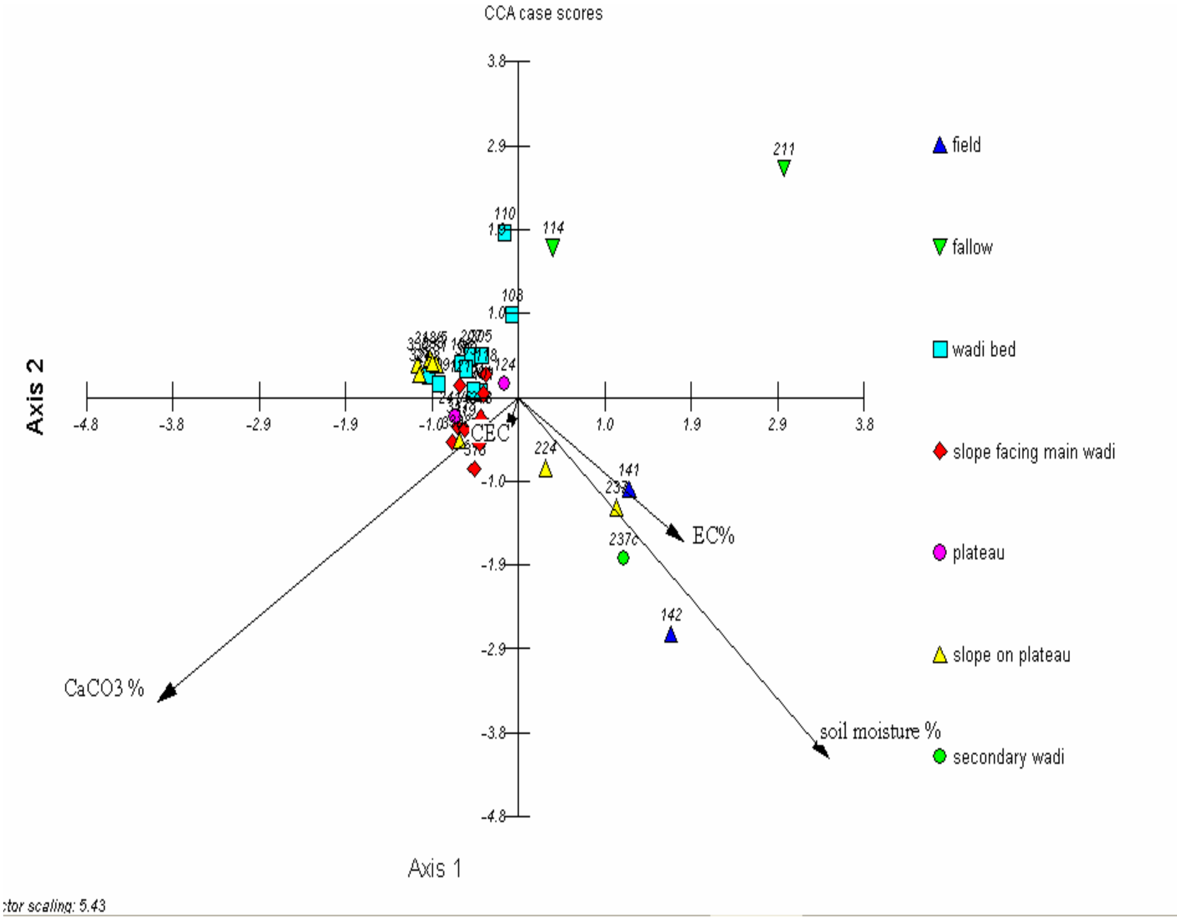


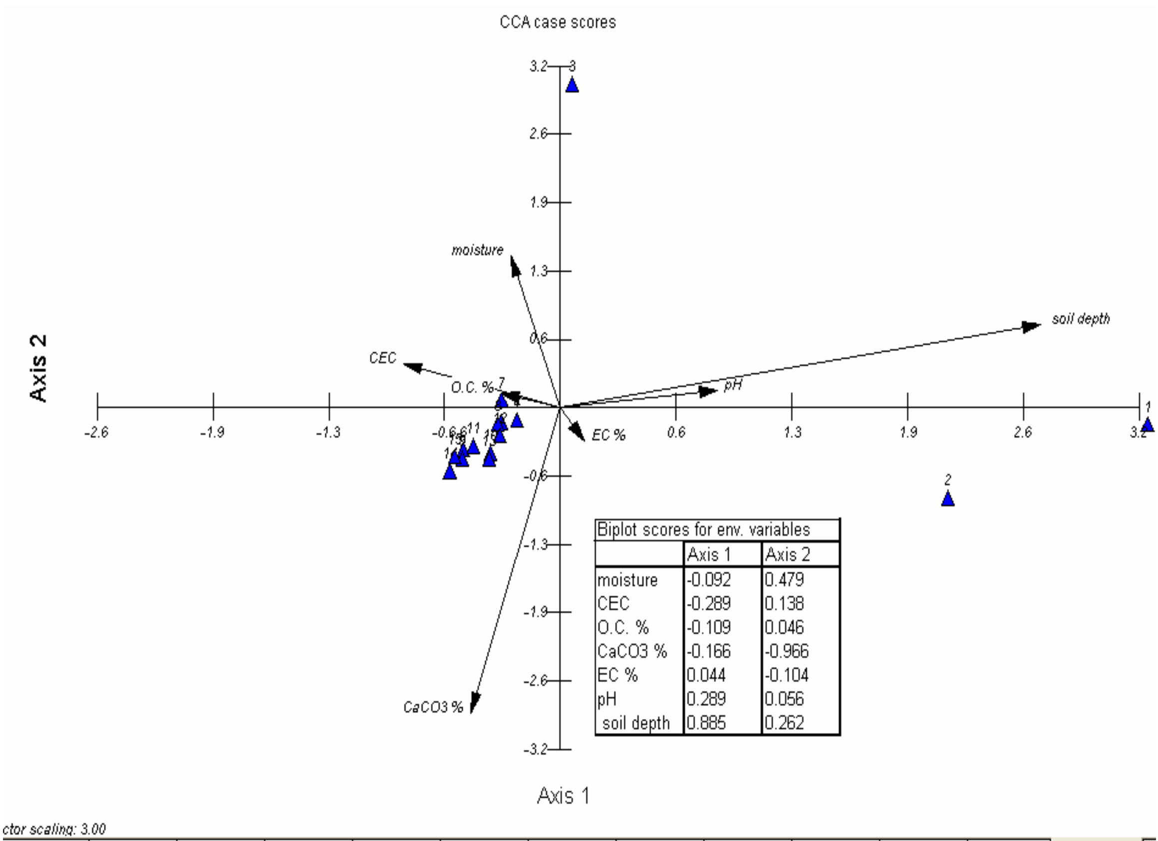
Figure 5.18b. Canonical Correspondence Analysis (CCA) ordination biplot of main landforms and 4 environmental variables. The species of the cultivated fields are negatively correlated with CaCO3, while the species of the main wadi bed, the plateau and the slope of the plateau are strongly positively correlated with CaCO3 and negatively correlated with EC% and strongly with soil moisture.

Some species such as *Zygophyllum decumbens, Halothamnus bottae* and *Tamarix arabica* resist the high content of EC%. *Tephrosia apollinea, Dichanthium insculptum, Pulicaria undulate, Farsetia linearis, Portulaca oleracea* and *Corallocarpus glomeruliflorus* are growing well on relatively flat moist sites. *Chascanum marrubifolium, Cadaba heterotricha, Tarenna graveolens, Jatropha spinosa, Maerua crassifolia, Hochstetteria schimperi, Commiphora kua* and *Grewia erythraea* grow well on dry stony steep slopes of the plateau, although the first 3 species are very rare. The

Aristida triticoides grows well on dry stony steep north-east slopes. The vegetation associations on the slopes of the plateau appear to be dominated by *Cadaba heterotricha, Tarenna graveolens, Maerua crassifolia, Aristida triticoides, Commiphora kua* and *Grewia erythraea* and adjacent secondary wadis by *Acacia mellifera, Acacia oerfota, Commiphora kua* with *Euphorbia rubriseminalis* and *Corallocarpus glomeruliflorus.* Most of these species are no longer found in many sites.

5.9.3. Main vegetation associations

The main vegetation associations of the study areas and their relationship to environmental factors have been analysed by Canonical Correspondence Analysis (CCA) using statistical software of MVSP version 3.1 (Figure 5.19).
Environmental data were available on: moisture, CeC, O.C %, CaCO3, EC %, pH and soil depth.



Biplot scores for env. variables	Axis 1	Axis 2
moisture	-0.092	0.479
CEC	-0.289	0.138
O.C. %	-0.109	0.046
CaCO3 %	-0.166	-0.966
EC %	0.044	-0.104
pH	0.289	0.056
soil depth	0.885	0.262

Figure 5.19.Ordination of main vegetation associations and environment yielded by CCA. Soil depth and CaCO3 are the most important environmental variables. CeC, OC%, pH and soil depth are strongly correlated with ordination axis 1, while soil moisture, CaCO3 and EC% are strongly correlated with ordination axis 2. The association of cultivated fields (1 and 3), the flooded wadi bed (2) are found to the right of the ordination, these associations are confined to site 1 and positively correlate with EC %, pH and soil depth, while the remaining associations are located to the left and positively correlate with caco3 and CeC. Numbers in the figure relate to the vegetation associations.

The most important variables in Figure 5.19 are soil depth and CaCO3. Vegetation association 1 of cultivated fields and 2 of sandy flooded wadis are strongly positively correlated with increasing pH, soil depth and EC%. Associations 1, 2 and 3 are negatively correlated with CaCO3. Associations 1 and 3 are characterised by being cultivated by both annual or perennial crops and wash out annually by floods. Association 7 of wadi bed of site 3 is strongly positively correlated with CeC and O.C%; this association characterised by species *Merremia hadramautica, Tephrosia nubica, Ziziphus leucodermis* and *Panicum turgidum.* CaCO3 variations between the associations are insignificant and generally range between 35.5 and 37.4, nevertheless the lowest record was found in association 3 (29.7) and the highest was in associations 14 (37.4), 9 (37.3) and 7 (37.2). The characteristic plant species of these associations are: *Merremia hadramautica, Tephrosia nubica, Ziziphus leucodermis* and *Panicum turgidum*, *Boerhavia elegans, Dichanthium insculptum, Cleome scaposa,* and *Cleome brachycarpa.* Organic Carbon (OC%) is low over most of the associations, especially on cultivated fields and places that are characterised by low vegetation cover such as slopes facing the main wadis. Onus et al. (2003) found that the amount of OC% was higher in natural sites than in cultivated fields due to presence of natural vegetation decomposing in the topsoil.

5.9.4. Vegetation structure and cover percentage

The structure of the vegetation in the study areas varies from sparse grassland to dense woodland (Table 5.16). The main wadis are generally characterised by a low cover of herbaceous plants, while palm grove areas are characterised by high tree cover. The plateaus with their slopes and secondary wadis are characterised by a high cover percentage of herbaceous plants (Figures 5.20 and 5.21). There are variations of structure within the main wadis over the study sites and on the slopes of plateau of site 2. The difference in vegetation structure in the main wadis may be due to environmental and land use conditions including wood cutting, severe flooding and over-grazing. On the plateau of site 2, oil working activities have changed the vegetation structure in some parts from grassland to woodland and from sparse grassland to dense grassland.

		Vegetation structure types									
The stu site	Land f	Dense woo 6	Wood-la 1	Open woodl 2	Shrub-lar 3	Sparse sh land 4	Dwarf sh land 9	Dense gra land 7	Grass-lan 5	Sparse gr land 8	Total spe per plot
1	w	-	-	2	3	3	-	-	2	4	14
	ms								1	10	11
	pla								2	2	4
	sp									2	2
	wp			1					3		4
	pal	1	1						4		6
11	w		2	2		3	1		2	4	14
	ms								1	2	3
	pla									1	1
	sp		1			5		3	3	7	19
	wp							1	4	1	6
111	w				1	3	3			5	12
	ms									9	9
	pla									1	1
	sp					1			1	5	7
	wp								1	1	2

Table 5.16 .The distribution of the vegetation structure classes over the study sites. w = main wadi, pal = palm grove and fields, ms = slopes facing the main wadi, pla = plateau, sp = slope on plateau, wp = secondary wadi. Slopes facing the main wadi, secondary wadis and plateaus are dominated by grassland structures; as can been seen most sample plots are located under the sparse grassland. There are variations of structure within the main wadis over the 3 study sites and on the slopes of plateau of site 2.

	W		F		MS		PLA		Wp		SP	
	total sample plots	%	total sample plots	%	total sample plots	%	total sample plots	%	total sample plots	%	total sample plots	%
Dense woodland			1	17								
Woodland	2	5	1	17							1	3
Open woodland	4	10							1	8		
Shrubland	4	10										
Sparse shrubland	9	23									6	21
Dwarf shrubland	4	10										
Dense grassland									1	8	3	10
Grassland	4	10	4	67	2	9	2	33	8	67	5	17
Sparse grassland	13	33			21	91	4	67	2	17	14	48
total sample plots	40		6		23		6		12		29	

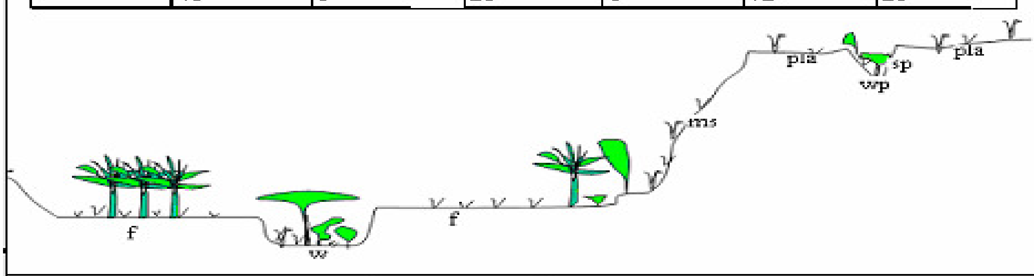


Figure 5.20. Number of sample plots and vegetation structure over the different landforms. w= wadi bed, f= cultivated fields including the palm areas, ms= slope facing the main wadi, pla= plateau, wp= secondary wadi, sp= slope on plateau. Grassland and sparse grassland are the dominant vegetation structures. Variation of structures is found on the wadi beds, slopes of the plateaus and secondary wadis; this can be a reflection of human activities on these landforms.

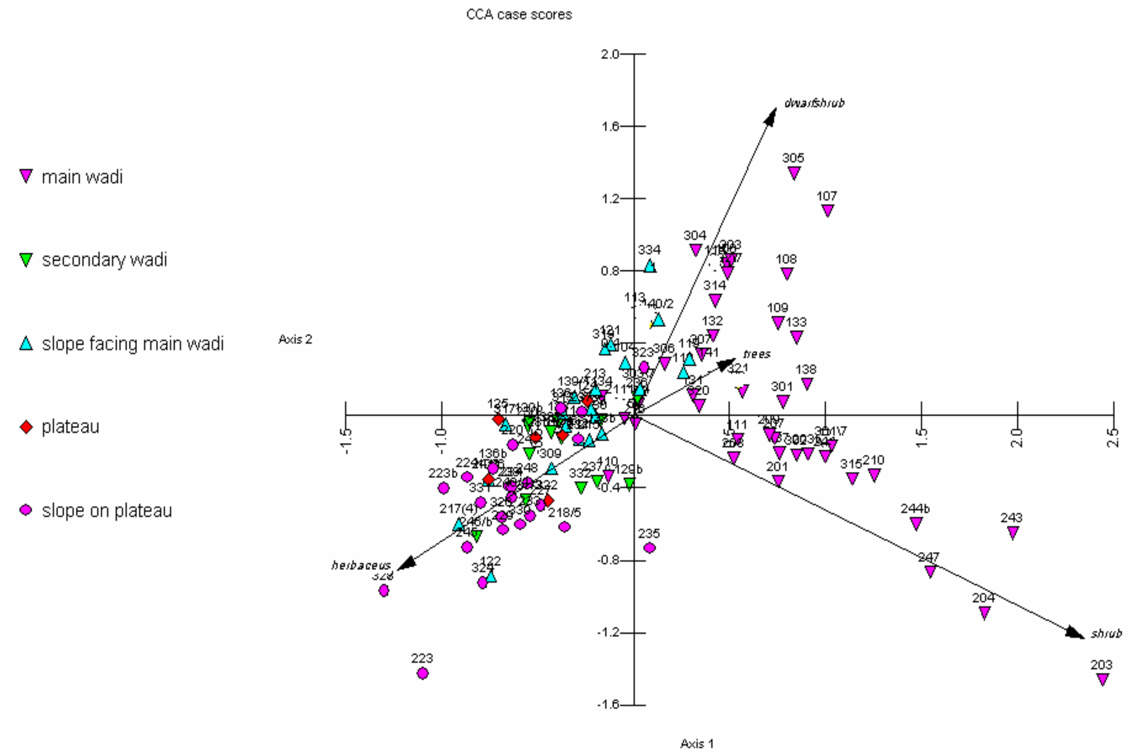


Figure 5.21a. Canonical Correspondence Analysis (CCA) of the percentage cover of vegetation structure and different landforms. Slopes facing the main wadi, secondary wadis and slopes on the plateau are characterised by a high percentage herbaceous cover, while main wadis are characterised by woody species cover. Herbaceous cover is most dominant vegetation over the different landforms in the study areas. Numbers refer to the sample plots

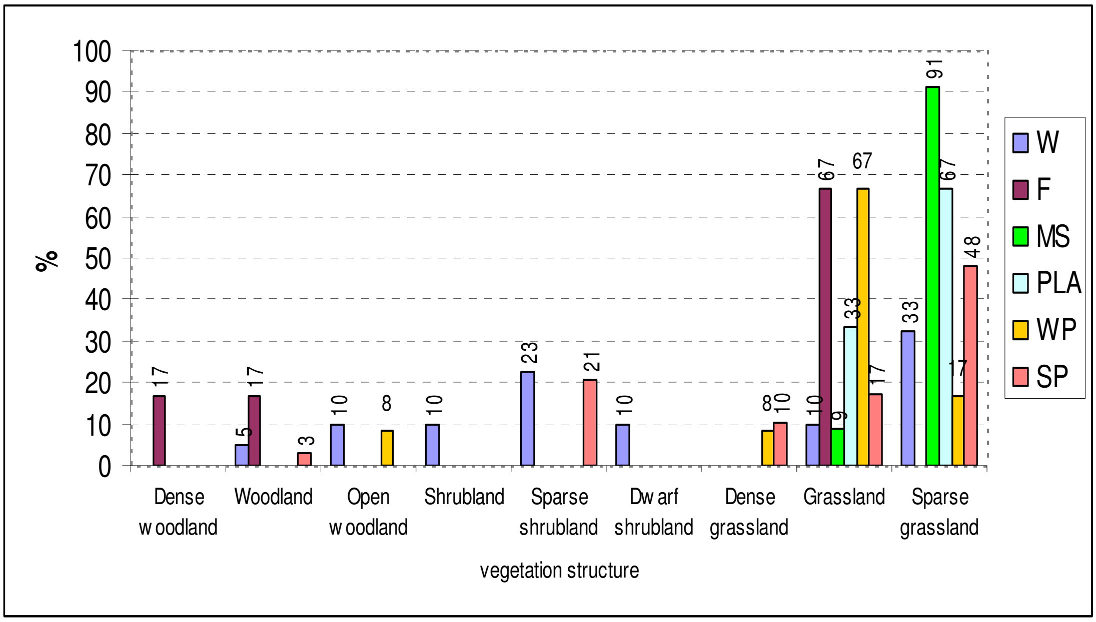


Figure 5.21b, The percentage of each vegetation structural type over the different landforms. W= main wadi, F= fields, MS= slope facing the main wadi, PLA= plateau, WP= secondary wadi on plateau, SP= slope on plateau. Grassland and sparse grassland are the dominant structural types especially on slopes facing the main wadis and on the plateaus. The percentage of vegetation structural types over the main wadis varies with relatively high percentages of structural types dominated by woody shrubs. The vegetation of secondary wadis on plateaus is dominated by grassland structural types, while the vegetation of the slopes on the plateau is dominated by sparse grassland and sparse shrubland.

Grassland and sparse grassland is the dominant structural types especially on the slopes facing the main wadis and on the plateaus. The percentage of vegetation structural types over the main wadis is varied with relatively high percentages of structural types dominated by woody shrubs. The vegetation of secondary wadis on plateaus is dominated by grassland, while the vegetation of the slopes on the plateau is dominated by sparse grassland and sparse shrubland. The mountain slopes facing main wadis and the plateaus are characterised by homogeneous vegetation composed mainly of sparse grassland.

The abundance of each species within different landform units was analysed using the BioDiversity software. The output of cover percentage against log species rank is shown in Table 5.14 and Figure 5.22. Table 5.17 and Figure 5.22 show that each landform is dominated by a few species. Steep curves indicates that the landform is only dominated by few species, for example, pla3 and pla2 have less than 3 species and are almost dominated by one species namely *Stipagrostis hirtigluma.* The vegetation cover percentage of this species ranges from 1 to 10% per 100 m². *Acacia campoptila* and *Fagonia indica* are the dominant species on the main wadis, *Stipagrostis hirtigluma* is the dominant on the plateaus while *Dichanthium insculptum* and *Stipagrostis hirtigluma* are the dominant species on the slopes and secondary wadis of the plateaus.

characteristic species	landform unit	characteristic species	landform unit	characteristic species	landform unit	characteristic species	landform unit	characteristic species	landform unit
	w1		**ms1**		**pla1**		**wp1**		**sp1**
Zygophyllum album	3.9	Aerva javanica	1.1	Stipagrostis hirtigluma	3.8	Cymbopogon schoenanthus	3	Cleome brachycarpa	2.5
Tephrosia apollinea	3.3	Fagonia indica	1	Farsetia linearis	1.7	Dichanthium insculptum	2.2	Stipagrostis hirtigluma	2
Tephrosia dura	2	Stipagrostis hirtigluma	1	Boerhavia elegans	1.5	fagonia paulayana	1.6	Dichanthium insculptum	1.5
Acacia campoptila	1.6					Chrozophora tinctoria	1.4	Seetzenia lanata	1.5
Fagonia indica	1.4					Acacia mellifera	1.2	Aristida triticoides	1
						Farsetia linearis	1.2	Boerhavia elegans	1
						Acacia oerfota	1		
	w2		**ms2**		**pla2**		**wp2**		**sp2**
Acacia campoptila	6.3	Dichanthium insculptum	1.6	Stipagrostis hirtigluma	1	Pulicaria undulata.	5	Dichanthium insculptum	2.8
Blepharis edulis	2.6	Stipagrostis hirtigluma	1			Chrysopogon aucheri	4.8	Farsetia linearis	1.4
Fagonia indica	1.5					Dichanthium insculptum	4.8	Stipagrostis hirtigluma	1.2
Indigofera spinosa	1.5					Stipagrostis hirtigluma	3	Zygophyllum decumbens	1.2
Ochradenus baccatus	1.1					Aristida triticoides	2.8	Aristida triticoides	1
						Zygophyllum decumbens	1.5	Jatropha spinos	1
						Barleria aff bispinosa	1.3		
						Farsetia linearis	1.3		
	w3		**ms3**		**pla3**		**wp3**		**sp3**
Tephrosia nubica	5.5	Stipagrostis hirtigluma	1.6	Stipagrostis hirtigluma	10	Stipagrostis hirtigluma	7	Dichanthium insculptum	9
Acacia campoptila	3.2	Cleome scaposa	1.5			Dichanthium insculptum	3.5	Stipagrostis hirtigluma	2.9
Indigofera spinosa	2.3	fagonia paulayana	1.4			Kohautia retrorsa	2.5	Jatropha spinos	1.3
Merremia somalensis	1.6	Boerhavia elegans	1.2			Boerhavia elegans	2	Halothamnus bottae	1
Fagonia indica	1.4					Crotalaria saltiana	2		
Aerva javanica	1.1					Hermannia paniculata	2		
Blepharis edulis	1.1					Corallocarpus glomeruliforus	1.5		
Rhazya stricta	1					Iphiona scabra	1.5		
						Aerva javanica	1		
						Chrysopogon aucheri	1		
						fagonia paulayana	1		
						Halothamnus bottae	1		
						Senna italica	1		

Table 5.17. Species covering more than 1% per 100 m² for each landform unit. w = wadi, ms = mountain slopes facing main wadis, wp = secondary wadi, sp = slope on plateaus, pla = plateau. The plateaus the mountain slopes are represented by a few species, while the main wadis and secondary wadis on plateaus have a relatively high number of species.

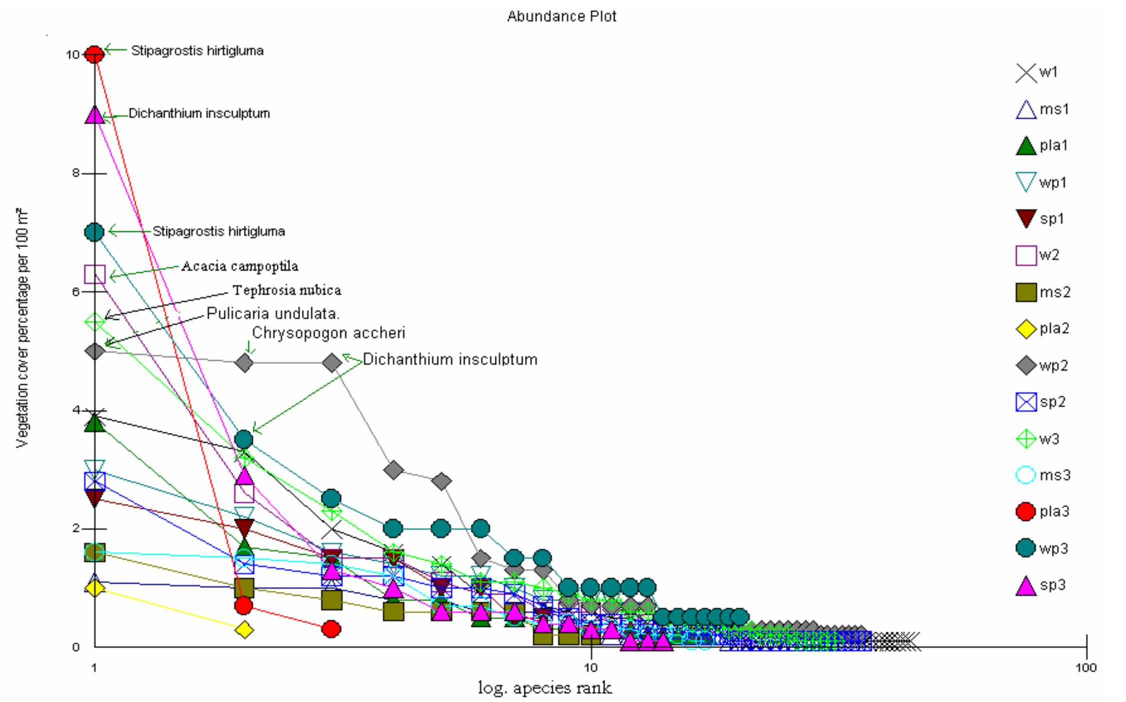


Figure 5.22. Average vegetation cover percentage per 100 m² against log. species rank. w = wadi, ms = mountain slopes facing main wadis, cliff = very steep cliffs facing the main wadis, wp = secondary wadi, sp = slope on plateaus, pla = plateau. pla3 and pla2 at the bottom have less than 3 species and dominated by almost one species namely *Stipagrostis hirtiglu;,* wp2 and wp3 at the top are dominated by more than on plant species. *Acacia campoptila* and *Fagonia indica* are the dominant species on the main wadis, *Stipagrostis hirtigluma* is the dominant species on the plateaus while *Dichanthium insculptum* and *Stipagrostis hirtigluma are* the dominant species on the slopes and secondary wadis of the plateaus.

Generally, the vegetation cover percentage on the plateaus and mountain slopes facing main wadis is very low and ranges between 1 and 9%. The main wadis and secondary wadis on plateaus have a high cover percentage ranging from 13 to 23% in the first case and from 8 to 29% in the second case (Figure 5.23). The vegetation cover percentage per 100 m² (Figures 5.23 and 5.24) varies across the landforms and is almost very similar to the number of species per hectare.

The vegetation percentage (Figure 5.24) over the plateaus increases steadily from the exposed flat surfaces to the slopes then to the bottom of the secondary wadis. In the main wadis the number of species for the study sites increases from the slopes facing the main wadis to the main wadi beds. The peak in the cover percentage (29% per 100 m²) is found at the bottom of the secondary wadis that cut the plateaus of site 2. The lowest is found on the plateau surfaces.

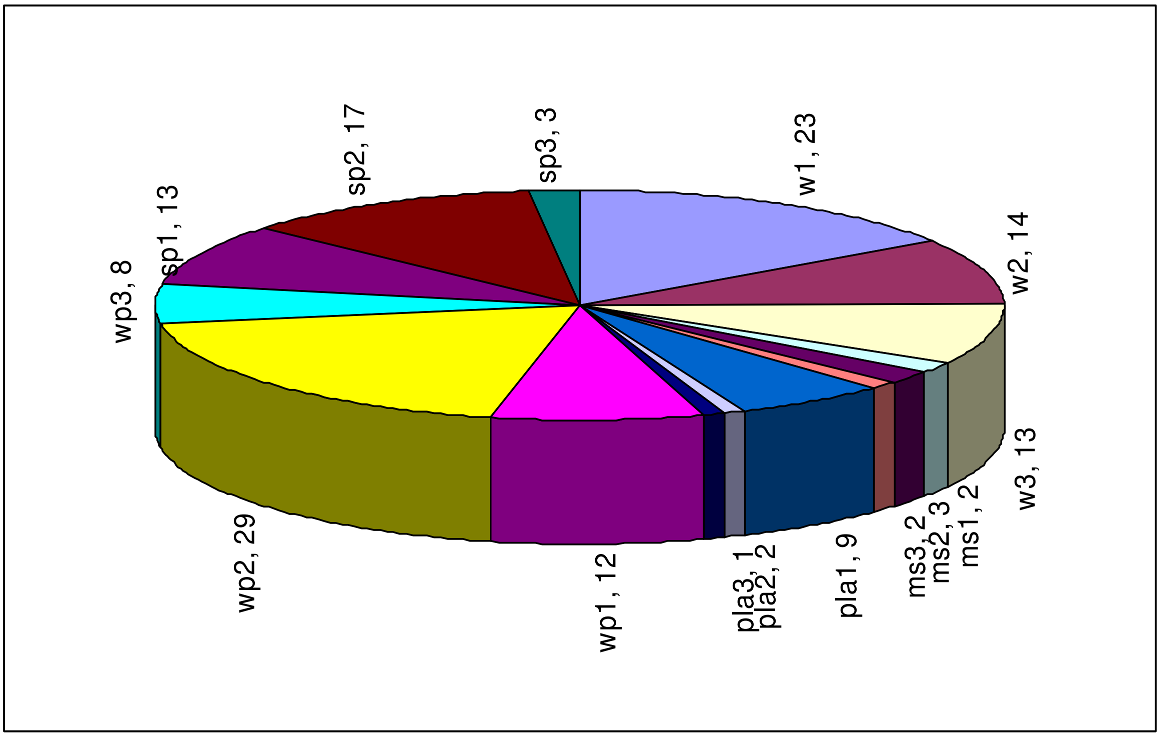


Figure 5.23. Average vegetation covers percentage per 100 m² for each landform. w = wadi, ms = mountain slopes facing main wadis, wp = secondary wadi, sp = slope on plateaus, pla = plateau. The average vegetation cover percentage varies across the landforms. The avarage cover on the main wadis is relatively high and ranges between 13 and 23%. The average cover in the secondary wadis of the plateaus is also high and ranges between 8 and 29%. The average cover of the plateaus and mountain slopes facing main wadis are very low and ranges between 1 and 9%. pla2 and pla3 have the lowest value.

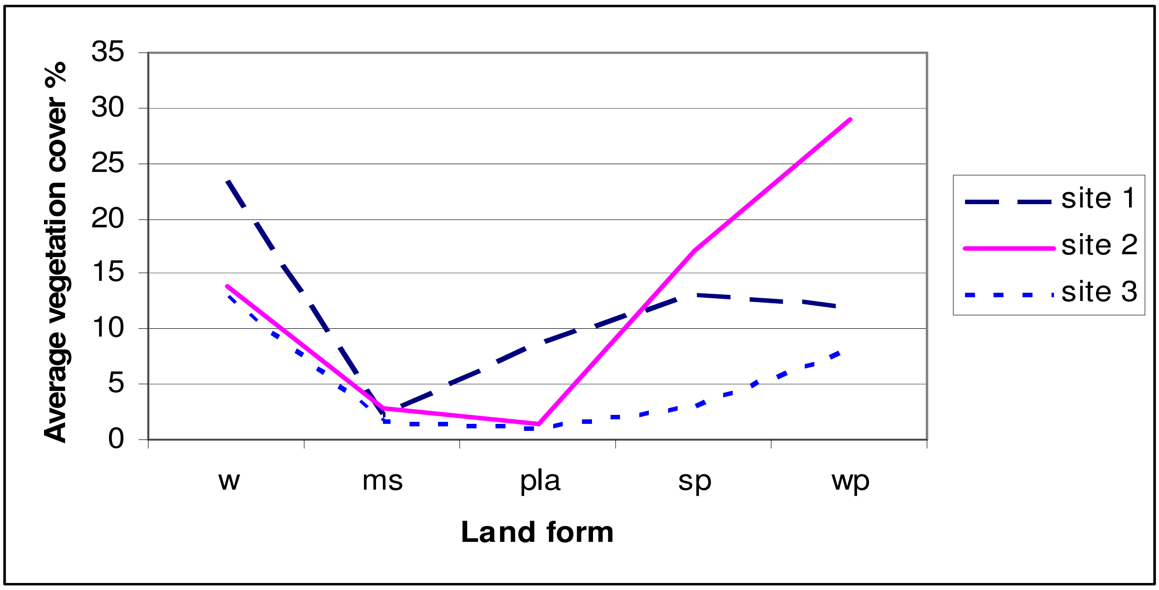


Figure 5.24. Average vegetation cover percentage per 100 m² over the different landforms. The vegetation percentage over the plateaus increases steadily from exposed flat surfaces, to the lopes then to the bottom of the secondary wadis. In the main wadis the percentage increases from the slopes facing these wadis to the main wadi beds. High percentage cover is found on main wadis and on the secondary wadis of the plateaus. The low percentage of cover at secondary wadis of sites 1 and 3 is due to the landform characteristic of being relatively narrow and shallow with steep short sides; in addition, the surface of these secondary wadis have solid pavement with a soil cover of less than 2%.

It is noticed from previous section that the structure of the vegetation in the study areas varies from sparse grassland to dense woodland. The main wadis are generally characterised by a low cover of herbaceous plants. The plateaus with their slopes and secondary wadis are characterised by a high cover percentage of herbaceous plants. There are variations of structure within the main wadis over the study sites. The difference in vegetation structure in the main wadis may be due to environmental and land use conditions including wood cutting, severe flooding and over-grazing or to the variation in soil properties.

Grassland and sparse grassland is the dominant structural types especially on the slopes facing the main wadis and on the plateaus. The percentage of vegetation structural types over the main wadis is varied with relatively high percentages of structural types dominated by woody shrubs. The vegetation of secondary wadis on plateaus is dominated by grassland, while the vegetation of the slopes on the plateau is dominated by sparse grassland and sparse shrubland. The vegetation cover percentage on the plateaus and mountain slopes facing the main wadis is very low while that of the main wadis and secondary wadis is high.

5.10. Summary of main findings

Using the Braun-Blanquet and Neighbour-Joining methods and Modelling Patterns in Environmental Data (MOPED) software (see Table 5.6), the plant species that behave similarly (Zonneveld, 1989) or are distributed similarly across the sample plots (Martin et al., 2003) were clustered in groups. These similar groups are named to as Sociological species groups.

The species of sociological group E and H occur throughout the entire area, in particular on mountain slopes facing the main wadis, the plateaus and their slopes and secondary wadis. These species are: *Acacia campoptila, Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus, Dichanthium insculptum* and *Boerhavia elegans.* With the exception of *Tephrosia apollinea,* they are not seen on the sandy, strong, flooded wadi beds and cultivated areas. *Acacia campoptila* is near-endemic, and the remaining species are also found in wadis in many parts of the tropical Sahara and Arabia regions.

A total of 116 sample plots in different landforms and ecologies throughout the study sites were combined according to the similarity in their species composition, following the classification methods of the Braun-Blanquet and Twinspan, to form 15 groups of floristic vegetation associations. Most of the vegetation associations are dominated by herbaceous plants Vegetation associations 1, 2, 4, 8 and 13 are confined to site 1; vegetation associations 3, 6, 13 and 15 are confined to site 2, while vegetation associations 7, 9 and 14 are confined to site 3. The vegetation associations of the main wadis are dominated by *Acacia campoptila, Fagonia indica, Tephrosia apollinea* and *Cymbopogon schoenanthus*. Associations 8, 9 and 10 are dominated by *Dichanthium insculptum, Boerhavia elegans, Cleome brachycarpa, Stipagrostis hirtigluma* and *Farsetia linearis.* Associations 13, 14 and 15 are dominated by *Dichanthium insculptum Zygophyllum decumbens, Jatropha spinosa* and *Stipagrostis hirtigluma.* The community dominated by *Acacia campoptila*, with association of *Panicum turgidum, Aerva javanica, Indigofera spinosa, Fagonia indica, Ochradenus baccatus, Dipterygium glaucum Calotropis procera* and *Rhazya stricta is* widespread over the wadi beds of arid areas of Yemen such as Marib and Rada' in Yemen (Al Khulaidi, 1989; Westinga and Thalen, 1980; Al Hubaishi and Muller-Hohenstein,1984).

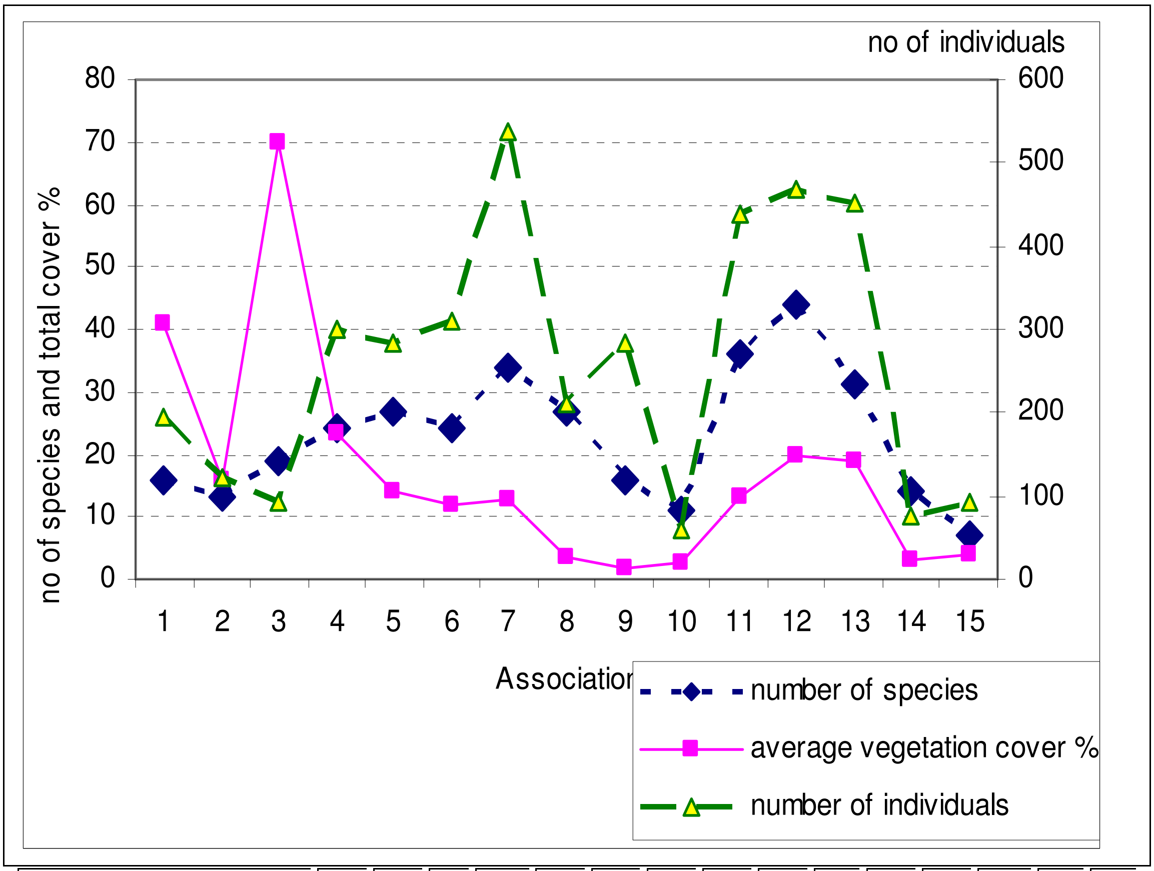
Acacia spp. (e.g. *A. tortilis* and *A. hamulosa*) form savanna-like communities in association with *Panicum turgidum, Leptadenia pyrotechnica, Aerva javanica, Calotropis procera* and *Ziziphus spina-christi.* They are widespread throughout the tropical Sahara region and in the wadis of Sudan, Egypt, Palestine and Arabia (Zohary, 1973; White, 1983).

The species *Calotropis procera* and *Dipterygium glaucum* are the most characteristic species of wadi borders, sand dunes and sands (Wood, 1997) throughout the coastal areas and desert. Association 2 reflects the transitional zone between arid and hyper-arid climate and is very similar to the associations that are common further west on the sand dunes of the Ramalat Al Sabaten desert area (chapter 3). Grass root systems on sandy soils extended to depth of 1.4 m or more likely to be an adaptation to capture more soil water from frequent small rainfall events (Gibbens and Lenz, 2001). Some species of this habitat (e.g. *Panicum turgidum* and *Zygophyllum album*) have very long roots which can spread over the surface as well as in depth utilizing both the available surface moisture and water that has infiltrated deep layers. Additionally the sandy soils of this habitat may offer better water supplies (Monger, 2002).

Wadi vegetation is found in hydrological disturbance areas, including annual floods, erosion and alluvial deposition. The active surface receives intense flooding events. Well-established vegetation associations are only found on parts of the flood plain that generally do not receive intensive flood waters. The associations on the active surface are adapted to rapid colonization of disturbed and flooded surfaces. Extreme floods are common on main wadis. Floods have significant effect on the structure of vegetation of wadis. The wadis have varied relationships with surface and ground water. Some associations develop under conditions where their deep root systems can utilize the water from basal gravels and lower, silty alluvial layers (Coode Blizard Ltd, 1997). In these habitats, woody perennial trees such as *Acacia campoptila, Ziziphus leucodermis*, the date palm *Phoenix dactylifera* and the invasive *Prosopis juliflora* form their own distinctive associations. Savanna-like vegetation on wadi beds and runnels in several locations has been transformed to woodland due to the encroachment and establishment of the invasive tree *Prosopis juliflora*.

The association dominated by *Zygophyllum album* and *Dipterygium glaucum* was only found on relatively wide wadis that are subjected to severe flooding, with loamy to loamy sand soils and high proportions of sand (86-88%). Other species?/included in this association are *Citrullus colocynthis, Heliotropium rariflorum, Dipterygium glaucum, Panicum turgidum, Prosopis juliflora,* and *Tamarix aphylla.* Most of these species have deep roots, which probably offer good mechanical support against the relative high water velocity (Wittmanna et al., 2004) during flood ?episodes/periods. Other species showing adaptations to extreme floods are *Acacia campoptila, Fagonia indica, Tephrosia apollinea* subsp. *longistipulata* and *Cymbopogon schoenanthus.* As a result of severe floods, woody vegetation dominated by *Ziziphus leucodermis, Acacia ehrenbergiana, Acacia hamulosa, Tephrosia dura* and date palm trees has disappeared or shrunk and has been replaced by other communities more resistant to the severe-floods, such as *Prosopis juliflora, Zygophyllum album, Acacia campoptila* and *Tephrosia apollinea.*

Association 12 (Figure 5.25) of secondary wadis of plateaus and association 7 of the main wadi beds of site 3 are the most diverse. The number of species in these associations range between 34 and 44 and the individuals range between 468 and 537. Associations 2, 10, 14 and 15 are characterised by a low number of species and individuals. Associations 1 and 3 have the highest vegetation cover percentages, the former is dominated by trees and shrubs namely *Phoenix dactylifera, Prosopis farcta* and *Alhagi graecorum,* while the latter is dominated by dwarf shrub and herbaceous cover namely *Merremia hadramautica, Crotalaria persica,* and *Heliotropium ramosissimum.*



Association															
number of species															
average vegetation cover %															
number of individuals											4				

Figure 5.25. Numbers of species, individuals, and the total vegetation cover percentages of the main floristic associations. Associations 7 and 12 are the most diverse and associations 2, 10, 14 and 15 are the least diverse.

There are distinct variations in vegetation structure on the main wadis over the study sites and on the slopes of plateau of site 2. These are indicative of human and natural activities that are significant on these landforms. In the first case, floods play an important part in changing the vegetation structure from woodland to grassland. In the second case, oil-exploration plays a role in changing the structure from shrubland or/and grassland to sparse grassland. Table (5.18) shows the relationship between vegetation association and structure. As can be observed from this table, two or more sample plots that belong to the same vegetation association may have considerable differences in vegetation structure. For example vegetation associations 5, 12 & 13 have 5 different structure classes. The difference in vegetation structure are likely to result from environmental and land use conditions, including wood cutting, severe flooding and over-grazing. In the study area cutting of wood, road construction and grazing are common in the study sites.

	vegetation association														
vegetation structure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	1				2			1					1		
2				1	3										
3				3											
4				3	2	1						2	5	1	
5	4	2			1	2			1	1	3	8	2		1
6	1														
7											1	1	1		
8		3			2	2	6	6	8	6	8	2	1	3	4
9			2			1	6								

Table 5.18. The relationship between vegetation association and structure. 1= woodland, 2= open woodland, 3= shrubland, 4= sparse shrubland, 5= grassland, 6= dense woodland, 7= dense grassland 8= sparse grassland, 9= dwarf shrubland. As can be observed from this table, two or more sample plots that belong to the same vegetation association may have considerable differences in vegetation structure. For example vegetation associations 5, 12 & 13 have 4- 5 different structure classes. The difference in vegetation structure are likely to result from environmental and land use conditions, including wood cutting, severe flooding and over-grazing.

Table 5.19 shows a summary of environmental characteristic of each vegetation association.

	sand %	silt %	clay %	moisture	CeC	O.C. %	CaCO3 %	EC %	pH	soil depth	altitude	slope %	surface stoniness	rock outcrops	erosion	trees	shrub	Dwarf shrub	herbs	total vegetation cover
1	49	40	10	3	6.2	0.4	35.5	3	7.9	50	724	1	1	0	2	24	0	14	2.6	41
2	87	5	8	1.3	1.7	0.2	37.1	0.3	8.7	30	700	2	1.6	0	5	1	0.3	0	16	16
3	60	32	8	5.5	6.1	0.5	29.7	0.5	8.1	30	676	2	1.5	0	4	0	0	60	10	70
4	55	37	8	2.1	5.3	0.4	37.1	7.4	8.3	20	733	3	82	27	4	2.9	12	1	7.7	23
5	59	36	5	1	5.5	0.3	37	3.8	7.9	20	686	2	45	0	4	8.2	2.2	1.4	2.8	14
6	58	35	7.5	2.8	6.2	0.5	37	0.2	7.6	20	681	2	64	1.7	4	1	0.3	5.3	3.8	12
7	54	36	8.7	3.1	10	7	37.2	1.4	7.6	20	668	2	77	2.3	4	2.2	1	9	2.5	13
8	50	40	10	1.6	5.2	0.2	35.7	1	8.2	20	757	30	84	2.3	3	1	0	0	3.6	3.6
9	45	43	13	7.4	7.6	0.2	37.3	0.6	7.9	20	685	36	93	8.2	3	0	0	0	2.5	1.9
10	52	39	9.7	3.2	5.7	0.2	37	0.4	8.1	20	763	42	90	13	3	0	0	0	2.9	2.8
11	52	35	13	3.3	8	0.3	37	1.6	8.1	20	995	12	89	0.8	3	1	1	0	14	14
12	60	36	4	3	6.1	0.2	37	6.9	7.4	30	979	8	85	3.7	4	2.5	0.2	1	17	19
13	56	35	8.7	1.8	4.3	0.4	36.8	0.3	8.1	20	977	30	85	3.7	2	2.7	1.8	0.5	14	19
14	57	31	12	1	5	0.6	37.4	0.4	8	10	955	29	97	4.5	3	1	1	1	1.3	2.7
15	56	38	6	3	5.2	0.5	37.2	0.5	8	10	949	36	95	2.2	2	0	0	0	4	4

Table 5.19. Main floristic vegetation associations with characteristic soil, strata and landform data..

Finally, it is understood from this chapter that the study sites have various vegetation associations and structure. Oil working activities and floods have affected vegetation associations, composition and structure. The vegetation cover percentage also varies from one landform to another.

Previously the main vegetation associations and the vegetation structure types, their environmental characteristics and similarities were described. In the next chapter the vegetation associations and the distribution of main plant species in the three study sites together with the distribution of some important endemic, near-endemic and rare plant species of Hadhramaut region will be analysed.

Chapter 6. Distribution and mapping of the vegetation and land cover.

6.1. Introduction

With the availability of new GIS techniques such as ERDAS Imagine and ArcView, the development of vegetation mapping and the plotting of the distribution patterns of plant taxa have taken rapid steps forward.

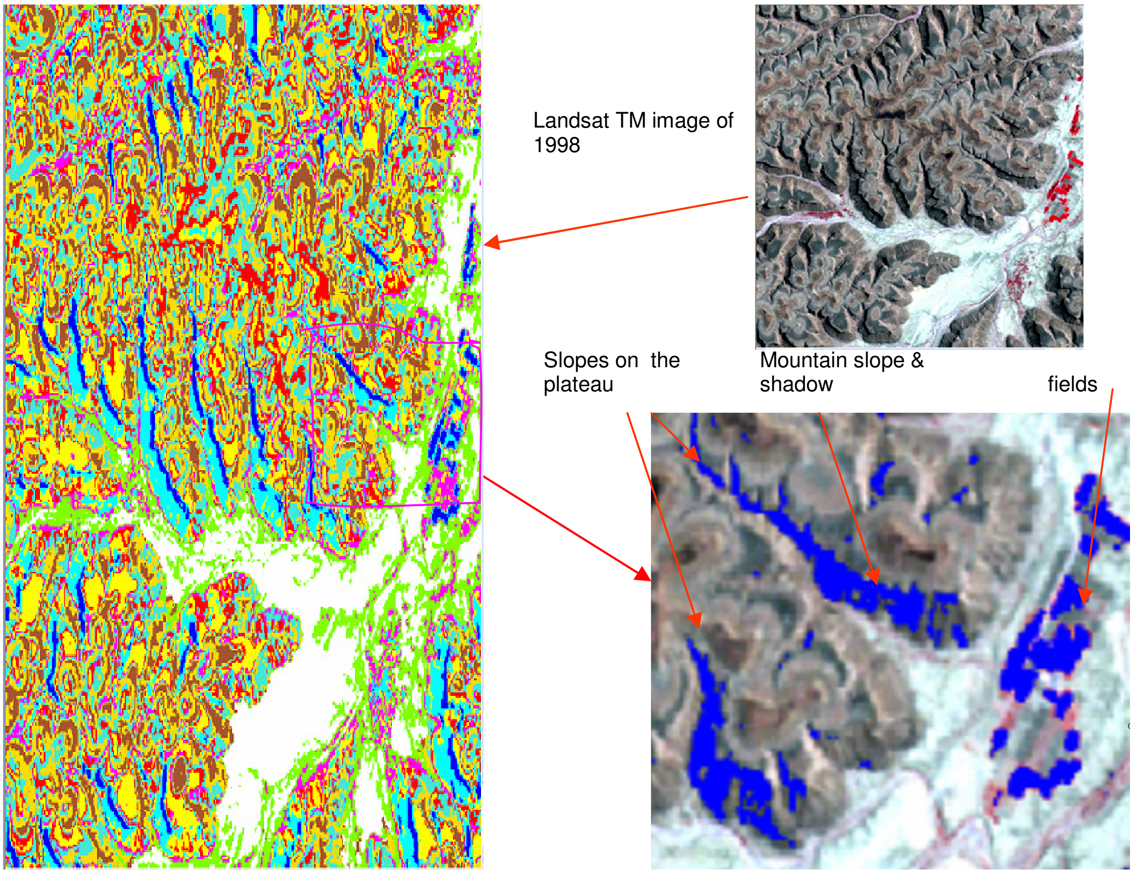
An understanding of natural distribution patterns and the environmental restrictions on natural plant species helps in the formulation of conservation strategies (Ferrier, 2002).Vegetation and land use maps support conservation activities and, consequently, mapping plant distribution patterns provides a valuable framework and rapid visual for land management strategies. In addition, vegetation and plant distribution maps provide essential information on setting conservation priorities; for example, this study has shown that the south-facing mountain slopes of the Hadhramaut region are an important centre for endemic and near-endemic plants. Vegetation and distribution maps are also basic sources of information for the regional and national mapping of plant species. Finally, they furnish a baseline database for vegetation, landscape and conservation biology studies in the future.
In previous chapters, the plant diversity and vegetation associations of the study sites were described in detail. The aims of this chapter are to:

- describe the distribution and the dynamics of the main plant species of the Hadhramaut region by plotting them on maps,
- outline the main vegetation associations on large scale vegetation maps,
- provide information on the names and geographic distribution of plant species in the Hadhramaut region – concentrating on those of special status, for instance, those that are rare, endemic or near-endemic, or of economic importance,

In this section, distribution maps of 60 plant species from the study sites and 24 from the Hadhramaut region are presented. These species are distributed across all landforms and habitats, including wadi beds, rocky mountain slopes and plateaus.

6.2. Methods of study:

The accuracy of the vegetation map depends on the spatial and spectral resolution and the seasonal variability in vegetation cover types and soil moisture conditions (Congalton, 1988). One of the main problems when generating land cover maps from digital images is the confusion of spectral responses from different features (Eiumnoh and Shrestha, 1997). When the vegetation classification using ERDAS IMAGINE was carried out, different features with similar spectral behaviour were grouped into the same class. For example, the cover of the mountain slopes and the slopes of the plateau were grouped with agriculture fields in the main wadis (see Figure 6.1). This confusion between vegetation areas, with greater soil moistures, geology materials and bare areas in shadow or steep sloped, limited the degree of differentiation possible in an automatic classification. As in other arid or semi-arid areas (Miller and Cope, 1996), the study sites are characterized by sparse vegetation cover with most of the land surfaces, in particular on the plateaus, being almost bare. Consequently, the spectral response in the area essentially represents the geology rather than the vegetation cover.



Land cover map produced by unsupervised classification using ERDAS IMAGINE 8.4

Different land cover units were grouped into the same class. Here the shadow, the cover on the mountain slopes and slopes on the plateau are classified grouped with the agriculture fields of the main wadi.

Figure 6.1. Vegetation and land cover map using ERDAS IMAGINE. The cover of the mountain slopes and the slopes of the plateau were grouped with agriculture fields in the main wadis.

In the study area, each landform has a combination of vegetation associations (for instance, associations 1 to 7 in the main wadis and 8 to 10 on the mountain slopes) and because of the difficulties of mapping each vegetation association separately, the main landform units of the study sites (see chapter 1) were used to create the vegetation association maps. The different landforms were identified by interpreting the satellite imagery and delineating their boundaries. Mapping the secondary wadis as a separate unit was not possible due to limited resolution of the image.

Therefore, a combination of landforms was used to describe the vegetation associations of these units. The resulting geomorphic maps of the study sites were generated using ArcView 3.2a. This was done by entering the available Landsat imageries of 1989 (pixel size 25X25) and of 2001 (pixel size 15X15) as data layer. Then, using the irregular polygon button, lines were drawn around the different landforms. The species distribution maps were plotted using ERDAS IMAGINE and DIVA-GIS software. The spot data for each species are based on the geographical coordinates of known localities obtained during fieldwork (using a handheld GPS) and from reliable literature sources (Lavranos, and Al-Gifri 1999; Lavranos, and Mies 2001; Lavranos, 1996; Thulin, 2001 and 2002; Thulin, and AI-Gifri 19953 and 1995; Kilian, et al., 2002).

ArcView 3.2a

ArcView is made by Environmental Systems Research Institute (ESRI). Over the past 20 years ArcView has proved to be a powerful tool that brings geographic information to the desktop and gives the power to visualize, explore, query and analyze land cover and land form data.

ERDAS IMAGINE 8.4

This is software designed for image mapping and visualization, image processing and advanced remote sensing.

DIVA-GIS

DIVA-GIS is a free mapping software package for biodiversity and ecological research that allows the user to analyze plant species distributions. DIVA-GIS 4 is developed by Robert J. Hijmans, Luigi Guarino, Prem Mathur, Rachel O'Brien and Andrew Jarvis and can be downloaded from . http://www.diva-gis.org/

6.3. Result

The initials stage of the analysis was depiction of the topography and wadis in the 3 study sites (as described in chapter 1). The results are shown in Figures 6.2 to 6.4.

6.3.1- Relief and drainage

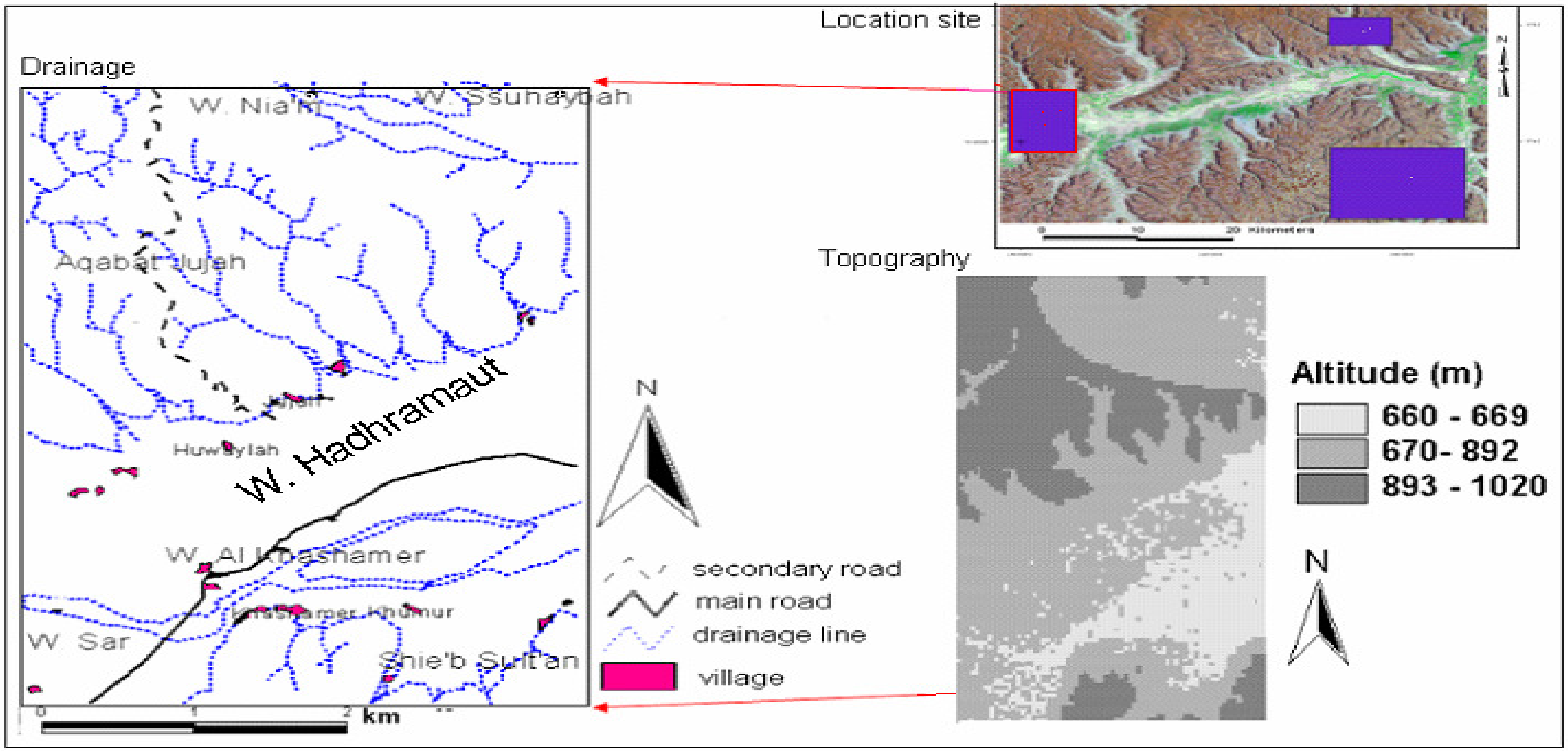


Figure 6.2. Topographic features of study site 1. The altitude ranges between 660 and 1020 m asl. The study site is located between 15º 45' and 15º 58' latitude and 48º 34' and 48º 35' longitude. The study site is located on the main Wadi Hadhramaut, the tributary wadis are: W. Nia'm and W. Ssuhaybah (north), W. Al Khashamer, she'b Sultan and W. Sar (south). The main villages are Jubah and Huwaylah (north), Khashamer and Khumur (south).

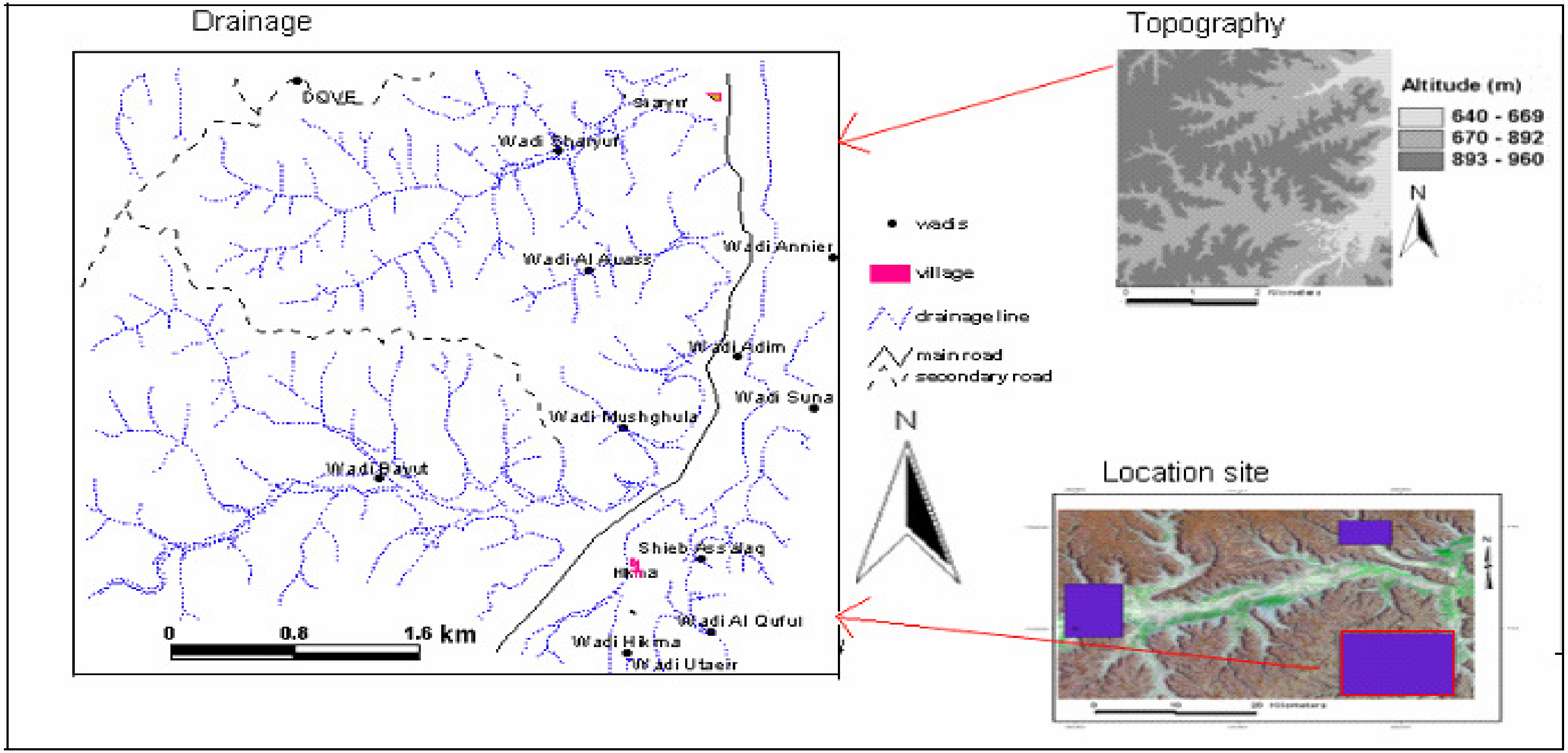


Figure 6.3. Topographic features of study site 2. The altitude ranges between 640 and 960 m asl. The study site is located between 15 52’ and 15 48 latitude and 48 53’ and 48 59’ longitude. The main wadi is W. Adim, the tributary wadis are; W. Bayut and W. mushghula (west), W. Hikma, W. Al Quful and W. Utaeir (south), Shei’b Assalaq and W. Suna (east), W. Annier, W. Al Auass and W. Sharyuf (north). The main village is Hikma.

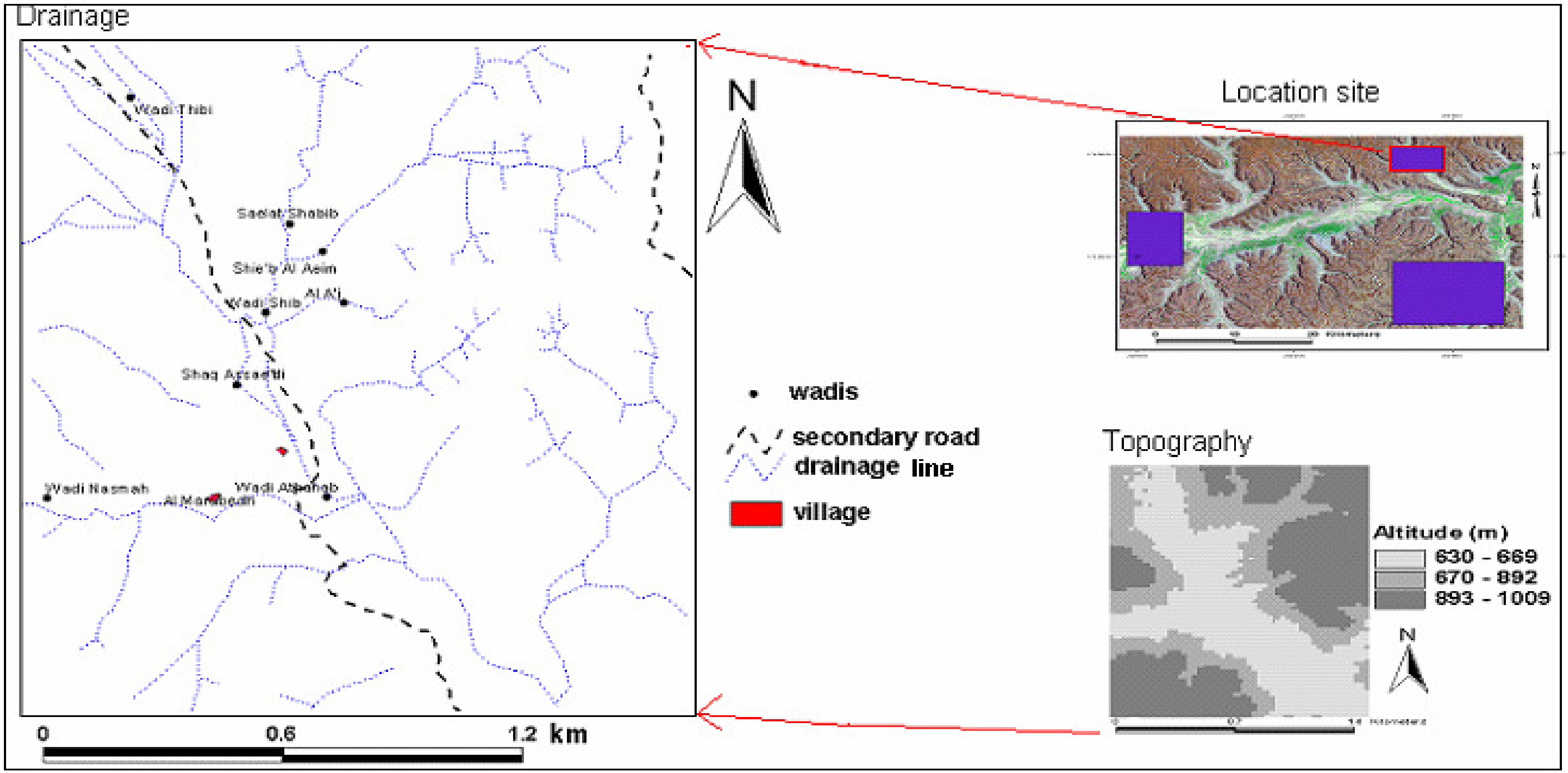


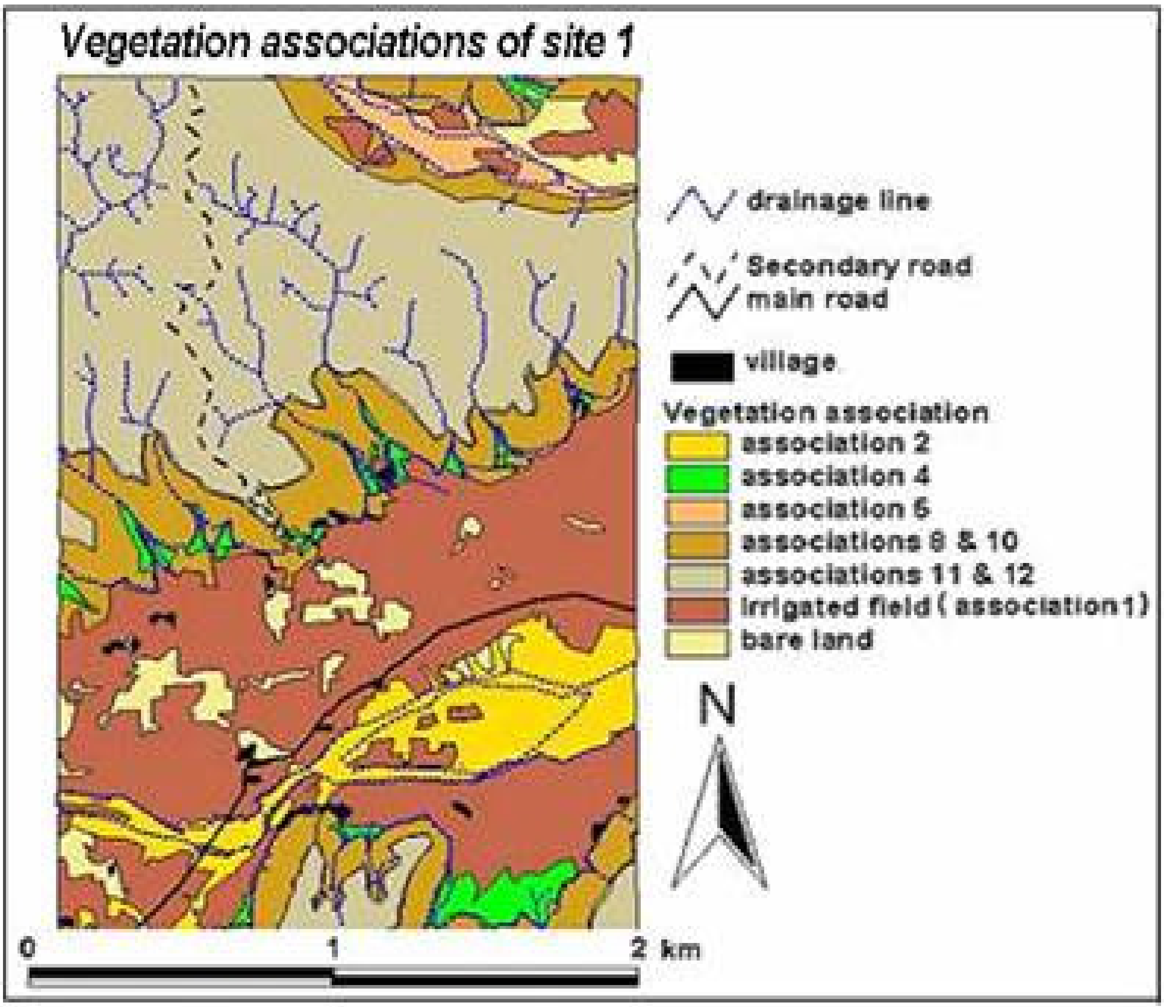
Figure 6.4. Topographic features of study site 3. The altitude ranges between 630 and 1009 m asl. The study site is located between 16 03' and 16 05 latitude and 48 55' and 48 59' longitude. The site is located on Wadi Athahab, the tributary wadis are: W. Thibi (north), Shie'b Al Aeim and W. Shib (east), W. Nasma (west). The main village is Al Marabedh.

6.3.2. The vegetation associations of the study sites

The next stage was the evaluating of the main vegetation associations (as outlined in chapter 5). These associations are overlain onto the relief and drainage maps. Table 6.1 shows the allocation of the vegetation associations across the 3 study sites, Figures 6.5 to 6.7 illustrate their distributions across the landscape. Landform units were used to plot each association.

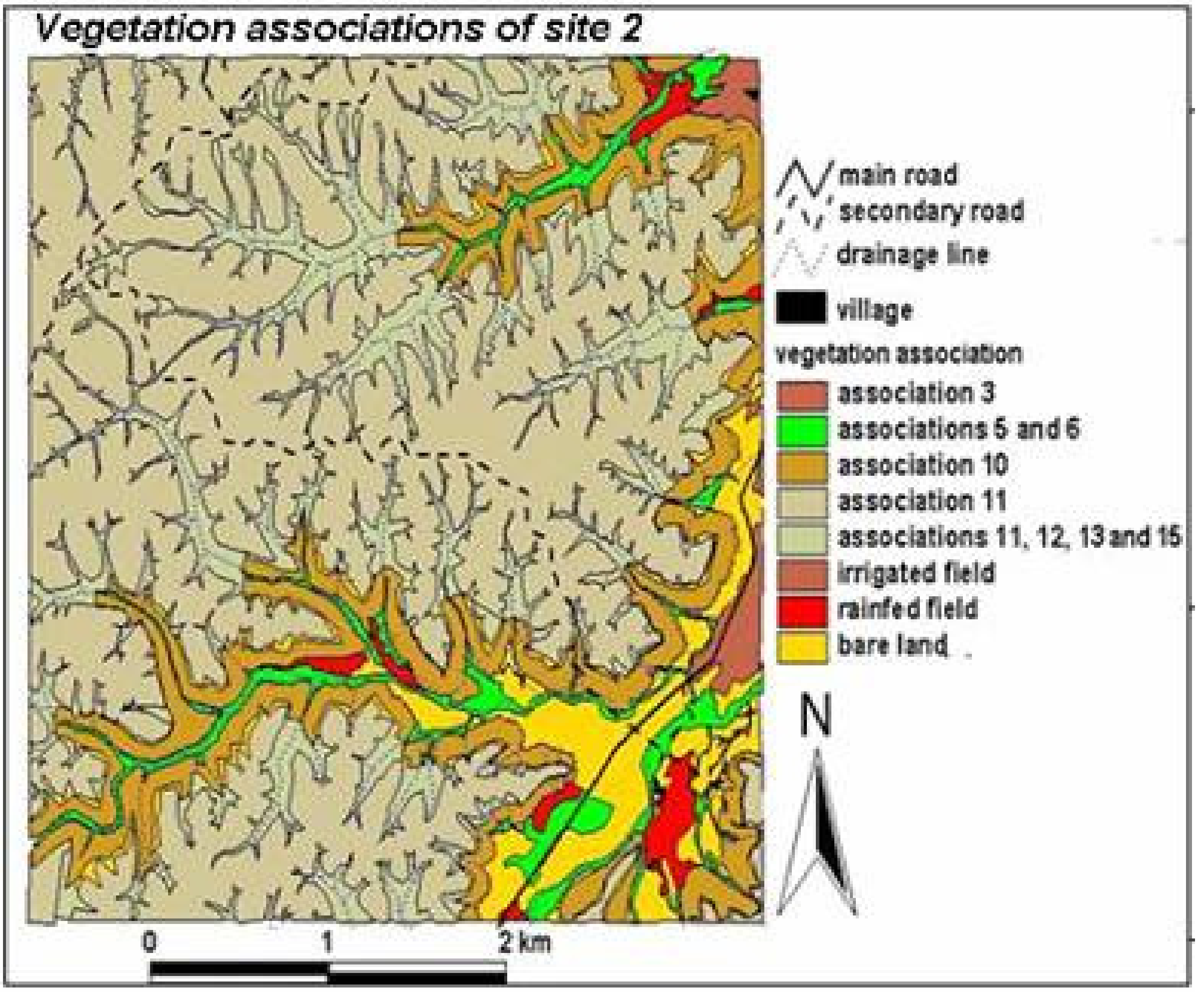
Association	Site 1	Site 2	Site 3
1	+		
2	+		
3		+	
4	+		
5	+	+	
6		+	
7			+
8	+		
9			+
10	+	+	
11	+	+	+
12	+	+	+
13		+	
14			+
15	+		

Table 6.1. Distribution of the vegetation associations across the study sites: associations 1,2,4,8 and 15 are confined to site 1; associations 3, 6 and 13 are confined to site 2; associations 7, 9 and 14 are confined to site 3; associations 5 and 10 are confined to sites 1 and 2, while associations 11 and 12 are distributed across all the study sites. The vegetation associations are described in detail in chapter 5.



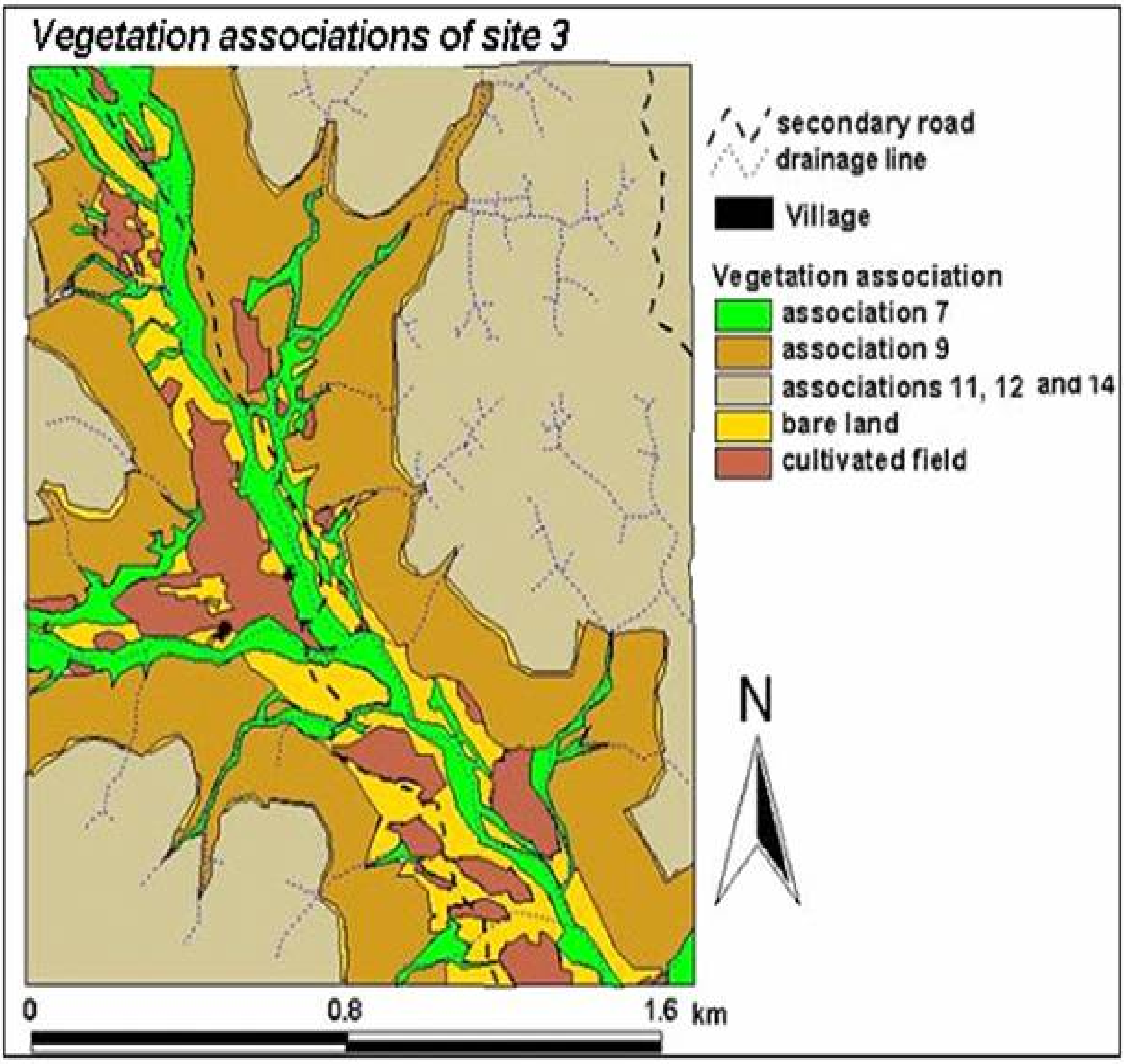
Legend	The vegetation association	Topography: landform	Altitude a.s.l. (m)	slope%	vegetation: cover %	structure: type	structure: %	soil: texture	surface stoniness%	rock outcrop%
1	*Alhagi graecorum - Phoenix dactylifera*	flat fallow and cultivated lands	670-722	1	41	1	17	sl,l	1	0
						5	83			
						6	17			
2	*Citrullus colocynthis - Zygophyllum album*	flooded wadi bed	670 - 700	1	16	5	40	l,ls	1.6	0
						8	60			
4	*Tephrosia dura - Tephrosia apollinea- Fagonia indica*	wadi beds and depressions	683-733	3	23	2	14.3	sl,l	82	27
						3	42.9			
						4	42.9			
5	*Acacia ehrenbergiana – Rhazia stricta – Acacia campoptila*	almost flat to undulating rocky wadi beds and banks	624-686	2	11	2	50.0	sl	88	0
						5	50.0			
8	*Forskohlea tenacissima - Boerhavia elegans*	moderate to steep rocky slopes and alluvial fans facing the main wadis	690-827	10 to 50	4	5	14.3	sl	84	2
						8	85.7			
10	*Indigofera spinosa - Stipagrostis hirtigluma*	eroded moderate to steep rocky slope, facing the main wadis	692- 763	20 to 60	2	8	100	sl,l	91	10
11	*Seetzenia lanata - Dichanthium insculptum*	plateaus	930-944	1 to 3	13	5	50	l	80	0
						8	50			
		slope on plateu	989-995	25 to 30	4	8	100	sl,l	95	1
12	*Chrysopogon aucheri - Stipagrostis hirtigluma*	narrow wadis and drainage lines of the plateaus	858-979	1 to 3	12	4	40	sl	84	0
						5	60			

Figure 6.5. Main vegetation associations of site 1. vegetation structure: 1- woodland, 2- open woodland, 3- shrubland, 4- sparse shrubland, 5- grassland, 6- dense woodland, 7- dense grassland, 8- sparse grassland, 9-- dwarf shrubland. sl= sandy loam, l= loam, ls= loamy sand.



	Legend	Topography			vegetation			soil		
No	The vegetation association	landform	Altitude a.s.l. (m)	slope%	cover %	structure typ e	structure %	texture	surface stoniness%	rock outcrop %
3	*Convolvulus glomeratus – Merremia hadramautica – Crotalaria persica*	old fallow land on narrow drainage line	675-677	1 to 2.	70	9	100	sl	2	0
5	*Acacia ehrenbergiana – Rhazia stricta – Acacia campoptila*	almost flat to undulating rocky wadi beds and banks	643-686	1 to 3.	15	1 2 4 8	28.6 14.3 28.6 28.6	sl	38	0
6	*Salsola imbricate - Blepharis edulis*	wadi beds and adjacent banks	632-692	1 to 5.	9	4 5 6 9	17 33 33 17	sl, sil	64.2	2
10	*Indigofera spinosa - Stipagrostis hirtigluma*	eroded moderate to steep rocky slope, facing the main wadis	692- 703	20 to 60	4.7	5 8	33 67	sl	88.3	18
11	*Seetzenia lanata - Dichanthium insculptum*	plateaus	930- 936	1	6	8	100	sl	95	0
		slope on plateau	925-946	20 to 50	48	7 8	50 50	sl	87.5	3
12	*Chrysopogon aucheri - Stipagrostis hirtigluma*	narrow wadis and drainage lines of the plateaus	858 - 928	1 to 25.	34	5 7	80.0 20.0	sl	82.8	8
13	*Maerua crassifolia - Jatropha spinosa – Stipagrostis hirtigluma*	slope of plateau	899 -977	30 to 50	19	1 4 5 7 8	10 50 20 10 10	sl, ls	85.4	4
15	*Zygophyllum decumbens - Dichanthium insculptum*	slope of plateau	926 -949	30 to 40	4	5 8	20 80	sl	95	2

Figure 6.6. Main vegetation associations of site 2. Vegetation structure: 1- woodland, 2- open woodland, 3-shrubland, 4- sparse shrubland, 5- grassland, 6- dense woodland, 7- dense grassland, 8- sparse grassland, 9-- dwarf shrubland. sl= sandy loam, sil= silt, ls= loamy sand.



Legend		Topography			vegetation			soil		
No	The vegetation association	landform	Altitude a.s.l (m)	slope%	cover %	structure type	structure %	texture	surface stoniness%	rock outcrop %
7	*Tephrosia nubica - Acacia campoptila - Merremia* hadramautica	wadi beds and adjacent banks	579-668	1 - 5%	12.6	8 9	58 42	sl.l,sil	77.1	2.3
9	*Fagonia paulayana - Boerhavia elegans – Cleome scaposa*	very eroded moderate to steep rocky slope facing the main wadis	590-685	15 -50%	2	5 8	11 89	sl,l	93	8
11	*Seetzenia lanata - Dichanthium insculptum*	plateau	900-905	3	3	8	100	sl	97	0
		slope on plateau	920-950	20 - 30%	4	5 8	50 50	l	97	3
12	*Chrysopogon aucheri - Stipagrostis hirtigluma*	narrow wadis and drainage lines of the plateaus	858-979	1	8	5 8	50 50	nd	90	1.5
14	*Cornulaca amblyacantha - Stipagrostis hirtigluma*	slope on plateau	932-955	5 - 40%	3	4 8	25 75	sl	96.7	4.5

Figure 6.7. Main vegetation associations of site 3. Vegetation structure: 1- woodland, 2- open woodland, 3- shrubland, 4- sparse shrubland, 5- grassland, 6- dense woodland, 7- dense grassland, 8- sparse grassland, 9--dwarf shrubland. sl= sandy loam, l= loam, ls= loamy sand, sil= silt, nd= no data.

For each land unit depicted in the previous maps, the surface areas have been calculated as shown in Tables 6.2 to 6.4. The total area of the 3 study sites is about 2541 hectares.

The class	**Area/ha**	**percentage**
Association 2	508	8.3
Associations 8 and 10	1006	16.5
Associations 11 and 12	2108	34.6
Association 4	160	2.6
Association 5	122	2.0
Cultivated field (association 1)	1877	30.8
Bare land	304	5.0
total	6085	

Table 6.2. The area in hectares of each association and other land forms of site 1.

The area of each land unit is calculated in hectare as following:

The class	**Area/ha**	**Percentage**
Association 3	11	0.1
Association 5 and 6	714	4.5
Association 10	2496	15.9
Association 11	9258	58.9
Association 11, 12, 13 and 15	2689	17.1
Irrigated field	238	1.5
Rainfed field	229	1.5
Bare land	70	0.4
Total	15705	

Table 6.3. The area in hectares of each association and other land forms of site 2.

The class	**Area/ha**	**Percentage**
Association 7	359	9.9
Association 9	1098	30.4
Associations 11, 12 , and 14	1542	42.6
Renfed field	237	6.6
Bare land	380	10.5
total	3616	

Table 6.4. The area in hectares of each association and other land forms of site 3.

Because of the complexity of landforms in the study sites and because of difficulties of mapping each vegetation association separately, combinations of associations were mapped together. For example, the landform and the vegetation associations of the secondary wadis of the plateaus and the adjacent slopes could not be satisfactorily separated. So, for instance, associations 11 and 12 in site 1 (Figure 6.8), 11, 12, 13 and 15 in site 2 (Figure 6.10) and 11, 12 and 14 in site 3 (Figure 6.11) were mapped together and presented on the previous vegetation maps as a group of associations. On the other hand, a specific landform can have more than one association, for example the mountain slopes of site 1 have a combination of associations 8 and 9 (Figure 6.9) and the slopes of the plateau of site 2 have a combination of associations 11, 13 and 15 (Figure 6.10).

Because of the difficulties in mapping the vegetation associations as separate units, the cover percentage of each association in these landforms was estimated by taking into consideration the number of the sample plots that formed each association.

The following figures show the estimated percentages of each association based on the number of sample plots. However, the percentage cover of each association in reality does not reflect the actual cover because each land form has a considerable number of bare sample plots. In particular, the mountain slopes facing the main wadis, the plateau surfaces and the slopes of the plateau have a large number of bare plots. As an illustration, 3 out of 4 sample plots on the plateau surface of site 2 were bare, which indicates that 75% of this landform is without vegetation. Similarly, 5 out of 21 sample plots on the slopes of the plateau in site 2 were bare, which indicates that 24 % of this landform surface is also without initially devoid of vegetation.

Site 1

Association 11 covers most of the plateau areas; this association is restricted to the exposed plateau surface and adjacent slopes while association 12 is confined to secondary wadis of the plateau.

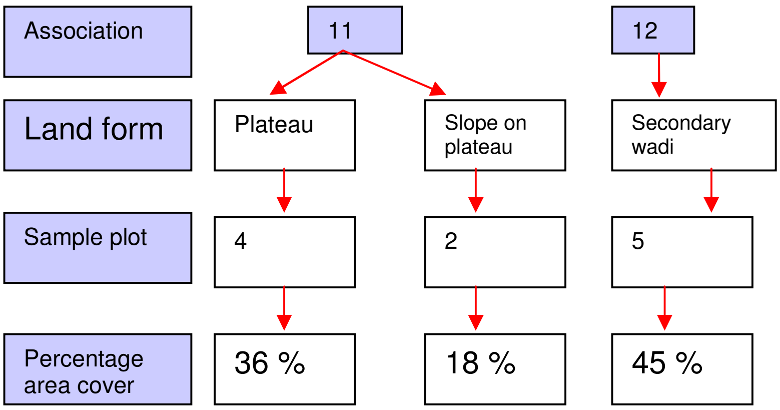


Figure 6.8. Percentage covers of associations 11 and 12 on the plateau of site 1

Figure 6.8 shows the percentage covers of associations 11 and 12 in each land form for the complex of topographical units on the plateau of site 1.

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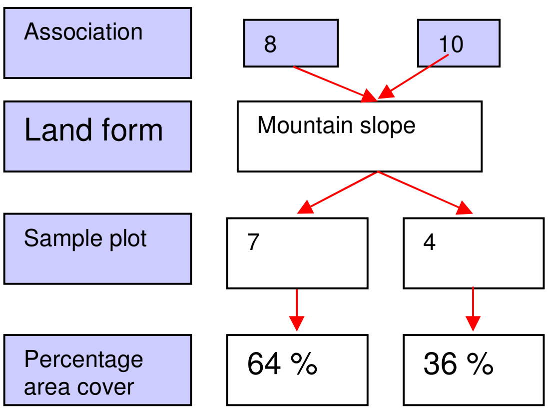


Figure 6.9. Percentage cover of associations 8 and 10 on the mountain slope facing the main wadi. Association 8 covers most of the mountain slopes.

Figure 6.9 shows the percentages of associations 9 and 10 in the mountain slope facing the main wadi of site 1. Association 8 covers 64 % of the slopes, while association 10 covers only 36 %.

Site 2

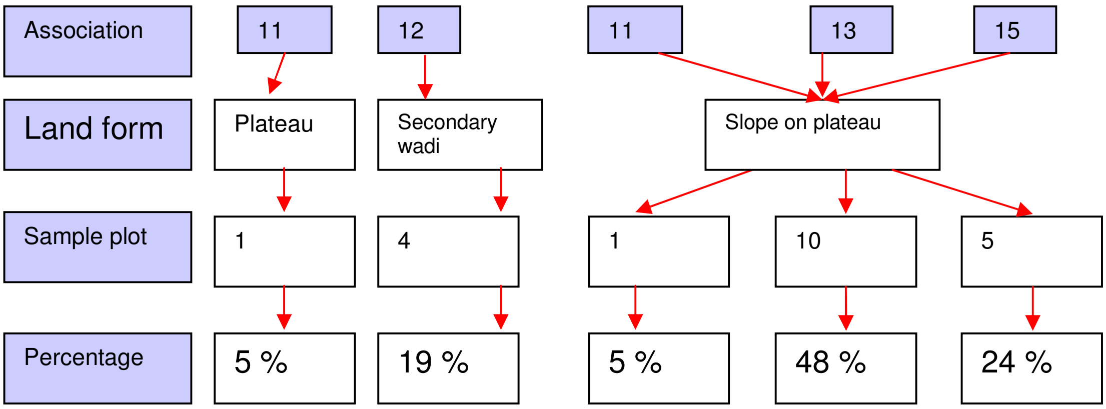


Figure 6.10. Percentage cover of associations 11, 12, 13 and 15 on the plateau area of site 2. Association 13 covers most of the slopes of the plateau; the plateau surface is composed mainly of association 11, while the secondary wadis are composed only of association 12. The slopes of the plateau have a combination of associations 11, 13 and 15 in which association 13 covers almost half of these land forms. Associations 11 found on 2 different landforms (plateau surface and slope of the plateau).

Site 3

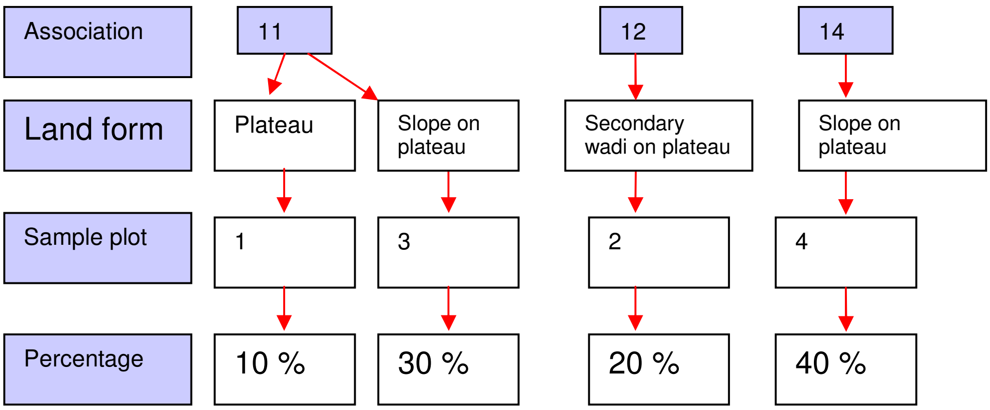


Figure 6.11. Percentage cover of associations 11, 12, and 14 on the plateau area of site 3. Association 14 covers most of the slope of the plateau; the plateau surface is composed mainly of association 11, while the secondary wadis are composed of association 12.

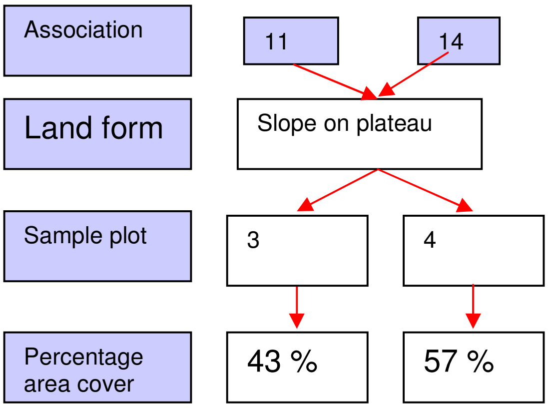


Figure 6.12. Percentage cover of associations 11 and 14 on the slopes of the plateau of site 3. The slopes on the plateau have a combination of associations 11 and 14 in which association 14 covers 57 % and association 11 43% of the land surface of these land forms.

6.3.3. Agricultural fields

The agricultural fields are mainly located in the main wadi. Most of the wadi bottom at site 1 is heavily cultivated, while few areas in sites 2 and 3 are cultivated.

The main crops in the region are:

5. Cereals (wheat, sorghum and sesame),
6. Vegetables (onion, potato, tomato, garlic),
7. Fodder (alfalfa – *Medicago sativa*)

Another type of cultivated area is represented by palm-groves. These are composed of pure stands of *Phoenix dactylifera*; sometimes mixed with annual crops such as Alfalfa, vegetables (e.g. onions, potatoes, tomatoes, garlic and okra) and sesame. Alfalfa is a major fodder crop in Wadi Hadhramaut.

The irrigated fields are mainly cultivated with palms, sorghum, wheat, alfalfa (*Medicago sativa*) and other vegetables.

The cultivated areas of the study sites were measured using ArcView and found to be as following (see Figures 6.13):-

Site 1: 1877 ha

Site 2: 467 ha (irrigated = 238 ha and rainfed = 229 ha)

Site 3: 237 ha

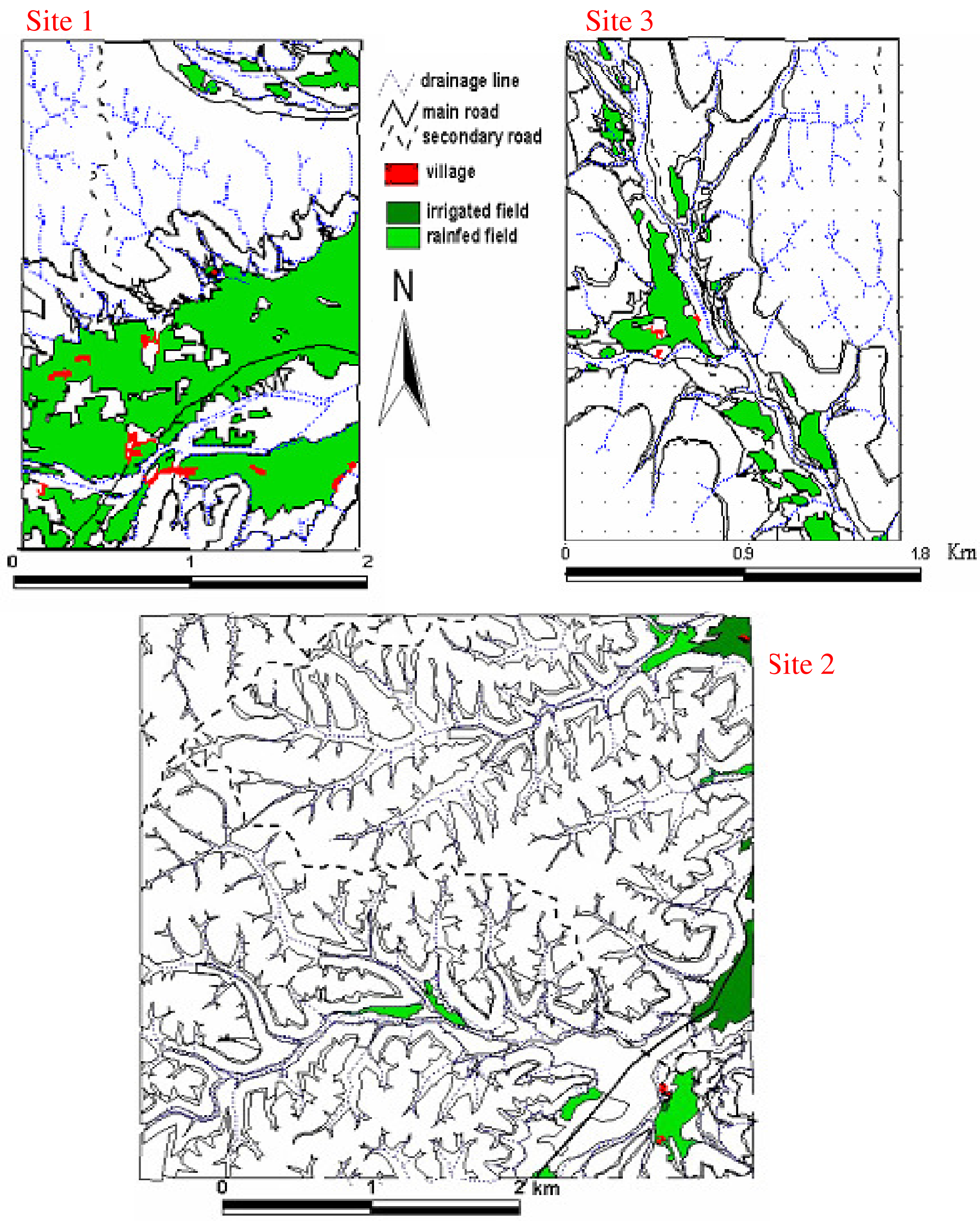


Figure 6.13. Maps of the cultivated fields of the 3 study sites. The areas are as following:-
Site 1: irrigated fields total 1877 ha.
Site 2: irrigated fields total 238 ha and rainfed fields total 229 ha
Site 3; rainfed fields total 237 ha

6.3.4- Plant species distribution within the study sites

Distribution maps of the main plant species in the 3 study sites were generated using ERDAS Imagine 8.4. Each point on each map represents the GPS location of a plant population. As expected, distribution patterns differ from one plant to another, however, some common patterns have emerged. Certain species occur across the 3 study sites whilst others are limited to only one or two study sites. Furthermore, distributions differ depending on landform; some species are restricted to the main wadis (e.g. *Prosopis farcta, Alhagi graecorum, Zygophyllum album, Rhazya stricta* and *Ochradenus baccatus*), others prefer the dry rocky slopes of the plateaus (e.g. *Jatropha spinosa, Maerua crassifolia, Hochstetteria schimperi, Commiphora kua, Grewia erythraea, Helichrysum pumilum* and *Cornulaca amblyacantha)*, and whilst yet others grow well on sandy deep soil (e.g. *Dipterygium glaucum and Panicum turgidum*). Many species in the study sites show altitudinal preferences (Table 6.5), but further surveys are needed over the whole study area to get a complete picture of the altitudinal range of all the species.

Table 6.5. The distribution of the plant species along an elevation gradient.

Plant species / Altitude	620	625	630	635	640	645	650	655	660	665	670	675	680	685	690	695	700	750	755	760	765	770	800	850	855	900	950	955	960	965	970	975	980	990
Boerhavia elegans	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cleome brachycarpa	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Fagonia paulayana	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Tephrosia apollinea	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Aristida triticoides	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Farsetia linearis	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Cymbopogon schoenanthus	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Fagonia indica	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Senna italica	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Cleome droserifolia	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Indigofera spinosa	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Acacia campoptila	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Merremia somalensis	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Ziziphus leucodermis	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Aerva javanica	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Blepharis edulis	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Kohautia retrorsa	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Heliotropium ramosissimum	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Rhazya stricta	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												
Ochradenus baccatus	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																			
Panicum turgidum	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																			
Tephrosia nubica	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																			
Indigofera oblongifolia	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																			
Dichanthium insculptum		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Plicosepalus curviflorus		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Calotropis procera		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Acacia ehrenbergiana		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Pulicaria undulata		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Senna holosericea		■	■	■	■	■	■	■	■	■	■	■	■	■																				
Tribulus arabicus			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												
Salsola imbricata			■	■	■	■	■	■	■	■	■																							
Cleome scaposa				■	■	■	■	■	■	■	■	■	■	■	■	■	■																	

Continued overleaf

Table 6.5. Continued

Plant species / Altitude	620	625	630	635	640	645	650	655	660	665	670	675	680	685	690	695	700	750	755	760	765	770	800	850	855	900	950	955	960	965	970	975	980	990	995
Barleria aff bispinosa					1			1							1			1							1	1									
Halothamnus bottae					1			1										1								1	1	1							
Seddera latifolia					1						1																			1					
Dipterygium glaucum						1	1				1	1	1	1			1					1													
Tephrosia dura								1						1	1			1																	
Heliotropium rariflorum								1			1		1				1																		
Tamarix aphylla								1				1	1																						
Corchorus depressus										1		1	1		1																				
Lasiurus scindicus										1		1			1																				
Stipagrostis hirtigluma											1		1	1		1	1	1			1		1		1	1	1	1	1	1	1	1		1	1
Enneapogon desvauxii											1		1			1	1										1	1							
Leptadenia arborea											1						1										1								
Citrullus colocynthis											1		1				1																		
Cressa cretica											1							1																	
Phoenix dactylifera											1				1			1																	
Ziziphus spina-christi											1	1	1					1																	
Zygophyllum album											1	1	1				1	1																	
Zygophyllum coccineum											1				1			1																	
Cynodon dactylon											1				1	1																			
Convolvulus arvensis											1				1																				
Chloris barbata											1				1																				
Prosopis juliflora												1	1				1	1																	
Zygophyllum album												1						1																	
Crotalaria persica												1	1											1											
Chrozophora tinctoria												1	1										1				1								
Convolvulus glomeratus												1	1			1								1											
Alhagi graecorum												1	1		1			1																	
Indigofera spinifolia												1	1														1								
Senra incana												1	1					1																	
Prosopis farcta													1		1		1	1																	
Rhynchosia memnonia													1																						
Zygophyllum simplex														1	1		1			1							1				1				

Continued overleaf

Table 6.5. Continued

Plant species / Altitude	620	625	630	635	640	645	650	655	660	665	670	675	680	685	690	695	700	750	755	760	765	770	800	850	855	900	950	955	960	965	970	975	980	990	995
Acacia hamulosa														1	1			1						1	1	1	1				1		1		
Capparis spinosa														1	1			1																	
Cometes abyssinica															1								1	1			1								
Salvadora persica															1																				
Cadaba farinosa																1																			
Iphionia scabra																	1		1							1	1			1	1		1		
Forskohlea tenacissima																	1						1												
Capparis cartilaginea																		1							1		1								
Cyperus conglomerates																		1							1	1	1								
Maerua crassifolia																		1									1	1	1	1		1			
Iphionia anthemidifolia																		1																	
Reseda sphenocleoides																							1	1											
Lindenbergia indica																							1				1								
Anticharis glandulosa																								1			1	1							
Aerva artemisioides																								1			1								
Commiphora kua																								1			1	1	1			1			
Heliotropium longiflorum																								1											
Chrysopogon aucheri																									1	1	1								
Commiphora foliacea																										1	1	1	1	1	1		1		1
Hochstetteri schimperi																										1	1		1			1			
Jatropha spinosa																										1	1	1	1	1		1			
Zygophyllum decumbens																										1	1		1	1		1			
Cornulaca amblyacantha																										1	1	1							
Acacia oerfota																											1		1	1	1		1		
Corallocarpus glomeruliflorus																											1	1				1	1		
Seetzenia lanata																											1							1	
Crotalaria saltiana																											1				1		1		
Acacia mellifera																											1		1						
Grewia erythraea																											1		1						
Helichrysum pumilum																											1		1						
Arnebia hispidissima																											1		1						
Tamarix arabica.																											1								
Cucumis canoxyi																											1								
Euphorbia rubriseminalis																											1								
Glossonema varians																											1								
Hermannia paniculata																											1								
Tarenna graveolens																													1						
Chascanum marrubifolium																													1						
Moltkiopsis ciliata																															1		1		

The altitudinal setting of plant species is usually regarded as a reliable marker of their ecological statute (Zohary, 1973), but still other factors such as human activities and climate, may be involved in this distribution. It can be noticed in Table 6.5 that some species occur over a wide range of altitude; examples being *Boerhavia elegans* and *Cleome brachycarpa,* while others are restricted to low altitude areas, for instance, some species of the main wadi, namely *Ochradenus baccatus, Panicum turgidum* and *Tephrosia nubica;* other species restricted to high altitude areas, for instance, *Commiphora foliacea, Hochstetteri schimperi, Jatropha spinosa, Zygophyllum decumbens, Cornulaca amblyacantha, Acacia oerfota* and *Corallocarpus glomeruliforus.*

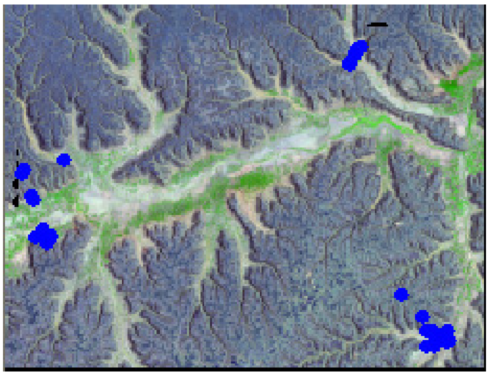
A number of species had a distribution that was clearly and always linked with altitude. For example, species only found below 700 m include *Tamarix aphylla, Lasiurus scindicus, Zygophyllum album, Alhagi graecorum, Prosopis farcta, Ochradenus baccatus, Tephrosia nubica, Rhazya stricta* and *Panicum turgidum*. Almost all of these species are Saharo-Sindian elements, while species restricted to higher altitude areas (over 800 m) include: *Commiphora kua, Commiphora foliacea, Grewia erythraea, Jatropha spinosa, Tarenna graveolens, Hochstetteri schimperi, Zygophyllum decumbensis, Euphorbia rubriseminalis, Chascanum marrubifolium, Moltkiopsis ciliata, Acacia mellifera* and *A. oerfota.*

Other environmental factors should also be taken to consideration. For example, some factors may influence plant species distribution differently over altitude (such as moisture and human activities). However, these factors may contribute to the decline in plant species that is often observed with a wide range of altitude. However, there is an overall decline in plant species with altitude as shown by Lawton et al, (1987). For example *Stipagrostis hirtigluma* is a widespread at high altitude but it often disappears or becomes rare at much lower altitudes, probably because of its vulnerability to over-grazing or due to other human or climate factors. Similarly, *Maerua crassifolia,* which is palatable in particular for camels and is common at high altitudes, is rare down at low altitude. Other example is *Jatropha spinosa,* which was not observed at low altitude in the study area, but is common at low altitude along the coastal plain of Yemen (Al Hubaishi & Muller-Hohenstein, 1984; Al Khulaidi, 1989; Wood, 1997). The absence of this species at a similar altitude in the main wadi of the study area may be because of the humidity that characterises the coastal area or due to the difference in timing of rainfall from the north (Wadi Hadhramaut) to the south (coastal area). The rainfall in the north falls in spring and summer, while in the coastal area falls mainly in spring and winter. Therefore, within the range of altitude of a vegetation type, smaller-scale variations in distribution may be controlled by smaller-scale features of environment such as soil type, moisture, human activities or topography (Woodward, 1987).

The following section comprises distribution maps of important species from the study sites and a selection from the wider Hadhramaut. The distribution is also described in the caption of each map. The maps are arranged to illustrate the following distribution patterns:-:

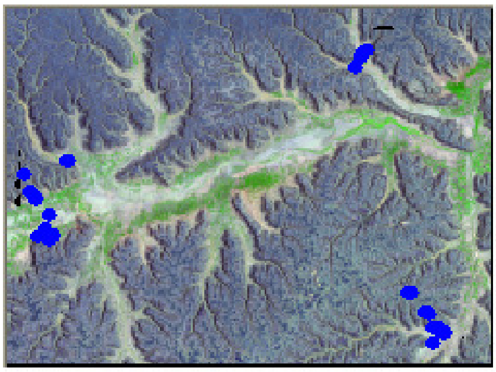
1. Widespread species found on the different land forms of the collated study sites in particular in the main wadi beds, occasionally found on the slope of the plateaus.
2. Widespread species found over the different land forms throughout all the study sites but occasionally or not common on the main wadi beds.
3. Widespread species found on all land forms throughout the study sites.
4. Species which are not abundant, but which are found in almost all the study sites.
5. Species found only in site 1.
6. Species occurring only in site 2.
7. Species found in sites 1and 2.
8. Species of sites 1 and 3.
9. Species of sites 2 and 3.

I. Widespread species found in a variety of land forms across the study sites but always in the main wadi beds and usually on the slopes of the plateaus.



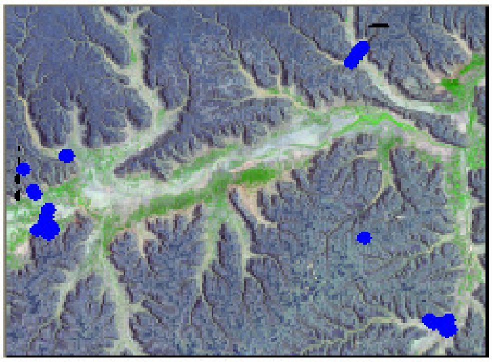
1- *Acacia campoptila*

Grows mainly in the wadi beds over the study sites between 600 and 770 m asl, but rarely found at the base of the mountain slopes facing the main wadis and on secondary wadis of the plateau between 890 and 920 m asl.



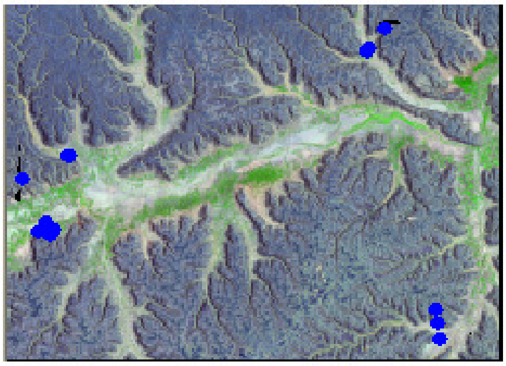
2- *Fagonia indica*

Grows on almost all landforms, but particularly in the wadi beds between 620 and 760 m asl; Found in less frequency on other landforms (between 800 and 970m asl.



3- *Tephrosia apollinea subsp longistipulata*

Mainly grows abundantly in the wadi beds between 600 and 730 m asl, but also occurs on sandy flooded sites and as a weed on cultivated fields and fallow lands. This species is also found in moist areas on the sides of rocky mountain slopes and plateau areas between 750 and 980 m asl.

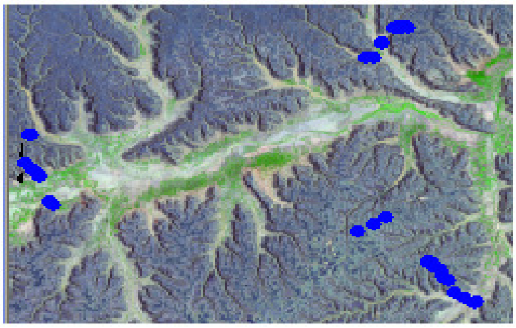


4- *Cymbopogon schoenanthus*

Grows mainly in rocky wadi beds, more or less throughout the study sites between 620 and 750 m asl; also found in relatively moist sites in the rocky drainage lines that cut the plateaus between 900 and 980 m asl.

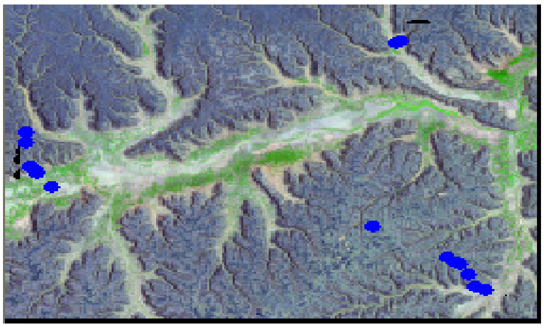
Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus and *Acacia campoptila* are widespread species found in a variety of land forms across the study sites but grow well in the main wadi beds. The first three species are widespread in the arid regions of east Africa, Arabia, Pakistan and India. The last one is near-endemic but similar to Sudano-Zambezian (Wood, 1997). The species of this group considered as the dominant plant species of the vegetation associations of the main wadi beds.

II. Widespread species found over a variety of land forms throughout the study sites but only occasionally or absent from the main wadi beds



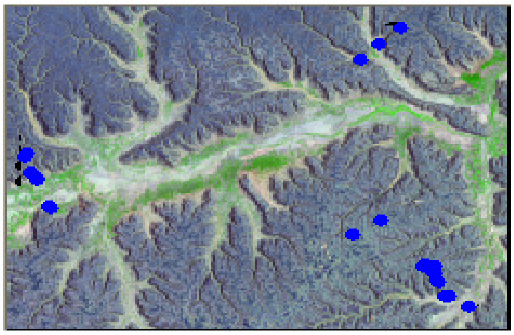
1- *Stipagrostis hirtigluma*

Abundant on the mountain slopes facing the main wadis, on the plateaus, as well as the slopes and narrow rocky secondary wadis of the plateaus (between 670 and 995 m asl). Rarely found in the main wadi beds where it is restricted to wide, very rocky hamada surfaces and to colluvial sites.



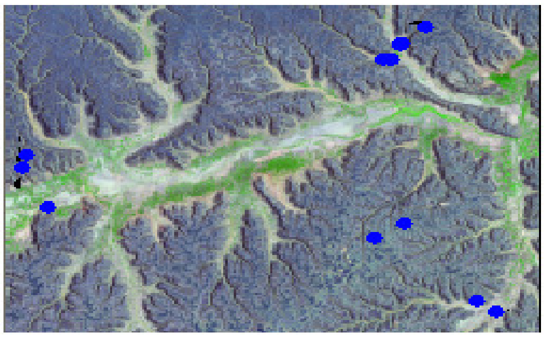
2- *Aristida triticoides*

A species of the stony mountain slopes facing the main wadis, of the plateaus, and drainage lines, as well as the slopes and narrow rocky secondary wadis of the plateaus (between 620 and 990 m asl). Rarely found on the main wadi beds where it is restricted to wide, very rocky hamada surfaces in site 1 and to wide rocky wadi beds near the bottom of the adjacent slopes at 620 m asl in site 3.



3- *Farsetia linearis*

Abundant on the stony mountain slopes facing the main wadis, on the plateaus, as well as the slopes and narrow rocky secondary wadis of the plateaus (between 680 and 980 m asl). It is not found in the main wadi beds

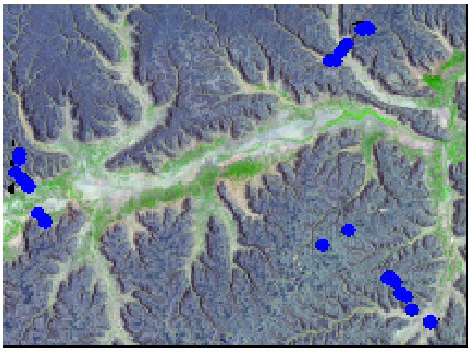


4- *Fagonia paulayana*

A species of the stony mountain slopes facing the main wadis, as well as on the slopes and narrow rocky secondary wadis of the plateaus. Not found in the main wadi beds.

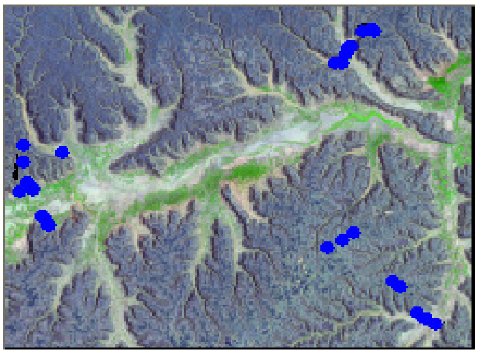
The species of this group are widespread across all the land forms of the 3 study sites, except the main wadis. They are mainly plants of the stony mountain slopes facing the main wadis, the plateaus, and the slopes and narrow rocky secondary wadis of the plateaus. They are rarely found in the main wadi beds. *Stipagrostis hirtigluma and Aristida triticoides* are widespread from Africa, Asia to India (Clayton et al., 2005)

III - Widespread species found on all land forms throughout the study sites.



1- *Dichanthium insculptum*

Widespread perennial grass, found between 600 995 m asl, in varied different landforms. It is not seen on cultivated or fallow lands and in less abundant in the wadi beds and grows well on the rocky and stony slopes. Where the floods are higher, it is found in less flooded tributary wadis and dry habitats such as rocky slopes and plateau.

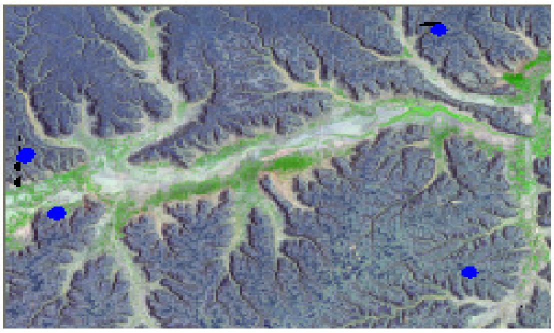


2- *Boerhavia elegans subsp. elegans*

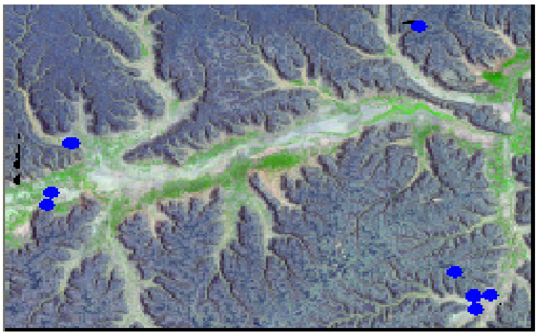
Widespread annual or perennial herb, found between 600 995 m asl, in varied different landforms. It is not seen on cultivated or fallow land and in less abundant in the wadi beds and grows well on the rocky and stony slopes.

The two species in this section are found on all the land forms throughout the study sites. They grow well on rocky and stony sites and are both important palatable plants which are sought out by livestock and collected by pastoralists during good seasons; as a result they are under some pressure and are sensitive to over-utilisation by pastoralists, *Dichanthium insculptum* is a widespread species in Africa, Yemen and Italy, while *Boerhavia elegans* is endemic to Arabia.

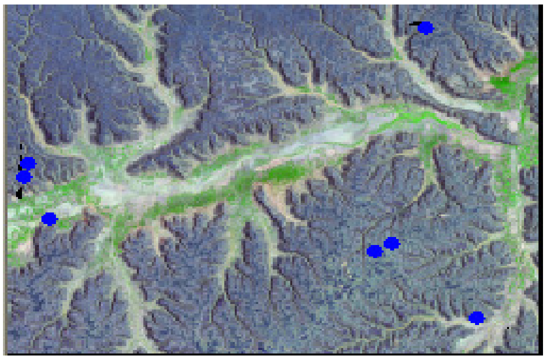
IV. Species which are not abundant, but which are found in almost all the study sites.



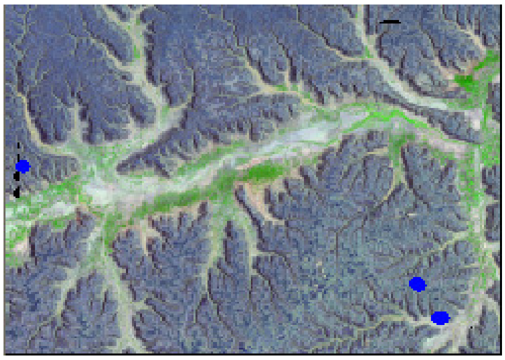
1- *Acacia hamulosa*
Species grows occasionally on the relatively moist wadi bed of site 1(between 685 and 750 m asl, and on the alluvial fans and drainage lines that cut the plateaus between 850 and 980 m asl.



2- *Acacia ehrenbergiana*
Occasionally found in moist sites along the wide flat sandy wadi beds and along river banks and on depressions near cultivated fields (between 625 and 750 m. Not often found on the plateau.

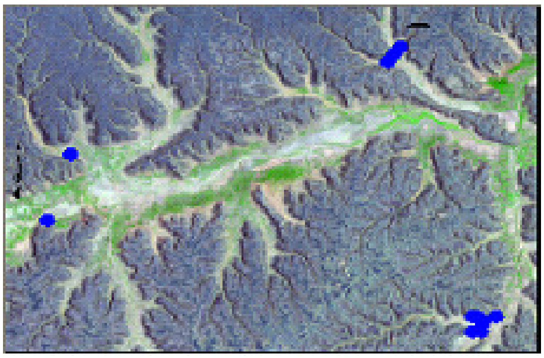


3- *Acacia mellifera*
This tree occasionally occurs on the moderately steep slope drainage lines and rocky dry steep slopes of the plateaus (between 950 and 960 m asl).



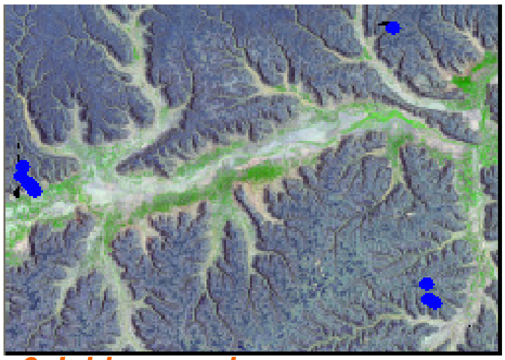
4- *Acacia oerfota*
A rare species occurring in the secondary wadis and on the rocky dry steep slopes of the plateaus of sites 1 and 2 (between 959 and 980 m asl).

There are 5 species of *Acacia* in the study area (*A. campoptila, A. ehrenbergiana, A. hamulosa, A. mellifera* and *A. oerfota*), 4 of them are also found in NE. tropical Africa one (*A. campoptila*) is endemic to Yemen. *Acacia tortilis* a drought-resistant species that occurs in the coastal area of Hadhramaut reaches its northern limit of distribution in the W. Daua'n (about 1000 m.). It is a plant of wadi beds, dry stony flat plains and depressions and dominates some communities in the coastal areas. *Acacia ehrenbergiana, A. hamulosa, A. mellifera* and *A. oerfota* occur across a range of land forms, but are not as common as A. *campoptila* (see section I) which is often abundant where it occurs. Acacia *oerfota* was not found in site 3.



5- *Rhazya stricta*

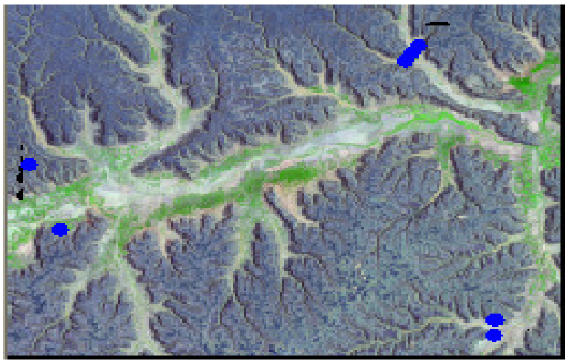
Occasionally found in wadi beds. it is restricted to remote wadi beds probably because it is collected for use in folk medicine by local people. This species is widespread and often abundant on sand dunes in the western part of the study area.



6- *Iphiona scabra*

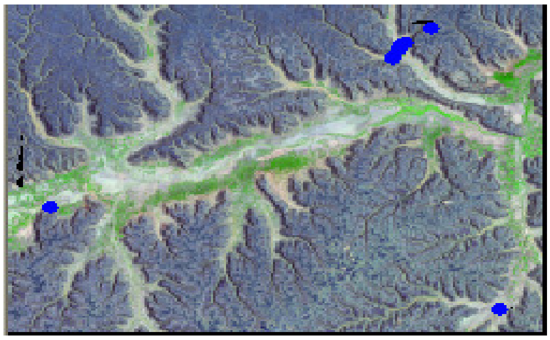
A species of the stony moderately steep, mountain slopes facing the main wadis, the plateaus, and in the narrow rocky secondary wadis of the plateaus (between 700 and 980 m asl). Rarely found on the slopes of the plateaus.

Rhazya stricta and *Iphiona scabra* are Saharo-Arabian species grow in hot desert areas from Egypt to Pakistan. The first is mainly grows in the main wadi beds and sand dune areas, while the second grows on the rocky surface of the plateau and secondary wadis in particular site 3.



7- *Ziziphus leucodermis*

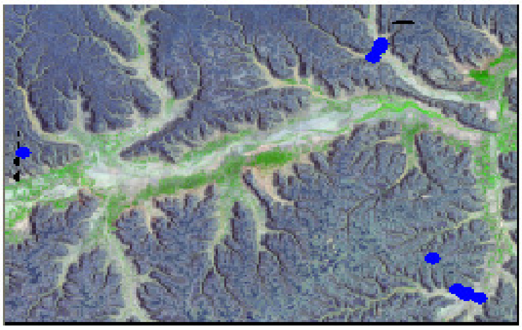
A rare near-endemic species occurring scattered on flat to undulating rocky wadi beds, river banks (between 550 m and 680 m asl), and occasionally in the drainage lines or narrow wadis that cut the plateaus.



8- *Merremia hadramautica*

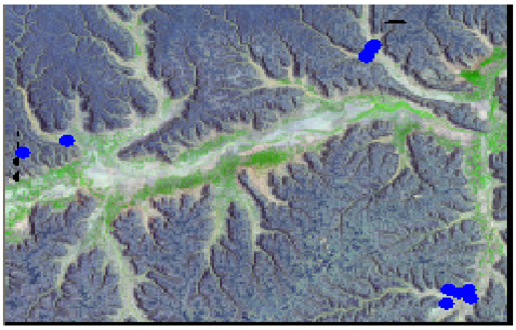
Abundant on the flooded wadi bed of site 3, and occasionally found near cultivated fields, fallow lands and disturbed wet sites between 550 and 675 m asl. In sites 1 and 2 it is restricted to relatively wet sites such as cultivated fields or fallow sites. It is very rare on the plateau, found only once in a secondary wadi of site 3 at an altitude of 915 m asl.

Ziziphus leucodermis and *Merremia hadramautica* are very palatable species and vulnerable to over-grazing, mainly found in the wadi beds. Where the grazing is less intensive such as site 3, they occur in high frequency. The first is near endemic. The second is endemic to Hadhramaut and adapted to rapidly colonise disturbed and flooded areas.



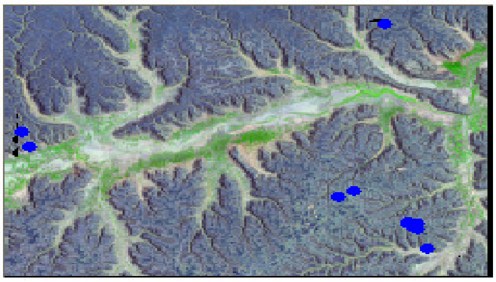
9- *Blepharis edulis*

Found on rocky wadi beds particularly in sites 2 and 3 (between 620 and 750 m asl). It is abundant on the flat rocky Hamada surfaces and colluvial sites. On the plateau it is restricted to SW-facing steep rocky slopes between 850 and 960 m asl.



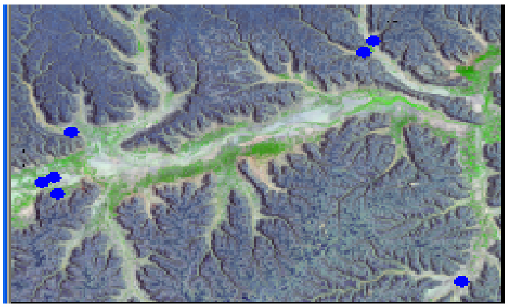
10- *Indigofera spinosa*

A species mainly of very rocky wide wadis (between 550 and 690 m asl), but which extends on to the adjacent rocky, moist slopes and on to the slopes of the plateau (over 700m above sea level).



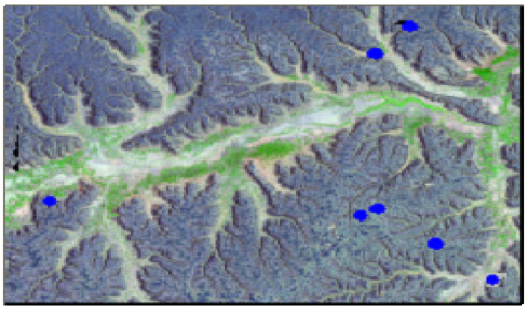
11- *Commiphora foliacea*

A species mainly of the rocky dry steep slopes of the plateaus at site 2 (between 900 and 965 m asl), but occasionally also found in secondary wadis and the adjacent slopes of the plateaus in sites 1 (between 975 and 979 m asl) and 3 (at 950 m asl).



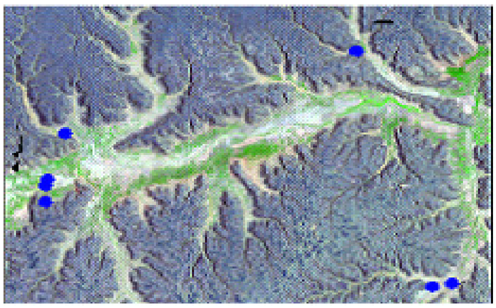
12- *Ziziphus spina-christi*

A species of fertile cultivated field margins (between 670 and 750 m asl. In particular in site 3.



13- *Maerua crassifolia*

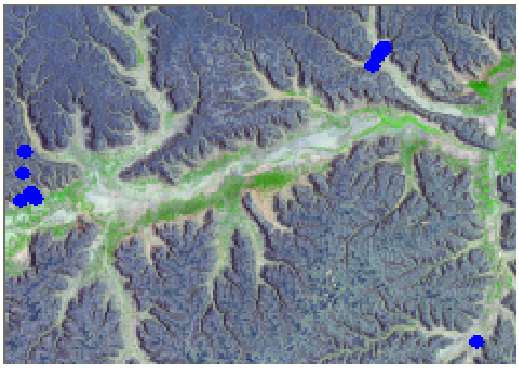
Restricted to rocky slopes on the plateaus in sites 2 and 3 (between 900 and 975 m asl). Occasionally found on the tributaries of the main wadis and adjacent to or on cultivated fields in sites 1 and 2.



14- *Dipterygium glaucum*

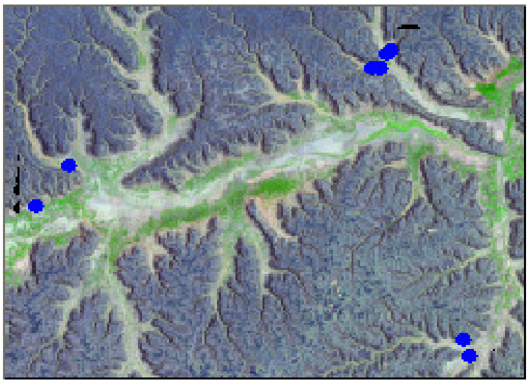
Most abundant on sandy and sand dune habitats between 645 and 750 m asl, but occasionally found in wet fallow lands and disturbed tributary wadi beds.

The species from 9 to 14 are African elements. *Blepharis edulis* and *Indigofera spinosa* are of very rocky areas, mainly in the main wadis and colluvial sites with high frequency in sites 2 and 3. *Commiphora foliacea* and *Maerua crassifolia* are mainly of the plateau with high frequency in site 2. Ziziphus spina-christi is mainly of agriculture fields, found with high frequency in site 3.*Dipterygium glaucum* prefer the sand dune and fallow lands.



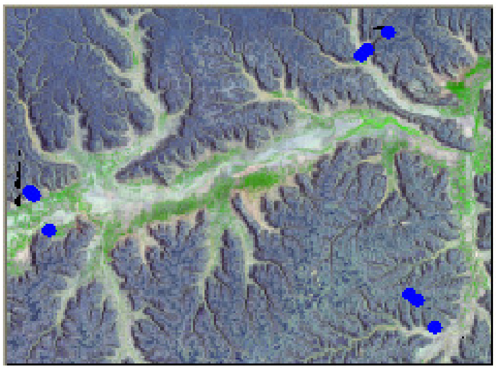
15- Cleome brachycarpa

A species with wide broad distribution, particularly in the northern part of the study area (between 615 and 995 m asl). It mainly occurs on the rocky mountain slopes facing the main wadis of sites 1 and 3, it is also occasionally found in wadi beds, in particular in site 3 and on disturbed sites on the plateau in site 1. It is very rare in site 2.



16- Cleome scaposa

Found on almost all flat moist wadi beds (between 600 and 700 m asl). Where annual rainfall is less than 50 mm, for instance in site 3, it is restricted to the relatively moist very rocky mountain slopes.

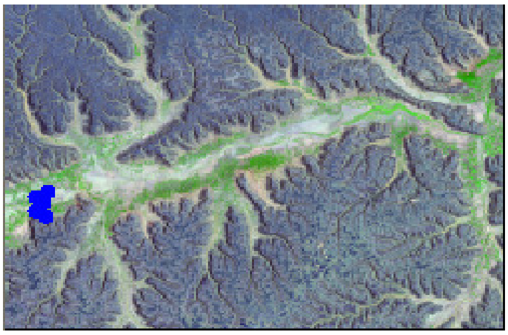


17- Cleome droserifolia

a species of the stony, moderately steep, mountain slopes facing the main wadis, the plateaus, and of the narrow rocky secondary wadis and alluvial fans of the plateaus (between 620 and 970 m asl). Rarely found in the main wadis.

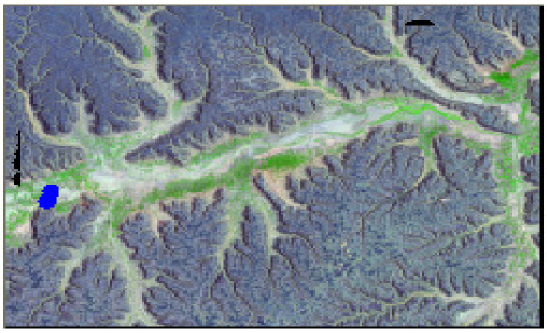
The 3 Cleome species are African elements grow on the arid and semi-arid areas from North Africa to Pakistan. They grow in high frequency in site 3 and prefer the rocky mountain slopes facing the main wadis.

V. Species found only in site 1



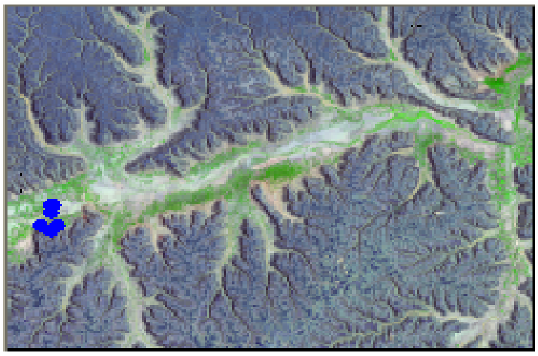
1- *Prosopis farcta*

A perennial shrub which is often dominant near cultivated fields and fallow lands at altitudes between 680 to 750 m asl in the western part of the study area.



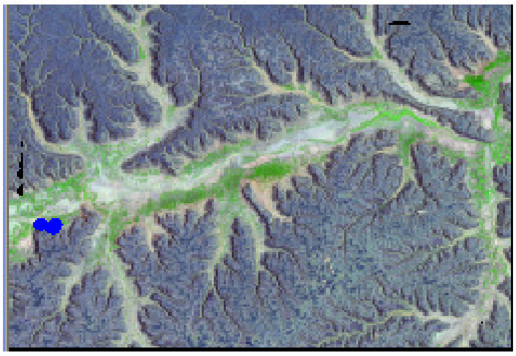
2- *Alhagi graecorum*

A perennial dwarf shrub which is often dominant near cultivated lands, waste, moist sites and fallow lands at altitudes between 675 and 750.



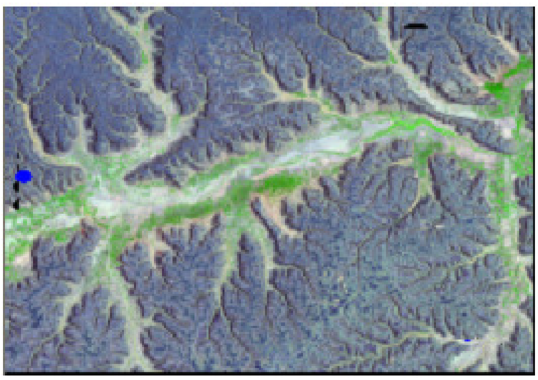
3- *Zygophyllum album*

A halophytic succulent herb found mainly in the western part of the study area. It grows mostly on sandy, flood plains at altitudes below 700 m, but is occasionally found in tributary wadis of site 1, in particular at the bottom of mountain slopes.



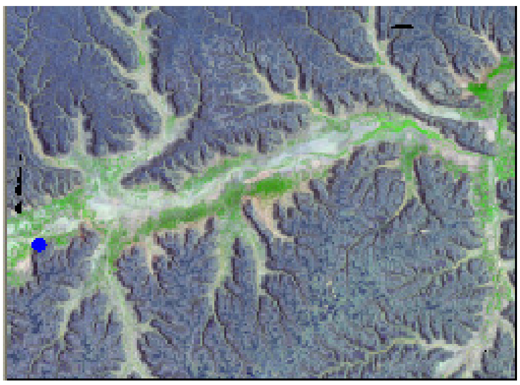
4- *Zygophyllum coccineum*

A species of slightly sloping but very rocky wadi beds in site 1, at altitudes between 700 and 740 m asl. It also extends on to north- and southwest-facing mountain slopes, between 667 and 690 m asl.



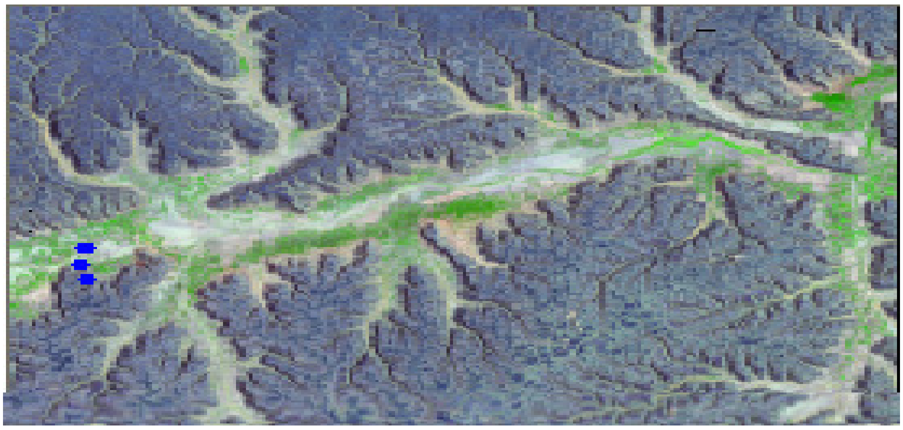
5- *Moltkiopsis ciliata*

A very rare species occurring on the shallow drainage lines that cut the plateau in site 1 (between 970-980 m asl).



6- *Iphiona anthemidifolia*

A very rare species found only once on rocky wadi beds at 750 m asl in site 1.

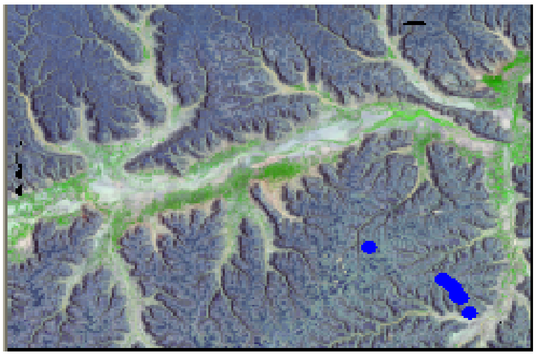


7- Prosopis juliflora

A fast-growing invasive tree. So far not found in sites 2 or 3. However, in many places the vegetation of the main wadi beds has been transformed into *Prosopis juliflora* woodland beneath which nothing else grows. It is spreading along the main wadis and represents a serious threat to the natural vegetation of the wadis.

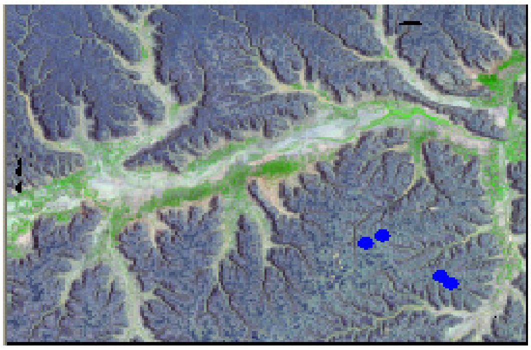
The species of this group are restricted to site 1. They are occasionally dominant or co-dominant in some plant association. Perhaps the most interesting species in this group is Zygophyllum album, which grows under the most desertic conditions further west. It forms a shrubland community with Prosopis juliflora, which is spreading further east and invading large areas of the main Wadi Hadhramaut. Some of these species are weeds of cultivated lands and others are very rare being found in only one location. *Alhagi graecorum* and *Prosopis farcta* are Irano-Turanian species probably they have been migrated from their origin areas in the past to study area and adapted to the arid with annual rainfall less than 40 mm that characterised site 1.

VI. Species occurring only in site 2



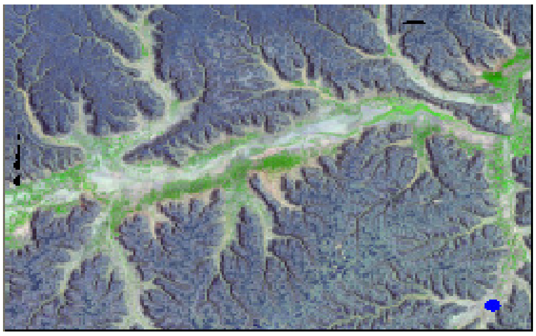
1- Zygophyllum decumbens

A species mainly occurring on rocky, dry steep slopes on the plateaus (between 900 and 975 m asl). Also seen once in a moist secondary wadi on the plateau.



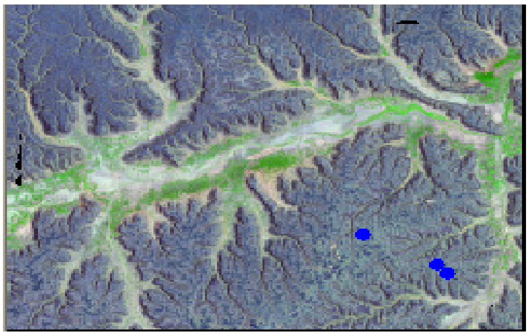
2- Hochstetteri schimperi

Restricted to dry rocky slopes on the plateaus (between 900 and 975 m asl).



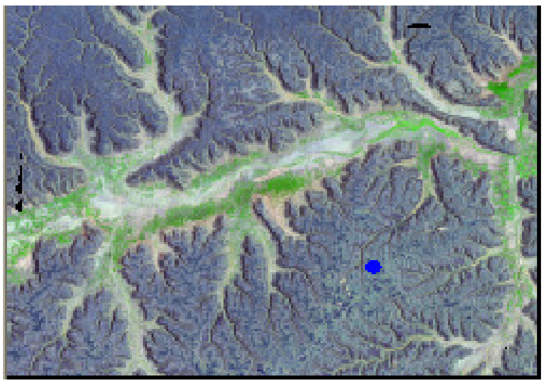
3- Cadaba farinosa

A very rare species found at the foot of a mountain slope in a tributary wadi (at 692m asl).



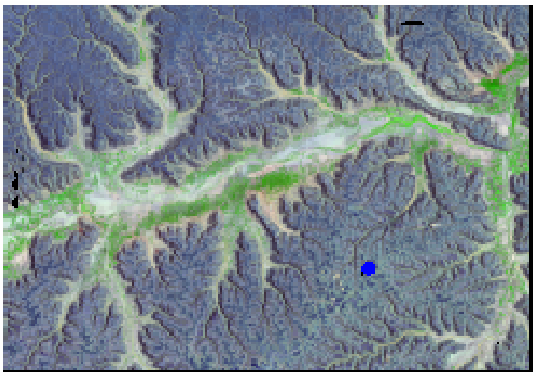
4- Grewia erythraea

A rare species restricted to moist rocky slopes on the plateaus (between 950 and 960 m asl).



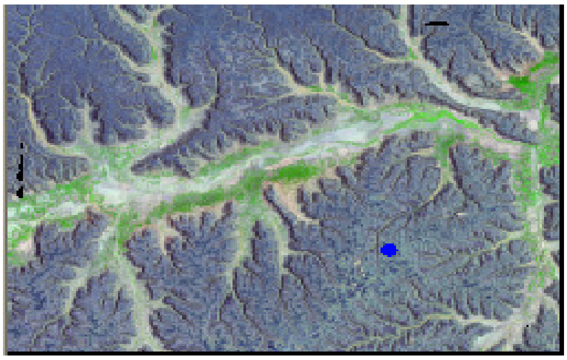
5- Chascanum marrubifolium,

Very rare species, only found on northeast-facing, relatively wet rocky slopes on the plateaus (at 950 m asl).



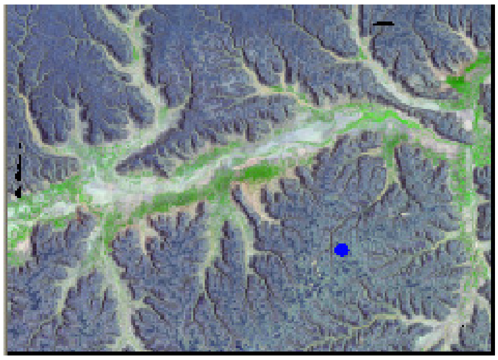
6- Euphorbia rubriseminalis

A very rare species, only found on northeast facing relatively wet secondary wadi of the plateaus (at 920 m asl).



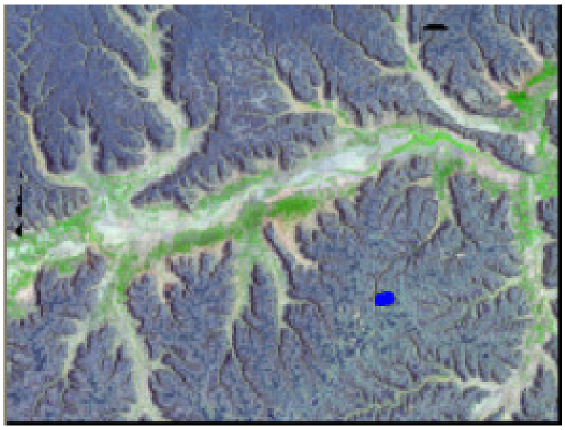
7- Tarenna graveolens

Very rare species, only found on northeast-facing, relatively wet rocky slopes on the plateaus (at 950 m asl).



8- Cadaba heterotricha

Very rare species, only found on northeast-facing, relatively wet rocky slopes on the plateaus (at 950 m asl).

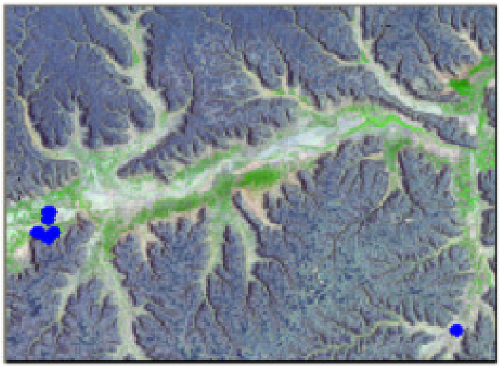


9- Arnebia hispidissima

A rare species, only found in site 2 on northeast facing, relatively wet rocky slopes on the plateaus (at 950 m asl) and in an adjacent secondary wadi (at 920 m).

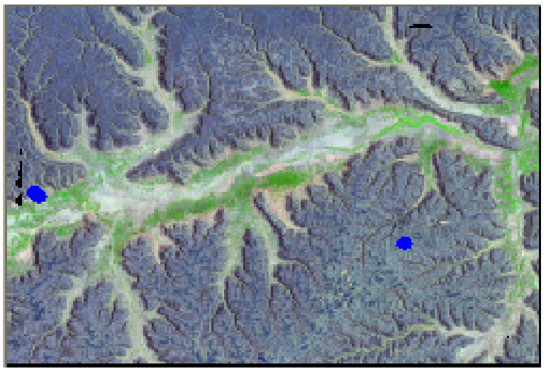
Most of the species confined to site 2 are of palaeotropical affinity, for example *Tarenna graveolens* is found in Kenya, Tanzania, Uganda and *Cadaba heterotricha* in Ethiopia , Kenya , Pakistan , Somalia, Oman (Apioi and Wronski, 2005). The exception is *Chascanum marrubifolium*, which is found in Saudi Arabia and India (Atiqur Rahman , et al., 2002; Al-Turki, 2004).

VII. Species found in sites 1and 2



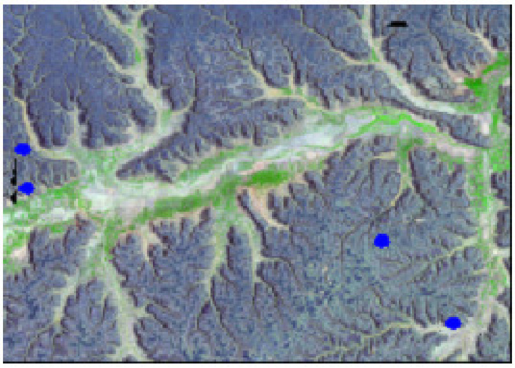
1- *Citrullus colocynthis*

A species of the flood plains and sandy wadi beds between 670-700 m asl, mainly in site 1. Also occurs on fallow lands and cultivated fields.



2- *Cometes abyssinica*

A rare species preferring moist sites on very rocky alluvial fans and the moister slopes as well as eroded surface sites on the plateaus in sites 1 and 2 (between 690 and 950 m asl).

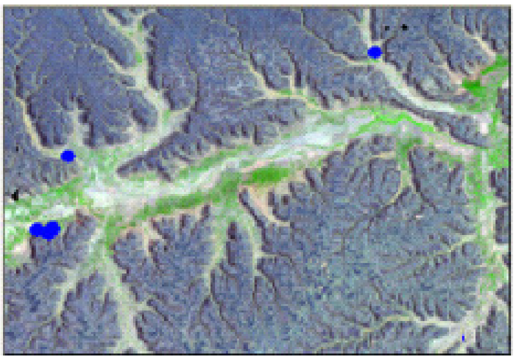


3- *Seetzenia lanata*

A rare species found only in moist sites such as on eroded surfaces on the plateaus and the very rocky slopes of the plateaus in sites 1 and 2 (between 950 and 990 m asl).

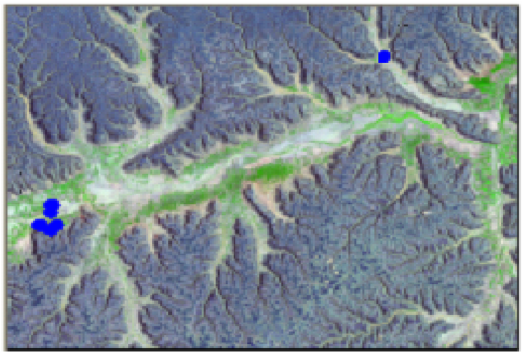
The species of this group are rare. The first species prefer the sand dune and fallow lands. The last 2 species prefer the disturbed rocky wet sites. Generally they occur in high frequency in site 1 and in low frequency in site 2.

VIII. Species of sites 1 and 3



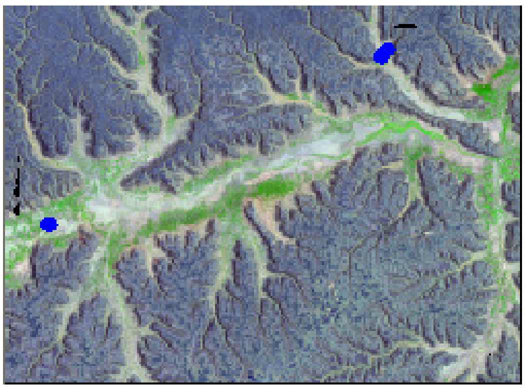
1- *Tephrosia dura*

A species of slightly sloping, very rocky tributary wadi beds, at altitudes between 655 and 750 m asl. Outside Arabia, this species is only found in Somalia .



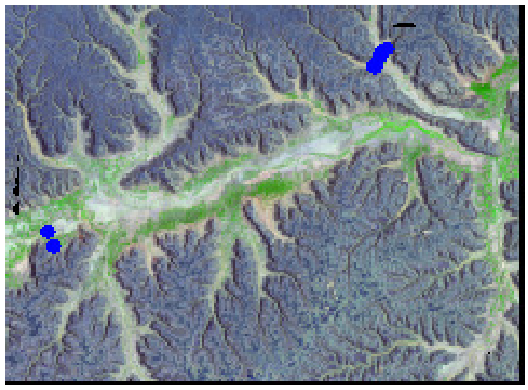
2- *Heliotropium rariflorum*

A species of flood plains and sandy wadi beds (between 655-700 m asl).



3- *Panicum turgidum*

A species of flood plains and sandy and rocky wadi beds. The distribution of this plant is limited to the north western part of the study area where the annual rainfall is less than 50 mm at altitude between 620 and 680 m asl.

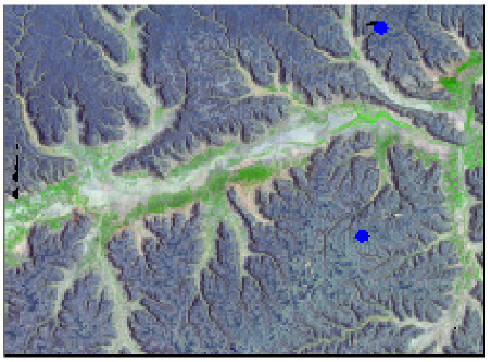


4- *Tephrosia nubica*

Abundant in the wadi beds of site 3 (between 550 and 670m asl) and occasionally in the tributary rocky wadi beds of site 1 at 690 m asl. It is palatable species and vulnerable to over-grazing.

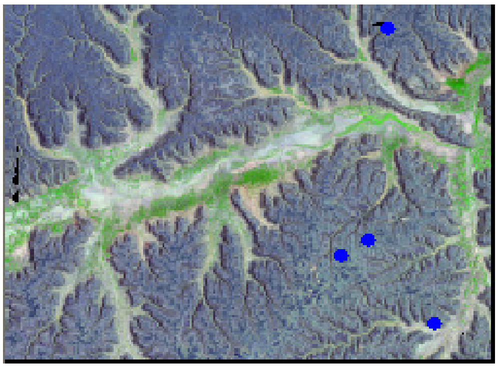
The species of this group which are confined to the northern plateaus and represent the Saharo elements. The low cover and the absence of some of these species from site 2, can be due to human activities. Panicum turgidum and Tephrosia nubica are palatable species and vulnerable to over-grazing. Tephrosia dura is Hadhramaut-Somalia connection and was also recorded as one single species by DOVE (2001) from colluvial fan of tributary wadi in site 2.

IX. Species of sites 2 and 3



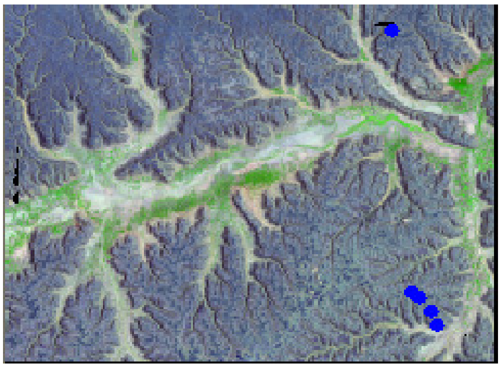
1- *Anticharis glandulosa*

A rare species found on moister sites on the moderately rocky slopes of the plateaus, between 850 and 955 m asl.



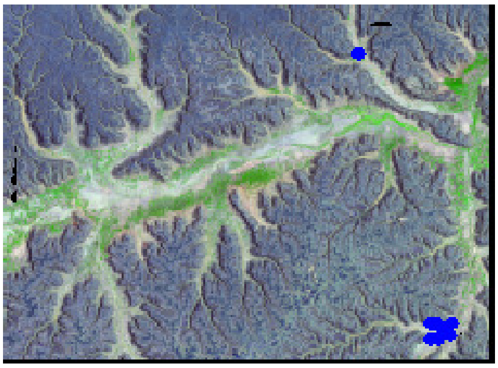
2- *Corallocarpus glomeruliflorus*

A rare species of the moderately steep slopes of secondary wadis and the rocky, dry, steep slopes of the plateaus (between 900 and 980 m asl).



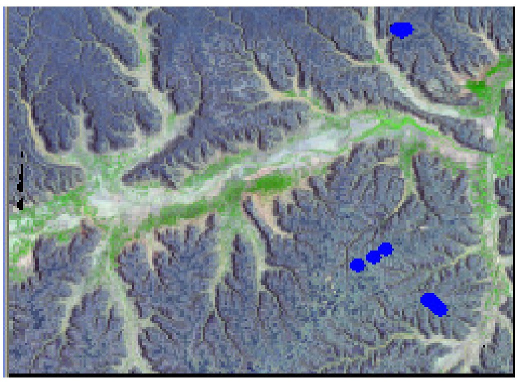
3- *Chrysopogon aucheri*

Restricted to the secondary rocky wadis of the plateau (between 855 and 950 m asl).



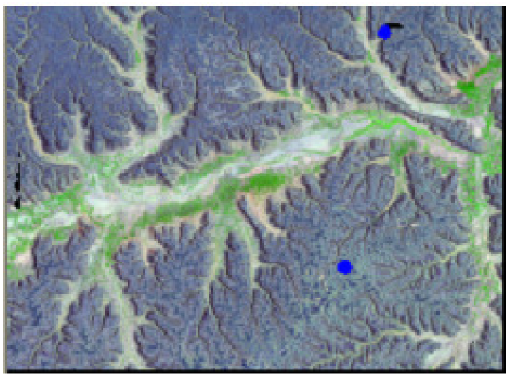
4- *Ochradenus baccatus*

Occasionally found in wadi beds, in particular along wadi sides between 620 and 690 m asl.



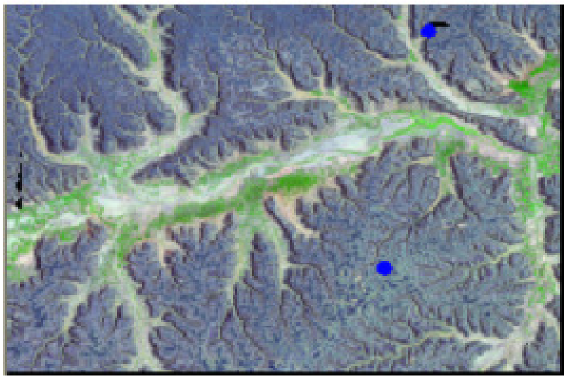
5- *Jatropha spinosa*

Restricted to the dry rocky slopes of the plateau (between 900 and 975 m asl).



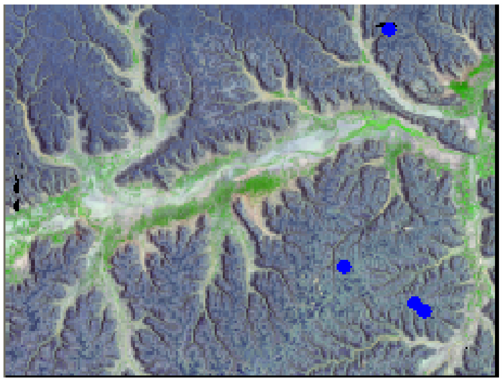
6- *Cornulaca amblyacantha*

A species mainly of the upper rocky slopes of the plateau in site 3. In site 2, it is restricted to relatively wet secondary wadis (between 900 and 955 m asl).



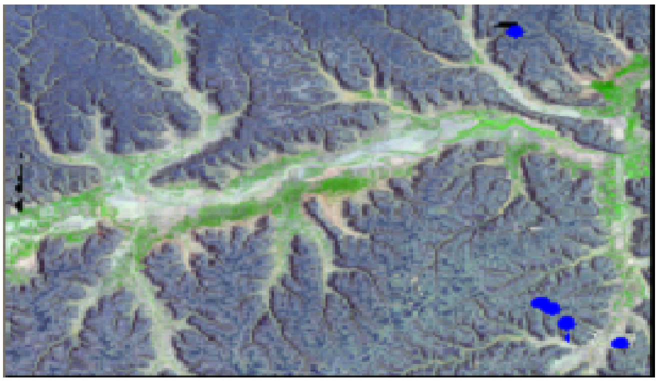
7- *Aerva artemisioides* subsp. *artemisioides*

A very rare endemic species found only on rocky surfaces on the plateau (between 850 and 950 m asl).



8- *Commiphora kua*

Restricted to rocky slopes on the plateaus in sites 2 and 3 (between 850 and 975 m asl).



9- *Cyperus conglomeratus*

Mainly found in secondary wadis on the plateau in site 2 (between 855 and 950 m asl)), but also occasionally seen on the slopes facing the main wadi, at 703 m asl (site 2) and on the rocky surface of the plateau at 903 m asl (site 3).

The species of this group are mixture of Saharo and Sudanian elements. Mainly found in site 2 but are penetrated the main wadi Hadhramaut and dispersed to the northern plateau of site 3.

6.3.5. The distribution of endemic, near-endemic and rare plant species in the Hadhramaut region

Using the coordinates of each plant species and GIS desktop software such as DIVA-GIS and Arc View, it was possible to plot the distribution of the endemic, near-endemic and rare species of Hadhramaut region.

The results indicate that the most important areas for endemics in the Hadhramaut region lie in the mountain areas above al Mukalla (see chapter 3 and Figure 6. 14a).

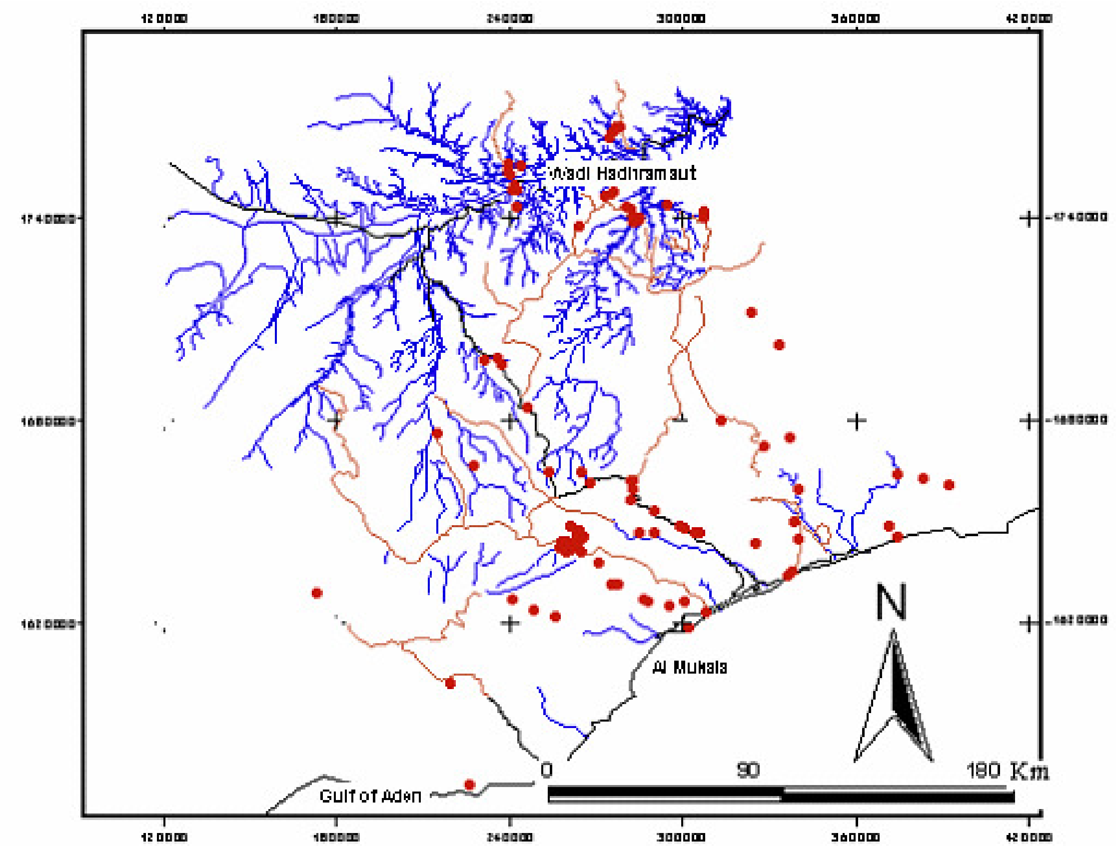
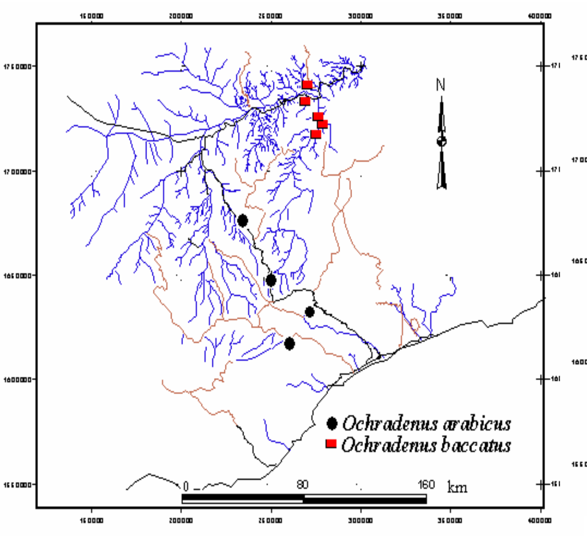
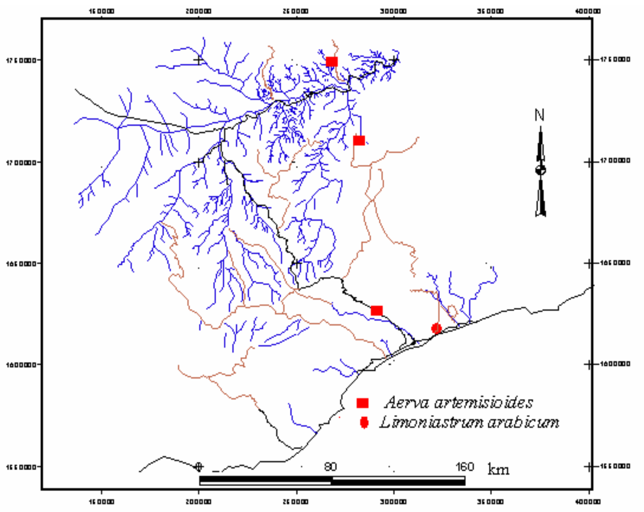


Figure 6.14a The distribution of endemic, near-endemic and rare species in Hadhramaut region, including the 3 study sites.

Figure 6.14a shows that from the reconnaissance surveys and detailed survey from the study sites, there is a concentration of species in the southern foothills and south- and southeast-facing slopes of the mountains of Hadhramaut region.

A selection of 25 rare, near-endemic or endemic species is mapped in the following figures. These maps illustrate common patterns of distribution. It is intended that these maps will provide an important tool for future plant biodiversity management.





1- Ochradenus arabicus and Ochradenus baccatus show interesting patterns of distribution. The first species is distributed from the coastal mountains and extends to altitudes of about 1200m in the north; the second species has a limited distribution from the eastern part of W. Hadhramaut towards the north. O*chradenus arabicus* is a near-endemic only known from Oman, central and south Saudi Arabia, the United Arab Emirate and Yemen (Figure 6.14b). Whereas *O. baccatus* is a widely distributed Saharo-Sindian region. There are other endemic *Ochradenus (O. spartioides)* to Hadhramaut, it is found on the southern summit above al Mukala (see Figure 6.14a)

2- Limoniastrum arabicum and Aerva artemisioides are species endemic to the Hadhramaut region, the first is restricted to the coastal area of Hadhramaut, and the latter is distributed from the southern mountain slopes to the plateau surface of the study sites 1 and 3.

The main factors affecting the distributions of former 4 species (1 & 2) appears to be climate and topography. *Ochradenus baccatus* is found in the northern part of the Hadhramaut region (the study area), which is characterised by dry hot temperatures with spring and summer rainfall, while *Ochradenus arabicus* is found in the southern part of the Hadhramaut region which is characterised by spring and winter rainfall and subject to frequent fogs. Outside the region *Ochradenus baccatus* is widely distributed and has a typical Saharo-Sindian distribution (Miller, 1984) being found in the deserts of eastern north Africa, Somalia, Sudan, Egypt, the Gulf countries, Iran and Pakistan (Miller, 1984), The species was seen flowering in spring and winter. In the deserts of SW Asia with winter rainfall, the flowering period is associated with the winter rains (Wolf and Burns, 2001; Zohary and Orshan, 1956).

The near-endemic species *Ochradenus arabicus* is a spiny perennial shrub, found in Oman, Saudi Arabia and UAE, the distribution patterns of this species is associated with fog-affected areas. There are several local endemics of *Ochradenus* in southern Arabia including *O. spartioides* endemic to Hadhramaut, *O. aucheri* subsp. aucheri from UAE and Oman, *O. harsusiticus* and *O. gifrii* from Oman (Ghazanfar, 2004; Miller, 1984) and al Mahara, Yemen (Thulin, et al., 2001) (see Figure 6.14a).

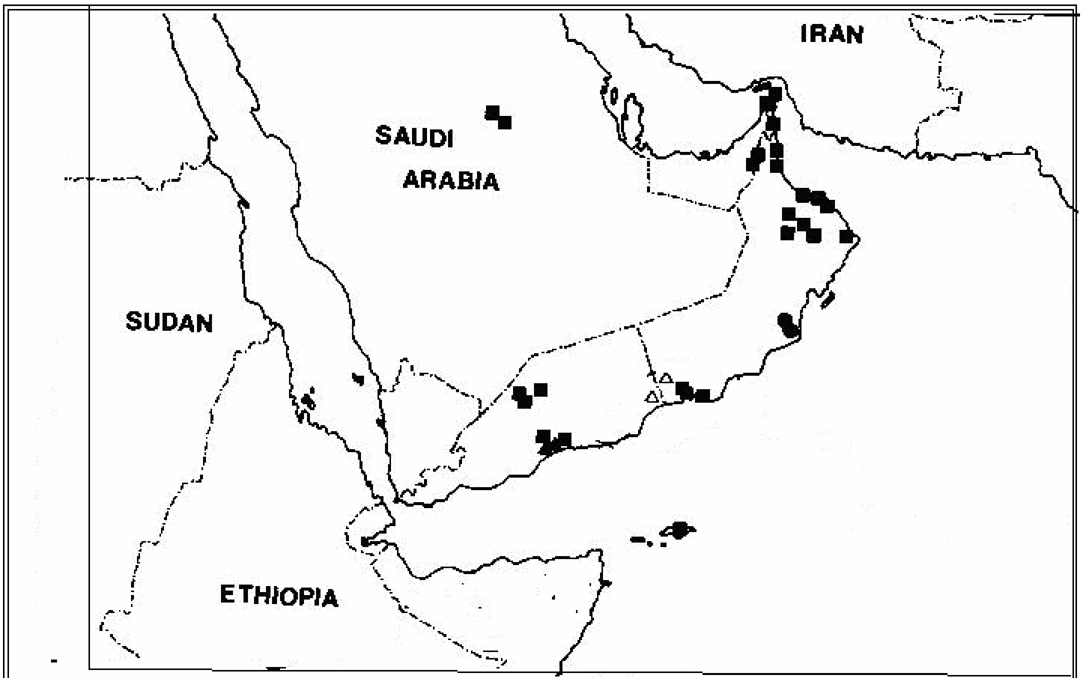
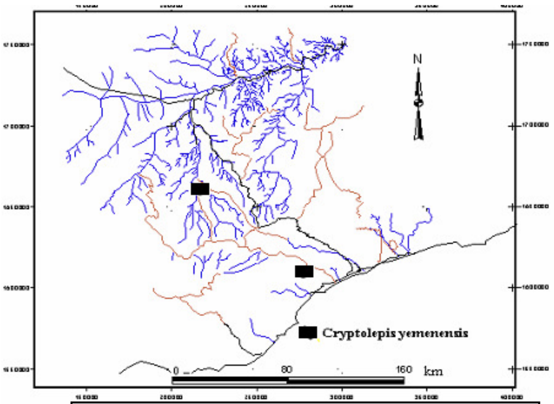


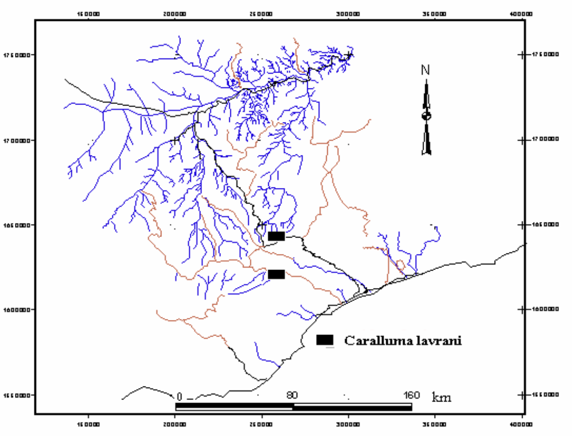
Figure 6.14b. O. arabicus ■ ; O. harsusiticus ● ; O. spartioides ▲ ; O. gifrii △
After Miller, 1984

Figure 6.14b. The distribution of 4 species of Ochradenus in Arabian Peninsula. (After Miller, 1984).

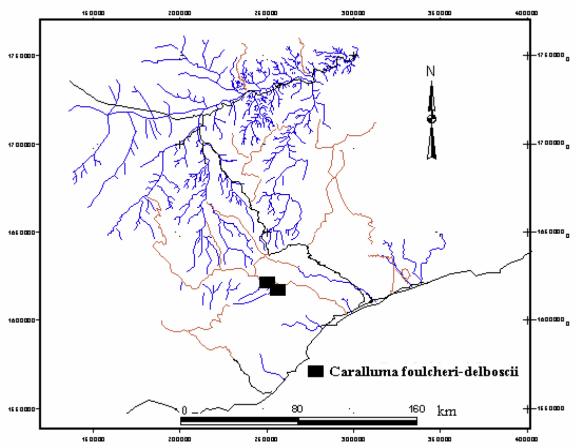
Limoniastrum arabicum is an endemic species to Hadhramaut which grows only on sandy plains near the coast. *Aerva artemisioides* subsp *artemisioides* has wide range distribution, but with very low frequency. For example in the study area it was only found in 2 locations. There are 2 sub species of *Aerva artemisioides*: subsp. *artemisioides*, which is endemic to Hadhramaut and subsp. *batharitica*, which is endemic to central Oman.



3- Cryptolepis yemenensis

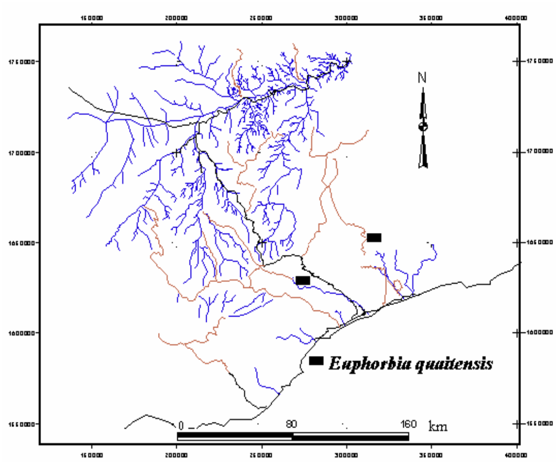


5- Caralluma lavrani

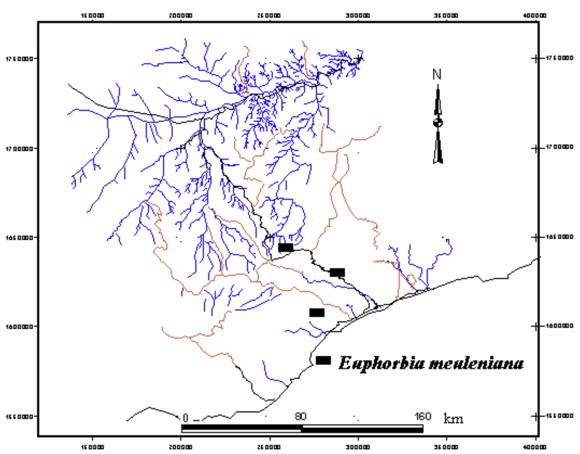


4- Caralluma foulcheri-delboscii var. greenbergiana

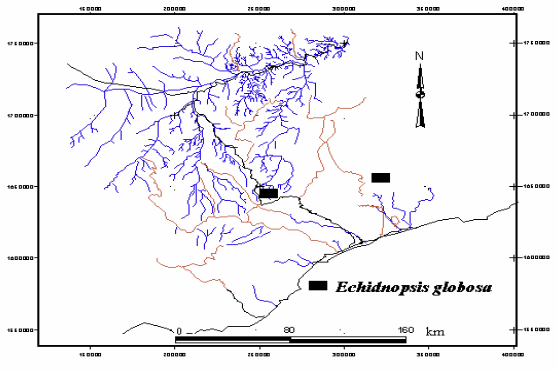
Cryptolepis yemenensis, Caralluma foulcheri-delboscii var. greenbergiana and *Caralluma lavrani* are endemic species to Yemen. They are common on mist-affected southern mountain summits of Yemen, the first extends farther north to W. Dawa'n (1100m). *Cryptolepis yemenensis* is a new endemic species to Yemen ((Venter and Verhoeven, 1999).



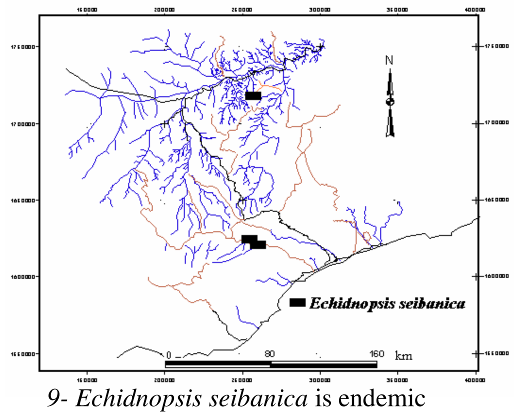
6- *Euphorbia quaitensis* is endemic to the Hadhramaut region, found only on the summits of the southern plateau.



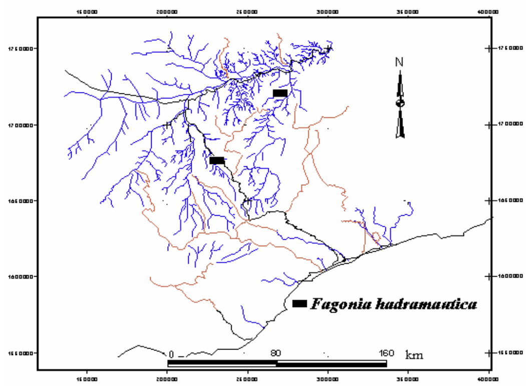
7- *Euphorbia meuleniana* is endemic to the Hadhramaut region, found only on the summits of the southern plateau (between 600 and 850 m asl)



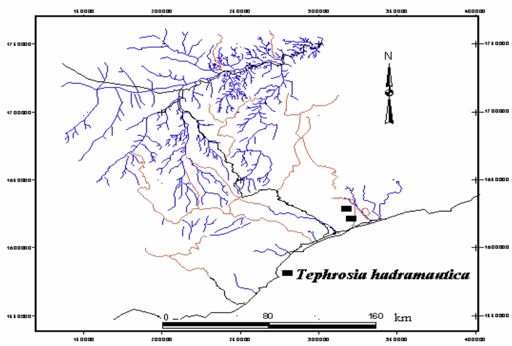
8- Echidnopsis globosa is endemic to the Hadhramaut region (Thulin & Hjertson, 1995) and Al Mahara (Kilian et al., 2002)



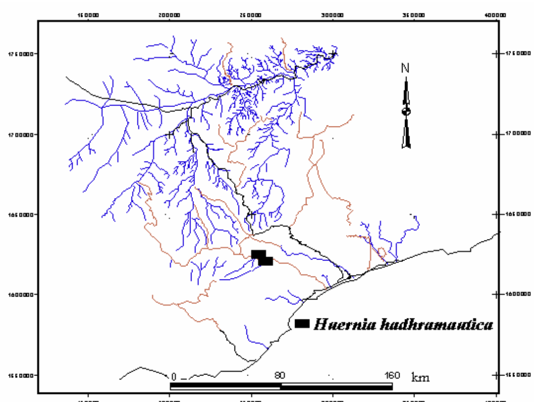
9- Echidnopsis seibanica is endemic species to Hadhramaut region, It is found on the southern summits and further north.



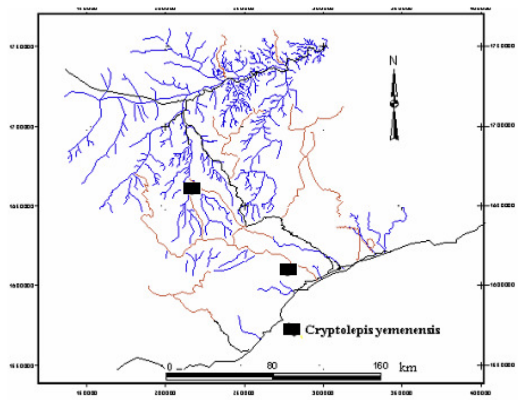
10- Fagonia hadramautica is endemic to the Hadhramaut region; it is found on the northern plateau (between 90 and 1100 m asl)



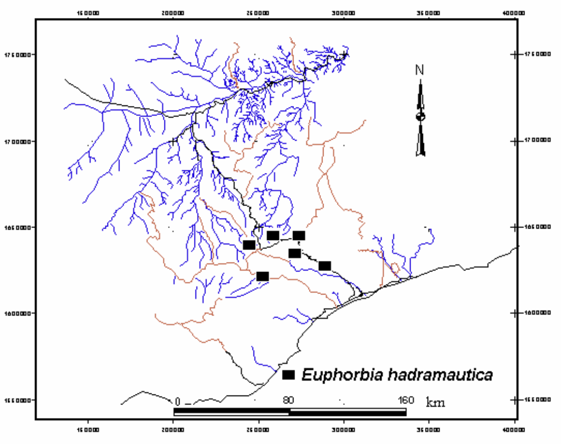
11- Tephrosia hadramautica is endemic to the Hadhramaut region; it is found on the southern hill slopes near to the coast.



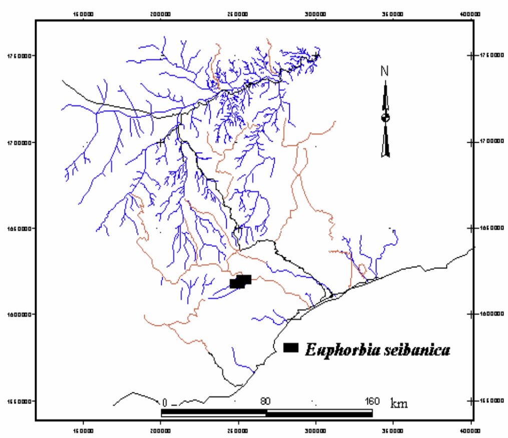
12- Huernia hadhramautica is endemic to the Hadhramaut region and is found on the summits above al Mukala.



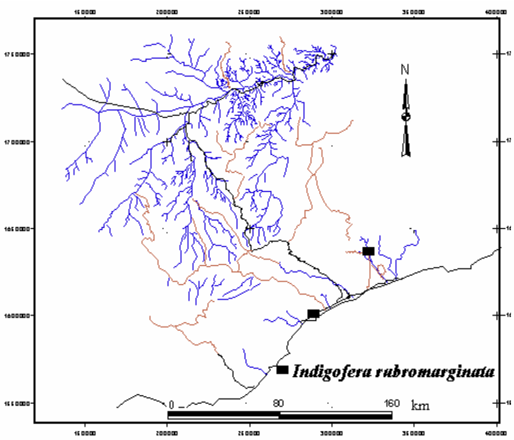
13- Cryptolepis yemenensis is endemic to the Hadhramaut, (Venter and Verhoeven, 1999).



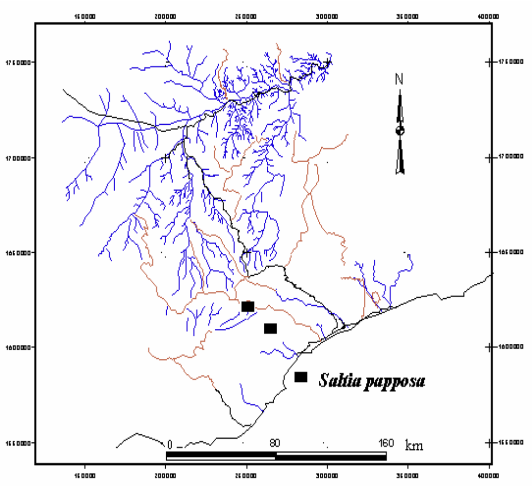
14- *Euphorbia hadramautica* is a near-endemic, found on the southern summit of the plateau (between 1300 and 1500 m asl)



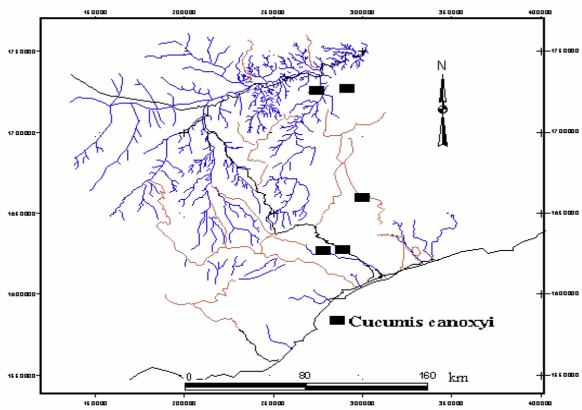
15- *Euphorbia seibanica* is endemic to the Hadhramaut region and is, found on the southern summit above Al Mukala.



16- *Indigofera rubromarginata* is a near-endemic found in the coastal plain and on the summit above al Rayan and coastal areas of Oman.



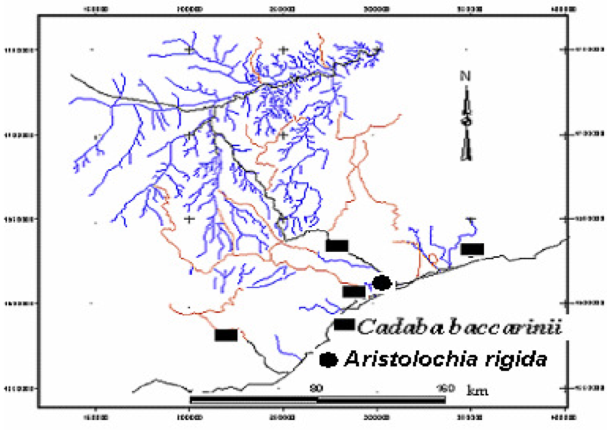
17- Saltia papposa is endemic to Yemen found and is found on the southern summit above al Rayan. Whidespread on the western coastal area of Yemen.



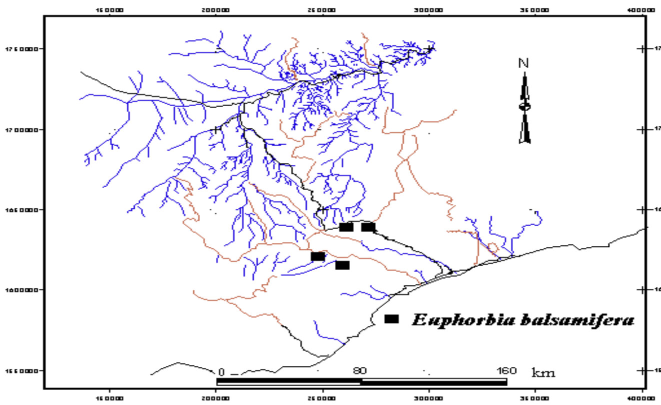
18- Cucumis canoxyi is endemic to Hadhramaut. It has a wide distribution from the southern mountains at 615 m asl to study site 2 at 950 m asl.

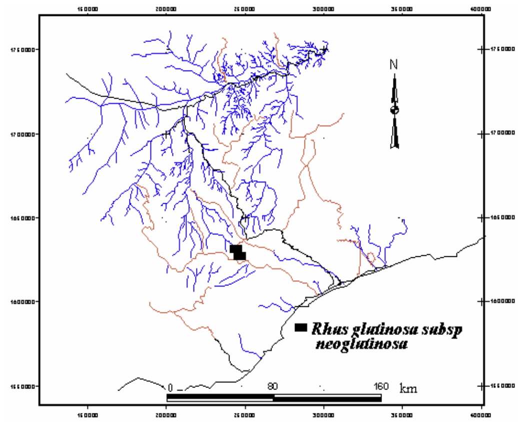
19- Cadaba baccarinii is a shrub or small tree found only in Yemen, Oman and Somalia (Miller & Cope, 1996; Barkhadle et al., 1994). This species is restricted to the southern rocky mountain slopes (between 400 and 600 m asl) of Hadhramaut region.

There are also some species that, outside Arabia are only found in Somalia; for example *Aristolochia rigida and Tephrosia dura.* The first was reported from Oman by (Nadaf, et al., 2004).

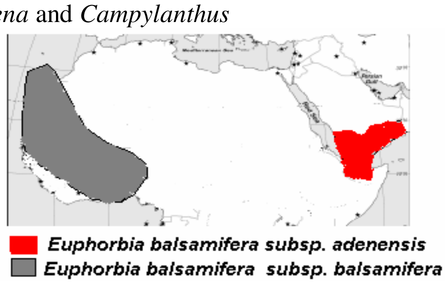


19- *Cadaba baccarinii* and *Aristolochia rigida*



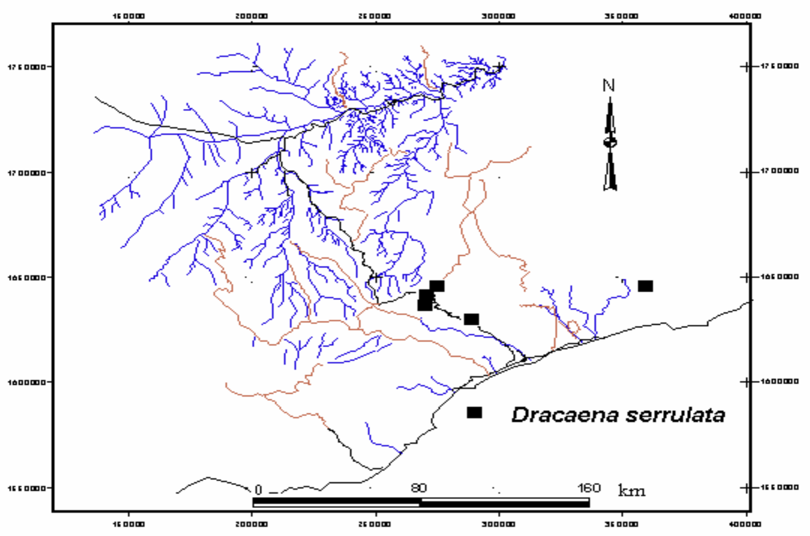


20- Euphorbia balsamifera is a plant of fog-affected areas. It grows only on rolling limestone plateau summits between 1300 and 1600 m asl. There are 2 sub species: subsp *adenensi* which occurs in tropical NW Africa and SW Arabia and subsp *balsamifera* which occurs in NW Africa and Macaronesian. There are several examples of taxa which show this "Tethyan" pattern of distribution; for instance species in the genera *Dracaena* and *Campylanthus*



Euphorbia balsamifera with an African/Arabian-Macaronesian distribution (after Ghazanfar and Fisher, 1998)

21- Rhus glutinosa subsp neoglutinosa is a near-endemic found at Kor Seiban on the southern sumit above al Mukala (between 1850 and 200 m asl). It was considered as endemic to Ethiopia (Kilian et al., 2002), but found in the Hadhramaut making it an outstanding refugium of a palaeo-African flora in the region.



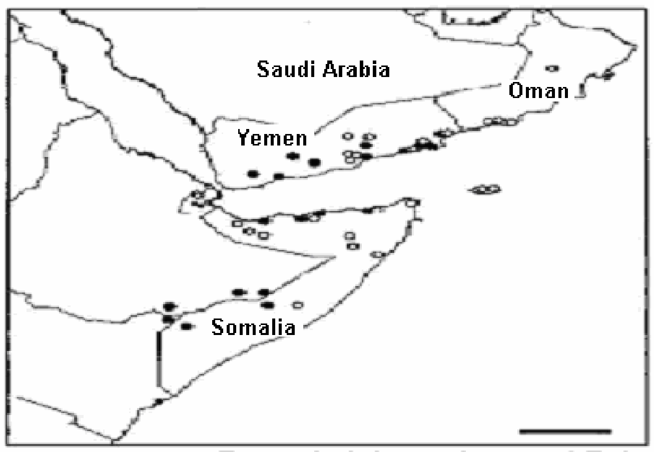
22- *Dracaena serrulata* (syn *D. ombet*) is a very rare tree, found on rocky slopes above narrow wadis on the plateau (between 750 and 1400 m asl). A slow-growing species of steep cliffs and mountain plateaus in different parts of Yemen – apparently usually restricted to fog-affected areas. *D. serrulata* is found in Djibouti, Egypt, Ethiopia, Saudi Arabia, Somalia, Sudan and Oman. It is considered as in endangered species in the 2003 IUCN Red List of Threatened Species (Abuzinada, 2001). This plant is becoming rare or endangered over most of its range. The populations of this species on the Red Sea Hills and Jebel Elba in Sudan and Egypt are particularly threatened. Other smaller populations have been discovered in recent years in southeastern Egypt near the Sudanese border at Gebel Shindeeb, and it may also occur on Gebel Shinodai (El Azzouni 2003). In northern Sudan it appears that the populations of *D. ombet* (= *D. serrulata*) have completely vanished (El Azzouni 2003). In Hadramaut it also is rare with scattered individuals found mainly in inaccessible areas with little sign of regeneration. It is clearly endangered. It is likely that it was once was a widespread tree on the fog-affected slopes of the Hadhramaut mountains – it is now threatened by over-grazing preventing regeneration, harvesting of the leaves for rope and possibly by a gradual drying out of the region (see notes on *Dracaena cinnabari* in the Ethnoflora of the Soqotra Archipelago, Miller and Miranda, 2004). Another related species of *Dracaena* is *Dracaena draco* in the Canary Islands and *Dracaena draco* subsp. *ajgal*, in the Anezi region of the Anti-Atlas Mts. in western Morocco (IUCN, 2004). So the Dracaena spp may now only exist as scattered relict population.

The distribution of plant species across the study sites is infected by the considerable variation of climatic and ecological factors (e.g. edaphic) moisture and topography) across the region. Generally, there are many factors other than climate that play as an important part in determining species distributions and the dynamics of distribution changes. Such factors include biotic interactions, evolutionary change and dispersal ability (Pearson and Dawson, 2003). Floristically, a few species are confined to particular habitats, such as those species restricted to the main wadis and not found on the plateaus, for example, *Rhazya stricta, Alhagi graecorum, Panicum turgidum, Zygophyllum album, Dipterygium glaucum, Acacia ehrenbergiana, Phoenix dactylifera, Capparis spinosa, Salvadora persica, Balanites aegyptiaca, Cassia italica, Forskohlea tenacissima, Ochradenus baccatus, Tamarix aphylla, Cadaba farinosa, Withania somnifera, Ziziphus spina-christi Tephrosia dura* and *Tribulus arabicus.* Most of these species represent Saharo-Sindian floristic elements (Zohary, 1973). Important African elements in the main wadis are: *Blepharis edulis, Calotropis procera, Cenchrus ciliaris* and *Dichanthium insculptum.*

Most dominant species of the study sites, in particular the plateau complex zone, are grasses, notably *Dichanthium insculptum* and *Stipagrostis hirtigluma*. These two grasses are important palatable grasses of arid and semi-arid areas. Plant species, which germinate quickly and uncommon or short-lived species that are selectively grazed or collected by local people during very good seasons are more likely to decline, example, being *Boerhavia elegans, Corallocarpus glomeruliflorus, Lasiurus scindicus, Commiphora kua, Commiphora foliacea* and *Tribulus arabicus,*

Overgrazing has affected the abundance of some species, in particula: *Merremia hadramautica, Boerhavia elegans* and *Tribulus arabicus.* The first species is abundant on wadi beds of site 3 and is found in low cover near cultivated and fallow lands in sites 1 and 2. The abundance of these species in site 3 is due to control of grazing by local people in the past. *Blepharis edulis* and *Boerhavia elegans* may represent the grazing-adapted species. Collecting some plants for medicinal or other purposes has an impact on certain species such as *Boerhavia elegans, Corallocarpus glomeruliflorus,* and *Rhazya stricta.* According to local people, *Boerhavia elegans* was abundant 15 years ago, the farmers are used to harvest about 3 sacks seeds of this plant. As a result of reduction of precipitation and over-grazing, specially uncontrolled grazing by local and Bedouin people, the cover of this species has dramatically decreased. The grazing was practiced mainly on the river beds and was not allowed on the slopes at specific times of the year, such as during cultivation and before harvesting of *Boerhavia elegans.*

The Hadhramaut flora has strong floristic relationship with adjacent parts of Africa and Arabia but some species and genera have interesting distributions. For example, *Dracaena serrulata* is a Tertiary relict with related species of *Dracaena cinnabari*, in Soqotra island and with *Dracaena draco* in the Canary Islands; Species of *Euphorbia balsamifera* are also found in Spain (Canary Islands), Mauritania, Senegal, Mali, Burkina Faso and Niger. Some species show strong links with Oman and Saudi Arabia, for instance *Aloe mahraensis, Atractylis kentrophylloides, Boerhavia eleganas, Boscia arabica, Calligonum crinitum* subsp. *arabicum, Caralluma adenensis, Caralluma arabica, Caralluma flava, Caralluma luntii,* and *Dracaena serrulata, Fagonia (F. lahovari and F. luntii*) have remarkable distributions between southern Arabia and the horn of Africa (for more see table 3.2, chapter 3). There are few species that, outside Arabia only found in Africa (e.g. Somali, Ethiopia and north Africa) example are: *Cadaba baccarinii, Aristolochia rigida* and *Tephrosia dura.*



Distribution of *Fagonia lahovari* • and *F. luntii*
Scale bar = 400 km (After Beier, 2005)

Figure 615. Remarkable disjunctions between 2 species of *Fagonia (F lahovari and F. luntii*) between southern Arabia and the horn of Africa (After Beier, 2005). This west-east migration took place during the Tertiary period, when Arabia and Africa were connected by land bridge that allowed the migration of African and Asian taxa along the coast of the Red sea.

6.8. Summary

A total of 15 vegetation associations were distinguished in the study sites. The three principal vegetation associations, *Seetzenia lanata - Dichanthium insculptum* of the plateau (association 11), *Tephrosia nubica - Acacia campoptila - Merremia hadramautica* of the main wadis (association 7) and *Maerua crassifolia - Jatropha spinosa – Stipagrostis hirtigluma* of the plateau slopes (association 13) are the dominant ones and cover 11%, 10% and 9% of the landscapes respectively. The vegetation on the plateau surfaces and on the secondary wadis is more uniform, while the vegetation of the main wadis, the mountain slopes and the slopes of the plateaus is not homogeneous. This is considered mainly to be the result of the impact of human activities in the past, such as grazing and woodcutting or other natural factors such as floods.

Because of complexity of landforms of the plateau areas in the study sites, it was not possible to map some of the vegetation associations separately; therefore, these associations were mapped together and presented in the vegetation maps as groups of associations. Association 11 covers most of the plateau areas in the all study sites; this association is restricted to exposed plateau surfaces and adjacent slopes.

Phytogeography attempts to divide the global into natural floristic units (Miller and Cope, 1996). In terms of the phytogeographical classification of White (1983), the ecosystem of the main wadis and the northern part of the plateau is regarded as a part of the Saharan regional transition zone. According to Zohary (1973), the Hadhramaut region falls within Saharo-Arabian (covering the northern part) and Nubo-Sindian province of Sudanian-region (covering the southern part). Most of the Saharo-Arabian elements are found in the main wadis, while most of the Sudanian-region elements are found on the plateau. The northern limit of the Sudanian-region in the Hadhramaut region can be drawn with latitude ranging from 15° 49' to 15° 50' on the plateau of site 2 (see Figure 7.1b). Most of the plant species of the study sites are desert-adapted species which botanists have classified as Saharo-Sindian, or Saharo-Arabian (Zohary, 1973). Some of these species are of African origin. These species have adapted to the current harsh climate. As a result, many of these plants cannot now live outside the arid and semi-arid landscapes that characterise the study area.

A total of 81 plant species were plotted on maps, 59 over the study sites and 25 over Hadhramaut region, in which 17 plant species were endemic and 7 near-endemic. It can be observed from the study that the distribution patterns show certain common features, some species are confined to the main wadis while others grow well on the rocky slopes of the plateau. Generally the species groups with the similar ecological features grow within similar ranges of altitude. For example, *Alhagi graecorum, Cressa cretica* and *Prosopis farcta* grow well in the cultivated and wet sites at low altitude areas of the main wadis. *Panicum turgidum, Zygophyllum album grow, Heliotropium rariflorum, Dipterygium glaucum* and *Citrullus colocynthis* prefer and grow well at low altitude in sandy wadi beds, while *Jatropha spinosa, Maerua crassifolia Commiphora kua* and *Hochstetteri schimperi* grow well at high altitudes on the steep rocky slopes in the plateau areas.

Grazing can be also considered a disturbance at the level of the individual but it may or may not be a disturbance at the level of the population (Milchunas et al., 1989). Grazing has contributed in reducing the distribution of some plant species and examples includes:

Boerhavia elegans, Panicum turgidum, Lasiurus scindicus, Stipagrostis hirtigluma, Aristida triticoides, Maerua crassifolia and others.

The results of this chapter provide a better understanding of the distribution pattern of some plant species for Hadhramaut region. The findings also emphasise that most of the previous plant collections were obtained from the areas that were accessible or easy to reach, leaving vast areas in this remarkable region without any exploration. Therefore, there are still many places to be visited in order to obtain a comprehensive idea about the population of the plant species. This is particularly true of endemic, near-endemic and rare species, so that they can be cited properly in the red list data of the Yemen.

With the help of data on distribution patterns of the species, the causes for decline in number and rarity may be identified. Identification of interesting and rich plant biological zones also helps in the move towards formulating conservation strategy. It is hoped that this work will contribute to the planning of priorities for the conservation of biodiversity in Hadhramaut region, particularly in the selection of areas suitable for the establishment of new protected areas as mentioned previously in chapter 3.

The next chapter discusses these issues further and explores the main findings of the study.

Chapter 7. Discussion and conclusion

7.1. Introduction

Studies on the vegetation of Hadhramaut go back to the last two decades of the nineteenth century but the present work is the first systematic survey of the vegetation of the region. As indicated before, previous studies concentrated on compiling floristic checklists or on general descriptions of the vegetation communities found in selected habitats without following any consistent scientific methodology. The study area is still the least known part of the whole of Yemen. It is intended that the present research should form the basis for any future management plants for the region.

Human activities and climate change have altered the natural environment over time; in particular they have tipped the ecological balance resulting in a fragmentation of habitats. Above all, human activities have contributed indirectly to the extinction of species by altering habitats in a way that favour certain species. For example, the increases of agriculture and over-grazing have allowed some species, such as *Prosopis juliflora,* to spread rapidly with a resultant detrimental effect on indigenous species.

This chapter presents the main findings of the study and explores some of the resulting suggestions. It discusses the distribution and dynamics of the plants of the study area, and attempts to evaluate the role of climate and human activities on the vegetation by:

1- evaluating the types of vegetation, the structure of plant communities and their distribution, the plant species composition, plant biodiversity, and areas with the greatest plant diversity,

2- determining the physical and anthropogenic factors affecting contemporary plant distribution and composition,

3- determining the changes in plant communities over the past few decades and the processes affecting vegetation change,

4- identifying the potential of the study to contribute to conservation and management issues.

7.2. Floristic and phytogeography

7.2.1. Floristic

The total number of plant species collected and recorded from the literature of the Hadhramaut region is 469 (see Appendix 3), of which about 23% (107 taxa) are either endemic or near-endemic (with distribution centred in Hadhramaut but also occurring just outside in Oman, Saudi Arabia and UAE). In total 134 species belonging to 41 families (about 30% of the known flora of Hadhramaut region) were recorded in the study area (Table 4.1) of these, 5 are endemic to Hadhramaut region, 7 species are endemic to Yemen and five are endemic to the Arabian Peninsula. A total of 117 plant species were collected in the sample plots (of which 4 have not yet been identified): 74 species in site 1; 83 species in site 2; and 61 species in site 3, with 39 plant species recorded in all 3 study sites. At each site, the detailed survey of the representative transects, is estimated as follows 0.46 ha (46 x 100 m^2 plots), 0.53 ha (53 x 100 m^2 plots) and 0.34 ha (34 x 100 m^2 plots). The following endemic and near-endemic taxa for the Hadhramaut were found in the study sites: *Aerva artemisioides* subsp *artemisioides, Iphiona anthemidifolia, Cucumis canoxyi, Fagonia hadramautica, Merremia hadramautica* and *Acacia campoptila.*

The largest families in terms of species in the study sites are:

- Poaceae (Gramineae) with 13 species
- Fabaceae with 12 species
- Zygophyllaceae with 11 species
- Capparaceae with 9 species
- Mimosaceae with 8 species
- Asteraceae (Compositae) with 7 species

17 families were recorded containing only one species (Table 4.1).

7.2.2. Phytogeography

Phytogeography attempts to divide the globe into natural floristic units (Miller and Cope, 1996). A number of phytogeographical classifications have been proposed for the Middle East. Below I have set out a summary of the most important of these (Table 7.1).

		Authority		
Kingdom	The region	Zohary	Takhtajan	White
Holarctic origin	Northern part of the Hadhramaut	Holarctic province of the Holarctic-Sindian region	Egyptian-Arabian Province of the Holarctic region	Arabian regional subzone of the Holarctic-Sindian regional zone
Paleotropical origin	Southern part of the Hadhramaut	Nubo-Sindian province of the Paleotropical-region.	South Arabian Province of the Sudano-Zambesian Region.	The Somalia-Masai regional centre of endemism

Table 7.1. Phytogeographical classification for the Middle East.

1. Zohary (1973).

According to Zohary, the northern part of the Hadhramaut region is of Holarctic origin falling within the Holarctic province of the Holarctic-Sindian region whilst the southern part of the region is of Paleotropical origin falling within the Nubo-Sindian province of the Paleotropical-region.

2. Takhtajan, (1986).

Taktajhan splits the Middle East into two floristic Kindoms: the Holarctic in the north and the Paleotropical in the south. The boundary between these floristic Kingdoms falls somewhere across the southern part of the Arabian Peninsula. The map on the end page of his book suggests that in fact this boundary runs across the middle of Hadhramaut. According to him, the northern part of Hadhramaut falls within the Egyptian-Arabian Province of the Holarctic region whilst the southern part falls within the South Arabian Province of the Sudano-Zambesian Region.

3. White and Léonard (1991).

White (1983) proposed a new phytogeographical system for Africa based on “regional centres of endemism” separated by “regional transition zones”. This system was later extended to cover SW Asia (White and Léonard, 1991). Using this system Arabia is subdivided into three main phytogeographical areas: the Holarctic-Sindian regional zone; the Somalia-Masai regional centre of endemism and the Afromontane archipelago-like regional centre of endemism. The Holarctic-Sindian regional zone is further divided into the Arabian regional subzone and the Nubo-Sindian local centre of endemism. It can thus be seen that according to White and Léonard (1991), the northern part of Hadhramaut Region falls into the Arabian regional subzone of the Holarctic-Sindian regional zone and the southern part into the Somalia-Masai regional centre of endemism.

These three systems are all fundamentally similar (see Table 7.1). They each place the northern part of the region in the Holarctic floristic Kingdom and the southern part in the Paleotropical floristic Kingdom. They differ only in the terms used to describe them. In the literature there is frequently confusion and mixing of these terms. To avoid this and for the sake of simplicity in the following discussion I have used the term “Holarctic” in the sense of the Holarctic-Sindian of Zohary, the Holarctic of Takhtajan and White and the term “Paleotropical” in the sense of the Nubo-Sindian or Paleotropical of Zohary, the Sudano-Zambesian of Takhtajan, the Somalia-Masai regional centre of endemism of White and Léonard or the more general term Paleotropical or tropical Paleotropical widely used in the literature. Figure 7.1a shows the general limits of the main phytogeographical regions of Africa and south west Asian.

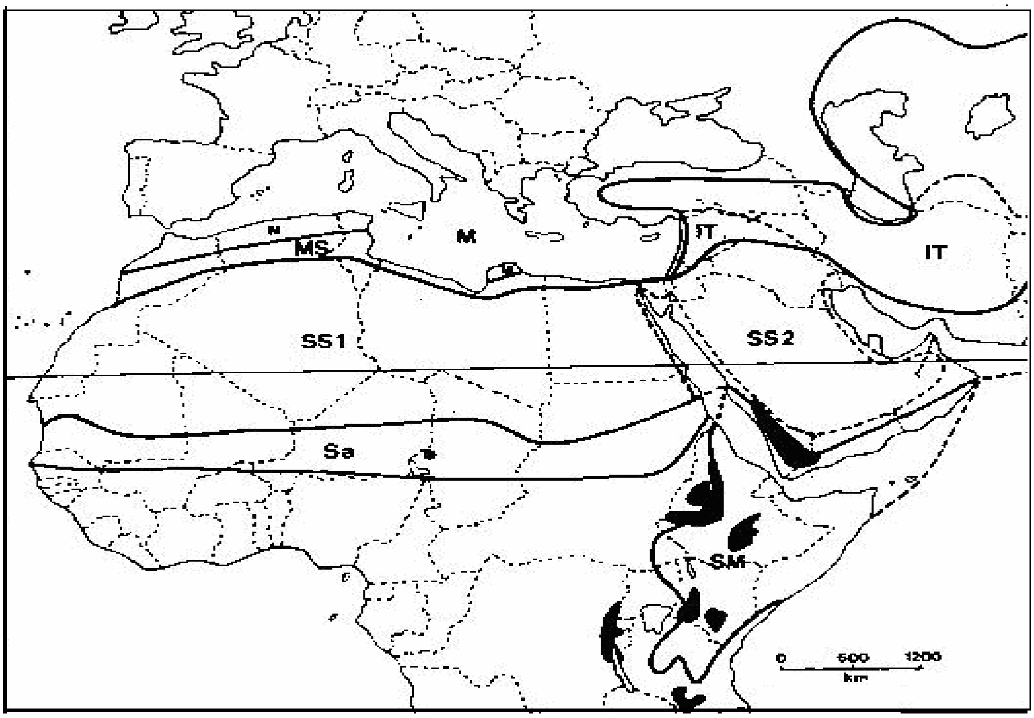


Figure 7.1a. General limits of the main phytogeographical regions of Africa and south west Asian; IT, Irano-Turanian regional centre of endemism; MS, Mediterranean-Sahara regional transition zone; SS, Saharo-Sindian regional zone further divided into the Arabian regional sub-zone (SS1), the Nubo-Sindian local centre of endemism (SS2); SM, Somalia-Masai regional centre of endemism; shaded black, Afromontane archipelago-like regional centre of endemism. After White and Leonard (1991) and Miller and Morris (2004).

The placing of species into different phytogeographical elements can be problematic, however, the following sources were found to be useful: Zohary (1973) Zohary and Feinbrun-Dothams (1966-1986), White (1983) and Takhtajan, (1986). From these it was possible to assign floristic elements to a large number of taxa within the region. For instance, Holarctic elements include: the endemic genus *Saltia papposa*, *Schouwia purpurea*, and species of *Echiochilon, Fagonia, Zygophyllum* and *Aristida*.

Paleotropical elements tend to be more numerous in the Hadhramaut region. According to Zohary (1973) they are largely confined to families and genera that are absent elsewhere in Asia or large parts of the Middle East. These include: *Acacia hamulosa, A. laeta, A. mellifera, A. oerfota, Aloe spp., Balanites aegyptiaca, Cadaba baccarinii, C. farinosa, C. heterotricha, C. rotundifolia, Caesalpinia erianthera, Caralluma spp., Celtis africana, Cassia senna, Commiphora foliacea, Commiphora gileadensis, Commiphora habessinica, Commiphora kua, C. playfairii, Crotalaria aegyptiaca, Dodonaea viscosa,* succulent *Euphorbia spp., Ficus* *cordata* subsp. *salicifolia, Grewia erythraea, Forsskaolea tenacissima, F. viridis, Jatropha pelargoniifolia, J. spinosa, Maerua crassifolia, Moringa peregrina, Olea europaea* subsp. *cuspidata, Psiadia punctulata, Sarcostemma vanlessenii, S. viminale, Tephrosia apollinea, T. nubica*

Apart from the species which can be identified as belonging to the two main elements described above, two species of Irano-Turanian origin (Zohary and Feinbrun-Dothan, 1966-1986) were also found. These are *Alhagi graecorum* and *Prosopis farcta.* Both species were found on or near cultivated and fallow lands in site 1 and both are probably introductions which have adapted to the arid conditions, with annual rainfall (that characterises the site) less than 40 mm.

Identifying the boundary between the northern, holarctic and southern paleotropical flora is problematic because the vegetation consist of a mixture of a paleotropical and holarctic elements. For instance, holarctic elements are common in the ground flora of the main wadis, whilst paleotropical elements are common on the plateau. However, the dominant trees in the main wadis are typically species of *Acacia*, a genus of paleaotropical origin.

Based on an analysis of the distributions of some holarctic and palaeotropical elements, I have here suggested a boundary between the two phytogeographic regions (see fig 7.1b). The northern limit of the paleotropical region in the Hadhramaut region runs between latitude 15° 22’ in Wadi Daua’n west to 15° 35’ in Wadi Sah east. However, considerable numbers of paleotropical elements are found further north between 15° 49’ to 15° 50’ on the plateau of site 2 (see Figure 7.1b).

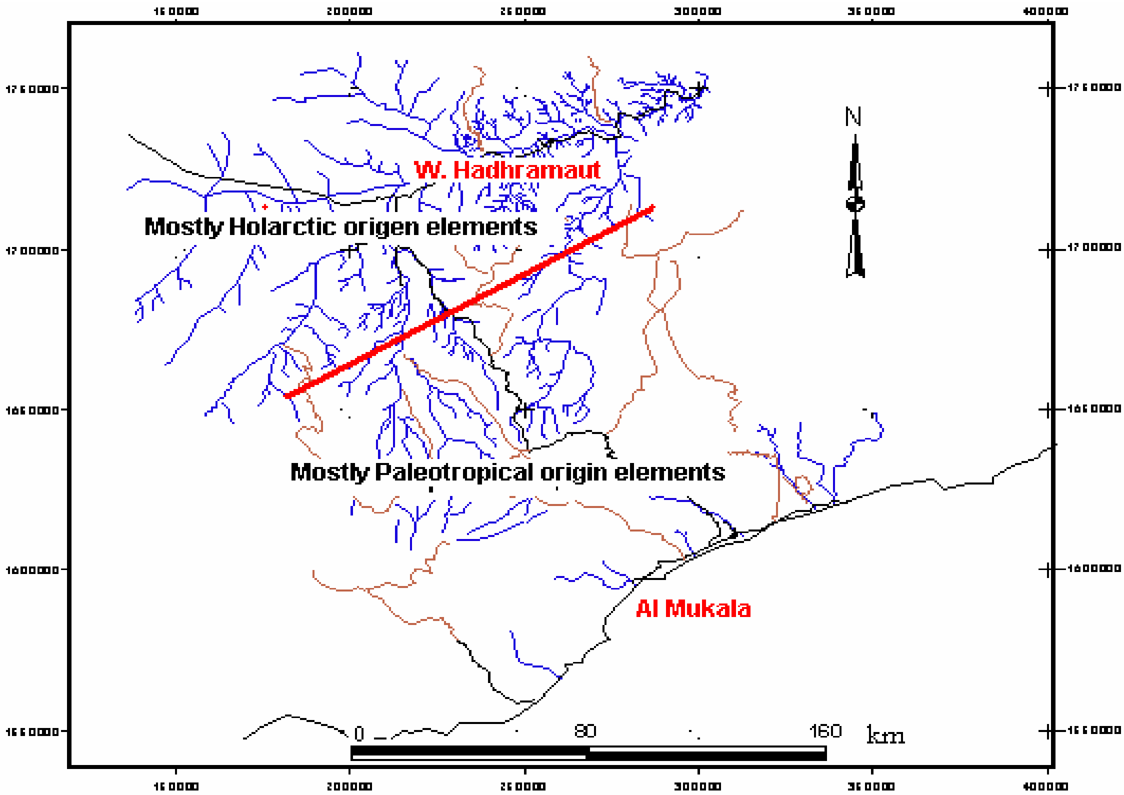


Figure 7.1b. The Phytogeography of the Hadhramaut region. The proposed (red line) boundary is based on the distribution patterns of some Holarctic and Paleotropical elements, such as palm cultivated fields, *Rhazya stricta, Ochradenus baccatus,* and *O. arabicus.*The boundary runs between latitude 15° 22' in Wadi Daua'n west to 15° 35' in Wadi Sah east.

The occurrence of paleotropical elements within the main wadis, which are largely dominated by holarctic elements, may be due to the large climatic fluctuation that took place in the Sahara over the entire Quaternary period (Takhtajan, 1986), which allowed paleotropical elements (e.g. Acacias) to migrate along the wadis during periods of higher rainfall (Mandaville, 1990). The wadi systems also provided channels for the migration of paleotropical vegetation into the future Arabian Peninsula, even into the present holarctic region, during late Pliocene or early Pleistocene times (Mandaville, 1984). After this the African-Arabian Shiele was divided by the Red sea and overland migration was no longer possible (Miller and Morris, 1988; Mandaville, 1990). It is now widely accepted that the Arabian flora underwent its main floristic colonisation events during the Tertiary. This was the main period of invasion, especially for the extra-tropical Holarctic element that developed under the increasing aridity of the mid to late Miocene. According to Zohary (1973) the northern border of the paleotropical element is marked in Arabia by open thorn woodland dominated by various *Acacia spp*. and with a strong decline in the abundance and diversity of annual plants.

Therefore, is seems likely that paleotropical species such as *Acacia campoptila, A. hamulosa, A. ehrenbergiana, Moringa peregrina, Balanites aegyptiaca, Ziziphus leucodermis, Salvadora persica, Ziziphus spina-christi, Tamarix aphylla, Tephrosia apollinea, Tephrosia nubica* in the main wadis are relicts of a "mesic Paleotropical vegetation" that once occupied the area. Due to the change of the climate from wet to the current arid and semi-arid, most of these species either survived in more mesic niches or adapted to the current hostile climate before Arabia broke away from Africa some nine million years ago. For example, the dominant species of the main wadi beds, *Tephrosia apollinea.* subsp. *longistipulata, Boerhavia elegans* and *Acacia campoptila* have strong (vicariant) links with closely related Paleotropical species.

The above argument is supported by fossil pollen of Miocene horizons which indicate that a Paleotropical flora existed in Arabia during the Mid Miocene (Mandaville, 1984) when conditions were much more mesic than today. It is largely due to the late separation of the Arabian Peninsula from the Paleotropical continent in the early Miocene, that the present flora of the southern part of Arabia exhibits close relationship with the Somalia-Masai regional zone. Most Paleotropical taxa reflect Tertiary migration routes dating from before the formation of the Red Sea (Mandaville, 1990). Mesic-Paleotropical relicts in the Hadhramaut region are: *Gnidia somalensis* the common species of the southern part of the Hadhramaut which has a link with the *Gnidia glauca* of afromontane taxa of Ethiopia (Takhtajan, 1986), other example of refugium of palaeo-African in the isolated areas of southern summits are *Rhus glutinosa* subsp. *neoglutinosa* and *Cadaba baccarinii* (see Table 3.2). There are numerous examples of taxa of paleotropical origin that have their closest relatives in Africa and a speciation centre in southern Arabia and which also extend eastwards across the Arabian Gulf, for example, genera such as *Anogeissus* (*A. leiocarpa* in Africa, *A. dhofarica* and *A. bentii* in Arabia), *Dracaena* (*D. draco* in Canary island, *D. draco* subsp. *ajgal* in Morocco *D. cinnabaria* in Soqotra and *D. serrulata* in Yemen, Oman and Africa), *Ephedra* (*E. major* and

E. intermedia in Iran, *E. alata* and *E. aphylla* in the northwest Africa desert, *E. foliate* in Arabia, Iran and north east Africa and *E. milleri* in Arabia), *Fagonia* (*F. acerosa* in Iran, *F. burguieri* in North Africa, Arabia and East Asia, *F. mollis* in Egypt, Palestine and Israel and Arabia, *F. arabica* and *F. scabra* in North Africa, *F. glutinosa* in Arabia, North Africa and Palestine, *F. luntii* in Arabia and Horn of Africa, *F. lahovarii in* Yemen and Horn of Africa and *F. Hadramautica* in Yemen (Beier, 2005; Bell et al., 2004), *F. paulayana* in North and East Africa, Pakistan and Arabia. *Farsetia* (*F. longisiliqua* and *F. stylosa* in Africa and Arabia , *F. Linearis*, and *F. dhofarica* in Arabia), *Gymnocarpos* (*G. decandrus* in Canary Islands, North Africa, and in Israel, Jordan, Syria, Saudi Arabia, Oman, Iran, Afghanistan and Pakistan (Brandes, 2004; Hassan, 2002), *G. parvibravtus* in Africa, *G. rotundifolius* in Arabia, *Ochradenus* (*O. randonioides* in East Africa, *O. arabicus*, *O. harsusiticus* and *O. spartioides*, *O. gifrii* in Arabia (Miller, 1984; Thulin, 1994), *O. aucheri* subsp. *aucheri* in Arabia (Miller, 1984; ICARDA, 1998) and subsp. *ochradenii* in Iran, subsp. *rechingeri* in and Iran Pakistan (Perveen and Qaiser, 2001) and *O. baccatus* in North and East Africa (Miller, 1984; Abd El-Fattah and Dahmash, 2002), Arabia and Pakistan), *Schweinfurthia* (*S. pedicellata* in Africa, S. *pterosperma* in Africa, Arabia and Asia, S. *papillionaceae* in Arabia and Asia, S. *latifolia, S. pedicellata* and *S. spinosa* in Arabia. *Vernonia (V. arabica* in Arabia and Africa, *V. areysiana in Yemen, V. spathulata* in Yemen and Somalia (Wood, 1997*).*

Endemism and Speciation

There are 105 endemic and near-endemic plant taxa recorded from the Hadhramaut region (Table 3.2), of these 67 are endemic to Yemen (40 are confined to the Hadhramaut region). The most endemic-rich family in the Hadhramaut region is Apocynaceae with 18 endemic taxa, and the most endemic-rich genera are *Caralluma* with 10 endemic taxa and *Aloe* with 9 endemic taxa. The relatively large number of endemics is largely due to the topography and climate of the region; many endemics are found on isolated, relatively mesic mountains, often with markedly different climatic regimes. The mountains of southern Arabia behave in many ways like an island archipelago - the sea in this case represented by hyper-arid deserts.

Adaptive radiation and speciation by geographical separation has occurred in many genera. For instance, each mountain range along the southern and western escarpments of the Arabian Peninsula has its own endemic species (Ghazanfar and Fisher, 1998). The southern mountainous region of the Hadhramaut follows this pattern. It is in effect an island, isolated from other mountains by large tracts of desert. Furthermore, the presence of frequent low cloud, during the summer or SW monsoon, results in relatively good conditions for plant growth. This isolation and presence of mesic conditions have given rise to refugia which have become local centres of endemism (Plate 7.1). The flora of the southern region of Hadhramaut shows every sign of having been linked at some point with the African flora. These endemics are mainly of paleotropical origin – their presence explained by their migration into the region thousands years ago when the climate was very different from that of today. The continued survival of these plant species can be explained by the winds of the SW monsoon which, during the summer months, blow dense fogs inland. These fogs blanket the seaward-facing escarpments and frequently spill-over onto the summit plateau and bringing important precipitation for the ecosystem.

Similar fog-affected seaward-facing mountain slopes occur in the mountains above Hauf in the Al Mahra Governorate of Yemen and in Dhofar in the southern region of Oman. Here, the slopes support dense deciduous woodland dominated by the regional endemic tree *Anogeissus dhofarica*, together with *Acacia senegal* and *Commiphora spp*., (Miller & Morris, 1988). As the influence of fog decreases further north, grassland is replaced by low succulent shrubland dominated by *Euphorbia balsamifera*. Beyond this, the vegetation becomes sparser and finally gives way to open desert (Miller, 1994).

Plate 7.1. Dense fog on the southern mountains of Hadhramaut region (above the arid coastal plain).This fog is influenced by the southwest monsoon. This dense fog supports an important moisture contribution and as a result high diversity of flora and fauna and brings the moisture necessary to sustain the wildlife and plant species found here. This habitat has very rich endemic near-endemic and rare plants. The high density of plant species, dominated by *Dodonaea viscosa* and *Dracaena serrulata* at about 1350 m inland, is probably reflecting the maximum inland extent of fog moisture (see chapter 3).

The fog-affected escarpments of Dhofar have the highest number of endemic species and some of the most species-rich habitats in Oman. About 900 vascular plants have been recorded from the fog oasis of Oman and Yemen, of which 60 are endemic, including two endemic genera, *Cibirhiza* and *Dhofaria* (Miller & Morris, 1988).

The volcanic mountain of Jebel al Areys, which lies west of Hadhramaut some 150 km east of Aden on the southern coast of Yemen, is another good example of a "fog oasis". Its upper seaward-facing slopes are covered in dense woodland and the summit by a succulent shrubland dominated by *Euphorbia balsamifera* with *Dracaena serrulata.*

These monsoon-affected mountains of the southern Arabian Peninsula harbour relict vegetation elements of paleotropical origin with some plant species such as the near-endemic *Justicia areysiana* showing a disjunct geographical distribution pattern with populations in the south Yemeni fog oases in Hadhramaut and in the Hawf /Dhofar region in east Yemen and western Oman. Past oscillations between humid and arid periods connected with glacial and interglacial episodes in the Pleistocene and Holocene are considered responsible for observed patterns of genetic variation between populations in the different refugia (Meister et al., 2005). These woodland refugia of the southern mountains of the Arabian Peninsula (including the Hadhramaut) show strong affinities to the Somalia-Masai phytochorion of Africa. (BIOLO, 2004).

Adaptations

Most of the plant species of the study sites are desert-adapted species belonging to the Holarctic (Zohary, 1973). These plants can be considered to be xerophytes, that is they have morphological adaptations that help them to survive the arid climate of the region (Batanouny, 2000; Western, 1988). The rainfall in the study area mainly falls in summer when the temperature is very high; the rate of evaporation exceeds rainfall throughout the year, in such environmental conditions only the vegetation that is adapted to a dry environment can survive. Generally, as in other desert areas in the world, the important limiting factor in the study area is the quantity of moisture available to the plants. In order to survive in the extreme desert, a plant must, on one hand, utilize the little rainwater available to it, and on the other hand, survive the very long dry periods that characterise the region. The lack of rainwater is not the only problem in the study area, but also the rainfall does not arrive regularly.

There are many examples of plants from the study area which exhibit xerophytic adoptions, for instance, plants with succulent leaves such as *Aloe* spp. and *Zygophyllum* spp. or plants with succulent stems such as *Adenium obesum,* the cacti form *Euphorbia* spp. and *Caralluma* spp. Other plants have very small or scale-like leaves which reduce the surface area of the plant and consequently reduce moisture loss, examples being *Ochradenus baccatus* in main wadi and *Periploca visciformis* in the plateau. Some grass species have extremely large and complex root systems that enable them to collect water over a wide area. Examples are *Panicum turgidum and Dipterygium glaucum*. Typically trees have deep root systems which can tap the ground water, for examples, certain trees which are abundant in the wadi beds including *Acacia campoptila*, *Prosopis juliflora, Tamarix sp, Ziziphus spina-christi* and the date palm *Phoenix dactylifera.* The ability to grow deep roots, has allowed some species such as *Prosopis juliflora* to migrate and survive in the region and become the dominant species in many parts of main wadis, especially in neglected areas. *Prosopis juliflora* has both an extensive lateral root system that collects surface water after rain and long taproots that penetrate to depth of 24 m and tap the ground water supplies (FAO, 1993).

Some species such as *Panicum turgidum* and *Dipterygium glaucum* have shallow but wide-reaching root systems for greater water-gathering ability (Western, 1988). Other species such as *Salsola imbricata,* and *Zygophyllum coccineum, Z. album, Tamarix arabica* and *T. aphylla* are much more salt-tolerant and grow well on some saline and alkaline sites of wadis (associations 2 and 4). These species were found evergreen and fleshy even during the dry season (during the field-work).

Vegetation of the Study sites

Some stands of typically paleotropical vegetation are found in sheltered slopes on the plateau of site 2. Typical paleotropical elements in this vegetation include, *Maerua crassifolia, Cadaba heterotricha, Acacia mellifera, Tarenna graveolens, Grewia erythraea Commiphora kua, Commiphora foliacea,* and *Aristida triticoides*. This vegetation possibly represents a relict of vegetation type that was previously widespread in this region. The present vegetation in the surrounding area is dominated by *Jatropha spinosa* with *Hochstetteria schimperi, Zygophyllum decumbens, Stipagrostis hirtigluma, Dichanthium insculptum* and *Indigofera spinosa.* This finding suggests that formerly the vegetation of the plateau was more favourable to tree life, which was then replaced gradually by vegetation dominated by herbaceous plants. In the main wadis a few stands of typically paleotropical vegetation with *Salvadora persica,* and *Tamarix aphylla* also gives an impression of what the previous climax vegetation might have been like when the climate was wet and before it was replaced by a vegetation association dominated by *Acacia campoptila* with *Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus, Rhazya stricta, Ochradenus baccatus* and others that can survive the present arid climate.

Paleotropical elements such as *Anogeissus bentii, Maerua crassifolia, Ziziphus leucodermis, Acacia ehrenbergiana, A. hamulosa* and *Moringa peregrina* were probably dominant in the main wadis in the past, but as the climate became drier in the region or as a result of human impact, their populations declined to their present levels. So now they are very rare and generally restricted to more favourable places such as areas of deep alluvial soil in wadis and around cultivated fields. These species are an important sources of browse for camels and fire wood in Arabia and so over-utilisation may also account of their present, limited, distribution (Zaroug, 1984). *Ziziphus leucodermis, Acacia hamulosa,* and *A. ehrenbergiana* are still abundant species in some wadis of Hadhramaut. According to Kenneth et al., (2001) the first two species have been present since 5239 yr B.P. but the third was not present until 2159 yr B.P. He suggests that the late Holocene appearance of *Acacia ehrenbergiana*, which is widespread throughout Yemen today, could indicate a return to moister climates following an extremely arid period in the late-middle Holocene. *Acacia ehrenbergiana* is now restricted to deep alluvial soils in the wadis and near or on old cultivated fields.

Recent plant migration is a very real phenomenon with evidence both from prehistoric times and from present observations (Pitelka, 1997). Human activities or changes in climatic conditions may force plant species to adapt or migrate and occupy new territory via dispersal and reproduction. In the study area, humans have contributed to plant migration through the introduction of exotic plants such as *Prosopis juliflora and Cuscuta campestris*. Generally, there are many factors other than climate that play an important part in determining species distributions and the dynamics of distribution changes. Such factors include biotic interactions, evolutionary change and dispersal ability (Pearson and Dawson, 2003). In the coming sections, and based on the main findings in chapter 3 to 6, the main abiotic and biotic factors that determine vegetation distribution in Hadhramaut region will be discussed.

Vegetation associations

The vegetation of the main Wadis of Hadhramaut (associations 1 to 7) comprises a mixture of two phtogeographical elements: that is holarctic species mixed with a few paleotropical plants. Zohary (1973) referred to this type of vegetation as pseudo-savanna. He considered it to be confined to depressions and wadis in eastern Egypt, Sinai, S. Palestine and Israel. It differs from the vegetation found in these areas because of the presence of *Acacia campoptila and Boerhavia elegans* but the occurrence of *Ochradenus baccatus, Panicum turgidum, Zygophyllum coccineum, Citrullus colocynthis, Blepharis edulis, Cleome droserifolia, Tephrosia apollinea, Senna italica* and *Fagonia indica* in both the Hadhramaut and these others regions is significant. The *Acacia campoptila* wadi communities with *Panicum turgidum, Aerva javanica, Indigofera spinosa, Fagonia indica, Ochradenus baccatus, Dipterygium glaucum, Calotropis procera* and *Rhazya stricta* is widespread over the wadi beds of arid areas Marib and Rada' in Yemen (Al Khulaidi, 1989; Westinga and Thalen, 1980, Al Hubaishi and Muller-Hohenstein, 1979). Species of *Acacia*. (e.g. *A. tortilis and A. hamulosa*) form savanna-like communities in association with *Panicum turgidum, Leptadenia pyrotechnica, Aerva javanica, Calotropis procera* and *Ziziphus spina-christi.* Similar communities are widespread throughout the tropical Sahara region and in the wadis of Sudan, Egypt, Palestine and Arabia (Zohary 1973, White, 1983). Therefore, it can be seen that the vegetation of the main wadis is dominated by holarctic elements with a few paleotropical elements and is characterised by being adapted to arid and semi-arid conditions.

Woodland in the main wadis is dominated by *Acacia campoptila.* This woodland is found over large areas but is thin and sparsely distributed. In areas where water is relatively abundant, such as in depressions and near cultivated fields, the vegetation is rich with species such as: *Acacia ehrenbergiana, Acacia hamulosa, Barleria aff. bispinosa, Boerhavia elegans, Dichanthium insculptum, Kohautia retrorsa,* and *Zygophyllum simplex.*

Association 2 (*Citrullus colocynthis - Zygophyllum album)* reflects the transitional zone between arid and hyper-arid climates and is very similar to the associations that are common further west on the sand dunes of the Ramalat Al Saba'tein desert area (see chapter 3) and the *Aerva javanica, Calotropis procera* and *Dipterygium glaucum* associations that are found on the wadi borders, sand dunes and sandy plains throughout the coastal areas and deserts of Yemen (Wood, 1997).

Some species in this habitat (e.g. *Panicum turgidum, Dipterygium glaucum* and *Zygophyllum album*) have very long roots which spread over the surface as well as deep roots; they can thus utilise surface moisture and as well as water that has infiltrated to deep layer (Plate 7.2). This is typical of the root systems of grasses on sandy soils which can extend to depths of 1.4 m or more and are likely to be adaptation to capture more soil water from the frequent small rainfall events (Gibbens and Lenz, 2001). Additionally, the sandy soils of this habitat may offer better water supplies (Monger, 2002). This vegetation association is currently confined to the western part of the study area (site 1) and represents the hyper-arid climate with sand dune landform type, but due to the frequent floods, this type of vegetation association is expected to spread further towards the eastern part of site.

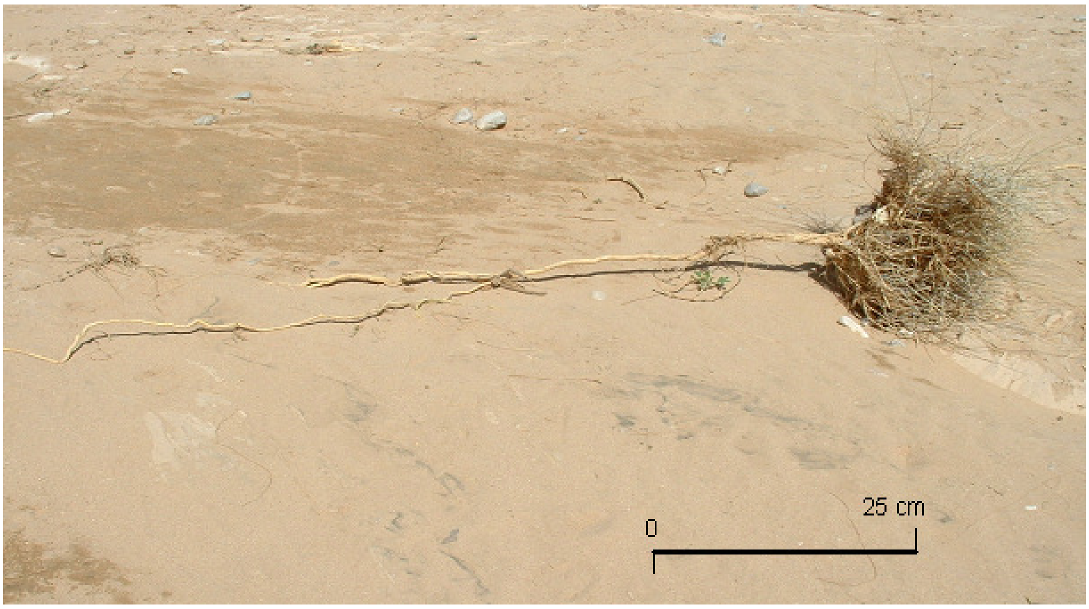


Plate 7.2. Methods of tackling water shortage. Some species have large root systems to improve the intake of water. The illustration is of the long root of *Dipterygium glaucum*, which can spread over the surface as well as into the soil utilizing the available surface moisture as well as water that has infiltrated deeper layers. The length of the root shown is about 100 cm representing the upper thick part of the root system.

Association 11 (*Seetzenia lanata - Dichanthium insculptum)* is predominantly grassland, dominated by *Dichanthium insculptum* and *Stipagrostis hirtigluma.* It is found mainly on the plateaus and surrounding slopes. This association is characteristic of the vegetation that covers the plateaus and surrounding degraded slopes.

Association 12 (*Chrysopogon aucheri- Stipagrostis hirtigluma*) of the secondary wadis of plateaus and association 7 of the main wadi beds of site 3 are the most diverse in the study sites. The number of species in these associations ranges between 34 and 44 and the individuals range between 468 and 537. Associations 2, 10, 14 and 15 are characterised by low number of species and individuals. Associations 1 and 3 have the highest vegetation cover percentages, the former is dominated by trees and shrubs, namely *Phoenix dactylifera, Prosopis farcta* and *Alhagi graecorum,* while the latter is dominated by dwarf shrub and herbaceous cover namely *Merremia hadramautica, Crotalaria persica,* and *Heliotropium ramosissimum.*

Association 13 (*Maerua crassifolia - Jatropha spinosa - Stipagrostis hirtigluma)* is confined to the slopes of the plateau in site 2. It consists predominantly of sparse shrubland, dominated by *Jatropha spinosa* with *Stipagrostis hirtigluma* and *Dichanthium insculptum* also frequently present. This association forms a climax vegetation type. When this association is disturbed and degraded a secondary succession occurs (Kent and Coker 1992). This degraded succession is represented by association 15, which is characterised by a species-poor association (up to 8 species) of herbaceous plants. The climax vegetation type of this area was probably woodland dominated in the past by *Cadaba heterotricha, Tarenna graveolens, Maerua crassifolia, Aristida triticoides, Commiphora kua* and *Grewia erythraea.*

Compared to other ecological zones, the vegetation cover of the wadis is generally rich with a relatively a extensive cover of plant species. All the rainfall from the slopes and drainage lines that cut the plateau runs into these wadis; they thus hold enough water in the rooting zone to support a variety of plant species, as well as being good for date cultivation.

7.3. The effect of biotic and abiotic factors on plant species

Human activities and climate change have altered the natural environment over time; they directly cause destruction of habitats and extinction of species resulting in fragmentation of habitats. Human activities also contribute indirectly to the extinction of species by destroying the balance of ecosystems in favour of species that are adaptable to changing conditions. For example, increasing human activity in Hadhramaut has allowed certain species such as *Prosopis juliflora* to invade natural habitats.

Different plant species have different environmental requirements; a better understanding of the demands of different species is important in determining what measurable variations affect their distributions.

7.3. 1. Climate

Vegetation depends on a combination of variables such as rainfall, temperature, evaporation, radiation and relative humidity (Kutiel et al., 2000). Climatic variables, such as changes in average air temperature and precipitation are a significant aspect of global environmental evolution (Anderson, 1997). Several studies have shown that there is a lack of clear correlation between rainfall and species diversity (Kutiel et al., 2000). Although there are marked relationships between mean annual precipitation (MAP) and vegetation growth (for example woody cover in African savannas, Sankaran et al., 2005). Other studies have shown that temperature and precipitation are the main variables determining the distribution of plants (Woodward 1987, Huntley et al., 1995). Both of these variables are being changed by increasing levels of greenhouse gases emitted mainly through the anthropogenic emission of fossil fuels (Todd, 1995). Over the next 100 years, these changes in both the macro and microclimate will alter the distributions of many plant species (Overpeck and Bartlein, 1989). Therefore, to understand the importance of these changes, the influence that environmental factors have on the floristic composition of plant associations need to be examined (Danin et al., 1975).

As in other arid regions, the study area consists of a considerable extent of barren lands with a scarcity of water for plant growth (Isani, 1999; Cook & Warren, 1973). Therefore, available moisture is the main factor influencing plant species in the study area. High temperatures in summer (mean monthly maximum of 34-36˚C in coastal areas and of 40-42˚C in the northern part of the region), result in evapotranspiration of 3-5 mm/day in coastal areas and 3-6.5mm/day in the mountainous north of the region. The highest levels of evapotranspiration at 8 mm/day occur in the deserts in northern part of the region. The yearly distribution of rainfall (nearly 80% of the rain falls from January to June) reduces the moisture available in the soil. Yet, landscape units have micro habitats or niches within them, such as secondary wadis on the plateaus and cracks in cliffs which capture run-off and increase the moisture available for plant growth.

The plateau and the large wadis which dissect them are the main topographic features of the Hadhramaut region. The Wadi Hadhramaut acts as a major ecological barrier dividing both the climate and the plant species of the northern plateau from those of southern plateau. The best example of this division, which is essentially climatic, is shown by species which are confined to the northern plateaus (corresponding to the 50 mm isohyet or less), such as *Glossonema varians, Hermannia paniculata, Crotalaria saltiana, Forskohlea tenacissima and Moltkiopsis ciliata* and those that are confined to the southern plateau such as *Arnebia hispidissima, Abutilon bidentatum*, *Cadaba heterotricha, Chascanum marrubifolium, Euphorbia rubriseminalis, Grewia erythraea, Helichrysum pumilum, Hochstetteria schimperi, Leptadenia arborea, Pluchea dioscoroides, Portulaca oleracea, Seddera latifolia, Tamarix arabica, Tarenna graveolens, Trichodesma calathiforme,* and *Zygophyllum decumbens.* The 40 mm isohyet in Wadi Hadhramaut also corresponds to the eastern limits of species such as *Zygophyllum album and Alhagi graecorum, Prosopis farcta* and *Heliotropium rariflorum* (Association 2).

In the study area, with no obvious macro-climatic variations, the influence of landscape variation is of major importance. Each landscape feature represents a distinct ecological zone with its own plant species. Some species were found in almost all ecological zones, whilst others had narrow ecological ranges and were confined to specific or favoured sites. The dominant species of the 3 study sites, in particular on the plateau were grasses, notably

Dichanthium insculptum and *Stipagrostis hirtigluma.* These two grasses are important palatable grasses of arid and semi-arid areas of Australia, East Africa, the Arabian Peninsula and India. The first is an important grass in the arid areas of NE Australia (Gupta et al., 1986), and the latter is found in the Somalia-Masai Region (White, 1983), and in the dry savanna areas of Namibia (Becker and Getzin, 2000). Some species are only found in sites with high moisture content (e.g. adjacent to fields or fallow lands) these include *Senna incana, Cressa cretica* and *Alhagi graecorum,* whilst others are found on rocky wet plateaus such as the endemic *Cucumis canoxyi.* Other species that grow well in relatively wet sites are *Acacia oerfota, A. hamulosa, A. ehrenbergiana, Pulicaria undulata, Crotalaria saltiana* and *Farsetia linearis.*

The vegetation in the region is concentrated in areas where moisture is available, such as: drainage lines, depressions, furrows, man-made channels, on the escarpments of the plateaus, near springs and in wadis. Over the plateau there is hardly any moisture, and consequently the vegetation is very poor or absent. Construction of the service tracks on the plateau (for oil exploration-companies) have created small linear runoff catchments or depressions along their sides, which trap soil and moisture and create conditions in which certain species such as *Farsetia linearis* and *Zygophyllum simplex* germinate and grow successfully. Other species such as *Acacia oerfota, Pulicaria undulata,* and *Crotalaria saltiana* also flourish in rain water reservoir on the plateau (Plate 7.3).

Other species are tolerant of continuously saturated soils. Particular examples are the species of sociological group D *(Pulicaria undulata, Crotalaria persica, Corchorus depressus, Convolvulus glomeratus, Chrozophora tinctoria, Indigofera spinifolia* and *Merremia hadramautica).* These species are common in the wet depressions that were in former times cultivated after rain and then left fallow.

Plate 7.3. Vegetation growing along the rain water reservoir on the plateau; species include *Acacia oerfota, Pulicaria undulata, Aerva javanica, Crotalaria saltiana* and *Stipagrostis hirtigluma*

A steady increase in moisture over just a few months can result in the establishment of lush vegetation. This is dramatically illustrated by the rapid growth of plants, including *Dichanthium insculptum, Farsetia linearis*, *Chrysopogon aucheriand, Pulicaria undulata,* in a wadi on the plateau in site 2, which has been regularly watered with large amounts of contaminated water from oil-related activities. Almost half of the plant species of the plateau in site 2 were confined to this wadi. From this example it is evident that the addition of water can rapidly alter plant cover and composition.

Although plateau habitats from all three sites are almost identical, the southern plateau where site 2 is located has a much richer flora and vegetation cover than those of sites 1 and 3. As indicate earlier, the southern plateau receives relatively higher rainfall than the northern plateau (SOGREAH 1979). However, there are some differences, *Indigofera spinosa, Jatropha spinosa, Maerua crassifolia, Commiphora foliacea Zygophyllum decumbens, Farsetia linearis,* and *Aristida triticoides* are abundant on the slopes and wadis on the plateau in site 2 but are very rare or absent in the same habitat in sites 1 and 3. The abundance of these species in the plateau of site 2 may support the theory of SOGREAH (1979), which suggests, using the evidence of the abundant floods in Wadi Adim, that the annual rainfall of this region approaches 300 mm. Therefore, these species, which require higher rainfall, in the order of

100-300 mm, become rare or absent in areas towards the north which receive less than 100 mm precipitation. Other species, such as *Indigofera spinosa, Jatropha spinosa* and *Maerua crassifolia* are also species which show a preference for areas of higher rainfall. These form an open woodland and grassland, at altitudes between 500 and 1900m, on the southern mountains and on some isolated mountains on the coastal plains (Al Khulaidi, 2000). These areas have a relatively higher annual rainfall than Wadi Hadhramaut (Figures 3.8, 7.2).

Similar vegetation is also found in other arid areas where moisture is the main limiting factor for plant growth. For example, some species that are common in the study area such as *Panicum turgidum*, *Fagonia indica, Rhazya stricta* and *Aerva javanica* are also restricted to wadi beds and the sands of the north-eastern and eastern desert areas of Yemen (e.g. Marib and Rada') and the deserts of Oman (Ghazanfar, 2004). It has also been reported that at lower altitude in the Hormozgan province in Iran a savanna-like community, of *Acacia tortilis, A. ehrenbergiana* and *Rhazya stricta,* is found along wadis (Zohary, 1973). The *Acacia campoptila* community association with *Panicum turgidum, Aerva javanica, Indigofera spinosa, Fagonia indica, Ochradenus baccatus, Dipterygium glaucum, Calotropis procera* and *Rhazya stricta* is also widespread in wadi beds in the arid areas of Marib and Rada', in western Yemen (Al Khulaidi, 1989, Wistinga et al., 1980, Al Hubaishi et al., 1979). Marib area (Figure 7.2) is characterised by more rainfall than the study area. Some characteristic species of wadi beds in these areas, such as *Leptadenia pyrotechnica, Lycium shawii, Jatropha spinosa* and *Acacia oerfota,* were absent in similar habitats in the study sites. These last two species were confined to wet slopes on the plateaus and were absent on the wadi beds in the study sites. Some characteristic species of the study area such as *Tephrosia apollinea* subsp. *longistipulata, Ziziphus leucodermis,* and *Merremia hadramautica* were not recorded in either Marib or Rada'. Within Yemen, these species are only recorded from Hadhramaut. Some species, for example *Jatropha spinosa* and *Acacia oerfota*, which are now restricted to areas of relatively higher rainfall on the plateaus may in the past, have also been found in the wadis. However, with decreasing moisture in the wadis, they are no longer found there.

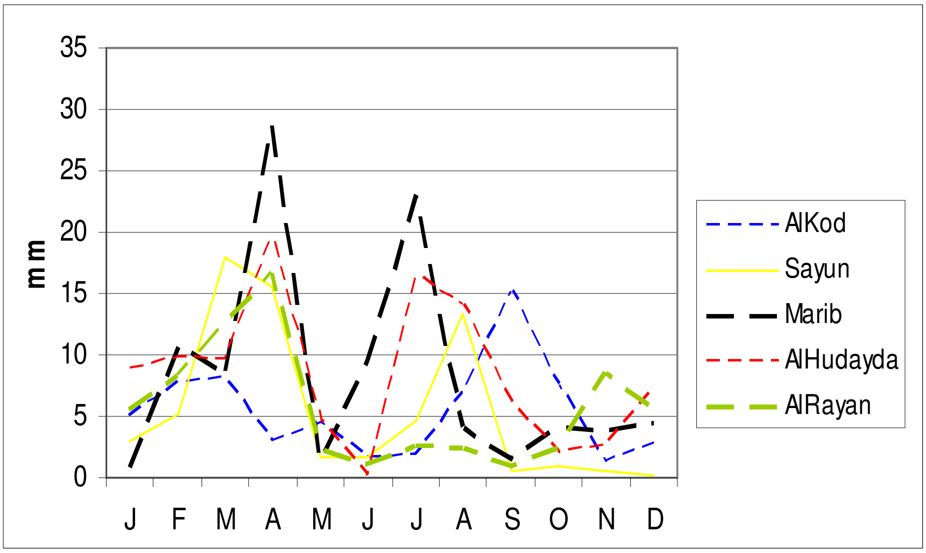


Figure 7.2. Average monthly rainfall of 6 areas in the coastal and northern and eastern dry zones, Yemen. It can be observed that the rainfall in the western coastal areas (alHudayda) is more than the southern coastal areas (al Kod and al Rayan). The rainfall in the western dry areas (Marib) is greater than eastern dry areas (Sayun). (Source FAO, 1997)

Places outside Yemen with a vegetation similar to the wadi vegetation of the study area, that is Acacia woodland or savanna-like communities in association with *Panicum turgidum, Leptadenia pyrotechnica, Aerva javanica, Calotropis procera and Ziziphus spina-christi,* are widespread throughout the Sahara-Sindian region and particularly in the wadis of Sudan, Egypt, Palestine and Arabia (Zohary, 1973; White 1983). *Ochradenus baccatus* corresponds to the southern limit of the northern zone of Hadhramaut where the rain falls mainly during the hot season, with 2 maxima, in spring and summer. This may correspond with the southern limit of Sahara-Sindian region (White, 1983). Other characteristic species of the main wadis, such as *Cressa cretica* inhabit saline fallow land in Egypt, inland salt marshes and *Alhagi graecorum* with *Tamarix nilotica* were found on sandy plains in Egypt (Abdul El-Ghani, 2000). This may indicate that the vegetation of the main wadis in the study area is of paleotropical origin (in this case with affinities to the Somalia-Masai reginal centre of endemism of White, 1983) although it is geographically located within the Saharo-Arabian or Saharo-Sindian elements of holarctic origin.

Arid and semi-arid regions are often characterised by an abundant flora of annual plants which complete their life-cycle within a relatively short favourable growth period (Zohary, 1973; Kutiel et al., 2000). Short-lived life forms such as annuals grow effectively in drought periods (Brown, 2001). The population of annual plants in the study area is high and comprises about 45% of the entire flora. Unlike other life forms, annual species respond directly to annual rainfall fluctuations (Kutiel et al., 2000). Annual plant species were seen to be strongly affected by the availability of moisture. They produce an enormous numbers of seeds which survive during the dry period and then grow rapidly with the onset of any short period of rain. During the fieldwork, annual species such as *Boerhavia elegans, Senna italica, Tribulus arabicus* and *Blepharis edulis* were abundant on the recently flooded wadi beds. Generally, over different visits to the study sites, the species richness and abundance was similar in the study areas, except for a slight increase in the number of individuals of some annual plant species such as *Boerhavia elegans, Senna italica* and *Blepharis edulis* on the flood plains. An experimental enclosure, located in Wadi Al-Khun (Bataher, 2004), in the northern part of the study area, shows also that *Tribulus arabicus, Cleome brachycarpa, C. scaposa, Cenchrus ciliaris, Dichanthium insculptum* and *Stipagrostis hirtigluma,* appear at very high densities in the rainy season and fall to low or absent in the dry season.

The amount of rainfall required to initiate the germination of annual plant species in arid areas has been studied by different scientists (Gutterman, 1993; Went, 1955). In the study sites, very light showers in spring were enough to create a large number of annual species.

Competition between plants in low density cover is negligible (Brown, 2001). Because the vegetation of the study sites is generally sparse, the competition is likely to be low or absent. Generally the most abundant species were found to be more competitive (Goldberg and Estabrook, 1998; Brown 2001). In the study sites, the most abundant annual species was the endemic *Boerhavia elegans,* which germinates quickly and survives successfully in the harsh environment and in over-used areas.

Because of possible toxic substances present in the oil, the problem of the extinction of plant species in certain areas is expected to be high in the long run. This is especially true for annual plant species, which rely on regular germination to maintain populations (Brown, 2001). The seed banks in the sand under the soil are also expected to be reduced. At sites near to oil-contaminated areas, species with similar ecological preferences such as *Stipagrostis hirtigluma, Maerua crassifolia, Hochstettera schimperi* and *Commiphora kua* were abundant. Some species such as *Farsetia linearis, Tamarix arabica, Dichanthium insculptum, Tephrosia apollinea, Boerhavia elegans* and *Dichanthium insculptum* seem to be tolerating oil contamination, but toleration may not last for long. Several studies have highlighted that the vegetation density of desert areas is closely related to soil moisture availability, so the high cover of these species on this site may be due to large quantities of seed in the "seed bank", and also because of the tendency for there to be more moisture available in the polluted areas. Generally, more studies and monitoring need to be done before a conclusion can be drawn on the long-term effects of soil pollution.

It is clear that moisture is an important factor for plant growth in the study area. The woody and perennial vegetation in the area is concentrated, or contracted, in areas where moisture is available such as drainage lines, depressions, furrows, man-made channels. Changes in the proportion and abundance of woody and perennial species require a steady increase in moisture over a period of months whereas slight increases in rainfall may rapidly alter plant cover and composition due to the rapid appearance of annuals.

7.3.2. Topography

Heterogeneity of the local topography, edaphic factors, microclimatic conditions and degree of slope lead to variation of the distribution of plant associations (Furley and Newey, 1983; Al Wadie, 2002). In Brazilian savanna, variations in topography and drainage have resulted in different forms of vegetation structure (Furley, 1999). As an analogous example, variations in microclimate with topography and elevation were a major factor of species distribution within a forest landscape in Hubei Province, China (Yu Hua, 2000). In the desert ecosystem, topography is an important related factor because of its effects on the runoff of water and potential or free water evaporation. Also rainfall is an important factor for determining the structure and composition of desert vegetation (David et al., 1993).

As elevation increases, precipitation increases and temperature decreases (Vandeven, 1999). Aspect, slope, and surrounding topography determine potential isolation so that in the northern hemisphere, south-facing slopes are warmer and north-facing slopes cooler. Environmental heterogeneity including topography is thought to have a significant influence on the dynamics and structure of plant communities (Morzaria-Luna, et al.,2004). The mountains can also offer maximum modification of the arid climate by reducing air temperature or by shade effects and air drainage among the peaks and valleys (Eyre, 1969).

In the study sites, there are obvious macro-features of topographic heterogeneity, from the wadis to the plateaus. At the micro-climatic scale, the topographic forms contain depressions, narrow channels and rock outcrops (plate 7.4 to 7.8). These different features have dramatically affected the distribution of vegetation as well as the type of plant community. The low plant density on the slopes of plateaus and those facing the main wadis may also resulted from topography that is characterised as being very rocky, with shallow soil of low fertility. On the cliffs, where the slope is very steep, there are hardly any plant species, because of the steepness and vulnerability to soil erosion. The inter-plateau slopes have more vegetation than the slopes facing the main wadis. Main wadis have a relatively high vegetation cover and are mainly composed of dwarf shrubs and herbs with scattered trees, mainly *Acacia campoptila*. The density of vegetation varies from site to another, for example the vegetation on wadis facing south was high except on areas with rock outcrops. In general the number of species is high in wadis that have a high percentage of rock outcrops. These create micro-climatic conditions for plants to grow such as *Cleome brachycarpa, Fagonia indica, Zygophyllum simplex, Aerva artemisioides* subsp. *artemisioides, Zygophyllum coccineum,* and *Ficus cordata* subsp. *salicifolia.*

Altitudes and topography also play an important role in governing plant distributions. Small changes in elevation are influential, for example, *Acacia oerfota, A. mellifera, Corallocarpus glomeruliflorus, Jatropha spinosa, Commiphora kua, Tarenna graveolens and Cadaba heterotricha* are confined to plateau drainage lines and slopes (over 700 m). The absence of these species in the main wadis and adjacent slopes can be due to the low altitude of these habitats (less than 600 m) and past human activities such as over-grazing and fire wood collections or most likely these species prefer cooler and moister sites that are characteristic of their current habitats on top on the plateau. Some of these species, especially *Corallocarpus glomeruliflorus, Jatropha spinosa, Commiphora kua,* have been and are still used by local people as folk medicines. Where sites have been affected by increased runoff or soil erosion, less common species such as *Seetzenia lanata* were rare or absent.

Variation in vegetation pattern was also seen due to disturbances of surface soil, or due to presence of micro-sites such as furrows cutting the slope and depressions or fallen rocks and finer particles accumulating at the base of the mountain slopes. These micro-sites contribute to additional species by improving soil moisture in the soil. For example *Periploca visciformis, Leptadenia arborea, and Ficus cordata* subsp. *salicifolia* were seen only on isolated slopes near water ponds or very wet slope drainage lines.

Plate 7.4. An example of microclimate change is stone ring on the plateau. As can be seen more vegetation cover is found around the site. This stone ring feature also plays an important factor in diverting water to the adjacent slopes and as a result,, the vegetation on that slope become denser than the rest of the slopes (see association 13). The origin of the stone ring is possibly archaeological site from the Stone age (McCorriston, 2000).

Plate 7.5. The vegetation is concentrated only on gullies and runnels, where moisture is available. Top: the main wadi (site 2): *Acacia campoptila* and *Rhazya stricta*, bottom: the slope facing the main wadi (site 3): *Acacia hamulosa* with *Stipagrostis hirtigluma* and *Farsetia linearis.*

Plate 7.6. The surface of some secondary wadi on the plateau is covered by bare pavement rocks with soil covering less than 3%.

Plate 7.7. Stones and rock outcrops (Shieb Sultan, site 1), under the arid conditions of the study area, this type of landform which is located directly at the bottom of the plateau, where different size of rocks and fine soil materials are accumulated, is favourable habitat for plants. Most of runoff water from the plateau above is well preserved here and protected against evaporation. In addition, big rocks become favourable habitats for several species such as *Acacia campoptila, Tephrosia apollinea, Tephrosia dura* and *Maerua crassifolia* (see association 4).

Plate 7.8. A desert pavement (a surface gravel deposit of tightly packed pebbles, devoid of vegetation) is found on wadi bed surfaces site 2, Pavements such as this occur in areas where the stream flow is restricted to relatively stable channels nearby (background).

Desert plants are highly sensitive to disturbance (Brown, 2001). Roads created by oil working activities and trampling by animals have resulted in compaction of the soil surface preventing roots from penetrating the soil (Plates 7.9a, 7.9b and Figure 7.4). Brown (2001) found that slight depressions caused by passage tracks on the desert surface can be regarded as important micro-sites for desert annuals; in these depressions, seeds may accumulate in large quantities. Off-highway vehicles have also disturbed large areas of the Mojave and Colorado deserts. The effects of these vehicles destroy soil stabilizers, resulted in soil compaction, increased wind and water erosion (Busack and Bury, 1974), and the destruction of vegetation (Webb and Wilshire, 1984). Off-road vehicle and hiking activity also have greatly expanded direct human use both spatially and temporally (Belnap, 2002).

On the disturbed sites of the plateau where the land surfaces have been cleared, the first species to colonise appear to be *Zygophyllum simplex* and *Farsetia linearis*. *Zygophyllum simplex* was the most common annual seen in the desert of Oman after rain, especially in sandy depressions. (Ghazanfer, 2004).

Plate 7.9a. Roads created by oil working activities have resulted in compaction of the soil surface (red arrow).

Plate 7.9b. Roads created by oil working activities have resulted in compaction of the soil surface. (photo by Henry Thompson).

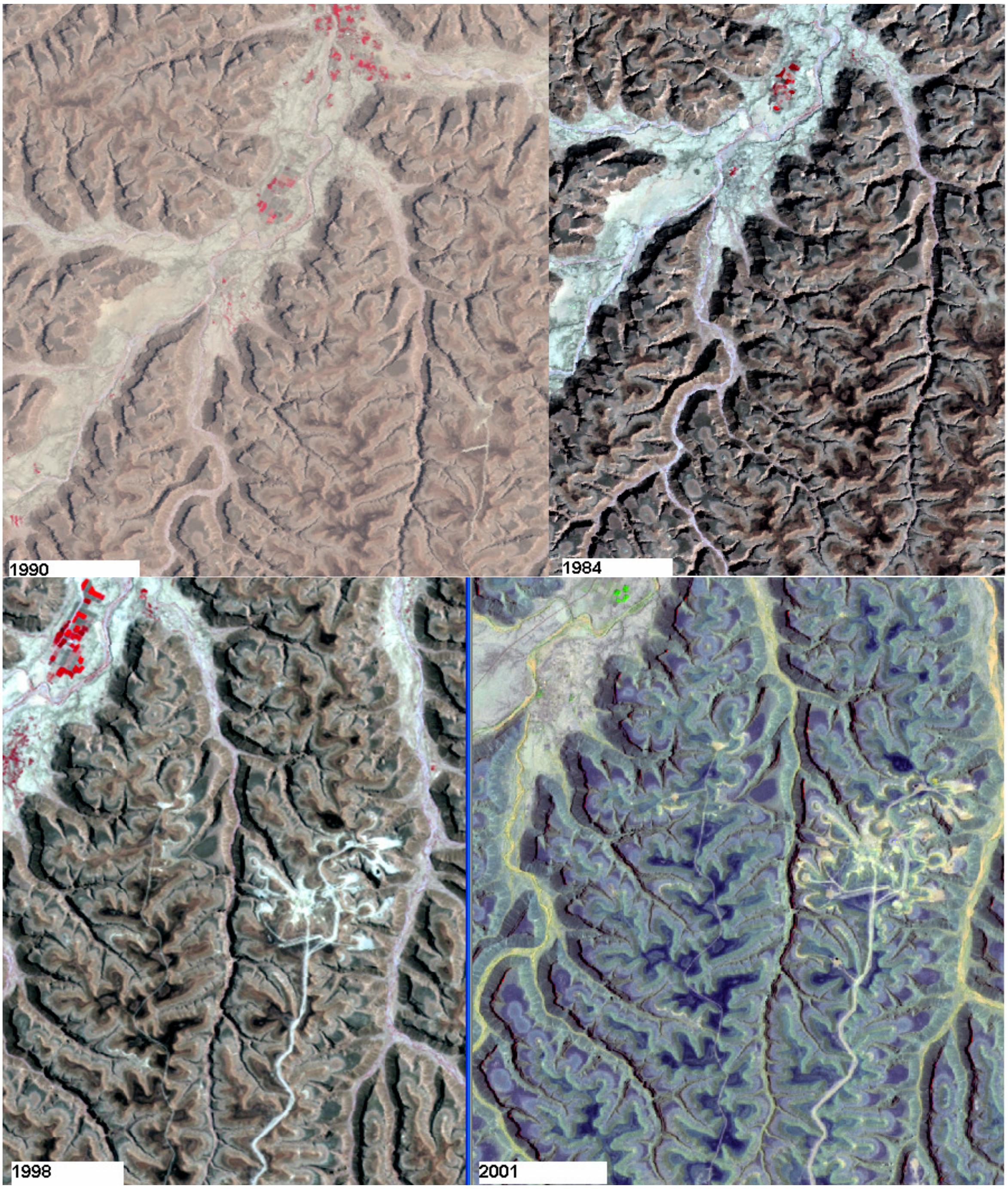


Figure 7.3. Off-road effect. Oil working activities have a high impact on soil and vegetation cover on the plateau. These satellite imageries show a negligible off-road impact in 1984 to very high impact in 2001. Soil cover and the sparse vegetation on the plateau surfaces have been altered by extensive off-road travel. Some damage will remain obvious for decades. The current oil exploration survey methods which incur a high density of trails and cover extensive areas are readily visible from the air. The potential for further damage still exists because of the large number of vehicles and facilities used for exploration.

It has been demonstrated here that one of the main factors related to vegetation variation in the study area can be linked to topographic position. Other variables such as soil moisture, soil type and pH are clearly a consequence of topographical changes. The influence of landscape changes was very dominant. Each ecological zone paralleling landscape change has its own plant species. Some species were found almost in all ecological zones, and others are confined to specific and favourite sites.

7.3.3. Floods

Wadi vegetation results from hydrological disturbance, including periodic floods, erosion and alluvial deposition (Robert and Thomas, 1997). Extreme floods have been recorded in the main wadis of the study area by Lewcock, (1987); INTERCONSULT and MacDonald (1993); SOGREAH (1979).

Sociological species groups showing adaptations to these processes were B, C and E, namely *Zygophyllum album, Prosopis juliflora, Tamarix aphylla, Citrullus colocynthis, Heliotropium rariflorum, Dipterygium glaucum, Calotropis procera, Acacia campoptila, Fagonia indica, Tephrosia apollinea subsp. longistipulata* and *Cymbopogon schoenanthus.* These species were most common on active wadi surfaces such as bare grounds gravel areas, flooded wadi beds and wet patches.

There is a very obvious vegetation transition from extreme to moderately flooded areas. This can be observed in the transition from former date palm fields to vegetation association 2 (Chapter 5). In this association, species which have the capacity of withstand the force of peak stream flows or to ability to colonize bare stone substrates rapidly are common. These are species of groups B and C (Table 5.6), the structure of this habitat is characterised by being sparse grassland. Vast areas of these habitats are occupied by *Prosopis juliflora*. This species was once planted widely for sand dune stabilization, probably around 1990, but it has become a major problem over large areas of the Wadi Hadhramaut (see 7.2.4).

The distribution of some species is related to stability of the surface for example sociological groups F, G and M (namely *Kohautia retrorsa, Acacia hamulosa, Barleria aff. bispinosa, Tephrosia dura, Zygophyllum coccineum* and *Ziziphus leucodermis).* These species prefer relatively stable less flooded surfaces such as tributary wadis or the base of mountain slopes. Some species show adaptations to extreme floods; these are *Zygophyllum album, Prosopis juliflora, Tamarix aphylla, Citrullus colocynthis, Heliotropium rariflorum, Dipterygium glaucum, Calotropis procera, Acacia campoptila, Fagonia indica, Cymbopogon schoenanthus* and *Tephrosia apollinea* subsp. *longistipulata.* These kinds of habitat contribute to raising number of the plant species especially, the exotic, which may be brought in by floods from other areas.

Well-established vegetation dominated by *Acacia campoptila* is found on parts of the flood plain that generally do not receive intensive flood waters (Plate 7.10). On the active surfaces a dwarf srubland consist of not more than 6 plant species dominated by *Merremia hadramautica* and *Tephrosia nubica* is common, since these plants are adapted to rapid colonization of disturbed and flooded surfaces.

Plate 7.10. Wadi bed of site 3 (plot 305). The active surface on the right and another less active, higher on the left only receive water during the most intense flooding events. Well-established vegetation dominated by *Acacia campoptila* is found on parts of the flood plain that generally, do not receive intensive flood waters. The plants on the active surface is a dwarf shrubland dominated by *Merremia hadramautica* and *Tephrosia nubica*; these plants are adapted to rapid colonization of disturbed and flooded surfaces.

Extreme floods are common in main wadis. Floods have a significant effect on the structure of vegetation of wadis which to have varied relationships with surface and ground water. Some associations develop under the conditions where their deep root systems can utilize the water from basal gravel and lower, silty alluvial layers (Coode Blizard Ltd 1997). In these habitats, woody perennial trees such as *Acacia campoptila, Ziziphus leucodermis*, the date palm *Phoenix dactylifera* and the invasive *Prosopis juliflora* form their own distinctive associations. Savanna-like vegetation or pseudo-savanna as defined by Zohary (1973), on wadi beds and runnels in several locations, has been transformed to Prosopis woodlands due to the encroachment and establishment of the invasive tree *Prosopis juliflora*. Pure stands of *Prosopis juliflora* woodlands are common now in the river beds of the main Wadi Hadhramaut

The association dominated by *Zygophyllum album* and *Dipterygium glaucum* was only found on relatively wide wadis that are subjected to severe flooding, with loamy to loamy sand soil combining a high proportion of sand (86-88%). Other species with this association are *Citrullus colocynthis, Heliotropium rariflorum, Dipterygium glaucum, Panicum turgidum, Prosopis juliflora,* and *Tamarix aphylla.* Most of these species form deep roots, which probably offer good mechanical support against the relative high water velocity during the flood periods (Wittmanna et al., 2004), see Plates 7.2 and 7.11.

Plate 7.11. Vegetation dominated by *Zygophyllum album* on extreme flooded wadi beds (site 1). A succession community from palm field cultivated lands and woody vegetation dominated by *Ziziphus leucodermis, Acacia ehrenbergiana, Acacia hamulosa* and *Tephrosia dura.*

It is has been shown that extreme floods have a significant effect on the structure of vegetation of wadis. Floods, as an abiotic factor, also contribute largely in destroying and disappearing of some individuals trees. Floods also contribute to raising the number of plant species especially the exotic, which may be brought in by floods from other areas, example are *Prosopis juliflora* and *Zygophyllum album.* As a result of severe floods, the woody vegetation dominated by *Ziziphus leucodermis, Acacia ehrenbergiana, Acacia hamulosa, Tephrosia dura* and date palm trees has disappeared or shrunk in coverage and has been replaced by other communities more resistant to the severe-floods and disturbances.

7.3.4. Human activities

The effect of man on the desert vegetation may be directed to the vegetation cover itself or indirectly through its influence on the other components of the ecosystem (Batanouny, 1983). Biodiversity is being affected in many parts of the world as a result of human activities, especially land degradation and the overuse of resources. As an example, in 1995, approximately 10% of species in the Himalayas were listed as threatened, and the number of extinctions has increased since then. (UNEP and WMO, 1996). Due to unrestricted cutting of wood of vegetation, over-grazing by livestock, and cultivation of unsuitable lands, many arid zones have an inadequate timber, fuelwood, and fodder resources (FAO, 1989). Human activities and overgrazing have resulted in the destruction of the natural vegetation and changing the vegetation structure in many parts of the world (Humphry, 1962; Eyre, 1969; Sutter and Ritchison, 2005). Over-grazing is considered as the major cause of desertification in arid and semi-arid areas of the world (Brown, 2001) and has a major effect on plant diversity and composition (Todd, and Hoffman, 1999) as well can causes soil compaction and contributes to erosion and decreases soil fertility, organic matter content and water infiltration and storage (FAO, 1997; Webb and Stielstra, 1979).

In the study area, uncommon or short-lived species that are selectively grazed or collected by local people during very good seasons are more likely to decline; instance of these are *Boerhavia elegans, Corallocarpus glomeruliflorus, Lasiurus scindicus, Commiphora kua, Commiphora foliacea* and *Tribulus arabicus,* Over-grazing has selectively affected the abundance of some species, in particular *Merremia hadramautica, Boerhavia elegans* and *Tribulus arabicus.* The first species is abundant on wadi beds of site 3 and is found with low cover near cultivated and fallow lands in sites 1 and 2. The abundance of these species in site 3 is due to control of grazing by local people in the past.

The people in the study area have used to have traditionally made sustainable use of their natural habitats and conserved biodiversity - for example through the protection of land above cultivated fields during cultivated season. However, this system is not any more found, as a result overgrazing and other human pressures, contributing to rarity of some species such as *Boerhavia elegans*, and probably have contributed the extinction of some native plants.

Roads and other human activities, especially on the plateaus, have affected vegetation cover. Many sites have been eroded and some species on eroded slopes have disappeared due to road construction, for example species such as *Seetzenia lanata*, and *Monsonia heterotropoides* are rare or absent in such conditions. Generally, soil surface disturbance and destruction of established plants offer small gaps (Focht and Pillar, 2003), which allow such areas be dominated or invaded by species that were not abundant in the site. Examples are the replacement of community dominated by *Dichanthium insculptum* with the community dominated by *Chrozophora tinctoria, Boerhavia elegans, Aerva javanica, Calotropis procera*, *Zygophyllum simplex* and *Fagonia indica* on the disturbed sites on the plateau of site 1.

The impact of waste water on vegetation seems more positive, since the release of water has produce vigorous germination and growth of plant species (Plate 7.12). Some of these species may be truly xerophytic and cannot tolerate high water levels, or they may intolerant of salts and chemicals in the waste water, as a result they may disappear from the site once the bank seeds in the soil have been exhausted. The surface disposal of water which flows over dry slopes can lead to rill or gully erosion and the concentration of salt in this water may kill sensitive plant species (Plate 7.13). According to Komex International Ltd (2001), the contaminated water impact can be very bad, because the water is highly mineralised, the total dissolved solids can reach around 2,000 - 3,500 mg/lt - of which chloride and sodium comprise around 75% and when the companies dispose of the water on the plateau, the water infiltrates into the Jeza formation and infiltrates through the Jeza clays to the top of the Umm er Radhuma. It then has to seep out into the small spur wadis and flow down toward the main wadis. On the way the water picks up more salts in the Jeza, and evaporates, so becomes hyper-saline. By the time the water reaches the small side wadis the salt content may be as high as 8,000 mg/lt. This water then runs into the small kareefs and wadis - and sits in the root zone of the small trees that line the side wadis which may die. On the plateau, dead trees were observed below the spray farms of surface water disposal systems of companies such as DNO, TOTAL, and DOVE.

Plate 7.12. The impact of waste water on vegetation. Some of these species may be truly xerophytic and cannot tolerate high water levels, or they may intolerant of salts and chemicals in the waste water, as a result they may disappear from the site once the bank of seeds in the soil is finished. The vegetation here may be dominated in future time by salt-tolerant tree species such as *Tamarix arabica.*

Plate 7.13. The impact of concentration of waste water on the vegetation cover. Completely bare lands due to concentration of waste water.

Waste water which flows from the slope to the wadi bed and contaminates the vegetation, has caused the death of some sheep and goats. This is one of the reasons why Bedouin are reducing grazing on the plateau and in areas near oil compounds. As a result, the pressure on natural vegetation of the main wadis has increased, and the Bedouin have started moving to other territories, thereby breaking the traditional way of grazing. Examples of this process are found in site 3, where the residents have complained of grazing invasion from Bedouins. Many of the traditional Bedouins have now settled in the study area. Changes in lifestyle, mobility and dependence on modern transport have affected the way people use the rangelands. In the past, every tribe had its own region for grazing. In dry times, a Bedouin from one tribe could move to the region of another tribe with his camels and sheep or goats. Some of these traditional grazing systems have been neglected as Bedouins have come to depend on cheap supplements such as sorghum, alfalfa (*Medicago sativa*) and *Prosopis juliflora*.

Grazing in the study area may be also an important factor but it was not evaluated completely in this study. The variations of vegetation structure found in each floristic vegetation association may be due to over grazing and woodcutting. *Tephrosia dura* in association 3 is found in some locations with a high ground cover, and its occurrence could be a sign of overuse. Over-grazing, has a direct impact on species richness in different parts of the study sites, especially on the species that grow close to the villages in localities such as wadi beds and surrounding mountain slopes. Some of the species of arid lands have adapted to survival by growing in open, overgrazed areas (Naveh and Whittaker, 1979), and *Blepharis edulis* and *Boerhavia elegans* may represent such grazing-adapted species.

The collection of some plants for medicinal or other purposes also has an impact on certain species such as *Boerhavia elegans, Corallocarpus glomeruliflorus,* and *Rhazya stricta.* According to local people*, Boerhavia elegans* was abundant 15 years ago and the farmers are used to harvest about 3 sacks seeds of this plant. As a result of reduction of precipitation and over-grazing in particular uncontrolled grazing by local and Bedouin people, the cover of this species has dramatically decreased. The grazing was practiced mainly on the river beds and was not allowed on the slopes at particular times, such as during cultivation and before harvesting of *Boerhavia elegans.*

Intensive grazing was noticed in sites 1 and 2. However, with the arrival of nomads to the study sites, in particular during rainy seasons from different parts of the Hadhramaut region, (Figure 1.20) grazing may become more intensive in previously less affected areas such as site 3, and local people have complained about this problem. As a result, some species that are abundant in sites 3 and are rare or become rare in other part of the study sites will be easily targeted by goats and camels in future time. For example palatable species such as *Merremia hadramautica, Tephrosia nubica* and *Panicum turgidum* are abundant and form shrubland communities in different locations in site 3 (see Sociological species group O, Table 5.6). The intensive grazing co-incident with extreme floods, has inhibited the development and growth of this woody vegetation in the other study sites. As a result, the vegetation composition and the vegetation structure have been changed. It is a general observation that in Mediterranean ecosystems, grazing inhibits the development and growth of woody vegetation (Carme and Kadmon, 1999) and results in larger herbaceous cover and lower tree cover. In contrast, grazing may create niches for woody seedling establishment, by trampling and/or reducing the biomass of competing herbaceous vegetation (Carme and Kadmon, 1999; Sutter and Ritchison, 2005). As a further illustration, because of grazing over the last 100 years, the structure, composition, and dynamics of semi arid western, interior forests of United States have changed dramatically (Belsky and Blumenthal, 1997). Batanouny (1979) reported that overgrazing between Jeddah-Mecca road, Saudi Arabia resulted in severe destruction of vegetation dominated by *Panicum turgidum* and replaced by habitat dominated by *Dipterygium glaucum*. In the study sites *Panicum turgidum* was rare and the degraded sandy wadi beds were dominated by *Dipterygium glaucum and Zygophyllum album.* Generally, to assess the effect of grazing on the structure and the composition of the vegetation in the study area, long-term monitoring research on the effects of grazing on vegetation dynamics is needed.

Land use varies across the region depending on its suitability for agricultural or grazing activities. For example, much of the main wadi beds, which run almost at the middle or near the foot slopes of the main wadis, are covered by desert alluvial wadi vegetation of shrubland with scattered trees of *Acacia campoptila* associated with *Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus, Boerhavia elegans* and *Dichanthium insculptum* (see associations 4 to 7). In contrast, much of the fertile land, such as the foot slopes at the bottom of the plateau, is privately held and intensively cultivated by palm trees and other annual crops such as sorghum and wheat. The rocky slopes facing the main wadis and the plateau surface are covered by stony and gravely desert vegetation type dominated by herbaceous plants namely *Stipagrostis hirtigluma, Farsetia linearis, Aristida triticoides Fagonia paulayana, Boerhavia elegans* and *Dichanthium insculptum.* The slope on the plateau and the secondary wadis are generally less affected by human activities due to inaccessibility. As a result, still quite dense vegetation can be seen in some favoured sites, the vegetation here comprises shrubland dominated by Jatropha spinosa with *Zygophyllum decumbens, Commiphora foliacea, Commiphora kua, Maerua crassifolia. Cadaba heterotricha, Tarenna graveolens, Aristida triticoides* and *Grewia erythraea.*

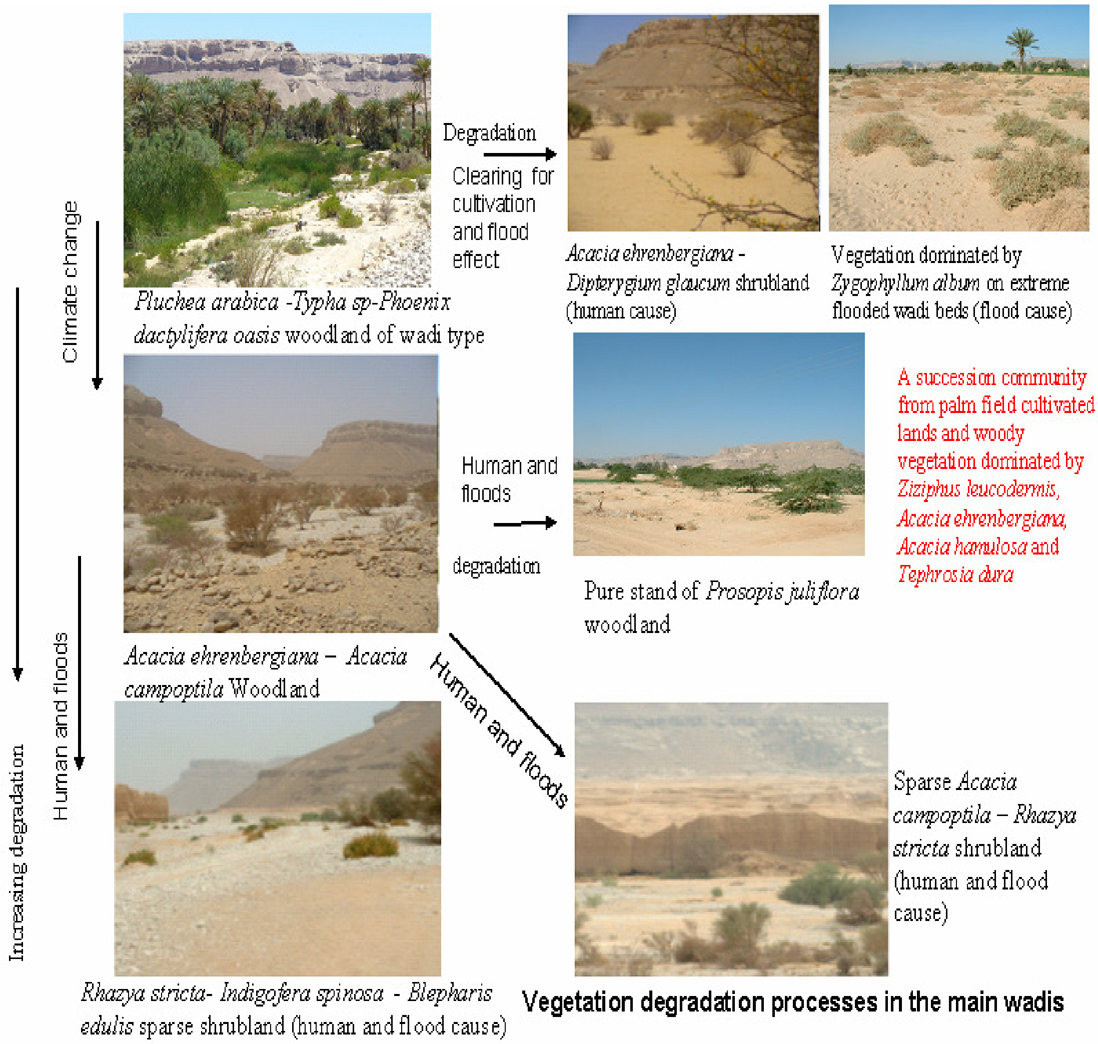
Native people influenced the vegetation intensively through grazing and agricultural clearing across the region from at least the post-Neolithic second millennium BC (McCorriston, 2000) until the 1880s, when many of the Hadhramaut people emigrated to Indonesia and Arabia (Boxberger, 2002). Lithic studies of surface material suggest that the study area was re-occupied or re-used as early-mid-first millennium BC (McCorriston, 2000). During the most recent glacial period in the northern hemisphere, the climate of the Arabian Peninsula was one of extremes of heat and cold, but this has gradually changed over the past 12,000 years into climate that we are familiar with today (Mundy and Musallam, 2000). Clearing of the land for agriculture and grazing or woodcutting peaked in the early 1900s, and then declined dramatically because of intensive of migration to the Far East Asia and Arabian Peninsula, after which lands were abandoned or naturally regenerated to woodland. Many of these abandoned lands have turned now to bare bad land severely eroded by deep gullies. Today, about 80 percent of the landscape in the study area is covered by range and marginal lands and less than 20 percent is utilised as agriculture, mostly irrigated.

The species composition has changed from species established as the result of past disturbances to more tolerant species and is adapted the current dry environment as the result of the decreased disturbance regimes after 1880. However, the disturbance has picked again after the unification of the countries (north and south Yemen) in 1990, with the development of the land use by human activities. This rapid development has caused high damage to the past vegetation and has led to the almost total disappearance of trees and shrubs from many places of the study area. For example, the vegetation in the main wadi, which was dominated *by Acacia campoptila, A. ehrenbergiana, A. hamulosa, Rhazya stricta, Ochradenus baccatus Ziziphus leucodermis, Tamarix aphylla* and *Salvadora persica* has vanished from several locations. Association 5 is probably a relict of this type of past vegetation community.

Most arid and semi-arid lands have sparse vegetation cover, low surface-soil organic matter content and significant nutrient loss (Heff et al., 2005). Due to human activities, there has been a long-term reduction of the vegetation over time in part of the world. The long-term depletion of soil nutrients by intensive pastoral activities has been proposed as a factor contributing to degradation in Australia and New Zealand (Harris, 2000). Long term extensive grazing in north-eastern Arabia and gradual depletion of soil resources have led to a transformation of what was once a very open savanna-like woodland, to steppe and perennial less palatable species (Brown, 2001).

Figure 7.4 shows the degradation processes in the main wadis, due to human activities and climate change, the former vegetation type has been altered to different forms of associations. Due to human activities and other disturbances, the unique areas of the study area covered by native species maybe replaced by species that are widespread and adapted to disturbed habitats such as *Prosopis juliflora, Calotropis procera* and *Zygophyllum album.* As a result, the vegetation of the study area could become more homogenous. This is already noticed in the main wadis, where past vegetation dominated by *Acacia campoptila, Ziziphus leucodermis, Tamarix aphylla* and *Salvadora persica* has been replaced by a pure stand of *Prosopis juliflora* woodlands. Studies conducted in the United States (McKinney, 2004) concluded that human activities have significantly increased the amount of homogenization by increasing the percentage of non-native plant species among disturbed communities. In the following figures (Figures 7.4 to 7.8) vegetation change processes are shown by changes in plant cover, biomass and biodiversity within time.

In contrast to the study sites, the flat limestone plateaus of the southern Hadhramaut region (Figure 7.6 top right) have a higher cover of vegetation than the northern plateau (bottom right) dominated by shrubs and dwarf shrubs. This is because the southern plateau has more rainfall than the northern plateau. The increase of moisture will turn the vegetation of the slopes and secondary wadis on the plateau in the study sites to a dense grassland dominated by *Dichanthium insculptum* and *Farsetia linearis* (bottom left, Figure 7.7), which then leads to its climax condition which can be a woodland dominated by *Acacia mellifera, Maerua crassifolia, Cadaba heterotricha, Tarenna graveolens,* and *Commiphora spp.* (top left, Figure 7.7).



Vegetation degradation processes in the main wadis

Figure 7.4. Vegetation degradation processes in the main wadis.

Figure 7.4 explains that the main wadi bed of site 2 (top left was dominated by *Typha* sp*,* and *Pluchea arabica* with Palm trees. Nowadays the river beds that used to be permanent have become seasonal, filled up after rain and remain dry during the rest of the year; as a result the vegetation cover has dramatically changed to the current savanna-like habitat dominated by *Acacia campoptila* and others that are adapted to arid habitats (middle left). With the extreme floods and human activities the vegetation in many parts turned to sparse cover with scattered of *Acacia campoptila, Rhazya stricta, Indigofera spinosa* and *Blepharis edulis* (bottom left and bottom right) or to sparse dwarf shrubland dominated by Zygophyllum album (top right) or to sand dune shrubland habitat dominated by *Acacia ehrenbergiana* and *Dipterygium glaucum*. (top middle). Generally in the main wadis, a few stands of typical paleotropical vegetation with *Salvadora persica,* and *Tamarix aphylla* also serve to give an impression of what the previous climax vegetation might have been like when the climate was wet and before it was replaced by a vegetation association dominated by *Acacia campoptila* with *Fagonia indica, Tephrosia apollinea, Cymbopogon schoenanthus, Rhazya stricta, Ochradenus baccatus* and others that can survive the present arid climate.

Figure 7.5. Vegetation degradation processes on the mountain slopes facing the main wadis

Figure 7.5 shows the degradation processes on the mountain slopes facing the main wadis. Due to over grazing, the slopes that were covered by dense grassland and were dominated by *Boerhavia elegans* and *Stipagrostis hirtigluma* have become degraded to bare lands or to sparse grassland with few *Cleome droserifolia* and *Fagonia paulayana* species.

Figure 7.6. Vegetation degradation processes in the mountain slopes facing the main wadis

The degradation processes on the plateau and in the secondary wadis are illustrated in Figure 7.6. The top 2 pictures show the current vegetation cover of the southern part of the Hadhramaut region. Probably the vegetation of the northern part of the region was similar to this type of vegetation, but due to climate change and human impact, the vegetation cover degraded to sparse cover with few scattered species that adapted to current climate. The vegetation of the plateau (top right) was more favourable to tree and shrub life and then replaced gradually by vegetation which is dominated by herbaceous plants.

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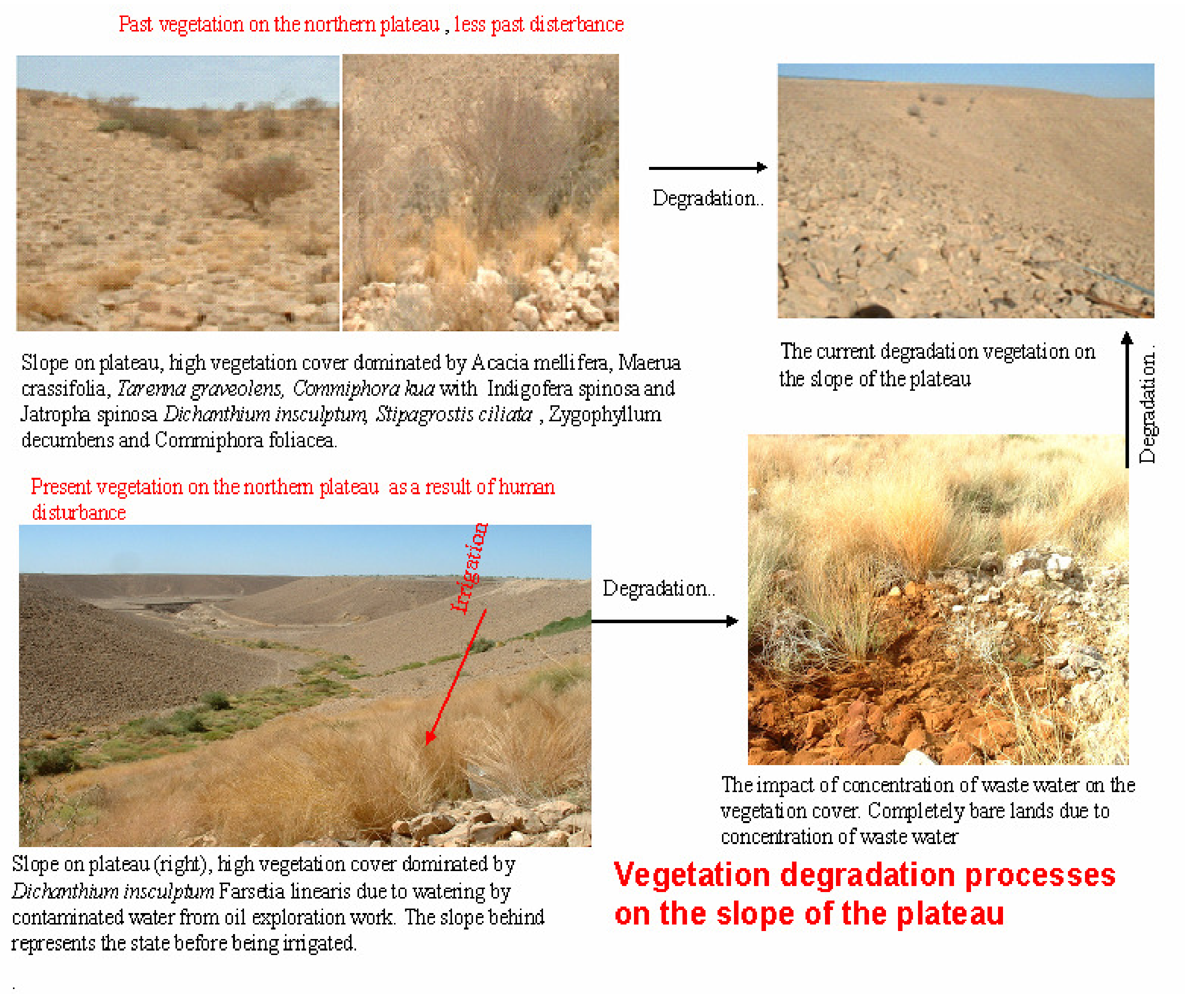

Figure 7.7. Vegetation degradation processes on the slope of the plateau.

The degradation processes on the slopes of the plateau can be noticed in Figure 7.7. The picture top left show the climax vegetation which may represents the past vegetation of these slopes. This vegetation type is dominated by *Acacia mellifera, Tarenna graveolens, Commiphora kua, Maerua crassifolia* and *Jatropha spinosa*, but due to human activities and climate change, the vegetation cover of these slopes has degraded to a sparse cover with few scattered species that adapted to the current climate, such as *Jatropha spinosa.* This stage represents association 13 (*Maerua crassifolia - Jatropha spinosa - Stipagrostis hirtigluma* association) which is dominated by *Jatropha spinosa* with *Maerua crassifolia, Commiphora* *foliacea Zygophyllum decumbens, Stipagrostis hirtigluma, Dichanthium insculptum* and others, then it has degraded again to sparse grassland with few plant species, such as *Zygophyllum decumbens, Dichanthium insculptum*, *Boerhavia elegans*, *Cleome brachycarpa* and *Indigofera spinosa.* This stage is represented by association 12 *(Zygophyllum decumbens - Dichanthium insculptum*). Increasing moisture on the slopes can results in dense vegetation cover dominated by *Dichanthium insculptum* and *Farsetia linearis.* This was noticed on the slopes that been irrigated by waste water (bottom left, plate 7.7).

The following figure shows a summary of the vegetation degradation processes on the slopes of the plateau.

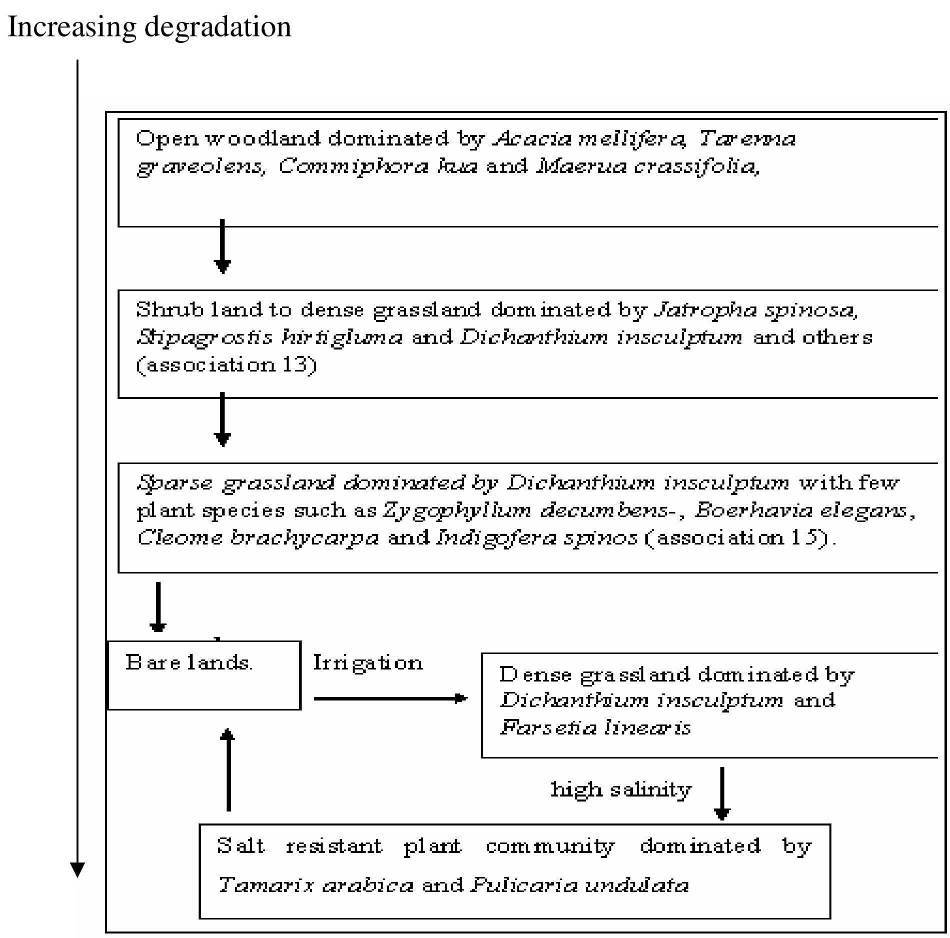

Figure 7.8. Vegetation degradation processes on the slopes of the plateau.

Prosopis juliflora (Mesquite) is an invasive species that was observed only in site 1, but it has recently invaded neglected agricultural land and wadi beds in many parts of Wadi Hadhramaut (Plate 7.14 and Figure 7.9). This can be as a result of the increase in modern agricultural activities in recent years (after 1800). In some locations, it forms a pure stand of woodland. Local people suggested that *Prosopis juliflora* reached Wadi Hadhramaut as recently as 1990. This species was not recorded from Wadi Hadhramaut in the report of Barkuda and Sanadiqi (1986). Mesquite is a fast-growing, deciduous tree native to the West Indies, Central America, and northern South America. It is an invader species that competes with native species in many parts of the world. The species grows in very hot regions with annual precipitation from 150 to 750 mm and from sea level to 1500 m (Tiedemann, 1973). The roots penetrate to great depths in the soil (more than 50 m) over a variety of soils, including saline and alkaline areas and in sandy and rocky conditions (Hultine, 2000). *Prosopis juliflora* avoids drought by developing root systems that can access deep groundwater that is unavailable to other plants. This phenomenon has allowed *Prosopis juliflora* to survive in arid regions that are generally not suitable for many plant species. As in a number of countries such as south western North America (Kevin, 2001) and in the arid and semi-arid parts of the India and Pakistan (FAO, 1993), the natural habitats of shrubland or grassland have been transformed to woodlands due to the encroachment and establishment of the *Prosopis juliflora*.

Plate 7.14. *Prosopis juliflora* has recently invaded abandoned agricultural land and flooded wadi beds in many parts of Wadi Hadhramaut. In some locations it forms a pure stand of woodland.

The following 2 satellite images show the area occupied by *Prosopis juliflora.*

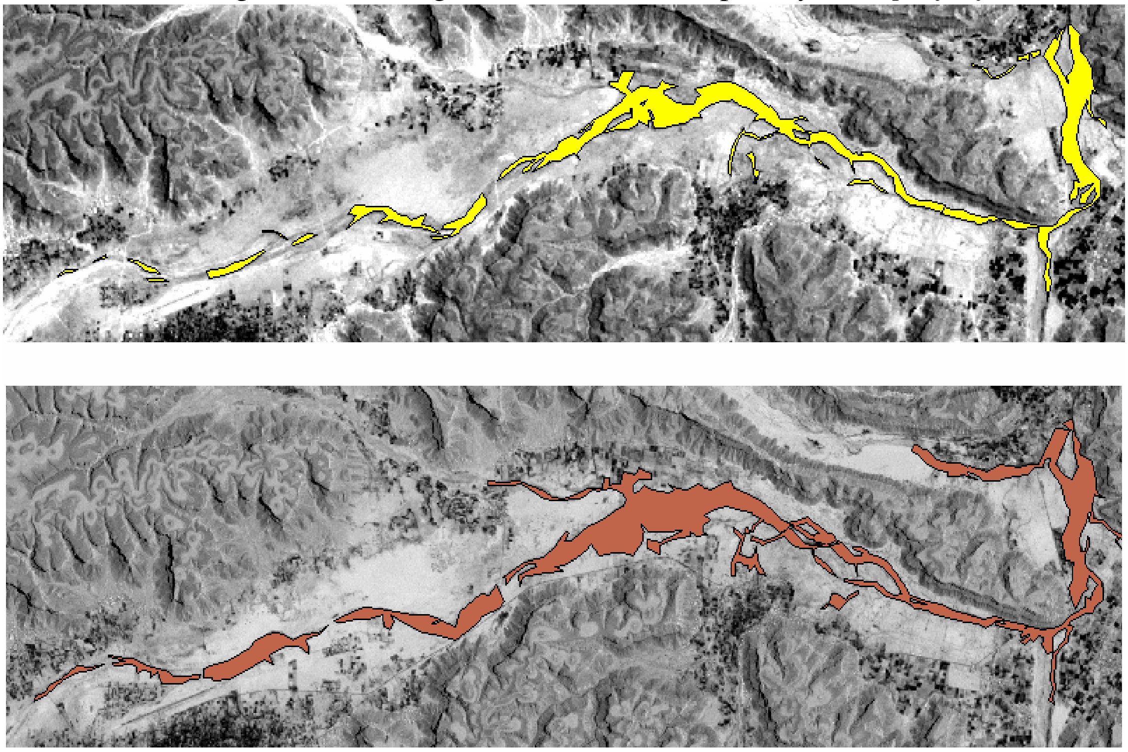

Figure 7.9. The change in *Prosopis* area in the Wadi Hadhramaut from 1998 (top) to 2001 (bottom), This image was generated using ArcView and Landsat imageries of 1998 and 2001.The total area of this tree has been increased from about 1000 ha in 1998 to 1654 ha in 2001. The Prosopis area is intensive in the middle of Wadi Hadhramaut and south Tarim. These areas are located near large government farms where intensive agriculture based on introduced crops and animal farming are practiced, this may indicate that *Prosopis juliflora* has started expanding from this place towards east and west mainly by means of domestic animals. The *Prosopis* area was identified by visual interpretation combined with field observations on false colour landsat imageries, using bands 2, 3 and 4 (BGR).

In the study area, pseudo-savanna-like vegetation in wadi beds and runnels in several locations, has been transformed to Prosopis woodlands due to the encroachment and establishment of the invasive tree *Prosopis juliflora*. Pure stands of *Prosopis juliflora* woodlands are common now in the river beds of the main Wadi Hadhramaut. Many fields are invaded by this tree (Plate 7.14), which forms thickets on marginal lands, sandy, fallow lands and along road sides in many locations along the main wadi Hadhramaut.

Because of its ability to invade lands it reduce the number of local plant species of areas, inhabits and competes with all indigenous species and covers many parts. Generally this invasive plant threatens to decimate indigenous vegetation and to reduce the plant diversity and the populations of many species in the main wadis.

However, this species is now one of the major sources of fuelwood, bees forage and fodder. Local people feed their animals with the pods of the *Prosopis juliflora* and nomads come with their herds from areas like Al Masila (eastern part of the study area) or from southern coastal areas to Wadi Hadhramaut to graze on the *Prosopis juliflora* pods or even to buy these pods from the farmers who are owning the lands that invaded by this tree and taken them to their areas. Awareness of the people living in the study area is important in order to draw out strategies in controlling this exotic species

It is understood from previous findings that plant biodiversity is being affected in many parts of the study area as a result of human activities, especially over-grazing, clearing for road construction, and plant collections. Human activities and overgrazing have resulted in the destruction of the natural vegetation and changing the vegetation structure in many parts of the study area. Over-grazing and plant collection selectively affected the abundance of some species, in particular *Merremia hadramautica, Boerhavia elegans* and *Tribulus arabicus.* Livestock grazing is the main factor of the spread of the exotic plant *Prosopis juliflora.*

The vegetation of the study area includes some plant species which are used by local people as food, medicinal, firewood and forage. Many of these plants are target and collect almost daily. For example, the continuous gathering of *Boerhavia elegans, Corallocarpus glomeruliflorus* and *Rhazya stricta* make these plants vulnerable.

The IUCN Red Data Book, presented information about threatened plant species from different countries, among these is *Dracaena serrulata,* which is rare in the Hadhramaut region and declining rapidly. This plant is becoming rare or endangered over most of its range. It is likely that once it was a widespread tree on the fog-affected slopes of the Hadhramaut mountains. It is now threatened by over-grazing, preventing regeneration, harvesting of the leaves for rope, mats, baskets and possibly by a gradual drying out of the region.

Roads and other human activities especially on the plateaus have affected vegetation cover. Many sites have been eroded and some species on eroded slopes have disappeared due to road constriction by oil working activities. Oil working activities in recent years resulted in increase of road construction and pipeline establishment. These activities caused the removal of soil surfaces and vegetation from vast areas in particular previous inaccessible areas and accelerated soil erosion and plant destruction. Examples of plants that may be affected are *Aerva artemisioides, Monsonia hetotropoides, Fagonia hadramautica, Cucumis canoxyi* and *Cleome albescens.* The impact of waste water from oil working activities on vegetation is also very obvious.

Thus, as a result of human activities and other disturbances, the unique ecosystem of the study area that was covered by native species is being replaced by species that are widespread and adapted to disturbed habitats such as *Prosopis juliflora, Calotropis procera* and *Zygophyllum album.*

7.3.5. Soil

Other factors, such as soil fertility, may also affect the patterns of species richness and plant growth along elevation gradient (Vetaas and Grytnes, 2002). In arid regions, however, the soil is largely chemically homogenous, usually without nutrient deficiencies. Soil development is slow due to the limited pace of weathering and leaching of the soil profile (FAO, 1989.). Physical properties on the other hand, notably soil depth, texture and water holding capacity, can be highly variable. Overall, the chemical composition and physical characteristics of the soil parent material can be just as important as precipitation, wind speed and other climate factors (Cooke and Warren, 1973). For example, soil texture especially in arid and semi-arid regions influences the water balance, evapotranspiration and soil moisture infiltration and consequently, affects vegetation distribution and growth (Hoekstra and Shachak, 1999). Because evapotranspiration and infiltration are higher in sandy soils, the plants in these habitats depend on their roots systems. Some species in these habitats (e.g. *Panicum turgidum, Dipterygium glaucum* and *Zygophyllum album*) have very long roots which can spread over the surface as well as into a depth utilizing the available surface moisture and water that has infiltrated to deep layers.

In arid regions, the quantity of rain is less important than the amount of water remaining in the soil after evaporation, and thus available to plants. Coarser soils hold more water, so unlike a humid environment, clay soils are actually the driest environments in arid regions. (FAO, 1989). Sandy textured soil and loamy fine sand have high permeability and coarse texture; this type of soil is easily removed by wind erosion especially when the vegetation cover is removed. Sandy loam and loamy textures are dominant in the study area, and substrate moisture and variations in soil (rooting) depth are major factors.

Because no soil data from all sample points has been taken, the results can be considered as first attempt to discuss the relationship between the plant species and soil factors in this region. Generally, the species of the cultivated fields are negatively correlated with CaCO3, which is often present in excess for plant growth, while the native species of the main wadi bed, the plateau and the slope of the plateau are positively correlated with CaCO3 and negatively correlated with EC% and, perversely, soil moisture. Some species such as *Zygophyllum decumbens, Halothamnus bottae* and *Tamarix arabica* resist the high content of EC%. *Tephrosia apollinea, Dichanthium insculptum, Pulicaria undulate, Farsetia linearis, Portulaca oleracea* and *Corallocarpus glomeruliflorus* grow well on relatively moisture soil sites. *Chascanum marrubifolium, Cadaba heterotricha, Tarenna graveolens, Jatropha spinosa, Maerua crassifolia, Hochstetteria schimperi, Commiphora kua* and *Grewia erythraea* grow well on dry stony shallow steep slopes of the plateau. The species *Aristida triticoides* grows well on dry, stony, steep north-east slopes. *Ficus cordata* subsp. *salicifolia, Cadaba heterotricha, Tarenna graveolens* and *Leptadenia arborea* grow well on wet rocky shallow slopes and along watercourses. *Acacia campoptila* occurs on deep soil, especially in the main wadis, where *Stipagrostis hirtigluma* and *Dichanthium insculptum* abundant on stony slopes and plateaus. Some species prefer the colluvial, very rocky fans and footslopes, which are distinct from other landforms by having high moisture, organic carbon, and other minerals than the surrounding landforms (Furley, 1974), example of these species are *Tephrosia apollinea, Cymbopogon schoenanthus, Barleria aff. bispinosa* and *Merremia hadramautica,* or prefer sandy plain and sand dune areas, such as *Acacia ehrenbergiana, Panicum turgidum* and *Dipterygium glaucum.*

The vegetation cover is sparser on the plateaus compared with other landforms. This is probably due to the effect of the thin limestone plateau soils which dry rapidly and are affected by sweeping winds (Plate 7.15). Generally most of the plant species are well adapted to calcareous soils which occur widely in the study area, and this type of soil is also widespread in some limestone mountain desert areas of the world such as Mule Mountains of Arizona. (Wentworth, 1981).

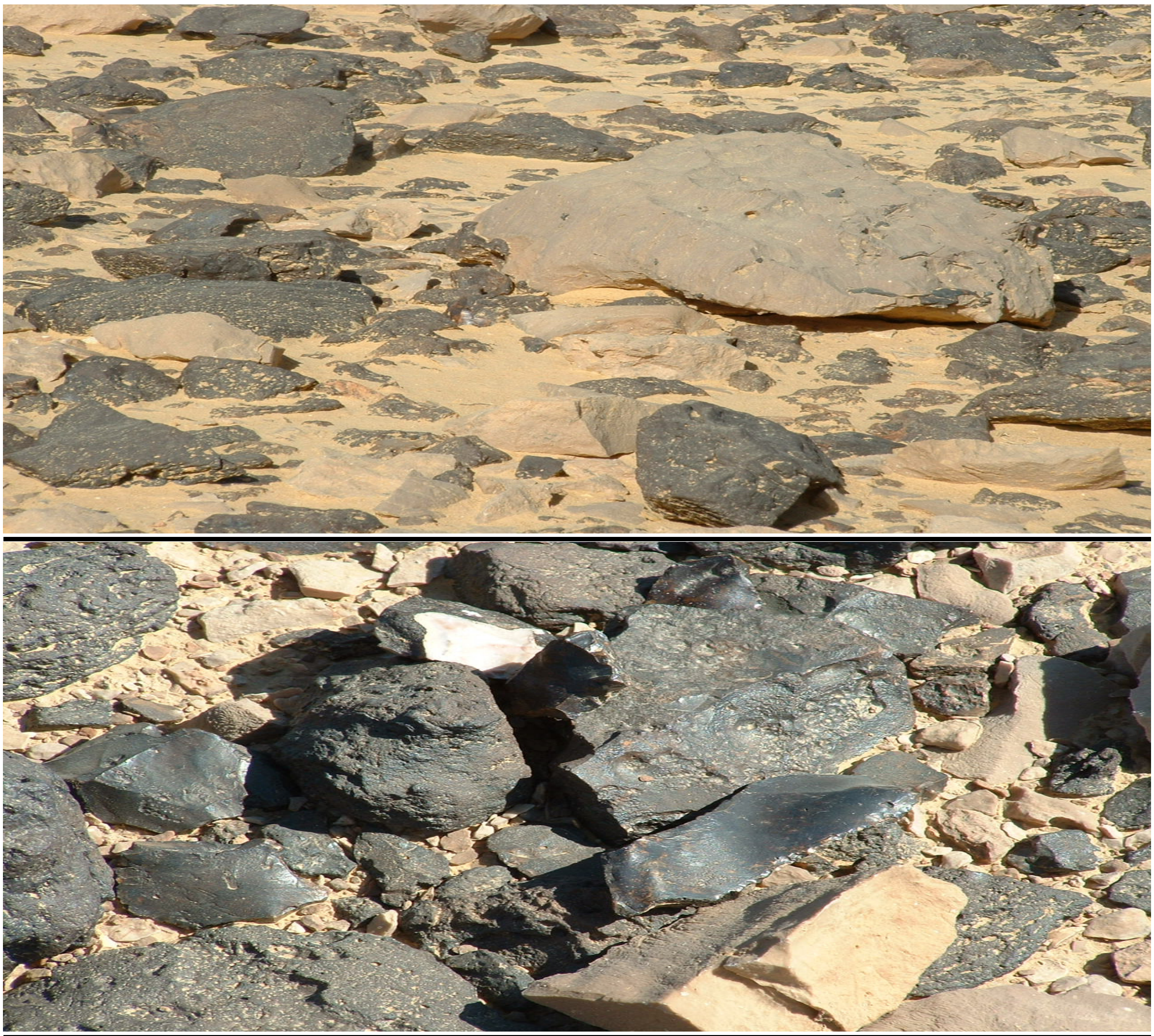

Plate 7.15. A close-up view of the plateau pavement (exposed flat surface) shows that the gaps between rock fragments are small or rarely visible. Wind and periodic rains keep the surface free of dust, and plants have a difficult time becoming established due to lack of soil. Most of the rock fragments shown here is limestone.

It is understood from previous sections that:-

(1) The plant species that settle in the study area through long distance dispersal are distributed in specific habitats because of their differential response to phytogeographical features of the ground, soil texture, micro-climate especially moisture and human destruction.

(2) Some obvious phenomena of human impact on natural vegetation can also be seen in the study area for example:-

- Decreasing areas of *Acacia campoptila, Salvadora persica* and *Tamarix aphylla* woodlands with the simultaneous increasing of *Prosopis juliflora* woodland,
- Decreasing density and frequency of some species such as *Boerhavia elegans* and *Rhazya stricta* due to over grazing and intensive collection.

It is suggested that future management activities should consider the above problems more seriously.

(3) The extensive oil working activities beginning at mid-1980 have made an intensive impact on vegetation and landscape distribution, and the effect can be seen clearly on the plateau.

(4) The introduction of modern agricultural techniques from 1980 were the primary causes of the significant variation for vegetation distribution pattern along the different topographic areas.

(5) Floods and over grazing played and still play as an important role in destruction, changing the structure and the composition of the vegetation in the study area.

7.4. Conservation and management of biodiversity

In the past the people of the Hadhramaut lived more or less in harmony with their environment, but with increasing population, changes in life expectations and oil activities, the ecosystem and its natural resources have come under threat. It is clear that the impact of climate change and human activities on plant species composition will increase in the coming decades. Many species will have difficulty in responding to the rapid changes in climate (too fast for adaptation or migration) and are likely to become more restricted in their distribution. Already, the development of the oil fields has had a rapid and fundamental impact on the study area. Direct effects include the removal of plant cover and soil erosion on the plateau.

7.4.1- Conservation: traditional knowledge and land ownership issues

Knowledge about the local and traditional uses of plant species (for instance, their importance as a source of food, for fodder, medicine, essential oils etc.) is vitally important in planning conservation strategies. However, this knowledge, often linked to local languages and dialects, is rapidly disappearing. It is often only old people who still retain this knowledge. It is no longer being passed on to the younger generation. Furthermore, local people and landowners play a vital role in the management of natural resources by following traditional and management systems. Therefore, the full cooperation and involvement of local people, communities, decision makers, students and local leaders plays a vitally important role in any conservation management plans.

Large areas of Hadhramaut region are privately owned and the rapid increase in population is creating an increased demand for land. It is clear that landowners must be involved in any future management plans for the conservation and protection of the ecosystems of the region. Local people also need technical and financial assistance and education programs on land management and the conservation of habitats and plant species is an important aspect of any conservation programme.

Financial and human resources are the main problems facing Yemeni Authorities, such as the Environmental Protection Authority, which are currently responsible for protected area management. Issues over land ownership and tenure can be a problem; most of the proposed protected areas belong to farmers, local people or tribes. Other problems are the need for trained staff, funding, proper conservation management and currently, poor infrastructure. As a result of these and other problems the protected areas remain no more than a list on paper.

7.4.2- Types of Threats

The main threats to the vegetation in Hadhramaut are from the direct and indirect impacts of human activities. In general, these relate to changes in the traditional land management practices which in the past have protected the vegetation. In particular the vegetation in the region has been directly and indirectly changed by the recent rapid economic growth.

Direct threats of development include:

1 The taking of land for building; this is widespread on the coastal plain where it will potentially effect important coastal communities such as at the beach east of al Mukala. The vegetation here is dominated by *Aristolochia rigida, Cleome macradenia* and *Limoniastrum arabicum* – the latter two are endemic and near-endemic to this particular habitat and of very limited distribution.

1. The building of new roads and pipelines. These affect the vegetation in various ways:
   a. by changing watersheds and creating micro-niches along the roadsides (see Plates 7.9a and b an Figure7.3.). It would be interesting to see if in future these act as wildlife corridors.
   b. in some areas opening up areas previously inaccessible to grazing; in other areas, the oil companies, for security reasons, are excluding transhumant pastoralists from some of their traditional pastures.
2. The pollution of the soil near oil installations.
3. The spreading of waste water; this has in some areas led to an explosion of plants; initially with high diversity, but it is expected that this will reduce as the area is overtaken by rank species. Also, it is expected that the build up of salts from the irrigation will gradually have an effect (see Plate 7.13).

Changes in traditional land management practices and traditions:

In direct threats of development include:

1. Change in grazing and browsing practices leading to changes in the vegetation. There are various examples of this:
    a. In certain areas access to traditional rangelands has been prohibited, for security reasons, on the plateaus around the new oil installations. This has fragmented the plateau into grazed and un-grazed localities. The obvious effect of this is to take pressure off from certain rangelands therefore allowing them to recover and ultimately to change. However, the pastoralist still needs to graze his animals and will move them into new areas. The effect of this can be seen in study site 3 where transhumant pastoralists who traditionally moved over large areas are now settling for longer periods in areas in the main wadis.
    b. Children who at one time herded animals now go to school. There are direct and indirect consequences of this, for example:.
        i. Directly, there has been a change in the practice of grazing on the rangelands, which has resulted in selling the animals or stopping grazing outside.
        ii. Indirectly, and perhaps more importantly, children lose a connection with their environment –traditional practices will no longer be passed on to them from their parents and understanding of them will be rapidly lost. In other areas where this has happened they become separated from their natural environment, no longer place a value on it and finally see no point in conserving it (Miller & Morris, 1985).
2. Changes in traditional practices have opened up habitats which can then be rapidly exploited by exotic species. The best example of this is the case of *Prosopis juliflora.* This is rapidly invading the main wadis and coastal areas. It is a serious pest of cultivated land and is, in many places swamping the natural vegetation in the main wadis. However, it is not all bad: some people welcome it as a major source of nectar and pollen for bee keepers (one of the most profitable and famous industries in the region) and it also provides fuelwood.
3. As people become settled they place more pressure on their immediate environment; their livestock grazes near the home and gathering of wood for fuelwood and timber increases.

On the whole the effect of oil exploitation in the area is complex. The most immediate effects are from pollution and waste water; these are very local and pose no major threat to the vegetation. Next in importance are changes to the vegetation caused by the creation of new ecological niches; for instance along roadsides; these again are not too dramatic and it is to be seen whether they will act as wildlife corridors. Of more importance are the affects of restricting access to traditional rangelands – the effect of this are twofold: decreasing grazing in some areas and increasing pressure on others; both outcomes effect the vegetation. Finally, and perhaps most importantly, are the radical and complex ways in which the new wealth and development is changing the area – everything from children no longer taking livestock into the range but now going to school and potentially losing their links with the environment; to major changes in grazing practices as age old practices of transhumance breakdown as people settle. All the various scenarios described above have been observed and recorded during the course of this study; to unravel simple cause and effect in such a complex situation has proven impossible.

So what are the observed changes in vegetation, again, it is difficult to separate anthropegenic and natural processes. The best example of this is the changes to the vegetation following the devastating floods which effect the main wadis from time to time. It can be seen that they are becoming more destructive. Many large trees and areas of woodland have been destroyed in recent times. This increase in the severity of the floods could be caused by changes in rainfall bought on by gradual climate change or global warming. However, other factors have to be taken into account:

- Changes in land-use – including the removal of the protective layer of vegetation by over-grazing is leading to flood plains becoming more vulnerable to erosion
- Over-grazing on the water catchment of the area increasing the run-off and causing flash floods
- Changes in the practice of by placing barriers in the wadis to divert water to the fields thus slowing the flow of the wadis
- An increase in the production of cement for building – this is removing lime-rich substrates in the wadis and changing the contours of the flood plains.

It can be seen that there is no simple cause for the increase in severity of the floods; it is a complex system involving many factors – both natural and anthropogenic.

7.4.3. National and International Framework for Protection of Yemen's Flora and vegetation

In Yemen, the main responsibility for wildlife conservation and environmental protection lies with the Environment Protection Authority (EPA). Miller (1994) reported that UNEP and IUCN had recommended that a network of reserves be created throughout Yemen. To date no such network has been established. A few sites have been identified as candidates for protected area status, but, until now, with the notable exceptions of Otuma, in the western mountains, Jabal Bura', a species rich area of relict woodland in the western escarpment mountains and the monsoon woodlands of the Huf area bordering Oman, none of these sites have any legal protection.

Most recently the National Biodiversity Strategy development process of Yemen (EPA, 2005) has been funded by the Global Environment Facility (GEF). The work of the technical groups involved in this are coordinated by the Environment Protection Authority (EPA) which is based in Sanaa. The National Biodiversity Strategy consists of 4 goals:

1. conservation of natural resources
2. sustainable use of natural resources
3. integrating biodiversity in sectoral development plans
4. and implementation of enabling mechanism.

The conservation of natural resources covers the following areas:-

1. Protected areas
2. Endemic and endangered Species
3. *Ex situ* conservation

4. Alien invasive species

1. Protected Areas (in situ* conservation*)

The conservation of species in their natural habitats or *in situ* conservation, has long been the conservation method of choice for wild species and ecosystems (OECD, 2003). It involves the process of protection and conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural habitat (Moore and Tymowski, 2004). Criteria and priorities that attract funds are necessary for conservation (Spellerberg, 1992).

The main goal of *in situ* protection is the conservation of eco-systems through developing and maintaining a comprehensive and adequate network of protected areas. Some important areas have already been proposed by scientists and at workshops (Al Khulaidi and El-Ghouri, 1996; Miller et al, 2006). Amongst these areas are the Jol plateau in the Hadhramaut – to date this has no protection. In 1999 Otuma, in the Western part of Yemen in the province of Dhamar, was the first locality to be declared a protected area in Yemen. Two more will be declared as protected areas shortly (UNEP, 2004), these area are Jabal Bura' on the SW escarpment mountains and Huf, in the Al Mahara Governorate in the eastern part of the country.

These protected areas fall within IUCN Protected Area Category II, under which the area is to be managed mainly for ecosystem protection and recreation (IUCN, 2004**,** Anon, 1994). Generally, most of the proposed protected areas are managed by local communities, village leaders or Sheikhs, this is done by using traditional management practices. The implementation and details of rules governing the management of these differs from one place to another. These protected areas represent the most successfully managed sites in Yemen.

The National Biodiversity Strategy Development Process in Yemen has recently been strengthened by the Global Strategy for Plant Conservation (GSPC), a global initiative, which could have an important impact on conservation in Yemen. Countries, such as Yemen, which are signatories to the Convention on Biological Diversity (CBD) are now also obliged to adhere to the GSPC. The ultimate and long-term objective is to halt the current and continuing loss of plant diversity. Under the GSPC, a series of global targets has to be met by the year year 2010. The present studies will directly help the government of Yemen in reaching some of these targets and thus fulfilling its international commitments. The following three targets are most directly relevant:

Target (i) a widely accessible working list of known plant species.

Target (ii) a preliminary assessment of the conservation status of all known plant species, at national, regional and international levels.

Target (v) protection of 50% of the most important areas for plant conservation assured – the most Important Plant Areas (IPAs) for plant diversity are to be identified according to the criteria including endemism, species richness, and/or uniqueness of habitats, including relict ecosystems.

The GSPC is being coordinated in the countries of the Arabian Peninsula by the Arabian Plant Specialist Group (APSG), a Specialist Group of the Species Survival Commission of the IUCN, and consisting of a group of botanists with an interest in the region. The results of this present study will feed directly into the GSPC process, through the APSG.

2. *Endemic and Endangered Species*

Endemism is a key component of biodiversity that particularly interests biologists and plant taxonomists (Shevock, 1996; Kruckeberg and Rabinowitz, 1985). Plants can be endemic to all kinds of features and geographic areas, and also to physical attributes such as soils and rock types. Endemism is also an important concept in conservation biology. Endemic species rely exclusively for their long-term health and continued existence on the management of the geographical area to which they are restricted. Furthermore, endemism is one of the criteria used to set priorities for species conservation efforts. Endangered species are a widely accepted favourites for conservation attention both nationally and globally and are frequently afforded high priority (Heywood and Dulloo, 2005; Sutherland, 2001). Endemic and near-endemic species that occur in restricted areas present particular problems. Their very rarity (in term of their limited distribution) is part of their vulnerability and turns them into key species in the conservation of biodiversity.

The flora of the Hadhramaut is very rich in endemic, near-endemic and rare plant species. The majority of endemic taxa in the region are associated with the southern mountainous area which provides a rich variety of ecological niches (see chapter 3). The endemic plants of this region include 103 endemic and near-endemic species. A summary of the status and number of endemic, near-endemic and rare plant species in Hadhramaut has been presented in Table 3, Chapter 3).

The southern mountain summits of the Hadhramaut, especially above Al Mukala and Al Rayan, can be considered a local centre of endemism. This region is characterised by a unique ecosystem (the summits, for instance, obtaining most precipitation from fog) with a very low population, isolated geographical location, dramatic landforms and an extensive range of altitude and climatic conditions. There is an urgent need to protect this unique ecosystem and its rich biodiversity. However, not only biological factors have to be taken into consideration. It is of vital importance for the long-term protection of the ecosystem that the people, who for generations have lived and preserved it, should be consulted. Any management plan for the area must take into account that, it is largely a man-made landscape, and that for millennia the region has provided a sustainable livelihood for local people.

3- Ex situ Conservation

The conservation of species outside their natural habitats or *ex situ* conservation typically is found in zoos, captive breeding programmes, botanic gardens and seed banks (Williams et al., 2001; Anderson et al., 1996). The selection of threatened species for ex situ management is guided by a variety of criteria (Havens, et al., 200; Heywood and Dulloo, 2005), these are:

a. Endemism (selecting taxa that represent a unique local or regional fancies)
b. Economic (selecting taxa that provide local or economic or social resources, such as medicinal plants),
c. Ecological (selecting taxa that have a role in maintaining ecological processes or supporting habitat restoration), and
d. Characteristic (selecting threatened taxa that can be used as flagships for promoting landscape-and habitat-level conservation).

Clearly the ideal for *ex situ* conservation is one where representatives from all ecological zones can be grown. In Hadhramaut a combination of the following sites would achieve this:

- A site on the plateau above Al Mukalla; this area has a geographical location, topographical features and climate suitable for growing a wide range of species from Hadhramaut, including plants of both the tropical and arid zones.
- The Agricultural Research and Extension Authority (AREA), regional station at Sayun. Here the plants of the Wadi Hadhramaut and surrounding areas can be grow successfully, as well as desert plants from the Ramalat Assaba'tain and Al Rub' al Khali.

5- Alien invasive species

Human activities in the study area, have allowed invasive species, such as *Prosopis juliflora,* to rapidly spread with a resultant detrimental effect on the abundance of indigenous species. This species becomes the dominant species in many parts of the main wadis forming a pure stand of woodland. Pure stands of *Prosopis juliflora* woodlands are common now in the river beds of the main Wadi Hadhramaut and neglected agricultural land. Other invasive species on cultivated areas include: *Cuscuta campestris,* and *Leptadenia arborea.*

Currently, local people are complaining about the negative impact of these species. Therefore, the full cooperation and involvement of local people, communities, decision makers, students and local leaders plays an essentially important role in any future activities directed to solve and control this problem**.**

7.5. Conclusions

Primarily, this study has improved the understanding of the distribution and ecology of plant taxa in the Hadhramaut. However, it also emphasises that vast areas in this remarkable region are still botanically un-explored.

The research is the first detailed vegetation survey to be completed in the Hadhramaut and provides data which can be used as a baseline for monitoring change. The methods and protocols developed during the study can be used as a basis for carrying out similar studies in other parts of Arabia and for helping to devise management and conservation programmes. In the study area, the major vegetation associations, their composition and biodiversity were identified and vegetation and landuse maps generated. Endemic, near-endemic, rare and threatened plant species were identified and presented in maps. These data are important in understanding the direct and indirect effects of oil development on the vegetation and environment of the region. This research has also been important identifying significant vegetation associations, habitats and areas of endemism thus allowing Yemen to fulfil its international commitments under the Global Strategy for Plant Conservation and in particular in reaching targets I, II and V for the year 2010. Such information will also feed into IUCN assessments of threat to endemic and near endemics by supporting certain criteria (habitat change etc). The data is also supporting the development of management plans and is relevant in supporting ecotourism and consequently wealth creation within the region, thus providing alternative employment for pastoralists.

Although soil data was not collected from all sampling points, the study has assessed topographic and micro-climatic factors and is the first attempt to discuss the relationship between the plant species and environmental factors in the region. The effects of human intervention on soil in the study area may not yet be visible in such a short time-scale, but studying the region has allowed us to draw certain conclusions about trends that will help in interpreting any further problems which may arise.

It has been shown that the distribution and structure of vegetation associations show a relationship to topographic position and related factors such as soil depth and available moisture.

The result of Braun-Blanquet and Twinspan analysis revealed 15 vegetation associations and demonstrated several distinct patterns of species distribution:

1. species found over wide range of ecological sites
2. species distributed mainly on wadi beds
3. species only found on slopes
4. species only seen on plateaus

Due to the varied topography over the study area, several important microhabitats were identified, including runnels, wet sites, and run-off areas at the bottom of slopes. Each of these microhabitats supports special types of vegetation, each with a characteristic floristic composition and distinct physiognomy.

It has been shown that plant migration during past geological periods, long-term geological and climatic change, recent changes in climate and hydrology and the effects of man and his livestock have all played a part in the establishment and development of the present flora and vegetation of Hadhramaut.

It is clear, because of the early development of agriculture and pastoralism in Hadhramaut that no area can be considered to be "natural"; all to a lesser or greater degree shows the impact of man and his livestock. Changes in vegetation have to be considered in this context. Until recently there was no way of directly examining this. However, the study of Hyrax middens (see chapter 2), although in its infancy is likely to revolutionise the understanding of recent vegetation change in the region.

Already, from a study of findings from surrounding regions it has been shown that the vegetation and flora of the Hadhramaut has been subjected to alternating periods of high and low rainfall. During periods of high rainfall plants of paleotropical ancestry migrated north, using the main wadis as corridors. During dry periods "desert" elements, the desert transition zone of the Saharo-Sindian (a mixture of holarctic and paleotropical elements which have previously adapted to the arid condition) have migrated back into the wadis and up on to the plateaus. With each alternation of conditions, palaeotropical and holarctic elements would have been “left behind” in refugia, now represented, for instance, by the relict woodlands found in gullies on the plateau. An analysis of the floristic elements in the Hadramaut region shows that the geographic boundary between the floras of tropical African origin to the south and the sub-tropical and temperate floras of the north lies somewhere across the middle of the study region. However, this boundary is blurred by the constant mixing of elements which has occurred in the region over the millennia. This explains the high number of endemics and the interesting floristic mix found in the area.

The study of past climatic change allows us to predict how global warming will alter the composition and distribution of vegetation in the future. The results of the present study should help in planning of economic, agricultural and conservation strategies in an uncertain future.

The southern mountains of Hadhramaut with their highly localized endemics are particularly vulnerable to the present rapid and uncontrolled development in the region. In particular oil-related activities, may have a serious impact on these species. On the basis of the findings of this study a recommendation will be made to the Environmental protection Authority that urgent action needs to be taken to protect this area and that priority should be given to the development of a conservation management plan.

It is clear that Hadhramaut is an area of great beauty with dramatic natural landscapes and picturesque desert cities. It is one of the most popular tourist destinations in Yemen. At the moment there is little “natural” or eco-tourism which could bring extra income and jobs when the oil runs out. It is important that protection of the environment and biodiversity is put on the political and economic agenda as soon as possible.

So has this research matched the objectives and answered the questions posed at the beginning of this thesis (chapter 1)

1. "The principal objectives of the research are to analyse the distribution and dynamics of the plants of the Hadhramaut region, and to evaluate the role of physical parameters and human actions on the vegetation. The area selected for detailed study is representative of the Hadhramaut as a whole and is further subdivided into 3 sites for intensive survey" (chapter 1).

The main objectives of this research were substantially achieved. The present distributions of all plants in the region have been analysed and the dynamics of their distribution discussed, including the importance of ancient floristic links, Quaternary migrations, or the more recent climate change and breakdown in traditional land management practices. The results of this study will serve as baseline against which future changes in the distribution plants in the region can be measured**.**

1. "The number and abundance of individual plant species has varied over time, especially over the past two decades."

It has been clearly shown that the number and abundance of species has changed over the last two decades. However, the reasons for this are complex - with the main factors including: environmental change (e.g. global warming), economic development (e.g. pollution and changing niches along road sides) changes in traditional practices (e.g. changing in grazing patterns), human activities have allowed invasive species, such as *Prosopis juliflora,* to rapidly spread with a resultant detrimental effect on the abundance of indigenous species. This species becomes the dominant species in many parts of main wadis forming a pure stand of woodland. Due to intensive floods, there is a very obvious vegetation transition from one form to another. Floods have a significant effect on the structure and the abundance of vegetation of wadis. Roads on the plateaus have affected vegetation cover. Many sites have been eroded and some species on eroded slopes have disappeared due to road construction, for example, species such as *Seetzenia lanata*, and *Monsonia heterotropoides* become very rare in such conditions.

2. "Plant communities and vegetation structure have remained relatively constant over the same period, although the populations of different plant species and their local distributions have changed".

In some areas there have been changes in the abundance of certain species as a result of selective grazing etc. It is also clear that the area has seen innumerable migrations over the millennia (witnessed by the mix of tropical and holactic elements); however, evidence for recent change (over two decades) is not so clear. Remote sensing imagery has shown the changes brought on by the invasion of *Prosopis juliflora* and change in land use in the wadis. It also shows changes to the extent of natural vegetation. Analysis of the survey sites has also shown more subtle changes to the vegetation between the sites. The most clear changes have been seen close to oil installations, for instance, where waste water has been dumped or where land has been cleared. The impact of waste water on vegetation in some areas seems more positive, since the release of water has produced vigorous germination and growth of plant species and as a result the population of plant species has increased. Floods have a significant effect on the structure of wadi vegetation and contribute largely to the destruction of individuals and the reduction of vegetation cover, Furthermore this has resulted in the introduction of other plant species especially, exotics, which may be brought in by floods from other areas, examples are *Prosopis juliflora* and *Zygophyllum album.* As a result of severe floods, the woody vegetation dominated by *Ziziphus leucodermis, Acacia ehrenbergiana, Acacia hamulosa, Tephrosia dura* and date palm trees has disappeared or shrunk in coverage and has been replaced by other communities more resistant to the severe floods and other environmental disturbances.

3. "Human activity has exploited the plant resources of the entire area but has preferentially targeted particular types of vegetation."

The present changes to the area brought on by the recent changes in economic development have not caused any major changes to the vegetation of the region. The area has a long history of human occupation and certain vegetation types, for example, woodland is either long gone or has been carefully managed. There is clear evidence of overgrazing in the wadis (but not in all study sites), the collection of firewood and timber from certain trees and the unsustainable exploitation of certain medicinal and culinary plants (eg *Boerhavia elegans*). There has been little direct targeting of the natural resources on the scale of, for instance, the clearing of the tropical rain or any seasonal forests. Generally, the adverse effects of human activity have been less direct – mainly through the breakdown of traditional practices. However, these changes although small are likely to have a considerable impact on the fragile desertic ecosystems across the region. Over grazing has a direct impact on species richness in different parts of the study sites. The occurrence of some species such as *Tephrosia dura* could be a sign of over-grazing. Human activities in the study area targeting particular plants, for example the collection of some plants for medicinal or other purposes also has an impact on certain species, such as *Boerhavia elegans, Corallocarpus glomeruliflorus,* and *Rhazya stricta.* These activities have resulted in reducing the abundance of these species. With the arrival of nomads, grazing become more intensive in areas previously less affected. As a result, some species that were abundant become rare, examples include *Merremia hadramautica, Tephrosia nubica, Maerua crassifolia* and *Panicum turgidum.*

Future research

Further study on the factors that influence the distribution of plant species of Hadhramaut region and the possible effects of climate change on the distribution patterns are needed. It would be helpful if vegetation surveys could be combined with data or abiotic factors such as altitude, aspect, soil, moisture and other environmental factors and biotic factors such as human and other living organisms to get a better and clear idea on the distribution, abundance and composition of plants in particular rare, endemic and near-endemic species.

Detailed vegetation as well as topography and landuse mapping of the whole region of the Hadhramaut using the modern softwares such as ArcView and ERDAS is recommended.

In addition, several lines of investigation would be helpful for policy formulation and management, these include: assess the available information on the existing endemic, near-endemic and rare plant species; the conducting of future targeted vegetation surveys to estimate the conservation status, population size and area of occupation of each of the endemic and threatened plant species and threatened habitats in the region; the .preparation of an IUCN red list of threatened plant species of the region and a list of Important Plant Areas; the conservation and rehabilitation of key endangered species through law enforcement; the collection of ethnobotanical data – before it is too late and, finally, the preparation of well grounded Recommendations to government on protecting key areas.

The research has provided the first quantitative and systematic survey of the vegetation of the Hadhramaut. It has shown that the area lies at the transition between northern (Holarctic) and south western (Paleotropical) floras and also contains very few elements of eastern Irano-Turanian vegetation zones. The area has been shown to possess a number of fascinating endemic and near-endemic plant species and, together with their distinctive landscape habitats, the data collected justify the proposal for protective status for parts of the region through the formation of a protected lands or national park or other type of locally and nationally accepted conservation management.

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Appendexes 1 Rainfall data

Rainfall data in mm from 1981 to 2002 for Sayun

months / year	J	F	M	A	M	J	J	A	S	O	N	D	total
1981	0	0	50	0	0	2.9	2.6	2	0	0	0	0	57
1982	33	2.2	16	1.1	0	0	4.3	68	0	0	0	0	125
1983	6.5	12	0.3	61	0	0	0	30	0	0	0	0	109
1984	0	0	0	0	16	0	1.8	0	0	0	4.5	0	22.3
1985	6	0	0	0.2	0	0	0.1	2.6	0.1	0	0	0	9
1986	0	12	0	19	0	23	1.8	13	0	0	0	0	68
1987	0	0	61	24	0	1.5	0	22	0	0	0	2.5	110
1988	0	0	0	0.5	0	0	5.7	1.5	0.7	0	0	0	8.4
1989	0	0	112	60	0	1	2.2	1.2	0	0	0	0	176
1990	0	57	0	4.1	0	0	11	0.5	0	0	0	0	72.6
1991	0	0	12	0	0	0	1	18	0	13	0.5	0	44
1992	4	0	0	44	6.2	0	8.5	7.2	1.5	11	0	0	81.7
1993	4.5	48	0	14	9	0	2.2	1.2	0	0	0	0	78.7
1994	0	0	0.6	0.8	0	0	0	29	0	0	0	0	30.3
1995	0	0	68	1.4	0	1.2	39	18	0.1	0	0	0	128
1996	0	0	1	0	1.2	66	21	0.7	0	0	0	0	89.4
1997	0	0	45	0.6	0	1.1	19	0.8	0	17	2.7	0	86.2
1998	0	0	0	0	0	0	4.4	35	0	0.4	0	0	39.6
1999	0	0	0	0	0	0	29	44	0	39	0	0	111
2000	0	0	0	0	0	0	0.5	2.7	7.5	12	0	0	22.7
2001	0	0	7.9	0	38	0	18	20	0	0	0	0	84.4
2002	0	0	0	39	0	0	0.2	6.3	34	0	0	0	79.6
average	2.5	5.9	17	12	3.2	4.4	7.8	15	2	4.1	0.4	0.1	74.2

Appendix 1a . Annual rainfall recorded in Sayun weather station. Most of the rainfall occurs in March, April and August A variation in both amount and time of occurrence from year-to-year and from month to month is obvious. The average monthly rainfall ranges from .1 mm in December to 17 mm in March. The maximum monthly rainfall took place in March 1989 with about 112 mm. The high figure of rainfall in March 1989 is due to heavy rain that last for about 9 hours and caused the most major floods in the this century.

Appendix 2. Rainfall data between 1996 and 1999 of 22 rainfall stations located along Wadi Hadhramaut. . ND no data collected. The highest rainfall was in 1989.

STATION	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	average
QASM	6.7	83	173	25	223	59	20	20	51	7	83	133	72	20	72	32	67.4
ALRUDOOD	0	45	66	42	112	21	80	85	44	21	108	121	48	42	12	25	54.5
SAH	7.5	66	72	13	92	26	10	77	59	0	ND	83	31	26	139	44	49.5
SHIBAM	0.7	89	99	20	11	43	34	129	68	0	8	ND	ND	ND	1	21	11
Al Qatan	2.2	20	85	0	106	44	14	55	56	0	ND	ND	ND	ND	ND	ND	38.1
Bahran	3.5	3.5	52	2.6	101	28	0	63	23	0	ND	ND	ND	ND	ND	ND	27.6
Al Mashhad	2.3	37	50	16	14	43	9.8	67	62	0	ND	ND	ND	ND	ND	ND	30.2
ALUGUBIEH	0	70	95	65	125	41	14	81	0	0	0	32	7	21	20	32	37.6
Qaren BAMSAOOD	6.1	45	53	53	107	86	64	161	93	30	3.2	21	18	11	14	0	47.8
AL HALEH	19	79	83	78	161	92	15	198	142	83	69	178	133	36	100	98	92..3
GAIDUN	ND	81	67	79	130	3.3	0	159	102	12	ND	179	12	ND	ND	19	52.1
ALKORIBEH	0	23	135	81	139	67	25	223	135	0	0	66	160	106	149	87	87.3
SOBEIKH	ND	ND	ND	44	123	56	43	92	125	67	38	127	97	44	38	665	120
ALHAJRAIN	ND	ND	ND	12	92	23	7.8	121	96	0	0	0	44	36	ND	49	40
AMD	ND	ND	ND	44	69	76	18	94	87	41	24	0	31	34	419	55	76.1
SHARJ ALSHARIF	ND	ND	ND	42	171	51	35	107	145	0	0	86	85	57	ND	38	68
GheilBin Yamain	ND	ND	ND	ND	47	8.1	9.4	33	70	0	ND	ND	ND	ND	ND	0	27.8
Alsalasil	ND	ND	ND	ND	90	34	13	33	99	0	0	0	0	24	90	0	31.9
Katbeh	ND	ND	ND	ND	0	44	4.5	15	0	0	ND	ND	ND	ND	ND	30	10.5
AL JAWADEH	ND	ND	ND	ND	121	26	18	79	58	14	47	28	84	32	66	51	51.9
AL MINSAF	ND	ND	ND	ND	127	19	22	15	70	0	0	210	0	31	65	11	47.5
Abd Gharieb	ND	79	95	54	134	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	72.2
WADI BIN ALI	ND	ND	ND	ND	ND	24	21	93	69	0	138	148	88	20	65	27	63
YABHOOD	ND	ND	ND	ND	ND	9.9	27	72	87	0	106	0	0	7.4	ND	46	35.6
HAINAN	ND	ND	ND	ND	ND	17	3.5	33	45	31	56	37	0	0	76	41	30.8
BODHAH	ND	ND	ND	ND	ND		160	165	237	0	23	486	ND	120	167	83	160
TARIM (DAMOON)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	127	60	35	91	ND	78.2
JUEIMEH	ND	ND	ND	ND	ND	ND	38	ND	ND	ND	ND	56	94	28	142	45	67

Appendix 3. Daily rainfall (mm) between 1981 and 2002 from Sayun

year	month / day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1981	March													2.5	22.4			5.4												19.2		
	June		1.9																				1.0									
	July		1.5																		0.8								0.3			
	August											2.0																				
1982	January											33.0																				
	February																0.6	1.6														
	march																													15.0	1.3	
	April																1.1															
	July																									4.3						
	August																	68.0	0.1													
1983	January																															6.5
	February											5.0	6.5																			
	March																															0.25
	April	0.20	16		25	10		7				1.0							1.25													
	August												0.25			24.0	0.25		5.0	5.0					0.5	0.25						
1984	May										16																					
	July																0.25								1.5							
	November	4.5																														
1985	January									6																						
	April																									0.2						
	July															0.1																
	August				0.1						1.5																		1.0			
	September									0.1																						
1986	February			4.10															7.5													
	April							9.1				5.5	3.3	0.2	0.4																	
	June														23.0																	
	July																						1.8									
	August				1.0						4.1												8.0									
1987	March													3.0	31.0									4.5							15.5	6.5
	April							13.6				9.9																				
	June		1.50																													
	August					16.8				0.4					1.0							4.1										
	December																															2.5

Appendix 3. Continue

year	month / day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1988	April																											0.5				
	July																					0.1		1.2		2.4			2.0			
	August	0.70				0.8																										
	September																		0.7													
1989	March																2.5		35.6	36.0			7.4	5.5	4.5					20.0		
	April					6.2	45.0																		8.0	0.5						
	June					0.2		0.8																								
	July										1.2															1.0						
	August				0.8																0.4											
1990	February							38.0							0.2		1.7					3.0	14.5									
	April						1.1			3.0																						
	July														0.4		0.2									9.0						1.0
	August										0.5																					
1991	March																										2.2	10.0				
	July											1.0																				
	August														17.5																	
	October																				12.8											
	November																								0.5							
1992	January																										4.0					
	April	2.5			35.0			6.3																								
	May												6.2																			
	July			8.5																												
	August					5.2				1.0											1.0											
	September																	1.5														
	October			1.5		9.0																										
1993	January																									0.5	4.0					
	February					14.7	21.3	10.5	0.7	0.5																						
	April					0.5							1.5						2.6	2.6									6.9			
	May	4.5																											2.5	2.0		
	July																				2.2											
	August													1.2																		

Appendix 3. Continue

year	month / day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1994	March																												0.6			
	April																					0.2	0.6									
	August								0.3				7.4		1.3							0.7		0.3	0.3	1.1	17.5					
1995	march	13.9	25.6		27.5								1.2																			
	April																								1.4							
	June																							1.2								
	July																						0.5				2.4					
	August					0.1	0.2		8.7							0.4				2.2				6.3							36.0	
	September		0.1																													
1996	March																1.0															
	May													0.2	1.0																	
	June				0.3								5.2	26.0	2.0	19.0	6.7	6.6														
	July								2.0					2.5				1.9		0.4		3.0	10.0		0.9							
	August																0.5														0.2	
1997	March																1.0							2.4		41.5				0.1		0.1
	April	0.6																														
	June			0.7														0.1	0.3													
	July																										12.6	6.8				
	August												0.1		0.7																	
	October																				0.3				16.2							
	November																							2.7								
1998	July										1.0		0.1						3.3													
	August																	0.4						0.6				5.0		21.6		7.2
	October					0.4																										
1999	July									14.5	0.4		7.7	4.7	0.7	0.7																
	August															0.2	0.5										1.0		42.5			
	October							5.5								33.0																
2000	July								0.5																							
	August													1.0							1.7											
	September					7.0																					0.5					
	October					12.0																										
2001	March																									5.2		2.7				
	May				34.4	0.4	3.0																									
	July																				0.3	1.0	7.9					3.5				5.7
	August			2.6								3.7	0.9	0.3		0.9	11.9															
2002	April						0.4					5.3	33.3																			
	July																												0.2			
	August																														3.3	3.0
	September	3.4	26.5	0.5		3.7																										

Appendix 4. List of plant species from Hadhramaut region

scientific name	family	local name
1. Abutilon bidentatum Hochst. ex A.Rich.	Malvaceae	
2. Abutilon fruticosum Guill. & Perr.	Malvaceae	
3. Abutilon pannosum (Forrsk.) Schlechl.	Malvaceae	
4. Acacia campoptila Schweinf. **	Mimosoideae	Sumur
5. Acacia ehrenbergiana Hayne.	Mimosoideae	
6. Acacia hamulosa Benth.	Mimosoideae	Qatad
7. Acacia laeta R.Br.	Mimosoideae	
8. Acacia mellifera (Vahl) Benth.	Mimosoideae	Dhubyan
9. Acacia oerfota (Forssk.) Schweinf.	Mimosoideae	Orfut
10. Actiniopteris semiflabellata Pichi-Ser.	Actiniopteraceae	
11. Adenia venenata Forssk.	Passifloraceae	
12. Adenium obesum (Forssk.) Roem. & Schult.	Apocynaceae	Aden
13. Aeluropus lagopoides (L.) Trin. ex Thev.	Poaceae (Gramineae)	
14. Aerva artemisioides Vierh. & Schwartz subsp. artemisioides. *	Amaranthaceae	
15. Aerva javanica (Borm.f.) Juss. ex Schult	Amaranthaceae	Ra
16. Aerva lanata (L.) Juss. ex J.A. Schult.	Amaranthaceae	Ra
17. Agrostis viridis Gouan	Poaceae (Gramineae)	
18. Aizoon canariensis L.	Aizoaceae	
19. Alhagi graecorum Boiss.	Fabaceae (Papilionoideae)	Wadha'
20. Aloe luntii Baker *	Aloeaceae	
21. Aloe abyssicola Lavr. & Bilaidi *	Aloeaceae	
22. Aloe doei Lavr. *	Aloeaceae	
23. Aloe eremophila Lavr. *	Aloeaceae	
24. Aloe fleurentinorum Lavr. & Newton **	Aloeaceae	
25. Aloe inermis Forssk. *	Aloeaceae	
26. Aloe luntii Baker *	Aloeaceae	
27. Aloe mahraensis Lavr.& McCoy **	Aloeaceae	
28. Aloe mccoyi Lavr.& Mies *	Aloeaceae	
29. Aloe serriyensis Lavr. *	Aloeaceae	
30. Amaranthus ascendens Lois.	Amaranthaceae	
31. Amaranthus graecizans subsp. graecizans L.	Amaranthaceae	
32. Anabasis setifera Moq.	Chinopodiaceae	
33. Anagallis arvensis L. var. caerulea	Primulaceae	
34. Aneilema aequinoctiale P.B.Kunth.	Commelinaceae	
35. Anisotes trisulcus (Forssk.) Nees.	Acanthaceae	
36. Anogeissus bentii E.G.Baker. *	Combretaceae	
37. Anticharis glandulosa Asch	Scrophulariaceae	
38. Anticharis linearis (Benth.) Hochst. ex Asch. **	Scrophulariaceae	
39. Aptosimum pumilum (Hochst.)Benth.	Scrophulariaceae	
40. Areca catechu L.	Arecaceae (Palmae)	
41. Argyrolobium roseum (Camb.) Jaub. & Spach	Fabaceae (Papilionoideae)	
42. Argyrolobium uniflorum (Decne.) Jaub. & Spach	Fabaceae (Papilionoideae)	
43. Aristida triticoides Henrard	Poaceae (Gramineae)	Sammana
44. Aristolochia rigida Duch.	Aristolochiaceae	
45. Arnebia hispidissima (Lehm.) DC.	Boraginaceae	
46. Arthrocnemum fruticosum (L.) Moq.	Chinopodiaceae	

47. Arthrocnemum macrostachyum (Moric.) K.Koch.	Chinopodiaceae	
48. Asepalum eriantherum (Vatke) Marais	Cyclocheilaceae	
49. Asphodelus fistulosus L.	Liliaceae	
50. Asystasia petalidiodes Defl. *	Acanthaceae	
51. Atractylis kentrophylloides (Bak.) F.G.Davis **	Asteraceae (Compositae)	
52. Atriplex coriacea Forssk.	Chinopodiaceae	
53. Atriplex griffithii Moq.	Chinopodiaceae	
54. Atriplex leucoclada Boiss.	Chinopodiaceae	
55. Balanites aegyptiaca Del.	Balanitaceae	Halaj, Ssur
56. Barleria acanthoides Vahl	Acacnthaceae	
57. Barleria aff bispinosa (Forssk.) Vahl	Acacnthaceae	Shakhadh
58. Barleria candida Nees	Acanthaceae	
59. Barleria farinosa Defl. *	Acanthaceae	
60. Barleria hochstetteri Nees	Acanthaceae	
61. Barleria proxima Lind.	Acanthaceae	
62. Barleria trispinosa (Forssk.) Vahl.	Acanthaceae	
63. Bauhinia ellenbeckii Harms.	Caesalpiniaceae	
64. Blepharis ciliaris (L.) B.L.Burtt	Acanthaceae	Shawk Adhib, Balma
65. Boerhavia elegans Choisy ssp elegans **	Nyctaginaceae	Haydawan
66. Boscia arabica Pestalozzi **	Capparaceae	
67. Bosnanthe berberoides (Chiov.) W.j.de Willde.	Passifloraceae	
68. Cadaba baccarinii Chiov.	Capparaceae	
69. Cadaba farinosa Forssk.	Capparaceae (Capparidaceae)	
70. Cadaba heterotricha Stocks ex Hook.	Capparaceae (Capparidaceae)	
71. Cadaba rotundifolia Forssk.	Capparaceae (Capparidaceae)	
72. Cadia purpurea (Picc.) Ait.	Fabaceae (Papilionoideae)	
73. Caesalpinia erianthera Choiv. var. pubescens Brenan	Caesalpiniaceae	
74. Calligonum crinitum Boiss. subsp. arabicum **	Polygonaceae	
75. Calotropis procera (Ait.) Ait.f.	Apocynaceae (Asclepiadaceae)	
76. Capparis cartilaginea Decne.	Capparaceae (Capparidaceae)	
77. Campylanthus antonii Thulin	scrophulariaceae	
78. Campylanthus junceus Edgeweirth	scrophulariaceae	
79. Campylanthus pungens Schwartz **	scrophulariaceae	
80. Capparis spinosa L.	Capparaceae (Capparidaceae)	
81. Caralluma a enensis (Defl.) Burg. **	Apocynaceae (Asclepiadaceae)	
82. Caralluma arabica N.E.Br.	Apocynaceae (Asclepiadaceae)	
83. Caralluma dolichocarpa Schwartz *	Apocynaceae (Asclepiadaceae)	
84. Caralluma flava N.E.Br. **	Apocynaceae (Asclepiadaceae)	
85. Caralluma foulcheri-delboscii var. greenbergiana Lavr. *	Apocynaceae (Asclepiadaceae)	
86. Caralluma lavrani Rauh & Wertel *	Apocynaceae (Asclepiadaceae)	
87. Caralluma penicellata (Defl.) N.E.Br. **	Apocynaceae (Asclepiadaceae)	
88. Caralluma quadrangula (Forssk.) N.E.Br. **	Apocynaceae (Asclepiadaceae)	
89. Caralluma shadhabana Lav. & Newton **	Apocynaceae (Asclepiadaceae)	
90. Caralluma subulata (Forssk.) Decne. **	Apocynaceae (Asclepiadaceae)	
91. Cassia senna L.	Caesalpiniaceae	
92. Caylusea hexagyna (Forssk.) M.L.Green	Resedceae	
93. Celtis africana Burm.f.	Ulmaceae	
94. Cenchrus ciliaris L.	Poaceae (Gramineae)	

95. Ceratonia oreothauma Hillc., Lewis & Verdc. **	Caesalpiniaceae	
96. Ceropegia botrys K.Schuhmann.	Apocynaceae (Asclepiadaceae)	
97. Ceropegia subaphylla K. Schuhmann.	Apocynaceae	
98. Chascanum marrubifolium Fenzl ex Walp.	Verbenaceae	
99. Chloris barbata Sw.	Poaceae (Gramineae)	
100. Chrozophora plicata (Vahl) Juss.	Euphorbiaceae	
101. Chrozophora tinctoria A. juss.	Euphorbiaceae	Tinwab
102. Chrysopogon aucheri (Boiss.) Stapf var. quinqueplumis	Poaceae (Gramineae)	
103. Chrysopogon plumulosus Hochst.	Poaceae (Gramineae)	
104. Cienfuegosia welshii (T.Anders.) Garcke	Malvaceae	
105. Cistanche rosea E.G.Baker	Orchidaceae	
106. Citrullus colocynthis (L.) Schrad.	Cucurbitaceae	
107. Citrullus schimperi (Naud.) Hook.f.	Cucurbitaceae	
108. Cladostigma dioicum Radlin.	Convolvulaceae	
109. Cleome brachycarpa Vahl. ex DC.	Cleomaceae	Quthaylaba, Khuwayma
110. Cleome albescens Franch.	Cleomaceae	
111. Cleome droserifolia Del.	Cleomaceae	
112. Cleome hadramautica Thulin *	Cleomaceae	
113. Cleome macradenia Schweinf. *	Cleomaceae	
114. Cleome nocam Boiss.	Cleomaceae	
115. Cleome pruinosa T.Anders. **	Cleomaceae	
116. Cleome scaposa DC.	Cleomaceae	
117. Cometes abyssinica (R.Br.) Wallich.	Caryophyllaceae (Illecebraceae)	
118. Commelina boissierana C.B.Clk.	Commelinaceae	
119. Commicarpus mistus Thulin	Nyctaginaceae	
120. Commicarpus stenocarpus (Chiov .) Cuf.	Nyctaginaceae	
121. Commiphora foliacea Sprague.	Burseraceae	
122. Commiphora gileadensis (L.) Christ.	Burseraceae	Busham
123. Commiphora habessinica (O.Berg.) Engl.	Burseraceae	
124. Commiphora kua (J.F.Royale) Vollesen	Burseraceae	Qafal
125. Commiphora playfairii (Hook.f. ex Oliv.) Engl.	Burseraceae	
126. Conocarpus lancifolius Engl.	Combretaceae	
127. Convolvulus arvensis L	Convolvulaceae	
128. Convolvulus glomeratus Choisy	Convolvulaceae	
129. Convolvulus littoralis Vatke	Convolvulaceae	
130. Convolvulus sericophyllos T. Anders. *	Convolvulaceae	
131. Corallocarpus glomeruliflorus Schweinf.	Cucurbitaceae	Mudrika
132. Corchorus depressus (L.) Christ	Tiliaceae	
133. Cordia nervillii Alston	Boraginaceae	
134. Cornulaca amblyacantha Bunge	Chinopodiaceae	
135. Cornulaca ehrenbergii Aschers	Chinopodiaceae	
136. Cornulaca monacantha Del.	Chinopodiaceae	
137. Cressa cretica L.	Convolvulaceae	Shuwayla
138. Crotalaria aegyptiaca Benth.	Fabaceae (Papilionoideae)	
139. Crotalaria dumosa Franch.	Fabaceae (Papilionoideae)	
140. Crotalaria persica (Burm.f.) Merr.	Fabaceae (Papilionoideae)	Nazaa'
141. Crotalaria retusa L.	Fabaceae (Papilionoideae)	
142. Crotalaria saltiana Andr.	Fabaceae (Papilionoideae)	

143. Cryptolepis yemenensis Venter & R.L.Verh. *	Apocynaceae	
144. Cucumis canoxyi Thulin & Gifri *	Cucurbitaceae	
145. Cucumis prophetarum L.	Cucurbitaceae	
146. Cuscuta campestris Yunker	Cuscutaceae (Convolvulaceae)	
147. Cuscuta kotschyana Boiss.	Cuscutaceae (Convolvulaceae)	
148. Cyamopsis tetragonoloba (L.) Traub	Fabaceae (Papilionoideae)	
149. Cyclocheilon somalensis Oliv.	Cyclocheilaceae	
150. Cymbopogon schoenanthus (L.) Spreng. subsp. schoenanthus	Poaceae (Gramineae)	Shahber, Shinan
151. Cynodon dactylon (L.) Pers.	Poaceae (Gramineae)	Rumam
152. Cyperus conglomeratus Rottb.	Cyperaceae	
153. Cystostemon kissenioides (Delf.) A.Miller & H.Riedl. *	Boraginaceae	
154. Dactyloctenium aegyptium (L.) P.Willd.	Poaceae (Gramineae)	
155. Datura innoxia Mill	Solaniaceae	
156. Delonix elata (L.) Gamble.	Caesalpiniaceae	
157. Desmostachya bipinnata (L.) Stapf	Poaceae (Gramineae)	
158. Dichanthium foveolatum (Del.) Roberty	Poaceae (Gramineae)	
159. Dichanthium insculptum (A.Rich.) Clayton	Poaceae (Gramineae)	Halta
160. Digera muricata (L.) Mart. subsp. muricata	Amaranthaceae	
161. Digitaria ciliaris (Retz.) Koeler	Poaceae (Gramineae)	
162. Digitaria nodosa Parl.	Poaceae (Gramineae)	
163. Diplotaxis harra (Forssk.) Boiss.	Brassicaceae (Cruciferae)	
164. Dipterygium glaucum Decne.	Capparaceae (Capparidaceae)	A'lqa
165. Dodonaea viscosa (L.) Jacq.	Sapindaceae	
166. Dracaena serrulata Baker	Agavaceae	
167. Ecbolium strictum Schwartz *	Acanthaceae	
168. Echidnopsis bentii N.E.Br. *	Apocynaceae (Asclepiadaceae)	
169. Echidnopsis globosa Thulin & Hjertson *	Apocynaceae (Asclepiadaceae)	
170. Echidnopsis seibanica Lavr. *	Apocynaceae (Asclepiadaceae)	
171. Echiochilon arabicum (Schwartz) I.M.Johns. *	Boraginaceae	
172. Echiochilon colona (L.) Link	Poaceae (Gramineae)	
173. Echiochilon longiflorum Benth	Boraginaceae	
174. Echiochilon strigosum (Defl.) I.M.Johns.	Boraginaceae	
175. Eleocharis geniculata (L.) Roem. & Schult.	Cyperaceae	
176. Enicostema axillare (Lam.) A. Raynal	Gentiaceae	
177. Enneapogon desvauxii J.E.Smith	Poaceae (Gramineae)	
178. Enneapogon lophotrichus Chiov. ex Scholz	Poaceae (Gramineae)	
179. Ephedra foliata Boiss. ex C.A.Mey	Ephedraceae	
180. Ephedra milleri Freitag & Maier-Stolte. **	Ephedraceae	
181. Eragrostis maharana Schweinf.	Poaceae (Gramineae)	
182. Eriochloa fatmensis (Hochst. & Steudel) W.D.Clayton	Poaceae (Gramineae)	
183. Eruca sativa Miller	Brassicaceae (Cruciferae)	
184. Erucastrum arabicum Fisch. & Mey.	Brassicaceae (Cruciferae)	Kitha
185. Euphorbia applanata Thulin & Gifri *	Euphorbiaceae	
186. Euphorbia arabica Hochst. & Steud. ex Boiss.	Euphorbiaceae	
187. Euphorbia balsamifera Ait.	Euphorbiaceae	
188. Euphorbia cactus Ehrenb.	Euphorbiaceae	
189. Euphorbia fodhliana Defl. *	Euphorbiaceae	
190. Euphorbia granulata Forssk.	Euphorbiaceae	Tuhilba

191. Euphorbia hadramautica E.G.Baker.	Euphorbiaceae	
192. Euphorbia meuleniana O. Schwartz. *	Euphorbiaceae	
193. Euphorbia noxia Pax.	Euphorbiaceae	
194. Euphorbia quaitensis S.Carter *	Euphorbiaceae	
195. Euphorbia riebeckii Pax. **	Euphorbiaceae	
196. Euphorbia rubriseminalis S.Carter *	Euphorbiaceae	
197. Euphorbia schimperi Presl	Euphorbiaceae	
198. Euphorbia seclusa N.E.Br.	Euphorbiaceae	
199. Euphorbia seibanica Lavr. & Gifri. *	Euphorbiaceae	
200. Euryops arabicus Steud.	Asteraceae (Compositae)	
201. Fagonia arabica L.	Zygophyllaceae	
202. Fagonia bruguieri DC.	Zygophyllaceae	Durayma
203. Fagonia hadramautica Beier & Thulin *	Zygophyllaceae	
204. Fagonia indica Burm.f.	Zygophyllaceae	Durayma
205. Fagonia lahovarii Volkens & Schweinf.	Zygophyllaceae	
206. Fagonia latifolia Del.	Zygophyllaceae	
207. Fagonia luntii Bak.	Zygophyllaceae	
208. Fagonia paulayana Wagner & Vierh.	Zygophyllaceae	Durayma
209. Farsetia linearis Decne Ex Boiss. **	Brassicaceae (Cruciferae)	Sabt'ah
210. Farsetia dhofarica Jonsell & Miller **	Brassicaceae (Cruciferae)	
211. Farsetia longisiliqua Decne.	Brassicaceae (Cruciferae)	
212. Farsetia stylosa R.Br.	Brassicaceae (Cruciferae)	
213. Ficus cordata L. subsp. salicifolia	Moraceae	
214. Fimbristylis polytrichoides R.Br.	Cyperaceae	
215. Flaveria trinervia (Spreng.) Mohr.	Asteraceae (Compositae)	
216. Forsskaolea tenacissima L.	Urticaceae	
217. Forsskaolea viridis Ehrenb.	Urticaceae	
218. Gaillonia jolana Thulin *	Rubiaceae	
219. Gaillonia yemenensis Thulin	Rubiaceae	
220. Glossonema varians (Stocks) Benth. ex Hook.	Apocynaceae (Asclepiadaceae)	
221. Gomphocarpus fruticosus (L.) Ait.f. var. setosus (Forssk.) Schwartz	Apocynaceae	
222. Grewia erythraea Schweinf.	Tiliaceae	
223. Gymnocarpos decandrus Forssk.	Caryophyllaceae (Illecebraceae)	
224. Gymnocarpos rotundifolius Petruss & Thulin **	Caryophyllaceae (Illecebraceae)	
225. Gypsophila montana Balf. f.	Caryophyllaceae (Illecebraceae)	
226. Halopeplis perfoliata (Forssk.) Bunge ex Asch. & Schweinf.	Chinopodiaceae	
227. Halopyrum mucronatum (L.) Stapf.	Poaceae (Gramineae)	
228. Halothamnus bottae Jaub. & Spach **	Chinopodiaceae	
229. Helichrysum pumilum (Klatt.) Moes.	Asteraceae (Compositae)	
230. Helinus integrifolius (Lam.) Kuntze	Rhamnaceae	
231. Heliotropium lasiocarpum Fischer & C.A.Meyer	Boraginaceae	
232. Heliotropium adenense Gurke.	Boraginaceae	
233. Heliotropium arbainense Fresen.	Boraginaceae	
234. Heliotropium bacciferum Forssk.	Boraginaceae	
235. Heliotropium bottae Defl. *	Boraginaceae	
236. Heliotropium fartakense Schwartz **	Boraginaceae	
237. Heliotropium lignosum Vatke	Boraginaceae	

238. Heliotropium makallense Schwartz *	Boraginaceae	
239. Heliotropium ophioglossum Stocks ex Ait.	Boraginaceae	
240. Heliotropium paradoxum Vatke *	Boraginaceae	
241. Heliotropium pterocarpum (DC.) Steud. & Hochst. ex Bunge	Boraginaceae	
242. Heliotropium ramosissimum (Lehm.) Sieb. ex DC.	Boraginaceae	Rimram
243. Heliotropium rariflorum Stocks	Boraginaceae	
244. Heliotropium steudneri Vatke	Boraginaceae	
245. Heliotropium strigosum Willd.	Boraginaceae	
246. Heliotropium wagneri Vierh. *	Boraginaceae	
247. Heliotropium wissmannii Schwartz *	Boraginaceae	
248. Hermannia paniculata Franch	Sterculiaceae	
249. Hibiscus micranthus L.f.	Malvaceae	
250. Hochstettera schimperi DC	Asteraceae (Compositae)	
251. Huernia hadhramautica Lavr. *	Apocynaceae (Asclepiadaceae)	
252. Hyoscyamus albus L.	Solanaceae	
253. Hypoestes forskalei (Vahl) Sol. ex Roem. & Schult.	Acanthaceae	
254. Indigofera articulata Gouan	Fabaceae (Papilionoideae)	
255. Indigofera coerulea Roxb.	Fabaceae (Papilionoideae)	
256. Indigofera nephrocarpoides J.B.Gillett *	Fabaceae (Papilionoideae)	
257. Indigofera oblongifolia Forssk.	Fabaceae (Papilionoideae)	Hasar
258. Indigofera semitrijuga Forssk.	Fabaceae (Papilionoideae)	
259. Indigofera spinosa Forssk.	Fabaceae (Papilionoideae)	Kindush, Raqma
260. Iphiona anthemidifolia (Bak.) A.Anderb. *	Asteraceae (Compositae)	
261. Iphiona scabra DC.	Asteraceae (Compositae)	
262. Iphiona senecionoides (Bak.) A..Anderb. **	Asteraceae (Compositae)	
263. Iphiona teretefolia A.Anderb. *	Asteraceae (Compositae)	
264. Iphiona vierhapperi Schwartz	Asteraceae (Compositae)	
265. Ipomoea pes-caprae (L.) R. Br.	Convolvulaceae	
266. Jatropha pelargoniifolia Courb.	Euphorbiaceae	
267. Jatropha spinosa (Forssk.) Vahl	Euphorbiaceae	Dumum
268. Justicia areysiana Defl. **	Acacnthaceae	
269. Justicia flava (Vahl) Vahl	Acanthaceae	
270. Kelleronia gillettiae Baker.f. var. gillettiae	Zygophyllaceae	
271. Kickxia pseudoscoparia D.A.Sutton	Scrophulariaceae	
272. Kleinia deflersii Defl. *	Asteraceae (Compositae)	
273. Kleinia odora (Forssk.) A.Berger **	Asteraceae (Compositae)	
274. Kleinia squarrosa Cufod.	Compositae	
275. Kohautia retrorsa (Boiss.) Bremek.	Rubiaceae	Harjal, Harajraj
276. Lasiurus scindicus Henrard	Poaceae (Gramineae)	
277. Launaea angustifolia (Desf.) O.Kuntze	Asteraceae (Compositae)	
278. Launaea capitata (Sprenq.) Dandy	Asteraceae (Compositae)	
279. Launaea castanosperma F.G.Davies **	Asteraceae (Compositae)	
280. Launaea crassifolia (Balf.f.) C. Jeffrey	Asteraceae (Compositae)	
281. Launaea hafunensis Chiov.	Asteraceae (Compositae)	
282. Launaea intybacea (Jacq.) Beauverd	Asteraceae (Compositae)	
283. Launaea massauensis (Fresen.) Sch. Bip. ex Kuntze.	Asteraceae (Compositae)	
284. Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze	Asteraceae (Compositae)	
285. Launaea procumbens (Roxb.) Ramayya & Rajgopal.	Asteraceae (Compositae)	

286. Lavandula macra E.G.Baker.	Lamiaceae (Labiatae)	
287. Lavandula subnuda Benth. **	Lamiaceae (Labiatae)	
288. Leptadenia arborea (Forssk.) Schweinf.	Apocynaceae (Asclepiadaceae)	
289. Leptadenia pyrotechnica (Forssk.) Decne.	Apocynaceae (Asclepiadaceae)	
290. Leptotherim senegalense (Kunth) W.D.Clayton	Poaceae (Gramineae)	
291. Limoniastrum arabicum J. Edmondson *	Plumbaginaceae	
292. Limonium cylindrifolium (Forssk.) Verdc	Plumbaginaceae	
293. Lindenbergia indica (L.) Kuntze	Scrophulariaceae	
294. Livistonia carinensis (Chiov.) Dransfield & N.Uhl	Arecaceae (Palmae)	
295. Lochia bracteata Balf.f. subsp. bracteata	Caryophyllaceae (Illecebraceae)	
296. Lycium schweinfurthii Dammer	Solaniaceae	
297. Lycium shawii Roem. & Schult	Solaniaceae	
298. Maerua angolensis DC.	Capparaceae	
299. Maerua crassifolia Forssk.	Capparaceae (Capparidaceae)	Sarh, Sarha
300. Maerua thomsonii T. Anders.	Capparaceae (Capparidaceae)	
301. Medicago sativa L.	Fabaceae (Papilionoideae)	
302. Megalochlamys linifolia (Lindau) Lindau	Acacnthaceae	
303. Megastoma pusillum Coss. & Durs.	Boraginaceae	
304. Merremia hadramautica (Baker) R.R.Mill *	Convolvulaceae	Matka
305. Moltkiopsis ciliata (Forssk.) I.M.John.	Boraginaceae	
306. Monsonia heliotropoides (Cav.) Boiss.	Geraniaceae	
307. Moringa peregrina (Forssk.) Fiori	Moringaceae	
308. Nannorrhops ritchieana (Griffith) Ait.	Arecaceae (Palmae)	
309. Nigella sativa L.	Ranunculaceae	
310. Nogalia drepanophylla (E.G.Baker) Verdc.	Boraginaceae	
311. Ochradenus arabicus Chaud. Hillcoat & Miller **	Resedaceae	
312. Ochradenus baccatus Del.	Resedaceae	Qardhiya, Dhaayan
313. Ochradenus gifrii Thulin **	Resedaceae	
314. Ochradenus spartioides (Schwartz) Abdullah *	Resedaceae	
315. Olea europaea L. subsp. cuspidata	Oleaceae	
316. Ophioglossum polyphyllum A.Br.	Ophioglossaceae	
317. Orbea luntii (N.E. Brown) Bruyns **	Apocynaceae (Asclepiadaceae)	
318. Otostegia fruticosa (Forssk.) Briq. subsp. fruticosa	Lamiaceae (Labiatae)	
319. Otostegia fruticosa (Forssk.) Briq. subsp schimperi	Labiatae	
320. Pancratium tortuosum Herbert	Amaryllidaceae	
321. Pancratum maximu Forssk.	Amaryllidaceae	
322. Panicum turgidum Forssk.	Poaceae (Gramineae)	Thummam, Mahsham
323. Pappea capensis Eckl. & Zeyh.	Sapindaceae	
324. Pavonia subaphylla Schwartz *	Malvaceae	
325. Pegolettia senegalensis Cass.	Asteraceae (Compositae)	
326. Pentatropis nivalis (Gmel.) Field & Wood	Apocynaceae (Asclepiadaceae)	
327. Pentzia arabica Thulin *	Asteraceae (Compositae)	
328. Pergularia tomentosa L.	Apocynaceae (Asclepiadaceae)	
329. Periploca somalensis Browicz	Apocynaceae	
330. Periploca visciformis (Vatke) K.Schum.	Apocynaceae (Asclepiadaceae)	
331. Peristrophe paniculata (Forssk.) Brummitt	Acanthaceae	
332. Perrolderia coronopifolia Cass.	Asteraceae (Compositae)	

333. Pistacia falcata Becc. ex Martelli	Anacardiaceae	
334. Phagnalon hypoleucum Schultz-Bip.	Asteraceae (Compositae)	
335. Phoenix dactylifera L.	Arecaceae (Palmae)	
336. Phragmites australis (Cav.) Trin. ex Steud.	Poaceae (Gramineae)	
337. Phyllanthus maderaspatensis L.	Euphorbiaceae	
338. Piper betle L.	Piperaceae	
339. Pithecellobium dulce (Roxb.) Benth.	Mimosoideae	
340. Pituranthos tortuosus Benth. & Hook.	Apiaceae (Umbelliferae)	
341. Plicosepalus curviflorus (Benth. ex Oliv.) Tiegh.	Loranthaceae	
342. Pluchea arabica (Boiss.) Qaiser & Lack **	Asteraceae (Compositae)	
343. Pluchea dioscorides (L.) DC.	Asteraceae (Compositae)	
344. Pluchea indica (L.) Less.	Asteraceae (Compositae)	
345. Polygala abyssinica R.Br. ex Fresen. var. abyssinica	Polygalaceae	
346. Polygala mascatensis Boiss.	Polygalaceae	
347. Polygala senensis Klotzsch	Polygalaceae	
348. Polygala thurmanniana Chodat	Polygalaceae	
349. Portulaca oleracea L.	Portulacaceae	
350. Potamogeton nodosus Poir.	Potamogetonaceae	
351. Primula verticillata Forssk.	Primulaceae	
352. Prosopis cineraria (L.) Druce	Mimosoideae	
353. Prosopis farcta (Banks. & Sol.) Mc Bride	Mimosoideae	
354. Prosopis juliflora (S.W.) DC.	Mimosoideae	
355. Psiadia punctulata (DC.) Vatke	Asteraceae (Compositae)	
356. Psilotrichum virgatum C.C.Towns.	Amaranthaceae	
357. Pteris vittata L.	Pteridophyta	
358. Pulicaria argyrophylla Franchet	Asteraceae (Compositae)	
359. Pulicaria cylindrica (Bak.) O. Schwartz	Asteraceae (Compositae)	
360. Pulicaria inuloides (Poir.) DC.	Asteraceae (Compositae)	
361. Pulicaria lancifolia Schwartz *	Asteraceae (Compositae)	
362. Pulicaria nivea Schwartz *	Asteraceae (Compositae)	
363. Pulicaria rauhii Gamal-Eldin *	Asteraceae (Compositae)	
364. Pulicaria somaliensis O.Hoffm.	Asteraceae (Compositae)	
365. Pulicaria undulata (L.) C.A.Mey.	Asteraceae (Compositae)	Jithjath
366. Reseda sphenocleoides Defl. **	Resedaceae	Amhid
367. Rhazya stricta Decne	Apocynaceae	
368. Rhus flexicaulis Baker *	Anacardiaceae	
369. Rhus glutinosa A. Rich subsp neoglutinosa Gilbert	Anacardiaceae	
370. Rhus natalensis Bernh. ex Krauss	Anacardiaceae	
371. Rhynchosia memnonia (Del.) DC.	Fabaceae (Papilionoideae)	Raqma
372. Rhytidocaulon mccoyi Lavr. *	Apocynaceae (Asclepiadaceae)	
373. Rumex vesicarius L.	Polygonaceae	
374. Salsola cyclophylla Baker	Chinopodiaceae	
375. Salsola imbricata Forssk.	Chinopodiaceae	
376. Saltia papposa (Forssk.) Moq. *	Amaranthaceae	
377. Salvadora persica L.	Salvadoraceae	
378. Samolus valerandii L.	Primulaceae	
379. Sarcostemma vanlessenii Lavr.	Apocynaceae (Asclepiadaceae)	
380. Sarcostemma viminale (L.) R.Br. subsp. stipitaceum (Forssk.) Meve & Liede	Apocynaceae (Asclepiadaceae)	

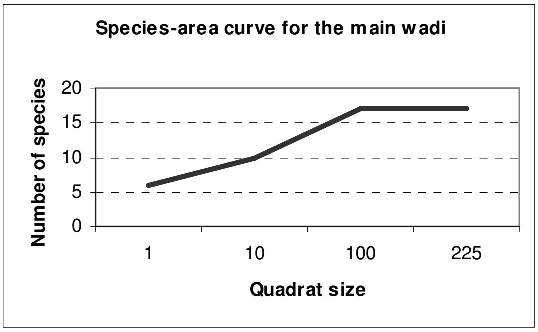
381. Schouwia purpurea (Forssk.) Schweinf.	Brassicaceae (Cruciferae)	
382. Schweinfurthia latifolia (Baker) Oliver *	Scrophulariaceae	
383. Schweinfurthia papillionacea (L.) Boiss.	Scrophulariaceae	
384. Schweinfurthia pedicellata (T.Anders.) Balf.f.	Scrophulariaceae	
385. Schweinfurthia spinosa Miller, Sutton & Short **	Scrophulariaceae	
386. Scirpus corymbosus Heyne & Roth.	Cyperaceae	
387. Sclerocephalus arabicus Boiss.	Caryophyllaceae (Illecebraceae)	
388. Seddera arabica (Forssk.) Choisy	Convolvulaceae	
389. Seddera hadramautica R.R.Mill	Convolvulaceae	
390. Seddera latifolia Hochst. & Steud.	Convolvulaceae	
391. Seetzenia lanata (Willd.) Bullock	Zygophyllaceae	
392. Segeretia thea (Osb.) M.S.John	Rhamnaceae	
393. Selaginella imbricata (Forssk.) Spring	Pteridophyta	
394. Senna holosericea (Fres.) Greuter	Caesalpiniaceae	
395. Senna italica Miller	Caesalpiniaceae	Eshriq
396. Senra incana (Cav.) DC.	Malvaceae	Afar, Enhaq
397. Sesamum indicum L.	Pedaliaceae	
398. Setaria verticillata (L.) P. Beauv.	Poaceae (Gramineae)	
399. Setaria viridis (L.) P.Beauv.	Poaceae (Gramineae)	
400. Sideroxylon mascatense (A.D.C.) T.D. Penn. *	Sapotaceae	
401. Solanum forskalii Dunal	Solaniaceae	
402. Solanum nigrum L.	Solaniaceae	
403. Solanum pubescens Willd.	Solaniaceae	
404. Solanum schimperianum Hochst ex A. Rich	Solaniaceae	
405. Sonchus oleraceus L.	Asteraceae (Compositae)	
406. Sporobolus helvolus (Trin.) T.Duran. & Schinz	Poaceae (Gramineae)	
407. Sporobolus ioclados (Nees ex Trin.) Nees .	Poaceae (Gramineae)	
408. Sporobolus ruspolianus Chiov.	Poaceae (Gramineae)	
409. Sporobolus spicatus (Vahl) Kuntze.	Poaceae (Gramineae)	
410. Sporobolus tourneuxii Coss.	Poaceae (Gramineae)	
411. Stachys yemenensis Hedge *	Labiatae	
412. Sterculia africana (Lovr.) Fiori	Sterculiaceae	
413. Stipa parviflora Desf.	Poaceae (Gramineae)	
414. Stipa tigrensis Chiov.	Poaceae (Gramineae)	
415. Stipagrostis ciliata (Desf.) de Winter	Poaceae (Gramineae)	
416. Stipagrostis hirtigluma (Steud. ex Trin. & Rupr.) de Winter	Poaceae (Gramineae)	T'afh
417. Striga asiatica (L.) Kuntze	Scrophulariales	Muzawila
418. Strobopetalum bentii N.E.Br.	Apocynaceae (Asclepiadaceae)	
419. Stultitia araysiana Lavr. & Bilaidi *	Apocynaceae (Asclepiadaceae)	
420. Suaeda aegyptiaca (Hasselq.) Zoh.	Chinopodiaceae	
421. Suaeda pruinosa Lange	Chinopodiaceae	
422. Suaeda vermiculata Forssk.	Chinopodiaceae	
423. Tagetes minuta L.	Euphorbiaceae	
424. Tamarix aphylla (L.) H.Karst.	Tamaricaceae	
425. Tamarix arabica Bunge	Tamaricaceae	
426. Tarchonanthus camphoratus L.	Asteraceae (Compositae)	
427. Tarenna graveolens (S.Moore) Bremek.	Rubiaceae	
428. Taverniera aegyptiaca Boiss.	Fabaceae (Papilionoideae)	

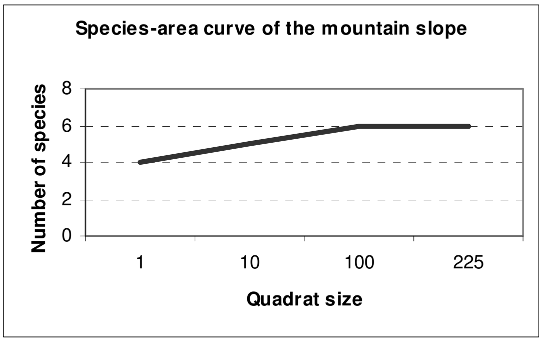
429. Taverniera glauca Edgeworth *	Fabaceae (Papilionoideae)	
430. Taverniera multinoda Thulin *	Fabaceae (Papilionoideae)	
431. Taverniera schimperi Jaub. & Spach *	Fabaceae (Papilionoideae)	
432. Tephrosia apollinea (Del.) DC. subsp. longistipulata Vierh.	Fabaceae (Papilionoideae)	Khudhayrah
433. Tephrosia dura Baker	Fabaceae (Papilionoideae)	Yaa'bur
434. Tephrosia hadramautica Thulin *	Fabaceae (Papilionoideae)	
435. Tephrosia heterophylla Varke	Fabaceae (Papilionoideae)	
436. Tephrosia nubica (Boiss.) Baker subsp. arabica (Boiss.) Gillett	Fabaceae (Papilionoideae)	Dhubiyah
437. Tephrosia purpurea (L.) Pers. subsp. leptostachya (DC.) Brumm.	Fabaceae (Papilionoideae)	
438. Tephrosia subtriflora Hochst. ex Baker.	Fabaceae (Papilionoideae)	
439. Tetrachaete elionuroides Chiov.	Poaceae (Gramineae)	
440. Tetrapogon villosus Desf.	Poaceae (Gramineae)	
441. Teucrium eximium Schwartz *	Lamiaceae (Labiatae)	
442. Teucrium leucocladum Boiss.	Lamiaceae (Labiatae)	
443. Teucrium rhodocalyx Schwartz *	Lamiaceae (Labiatae)	
444. Tragus berteronianus Schult.	Poaceae (Gramineae)	
445. Tragus racemosus (L.) All.	Poaceae (Gramineae)	
446. Trianthema salsoloides Olive.	Aizoaceae	
447. Tribulus arabicus H.Hosn.	Zygophyllaceae	Zahr
448. Tribulus terrestris L.	Zygophyllaceae	
449. Trichodesma calathiforme Hochst.	Boraginaceae	
450. Turraea parvifolia Defl.	Meliaceae	
451. Typha sp.	Typhaceae	Allal
452. Verbascum luntii E.G.Baker. *	scrophulariaceae	
453. Vernonia arabica F.G.Davis	Asteraceae (Compositae)	
454. Vernonia areysiana Defl. *	Asteraceae (Compositae)	
455. Vernonia spathulata (Forssk.) Sch. Bip.	Asteraceae (Compositae)	
456. Viscum schimperi Engl.	Viscaceae	
457. Withania somnifera (L.) Dun	Solaniaceae	
458. Xerotia arabica Oliver. **	Caryophyllaceae (Illecebraceae)	
459. Zehneria anomala C. Jeffrey	Cucurbitaceae	
460. Ziziphus leucodermis (E.G.Baker) Schwartz **	Rhamnaceae	Habdhah
461. Ziziphus lotus (L.) Lam.	Rhamnaceae	
462. Ziziphus spina -christi (L.) Willd.	Rhamnaceae	
463. Zygophyllum album L.var. amblyocarpum	Zygophyllaceae	
464. Zygophyllum coccineum L.	Zygophyllaceae	Rabl
465. Zygophyllum decumbens Del. var. decumbens	Zygophyllaceae	
466. Zygophyllum decumbens Del. var. megacarpum	Zygophyllaceae	
467. Zygophyllum fontanesii Webb.	Zygophyllaceae	
468. Zygophyllum hamiense Schweinf.	Zygophyllaceae	
469. Zygophyllum simplex L.	Zygophyllaceae	Rabl

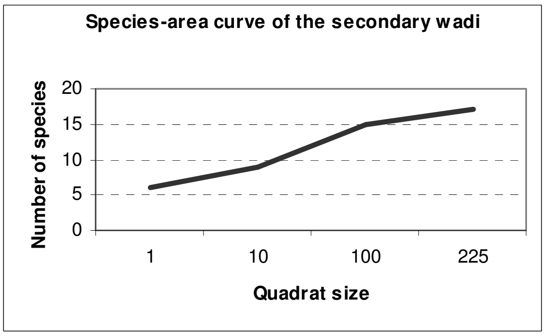
- * = endemic to Yemen
- ** = endemic to Arabia

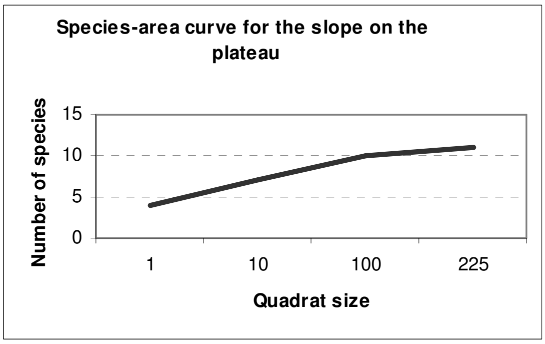
Appendix 5. Name of local people contributed to the study

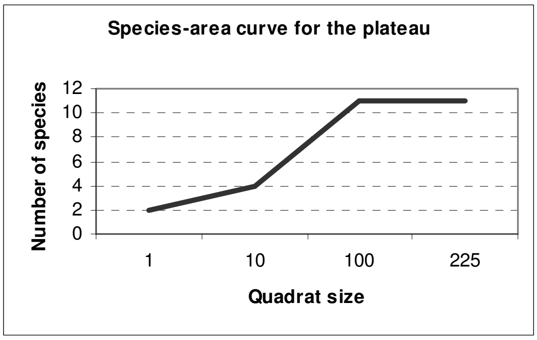
Site 1:	**Site 2**	**Site 3**
Abdul Lah Saed Al Naser	Abud Karama Azubaydi	A’ref Rizq Nassr
Abdul Lah Saed bin Hadh	Abud Salem Saed Al Kuthayri	Abdul Lah AZzubaydi
Abdul Majid Saed	Karama Abdul Lah bin Ebrahe	Ahmed Sirri
Amer Ssaleh Al Ssua’yri	Saed Al Jabiri	Hadi Abdul Lah Al Kharaz
Aydhah Ssaleh Al Ssu’yri	Saed Hamtut Al Ali	Hasan Al A’miri
Aynan Saed hashem Al Kuthayri	Saed Saleh Al Ali	Jaa’far Salem
Emad Jaa’far Jaber	Saleam Umar Ba Wazir	Muhammed Ba Shua’yb
Husayn Abdul Lah Al Ssu’yri	Saleh Abdul Lah Ba Wazir	Muhsen Al A’miri
Jamal Abdul Lah	Saleh Attumar Al Uwaythaly	Saed Badr Al Kuthairi
Juma’an Masser Al Shan	Saleh bin Ali	Saed Rizq Bin Nassr
Juma’an Mohammed Badhawi	Yaser Abdul Lah Malss	Salem A’ydhah Al A’miri
Khaled Ahmed Zabir		Salem Bin A’aydhah Al A’amiri
Khamis Juma’an		Salem Bin Mubarak Assibae’i
Mohammed Ahmed Aqil		Salem Rizq Nassr
Mohammed Omar banaduh		Salem Ssaleh A’bidi
Mubarak Saed Hadi		Shaykh Ubaid Ba Shua’yb
Muhsin Mohammed Badhawi		Ssaleh Bin Ubayd Al A’amiri
Nasser Juma’n Al Aa’wash		Ssaleh Maqt’un
Omar Ssaleh Al Qua’yti		Ubaid Muhammed Ba Shua’yb
Saed A’wadh hassn		Umar Ubaid Abdul Lah
Salah Mubarak bin Hassn		Uthman Attamimi
Saleh Al Abd Attamimi		
Saleh Yaslem		
Shaikh Rabie’ Omar Al Kuthairi		
Subayt Bajandue		
Yaslem Awadh Jaber		











Appendix 6. Progressive doubling of quadrat size for minimal area of species-area curves for the different landforms in the study sites. Generally the method showed that 10 x 10 m quadrat (100m²) was adequate for sampling most of the plant species recorded in each landform. Quadrat size is in square metres.