Aspects of vegetation resilience and change in relation to major environmental disturbances in the semi-arid parts of Kordofan region-Sudan

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Aspects of Vegetation Resilience and Change in Relation to Major Environmental Disturbances in the Semi-Arid Parts of Kordofan Region-Sudan

by

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**A Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy**

Department of Geography

The University of Durham

1990

Abstract

The aim of this study has been to investigate the different responses of vegetation to the major environmental disturbances and discontinuities in Kordofan region of the Sudan. Data used have been obtained from fieldwork survey, aerial photographs and a landsat image in combination with existing maps and statistics on vegetation, climate, agriculture and population.

Results obtained have shown that most plant species are neither randomly distributed nor indications of the postulated regularity of distribution were detected. Such a distributional pattern was explained through the pattern of surface properties. These have included rainfall, soil characteristics, micro-topography and the type of vegetation itself.

The different types of vegetation identified were shown to reflect various successional stages following either excessive cultivation, grazing or both. Climatically conditioned natural vegetation is virtually absent as the effect is almost entirely masked by man's activities. Evidence presented showed that various types of woodland were formerly more extensive and that they have been replaced by secondary shrubland, bushland and grassland.

Most plant communities have been explained by their history of cultivation and grazing pressure. These two were found to interpret the process of successional changes, to radically alter its dynamics and to set plant species on a wide variety of paths which is largely controlled by the pressure exerted.

Achieved result indicated that vegetation in the area has persisted to exist and to re-establish itself after virtual elimination. This is shown to reflect a high degree of resilience in the system. Evidence were shown that if the vegetation is protected

and the climatic and edaphic conditions were favourable, it will eventually be succeeded by a richer type of vegetation.

It has not been possible to prove neither to reject the claim often found in literature that the vegetation zones in this region are constantly shifting southward as a result of overgrazing, overcultivation and accelerated soil erosion. However, it has been possible to recognise a process of successional changes which varies from one place to another in terms of nature and intensity depending largely on site characteristics.

Acknowledgements

This work has been sponsored through a grant by the Sudan Government. Many people and institutions have contributed to the completion of this thesis, not all of them can be mentioned here. I must however express special thanks to some.

To Prof. I.G. Simmons who had earlier supervised the beginnings of this research and Dr. W.T.W. Morgan who had closely followed my work throughout the writing-up phase. To both my deepest gratitude for their advice, comments, encouragements and fruitfull discussion.

To Dr. William and other staff members at the Computer Centre who have been of irreplaceable help with all kinds of comuter problems.

To the staff at the Gizera Research Unit-Wad Medani for the assistance they offered with soil analysis.

To Christopher Cox Memorial Fund, Gordon Memorial College Trust Fund and the Geography Dept. of Durham University for jointly financing the purchase of the satellite image used in this study.

To the many individuals who assisted me during fieldwork and my warmest gratitude to the local people of the study area who have received me and my assistants with a great hospitality in the numerous villages we have visited.

Finally, and not least, my sincere acknowledgements to my wife (Sumaia) and my son (Muhannad) who suffered in silence to allow this work getting some light.

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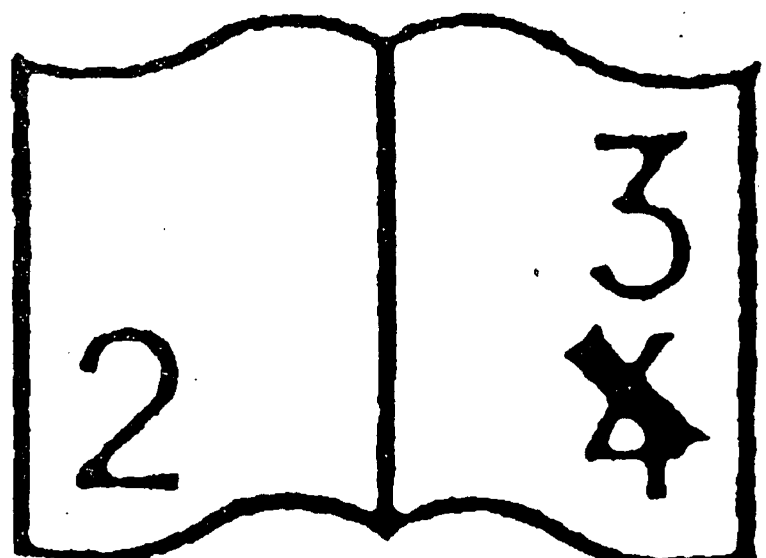

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Chapter I

Introduction

1.1 Problem and Rationale

The Republic of the Sudan, with approximately two thirds of its total area being located in the arid and semi-arid zones of Africa, has been faced during the last three decades, as most other parts of the Sahel † Zone of Africa with what has recently become known as a complex of land degradation processes. This is a phenomenon which has attracted the attention and become the most serious and pressing problem throughout the entire zone. Many terminologies were coined to define and describe it such as "desert encroachment", "desertification" and "desertisation" ‡

On the other hand, savanna which occupies the rest of the country, has been considered by many ecologists as among the most variable and vulnerable of terrestrial ecosystems. According to Walker & Meir (1982), savanna ecosystems undergo large and frequent changes in production, composition and structure, and they contain some of the worst examples of degradation by man. There are, accordingly,

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† Sahel is an Arabic term signifying coast or border. In this research it will be used to refer to the zone, as identified by the National Research Council of America (1983), approximately 200 - 400 km wide, central on latitude 15° N Sub-Saharan Africa

‡ Discussion on this issue had been highlighted by the Sahelian drought in 1968-74 which was followed by the UN Conference on Desertification held in Nairobi in 1977. Several definitions for desertification were speculated. The mostly widely accepted one is, "the spread of desert-like conditions in arid and semi-arid areas due to man's impact or to climatic change". Regarding the controversies which had accompanied this term and its definition, a more neutral term with a more generalized definition was added describing the phenomenon as a long-term decrease of land biological productivity caused or accelerated by human activities in combination with climate.

many references to them as *fragile* and *brittle* with frequent prediction of impending collapse.

The location of Kordofan Region within this fragile zone, and more importantly, fringing the southern margins of the tropical desert, has rendered most of its parts unstable and susceptible to destruction. Long ago Andrews (1948) stressed the notion that Kordofan is being located in a region of instability where nature's balance is so delicate that it can easily be tipped towards destruction in response to slight diturbances in its components. The region has recently become a synonym for land degradation, considerable human suffering and the desperate struggle for survival by both humans and animals.

This land degradation process in Kordofan, which is commonly being termed desertification, does not mean the southward extension of the desert into the region, nor necessarily indicates the creation and/or expansion of desert-like conditions or patches, but it rather implies the impoverishment of the area's ecosystem by the combined impact of man's activities and drought. It is a process of change in the region's ecosystem such that can be measured by the reduced productivity of local plants, alterations in the biomass and diversity of the micro and macro flora and fauna, accelerated soil deterioration and increased hazards to both human and animals.

Ecologists have increasingly emphasized the decisive role played by vegetation in the conservation and maintenance of ecosystems. In fact vegetation plays the greatest part in soil conservation and fertility. A non-vegetated soil, in such dry lands, is always susceptible to wind erosion which eventually leads to decline in productivity. While, on the other hand, a vegetated soil is constantly enriched by the addition of organic and inorganic materials from shedded leaves and dead branches and from roots. Moreover, the vegetative-cover in such a dry land ecosystem, forms the backbone for both human and animals life, i.e. woody plants are utilized for houses construction, as firewood or charcoal, are used for cooking and other domestic purposes, branches are employed for making fences and enclosures around homesteads and farms. Many species are valued for their economic, food and medicinal properties. More importantly, animals get most of their food and nourishment from consuming wild grasses, pods and tree leaves. These different aspects, more or less, emphasize the very important part played by the vegetative-cover in the region's ecosystem as elsewhere in tropical Africa. Therefore, a degradation or any other similar type of changes in this cover is bound to have direct and can be far reaching destructive consequences on both the natural and the human components of the area.

The above assumption and its related ecological consequences has attracted our attention and has formed the basis of the present research work plan. The research, therefore, shall focuss on quantitatively measuring and qualitatively assessing the changes that have ensued in the vegetative-cover in a portion of the Kordofan Region, investigating the factors that have caused them, and shedding more light on the resultant ecological consequences on the light of the so called land degradation phenomenon. The subject of this research seems to be of vital importance in contemplating the phenomenon and apparently one of the main keys for working out practical solutions, an area of research still not adequately covered.

1.2 Aims of the Research

In Sudan, as elsewhere in tropical Africa, vegetation as a renewable resource, plays a crucial role in economy and development. The increasing demand for biomass for domestic use and for commercial utilization as a result of population increasing pressure and the rising prices of imported fuel and manufactured wood materials, has increased the process of removal of the natural vegetation and has recently raised the doubt that the degree of the present exploitation trend may have exceeded the annual growth rate. If this assumption is true, then a gradual impoverishment in the region's vegetation cover must have occurred, a process which eventually would end with the devegetation of the entire region. When this is considered along with the successive severe climatic failure, the effect could be devastating.

Aspects of land degradation in Sudan, including desertification as a human problem, has received great attention from the national government as well as from some foreign ones. This problem has been under study for several years, and a number of research projects were launched in different parts of the country inspecting this phenomenon and working out plans to escape it.

Since the removal of the vegetative-cover is considered as among the most important causal and consequential factors of land degradation in such arid and semi-arid lands, the present investigation of the changes in the vegetative- cover in Kordofan Region is, therefore, expected to fill gaps in the knowlege and to contribute, more or less, in the understanding by providing additional dimensions towards solving this problem through the study of vegetation dynamics.

On the light of what have been said so far, this research aims at achieving the following objectives:

First, and most importantly, to uncover different aspects of changes that have taken place in the vegetation of Kordofan during the last three decades as the destruction in the region's ecosystem is generally held to have been accelerated during this particular period. Although the focus will be made to investigate vegetational changes at community levels, the study shall put similar emphasis and in turn detect aspects of changes at the population levels as well. By doing so, the nature, magnitude and the ecological implications of such changes shall be revealed and evaluated.

Second, to assess, in the light of the recent drought incidences, the impact of the different natural processes as climatic, edaphic and biotic on the stability and resilience of the area's vegetative-cover.

Third, to see how far the effect of drought has been worsened by the overuse of land. In other words, to investigate the impact of the anthropogenic factors on the area's vegetation.

A fourth aim to be achieved would be to suggest, based on the findings, possible means for controlling and protecting the vegetative-cover of the area. It will consider remedial measures and possible management techniques whose application could add to the efforts towards restoring this important natural resource.

A final point worth mentioning in this section is that, although this research was primarily conceived and is being carried out and executed in the context and realities of the Sudan, it was at the same time thought to be relevant to the further development of ecological theory in the tropics and in arid and semi- arid lands ecosystems.

1.3 Hypothesis

To carry out this research within the proposed framework and to achieve the above aims and objectives, the following hypotheses are put forward for testing:

1. The chosen area has been severely hit by series of drought incidences throughout its history, but through certain exploitive land use practices, man and his animals had aggravated the situation by putting more pressure on the meagre resources of the area. The process has caused serious soil depletion and as a result, it has become loose and susceptible to wind erosion which consequently precipitated changes into the character of the area's vegetation. Trees are being replaced by shrubs and bushes, while palatable and perennial grasses have been seriously depleted. This assumption stemmed from the notion that the symptoms of arid and semi-arid land degradation include loss of productive native vegetation cover and erosion of soil surface by wind and water.

2. Based on the work of a number of authors in tropical and sub-tropical vegetation, grasses are the main and often the dominant component of the vegetative-cover. This aspect paves the way for the assumption that, depleted grass-cover will indicate a higher degree of vegetation changes. Therefore changes to be monitored will be primarily, although not entirely, by the grass-cover.

3. Theoretically, those sites which lie in the same geomorphic type should have the same potentials and, accordingly, would be expected to support the same type of vegetation stands if they had experienced the same pattern of use. Therefore, differences encountered within these vegetation units are assumed to represent differences in successional patterns of growth.

4. A sort of ecological balance between man, animal and nature had existed and

had been maintained in this area in the past. Disequilibrium occurred when the pressure on the area's fragile environment exceeded a critical level, leading to more burden being put on the limited resource-base of the area. The outcome is, therefore, the continuous transformation of the original vegetation cover. This disequilibrium is assumed to have resulted partially from the natural population growth in the area at an annual rate of 2.7%, meaning that the total population of the area has almost doubled during the last thirty years. Both human and livestock population growth has been promoted by the continuous provision of modern medical and veterinary services which in turn had greatly reduced the natural mortality which in the past was mainly controlled by nature. This removal of natural barriers controlling over-population is assumed to have widened the damage inflicted upon the area's ecosystem.

5. Abandonment of certain land use systems and rationalization of others would eventually release the area from the burden exerted on it and the chances will, therefore, increase for the area to restore part of its vegetation cover. This is because the trend of the present depletion has in the first place been intensified by the exploitive nature of land management.

1.4 Methodology

As outlined earlier, carrying out an integrated quantitative and qualitative investigation of the changes and signs of changes in the vegetation of Kordofan Region constitutes the theme of this research. Therefore, to achieve this theme and to test the hypotheses put, a range of appropriate refined methods were applied. These have included: analysis of fieldwork data collected from a limited area sufficiently large enough to represent the whole, the interpretation of aerial photographs and satallite data, and the careful revision of relevant classified records. Results obtained from these diverse sources will be used and simultaneously handled to detect pattern, magnitude and direction of changes in the entire area.

The work, however, has proceeded from the initial investigation and description of vegetation in the field to the subsequent stage of analyzing the records obtained. These two phases of the research fundamentally reflect different concepts of vegetation. The first, which is the description of vegetation, is made to allow transmitting and drawing an image of the area's vegetation and equally to enable comparison and the ultimate classification of the different units of vegetation recognized. While, on the other hand, analysis is concerned with the further processing of the raw data, the formulation of abstractions and the working out of keys for significantly assessing the problem of the study.

1.4.1 Approach of the study

The primary objective used to select an appropriate approach to execute this study has been its informativeness and relevance to the nature of the research. Other criteria have included, speed, accuracy and the type of vegetation itself. Because the most objective approach may not be the fastest, or the most accurate may be impossible to apply, for whatever reasons, the outcome has been a methodology based on a synthesized approach making compromise and use of different range of concepts in the realm of vegetation ecology. This had been accomplished by means of evaluating and comparing the information return from a number of techniques and the most appropariate among them were selected.

The approach adopted views the vegetation of the area as an integral part of the environment and, therefore, it examines vegetation as forming a functional system with the surrounding biotic and abiotic elements. In other words, our approach is based on an ecosystem† orientation diagnozing the different structural, functional and typological aspects. This concept was first highlighted in the Symposium on Forest Ecosystems held at the Ninth International Botanical Congress in Montreal. It has been described as a thorough approach which allows the the creation of a formula that incorporates a number of concepts available in vegetation science.

The reasons behind selecting this particular approach stemmed from the fact that vegetation as a vital component of the ecosystem, displays the effects of the major environmental conditions and the historic factors in an obvious and easily measurable manner. Therefore, approaching the study problem from this holistic framework will facilitate the handling and the careful treatment of the different ecological features of the area and in turn provide useful information on its assessment. The application of this approach would help formulating a theoretical sound methodology for studying and monitoring vegetational changes in the study area and would provide a reasonable range of data.

1.4.2 Sources of evidence

The evidence for carrying out this research was obtained from a variety of sources. These were namely, analysis of fieldwork data, interpretation of aerial photographs and satallite data, and from the review of literature, records, maps and other relevant written materials.

(A) Data collected during fieldwork survey

Evidently no complete realization in such a study could have been reached

† Tansely (1935) introduced this term to describe the interaction of terrestrial communities with their habitats as equivalent to Woltoreck's (1928) "ecological system" for aquatic habitats

without a thorough ground survey being made through which data necessarily required to structure its basics is collected, compiled and manipulated in accordance with its aims and objectives. Based on this notion the, fieldwork operation was conceived as a detailed investigation of the different elements pertaining to the study problem on the light of the approach adopted. Due to the impracticability of measuring or surveying the entire area, some sampling techniques have been employed by selecting sufficiently representative samples to obtain, more or less, the same data that would have been gathered if a complete coverage of the area has been made.

Two field visits were made, and through sampling measurements illustartive sketching, photographing, observations and interviews, a wide range of surface ecological features were fairly well covered, checked and recorded. The first visit was made in August-September and the second one in October-December 1987. The timing of these visits was made in such a way that to allow for a chance of obtaining data on the two main seasons, the wet season for the first visit and the dry season for the second one. A Third visit, initially planned was cancelled due to the limited research fund. Although this had, to some extent, restricted the degree of work, the intensive survey carried during the two visits made partial compensation.

Although the first visit was planned to make as much vegetation and soil sample measurements as possible, some interviews were made while passing by villages, nomad camps, farms, water supply centres and other sites of particular interest. Also additional interesting sites were plotted to be surveyed in more detail during the forthcoming visit. During the second visit, a more comprehensive examination of the different perameters of the study problem was made. Based on the first visit experience, some methods were modified while yet others were added so that optimum results could be achieved. Moreover, during this visit, a questionnaire was conducted in order to check different aspects related to land management, (appendix D).

Prior to starting the field survey, a careful stereoscopic examination of aerial photographs covering the area was carried out. Based on this preliminary photo study, field traverses were planned and routes to be followed were plotted on a field orientation map so that a thorough form of data could be obtained and areas of particular significance could be visited and sampled. Sample sites were selected in terms of their potentialities to provide adequate range of data to test the general principles of the structure and dynamics of the area's ecosystem. Such route planning limited, to some degree, the risk of missing important sites and allowed greater chances for a reasonable coverage of the area. The techniques used to collect field data were namely, sampling measurements of vegetation and soil attributes, formal interviews(questionaire), besides, observation and informal interviews.

(A.1) Field measurements

These have included taking a number of measurement samples for different vegetation and soil attributes in the study area for the purpose of further analysis.

(A.1.1) Vegetation measurements

Quadrats and transects were the two sampling techniques used to investigate important vegetation attributes and collect quantitative readings on the different physiognomic and floristic characteristics of the vegetative-cover.

Physiognomic measures were used to describe and characterize the different assembleges of plant species, their general appearance as height, luxuriance, shape, horizontal and vertical arrangement of component members, spacing between individuals..etc. Based on this measure, the properties investigated are lifeform, periodicity and the stratification of species.

Lifeform properties will be used to describe the morphological expression of adaptation of the predominant plant species to their environment. Such vegetation criteria clearly reflects adaptation of different species to climate and provides a more useful functional criteria for describing vegetation. In this sense, lifeform classes being recognized, will be expressed as a percentage of the total number of species and the resulting lifeform spectrum will allow a more objective comparison to be made through a graphical interpretation of these lifeform classes.

The second physiognomic property which has been recorded is the periodicity or growth phases of plant communities or individual species. This approach has an obvious attraction for describing the vegetative-cover of the area in seasonal climates. In this sense, the vegetation of the study area will be described in the two main growing seasons, the wet season and the dry season, and a kind of phenological demonstration shall be made for presenting the main species encountered.

The third physignomic property used to describe the organization of the complex vegetation types was the readings obtained from the different layerings of plant species on the basis of height differences or their stratifications. This will be applied not only to above ground parts of vegetation stands, but also to the root component of some species after exposing them. Information obtained will provide useful preliminary guides and further facilitates the investigation of plant/environment relationships in the area.

Although the description of the area's vegetation through these physiognomic properties will essentially be generalized, its advantages lie in the fact that it provides means of arriving at informative description based on easily and relatively quickly characteristics of vegetation.

To obtain detailed data on species composition, abundance and distribution, floristic measures were applied in order to assess the amount or intensity of each species in the different parts of the study area based on their floristic characteristics. Non-destructive measures were used for they have the obvious advantages of repeatability and of causing minimal damage to the vegetation. This involved the use of sampling units to determine density and frequency of species.

Density calculation was simply made by counting the number of individual species in each sample plot multiplied by the area covered and divided by the area sampled. The determination of the density of trees, shrubs and other conspicuous individual herbs and grasses was simple, but species which spread vegetatively were difficult to deal with in this manner and, instead, percentage cover was employed.

Frequency of species, on the other hand, had been obtained from the same data by using quadrats occupied by a given species per number thrown or as a percentage. Data obtained from frequency and density was compiled to determine the distribution of different species in each site and to compare different sites on the basis of species abundance and curve of distribution. This will be achieved by comparing the density and frequency distribution of the predominant species in the different types of stands. The comparison will also be extended to cover suitable environmental measurements so that the distribution of species in different sites can be related to the distribtion of other species or to environmental factors.

The preparation for such detailed field measurements had consisted of preparing a kind of index for each item or vegetation attribute. These have included preparing a comprehensive annotated species list for all species identified in the area together with their main characteristic features and importance or value, and a density summary sheet for counting individual number of trees and percentage coverage of grasses and herbs per unit area.

Based on the preliminary photo inventory, 25 sites were selected and plotted on the accompanying field-base map to make stratified random readings from them. In each of these sites, 20 quadrats each 10 × 10 metre were randomly thrown and a total number of 34 transects of varying lengths from 300 metres to 10 kilometres were laid down. These transects were particulary used to describe changes of vegetation along certain environmental gradients or in relation to some marked geographical features. Data reproduced will be presented in different ways like graphs, histograms of species abundance plotted against position on transects. The use of transects was particularly significant in areas where the variation of vegetation in response to a changing environmental factor is fairly well marked on landscape.

Beside these observations, additional systematic ones were made to investigate particular ecological aspects. These have included :-

(a) Investigating plant communities along certain environmental gradients. These have included areas of certain topographic or edaphic heterogeneity. In sand dune areas and those which on visual inspection appeared to have different soil types, systematic sampling was applied by subdividing such areas and samples were then taken from each sudivision.

(b) Assessment of the impact of man on the vegetation cover. Special readings have also been made to quantitatively and qualitatively determine the gross effects exerted by man upon the vegetative-cover. The emphasis in this respect was made to assess the followings:-

- The impact caused by rainfed cultivation: Data on this issue was collected by making readings from intensively cultivated lands situated near villages, from slightly cultivated lands lying away from villages, and from lands not cultivated at all (no-man's lands).
- The impact caused by grazing animals: Systematic readings were also taken from different grazing areas especially around water supply centres which will be compared with readings made from areas inaccessible to grazing animals in order to quantify the impact caused.
- The impact caused by concentrated human activity centres: This had comprised measuring the overall impact caused by the agglomeration of people in villages, around water points, and around small rural market centres upon their immediate hinterlands. The measurements were carried out by making a set of systematic sampling around some of these centres at regular intervals to produce data representing spatial abundance in terms of distance from these centres.

The methods and techniques mentioned so far have been concerned with the description of the vegetation and the methods used to provide an appropariate range of quantitative data for the subsequent analysis stage. Additional methods have been used to analyze these data, compare different sites and to relate vegetational variations to environmental factors and for identifying factors on vegetation.

An important aspect of community structure which has been analyzed is the relationship between the quantities of species present rather than the mere presence or absence of species. These relationship patterns shall be calculated and statistically expressed by using numerical analysis for species associations, correlations and regressions. The sorting out which had been computerized, removed the tedious procedure required to compare and analyze hundreds of vegetation lists, and therefore very large samples generated were handled with great ease and less time was needed to detect the several patterns in the vegetation of the area.

The causal factors, after analyzing such scales of patterns will be studied by employing the same techniques used for detection of pattern. This will be done on the light of the following considerations:

1. Every species population has certain essential requirements of its physical environment or habitat

2. Several species have pronounced climatic and/or edaphic requirements and will grow only under such conditions.

3. Every species has a characteristic requirement for a range of external physical environmental conditions for growth, i.e., ecological amplitude.

4. Different species have different ecological amplitudes, and this will result in variations in the specific composition of vegetation.

For convenience, the causal factors will be analyzed through different lines of investigations which shall include:

- Similar or dissimilar environmental requirements of different species.
- Competition leading to positive or negative associations between species.
- Modification of the local environment by certain species or by external factor like man allowing other species to become established.

Furthermore, using another technique, vegetation stands that possess similar attributes will be assigned to same classes or clusters. This classification or clustering procedure will be carried out by means of manipulating the species abundance input data into a two-way sample-by-species data matrix based on a hierachical polythetic divisive method. This will be achieved by assigning at the onset all samples together in a single cluster and then successively dividing these samples into a hierarchy of smaller and smaller clusters, until finally, each cluster contains some specified small number of samples which share typical species and habitat characteristics.

This method has the advantage that it theoretically makes use of the available information on all the species and at the same time it considers the habitat factors and therefore clustering the plant species on that basis. As advocated by Goldsmith-Harrison (1976) and Ellenberg & Mueller-Dombios (1967), this method brings together into one system many of the useful characteristics of other forms of classifications. Moreover, it is more flexible and allows extrapolating and adding to the classification data obtained from aerial photographs and from landsat images. For these reasons, it satisfied the needs and purpose of this research and the range of data available, and therefore has been adopted and applied for classifying the vegetation of the area.

(A.1.2) Soil measurements

This was the second type of sample measurements made during field survey to collect data on important edaphic factors and soil attributes essentially needed to carry out this study. The work, as mentioned before, had involved the maximum use and interpretation of aerial photographs through which the major topographic features in the study area were marked off and transferred onto a map for field orientation. Additional visible and/or possible indicators of variation in soil or topography such as vegetation patterns or other distinctive ground patterns, or differences in tone of aerial photographs were noted. Field traverses were then made to cross as many of these various features as possible.

During field survey, selected areas were visited for detailed soil inspection and sampling. Site sampling was based on specific topographic positions which reflected different site and profile drainage characteristics beside areas which appeared to contain different types of plant growth from their surroundings. Also special soil sampling was made in areas of intensive human interference in order to determine the impact inflicted on the soil and in turn on the vegetative-cover by means of comparing and statistically expressing the outcome from these areas with those not accessible to man. After careful examination, representative soil samples were collected by means of pits and/or soil auger down to a maximum depth of 1.5 metres. These samples were collected from different levels within the pit/core and then bulked to provide one sample from each site for analysis. 21 sites were inspected and a total of 97 soil samples were taken for the subsequent chemical and mechanical laboratory analysis.

Data obtained will be used to describe, classify and map the different types of soils encountered in the area using the same method described for the vegetation attributes. Beginning with the whole area as having a zonal soil the area will be subdivided into soil combinations as the major mapping units, each of these combinations will be given a geographical name from the area where it dominates. Soil combinations will be further sudivided into distinct soil association groups which finally will be broken into soil types denoting the finest clusters containing typical characteristics.

(A.2) Questionnaire

During the second field visit, a questionnaire designed to investigate the human aspects of the study problem had been conducted. The main purpose of this questionnaire was to check the degree of man's interference with his surrounding environment and to see how far he can be accused of overusing the meagre resource-base of the area and the implications of all these upon the area's vegetative-cover. From this point-of-view, the questionaire sought to determine the harmful effects caused by man through the following:

(1) Investigating the impact caused by cultivation.

- Examining the land rotation system of cultivation in the area in which a plot of land is allowed to rest for a number of years in order to regain fertility after having been depleted in the process of continuous cropping, and to determine pressure on land by comparing the length of fallow and cultivation at present and in the past, beside investigating the gum-cultivation cycle in different times during the last three decades. This will be considered along with the measurements carried out in intensively cultivated lands situated near villages, slightly cultivated away from villages and those not cultivated in order to determine the degree of overcultivation in different parts of the area. Land productivity will also be used to make this assessment.

- Assessment of the events that are likely to have promoted the use of more land or to the expansion in the cultivated area such as natural population growth, rainfall variability, nomads adoption of cultivation...etc.

(2) Investigating the impact caused by grazing animals.

- Investigating the traditional grazing patterns of nomads and seeking evidence for any upset in this pattern following the many events that have recently happened in the area such as the increase in animal population due to improved veterinary services, establishment of more water supply centres and the successive drought incidences. Again these observations will be considered along with the sample measurements taken from intensively grazed areas and those areas not accessible to grazing animals.

- Seeking evidence for the disappearance of some palatable species from certain parts of the area, besides, checking if there are any less desirable species being consumed during arid seasons as in such times of food shortage, animals will become less selective and can consume whatever is available.

(3) Investigating the impact caused by the uncontrolled felling of trees.

- Estimating the total biomass annually consumed by inhabitants for fuelwood, charcoal and house construction and to specify which types of species are favoured for the different uses and the implications of these upon the vegetative-cover of the study area. On a larger scale, to determine the impact of settlements on their surrounding parameters regarding the removal of these species.

This step will be taken along with the measurements made from areas severely exploited and those slightly affected.

- Projecting biomass consumption in the area in the past through to the present time to seek evidence for an increased damage inflicted on the vegetative-cover of the area.

The questionnaire was also designed to assess the perception of inhabitants regarding the different ecological aspects of the area and to answer questions like:

1. Could these farmers and animal herders be blamed of ignorance operating in an area that is increasingly losing its natural resources?

2. Are these people aware of the ecological consequences of their practices?

3. Do they possess any ecological understanding within their heritige?

4. Will they be ready to participate and contribute in conservation projects?

(A.3) Observation and informal interviews

These were the simplest and easist means used during ground survey. Although, both had consumed less time and energy, data obtained in most cases appeared incomplete and rather subjective and, therefore, have always been checked or supplemented by data obtained through other techniques. In certain circumstances observation and informal interviews have provided some valuable information and covered certain gaps which were missed by the other means. These have included the investigation of the impact of the intrusion of external and modern factors and the incorporation of the area into the world economy which seem to be the crucial turning point in man-land relationships that set into train the present trend of land degradation process in the entire zone.

(B) Interpretation of aerial photographs and satallite data

As already mentioned, the work has consisted of the full use and interpretation of aerial photographs beside the manual interpretation of an MSS5 landsat image which together had provided a wide range of useful information on the different ecological aspects of the study area. Aerial photographs provided the guidelines for field excursion and particularly helped in drawing sets of vegetation, soil and land use maps for the study area which were later modified by landsat data.

Although it is appreciated that the whole area was flown and covered by aerial photographs prepared by Sudan Survey Department in 1958 nothing was done ever since. The present and any subsequent research would have been greatly improved and widened should additional surveys had been carried out. Moreover, these photographs at scales of 1/48,000 and 1/40,000 are rather small ones for such arid and semi arid areas. Considerable difficulties were experienced due to the fact that these photographs were taken over a period of more than one year and in many seasons, whereas for the purpose of such an ecologically orientated study it would have been far better if they were acquired at one season and all of them in the same year. The optimum season would have been the end of the rainy season. But perhaps the short duration and variablity of the rainy season in this area make such a balanced vegetation survey much more difficult. The tree vegetation was readily assessed, but the herbs and grasses are often present for identification for a relatively short period. Also the quality of prints is rather low regarding uniformity and the degree of contrast and as a result their reliability and the confidence of extrapolating results from them were seriously reduced.

The area had also been surveyed in 1962 by Hunting Technical Services, and in addition to the difficulty faced in accessing a whole set of photographs, the prints are again of the same quality and scale. This is beside the fact that the time difference between the two surveys is too short to allow for the detection of significant variations in vegetation and related features.

(C) Literature and previous research-works

Literature and other documentary sources containing data of particular relevance to this study were reviewed especially for extracting information dealing with the past. These have included:

(1) Written documents

These had comprised a number of reports and treatises previously prepared by specialists and non-specialists for different governmental purposes especially during the colonial period. Although most of these documents are often descriptive and based on subjective estimates, particularly maps and other data of statistical nature, sometimes they are the only sources of information available.

(2) Departmental publications and relevant contributions

This covered a number of reports regularly being published by different national departments in Khartoum or regional ones in Kordofan, as the Forestry, Agriculture, Soil Conservation, Rural Water Supply, Geology, Natural Resources, Range and Pasture, and the Survey Departments. This was beside the consultation of the publications and reports of the major International Organization on Sudan in general and Kordofan in particular, like the FAO, DECARP, HTS, ETMA, CARE, UNDP, and Ford Foundation †.

In addition to these, a number of books, periodicals, monographs, papers and other relevant contributions on the area and the subject were reviewed. All these sources of information will be referred to in the course of the research whenever it is necessary.

1.4.3 Plan of the thesis

Eight chapters were planned for the presentation of this research. They were made in such a way as to proceed from the simple to the complex, from the description to the analysis, and from the data input to the findings output.

The first chapter, as an introductory one, is mainly devoted for the identification of the theoretical framework and general working plan of the research. It justifies the reasons behind the selection of this particular issue, remarks the study problem dimensions, aims and objectives it is likely to achieve, hypothesis put for testing, and sorts out the general methodological approach selected for its execution.

The second chapter introduces the study area, justifies the reason behind its selection and outlines the main geographical characteristics including elements of the physical environment.

The third chapter approaches the study area from a more specific ecological perspective, putting all the emphasis on its vegetative-cover. It investigates more concrete aspects of vegetation in the area ending with classifying it into units of

† FAO:Food & Agricultural organization, DECARP:Desert Encroachment Control & Rehabilitation Programmes, HTS:Hunting Technical Service, ETMA:Environmental Training & Management in Africa, CARE: Cooperation of American Relief Everywhere, UNDP:United Nations Development Programme

similar characteristics for further analysis.

The fourth chapter processes the end products of the third one, extending the investigation to detecting different patterns in the distribution of the study area's vegetation, its interaction with the different elements of the physical environment, its dynamical nature and the different aspects of change potentialities.

The fifth and sixth chapters go deeper and scrutinize factors of the environment that interact with vegetation and which in turn produce detectable changes in its composition, structure or distribution and weighs them accordingly.

The seventh chapter, as a core of this research, surveys the different short and long term successional changes that were precipitated into the study area's vegetative-cover and monitors current signs of change.

The last chapter, as a conclusion, will be devoted to outlining the main findings of the study, to indicating some of the control measures and recommendations perceived and ultimately to define the task ahead for further investigations as the final words of the research.

Chapter II

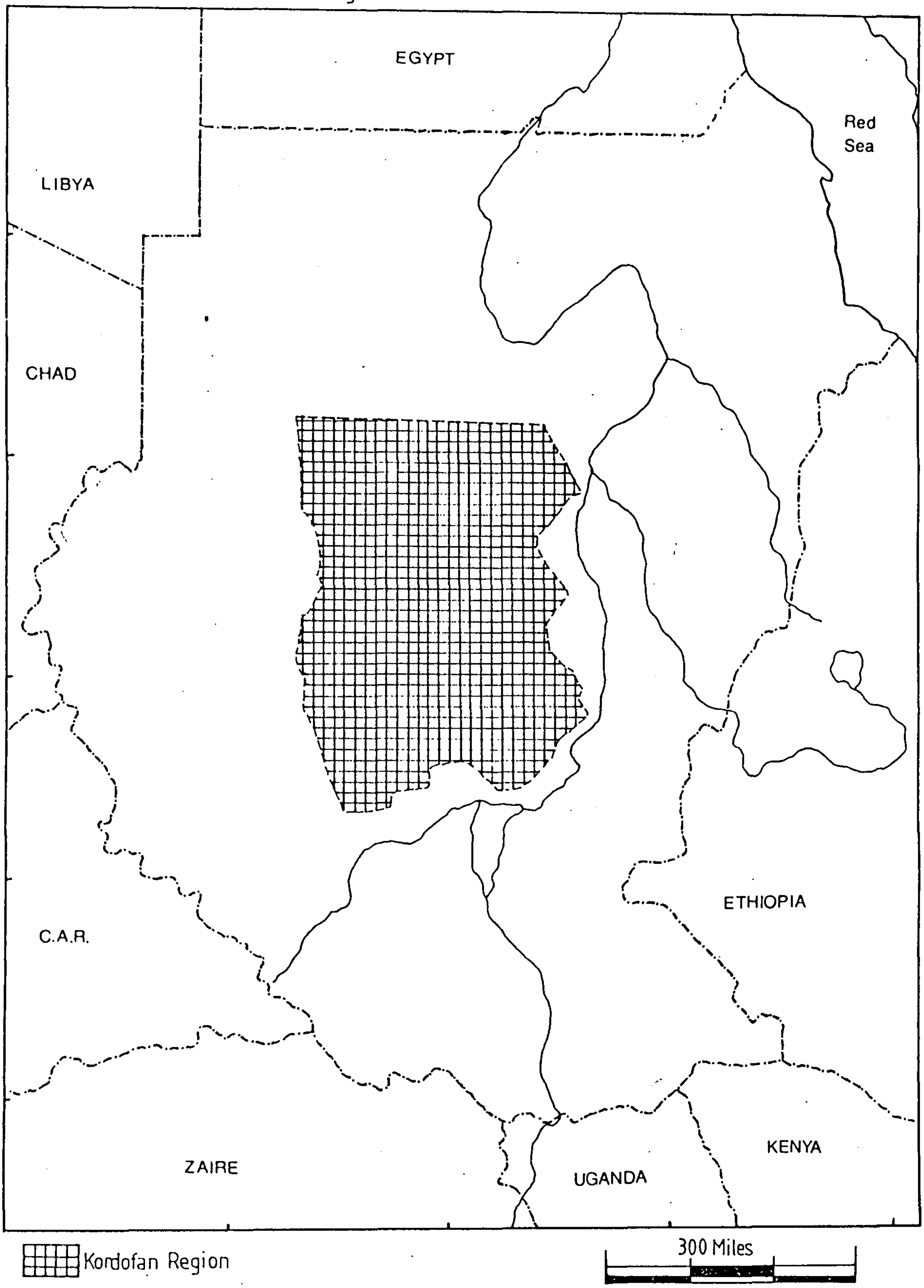
Geographical Background

2.1 The Study Area

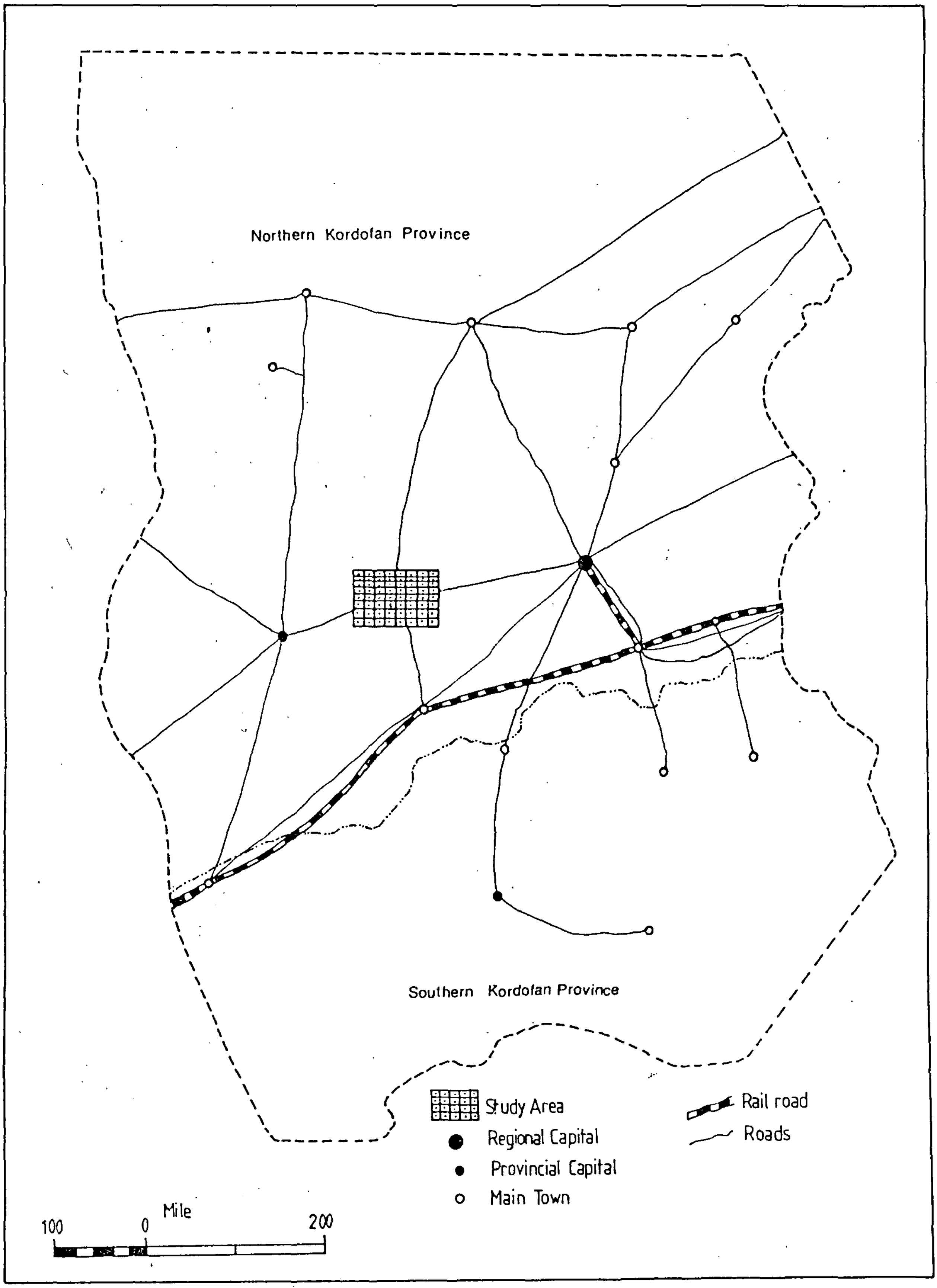
The study area lies wholly within the central-western part of Kordofan Region of the Sudan. It is rectangular in shape, bounded on north and south by the 13°25¨ N and 12°46¨ N lines of latitude, extending for about 63 kms. Its western and eastern boundaries are the 28°39¨ E and 29°32¨ E lines of longitude, extending for 90 kms. The study area as a whole covers approximately a total area of about 5670 square kilometres, Fig (2.1) and (2.2).

This part of Kordofan is the most heavily populated zone of the region where animal husbandry, rainfed cultivation and gum production are the main human activities, Fig (2.8). The study area in particular is inhabited by sedentary Arabs and it is the traditional domain of the Hamar tribe which in the past comprized fundamentally nomadic communities following their herds. However, due to certain events, the majority had adopted a sedentary way of life and consequently they settled around water supply sources, farmlands and areas where they used to stay only temporarily in the past. This had led to the growth and expansion of many settlements in the area, a process further promoted by the establishment of many artificial water supply centres and the provision of better services in these neighbourhoods, Fig (2.3). The outcome is a steady increase in the population of the area due to the settled conditions, better standard of living, increased medical attention and more families abandoning traditional nomadic movements and

Figure(2.1) Location of Kordofan Region. within Sudan



Figure(2.2) Location of the Study Area within Kordofan Region



adopting sedentary habits. The total population of the study area as estimated from the 1955/56 national population census was 85,670, according to Watson (1976) it was 101,338, according to the 1983 national population census it was 116,538, and according to the latest district records in 1987 is 143,181.†

The area is seasonally visited by some nomads from the surroundings including "Abbala"‡ herders of the north during the summer dry months like the Kababish, Dar Hamid and Maganeen. On the other hand, some "Baggara"* herders occasionally infiltrate from the south particularly during seasons of good rains to graze their animals in the most southern parts of the area and with the progress of the rainy season they gradually move southwards out of the area, Fig (2.3).

This particular area has been carefully selected because it was found to provide an interesting site for testing the hypothesis and achieving the different objectives identified in the previous chapter. These are summarized in the following two points:

i. This area lies in a transitional zone between the northern arid and the southern humid savanna. It exhibits, in various combinations, the ecological characteristic of both regions and, therefore, provides a reasonable basis for making judgements on these neighbouring vegetation zones. This zone is particularly being mentioned as among the areas being most affected by a series of sucessive droughts and many researchers pointed out the severe ecological imoverishment and degeradation that have taken place as a result.

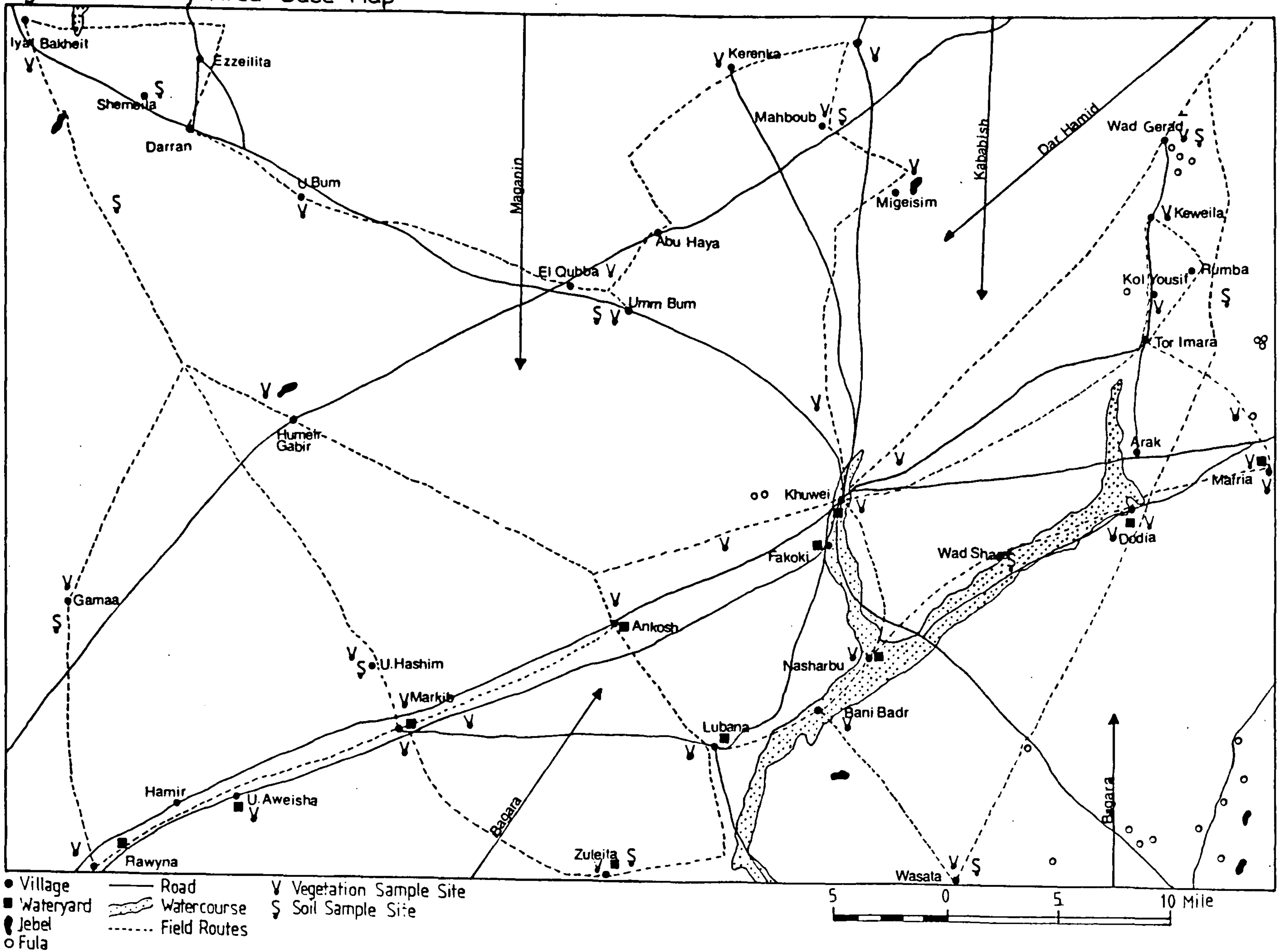
ii. This area represents the most heavily populated zone in Western Sudan in gen-

† Unpublished figure obtained from Khuwei Rural Council.

‡ An Arabic word signifying camel herders.

* An Arabic word signifying cattle herders.

Figure(2.3) Study Area Base-Map



eral and Kordofan in particular which has been settled and used for centuries by both sedentary inhabitants and nomads. The intensive and extensive pattern of land use practiced for centuries is assumed to have left a type of vegetation that is greatly modified by man. It is particularly in this area that almost all of the types of land managements to be found in the African tropics are practiced i.e., rainfed cultivation, animal husbandry, gum production, uncontrolled biomass harvesting and fires. Furthermore, the establishment of many artificial water posts in this arid part of Kordofan had provided additional water supplies which formerly used to be the governing factor that determine population mobility and settlement in the region. Consequently, this had lead to the emergence of large centres of concentrated human activities without the necessary provision of adequate basis for that. This is a development which is bound to have its direct effects on the area's vegetative-cover that needed to be carefully studied.

2.2 Climate of the Study Area

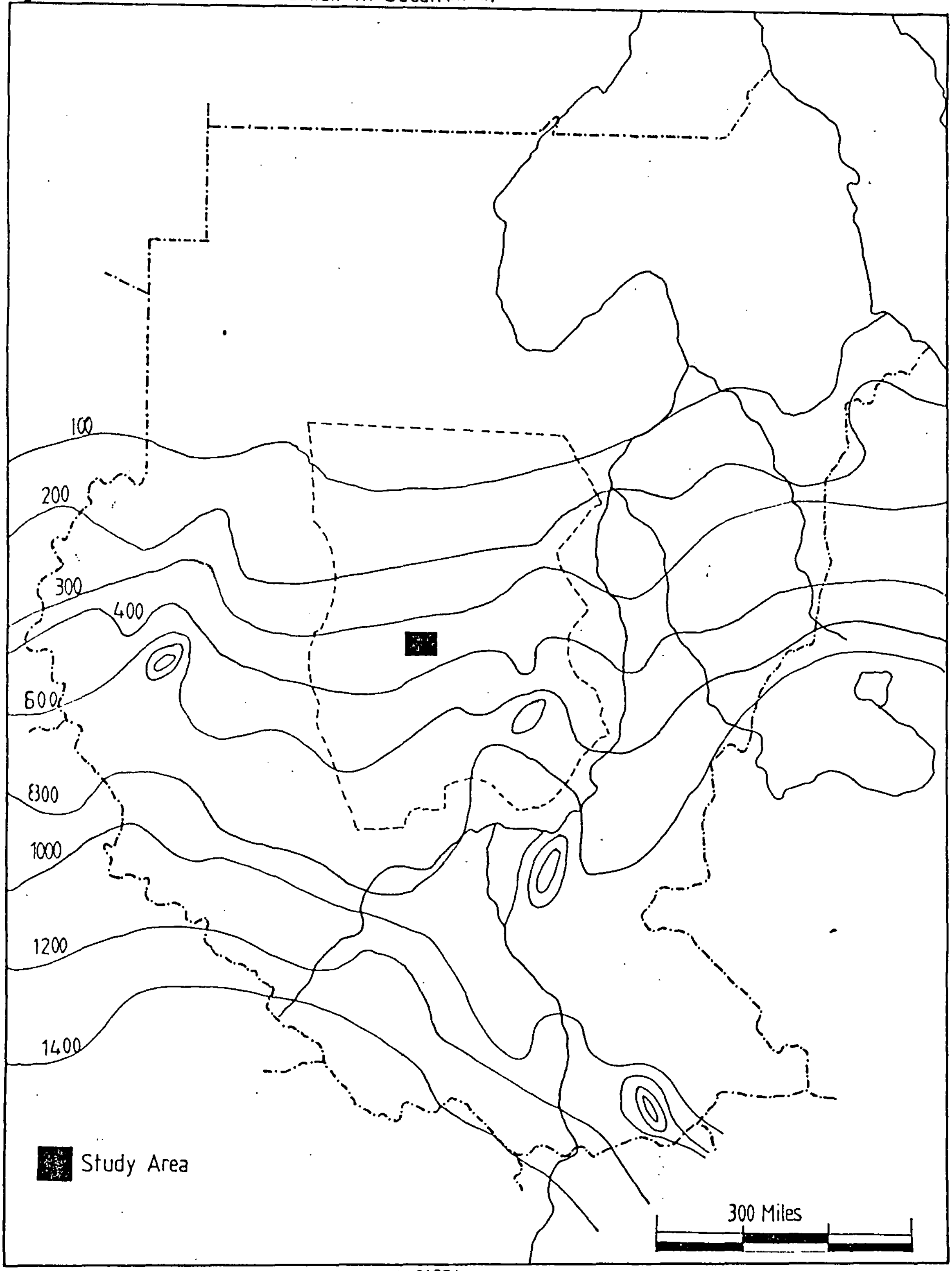
The climate of this area, as other parts of the Sudan, is of tropical continental type and is largely determined by the movement of the Inter-Tropical Convergence Zone (ITCZ) which represents the boundary between the dry north easterly trade winds that originate over the Sahara Desert and the moist south westerly monsoonal winds which originate over the Atlantic Ocean. The ITCZ reaches its northern most limit in this area in mid June and its southern one by early October.

Rainfall in this region is governed by the nature and behaviour of this zone which itself is controlled by the atmospheric pressure conditions over and in the vicinity of the entire continent, El-Tom (1983). It is connected with the moist south westerly monsoonal winds and, as claimed by Ireland (1948), is particularly associated with the zone he specified as extending 500 miles south from the actual boundary, and accordingly the rains are confined to its southern sector. The study area, therefore, has a rainy summer and a dry winter with a rainy season generally extending from early July to mid October with the heaviest falls occurring in August. El-Tom (1983), taking the rainy month as the one receiving at least 10% of the mean annual rainfall, has recognized the rainy season in the extreme southern parts of Kordofan region as covering the period from July to September inclusive, whereas in the extreme north, he recognized August as the only rainy month. The study area lies roughly between the 300 mm. and 400 mm. mean annual isohyets, Fig (2.4). Rainfall variability increases from south to north with a mean annual coefficient of variation varying, according to El-Tom (1983), between 25% in the south and 75% in the north. He added that, *over most of Kordofan rains are very unreliable and the probability of receiving an amount of rainfall that allows a safe practice of rain-fed cultivation is practically nil.*

Due to the lack of meteorological stations in the study area, reference will be made from neighbouring stations. Using records from El Obied and En Nahud Meteorological stations, which lie slightly to the east and west of the study area, the following results were obtained on the mean, coefficient of variations and the inter-annual variation of rainfall for the period 1975-1987, Table (2.1).

For both stations the mean daily maximum temperature is highest in May (39° C) and lowest in January (31° C), while the mean daily minimum temperature is highest in May (23° C) and lowest in January (13° C). Accordingly, May witnesses the highest mean daily temperature values (30.5° C) while January the lowest mean daily values (22° C). Due to these high temperature levels, high evaporation

Figure (2.4) Mean Annual Rainfall in Sudan (mm.)



Redrawn from Survy Dept. 1974, Topo. No S-91254

Table 2.1 : **Annual Rainfall at Elobied and EnNahud**

Station	Latit.	Long.	Mean	CV	IAV
Elobied	13 12	30 13	367	32	36
EnNahud	12 34	28 12	394	27	28

Source : Data obtained from the meteorological office, Elobied

ratios are expected. On comparing the values of the mean annual rainfall and potential evapotranspiration, a large water deficit in this area could be revealed, and as potential evaporation decreases from north to south, the magnitude of this water deficit increases from south to north. More emphasis on climate will be made in section (5.2).

2.3 Geology and some Hydro-Geological Considerations

The main rock formations found in Kordofan Region as a whole are, Basement Complex of Pre-cambrian age, Nawa series of Late Paleozoic age, Nubian series of Mesozoic age, Laterite of early to middle Terrtiary age, Umm Ruwaba series of Pliocene to Pleistocene age, and the superficial deposits of Quaternary age.

The oldest rocks in Kordofan that now constitute the Basement Complex were formed in the Pre-cambrian age. Following the emplacement of these rocks, the region was subjected to a period of prolonged erosion which apparently lasted through most of Paleozoic time. Shallow seas invaded parts of the region in the Paleozoic and deposited the sediments of the Nawa series. Before the close of Paleozoic time, however, the region was uplifted and most of the Nawa sediments were removed by erosion. Only few isolated remnants of the Nawa series are now left in Kordofan as evidence of their once extensive existence, (HTS 1963, Rodis *et al* 1963 and FAO 1963)

Deposition of rock-forming materials in the region did not again take place until Mesozoic time when shallow continental seas covered most, if not all, of the region. During this time, the elastic sediments of the Nubian series were laid down over a Basement rock surface. Near the close of Mesozoic period, the seas receded as the region was again uplifted and subjected to prolonged subaerial erosion that apparently lasted until the Pliocene time, (Rodis *et al* 1963). During this interval of erosion, most of the Nubian rocks were stripped away and those occupying the deeper basins in the Basement rock surface were left untouched. Extensive laterization of Nubian and possibly older rocks occurred during early or middle Tertiary time when climate conditions favourable to the formation of Laterites prevailed over much of the area. According to Rodis *et al* (1963), tectonic movements in eastern Africa, probably during late Tertiary time, resulted in the formation of several structural basins in the Nubian and Basement rocks of Kordofan Region. During Pliocene and early Pleistocene periods, these basins were filled with fluvial and lacustrine sediments that now comprise the Umm Ruwaba series in Kordofan.

In late Pleistocene, strong northerly wind prevailed in the northern part of Kordofan and denuded the land surface of much of its residual soil-cover. A considerable part of the eroded materials were carried southwards by wind and deposited in the form of sand sheets and dunes over much of the central part of Kordofan region. The residual soils in the north, the fixed aeolian sand in the centre, and the clay deposits in the south of Kordofan stand today as evidence of the region's geologic history and its climatic conditions since the Pleistocene period.

The dominating geological formations in the study area in particular are the Basement Complex rocks and the Nubian Sandstone series beside a few occurrences of Laterites, Fig (2.5).

2.3.1 The Basement Complex

This formation occupies the most northern and north western parts of the study area. It is the oldest rock unit composed of crystalline high metamorphosed rocks and slightly unmetamorphosed sedimentary ones.

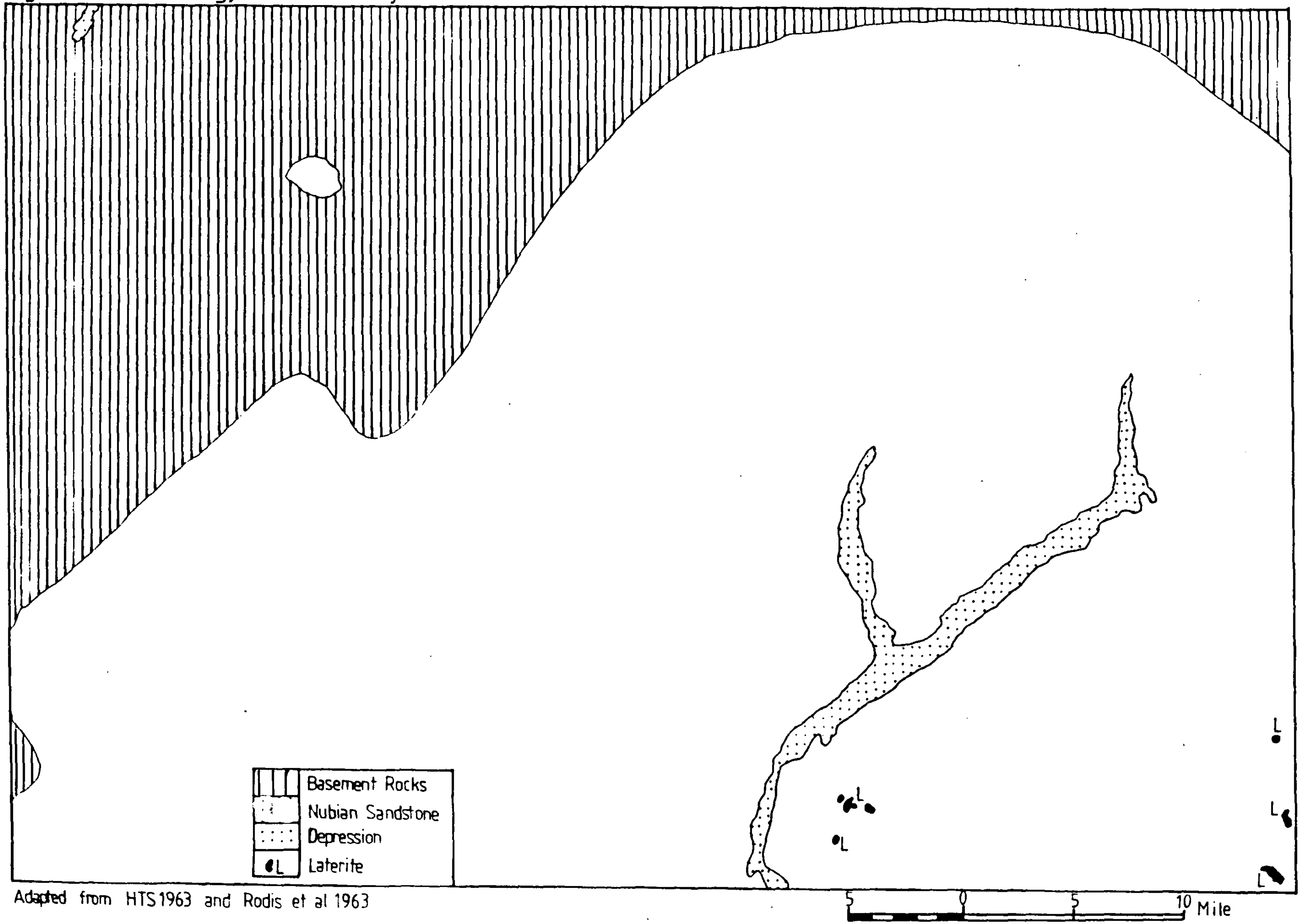
The crystalline rocks of the Basement Complex have little hydrological significance and they form a relatively impermeable base. They contain no significant acquifers and since the recharge is entirely dependent on rain water during the short rainy season, water may only be found in limited quantities in joints and fracture zones. Additional useful supplies are found in weathered and superficial deposits filling depressions and basins eroded on Basement rocks. Therefore, of the numerous wells that penetrate Basement rocks, relatively few provide water in sufficient amount for the minimum requirements of domestic and livestock use throughout the year. Many wells are either dry over most of of the year or provide so little water that they are eventually abandoned.

2.3.2 The Nubian Sandstone

This is the second and most extensive geological formation in the study area, dominating its north eastern, central and the whole southern parts, Fig (2.5).

Nubian rocks are composed mainly of sandstone and conglomerates beside a few occurrences of mudstone, marls and ironstone. Commonly, the sandstones and conglomerate beds are sandy and mudstone is silty. This series underlies large

Figure(2.5) Geology of the Study Area



Adapted from HTS 1963 and Rodis et al 1963 parts of Kordofan region but generally is not extensive at the land surface. The greater part of Nubian outcrops is masked by superficial cover and it is found resting on Basement Complex strata. Within the study area there are two main outcrops of Nubian Sandstone. The largest and most important of these is the large outlier of what is known as En Nahud-Saata basin. The second is of much smaller extent centred round Umm Bum village in the northwestern part of the area.

It is this series of flat lying sediments which contains the most important aquifers in the area. Water has been extracted from these aquifers for a considerable period. In these Nubian rocks, water is confined largely to the more permeable sandstone and conglomerate beds under low arstesian pressure. Some water is found, however, in crevices and bedding planes of consolidated mudstones where these lie in the zone of saturation. Groundwater bodies that are virtually continuous extend through most of the areas underlain by Nubian strata. The yield of the average well ranges between 800-1200 gallons/hour. But these water bodies generally terminate against Basement rocks where the strata are less than 60 metres thick. This happens particularly in the ring of unsaturated Nubian strata that border the Basement rocks in the most north and central northwest parts of the study area.

2.3.3 The Laterites

These comprise a few occurrences of ironstones mentioned and mapped in the southeastern parts of the study area by HTS (1963). According to Rodis *et al* (1963), this rock formation was developed on Nubian Sandstone over much of Kordofan during early and middle Tertiary time. This corresponds to a prolonged period of deep *in situ* weathering of the host rock under tropical climatic conditions of alternating wet and dry seasons. HTS (1963) identified erosional remnants of this once extensive deposits in the area east and southeast of En Nahud outside the study area. These deposits were mentioned as resting on the Nubian series, consisting mainly of ferruginous layers of hematitic/limonitic ironstone.

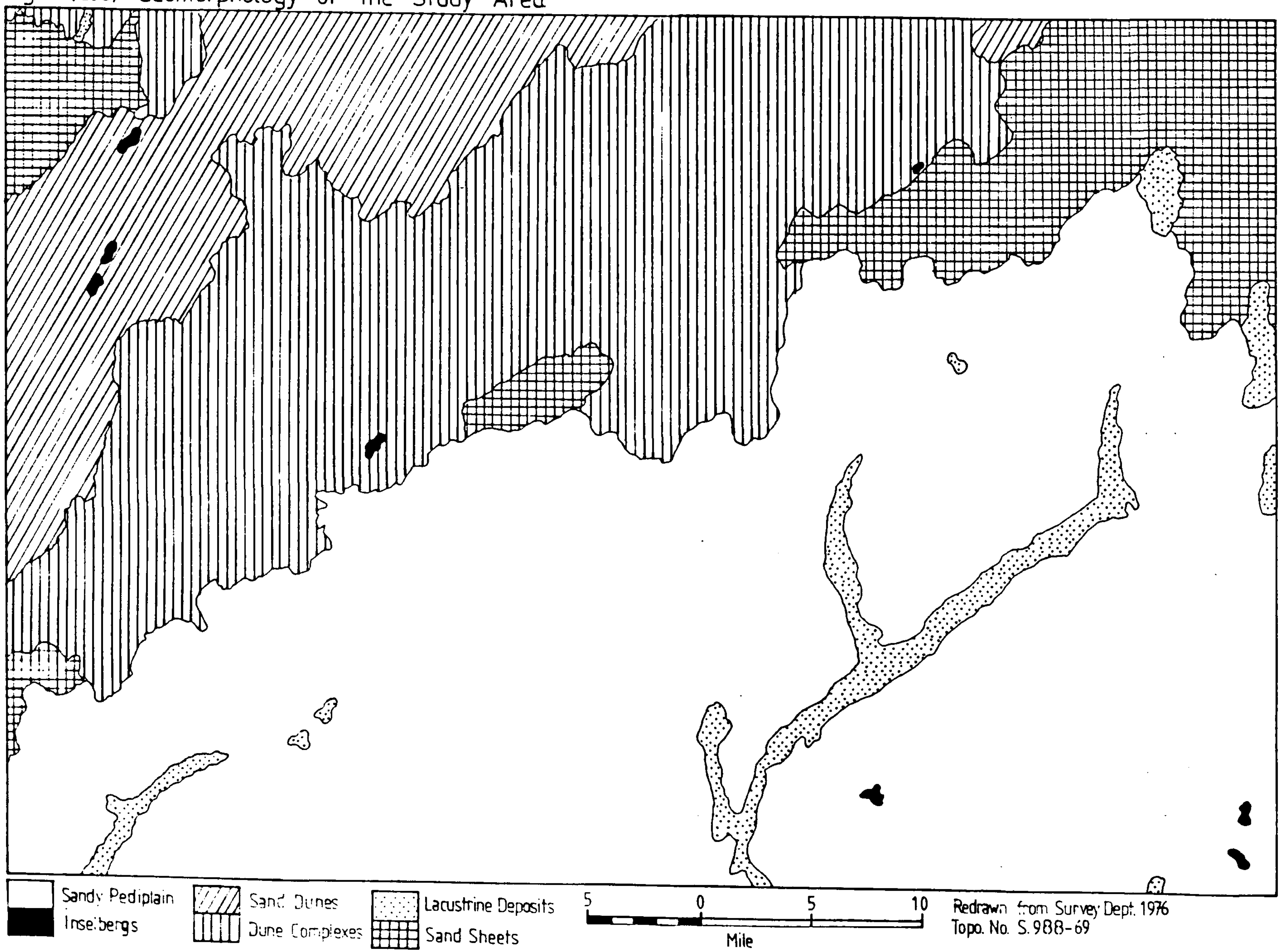
Regarding the hydrogeological significance of this formation, it is important as a source of groundwater as it occurs above the zone of saturation , but from the information provided by hand-dug wells, it was found to yield a rather limited supply of water not exceeding a hundred gallons per hour. No boreholes were found in the study area penetrating these type of rocks.

2.4 Geomorphology of the Study Area

The geomorphology of this area, as described by Andrew (1948) is the product of the interaction of Pleistocene to recent neotectonic movements and the climatic fluctuations. The area has undergone several cycles of geological erosion and aggradation which have resulted in a surface described by HTS (1963) as rather monotonous, gently undulating pediplain which is shallowly dissected by few seasonal watercourses as will be shown in section (2.6). Occasional inselbergs stand out above the general level of the plain. In the northern part of the study area, the pediplain has been covered by wind-blown sand and later on wind action has reshaped the original deposits and formed several types of dune formations.

Two major geomorphic units were recognized in the study area each of which carries significantly different soil characteristics that resulted from ancient and recent soil forming processes. These geomorphic units are namely Pediplains and Aeolian sands, Fig (2.6).

Figure(2.6) Geomorphology of the Study Area



2.4.1 Pediplains

This geomorphic unit occupies the largest southern parts of the study area and for convenient description and mapping, it is subdivided here into: Inselbergs and Pediments, Sandy Pediplain, Alluvial Flood Plains, and Fluvio-Lacustrine Deposits.

(A) Inselbergs and Pediments

Inselbergs comprise the few scattered hills found rising abrubtly on the plain. These are namely, J. Zuleita, J. Migeisim, J. Lubana, J. Shemeila and J. Humier Jabir.† These seldom exceed 200 metres in height. On the other hand, pediments are those portion extending in a concave cross-section from the base of these inselbergs down the plain. These pediments are usually covered with weathered rock debris and in more cases obscured by wind-blown sand.

(B) Sandy Pediplain

This comprises that portion of the gently undulating pediplain which carries soils of more sandy characteristics. It includes all soils formed over the Nubian Sandstone. HTS (1963) mentioned the occurrence of this pediplain on weaker rocks of Basement Complex near EnNahud to the west of the study area.

(C) Alluvial Flood Plains

These cover the narrow strips of relatively smooth land which border the few seasonal watercourses (Khors). These were formed by the deposition of sediments when water velocity decreases and at curves on these courses. These flood plains

† J. is an abbreviation for the Arabic word Jebel which signifies hill or mountain. These Jebels are named after the nearest settlement to each.

are rather broad and flat, sometimes exceeding 3 kms. as in Nasharbu area, and they are generally incised 5-10 metres below the general level of the plain.

(D) Fluvio-Lacustrine Deposits

These consist of widespread deposits of sands, marls and clays precipitated by slowly moving water in low lying areas as interdune hollows, depressions, bottoms of lakes and along watercourses. According to Rodis *et al (1963), these deposits are signs of one or more of the wetter periods that might have occured during the Pleistocene.*

2.4.2 Aeolian sands

This geomorphic unit covers the largest northern zone of the study area. It consists of variable layer of wind-blown sand which is shallow in the southern portion of this zone as areas around El Qubba and Humier Jabir but is fairly deep northwards. Near Mazroub, just north of the study area, the mantle was estimated by HTS (1963) to be as high as 550 metres above mean sea level. In the study area it is estimated to be 10-20 metres thik. The main mappable features within this geomorphic unit are, Sand sheets and low dune complexes, Sand dune systems and Dune complexes.

(1) Sand sheets and low dune complexes.

These cover areas of flat to very gently undulating layers of wind blown sand and areas with very low dune systems generally less than 5 metres high. These geomorphic features dominate most of the northeastern corner of the study area, areas around Umm Bum, Iyal Bakheit and a small area to the southwest of Gamaa.

(2) Sand dunes

These consist of parallel sand ridges separated by wide flat bottomed hollows often orientated in a north south direction, but occasionally in a north easterly one. Lacustrine deposits are often found in the hollows between the dune ridges. This system dominates the northwestern parts of the area and a confined area to the east of Umm Kherein. These dunes vary from small ones with height not exceeding 10 metres to large dunes with height sometimes reaching 40 metres, but more often they are regular in height and spacing.

(3) Dune complexes

This is the most widely occurring aeolian sand feature in the study area occupying the area between the sandy pediplain and that covered by sand dune systems. These complexes consist of masses of sands with no specific orientation and are usually 5-15 metres high. Lacustrine deposits are occasionally found in bottoms of low lying areas. According to HTS (1963), these areas were originally covered by sand dunes and only have been reshaped by wind.

Other minor geomorphic features found associated with wind-blown sand include sandshadows and sand drifts. The former resulted from obstruction offered to sand-driving-wind by rocky surfaces, bushes, farm enclosures, and through time mounds of mobile loose sand develop. On the other hand, sand drifts are found where there are gaps in the rocky ridges, for the concentration of the sand stream from a broad front on the windward side will be faced by a narrower one on the lee side. This feature is particularly found in the extreme northwestern part of the study area near J. Shemeila where the necessary conditions of formation are met. These two last geomorphic featured can not be shown at the scale of the present map.

2.5 Soils of the Study Area

From the chemical and mechanical analysis of the 97 soil samples taken from the study area, a number of soil units have been identified and they are closely correlated in their distribution with the geomorphic units mentioned above, Fig (2.7).

The properties of these soil units are largely determined by the parent materials and the slight differences encountered are mainly attributed to different geomorphic features such as the type of dune formation or to local differences in topographic position. Soil formed *in situ* from Nubian sandstone rocks are strongly acid reddish brown sandy loam, while those formed on Basement complex rocks varies from strongly acid reddish brown sandy loam with marked increase in clay content on ridge crests to dark grey brown alkaline sandy clays and clays on low lying areas. Soils formed from wind-blown sand vary from neutral to slightly alkaline reddish brown sands and loamy sands, whereas on sand sheets and interdune hollows, lacustrine deposits prevail with dark grey-brown alkaline clays to greyish-brown alkaline loamy sands and sandy loams characteristics. The seasonal watercourses and other water retaining sites are mainly occupied by dark grey-brown alkaline sandy clays.

The chemical investigation of these soils showed that the chief nutrient shortage in these soils are phosphorus, nitrogen, potassium and organic carbon, and while calcium and magnesium values are low on the sandy soils formed on Basement complex, they are very low on acid sandy pediplain soils of the Nubian sandstones. More elaboration on these aspects will be made in section (5.3.).

Based on the chemical and mechanical characteristics, the following classification system has been adopted to show and map the different soil units identified in the study area. The system is based on a heirarchical divisive approach, beginning with the whole area as having a zonal soil, then subdivides it into soil combinations as the major mapping soil units and each is given a name after the area where dominates or was first observed. These combinations will further be subdivided into soil associations and in turn into soil types which contain typical soil characteristics in terms of chemical or physical properties. Although it was possible to map soil combinations and their associations, soil types are quite difficult to be mapped especially at the large scale of aerial photographs, besides, these soil types may occur in more than one soil association.

Basically, six soil combinations have been identified in the study area and each will be considered separately.

2.5.1 Shemeila soil combination

This combination covers the area mapped by HTS (1963) as Nuba soils. It is found round hills and usually very stoney and has a shallow depth to the hard rock underneath. Runoff is rapid to medium and the soils are severely eroded. One association has been recognized dominating pediments and foot of inselbergs mentioned in section (2.2.4). On these areas HTS (1963) describes a catenary sequence of soils similar to the "alkaline catena" recognized by Greene (1948). The hillfoots are dominated by brown neutral gravelly loamy sand giving way to reddish brown neutral loamy sand on the pediments and this grades into dark brown moderately alkaline gravelly clay loam on the plain. This soil is covered by scant vegetative-cover of *Acacia nubica* and occasional *Commiphora africana* tree species.

2.5.2 Markib soil combination

This is the most extensive soil combination in the study area occupying most of the east central and southern parts. It includes all the sandy soils covering the sandy pediplain geomorphic unit. Soils in this combination are, more or less, being formed *in situ* over Nubian sandstone and they are commonly being termed "Qoz"† soils. The characteristic feature of these soils is their inherent low fertility. The plant food reserves are very low and they have little resistence to drought conditions. They are extremely permeable, thus all the rains falling on them go deep and causing little runoff. This soil combination has been classified by GITEC (1981) as sandy loam and corresponds to Abu Zabad soil type of HTS (1963). Chemical analysis showed that, these soils are short of phosphorus and nitrogen, but the potassium status is adequate. Three associations have been identified within this soil combination.

(a) Soil association one

This is the most widely occurring association in Markib soil combination. The soils here are deep well drained dark red to dark reddish brown sand loams and being more acidic than the two other associations. Sheet erosion is very common and sand has been piled around bushes and trees by wind erosion. These soils are low in nitrogen, very low in phosphorus and moderately supplied with potassium. The vegetative-cover on these soils is dominated by *Albizzia amara*, *Boscia senegalensis* and *Dalbergia melanoxylon*.

† Qoz is a local Arabic word meaning sandy soil and it is generally being used to describe light sandy soils which are easily cultivated by hand. So the term applies to land use capability and not a soil class.

(b) Soil association two

This association is covered by long narrow sand dunes orientated in a northeast southwest direction and were spotted clearly on aerial photographs from the difference in vegetation communities occupying the hollows and ridges. Soils in the hollows are slightly heavier with higher pH content, the vegetative-cover is dominated by *Albizzia amara* and *Guiera senegalensis.* The adjacent ridges carry soils of slightly less pH and a vegetative-cover consisting mainly of *Acacia senegal* and *Boscia senegalensis.* These soils have low available phosphorus and nitrogen and the exchangeable potassium values are lower than average for the area, available potassium is moderate.

(c) Soil Association three

These are usually shallow soils carrying poor stands of *Albizzia amara* and *Boscia senegalensis* arranged in a concentric pattern of arcs that show up clearly on aerial photographs. Unvegetated areas are severely sheet eroded and runoff of rain water is rapid leading to destruction of the vegetative-cover by decreasing water infiltration into the soil, developing compacted very hard surface, and, consequently causing droughtiness conditions. These soils have very low fertility status as evidenced by the fact that non of them is being cultivated. They lack exchangeable calcium and available phosphorus is rather low.

2.5.3 Wad Gerad soil combination

This combination comprises the soils developed on sand sheet and low dune complexes in the northeast and the extreme northwestern corner of the study area. They are transported soils of aeolian origin where the sand grains were formed by weathering outside the area and blown in by wind action. Generally, the soils of this combination are neutral to slightly alkaline reddish brown sands and loamy sands. They are excessively drained and wind erosion is widespread especially where the surface is exposed by loss of vegetative-cover. Two soil associations have been recognized.

(A) Soil association one

This association dominates the sand sheets and dune complexes of the north-east and extreme northwest. There are slight difference between soils on dune crests and in interdune hollows in terms of colour and pH content with soils on the crests slightly redder. Runoff is slow and both soils are excessively drained especially on dune crests. These soils are low in nitrogen and phosphorus but the potassium status is moderate. Both soils have been intensively cultivated in the past, but at present they are partially abandoned and, more or less, utilized for gum production. The dominant vegetation stands are *Acacia senegal* and *Leptadenia pyrotechnica.*

(B) Soil association two

This association occurs in a confined cluster just to the south of El Qubba and in a limited area in the south western parts of the study area. It is commonly found on very gently undulating sand sheets and low dunes dominated by *Acacia senegal.* Soils on upper lying areas are slightly sandier than low lying areas. These soils are excessively drained, phosphorous and nitrogen are low, while potassium values are moderate.

2.5.4 Umm Bum soil combination

This soil combination comprises the transported aeolian sand formed by weathering outside the area and blown in by wind and precipitated onto the sand dune geomorphic unit. This combination occupies the northwestern parts of the study area and a confined cluster to the east of Umm Kherein. Only one association has been recognized within this soil combination. The soils of this combination are rather uniform reddish brown alkaline sands to loamy sands which merge into fine textured grey brown soils derived from the lacustrine sediments in dune hollows.

The sand dunes are dominated by *Combretaceous* spp. with *Acacia senegal*, while the lacustrine sediments in hollows carry a vegetative-cover consisting of *Balanites agyptiaca* and *Maeura crassifolia.* Phosphorus and nitrogen figures are low in these soils, potassium is moderate and exchangeable sodium and soluble sodium are low. These soils have poor water holding properties, they are excessively drained and are subject to severe wind erosion when cleared for cultivation, and therefore are not normally suitable for cultivation. Cultivation here is confined to hollows where the internal drainage is comparatively slower, watermelon is the only crop grown. Recently farmers from areas as far south as Khuwei started to establish large-scale farming fields over this area, concentrating mainly on commercially growing watermelon.

2.5.5 El Qubba soil combination

This combination has also originated from aeolian sands and is formed on the dune complex geomorphic unit occupying the area between Markib and Umm Bum soil combination, plus a confined area to the north and west of Iyal Bakheit. One association has been recognized with reddish brown loamy sands on dune crests and reddish brown sandy loam in low lying areas. These soils are low in phosphorus and nitrogen with a moderate supply of potassium especially on sands but is below average in lacustrine sediments. The vegetative-cover of these soils is dominated by *Acacia senegal* on dune ridges, and in the lower wetter slope positions, *Albizzia amara* and *Guiera senegalensis* are abundant with much richer grass-cover. These soils are locally termed "Hamaraya" meaning red and signifying sandy loam or loamy sand and again this term applies to a land use type of soil. These soils, except in the vicinity of El Qubba, are usually not cultivated and mainly because of lack of water supply. Crops grown in the neighbourhood of El Qubba include groundnuts, sorghum and watermelon.

2.5.6 Wad Sharif soil combination

This is the last soil combination recognized in the study area. It consists of soil formed on the alluvial terraces and the flood plains of the few seasonally flowing watercourses, on lacustrine deposits in wetter interdune hollows, in depressions, bottoms of lakes and other scattered water retaining sites. One association was identified with variable soils ranging from fine textured grey brown cracking clays to coarse textured soils. Where drainage is free, reddish sandy loam soils develop containing more clay, and where drainage tends to be impeded, grey alkaline soils are found. These soils are low in nitrogen and phosphorus while the potassium level is moderate. Based on their drainage characteristics, these soils have been divided by HTS (1963) into two groups. The first group comprised well drained soils and were described as dark grey brown clays or sand clays which crack deeply when dry. The second group, however, consisted of the poorly drained sands and was described as having a grey clayey matrix with many distinct yellowish red mottles. Both these group were recognized by HTS (1963) as remnants of the shallow continental seas and lakes that presumably occupied the landscape during Mesozoic.

On these soils the vegetative-cover is very rich owing to the better soil moisture conditions. These soils are locally termed "Jurraba" signifying clay soil, and although they are comparatively heavier to cultivate by hand, but still they have been intensively cultivated for quite a long time. HTS (1963) and GITEC (1981) believe that the "Jurraba" soil is much more fertile than both the "Qoz" and the "Hamaraya" soils. The main crop grown on these soil is sorghum.

2.6 Topography and Drainage of the Study Area

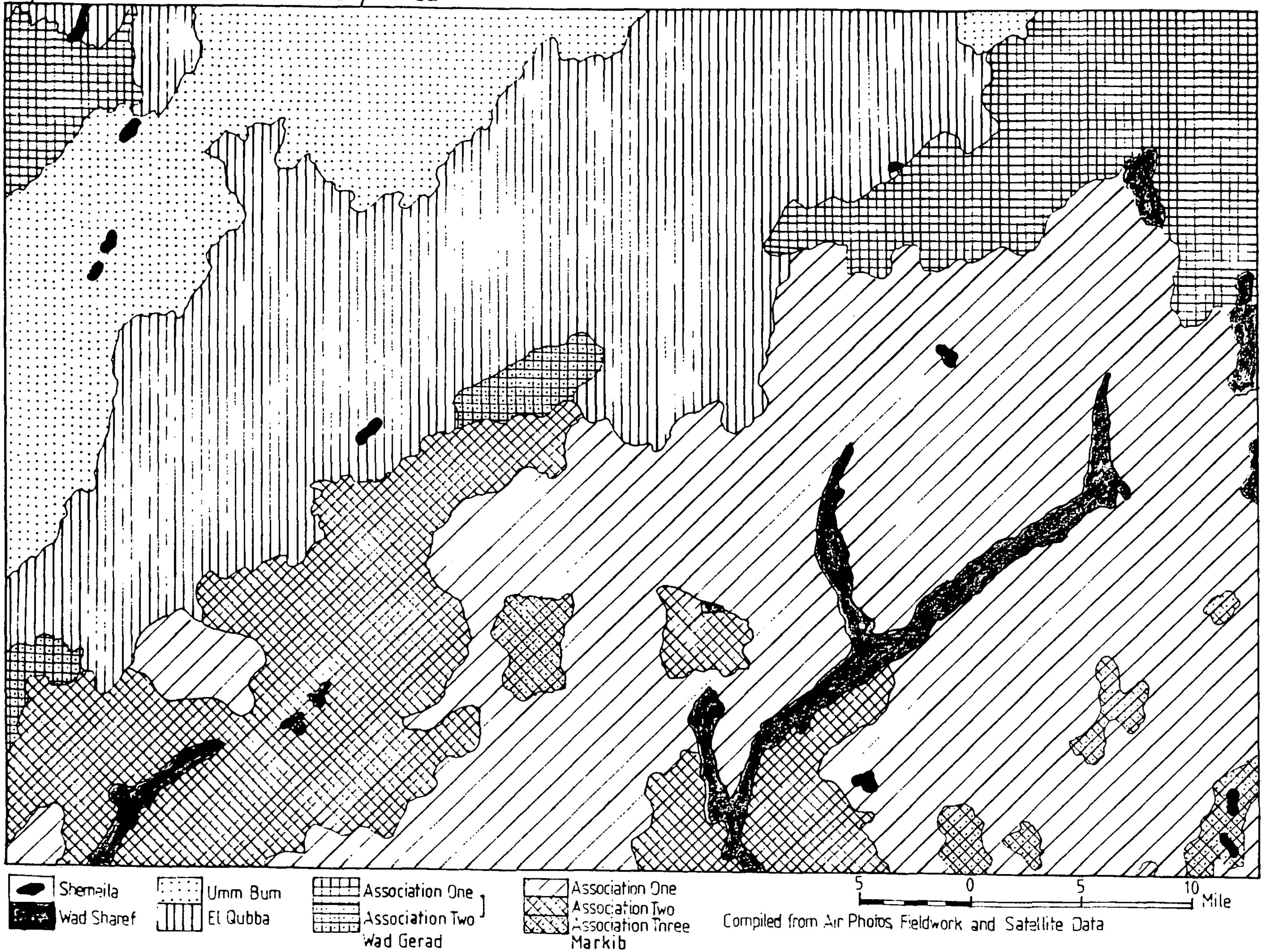
2.6.1 Topography

The relief of the study area is, with the exception of a few isolated inselbergs that dot the landscape, generally low and simple. For convenient description the topography of the study area will be studied here through the main geomorphic units outlined in section (2.4).

The sandy pediplain area of the south is simply a gently undulating rather monotonous planated land surfacee underlain by rocks of Nubian sandstone. This area has a remarkably constant height and few occurrences of hills recognized by Rodis *et al* (1963) as not exceeding 600 metres above sea level.

To the north of this sandy pediplain, however, the planated surface has been covered by varying mantle of sand grains weathered in the north and carried into the area by wind action. At a later stage, wind from other directions redistributed and reorientated the sand deposits and built the types of dunes that exist today. According to HTS (1963) the extremely wet conditions which prevailed in the past

Figure(2.7) Soils of the Study Area



had, more or less, stablized these sand dunes.

These various dunes together with the occasional inselbergs that pierce the sand mantle offer frequent relief in this part of the area. The individual ridges of these dunes are separated by easily recognized wide flat bottoms which are usually filled with lacustrine sediments. The average distance between consecutive dune ridges varies from 1-3 kms., whereas the height from dune crest to valley bottom was estimated to reach as high as 30 metres.

2.6.2 Drainage

In this area, as elsewhere, drainage is determined by the underlying rock formation, the nature of superficial deposits and the degree of slope. Surface drainage is confined to the southern part of the study area where the land surface is slightly harder and rains are relatively heavier.

In the south, a superficial dendritic runoff has developed flowing in a northeast-southwest direction. This system is part of Wadi El Ghalla which drains most of central and southwestern parts of Kordofan Region in a southwest direction towards Bahr El Arab in southern Sudan. This system has flowing water for just one or two hours after rains stop. The frequent occurrence of lakes in low lying areas normally interrupt the flow of water for they absorb most of the water and downstream flow from them occurs only during heavy falls. Therefore, it is rare for this drainage system to have water flowing its full length without breaks.

In the northern part of the study area, which is covered by relatively thick aeolian sandy soils, most of the rain water is absorbed by the sands, and any runoff is chanelled into the wide shallow depressions where surface flow is infrequent.

The underlying Nubian sandstones are characterized by high permeability and accordingly absorb all the water available leaving nothing for surface runoff.

2.7 Vegetation of the Study Area

The study area, as previously mentioned, lies in the arid and semi-arid parts of the tropics. Generally, the vegetative-cover of this climatic region suffers from lack of water as a result of low rainfall and high evaporation throughout the larger part of the year. Consequently, the plant cover of the area is sparsely distributed showing various signs of adaptation to this unfavourable water conditions.

The cover has marked xerophic characteristics due to the rather long dry season and the seasonal nature of rainfall. This has produced scattered tree and grass-cover made primarily of drought-enduring trees and annual grasses, while yet some areas exist without tree species supporting only a scanty shrubby flora and a poor grass-cover. Only on the few wetter parts of the study area, as along seasonal watercourses and in the water retaining sites, some mesophytic characteristics are evident in the vegetation.

Due to water stress during the prolonged dry season, the vegetative-cover of the area has developed various adaptive habits and characteristics for survival. Some species have deep tap roots penetrating towards moist soil below, while those species which fail to develop these system of roots, tend to improve water intake by the wide spacing to enlarge the catchment area for each and by sending out extensive lateral roots. To tackle high water loss resulting from transpiration, some species have responded by reducing leaf surface area and by shedding these leaves during the dry season. Annual grasses are the dominant species and perennial grasses that keep dormant for long periods and commence growth with the first rains are rare and decrease in abundance northwards.

Generally, the character, composition and distribution of the vegetation are determined by the climatic and edaphic characteristics of the area. Accordingly, the type of vegetation stands in the study area are found to follow, more or less, a latitudinal pattern similar to that of rainfall modified locally by soil changes. However, it must be understood that, there is no abrupt line of division between adjacent vegetation communities, instead, outliers of one type grade into neighbouring ones whenever the climatic, edaphic and topographic conditions make it possible.

In reference to the work of Andrews (1948) on the vegetation of the Sudan, the study area was classified and mapped as "*Acacia* Short-Grass Scrub". Andrews describes this region as a country with scattered bushes of *Leptadenia pyrotechnica* with occasional *Acacia albida.* He mentioned a number of grasses mixed with drought-resisting plants such as *Polycarpaea.*, *Monsonia senegalensis* and several herbaceous *Euphorbias.* He recognized *Acacia senegal* as increasing westwards until the land is covered with what he described as "open forest". Andrews mentioned the occurrence of *Terminalia brownii* and *Dalbergia melanoxylon* as outliers of the next vegetation region. His principal botanical interest lies in the fact that, the *Combretaceous* belt, which stretches across Africa, has its northern limit at the southern boundary of this division.

Regarding the work of Smith (1949), the study area lies in the "*Acacia* Short-Grass Country" division with *Acacia senegal* as a characteristic species beside *Balanites agyptiaca* and *Leptadenia pyrotechnica* in the north and *Combretum cordofanum* and *Terminalia brownii* in the south.

Referring to the work of Harrison and Jackson (1958), except for a small portion in the southeastern part of the study area which occupies their "*Combretum-Albizzia-Dalbergia* Savanna", the rest of the area lies in their "*Acacia senegal* Savanna" of the "Low Rainfall Woodland Savanna on Sand". They described this zone as having a vegetative-cover of thorny low strature trees "*Acacias*", few broad-leaved deciduous trees, few herbs and few perennials. They mentioned *Acacia senegal*, *Combretum cordofanum*, *Dalbergia melanoxylon* and *Albizzia amara* as widely occurring tree species.

The work of HTS (1963) divides the area into two main vegetation types. The northern part that consists of aeolian sands occupies the "*Acacia senegal* Savanna on sand" which is dominated according to the report by *Acacia senegal*, *Acacia tortilis* and *Combretum cordofanum* tree vegetation with *Aristida pallida* as the main grass species. On the other hand, the sandy pediplain of the south lies in the "*Combretum cordofanum-Albizzia-Terminalia* Savanna Woodland". *Combretum cordofanum* is reported to dominate sandy soils while *Albizzia amara* and *Terminalia brownii* previal on loamy and clayey soils with *Digitaria spp.* as the common grass species.

The primary manipulation and analysis of data collected indicated that, the northern part of the study area and especially on Wad Gerad soil type, the vegetative-cover is very sparse and denser stands are confined to the more sheltered and moister low areas in interdune hollows. The dominant tree species are *Acacia senegal*, *Acacia tortilis* and *Leptadenia pyrotechnica* with *Aristida pallida* as the widely occuring grass species. On El Qubba soils, the moisture conditions is slightly better than the former one, and consequently a richer stands grow dominated by *Acacia senegal*, *Balanites agyptiaca*, *Sylerocarya birrea* and *Maeura* *crassifolia* and again *Aristida pallida* is the dominant grass species with a few occurrences of *Cymbopogon nervatus* and *Tribulus terrestris.*

Southwards, where the soils change from aeolian mobile sands to the more stablized Markib soil type , and as relatively more rainfall is being received, a much denser and richer vegetative-cover invariably dominates the landscape. The main tree species are *Combretum cordofanum*, *Guiera senegalensis*, *Boscia senegalensis* and *Sylerocarya* on sandy soils, and *Albizzia amara*, *Lannea humilis*, *Dalbergia melanoxylon*, *Balanites agyptiaca*, *Acacia nubica* and *Adansonia digitata* on clayey soils. The main grasses on these soils are *Aristida pallida*, *Cenchrus biflorus*, *Andropogon gayanus* and *Shoenefeldia gracilis.*

Detailed description and classification of the study area's vegetation will be made in the next chapter.

2.8 Land Management in the Study Area

The main types of land use found in the study area, as elsewhere in western Sudan, are crop production by traditional shifting cultivation, forestry with emphasis on gum production, livestock raising and the felling of trees for charcoal manufacturing and other domestic use, Fig (2.8).

2.8.1 Cultivation

Generally, cultivated areas are scattered and only become concentrated and intensive around villages and water sources. Crops are grown in a traditional rainfed shifting cultivation cycle with a commonly defined rotation. The arable areas are mapped as densely and lightly cultivated ones depending on the length of the cultivation and fallow within arable blocks.

Basically, the crops cultivated in this area are of two types, stable food crops and cash crops. The former includes *Pennisetum* (millet) and sorghum, while the latter includes *Arachis hypogea* (groundnuts), *Sesamum orientum* (sesame), *Hibisus sabderiffa* (kerkade) and *Colocynthis* (watermelon).

The patterns and types of cultivation, however, vary between different localities depending on soil nature in each. Shemeila soils are entirely not cultivated due to their gravely surface. Markib soils are rarely utilized due to their low fertility and extreme permeability and here millet is the only crop grown. Wad Gerad soils are cultivated whenever there is a source of water supply nearby. Crops grown are millet and some sorghum, while watermelon is extensively grown as a cash crop and as a source of water during the hot summer months. These crops are basically grown in a rotation system with *Acacia senegal* gum-producing tree. Umm Bum and El Qubba soils occur in areas where drinking water is scarce and, therefore, little cultivation is practiced on both soils. Here small quantities of millet are grown near villages and cultivation is usually restricted to interdune hollows. Watermelon and groundnuts have recently been introduced and are extensively being grown. Wad Sharif soils are the most intensively cultivated type of soil in the study area due to their relatively higher fertility and the availability of drinking water in the area. Sorghum is the main crop grown.

2.8.2 Gum production

The practice of gum production in the study area is significant in the sense that, as a cash crop, it adds substantial income to farmers, and as a tree-cover, *Acacia senegal* maintains the soils of the area for this species is often mentioned as being associated with root-living nitrogen fixating organisms. Although the farmers main concern in growing *Acacia senegal* centres around the economic return, some farmers are aware of the secondary role played by the species.

Acacia senegal is the main gum producing tree. It is grown in a gum-cultivation cycle which traditionally consists of about 4 years of cropping followed by a period of 10-14 years of fallow under regenerated *Acacia senegal.* The system is essentially a shifting agricultural practice to allow, during the long fallow period, the regeneration of the soil so that a further period of cropping can be safely supported.

In areas of high population densities, especially around permanent water supply centres like Khuwei, Umm Lubana and the area between Rawyana and Umm Aweisha, the fallow period is increasingly diminishing owing to the high demand for land. Consequently, *Acacia senegal* has gradually decreased around these localities. Further north, *Acacia senegal* had less been affected and to some extent, the traditional gum-cultivation cycle is still being practiced.

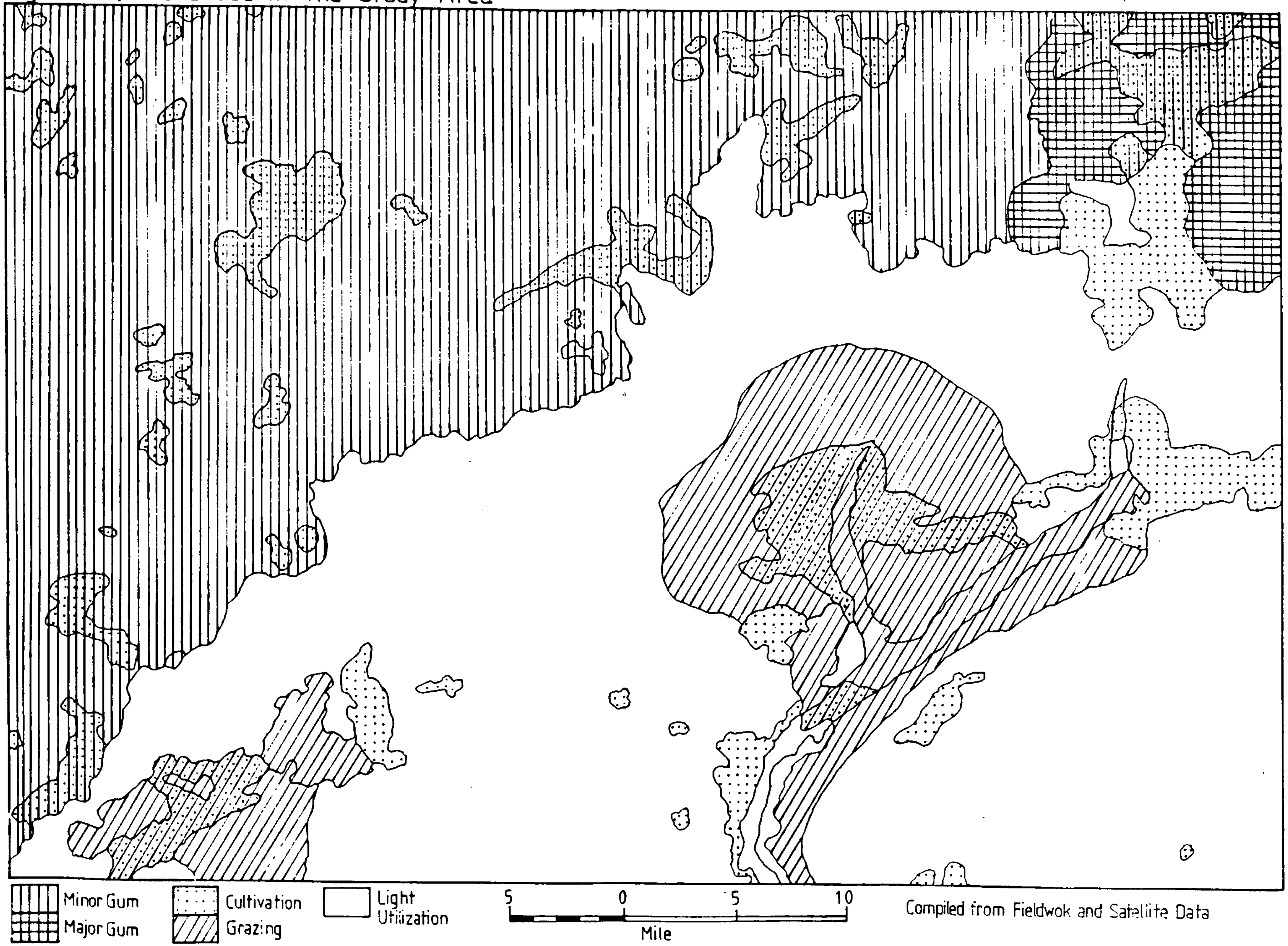
As a gum producing tree, *Acacia senegal* is found growing at varying densities on nearly all the soils of Wad Gerad, El Qubba and Umm Bum. These gum-producing areas are mapped as major and minor areas based on the degree of cultivation, the rotation cycle, gum productivity and the density of the species itself.

2.8.3 Livestock raising

Livestock is raised in the study area by both the settled population and the nomads of the area as well as those entering from north and south.

Animals raised by settled communities are goats, cattle and sheep. The goat is the most prevalent animal in villages where the average family holding is five heads.

Figure(2.8) Land Use in the Study Area



As a tough animal, goats tolerate the harsher conditions of the area especially late in the dry season where grazing and water supply become meagre. Cattle do not match goats in number, but seems to have increased tremendously during the last decade or so. This could be explained by the expansion in the provision of drinking water and by the increase in savings made from working abroad particularly in the Gulf. However, in the light of successive cash crop failure, the inhabitants shifted to invest in animals more than they used to do in the past.

The area is visited alternately by nomads from the north and south in the dry and the rainy season respectively. The intensity of nomadic movement into the area varies from one year to another depending on intensity of rains in the south and on the conditions of pastures and water availability in the north. In years of good rains and abundant pastures, less in-migration occurs from the north while nomads in the south extend their movement further north. However, during years of below average rains, nomads arrive in large numbers from the north but, on the other hand, the area will be relieved from the southern nomads who tend not to extend their movement northwards.

Grazing is concentrated in the central and southern parts of the study area where there are numerous natural as well as artificial water resources. The northern part is relieved from this activity as it lacks water for both man and animal use. The boundaries drawn around these grazing areas (Fig 2.8) were based on the quantity of water supply available, the nature of animals present and the distance travelled between the source and the surrounding pastures. Based on the number of grazing animals present, these areas are divided into heavy and light grazing.

2.8.4 Biomass harvesting

Felling of trees as a type of land use is practiced almost throughout the study area by both sedentary people and the nomads. In this area, trees are felled either as a means to clear or open new land for cultivation, or to meet the domestic need for fuelwood, charcoal and other woody materials for house construction and in some cases even for commercial purposes. The different aspects of this land use activity will be dealt with in detail in section (6.3).

Chapter III

Vegetation Classification of the Study Area

3.1 Introduction

This chapter will be dealing with the sorting out of community data collected and the grouping of similar entities together into clusters (types) defined by the possession of certain similar attributes. This procedure, as recognized by Poore (1962), Shimwell (1971), Sokal (1974) and Blashfield & Aldenderfer (1978), is a fundamental activity in community ecology as it is in any other branch of science or process of thinking.

Community data collected from the study area are based on the abundance of species in various sample sites. In other words, the data obtained are multivariate in nature in the sense that, a number of characteristics "species abundance" are measured on a number of individuals "samples" which make it necessary for them to be studied simultaneously. However, numerical methods seem to lend themselves to this concept and, therefore, they have been used to treat these multivariate data as a whole, summarizing them and revealing their structure and types.

The application of numerical analysis to community data have long been advocated by ecologists as efficient (Poore 1962), and as objective in providing an easy summary which both facilitates the comprehension of the data and the provision of means for active communication of results, Cauch (1980). Williams & Gillard (1971) argued that these methods of analysis have the advantage that they begin with no specific hypotheses, their function is to elicit from a quantity of data some internal structure from which hypothesis can be generated and tested. This, according to Gauch (1982), is in contrast to statistical methods which treat only one to several variables at a time and, therefore, are generally tedious, impractical and ineffective for the analysis of such data. In addition, statistical methods are concerned, more or less, with the testing of hypothesis in the form of a probability that a null hypothesis is true rather than generating any further hypothesis.

The community data collected on the abundance of species in a number of samples have been reproduced in a primary two-way table matrix with species on one side and samples on the other. This data matrix will be manipulated through multvariate analysis procedures to achieve the following objectives:

(1) The first targeted objective is to uncover the main characteristics of the raw data itself. This was termed "intrinsic analysis" by Williams & Lance (1968), "taxonomic analysis" by Whittaker & Gauch (1978) and by Gauch (1982) as "internal analysis". The emphasis here will be made to reveal the four main aspects of community data, (a) Noise i.e. the detection of variation in species abundances (Poore 1956, Gauch 1980). (b) Detection of redundancy in data, i.e. the identification of samples resembling others in their species composition and species resembling others in their occurrences in samples, (Moore *et al* 1970, Orloci 1974, Gauch 1980). (c) Elucidation of relationships among samples and species considered jointly, Gauch (1980). (d) Detection of samples and species outliers in the data, i.e. the identification of samples of peculiar composition that have low similarity to all other samples (Everitt 1978, Gauch 1980), and species with low similarity to all other species in their occurrences in samples, Gauch (1980).

By so doing, objective means will be provided for shifting the level of abstraction from raw data in terms of species abundance in samples to community level properties of community types. This will facilitate the identification of recurring similar and dissimilar species and sample groups, the identification, description and analysis of different types of communities encountered, the delimitation and better naming of these communities and the assignment of new community samples to previously defined community types. By incorporating other techniques, the proper mapping of communities can be recognized and not least the generation of hypothesis for further testing. A task which will be achieved by this chapter

(2) The second target will be to relate types of communities identified to other types of data obtained as environmental and historical. This was termed by William & Lance (1968) "extrinsic analysis", by Whittaker & Gauch (1978) "ecological analysis" and by Gauch (1982) as "external analysis". Analysis here will cover investigating structure, regulation and maintenance of communities, spatial distribution and patterns exhibited by different species along environmental gradients, species niches and habitats revealing competitive interactions among species and between species and external environment. This target will be the subject of the next chapter.

(3) The forthcoming stages of analysis will be orientated towards further improving and comprehending knowlege about the study area's vegetative-cover, for the prediction of plant communities from environment and environment from plant communities, for the reconstruction of past green-cover and in turn for the assessment of the course of change and succession, the short and long-term responses to disturbances and for acknowledging the factors behind these successional changes.

3.2 Classification Theory and Method Adopted

Early ecologists debated whether ecological communities actually occur in discrete, continuous classes or types, or in a rather continuous community variation. Regardless of the controversy, *classification* is the appropariate framework for conceptualizing communities if variation is discontinuous, and *ordination* if it is continuous. The current trend in community ecology, however, emphasizes the complementary use of classification and ordination and strongly recommends the use of the former for many practical purposes, Goodal (1954), Whittaker (1962,1978), Hill (1979), Gauch (1982).

According to Gauch (1982), classifications as a means of putting similar samples and species together into groups, is relevant to aspects of community data in that, first, noise can be reduced by combining samples of a cluster into a single average or composite sample. Second, it is effective in summmarizing redundancy in the data and gives a workable number of entities for contemplation and communication. Third, it is effective in expressing relationships among samples and species. Fourth, it is also efficient in detecting outliers in the data by simply noting samples that fail to cluster with other samples at a given fairly low level of similarity. Moreover, classification is efficient in relating community gradients to environmental, historical and other data and in hypothesis generations on such relationships.

Classification is, therefore, the choice and will be used as a tool in the ongoing efforts to understanding communities better and to achieve the targets mentioned above. Although species abundance in samples are the primary sort of data used, still there are difficult issues remaining to the particular emphasis and calculations to be used in classifying such data. At the level of this study, there are a number of schools of classification available with various emphasis regarding the most important information in the data to be used. The choice adopted in this respect is to place equal emphasis on the abundance of all species measured in the area in all sites sampled. This choice has the advantage of working out objective conclusions by treating all species on equal basis. This decision still leaves room for a great diversity of classification techniques and, therefore, further criteria were added to choose among them, these have incluced:

(1) The method should be able to classify all the range of data collected in order to provide a convenient framework for summarizing the range of variation in the study area's vegetative-cover. Added to this as suggested by Hill *et al* (1975), the method should be open-ended, i.e. being capable of accommodating new species into their correct places in the resulting classification without necessitating further calculations.

(2) The method should be computationally efficient and not making too many serious errors of misclassification.

(3) More importantly, the method should be integrated within the overall research plan and objectives.

Based on these criteria, a "Divisive Polythetic Hierarchical" system of classification had been adopted. First, the system is divisive in a sense that it begins with all entities in a single class and starts dividing this class into progressively smaller ones stopping when each class contains the minimum required combination of species. This is contrary to agglomerative methods of classification which begins with each entity in a class of its own and then agglomerate these classes into larger ones. Although agglomerative methods have been widely advocated by ecologists (Sneath & Sokal 1973), yet they are neither open-ended (Gauch 1982) nor they are easy to apply to large set of data (Fostberg 1961). Second, the system of classification adopted is polythetic as it uses information on all species encountered in the processes of deriving clusters assignment, contrary to monothetic ones which work out clusters on the basis of presence or absence of a single species, a method according to Gauch (1982) prone to make too many serious misclassification even if the best possible species is selected for division. Third, the system adopted is hierarchical in that, it puts similar samples and species into groups and additionally arrange these groups into a hierarchical, tree-like structure (dendrogram) which indicates relationships among groups, Sneath & Sokal (1973), Everitt (1978), Gauch & Whittaker (1981) and Gauch (1982). This is contrary to non-hierarchical methods which merely put similar samples into clusters but ignore the larger picture of relationships among the clusters.

Acceleration in work on classification theory coupled with computers becoming widely available to ecologists, have paved the way for many classification methods to be computerized which, consequently, had increased their objectivity and efficiency, reduced time required and eased the analysis and handling of larger sets of data.

Among the many available divisive polythetic hierarchical techniques and computer packages, there is a general preference for Two-way Indicator Species Analysis (TWINSPAN) of Hill (1979) which is essentially a refinement of a method published under the name "Indicator Species Analysis" by Hill *et al* (1975). Strictly speaking TWINSPAN, as written by Hill (1979), *is a polythetic divisive method which begins with constructing a classification of the samples and then proceeds by* *using this classification to obtain a classification of the species according to their ecological preferences..., these two classifications are then used together to obtain an ordered two-way table that expresses the species synecological relations as succinctly as possible.*

TWINSPAN, being divisive and polythetic, is strongly being advocated by many ecologists as robust and an efficient tool of classification, (Whittaker & Gauch 1981, Gauch 1982), and as it fulfills the basic requirements previously identified, and needs minimum computer skills, this method has therefore been selected and applied. The computer programme used was that of Hill (1979) and has the same name as the technique.

3.2.1 Strategy of analysis with TWINSPAN

The basic activity in TWINSPAN is to classify the samples and species in a divisive hierarchy by dividing them up first into 2 subsets, then 4,8,16...etc, Fig (3.1). The programme does so by first ordinating the data by reciprocal averaging (RA) and those species which characterize the RA axis extremes are emphasized in order to polarize the samples, and the samples are then divided into two clusters by breaking the RA axis near its middle. The sample division is refined by a reclassification using species with maximum indicator value. The process is then repeated on the two subsets to give four clusters and it carries this on until each cluster has no more than a specified minimum number of members. A similar species classification is produced using the same procedure and the sample classification as the basis. The sample and species clusters are used together to produce a re-orderd two-way table (Appendix A).

TWINSPAN, besides satisfying the classification criteria previously outlined, uses separate ordinations for each subset it produces, and consequently the various divisions obtained at a given level reflect different gradients which are important for the individual data subsets. This feature of the programme has the advantage that it helps in the process of extracting the major trends in the data and, thereby, in presenting an overall picture of the vegetational variations in the study area and in providing a basis for correlation with other environmental and habitat factors.

The ordered two-way table is the sort of structure that TWINSPAN aims to exhibit, which clearly shows the relationship between species and samples. The programme achieves that by throwing the salient features of the data into sharp relief and, thereby, grouping like samples with like and like species with like.

The raw data constituted the 33 sites which have been surveyed and sampled using the abundance of species derived from the 20 random plots recorded at each site. Thus species abundance was the type of data used in this numerical procedure and the assumption being that, each plot and each site contains enough species for its floristic affinities to be judged from the number of species present. The data, therefore, consisted of records from 660 units of vegetation at the plot level (33 sites with 20 plots in each) 33 units at the site level, and have included 54 species which is the total number of species recorded in the study area.

The table, therefore, is not merely an ordination, in addition to that, it arranges the data in such a way that species with similar pattern of occurrence are clearly separated from dissimilar ones, i.e. species widely occurring on one side of the division from species occurring on the other side. TWINSPAN does so by identification of *differential species* which are ones with clear ecological preference, so that their presence can be used to identify particular environmental conditions.

As written by Hill(1979), *the procedure in TWINSPAN resembles the hand method of classification made by* Muller-Dombois & Elenberg (1974), *but while their method classifies the samples at the same time as the species, TWINSPAN classifies the samples first and uses this classification as a basis to obtain a classification for the species.*

3.2.2 Clusters produced by TWINSPAN

TWINSPAN executes the clustering procedure according to the scheme shown in Fig (3.1), and produces clusters in such a branching tree-like shape customarily known as dendrograms which are the most frequently presented results of hierarchical classifications. The scheme begins, as earlier outlined, with all samples in a single cluster and successively divides them into two, a "positive" and a "negative" group according to the ordination score of each sample which is calculated by adding +1 for each *positive indicator species* and -1 for each *negative indicator species* that is contained. The programme specifies at least one to several negative and/or positive indicator species for each division and lists them in an approximate order of effectiveness. Accordingly, samples with an indicator score of -1 or less are included in the negative group, whereas samples with scores of 0 or more are assigned to the positive one. Moreover, TWINSPAN identifies species that are at least twice as likely to occur on either side of the dichotomy than on the other. *Negative preferentials* is used to specify species occurring on the negative side and *positive preferentials* for those on the positive one. Species reasonably common on both sides are termed *non-preferentials.*

For each division TWINSPAN produces a scatter distribution which shows a refined ordination reproduced by dividing up the primary ordination into segments,

Figure 3.1

Scheme of Classification by TWINSPAN

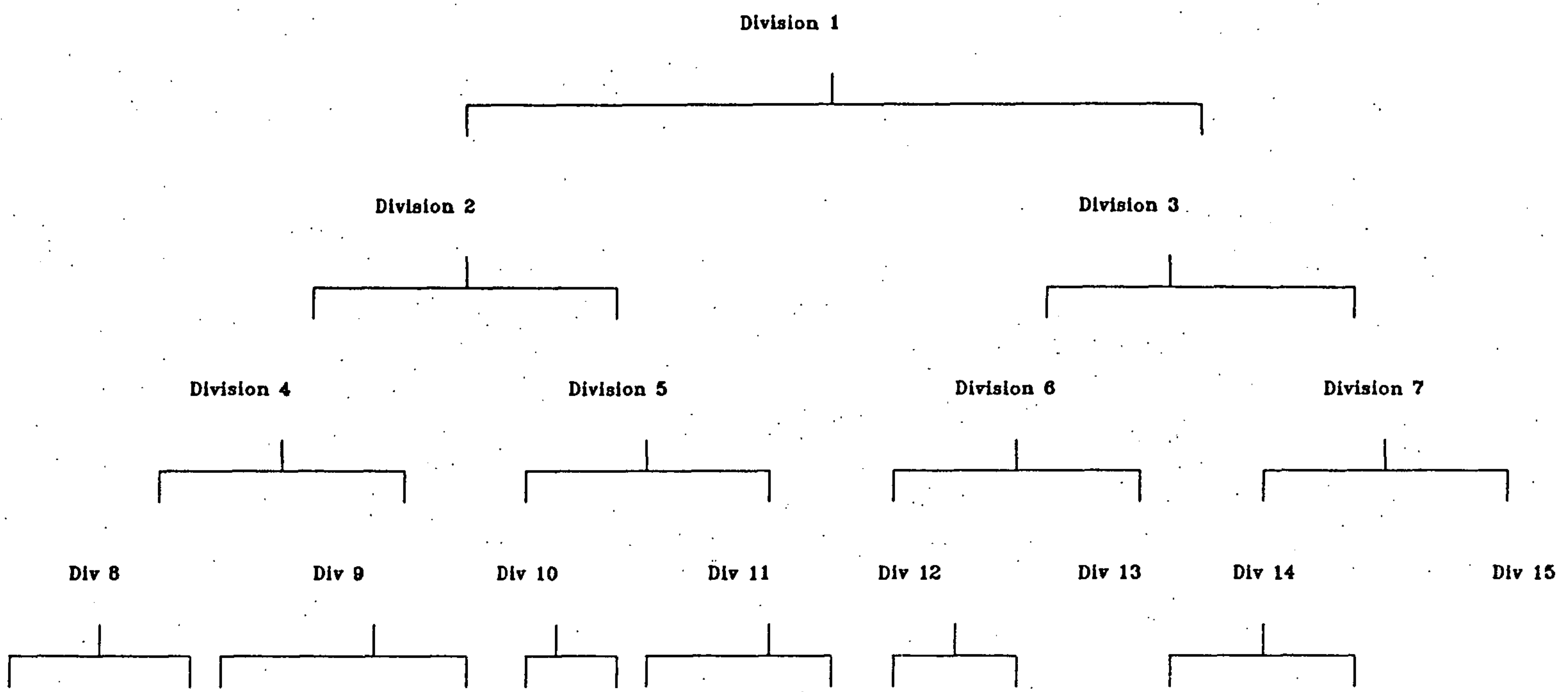


Table 3.1. These have no special significance except that they are a convenient way of calculating where to locate the "zone of indifference", (Hill 1979). The "critical zone", segments 5-12, is 20% of the length of the whole ordination. The length of the segments within the critical zone is, therefore, one quarter of the length of the segments outside it. Hence there are five possible positions for the zone of indifference such that it lies entirely within the critical zone. TWINSPAN selects this zone of indifference in order to minimize "misclassified" samples which are those, either lying to the left of the zone of indifference but whose indicator scores would assign them to the positive arm of the dichotomy, or those samples lying to the right but their indicator scores would assign them to the negative one. All samples that lie in the zone of indifference are designated as "borderline" cases and assigned to the negative or positive group according to their scores. According to Hill (1979), the polarized nature of the refined ordination reduces borderline cases to the minimum. The detailed procedure and clusters produced by TWINSPAN are summarized in Appendix A.

Table 3.1: Scatter Distribution for the First Level of Divisions

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0	0	0	0	0	0	1	0	1	0	0	1	1	4	2
6	10	4	2	1	0	0	0	0	0	0	0	0	0	0	0

3.3 The identification and description of vegetation types

In this section the clusters produced by TWINSPAN will be used to describe and map the main types of vegetation encountered in the study area. However, it should be noted that, the initial efforts were made to produce a classification for the area's vegetation in such a way that can be, more or less, easily interperted and integrated into the most widely accepted systems of vegetation classification both at the regional and the continental levels. But, unfortunately, this has never been easy, because at the regional level the units used by many of these systems are too briefly defined or not defined at all which make such studies to have restricted scientific values and could, in this connection, be described as just good approximations to the real situation. On the other hand, comprehensive vegetation studies involving tropical and subtropical regions are yet to come and the available ones are far too generalized. Thus it seems that the remarks coined long ago by Richard *et al* (1939) regarding classification of tropical vegetation, namely that existing knowledge for the construction of such a classification does not exist, still remain true.

Our failure to integrate other systems of classification into the present one, shifted the emphasis to producing a more coherent and precise nomenclature in order to avoid the unnecessary confusion often found in tropical and subtropical vegetation studies which results from different reseachers calling the same thing by different names and probably different things by the same name. This beside, by using a more objective and consistent procedure, to try and present a work such that subsequent researchers could both make use of and integrate as a scientifically sound system of classification.

Although, as shown above, floristic composition had been used as a basis for the clustering procedure, it was found necessary to take into account as well ecological, dynamical and physiognomic features of vegetation in order to achieve a realistic classification scheme and for the better recognition and description of various types of vegetation in the study area. Thus floristic grouping will be of less and less practical meaning towards the higher levels of the hierarchy for which physiognomic, ecological and dynamical aspects will be the characteristic attributes. So the aim will be to bring together the floristically related divisions by their structural and habitat features into a combined higher distinctive vegetation units defined by the dominant or most conspicuous growth forms.

The numerical divisions produced by TWINSPAN and their structural characteristics were used to abstract more formal terminologies for defining community types that can be communicated and comprehended. These terminologies define classes or groups of individuals which were produced as types of vegetation recognized by their floristic composition and structural characteristics which better express their relationships to one another and to the environment. Thus these classes hierarchically unite stands that are alike in ways that phytosociologically and phytogeographically appear significant. However, description of these classes varies with each level of divisions as interest and view of what is important for classification differs. The terminology used are Associations, Sub-formations, Formations and Formation-Types. These are summarized below and will be considered in that order:

Associations, correspond to the fourth level of divisions produced by TWINSPAN. They are the fundamental units of the hierarchy produced consisting of plant communities characterized by definite floristic and sociological (organizational) features that are unlike other neighbouring associations. In this sense, associations will be used and applied in a phytosociological manner signifying vegetation units which are characterized mainly by differential and preferential species as used by Braun-Blanquet (1933). These associations will be named after their most dominant species but characterized by their total flora in which some species have greater significance or indicator values than others. These will be dealt with as indicator species, differential species, preferential and non-preferential species. Indicator and differential species are those centred in or relatively confined to a particular division compared with all others and, therefore, characterize it and indicate its environment. Preferential species are those which distinguish two closely related divisions by presence in most samples of one association and absence in most samples of the other. Non-preferential species are those not restricted to a given division but help to characterize it and indicate its relationship to higher units. Smaller components within associations will be recognized under the Tansley (1920) terminology *Societies.*

Definition of classes above associations will be based on a phytogeographical criteria which comprise a wider range of morphological, dynamical and environmental measures beside floristic ones rather than on a purely phytosociological criterion as used for associations. This shift of emphasis was required because floristic composition or phytosociology is only one of several important attributes of vegetation that merit similar attention which can equally be employed as useful basis of classification, Whittaker (1973).

Sub-formations define similar associations characterized by their structure and most dominant and conspicous species. Structure here is meant the organization of height and degree of density . Similar sub-formations are grouped into **formations** which are defined by the possession of similar floristic and physiognomic characteristics and range of environment to which that physiognomy is a response. Similar formations, defined by the possession of similar physiognomic and floristic attributes and occurring in, more or less, the same range of environmental conditions are grouped together as **formation-types**. These classes are the same clusters produced by TWINSPAN in Fig (3.1) and are presented in their revised hierarchical order in Figure (3.2).

As to nomenclature, it was found that sufficient English terms were available to cover satisfactorily the main physiognomic types identified in the study area. Terms like *Savanna* were found to have been defined and used in ecological literature in so many different ways that they become quite confusing to be used in a precise classifactory sense and, therefore, have been avoided. However, in order to facilitate understanding and to pave the way for comparing the study area's vegetation with other similar parts of the African tropics, a serious attempt has been made to ensure that the names used are those which satisfy the requirements of the International Code of Botanical Nomenclature. Occasionally, climatic terms like "semi-desert" are used but only as a convenient nomenclatural shorthand for important physiognomic and floristic differences which it would be impossible to designate concisely in purely physiognomic or floristic terms. Economy has been exercised in the selection of representative species in the attempt to characterize each type of vegetation. Appendix A gives full list of species in each unit.

With the aid of satellite data and aerial photographs, these vegetation types have been located and mapped as shown in Fig (3.3). On this map, the eight recognized sub-formations have been given a number I to VIII with each association having its own type of shading. Subordinate units recognized within associations have been indicated by their dominant constituents. Where vegetation has been greatly disturbed by cultivation the suffix (C) is added to the sub-formation number and the suffix (G) to denote disturbance by grazing animals.

Formation-Type	Formation	Sub-Formation	Association
Wooded Grassland	Transitional Grassland	I Semi-Desert and Secondary Grassland	Aristida Grassland
			A.senegal-Boscia
		II Succulent Shrub Grassland	Combretum-Lannea
			Guiera-Boscia
	Secondary Shrubland and Grassland	III Shrubland and Secondary Grassland	Boscia-Lannea
			A.senegal-Boscia
		IV Scrub Woodland & Secondary Grassland	A.senegal-A.nubica
			Boscia-A.senegal
Shrub and Acacia-Wooded Bushland	Secondary Acacia-Wooded Shrubland	V Secondary Acacia Shrubland	A.senegal-Boscia-A.nubica
			A.senegal-Albizzia-sylerocarya
		VI Dwarf Shrubland	A.senegal-Balanite.-Sylerocarya.
	Open Bushland	VII Bushy Shrubland	Guiera-Boscia-A.senegal
			Boscia-Guiera-Albizzia
		VIII Stunted Bushland	Boscia-Calotropis

Figure 3.2 Vegetation Units of the Area

3.3.1 Wooded grassland formation-type

This formation-type includes land covered with grasses and other herbs and sparsely dotted with scattered or more rarely grouped woody plants which are often, but not necessarily, shrubs. Woody plants comprise between 10-15% of the vegetation the density of which vary greatly especially in relation to water supply and the density of human interference. They are frequently associated with drainage lines and low lying areas as depressions which receive relatively more water than that supplied by incident rainfall. Walter (1971) uses "Wooded Grassland" in a broader concept to indicate a zonal vegetation on deep sandy soils in tropical and subtropical regions to which he restricted the term "savanna".

The grass-cover in this formation-type is no more than 60 cm tall mostly consists of annual species principally *Aristida pallida, Brachiaria xantholeuca* and *Cenchrus biflorus*. Perennial grasses are localized but *Andropogon gayanus* sometimes occurs in widespread stands, especially on deeper sands towards the south. Evidence suggests that, formerly this species was widespread, but it has been eliminated from large areas by cultivation which is a characteristic human activity in these parts of the study area. Two formations have been identified in this formation-type, these are namely (1) Transitional grassland (2) Secondary shrubland and grassland.

(A) Transitional grassland formation

This formation is here regarded as a transitional zone to the northen "desert grassland". The transition is not a gradual one as would be expected from a climatic view point, but it is rather greatly modified by local edaphic factors particularly the relief of the sandy cover which in places brings about abrupt changes.

On sandy plains and low dunes, this transition was reported by HTS (1963) to take place at about the 100 mm. isohyet outside the study area, but where the dunes are unstable, desert grassland extends sporadically much further south. Thus patches of semi-desert grassland dominated by the perennial species *Panicum anaboptistum* and *Aristida pallida* extend as far south as the 250 mm. isohyet occupying dune crests. They alternate with patches of typical grassland dominated by the annual species *Cenchrus biflorus* and its habitat associates which cover the stable sand of the lower dune. The two subformations within this formation are "Semi-desert and secondary grassland" and "Succulent shrub grassland".

(A-1) Semi-desert and secondary grassland sub-formation

The plant cover of this sub-formation is sparse and shows various adaptation to the unfavourable water conditions which result from the lack of sufficient water on the one hand and high evaporation on the other. In this sub-formation, the soil is often more conspicuous than the vegetation so that the landscape is generally dominated by the colour and character of the soil rather than by the plants themselves. Still, vegetation is sufficiently numerous to be meaningful to refer the communities it forms to general physiognomic and floristic categories.

The vegetation of this sub-formation has been, to varying degrees, greatly affected by cultivation and to a lesser extent by grazing animals. Based on the floristic composition of this sub-formation, "*Aristida* grassland" and "*Acacia senegal-Boscia*" Associations are recognized.

Aristida grassland Association.

This area has been shown by Harrison & Jackson (1958) as "semi-desert grassland on sand" and as "*Aristida* grassland" by HTS (1963). It consists of varying mixture of grasses and herbs either without any woody vegetation or in most cases with a varying scatter of shrubs and bushes mainly in protected areas and sites of better soil-water conditions. Annual and perennial grasses are present with the former as predominant but likewise, the grass-cover is generally sparse. *Aristida pallida* and *Cenchrus biflorus* are the commonest grasses of the higher ground with *Panicum anaboptistum* on the exhausted abandoned lands trapping wind blown sand and forming sand mounds. Site analysis revealed the following societies within this association.

Leptadenia-Acacia senegal

This society is found to the west of Kerenka. This area appears to have been heavily cultivated in the past and is now, more or less, partly abandoned. The development of this society could be related to soil exhaustion or possibly to poor soil-water relations. In places, the vegetation is very open approaching grassland. *Leptadenia pyrotechnica* is the dominant tree with *Acacia senegal, Balanites aegyptiaca* and *Boscia senegalensis. Cymbopogon nervatus* is either the dominant grass or co-dominant with *Aristida pallida, Panicum anaboptistum* and *Tribulus terrestris* is also present.

Acacia senegal-Balanites aegyptiaca

This society is found mainly on the low dune complex of the western parts of this association. *Acacia senegal* is the dominant tree, though rather thinly scattered. *Balanites aegyptiaca, Acacia tortilis* and *Ziziphus-spina-christi* are found in the dune hollows. *Aristida pallida* is the dominant grass but in the less well drained hollows, *Brachiaria xantholeuca* is to be found with varying abundance of *Panicum anaboptistum.*

Acacia nubica

This society is found in depressions and the fewer water-retaining sites of this association. *Acacia nubica* dominates the better drained parts of these sites with *Boscia senegalensis*. *Aristida pallida* is the dominant grass species along with *Acanthus spp.* and *Cassia italica* in wetter areas.

Acacia senegal-Boscia Association.

This association was shown by HTS (1963) as "*A. senegal-Combretum cordofanum*" and as "*Acacia mellifera-Commiphora* Desert Scrub" by Harrison & Jackson (1958). Grasses are the prevalent type of vegetation and usually contain an admixture of shrubs and small bushy trees the density of which is partly determined by local conditions. Due to the lack of drinking water, this association is in places ungrazed, but has been subjected to relatively intensive cultivation and the extent to which tree-less areas are natural is largely conjectural. The following societies are identified within this association.

Boscia senegalensis-Maeura crassifolia

Around certain areas of this association, population pressure on arable land has excluded *Acacia senegal* from the gum-cultivation cycle and continuous cultivation is now being practiced. *Calotropis procera, Guiera senegalensis, Boscia senegalensis* and *Maeura crassifolia* are the dominant type of vegetation which could well be considered as indicators of overcultivation and soil exhaustion trends. An occasional *Combretum cordofanum* and *Acacia senegal* may be found. *Aristida pallida* is the dominant grass, *Cymbopogon nervatus* being frequently to locally dominant. *Eragrostis aspera* and *Cenchrus biflorus* are among the grasses found.

Acacia senegal-Leptadenia pyrotechnica

This society occurs on the sand dunes in the area northeast of Zeileita and north of Umm Bum. The area is heavily cultivated and it appears that the abundance and probably even the presence of *Leptadenia pyrotechnica* is due to this fact. *Acacia senegal* is the dominant tree with *Lannea humilis* and *Balanites aegyptiaca, Ziziphus-spina-christi* and *Boscia senegalensis* are also present with varying degree of abundance. *Acacia albida* also occurs and generally scattered throughout the area. *Leptadenia pyrotechnica* occurs on the dune crests where the tree-cover is more open, whereas on the sides which are heavily cultivated, scrubby specimens of *Balanites aegyptiaca, Acacia nubica*, and *Ziziphus-spina-christi* are abundant constituents. The incidence of *Calotropis procera* is held to be responsible to a degree of overcultivation. *Aristida pallida* dominates the ridges while *Cenchrus biflorus* and *Brachiaria xantholeuca* the cultivated areas. *Eragrostis aspera* appears late in the rainy season giving a general late aspect dominance.

Acacia senegal

This society is found in the area around Mahboub and is essentially a patchwork of gum-gardens of varying ages representing stages of the gum-cultivation cycle. *Acacia senegal* is the dominant tree often forming dense thickets in the early stage of coppice regeneration and thinning out as the tree matures. In localities of heavy cultivation, the efficiency of *Acacia senegal* to regenerate is greatly impaired and poor stands often result. *Acacia tortilis* is occasionally present especially towards the north. *Balanites aegyptiaca* is frequently present but often reduced to gnawed stumps in the vicinity of villages. *Boscia senegalensis*,which is avoided by stock, thus favouring its reproduction, increases greatly around cultivated areas. *Aristida* *pallida* is the dominant grass away from cultivation with *Cenchrus biflorus* being dominant on cultivated areas. *Eragrostis aspera* again gives a late-rains aspect dominance to the whole area. In the eastern parts of this association, *Cymbopogon nervatus* is frequently present. Harrison & Jackson(1958) suggested that this is due to a moisture being near to the surface.

(A-2) Succulent shrub grassland sub-formation

This is the second sub-formation of the "transitional grassland", Fig (3.2). It occupies the relatively wetter parts of the lacustrine depressions which is a feature of this part of the study area. Structurally and floristically, this sub-formation is intermediate between the drier north and relatively the more luxuriant types of the south. As would be expected from the moisture conditions, this sub-formation supports a variety of woody species predominantly shrubs especially *Combretum aculeatum* and *Lannea humilis* with the latter sometimes locally dominant and forming dense thickets. In wetter areas, *Balanites aegyptiaca* and *Combretum hartmannianum* are more frequent. The tree-cover is generally open and to the north is particularly restricted to interdune hollows. *Aristida pallida* is the dominant grass species with *Sporobolus festivus* and *Cenchrus dilorius, Calotropis procera* and *Cenchrus biflorus* specially dominate cultivated land. In dune areas, the grasses show a catenary sequence with *Aristida pallida* dominating the crests and sides of the dunes. The change in the drainage at the bottom of slopes is marked by *Cenchrus biflorus* which is successively replaced by *Cenchrus dilorius.* The two associations which constitute this sub-formation are, "*Combretum-Lannea* association" and "*Guiera-Boscia* association".

Combretum-Lannea Association.

The area covered by this association was classified by Harrison and Jackson (1958) as "*Combretum cordofanum-Albizzia-Dalbergia* savanna woodland" and by HTS (1963) as "*Combretum cordofanum-Albizzia-Terminalia* savanna woodland". This association is characterized by a moderately open stand of predominantly deciduous, non-thorny trees and shrubs. The area, however, has been so much cultivated and grazed by domestic stock that much of the vegetation is now merely secondary regrowth. The main societies found within this association are described below.

Combretum hartmannianum-Acacia senegal

This society is found in the transverse dune systems to the north of El Qubba, occupying a transitional stage between shrub grassland and secondary shrubland. In the north, *Acacia senegal* is the dominant tree, *Combretum hartmannianum* gradually insinuates itself, first in the interdune hollows, and then imperceptibly creeps up the slope until it finally replaces the *Acacia senegal* which in turn is relegated to the hollows where it is being maintained through the cultivation cycle. In a similar manner, *Balanites aegyptiaca* and *Lannea humilis* gradually decrease but not entirely disappear. *Sylerocarya birrea, Albizzia amara* and *Terminalia brownii*, in that order, are slowly and gradually introduced into the vegetation. Village sites in this association are centred around clumps of *Balanites aegyptiaca* which away from immediate protection of village compounds are reduced to gnawed stumps. Further south, villages are clustered around clumps of *Acacia nilotica.* Neither sites are necessarily occurring in obvious depressions. *Balanites aegyptiaca* is highly valued for its fruits and therefore protected from felling. The eating of the fruits and the discarding of the seeds by the people in the vicinity of the villages encourages the local regeneration of the tree and the removal of all other species ensures its dominance. *Adansonia digitata* and *Acacia nubica* grow in low lying areas, *Lannea humilis, Combretum cordofanum* and *Dalbergia melanoxylon* are the shrubby constituents of dunes. *Aristida pallida* is the dominant grass of upper dunes, *Sporobolus festivus* occurs locally and dominates with *Cenchrus biflorus* on the lower slopes. *Cymbopogon giganteus* fringes dune hollows with *Schoenefeldia gracilis* in the wetter bottoms. *Eragrostis aspera* occurs late in the rainy season giving a false impression of dominating the whole area. *Andropogon gayanus* is occasionally present following cultivation and in disturbed areas such as along traffic roads. On steep sided dunes to the northeast of El Qubba *Cymbopogon giganteus* dominates the steeper south slopes and *Digitaria ciliaris* the less steep north slopes. *Calotropis procera* is not very frequent, its place in near exhausted arable lands being taken by *Guiera senegalensis.*

Acacia senegal-Acacia nubica

This is a similar society to the previous one found to the south of El Qubba but differs from that one by the noticeable abundance of *Acacia nubica* in the shallow dune hallows. The grasses are similar in both species and distribution. Late in the season *Schoenefeldia gracilis* occurs in dune hollows. Due to the lack of drinking water, this society is in places not grazed at all.

Acacia senegal-Combretum.hartmannianum-Acacia nubica

This society is particularly found on dune systems. Crests are either dominated by *Combretum hartmannianum* or with *Acacia senegal. Maeura crassifolia* and *Boscia senegalensis* are other associates. *Leptadenia pyrotechnica* is rather rare but generally to be found in the more exposed areas of the north of this association where the vegetation-cover is rather poor. The lower slopes which are cultivated include *Acacia senegal* as the dominant tree where it is maintained by the gum-cultivation cycle. It also dominates the shallow better drained troughs between dunes which are also cultivated. With increasing moisture, *Acacia nubica* dominates the troughs, sometimes *Lannea humilis* is locally dominant in close thickets. *Ziziphus-spina-christi* and *Adansonia digitata* are to be found in varying degrees of abundances. *Aristida pallida* dominates the crests while *Eragrostis aspera* dominates the drier cultivated troughs. *Schoenefeldia gracilis* and *Aristida adscensions* dominates the wetter depressions sometimes forming large areas of grassland devoid of any tree or shrub.

Guiera-Boscia Association.

This is the most widespread association in the study area. It is classified by Harrison & Jackson(1958) as "*Combretum cordofanum-Dalbergia-Albizzia*" and mapped by HTS(1963) as "*Albizzia amara-Dalbergia*". This association occupies the old land surface of the sandy pediplain where the sand overburden is relatively thin. It is relatively wetter than the preceding association as evidenced by the appearance of some few broad-leaved trees such as *Terminalia brownii, Sylerocarya birrea* and *Terminalia laxiflora* which are characteristic species of the more wet southern parts, but still the dominant woody species are shrubs and shrub-like trees. Societies found within this association are described below.

Acacia senegal-C.hartmannianum-Guiera senegalensis

This society occurs on the low dune complex to the north and west of Gamaa. This area seems to have been heavily cultivated in the past. The woody vegetation consists of dense, scrubby coppice regrowth of *Combretum hartmannianum*, thickets of *Lannea humilis* and *Guiera senegalensis* all of which increase following cultivation. *Dalbergia melanoxylon* is occasionally found. *Acacia senegal* borders the broad, shallow drainage depressions which are dominated by *Acacia nubica* and *Adansonia digitata* with the latter preferring the shallow depression and the former the slightly heavier soils.

Albizzia amara-Boscia senegalensis

This society occupies the area south of Dodia and southeast of Nasharbu. *Albizzia amara* is the dominant tree with *Boscia senegalensis* and *Guiera senegalensis.* *Combretum hartmannianum* and *Lannea humilis* occur in varying degrees of abundance. All these species often occur following cultivation which is heavily practiced in these parts of the study area. *Acacia senegal* occurs locally and basically is maintained through the cultivation-cycle. *Terminalia brownii* is found either singly or in clumps especially where moisture collects. Under cultivation, apart from coppice regrowth of the major species, *Calotropis procera* frquently occurs. *Aristida palliad* and *Digitaria ciliaris* are the dominant grasses with *Andropogn gayanus* as less frequent.

Guiera senegalensis-Acacia senegal

This society is found to the northeast of Markib dominated by *Guiera senegalensis* with *Acacia senegal* as being maintained through cultivation-cycle. The most extensively occurring grass species are mostly annuals notably *Cenchrus biflorus, Schoenefeldia gracilis* and *Aristida adscensionis.* Intensive cultivation and heavy grazing have, apparently stripped this area of most of its original vegetation.

Guiera senegalensis

This society is found to the south of Markib and to certain degree resembles the one described above. It represents the most extremely degraded vegetation to be found in the study area. Continuous cultivation, overgrazing and the recent widespread sheet erosion have stripped this area of vegetation. A few straggly *Guiera senegalensis* and *Boscia senegalensis* and a sparse cover of *Eragrostis aspera* and *Cassia italica* are all what is now left to be described.

(B) Secondary shrubland and grassland formation

This is the second formation recognized as belonging to the "Wooded Grassland Formation-Type". Due to the availability of drinking water in these parts of the study area, the vegetation has, more or less, been greatly modified by man and particularly his domestic animals. Comparison of sparsely populated parts of this formation with other areas of similar environmental conditions had confirmed these observations, more details on this subject will be made in chapter six. Thus the term *secondary* is here used as a dynamical phase in a degradation series where one type of vegetation replaces another or to refer to successional changes leading to the establishment of a particular vegetation type.

Vegetation here varies greatly in the case with which the constituent species can be replaced by secondary grassland or shrubland following human interference. In the wetter parts, the regeneration of trees after cultivation is so rapid that grasses have difficulty in becoming re-established. By contrast, the drier peripheral parts are much more vulnerable and can easily be replaced by secondary grassland over extensive areas. Even more vulnerable has been the vegetation lying in the transition zone to the north and the south.

Nearly everywhere in this formation, the original vegetation that was earlier described by many workers is believed to have gone and the landscape is but dominated by secondary grasses and/or shrubs. The grass and herbal cover is sparse as would be expected in such a heavily cultivated and grazed areas with a woody cover predominated by shrubs following the destruction of a rich tree-cover which previously may have existed. Two sub-formations were identified here, these are (1) Shrubland and secondary grassland (2) Scrub woodland and secondary grassland.

(B-1) Shrubland and secondary grassland sub-formation

Shrubland is here meant to signify land dominated by shrubs which vary in height from just 50cm. to 2 metres or even more. This sub-formation occurs where taller woody plans have been excluded by man. It constitutes part of the transition to the moister conditions of the south but mainly confined to the sandy pediplain where the sand cover is thin or relatively absent. Where the sand is restricted, the most characteristic species on sandy soils are *Boscia senegalensis* and *Guiera senegalensis* with *Lannea humilis* often occurring in almost pure stands. *Acacia senegal* is occasionally found and frequently follows cultivation which suggests its secondary nature. The grass-cover is fairly poor as a result of heavy grazing and around areas like Umm Hashim and west of Nasharbu, which are heavily grazed round-the-year, the grass-cover is extremely degraded and annual weeds like *Tribulus terrestris* and *Cassia italica* only grow. The two associations recognized within this sub-formation are *Boscia-Lannea* association and *Acacia senegal-Boscia* association.

Boscia-Lannea Association.

This association occupies the area to the north and northwest of Nasharbu. This area was mapped by Harrison & Jackson (1958) as "*Combretum cordofanum-Dalbergia-Albizzia* Savanna Woodland" and by HTS (1963) as "*Albizzia Dalbergia* Association". The secondary dominance of *Acacia senegal* has emerged since this area has been heavily cultivated in the past and its partial abandonment had ensured the secondary dominance of shrubs like *Boscia senegalensis, Lannea humilis* and *Guiera senegalensis.* Due to the availability of drinking water, this area is being heavily grazed, a fact which resulted in a rather poor and degraded grass-cover which is mainly dominated by xerophilous species like *Cassia italica, Aristida pallida* and *Eragrostis aspera.* The societies found within this association are listed below.

Boscia senegalensis-Maeura crassifolia

This society is found in the very open flat land to the west of Nasharbu. This area appears to have been heavily cultivated and now is partially abandoned. The development of this society is possibly related to a degre of soil exhaustion. *Maeura crassifolia* is the dominant shrub with *Boscia senegalensis* and a few occurrences of *Acacia senegal*

Boscia-Dalbergia

This is a very similar to the above with appreciable increase in *Dalbergia melanoxylon*, a small tree which is found in this society to increase considerably following cultivation.

Guiera-Dalbergia

This society is found on abandoned fallow lands. *Dalbergia melanoxylon* is dominant often forming fairly close thickets or patches of scrub alternating with *Guiera senegalensis* and *Lannea humilis. Sylerocarya birrea* occurs in the more open areas forming a well grown woody cover giving a startling contrast to the otherwise surrounding shrubby vegetation. *Terminalia brownii* and *Albizzia amara* are to be found around water retaining sites and the impression obtained from this observation is that *Terminalia brownii* and *Albizzia amara* were once more widespread than they are at present having been destroyed during cultivation or cut for their timber qualities. *Aristida, Digitaria ciliaris, Cenchrus biflorus* and *Eragrostis aspera* are the chief grasses.

Acacia senegal-Boscia Association.

This association occurs over quite a considerable area to the west and south of Markib, round Khuwei and the area to the east and northeast of Arak. These areas were classified and mapped by Harrison & Jackson (1958) and by HTS (1963) as the previous association. The interpretation of aerial photographs suggested that a far larger area seems to have been under cultivation here several decades ago than there at present. Near Khuwei, trees are relatively bigger indicating that the area was abandoned even earlier. The evidence so far suggests that the original vegetation and that described by Harrison & Jackson (1958) and by HTS (1963) was destroyed in parts or as a whole and the area was cultivated to exhaustion. Only *Albizzia amara* has survived in this association, and the present essentially secondary shrubby cover has developed under conditions of low fertility and probably less available soil moisture due to increased run-off from denuded surface. The abundance and possibly even the presence of *Acacia senegal* appears to be associated with cultivation as it has not been mentioned Harrison & Jackson (1958) and only as a minor constituent by HTS (1963). The following societies have been recognized within this association.

Albizzia-Acacia senegal

This society is found to the west of Markib. The soil of this area has deeper sandy horizons and is, therefore, at present more heavily cultivated than the surroundings. *Acacia senegal* is dominant and is maintained under cultivation as gum-gardens. *Albizzia amara* dominates abandoned lands with *Dalbergia melanoxylon* occurring where the sand cover is thinner and near drainage lines. The deeper sand favours *Eragrostis aspera* and *Cassia italica* especially on the shallow lands.

Acacia senegal

This society is found in the area east of Arak. Field observation suggested that the vegetation of this society gradually becomes sparser northwards and eventually grades into semi-desert grassland. *Guiera senegalensis* is generally scattered over the area along with *Boscia senegalensis.* Shrubs and other woody species tend to shelter in the wetter parts and increase in doing so towards the north. *Acacia senegal* is the dominant tree, widely spaced and unevenly aged. This area is interesting because of the natural regeneration of this species from seeds instead of vegetative regrowth, which is an unusual occurrence in the other parts of the study area. *Balanites aegyptiaca* is a frequent tree with occasional *Sylerocarya birrea. Blepharis linariifolia* is the dominant grass in the drier parts and co-dominant with *Aristida adscensionis* and *Eragrostis aspera* on the relatively wetter ones. This area is being heavily cultivated but less affected by grazing animals, although some nomadic

Kababish occasionally visit the area especially during drier seasons.

(B-2) Scrub woodland and secondary grassland sub-formation

The term scrub woodland is here used to indicate the relative abundance of taller woody plants, 4-6 metres tall, the density of which is largely determined by local soil conditions and the degree of human interference. Evidence suggests that these woody plants were probably more extensive in the past but only tiny remnants seem to have survived either through being sufficiently distant from the depredation of man or through being protected for their value as are *Balanites aegyptiaca* and *Acacia albida*. The grass-cover is invariably poor. The two associations recognized within this sub-formation are (1) *Acacia senegal-Acacia nubica* (2) *Boscia-Acacia senegal*

Acacia senegal-Acacia nubica Association.

This association is confined to the area lying between Markib and Umm Hashim. This area was mapped by Harrison & Jackson (1958) as "*C.cordofanum Dalbergia Albizzia* Savanna Woodland" and by HTS (1963) as "*Albizzia amara-Dalbergia* Association". This association represents an extremely degraded vegetation which resulted from the intensive cultivation and grazing practiced in the area. Isolated stands of *Combretum cordofanum* and *Dalbegia melanoxylon* and the absence of any signs of younger age classes suggests their former wide occurrences. Few stumped *Guiera senegalensis* and *Boscia senegalensis* mixed with a sparse cover of *Cassia italica* and *Eragrostis aspera* are the most common species found. Only *Acacia senegal* seems to have survived by being maintained through cultivation, though in places it has been succeeded by *Acacia nubica*. The following societies were recognized within this association.

Acacia senegal-Combretum hartmannianum

This society occupies the northern parts of this association. *Combretum hartmannianum* is the dominant tree or coppice regrowth, generally rather thinly scattered but forming denser patches in the vicinity of villages and sites of former cultivation. *Guiera senegalensis* becomes dominant on sites of former cultivaton. *Acacia nubica* dominates the wetter parts with a few occurrences of *Dalbergia melanoxylon, Albizzia amara*, and *Sylecaroya birrea* as other occasional trees. *Acacia senegal* is frequent as gum-gardens through which it is being maintained. *Cassia italica* is the dominant grass with *Eragrostis aspera* locally abundant towards the end of the rainy season. *Cenchrus biflorus* sometimes dominates fallow lands.

Acacia senegal-Acacia nubica

This society lies to the south of the previous one and occurs under similar conditions with similar constituents. The noticeable difference is the increase in *Acacia nubica.* This species is either much more extensive in its natural habitat on depression margins as described for the above society, or as a secondary species following the cultivation of areas formerly dominated by *Acacia senegal.* Abandoned cultivation in depressions were observed either to remain open or fairly rapidly becoming dominated by *Acacia nubica.* It is not grazing pressure which determine the presence or absence of *Acacia nubica* since due to its strong unattractive smell, it is distasteful to stock. Further colonization by other plants was observed to be very low. It is possible that the roots of *Acacia nubica* produce a substance which inhibits the germination of other species.

Boscia-Acacia senegal Association.

This association occupies the dune complexes around Umm Bum. This area has been mapped by both Harrison & Jackson (1958) and HTS (1963) as "*Acacia senegal* savanna". Although *Acacia senegal* has been taken as the typical tree for this association, it should be regarded as a secondary species associated with the system of agriculture for quite a large portion of this area. This association imperceptibly grades into "semi-desert grassland" from the north and into "succulent shrub grassland" from the south. Consequently, in the south trees and shrubs are fairly distributed over the landscape, whereas northwards it tends to become increasingly sheltered in the wetter parts of the dune hollows. The following societies are recognized within this association.

Boscia-Acacia senegal

This society is found to the northeast of Humier Jabir and apparently represents a secondary vegetation following cultivation. In this society there is a noticeable tendency for *Balanites aegyptiaca* and *Boscia senegalensis* to increase under cultivation. *Acacia senegal* is being maintained through the cultivation-cycle and tend to increase in abundance northwards. The grasses are thin and patchy, generally confined to the patches of thin wind-blown sand, whereas elswhere, the sheet eroded surface is a poor medium for seed germination. The most abundant grasses are *Schoenefeldia gracilis, Eragrostis aspera* and *Sporobolus festivus. Cenchrus biflorus* occurs but is rather rare away from cultivation sites.

Acacia nubica-Boscia senegalensis

This society resembles the one mentioned above with *Acacia nubica* occuring as a co-dominant with *Boscia senegalensis.* Due to intensive cultivation in this area, *Acacia senegal* has partially been excluded and succeeded in the wetter parts by *Acacia nubica* and *Boscia senegalensis* in the drier ones.

Acacia senegal-Balanites aegyptiaca

This is a very open society found in the sand sheets around Umm Bum. This area is waterless and therefore is not grazed and only slightly cultivated. Occasionally the nomadic tribes of the north graze their animals in this area during the rains. *Acacia senegal* is the dominant tree with *Balanites aegyptiaca* either locally dominant or abundant. *Acacia nubica, Acacia albida* and *Syleracoraya birrea* are occasional scattered constituents with *Boscia senegalensis* dominating abandoned fields. *Aristida pallida* is the dominant grass. *Schoenefeldia gracilis* and *Aristida adscensionis* occur in few sites together with *Cyprus Obtusiflora.*

Boscia-Balanites aegyptiaca

This society occupies the low dune complex area to the north and west of Umm Bum. *Balanites aegyptiaca* is mainly concentrated within the hollows with *Boscia senegalensis* indifferently spreading over the entire area. *Acacia senegal, Maeura crassifolia* and *Leptadenia pyrotechnica* are other minor constituents of this society. Although a rather long list of tree species has been supplied here, it must be emphasized that these species are very thinly scattered over the ground. *Aristida pallida* is the dominant grass species with *Cassia italica* occasionally present.

3.3.2 Shrub and Acacia-wooded bushland formation-type

This is the second formation-type identified in the study area in which, bushes and shrub-like trees constitute more than 40% of the vegetative-cover. In this work, a bush is defined as a woody plant intermediate in habitat between a shrub and a tree and usually 3-5 metres tall. They are usually multiple stemmed and the main axes are frequently 10cm. or more in diameter at the base. Taller trees somtimes occur in this formation-type as emergents and they are either localized in groups or widely scattered. Grasses are poorly developed and usually perennials, but annuals are predominant in the drier parts especially under the influence of heavy grazing and fire and consequently are physiognomically subordinates.

In fact this formation-type is found in places which are reasonably unfavourable for the growth of taller plants, but the removal or destruction of grasses over larger parts of this area by grazing and/or by fire, has given a false physiognomic dominance of woody vegetation. The two formations recognized here are (1) Secondary-Acacia wooded shrubland, and (2) Open bushland.

(A) Secondary Acacia-wooded shrubland formation

In this formation, cultivation has been carried out over centuries in, more or less, reasonable cycle of gum and cultivation through which *Acacia senegal* has been permitted to remain and regenerate. Scattered individuals of *Syleracoya birrea, Balanites aegyptiaca* and *Albizzia amara* have better survived the effect of felling either through being protected for their value, through their capabilities to coppice after felling or lopping of their branches, or more often by sufficiently being distant from the depredation of man. The presence of such species had made this formation, unlike the surounding, to have a park-like appearance. The grass-cover is fairly dense as the lack of drinking water had reduced the number of grazing animals in some parts of this area. The sub-formation identified within this formation are (1) Secondary Acacia shrubland, and (2) Dwarf shrubland.

(A-1) Secondary Acacia shrubland sub-formation

This sub-formation occupies the flatter of the sandy pediplain extending between Kol Yousif in the east to J. Zuleita in the west. This part of the study area has been moderately cultivated a fact which accounted for the secondary dominance of *Acacia senegal.* Based on the floristic characteristic of this sub-formation the following association were recognized.

Acacia senegal-Boscia senegalensis Association.

This association is confined to the immediate surrounding of Kol Yousif. Harrison & Jackson (1958) and HTS (1963) had mapped this area as "*Acacia senegal* woodland" and as "*Albizzia amara-Dalbergia* association" respectively. In these parts of the study area there is an ever increasing demand for cultivable land and so the partly recovered land is brought back into cultivation again before tree growth has a chance to become re-established which eventually leads to a secondary bushland conditions. *Acacia senegal* is becoming increasingly squeezed out as not enough time is being allowed for its full regeneration, but still it is the most conspicuous woody species to be recognized. The lack of drinking water has reduced grazing pressure and in turn resulted in a noticeable richer cover of grasses. Within this association the following two societies were recognized.

Acacia nubica-Boscia senegalensis

This society is found in the area south of Kol Yousif in which *Acacia nubica* is the dominant tree with *Boscia senegalensis, Guiera senegalensis* and *Lannea humilis* occurring locally dominant or abundant. *Acacia senegal* occasionally found on old fallow lands with *Syleracoraya birrea, Dichrostachys glomerata* and *Balanites aegyptiaca* as other minor associates. *Aristida pallida* and *Digitaria ciliaris* are the dominant grasses, *Certalotheca sesamoioes* and *Blepharis linariifolia* are other less common grasses.

Albizzia amara-Acacia senegal

This society occupies the area south of the previous one. The soils here have deeper sandy horizons and are, therefore, heavily cultivated than the area just described above. The vegetation is very similar, but with marked increase in *Acacia senegal* which increase under cultivation cycle. *Albizzia amara* dominates the wetter parts and lands previously were under cultivation and at present mainly bush fallow. Elsewhere, *Boscia senegalensis* and *Calotropis procera* are frequently found. *Cenchrus biflorus* and *eragrostis aspera* are the dominant grass species.

Acacia senegal-Albizzia Association.

This association is found under similar conditions to the previous one but with a noticeable increase in the abundance of *Acacia senegal.* Evidence indicates that cultivation in these parts has not yet reached a stage to affect this species and, accordingly, it is still being fairly maintained and preserved as part of the cultivation-cycle. Societies found within this association are described below.

Acacia senegal-Acacia nubica

This society is found in the area around Miqeism and it represents a stage in the intensity of cultivation pattern. In the immediate vicinity of this village, *Acacia senegal* has partially been affected and increasingly being succeeded by *Acacia nubica.* Northwards, cultivation intensity is slightly lower and, thereby, *Acacia senegal* is maintained as part of the cultivation cycle. Away from cultivation, *Albizzia amara* and *Balanites aegyptiaca* are the dominant species found. Due to the relatively light grazing in this area, the grass-cover is fairly rich with *Blepharis linariifolia, Aristida pallida* and *Digitaria ciliaris* as the most commonly found species.

Acacia senegal-Albizzia amara

This society occurs on the area to the south of Umm Bum. This area is either cultivated in patches leaving thickets of *Acacia senegal* or sufficient time has elapsed for *Acacia senegal* to start colonizing the area again. Otherwise, the vegetation of this society is similar to the previous one with occasional *Balanites aegyptiaca, Albizzia amara* and *Boscia senegalensis.*

(A-2) Dwarf shrubland sub-formation

This sub-formation occupies the sand sheets and low dune complexes of the northwestern corner of the study area. This area was shown by Harrison & Jackson (1958) and by HTS (1963) as "*Acacia senegal* woodland" and as "*Acacia senegal* association" respectively. Cultivation in this part of the area has not yet thrown *Acacia senegal* out of the cycle as it is the case throughout this zone of the study area. Some evidence suggests that pressure on arable land has recently increased which may in time lead to the dropping of *Acacia senegal* as happened in the neighbouring areas. On the other hand, the long fallow periods under *Acacia* bushes had resulted in more pressure on other minor constituents which either survived in dune hollows or through their capabilities to regenerate after having been cut down as *Balanites aegyptiaca* and *Syleracorya birrea.* Again the lack of drinking water in these parts has resulted in minor grazing and in turn in a richer grass-cover which is dominated by the annuals *Aristida pallida* and *Cassia italica.* The following association is the only one which was recognized within this sub-formation.

Acacia senegal-Balanites aegyptiaca Association.

The following three societies were found within this association.

Acacia senegal-Balanites aegyptiaca

This society found on the dune complexes to the south of Iyal Bakheit. Here *Acacia senegal* is the dominant tree although rather thinnly scattered. *Balanites aegyptiaca* dominates shallow dune hollows where it is protected. The grass-cover is rather poor with plenty of bare grounds. *Aristida pallida* is the dominant grass with occasional *Aristida adscensionis* and *Cymbopogon nervatus* dominating the less well drained hollows.

Acacia senegal

Due to the lack of drinking water in Iyal Bakheit area where this society is found, grazing is lighter but cultivation is heavily practised which suggests that this society is essentialy a patchwork of the gum-gardens and represents stages of gum-cultivation cycles through which stands of *Acacia senegal* are maintained. This species is the most dominant one often forming open stands with *Balanites aegyptiaca* and *Sylerocarya birrea* as frequent associates. *Boscia senegalensis* increases greatly around cultivated areas. *Aristida pallida* is the dominant grass away from cultivation, while *Cenchrus biflorus* and *Eragrostis aspera* increase under cultivation with the latter giving the area a late dominance aspect.

Balanites aegyptiaca-Sylerocarya birrea

This society occupies the area to the east of Iyal Bakheit and is found under similar conditions to the previous one with similar constituents. The noticeable difference is the increase in *Sylerocarya birrea* and *Boscia senegalensis* with the latter following the partial elimination of *Acacia senegal* which is attributed to the intensive cultivation in the vicinity of Iyal Bakheit where in many places has been forced out.

(B) Open bushland formation

In most parts of this formation, vegetation has, more or less, been greatly altered by human activities and thus few natural stands remain. In places where the natural vegetation has been totally eliminated, as the immediate surroundings of Khuwei, cultivation and grazing have been continuous for quite a long time. In other places where man's interference is less, sufficient relics remain to permit plausible reconstruction of the original vegetation. Evidence obtained indicated that various types of woodland were formerly more extensive and that they have almost been replaced by secondary bushland following cultivation and the uncontrolled felling of trees. Meanwhile, grazing had removed much of the grasses a situation which favoured the competitive vigour of the secondary bushland. Based on the physiognomic characteristics of this formation, the following two sub-formations were recognized, these were namely (1) Bushy shrubland and (2) Stunted bushland.

(B-1) Bushy shrubland sub-formation

This sub-formation is characterized by the abundance of various types of shrubs and bushes which vary in height from 2-4 metres. Apparently, taller woody species have, to varying degrees, been excluded through continuous cultivation and are only manifested in occasional mature stands found either singly or in typical clumps away from the reach of man with no signs of younger age classes. The following two association were recognized within this sub-formation.

Guiera-Boscia senegalensis Assocaition.

This association occupies the area bounded by Zuleita to the south, Markib to the northwest, Ankosh to the north, and Lubana to the west. It comprises the "*Combretum cordofanum-Dalbergia-Albizzia* woodland" of Harrison & Jackson(1958) and the "*Combretum cordofanum-Guiera* association" of HTS (1963). Due to the lack of drinking water in most parts of this association, the area is relatively relieved from the impact of heavy grazing, but cultivation has its obvious impression as evidenced by the abundance of *Acacia senegal* which, throughout this association, is being maintained in gum gardens. Societies identified within this association are described below.

Boscia-Acacia senegal

This society is found in the area to the north of Zuleita. *Acacia senegal* is here found restricted to the hollows. *Boscia senegalensis* is found scattered rather thinly throughout the area with fewer occurrences of *Guiera senegalensis. Albizzia amara* and *Sylerocarya birrea* increase away from sites of human habitation and, more or less, are confined to sheltered dune hollows.

Guiera-Acacia senegal

This society occupies the area between Markib and Ankosh which is dominated by *Guiera senegalensis* with *Acacia senegal* locally dominant. *Combertum hartmannianum, Dalbergia melanoxylon* and *Syleracoraya birrea* are other occasional constituents. *Aristida pallida* is the dominant grass with occasional *Cenchrus biflorus* and *Certatotheca sesamoioes.*

Boscia-Guiera senegalensis Association.

This association occupies the area north of Bani Badr and east of Lubana. It is found in a similar conditions to the previous one with similar constituent species but with a conspicuous decrease in the abundance of *Acacia senegal* which could be related to an increasing degree of overcultivation. The following two societies are recognized here.

Acacia nubica

This society occurs in the wider shallow valleys southeast of Bani Badr with a type of vegetation indicating a better soil moisture conditions. These depressions are often intensively cultivated. *Acacia nubica* is abundant throughout the area with *Adansonia digitata* being locally abundant especially in intensively cultivated areas. *Acacia senegal, Albizzia amara* and *Boscia senegalensis* are other frequent associates. *Schoenefeldia gracilis* is the dominant grass over moister soils with *Aristida pallida* and *Eragrostis aspera* occuring on the drier soils.

Boscia senegalensis

This represents a near final stage in the degeneration of taller trees. *Boscia senegalensis* and *Guiera senegalensis* are the dominant shrubs with a few scattered *Acacia nubica* indicating the derivation of the present vegetation. The grass-cover is poor with *Eragrostis aspera* as the dominant grass late in the rainy season.

(B-2) Stunted bushland sub-formation

This sub-formation comprises the outskirt of Khuwei where population pressure on arable land had excluded *Acacia senegal* from the gum-cultivation cycle in the past and the continuous cultivation which had been practiced ever since had left but bare ground devoid of any type of vegetation that could be described except of stunted specimens of *Boscia senegalensis* and *Calotropis procera* which are often mentioned as transient components of cultivation regrowth and excessive soil exhaustion trends (Ramsay 1958). Besides, the dominance of these species is maintained further by the fact that both species are inedible and unusable which in turn has enhanced their establishment spread over this degraded area. One association is recognized here and is described below.

Boscia-Calotropis Association.

The following two societies are identified within this association:

Boscia-Calotropis procera

This society is found at the eastern outskirt of Khuwei. A few occurrences of *Boscia senegalensis* mixed with *Calotropis procera* is all that could be said about the woody cover of this area. The grass-cover is, likewise, very poor as to be expected in such a heavily grazed area. *Tribulus terrestris* and *Cassia italica* are just to be mentioned.

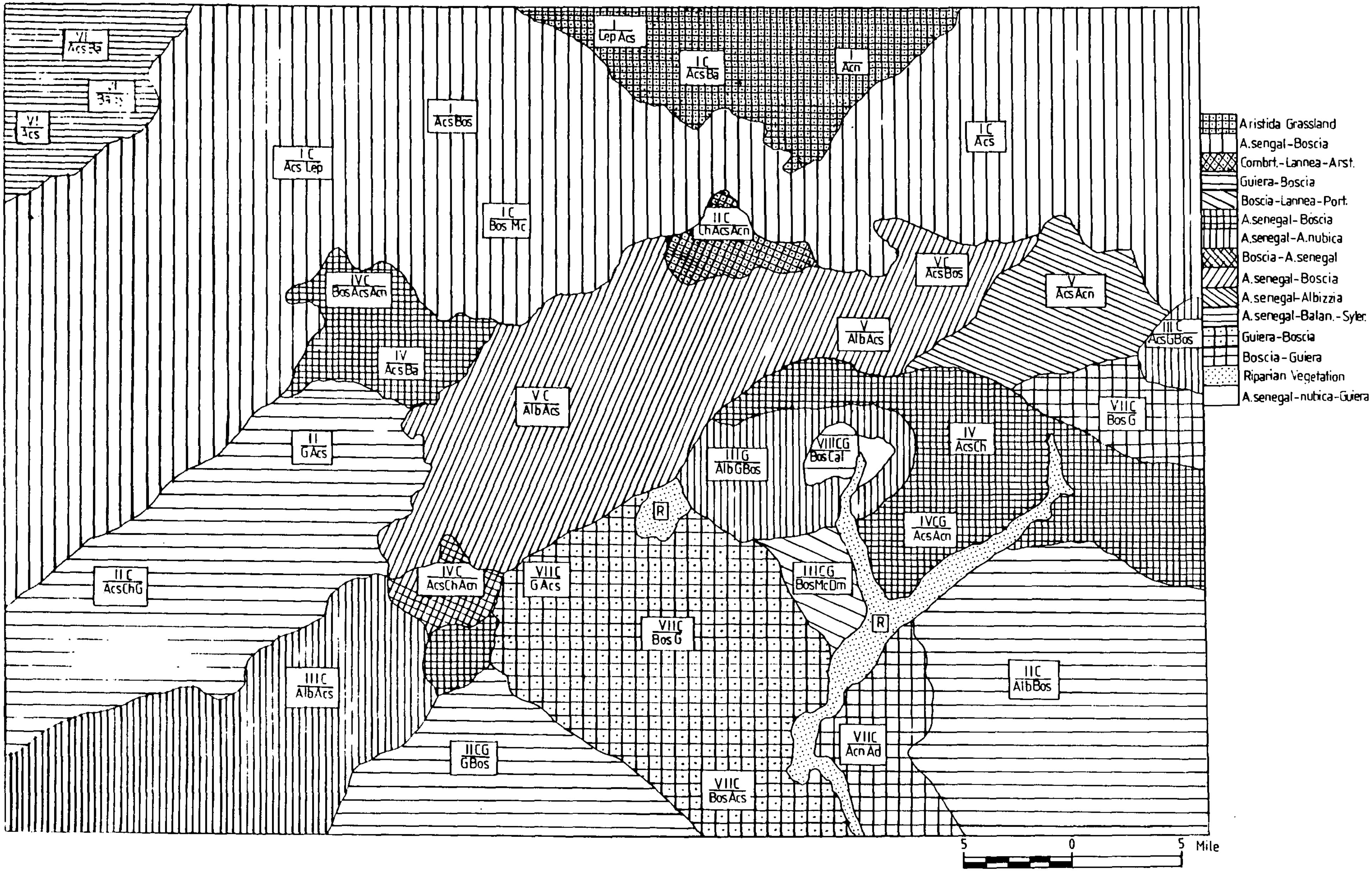
Boscia senegalensis

This society occupies an area to the west of the town, and it is found under similar conditions to the previous one but with a slightly denser stands of *Boscia senegalensis* and singly isolated stands of *Maeura crassifolia, Dichrostachys glomerata* and *Albizzia amara* which suggests their former wider occurrences. Occasional stands of *Acacia senegal* are found and it is likely that this species had once been a part of the cultivation cycle through which it was maintained. Again the grass-cover is very poor and similar in its constituents to the previous one.

3.3.3 Riparian vegetation

This formation-type has not been produced by TWINSPAN, but it was thought necessary to be added at this level of the classification as it represents a unique type

Figure(3.3) Vegetation Map of the Study Area



of vegetation growth not found in any of the above formation-types. As the name indicates, this type of vegetation mainly occupies areas where water accumulates.

Although there are no perennial watercoures in the study area, Wadi El Ghalla, which drains the whole of Kordofan region during the rainy season, has its northern reaches penetrating through the southern part of the study area. This system, beside a confined low lying area to the southwest of Ankosh, collects and retains water for a period of 3-4 months during and after the rainy season, a condition which has given way for the development of richer flora. This feature is of great interest as it could be taken as an evidence of the type of vegetation that possibly had a wider distribution and now only is confined to the shelter of these moister sites where is protected. These areas are characterized by a denser grass-cover which may reach 1.5 metres high, and by even a more dense woody cover consisting of *Acacia nilotica, Acacia nubica, Terminalia brownii, Combretum hartmannianum, Adansonia digitata, Albizzia amara, Guiera senegalensis, Balanites aegyptiaca* and *Tamarindus indica.*

3.4 Concluding Remarks

As the identification and description of such various types of vegetation in the study area is not an end in itself, in the next chapters, these results on community types will be correlated with other types of data collected as environmental and historical. Therefore findings here will, hopefully, make it possible to investigate in more details, the structure and maintenance of these communities, how they are spatially organized and, accordingly, the pattern, or more usually the several patterns, created along different environmental gradients like soils, topography and similar habitat factors. Comparisons, whenever necessary, will be made between different communities and between species occurrences in these communities in order to study the interactions among different species on the one hand and between species and external environment on the other. This is likely to add another dimension and allow us to be in a better position to make scientifically base judgements.

Chapter IV

The Spatial Distributional Patterns of vegetation and its Causal Factors

4.1 Introduction

In this chapter, it is intended to present data on the spatial arrangements of species in the different stands of vegetation mentioned in the previous chapter as well as those concerning individual species within these stands. This would eventually pave the way for determining the extent to which regional and local factors have produced any detectable pattern in the abundance and distribution of individual species together with that in the structure of different communities.

Gleason (1920), Greig-Smith (1957,1983), and Kershaw (1957, 1959, 1973) demonstrated that, individual plant species as well as plant communities exhibit certain degrees of spatial pattern, i.e. a departure from random distribution, and they showed that many environmental and biotic processes determine the nature and scale of that pattern. Differences in type and amount of vegetation associated with soil differences, climate and other environmental factors have long been studied in Sudan by authors like Colvin (1939), Morrison *et al* (1948), Andrews (1948), Smith (1949), McCall (1950), Harrison (1953), Eyre *et al* (1953), Kassas (1956), Harrison & Jackson (1958) Worral (1960) and HTS (1963). Most of these contributions were basically large-scale studies and largely based on qualitative arguments with the result that the conclusions drawn are often mere generalizations.

However, the emphasis here shall be, through the application of certain theories on pattern, to quantitatively examine the patterns spatially exhibited by vegetation at the very small-scale level of the study area. This shall cover the distributional pattern in communities as a whole beside particular patterns of species in the several communities as a contribution to the understanding of the interaction between plants and their environment. Patterns revealed will be compared with surface properties and eventually to be used to indicate their causal agents with the prospect of elucidating the relationship between vegetation performance and the factors that control it.

4.2 Methods of Analysis of Pattern

The purpose of analysis here is to present the fieldwork data, obtained on species abundance recorded in quadrats and transects, in a way which is suggestive of their underlying structure. With most species we shall be dealing not merely with their presence or absence in different sites, but also with their behaviour and performance. This, more or less, is likely to reveal some of the responses of vegetation to changes in environmental factors.

Among the numerous tests available on the assessment of vegetational patterns, two methods have been selected here according to their relative merits and applicabilty. These are namely, detecting pattern exhibited by the negative and positive association between species, and pattern exhibited by the non-randomness in species distribution.

4.2.1 Pattern exhibited by negative and positive associations

Basically, this method consists of sorting out species in associations (negative and positive) by calculating the correlation coefficient between different pairs of species. This technique, as demonstrated by Kershaw (1973), provides one of the most appropariate measures that explain vegetation pattern through the degree of association between species in different communities. In doing so, a matrix of species associations for each community was produced, Table (4.1). The results obtained from these matrices will be used to examine the detailed relationships that exist between different species as a key to revealing the patterns and scales of spatial arrangement in the study area's vegetation. The argument here is that, the presence of such associations between species, whether positive or negative, in itself reflects a pattern, or more usually, different scales of pattern in each community.

Table 4.1: Correlation Coefficient between Selected Species in *Acacia senegal-Guiera senegalensis* Community

Species	*A.senegal*	*G.senegal.*	*B.aegypt.*	*S.birrea*	*T.brownii*	*Z.christi*
A.senegal						
G.senegal.	-0.31					
B.aegypt.	0.24	0.31				
S.birrea	0.47	0.52	-0.21			
T.brownii	0.18	0.12	0.11	0.38		
Z.christi	-0.22	0.34	0.06	-0.24	-0.42	
A.amara	-0.61	0.34	-o.32	0.27	0.13	-0.23

Source: Fieldwork data 1987

This method will not only be used to display interactions between different species, but also to indicate the inter-relationships that exist between vegetation on the one hand and the surrounding environment on the other. To achieve that, a second set of a series of matrices that comprises the underlying most significant environmental variables (soil, drainage, slope, impact of man ...etc) was produced for each community. Through the use of simple correlation analysis between these variables and species abundance, possible causes of the spatial arrangements of these species could be suggested.

4.2.2 Pattern exhibited by the non-randomness in vegetation

Blackman (1942), Whitford (1949), Greig-Smith (1957, 1983) and Kershaw (1957, 1960, 1963) have shown that plant species are rarely randomly distributed over any area. This fact, as demonstrated by Greig-Smith (1957), reflects the non-random pattern in the distribution of the factors which have greater control on the performance or survival of plants. The ecological significance of this departure from randomness lies in the indication it provides on the particular factors that control the distribution of individual species and eventually the type of spatial pattern that is consequently created. At the level of this study, there are wide range tests and measures of departure from randomness expectation, and according to their relative values the following two tests have been applied here.

X^2-Test of Goodness of Fit: According to Greig-Smith (1957) and Kershaw (1973), this method was first coined by Svedberg (1922), and as they added, has since become one of the standard techniques used to detect non-randomness in vegetation distribution. Principally, this method consists of relating the observed number of individuals in a sampled plot to the expected number of individuals in that plot derived from the Poisson Series,

$$e^{-m}, me^{-m}, \frac{m^2}{2}!e^{-m}, \frac{m^3}{3}!e^{-m}, \frac{m^4}{4}!e^{-m}, \ldots$$

Where m is the mean density of individuals. Successive figures of the series give the probability of samples containing 0,1,2,3,4.. individuals and thus the expected number of samples falling into each of these classes would be calculated. A X^2 (chi) significance test will then be used to compare the terms of the Poisson Series with the observed data, (Greig-Smith 1957, Appendix B, Table 3). The goodness of fit is calculated as the sum of the differences between the observed and the expected values squared and divided by the expected frequency. The results will indicate the degree of fitness of the observed data with the expected series and, therefore, whether the population sampled is above or below the random expectation. Higher values will indicate that the individuals are clumped together while lower values would mean they are scattered evenly on the sampled area or community. Greig-Smith (1957) referred to the former as *contagious* and the latter as *regular*. Contagion, therefore, characterizes large number of both empty samples and those containing a large number of individuals, whereas regular means that the majority of samples contain intermediate number of individuals.

Abundance:Frequency Ratio: This method was suggested by Whitford (1949) and is based on the ratio of abundance to frequency as a measure of contagion. Abundance is related to density and frequency for:

$$Abundance(A) = \frac{Total\ number\ of\ individuals}{Number\ of\ occupied\ quadrats}$$

$$Density(D) = \frac{Total\ Number\ of\ individuals}{Total\ number\ of\ quadrats}$$

$$Frequency(F) = \frac{Number\ of\ occupied\ quadrats}{Total\ number\ of\ quadrats} \times 100$$

that is

$$A \times F = 100D$$

So

$$Abundance : Frequency\ ratio = \frac{100}{F^2}$$

The idea of the test is that, contagious distribution give a value greater and regular distribution a value less than the random expectation, (Greig-Smith 1957, Appendix B, Table 6).

This method has already its critics as the ratio has no fixed expectation for a random distribution which severely limits its utility. Therefore, this method will not be used here as an absolute measure of contagiousness, but rather to provide an index that would help comparing regularities and contagiousness of species in different communities which eventually would indicate the relationship between the degree of distribution exhibited and the underlying causal factors of that pattern, Table (4.2).

As the use of these two tests of departure from randomness is not an end in itself, but rather for achieving an understanding of the causal mechanism behind such a pattern, its spatial extent would only be appreciated by determining over what area the non-randomness occurs. This knowledge will eventually facilitate the task of finding the causal factors, i.e. when the detected non-randomness operates in a very large area, the causal factors are more likely to be related to factors like topography and soil whereas when the scale of pattern is of order of few metres, explanation could probably be through the morphology of species or through the interaction between them.

Table 4.2: Abundance Frequency Ratio of Eight Species in Five Stands in *Acacia senegal-Boscia* Association

Species	1	2	3	4	5
L.humilis	150.3	172.8	371.6	218.4	212.8
A.nubica	161.8	76.1	103.5	136.7	68.3
A.amara	121.5	61.2	221.6	83.2	117.8
T.brownii	61.2	31.6	18.0	22.1	34.3
G.senegalensis	217.6	318.5	161.6	78.9	134.3
S.birrea	31.3	49.6	65.9	22.7	81.4
A.senegal	131.7	18.2	211.3	39.6	176.7
B.aegyptiaca	11.8	19.1	36.2	21.5	31.9

Source: Fieldwork data 1987

4.3 Correlation and the Causal Factors of Species Association

Presentation of the results obtained from the analysis of the negative and/or positive associations between species will be here discussed under the following sub-headings:

(a) Similar or dissimilar requirements.

(b) Competition between species.

(c) Modification of the micro-environment.

Each of these sub-headings stand for the level of detail at which it was studied and should not be interpreted as an attempt to classify association patterns. So these divisions are rather for convenience of presenting results and in no way imply that they exist separately and, therefore, must be considered in that manner.

4.3.1 Similar or dissimilar requirements

Kershaw (1973) has demonstrated how this intrinsic aspect of plants is of fundamental importance in explaining the negative and positive relationships that exist between individuals of different species. The emphasis here was made to detect small-scale relationships which were not obvious at the field but statistically have shown certain ecological significance.

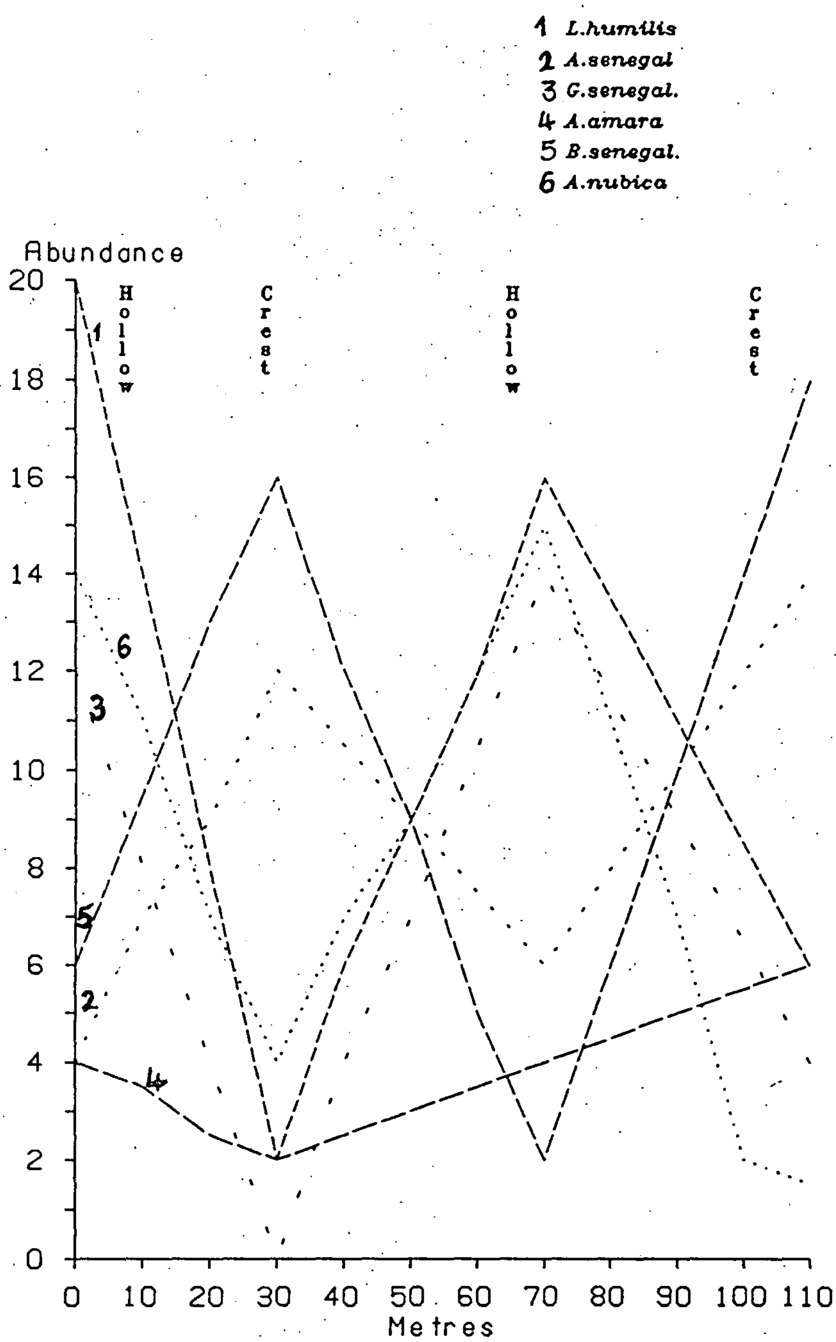
In the *Acacia senegal-Boscia* vegetation type that covers the low dune complex area to the northeast of El Qubba, the spatial distribution of the most abundant species showed a marked correlation with the underlying topographical position as exhibited by the significant values of negative and positive association between them, Fig (4.1). The pattern clearly indicates the apparent preference of *Lannea humilis, Guiera senegalensis* and *Acacia nubica* for the hollows, species of *Acacia senegal* and *Boscia senegalensis* for the crests, while *Albizzia amara* showed no particular inclination for either. This pattern could only be explained by the differential requirements of these species in terms of moisture availability. The first group of species dominates the sites of better moisture conditions where they could only maintain that dominance, while the second group represents species that can endure arid conditions and possibly indicates their wider distribution over these relatively arid surroundings.

Another example of such an environmentally controlled relationship is taken from areas of different soil texture (sandy, sandyclay, clay). Species data represent species frequency obtained from 480 quadrats from all the vegetation formation previously identified, Table (4.3).

The preference of each species for a particular soil type was tested by means

Figure 4.1

Distribution of six Species Across a Sand Dune in the Low Dune Complex NE El Qubba



Source: Fieldwork data 1987

Table 4.3: The Relationship between Soil Texture and the Frequency of the most Abundant Six Grass Species

Species	Clay	Sandclay	Sandy
D.ciliaris	60	22	18
S.cordifolia	58	26	16
S.gracilis	6	19	75
C.nervatus	18	1	81
A.pallida	17	31	52
A.gaganus	21	34	45

Source: Fieldwork data 1987

of a t-test which showed highly significant differences between them giving a clear idea about species positively and negeatively associated. *Cymbopogon nervatus* and *Schoenefeldia gracilis* are strongly positively associated on the sandy soils (+0.73), while on clay soils this sort of association tend not to exist. The remarkable increase of *Cymbopogon nervatus* reverses such an association pattern into a negative one (-0.53) which cleary reflects differences in habitat requirements between the two species. *Digitaria ciliaris* and *Sida cordifolia* are significantly positively associated on all the three soil types, (+0.78) on clay, (+0.41) on sandclay and (+0.53) on sandy soils, and that these two species are mostly negatively associated with all the other four grass species.

On a depression in the *Boscia-Lannea* association to the west of Nasharbu, five species were found to show a marked correlation with drainage lines. The abundance of these species along a transect orientated at a right angle to the depression had clearly indicated their differential requirements. *Acacia nubica* was abundant on the bed of the depression and was strongly negatively associated with *Acacia senegal*, (-0.67). and *Balanites aegyptiaca*, (-0.53). *Acacia senegal* and *Boscia senegalensis* were found more abundant on the higher areas at the margins with (+0.32) degree of association. *Balanites aegyptiaca* and *Combretum cordofanum* showed an intermediate distribution on the sides of the depression with no significant degree of association between them, Fig (4.2).

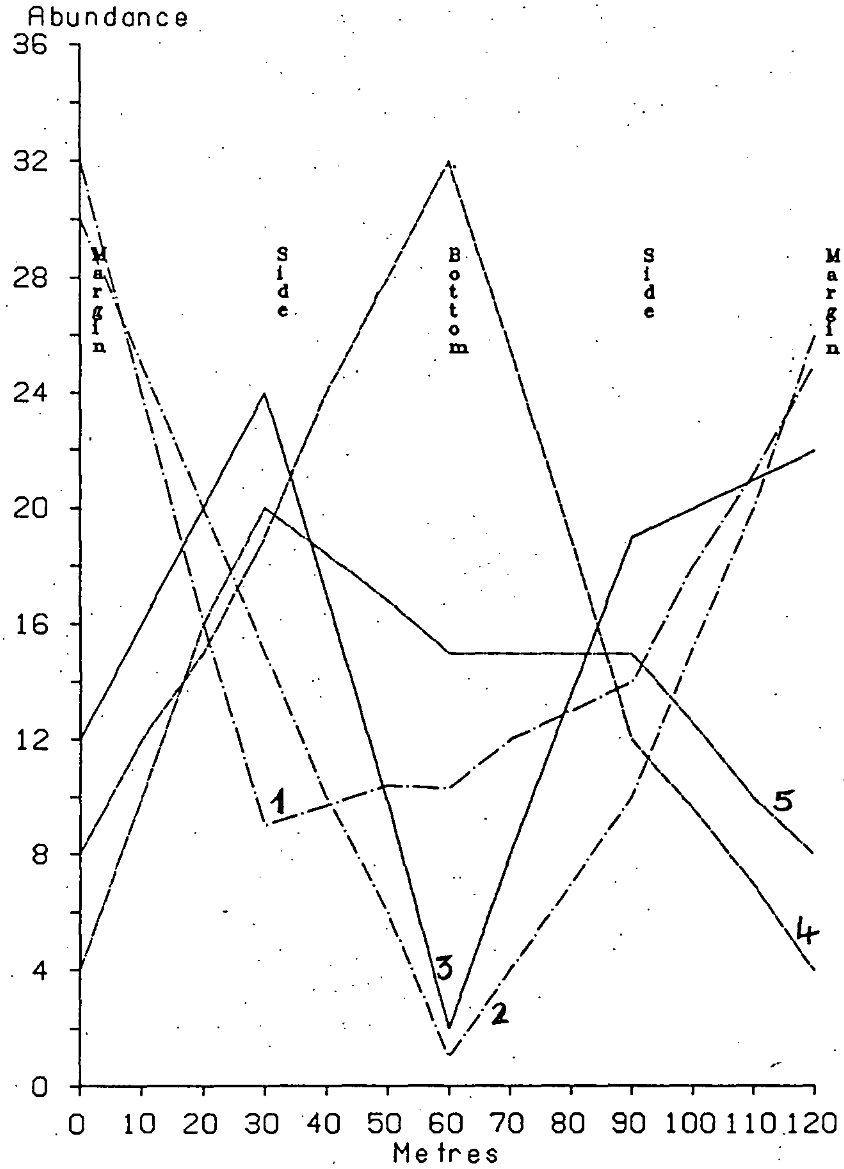
The relative abundance of each of these species is, apparently, determined by the markedly variable habitat characteristics that were created by the variations in the micro-environment. In seeking explanation for this particular pattern, soil moisture availability obviously plays the crucial part, but together with that other soil parameters were noticed to have similar effects over the pattern produced. As the bottoms of such depressions act as runnel for base-rich water after water flows, the pH contents of the soil at these localities was found to be strongly alkaline, (7.5-8.5). Conversely, leaching from the higher grounds, together with the steady accumulation of humus, had left the soils there slightly to strongly acidic with a pH contents ranging between 4.9 to 5.8. The relationship between the pH and the above five species shows a clear correlation between species positively associated and the pH content, Fig (4.3). We are not claiming here that the distribution of these species is directly governed by the pH of the soil, but more probably by the other soil elements which are in turn correlated with the pH.

4.3.2 Competition between species

The term competition here is used as a general reference to describe the struggle between individual species due to their close proximity for some environmental

Figure 4.2

The Distribution of Five Species Across a Depression Near Nasharbu

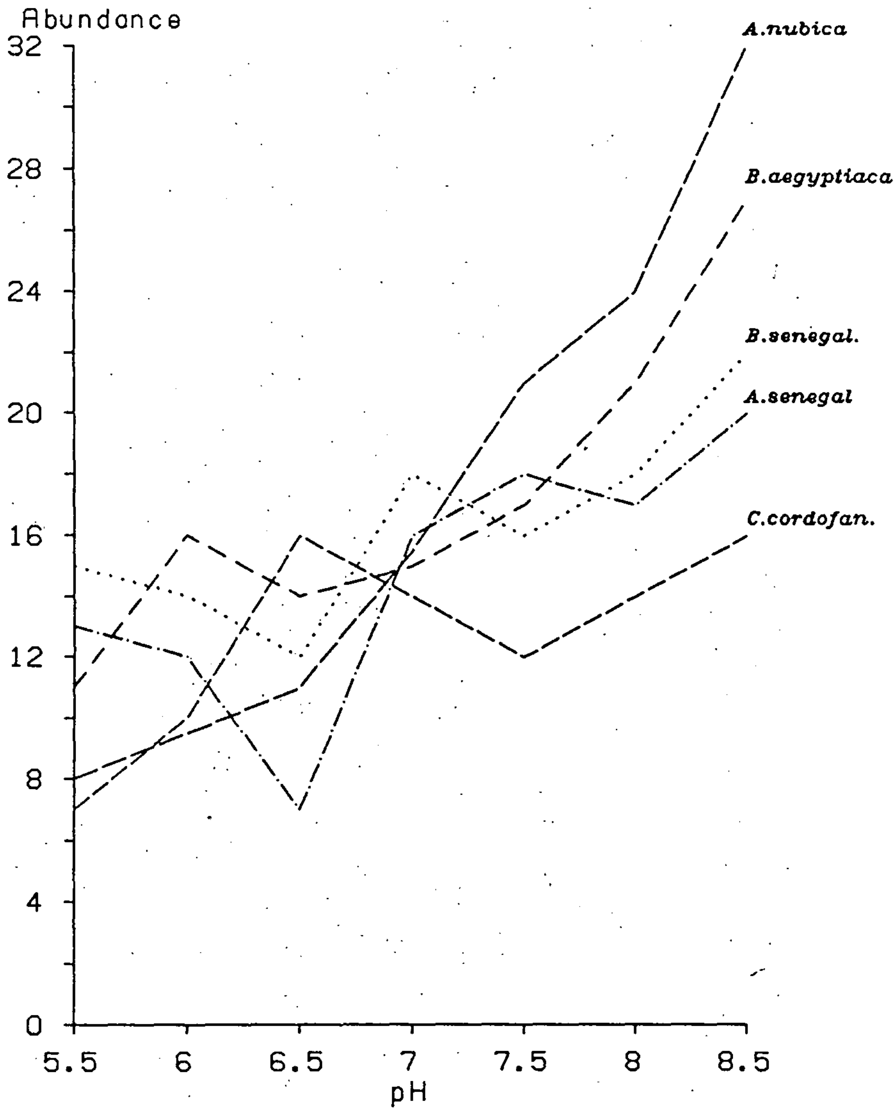


1 *B.senegalensis*
2 *A.senegal*
3 *B.aegyptiaca*
4 *A.nubica*
5 *C.cordofanum*

Source: Fieldwork data 1987

Figure 4.3

Relationship Between pH and the Abundance of Five Selected Species



Source: Fieldwork data 1987

factors, with particular emphasis on the different patterns of arrangement in the distribution of these species that resulted from such a process. The final outcome of competition, as explained by Kershaw (1973), is not necessarily one of complete elimination of one species by another, but significantly a reduction in the performance and density of one of the competing members in relation to another. As would be shown, this is usually manifested in a significant negative association between competing individuals. Among the numerous habitat elements known to cause competition among plant species, moisture availability and nutrients supply were found to be of particular significance in this area.

Investigating the soil moisture factor and its role among competing species in dune bottoms, a well marked negative association between *Maeura crassifolia* and *Balanites aegyptiaca* was detected throughout the northern half of the study area (-0.35 to -0.78) which suggests an intensive interference between these two species. The results obtained have revealed that the abundance of *Maeura crassifolia* is very low in all stands where *Balanites aegyptiaca* grows abundantly and luxuriantly. This pattern could partly be explained by the strong competitive abilities of *Balanites aegyptiaca* though these sites are slightly favourable from moisture point-of-view. On the other hand, on dune crests where the water element is lacking, a less significant positive correlation between these two species was detected (+0.16 to +0.28), which in turn suggests another type of pattern. The explanation of this pattern could lie in the fact that, *Maerua crassifolia*, which is comparatively equipped to stand such arid conditions, was capable of establishing itself there, while in the same time the less adapted *Balanites aegyptiaca* is increasingly being confined to the hollows. Based on these findings, it could even be assumed that in the most arid parts of these dunes, a negative association may exist between the two species with *Maeura crassifolia* becoming the dominant species.

In *Albizzia amara-Guiera* association, isolated stands of mature *Terminalia brownii* were frequently present either singly or in their typical clumps with an absence of any signs of the younger age classes. This suggests its former wider occurrence and the readiness with which wilting occurs indicates the difficulties under which this species survives. It was observed that, the drought-resistent *Albizzia amara* increasingly becoming dominant while *Terminalia brownii* restricted to moister sites with the result that a very strong pattern of negative association between these two species (over -0.70) was detected in almost all the stands surveyed in this type of vegetation.

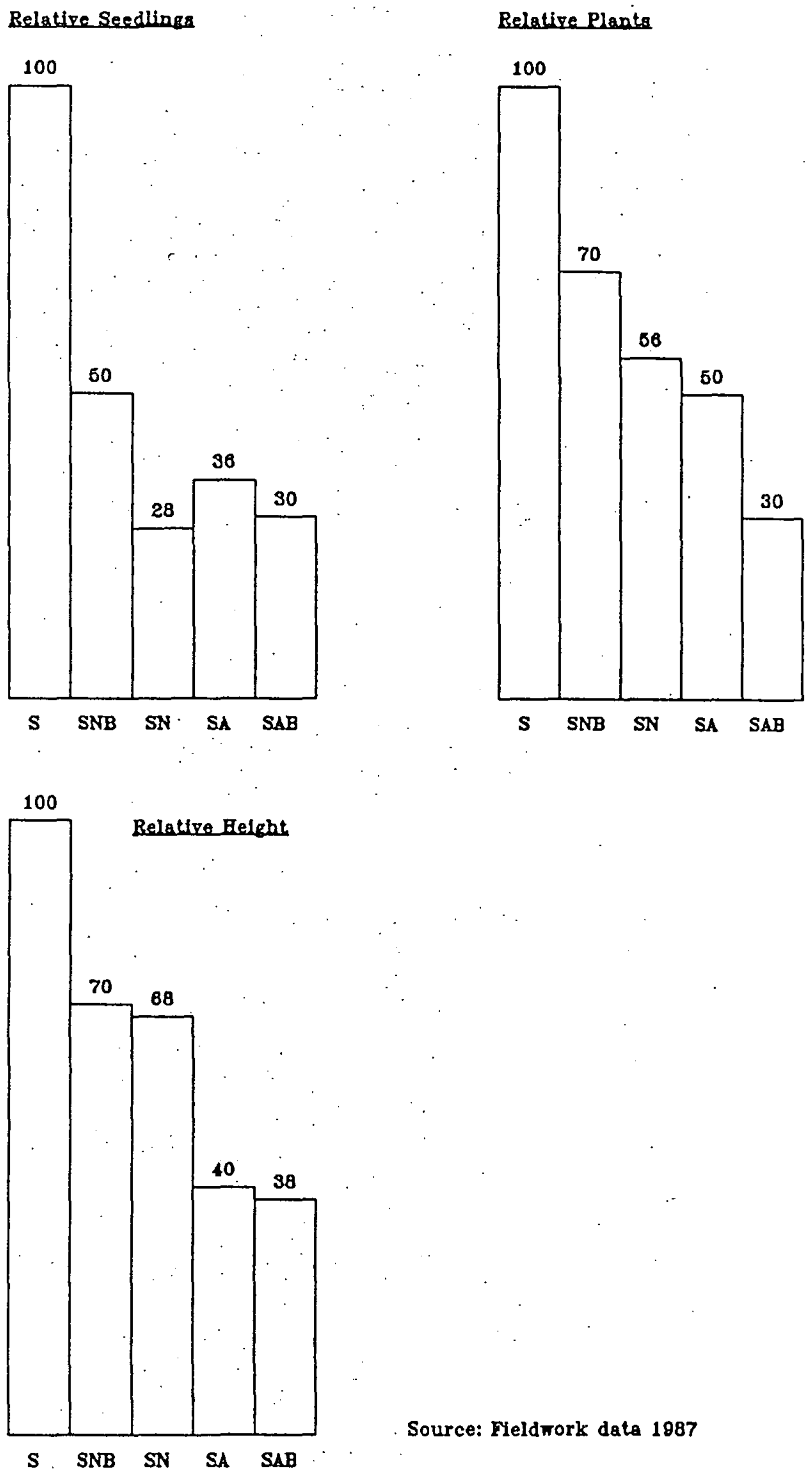
Regarding levels of soil fertility and its effect on plant associations, Willis (1963) and Bradshaw (1969) have demonstrated how simple N,P,K,Ca fertilization experiments could cause extensive changes in plant assemblages. A similar pattern to that was detected in the distribution of *Combretum aculeatum* and *Lannea humilis* in the *Acacia senegal-Albizzia-Sylerocarya* association. In this vegetation type, where nitrogen is lacking, a negative association between these two species occurs (-0.47) and apparently *Lannea humilis* seems to have favoured these conditions with the result that *Combretum aculeatum* is being progressively pushed out of the community. However, in the neighbouring *Boscia-Acacia senegal* association where there is a relatively higher levels of nitrogen, *Combretum aculeatum* was found to grow satisfactorily and such a suppression by *Lannea humilis* disappears with the result that the above mentioned association pattern tend not to exist.

Association analysis had also shown that competition varies in the pressure it exerts not only from one species to another, but similarily at the particular point of the life-cycle it is most effective, i.e., whether at the seedling stage, the maturity stage, or the effect is over a longer period of time. Obviously, the effect of competition at the seedling stage is of greater importance as it greatly controls the number of individuals which can survive to maturity.

An explanation for this aspect of competition was made by investigating the effects of the close proximity of different species on seedling survival, density and performance of stands of *Acacia senegal* at different levels of soil fertility. Five combinations of species were studied, *Acacia senegal* (S) growing alone, *Acacia senegal, Acacia nubica, Boscia senegalensis* (SNB), *Acacia senegal, Acacia nubica* (SN), *Acacia senegal, Balanites aegyptiaca* (SA) and *Acacia senegal, Balanites aegyptiaca, Boscia senegalensis* (SAB), Fig (4.4). The results showed a remarkable reduction in the number of species, number of seedlings and the performance (height) of *Acacia senegal* in all competition combinations used and at all nutritional levels. Although these are not conclusive findings, as these measurements were not taken under fairly controlled field conditions, but they broadly demonestrate the sort of effect which is expected to be found.

Competition was also found to produce a particular pattern of distribution even among individuals of the same species (intraspecific competition). The abundance of *Acacia senegal* showed a steady decline in the number of mature plants relative to the rise in the density of seedlings. Also in high density stands, the competition between mature species for water and nutrients was found to produce as much as 40% reduction in plant size whereas the same species grows satisfactorily in low density stands. The density and performance of lower plant age-classes especially seedlings were found not to be totally dependent on the density of mature plants as no significant values were obtained in that respect. This could partially be

Figure 4.4 Relative Plant Number, Seedlings and Height of A.senegal with Different Species Combinations



Source: Fieldwork data 1987

explained by the fact that the requirements of these species can easily be met and that they are not in direct competition with mature trees and shrubs, though competition from other life-forms particularly annual grasses constitutes a real threat to their survival.

One of the most striking results obtained from this association analysis is that, in over 90% of the vegetation stands studied, *Acacia nubica* had shown a highly significant value of negative association with most other species, Table (4.4). Although these field observations could be explained in parts by competition, the pattern is still found in situations where this process is unlikely to produce such an extreme pattern.

Table 4.4: Association Pattern of Acacia nubica with Other Species in Five selected Stands

Species	1	2	3	4	5
A.senegal	-0.34	+0.12	-0.46	-0.37	-0.72
B.senegal.	+0.21	-0.23	-0.61	-0.42	-0.28
L.humilis	-0.39	-0.27	+0.14	-0.69	-0.52
A.amara	-0.18	-0.63	-0.19	-0.31	-0.47
C.cordofanum	-0.86	-0.28	-0.21	-0.72	-0.16
S.birrea	-0.67	-0.69	-0.61	-0.63	-0.76
G.senegal.	-0.16	-0.37	-0.37	+0.19	-0.26
T.brownii	-0.75	-0.88	-0.71	-0.69	-0.78
B.aegyptiaca	-0.26	-0.21	-0.56	-0.17	-0.58

Source: Fieldwork data 1987

This, however, paves the way for the assumption that *Acacia nubica* may produce a substance or substances which are intolerable or toxic to other species. Unlike the other species, grazing pressure does not determine the presence or absence of *Acacia nubica* as it is often being avoided by stock presumably because of its strong unpleasant smell. Further colonization by other species was observed to be very rare. Again these observations are not conclusive as it was considerably difficult under field conditions to measure and/or differentiate between a toxin effect and one due to competition.

4.3.3 Modification of the micro-environment

Kershaw (1973) and Etherington (1975) had pointed out that plant species continuously modify and change their immediate surroundings and they demonestrated how disturbances in ecosystems and the selective pressure by man and animals can cause extensive variations in the competitive status of plants. The ecological significance of these processes is that some species will be permited to increase and multiply while others will be extremely regressed resulting, through time, in significant alterations in the association pattern that once existed between plant species.

As shown in table (4.4), a very strong negative association between *Acacia nubica* on the one hand and *Sylerocarya birrea* and *Terminalia brownii* on the other was observed in virtually all the vegetation stands these species occur together. This pattern of association is probably due to a certain degree of modification of the local micro-environment and, as shown above, it is very likely that the factor or factors which are limiting the distribution of *Sylerocarya birrea* and *Terminalia brownii* may in the first place have been imposed on the environment by *Acacia* *nubica.*

Another association pattern produced by changes in the environment was observed in areas where there is a considerable diposition of wind-blown sands. In such areas, low mounds of sands frequently develop around the base of perennial plants, *Boscia senegalensis* is a good example of this phenomenon. In these habitats, a significant positive association between this species and the annual *Cenchrus biflorous* was observed. This pattern of association could be explained by the interaction of two major factors. The first is the protection provided for *Cenchrus biflorous* by *Boscia senegalensis* from grazing animals which elsewhere greatly reduces the abundance and luxuriance of the species. The second factor is the accumulation of sands which provides extremely dry conditions relative to the surroundings and, thereby, providing insufficient moisture to support dense plant growth, an environment which could only be tolerated by such a drought-enduring grass species. Further increments of sand was observed to exclude even *Cenchrus biflorous* leaving *Boscia senegalensis* standing alone.

Table 4.5: The Association Pattern of Six Selected Species in Boscia-Guiera Vegetation Type

Species	*A.senegal*	*G.senegal.*	*C.procera*	*A.amara*	*A.nubica*
G.senegal.	-0.79				
C.procera	-0.63	+0.32			
A.amara	-0.42	+0.25	+0.37		
A.nubica	-0.82	-0.31	0.11	-0.48	
B.senegal.	-0.53	+0.45	+0.42	+0.27	+0.38

Source: Fieldwork data

The role of man in changing the association patterns between species is remarkably clear in many parts of the study area. As shown in table (4.5), the strong negative association between *Acacia senegal* and most of the other species in *Boscia-Guiera* vegetation type, clearly indicates that the population pressure on arable land may have reached a near stage of excluding *Acacia senegal* from this association with the result that this species is being dropped out and replaced by species like *Guiera senegalensis* and *Acacia nubica.*

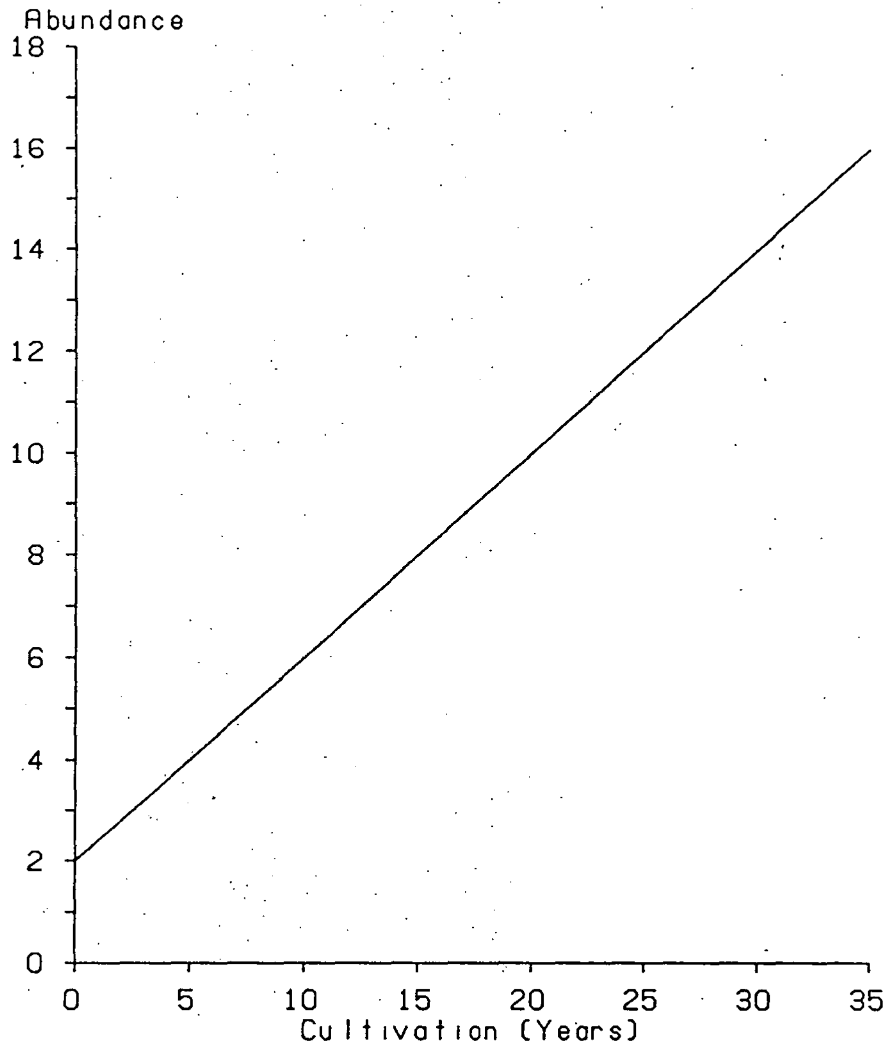
Here the abundance of *Calotropis procera, Guiera senegalensis* and *Boscia senegalensis* could well be considered as a successional trend following cultivation, Fig (4.5). In similar areas where cultivation pressure has not reached that stage, *Acacia senegal* is widely present where protected and being maintained through a regular cycle of cultivation. In both cases, the general patchwork effect on vegetation due to man's interference emphasizes the secondary nature of these association patterns. *Cenchrus biflorous* is often associated with areas of certain degree of overcultivation. This grass species is either very rare or absent in those areas sufficiently far from cultivation and grazing. HTS (1963) suggested grazing as being the means of introduction of *Cenchrus biflorous* into the area classified here as *Boscia-Guiera* Association.

4.4 Major Patterns Identified

As described above, the data on the relative abundance of species in the various vegetation stands surveyed in the area were found to contain several types of association patterns between species. The presence of such correlations, however, reflects a degree of pattern in the spatial arrangement of these species. The emphasis in the following part shall be to extend the results derived by association

Figure 4.5

Regression Showing Increase in Calotropis procera with Increase in Cultivation Intensity



Source: Fieldwork data 1987

analysis along with the non-randomness detected in the distribution of species in order to determine the size and shape of patches that were created by these series of patterns. By simultaneously considering association trends and non-randomness, it would be possible to interpret spatial pattern in terms of the possible causal factors.

Table 4.6: Correlation Coefficient Between the Abundance of *Guiera senegalensis* and Nine Habitat Factors

Variable	Abundance	N (%)	P pmg/100g	Clay (%)	Sand (%)	Graz.	Cultiv.	Dune Crest	Dune Bed
N	+0.27								
P	-0.12	-0.13							
Clay	-0.23	+0.27	-0.12						
Sand	+0.61	+0.35	+0.36	-0.92					
Grazing	+0.42	-0.31	-0.52	-0.12	-0.52				
Cultiv.	+0.52	-0.67	-0.41	+0.13	+0.61	+0.08			
Crest	-013	-0.39	-0.23	-0.99	+0.98	-0.21	-0.23		
Bed	+0.32	+0.60	+0.21	+0.11	-0.13	+0.76	+0.62		
pH	+0.41	+0.25	+0.37	+0.46	+0.15	-0.23	-0.67	-0.23	+0.62

Source: Fieldwork data 1987

Data obtained on environment from the different sites were analyzed where possible in a similar way to that of vegetation data and correlation coefficient between important variables will be used to explain the degree of abundance among individual species and the type of spatial arrangement consequently produced in different vegetation stands, Table (4.6).

The results obtained from these correlation coefficient procedure had, more or less, indicated significant inter-relationships between scales of pattern in the distribution of different species and scale of pattern in the distribution of these vital environmental factors. These results will be discussed under the following two sub-headings which in a way represent the origin and nature of these patterns and the processes involved. These are:

- Environmental Patterns.
- Sociological Patterns.

4.4.1 Environmental patterns

This section will cover those scales of pattern which have resulted from the interaction of vegetation with the major environmental discontinuities in the study area. In general rainfall in this area, as will be explained in the next chapter, is not sufficient to allow for a continuous vegetational cover, with the result that vegetation often occurs in patches on the most favourable sites. Plant growth is vigorous and dense in low lying places and in sites where water accumulates with bare surfaces becoming increasingly extensive northwards. Accounting for these patchy distributional patterns, factors like soil characteristics and topographic position were found to be of particular significance either singly or together.

(A) Edaphic Pattern

Results of correlation coefficient and regression analysis between various species and the different soil parameters were found to be of vital significance in explaining inter-community difference and the spatial heterogeneity in most of the vegetation stands identified in the area. These soil factors have included, texture and structure, level of soil fertility (nutrients supply), and soil moisture which controls the actual amount of water available to plants. In this respect, soil texture plays an important role in determining that quantity, for on sands water penetration is deeper than on clay with the latter holding more water near the surface. Smith (1949) and Worral (1960) recognized that sandy soils favour the growth of deep rooted trees and perennial grasses, while clayey soils often carry annual grasses and herbs.

To reveal the part played by soil texture in the association pattern between different species, six pairs of combinations were made from two tree species, *Acacia senegal* (1) and *Albizzia amara* (2) and two grass species *Aristida pallida* (3) and *Digitaria ciliaris* (4) at different soil textural levels, Table (4.7).

Table 4.7: Correlation Coefficient Between Two Grass & Two Tree Species at Various Soil Textural Types

Soil	1-2	1-3	1-4	2-3	2-4	3-4
Clay	+0.56	-0.13	-0.13	+0.06	-0.14	-0.17
Sand-clay	+0.41	+0.21	-0.23	-0.41	-0.13	+0.21
Sand	-0.23	-0.15	+0.09	-0.18	-0.41	+0.76

Source: Fieldwork data 1987

These results showed that, on clay soil and on sandy soil there is a consistently positive association between species of grasses and species of trees respectively. Whereas a significant negative association was revealed between species of grasses and species of trees on both soil types. These findings significantly indicate the differential requirements of trees and grasses and show the inclination of woody species to grow on sandy soils while a dense herbaceous cover is favoured by the increase in the clay contents of the soil.

The part played by soil texture in the pattern of species distribution was examined by comparing the values of 20 species (10 grasses and 10 trees) in different stands of particular soil textural characteristics, Table (4.8). The figures obtained showed that certain species have a much higher abundance:frequency ratio in stands of particular soil type than in others indicating a contagious pattern of distribution in these stands. Such species reflect a definite relationship between their degree of contagiousness and the underlying soil habitat.

Vegetation on clay soils consisted mainly of species of annual grasses as exemplified by the greater numerical values of *Cymbopogon nervatus, Schoenefeldia gracilis* and *Panicum anaboptistum* than they have on sandy soils. These grasses are often thicker and taller with a very scattered tree cover. On the contrary, the vegetation-cover on the sandier soils, is dominated by trees as shown by the values of *Lannea humilis, Guiera senegalensis* and *Boscia senegalensis* with a patchy covering of the perennials *Panicum anaboptistum* and *Schoenefeldia gracilis.* The explanation of this distributional pattern could be made through the degree of moisture absorption by the two types of soil. Since drainage is freer on sands, water penetrates more deeply with the upper layer being frequently dry, while on clays, there is more available water in the top layer during and shortly after the rains before it later evaporates. This implies that, on sands water is available to trees and deep-rooted perennials, whereas on clays, annual grasses and shallow-rooted species could only survive there. This explanation, however, does not fit all the stand mentioned above. In the second soil group, contrary to what is expected according to the above theory, the vegetation-cover is dominated chiefly by herba-

Table 4.8: Abundance:Frequency Ratio of Twenty Species in Five Vegetation Stands of Varying Soil Texture

Species	> 70% Sand	70-56% Sand	55-45% Sandclay	56-70% Clay	> 70% Clay
A.nubica	3.6	1.7		3.2	65.2
A.amara	5.9	6.3	1.3	4.1	26.1
A.senegal	42.3	38.2	12.7	64.5	21.6
T.brownii	32.6	0.4	1.1	13.6	4.3
C.aculeatum	14.5	11.3	2.0	6.0	6.5
M.crassifolia	42.9	4.7		5.9	1.2
B.senegal.	119.8	74.9	34.2	88.5	116.5
L.humilis	192.8			19.2	11.1
G.senegal.	128.6	83.2	41.6	64.2	94.5
S.birrea	15.3			7.2	1.6
C.obtusif.	1.2	1.7			13.6
C.nervatus	3.2	11.2	11.7	67.3	117.5
A.pallida	11.4	16.2	24.6	52.2	78.2
S.gracilis	22.7	47.1	21.4	121.6	201.2
P.anabopt.	24.2	41.3	14.1	65.3	198.1
T.terrestris	3.4	3.4	1.1	5.4	26.2
C.italica	2.1	6.7	1.0	4.1	12.4
D.ciliaris			0.7	31.9	19.7
A.gaganus	1.2	5.9	3.1	6.8	3.2
C.biflorous				3.5	21.1

Source: Fieldwork data 1987

ceous species with a very low ratios for woody plants. It is most probably that in this stand, there is a better water retention on the upper layers due possibly to the shallow depth of the sand layer, or rather the tree-cover may have been cleared by man, though no indicators were obtained to prove the second argument.

Species like *Acacia senegal, Boscia senegalensis* and *Guiera senegalensis* were noticed to be common over the full range of the five soil types mentioned above, showing no particular preference to either type, thus, reflecting a wider ecological range. This could partly be explained by the biological characteristics of these species. *Acacia senegal* has a spreading system of lateral roots almost immediately below the surface and a deep tap root. It is, therefore, able to make use of the very slight showers that barely penetrates the surface as well as being capable of utilizing moisture from lower depths. Both *Boscia senegalensis* and *Guiera senegalensis* were found to have no deep tap root systems but are endowed with an exceptionally extensive systems of lateral roots which measured in one instance to be in excess of 60 metres for *Guiera senegalensis.* From soil moisture point-of-view this type of rooting system makes the two species at a considerable advantage regardless of the type of soil.

The third group has a sandyclay soil and based on the above observation, it is expected to have a vegetation-cover intermediate between that of sands and clays. But actually, as indicated by its numerical values, this vegetation type has a poorer vegetation-cover both in terms of grasses and trees. The soil here was found to be compact, structureless, occurring in gentle slopes with frequent occurrence of stones and/or coarse sand. The amount of clay is sufficient to make the soil surface becoming panned and in consequence water swiftly moves over the surface washing away seeds and, therefore, reducing any chance of plant regeneration. These runoff surfaces vary in size and may be of natural origin but most probably were artificially induced by cultivation followed by sheet erosion. This, however, shows that plant growth is not only determined by soil texture, but on a smaller-scale, soil structure is equally important.

Moreover, the effect of small variations in soil depth was found to bring about a measurable change in the distributional pattern of vegetation, which is particularly clear for grasses. This could be demonstrated by the pattern of *Schoenefeldia gracilis, Aristida pallida, Cymbopogon nervatus* and *Andropgon gaganus* in the *Boscia-Guiera-Albizzia* association. *Andropogon gaganus* and *Cymbopogon nervatus* were more abundant on the shallow areas of the soil, while conversely, *Schoenefeldia gracilis* and *Aristida pallida* were particularly dense on the deep parts of the soil spectrum. A possible explanation for this pattern is suggested by the mean rooting depths of these species. The first two were found to produce a shallow root system which measured as not exceeding 33 cm., whilst the second two species were found to root at a much greater depths (86 cm.). Presumably the limitation of root development in *Andropogon gaganus* and *Cymbopogon nervatus* seriously affects the capabilities of these species and accordingly they are only likely to survive on areas of shallower soils.

Regarding woody species, the patterns produced by differences in soil depths were not as clear as that described for the herbaceous plants as such patterns are always masked by the relatively extensive root systems of trees which allow them to tap very deep, and accordingly survive on extremely arid soils. Occasionally, *Acacia senegal* was noticed to extend further to the north in the eastern parts of the area than it does in the western parts. This is possibly due to a difference in soil permeability and a degree of soil depth, but again the explanation could partly involve man as the density and even the presence of *Acacia senegal* is largely controlled by the system of cultivation in this area.

Efforts were also made to detect any measurable pattern in vegetation produced by variations in levels of soil fertility, Table (4.9). Association analysis between the concentration of nutrients and species abundance indicates a significant positive correlation between *Combretum aculeatum, Terminalia brownii* and the nitrogen content of the soil, while both species are negatively associated with phosphate. In contrast, *Acacia senegal* and *Albizzia amara* are significantly positively associated with both nitrogen and phosphate, Table (4.9).

Table 4.9: Correlation Coefficient Between the Abundance of Five Species and Soil Nutritional Status

Species	N (%)	P pmg/100g	C (%)	K kmg/100g	OC (%)	pH
A.senegal	+0.46	+0.38	-0.09	+0.16	+0.19	+0.05
L.humilis	-0.13	-0.13	+0.07	+0.13	+0.14	-0.02
C.aculeatum	+0.42	-0.29	-0.02	+0.11	-0.21	+0.17
A.amara	+0.27	+0.44	+0.12	-0.23	+0.23	-0.04
T.brownii	+0.39	-0.36	+0.11	-0.17	-0.03	+0.16

Source: Fieldwork data 1987

Hogberg (1986) showed how deficiencies in nitrogen limit the growth of non-nitrogen-fixing species and phosphate the growth of nitrogen-fixing species. This could partially explain the sort of relationship measured between the level of these two elements and the abundance of the four above mentioned species. *Terminalia* *brownii* and *Combretum aculeatum* being none nitrogen-fixing while *Acacia senegal* and *Albizzia amara* are nitrogen-fixing species.

To conclude this part, the measured soil properties were found to vary from place to another exerting varying degrees of pressure on vegetation. While the effect in certain vegetation stands is very clear and significantly indicative, in others it was hardly detectable. Similarily, the reaction by individual species was shown to vary from those being greatly affected by these properties to those barely reflecting any significant response.

(B) Topographic Patterns

Topography was mentioned by Smith (1949), Kasses (1956), Harrison & Jackson (1958) and by HTS (1963) as a major factor which controls and governs the proportion of rainfall entering the soil and, therefore, the amount of water that becomes available for the use by plants. Water movements on these soils is a regular occurrence wherever there is a slight slope. The reason for this is due, to some extent, to the lack of adequate vegetation-cover which could slow surface water flow and in turn allow more time for absorption by soil. Crude field measurements made on soil moisture have shown that, water penetration immediately after rainfall could be as deep as 50-80 cm. under a grass cover but rarely reaching 20 cm. under the intervening bare ground.

Investigating the pattern formed by the alternating dune hollows and crests, it was found that, drainage, water availability, leaching, pH, nutrient supply among many other elements tend to vary with changes in the micro-topographical position. Such a combination of processes makes it difficult, in the light of the available data, to decide which factor or group of factors are directly controlling the distribution of any particular vegetation stand. Because of that, the term topography here will be used in its literal meaning, i.e., to indicate high and low surfaces and the pattern of vegetation associated with that phenomenal sequence.

Aerial photographs and satellite data used have clearly shown several types of vegetational patterns created by these topographical features. These patterns appeared as green bands often curved and running in broken lines approximately parallel to each other and with spacing apparently several times greater than the vegetation bands themselves. Dense vegetation growth tends to shelter in the inter-dune hollows and increasingly doing so towards the dry north. Within this large-scale heterogeneity, several small-scale patterns have been observed which vary from one locality to the other depending on local landscape properties.

Deep-sided dunes often show a catena effect downslope towards the hollows. The results of a transect laid across a series of low dunes to the northwest of El Qubba showed that, *Acacia nubica* with *Acacia senegal* growing under cultivation dominate the higher grounds, then *Balanites aegyptiaca, Terminalia brownii* and *Sylerocarya birrea* occur on the sides and finally *Albizzia amara* and *Adansonia digitata* occupy the inter-dune hollows. A same catena was also observed for the herbaceous cover. *Aristida pallida* dominates the crests with *Eragrostis aspera* on the sides. *Aristida mutabilis* marks the change in drainage near the bottom of the slope. The change is then through *Cymbopogon nervatus, Schoenefeldia gracilis* and finally bare soils in the wettest parts.

In the longitudinal dunes system, the vegetation shows wider pattern of distribution than that on the transverse systems, and where there is restricted drainage, the inter-dune hollows support very poor tree-cover consisting mainly of *Balanites* *aegyptiaca.* In the dry most northerly fringes of the study ares, the tree-cover shelters in the inter-dune hollows leaving *Acacia senegal* to survive on the extremely dry exposed crests where it is being maintained as part of the cultivation system. Further south, as moisture conditions become relatively better, other trees gradually move upslope. This observation, however, may support the view made by Worral (1960) that vegetation heterogeneity in Sudan increases from the wet south to the arid north. On these longitudinal dunes, numerous signs of instability were noticed, like the exposure of some lateral roots of *Andropogon gaganus* and the signs of successive burial of *Aristida pallida.* These internal dune movements, bury and expose these sparsely vegetated areas particularly the crests resulting in extremely degraded cover. Only *Panicum turgidum* seemed to have managed to escape that effect as it is endowed with an extensive fibrous root system which helps to bind the sands.

On the transverse dune systems, the grass-cover is luxuriant in the hollows dominated chiefly by *Aristida pallida, Andropogon gaganus* and *Cymbopogon nervatus.* On the intervening crests, a few occurrences of *Panicum turgidum, Schoenefeldia gracilis* and *Aristida pallida* are widely scattered over these dry areas. Most of these grass species are small and more rapidly maturing than in the hollows probably because of water deficiency.

The lacustrine depressions which characterize most of the southern half of the study area, support a variety of species as would be expected from the soil moisture contents. In these depressions, *Panicum turgidum* dominates the margins while *Schoenefeldia gracilis* and *Cymbopogon nervatus* the heavier moister soils of the depressions. The tree-cover is likewise richer with a noticeable dominance of *Adansonia digitata* and *Albizzia amara* towards the wettest parts giving way to

Sylerocarya birrea, Guiera senegalensis, Acacia senegal, Acacia nubica and *Boscia senegalensis*, in that order towards the margins.

In the lowest parts of these depressions, water intermittantly flows particularly during and shortly after heavy falls. It was observed that, there is an absence of vegetation on these surfaces, while the banks are richer in both tree species and grass species. This would probably support the view earlier made in the chapter that the coarse sand on these beds is too dry to permit seed germination. On the other hand, the flow of water washes away seeds as it does with fine particles. With the reduction in the gradient, the water drops its load of suspended materials and soon the depression becomes infilled with fine materials which makes it a good seed bed for plant growth, first at the edges and later over the whole depression.

A similar pattern to the one described above was also noticed in extremely low lying areas where water accumulates during the rainy season. Due to the presence of such a strong environmental factor, vegetation stands, to some extent, tend to be structurally and physiognomically isolated from their surroundings, thus, creating a mosaic-like pattern even stronger than that produced by the sequence of dune tops and bottoms.

A case which has been investigated from this isolation point-of-view concerns the complex of low lying areas to southwest of Ankosh. Although the distances between these patches may be as short as few metres, significant discontinuities in the distribution of many plant assemblages were measured. The central parts of these water retaining sites, which is usually the wettest area, are dominated by dense stands of *Terminalia brownii, Combretum cordofanum* and *Albizzia amara*, sometimes forming dense hardly penetrable thickets, while grasses are remarkably absent. The margins are marked by a relatively widely spaced stands of *Combretum hartmannianum* and *Acacia nilotica* with a noticeable grass-cover. Moving few metres outwards, the area abruptly turns into a totally different community mainly dominated by *Boscia senegalensis* and a poor herbaceous cover chiefly *Aristida pallida, Cymbopogon nervatus* and *Schoenefeldia gracilis* with non of the species mentioned above being encountered even singly.

This example as the previous ones, illustrates how slight variations in the micro-topography can modify the pattern of association between species and can lead to the creation of new one that differs from the surroundings structurally as well as physiognomically. These new patterns have either resulted from the topographical phenomenon itself, or more probably through the other inter-related factors of soil moisture, nutrient supply, pH, drainage and leaching which are reflected in the non-uniformity in the soil surface. In all cases, water availability seems to be the governing factor which controls the nature and magnitude of these patterns as would be expected in these arid land ecosystems.

4.4.2 Sociological patterns

Principally, this concept covers a wide range of small-scale patterns that results from the interactions of several causal factors, partly intrinsic properties of plant themselves and partly a reflection of the micro-environment, Kershaw (1957, 1963, 1973), Hill (1973). Here this term will be confined to describe patterns produced by seedlings/performance interaction as it is obvious in shaping and reshaping vegetation stands.

As elsewhere, a noticeable general pattern of structure and floristic composition was observed to have resulted from the process of rejuvenation in the different types of vegetation surveyed. Through this process, trees and grasses die and become replaced, vegetative spread and seed dispersal are the two controlling factors. Regarding the pattern produced by the dispersal of seeds, it was noticed that there is a general decrease in pattern with increasing age of the stands, Fig (4.6).

Seeds germinate in the short rainy season, growing rapidly at first, then slow down as the soil dries out and moisture increasingly becomes a limiting factor. Thus, seedlings become particularly vulnerable and have to compete among other species for available water before reaching deep to the permanent water supply. At this stage, seedling mortality due to water shortage becomes very high which explains the pattern shown in Figure(4.6). This pattern could not be satisfactorily explained in terms of grazing pressure as suggested by many authors, for dead but ungrazed seedlings were frequently encountered. Besides, in the most favourable parts, the ratio of adults to seedlings was noticeably lower. The pattern of *Acacia senegal* often forms dense thickets in the early stage of regeneration and thinning out as the stand approaches maturity. This implies that, the distribution pattern of adults is produced from that of seedlings by a process of progressive random mortality.

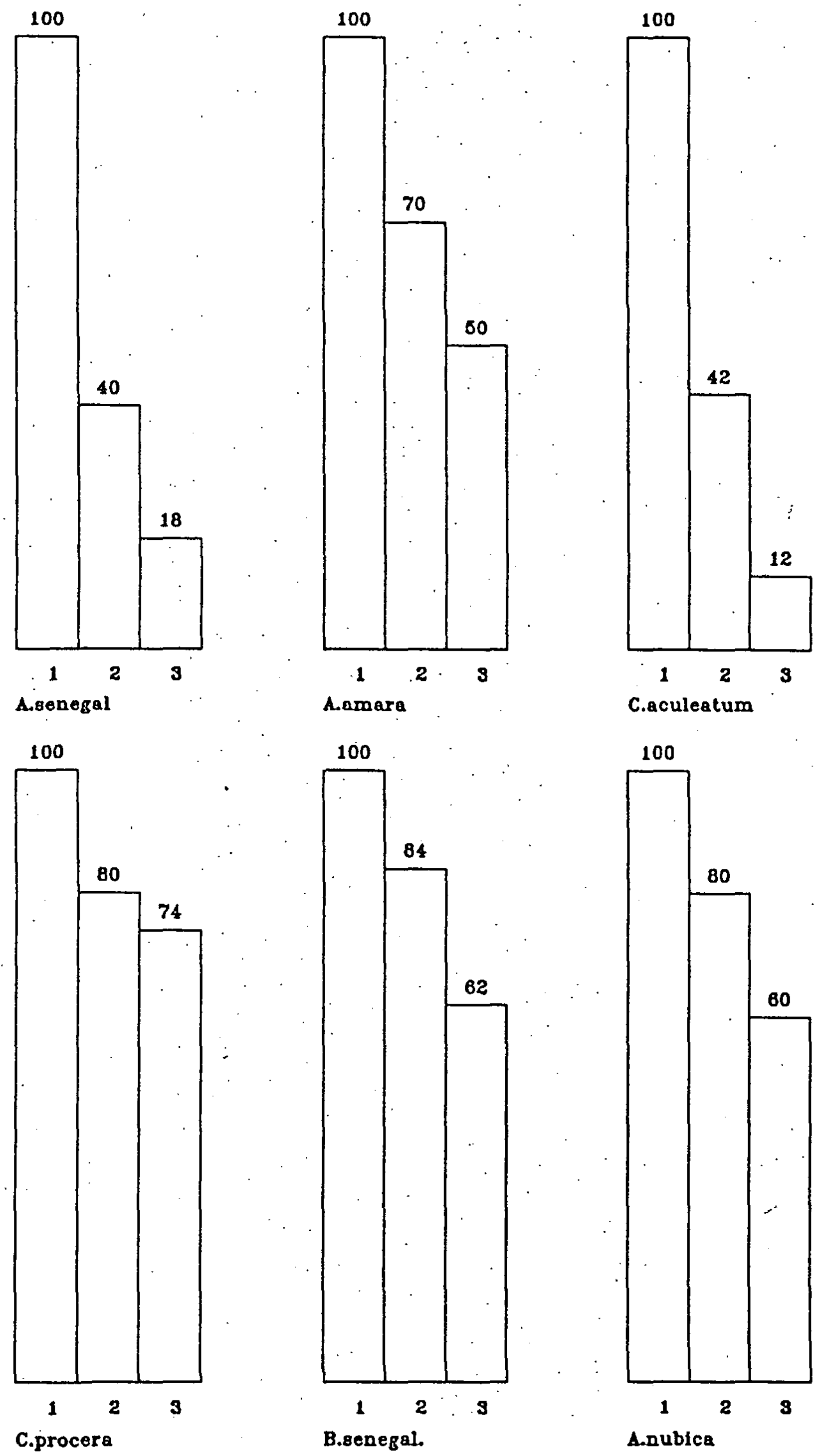
Greig-Smith (1965) pointed out that, the number of individuals reaching maturity in a population is not only a function of how many seeds are available, but also of what physiological state they are in. Species like *Sylerocarya birrea* and *Adansonia digitata* are seed producers but only extremely few seedlings of the former were seen while not a single seedling of the latter species was encountered throughout the area. This may suggest that, seeds produced by these two species do not successfully germinate immediately after being laid, instead they lie dormant until a particular event triggers germination. Thus, the nature of seeds and tolerance of seedlings seem to control subsequent pattern of establishment and growth.

Unlike species germinating from seeds, those growing by vegetative spread were noticed to have a better chance of establishment as reflected in the less drastic differences between various age classes of *Guiera senegalensis* and *Lannea humilis*, Fig (4.7). Such mode of propagation may have caused these species to often be clumped together with offspring being immediately surrounding the parent species. These types of vegetation apparently require less water and nutrient supplies than the others do as evidenced by their dense growth in extremely unfavourable sites having, therefore, greater competitive abilities. The immediate result of that is the distribution of these species in, more or less, homogeneous colonies rather than as scattered individuals. Such a strong pattern was found to drive other species into secondary aggregation more often in the unfavourable localities. Subsequent colonization by seed-bearing species of areas previously dominated by vegetatively spreading ones was noticed to be negligible.

Investigating the general pattern of *Lannea humilis*, it was found that this species often forms dense blanket thickets that cover lower grounds. The interpretation offered here is that, these mosaics of density reflect local soil depth variations induced by the strong propagation of the species. Stability and increase in the age of the stand was noticed to bring about a substantial decrease in the intensity pattern of the species but again no signs of colonization by other genera were observed. A similar pattern was also observed for *Guiera senegalensis*, except that its decreasing intensity pattern is believed to be produced by stability alone as mature stands of this species, unlike *Lannea humilis*, were frequently found maintaining the same close cover.

Figure 4.6 Relative Scale of Pattern of Different Age-Classes of Species Germinating by Seeds

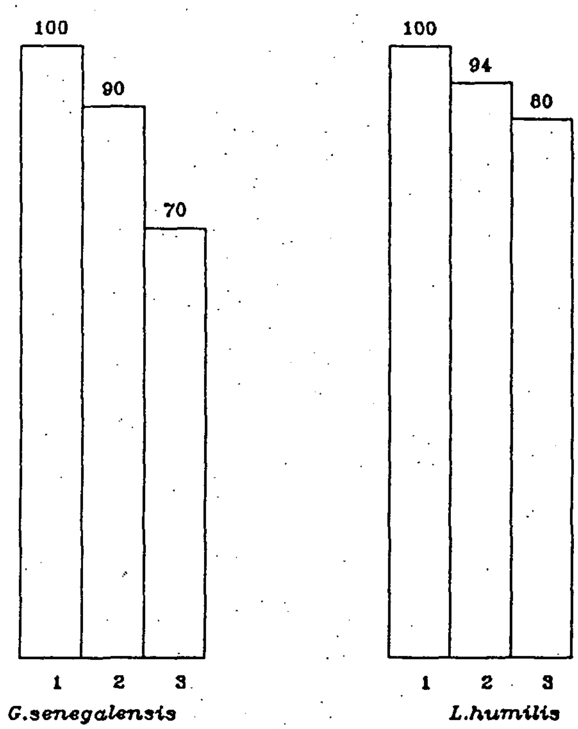
(1) Seedlings (2) Middle Age (3) Mature



Fieldwork data 1987

Figure 4.7

Relative Scale of Pattern of Different Age-Classes for Two Species Vegetatively Spreading



(1) Seedlings
(2) Middle Age
(3) Mature Species

Source: Fieldwork data 1987

4.5 Concluding Remarks

Several scales of pattern were detected in the vegetation of the area ranging from very small-scale ones that resulted from the close proximity of a number of individuals to large-scale patterns which reflected micro and macro-variations in the environment. Data obtained on the relative abundance of species revealed strong trends of association between species. The presence of such correlations reflected several scales of pattern behind which a number of causal factors were identified.

Most species were found to be markedly non-randomly distributed and thereby exhibiting additional scales of pattern. The data presented gave no indication of the postulated regularity of distribution. In fact only a very few species at very local levels did fall below the random expectation. On the contrary, at all sites surveyed there was a clear evidence of contagious distribution. Additionally, it has been found that, there is a close correlation between the spatial pattern of distribution and abundance of plant communities on the one hand and the pattern of surface properties on the other. Extremely small variations of environmental parameters were shown to produce a corresponding variation in the structure and composition of the vegetation.

It must be admitted here that due to the time factor and the resources available for this research, the data on the environment had not been obtained by extremely critical samplings. Thus findings in certain instances could hardly be extrapolated to define causality of pattern with greater precision and, accordingly, some of the arguments given would obviously be open to some criticism.

The different scales of pattern identified were shown to reflect underlying pattern in edaphic conditions, micro-topographic diversity and modes of propagation of the species themselves. Numerous soil factors, including depth, texture, structure, level of fertility and the moisture content were shown to have a measurable effect on species distribution within areas at first sight apeared uniform. Variations in micro-environment produced by topography were found to produce similar effects.

Moreover, the structure and floristic composition of the vegetation at any given community was found to be a manifestation of the pattern produced by the generation cycle of the dominant species. However, these scales of pattern show consistent signs of instability in the sense that certain species appeared to be struggling for survival even at their known typical habitat range, while yet others, probably agressive by nature, appeared strongly encroaching and multiplying in areas previously occupied by other species. Factors like increase in aridity, impoverishment of the soil, species tolerance and intolerance and the effect of man and animals are likely to cause a degree of successional changes in the vegetation and ultimately in additional scales of pattern. The detailed investigation of these processes shall be the subject of the next two chapters.

Chapter V

The Physical or Natural Factors Affecting Vegetation in the Study Area

5.1 Introduction

The types of vegetation found in the study area, as elsewhere in tropical Africa, is in part a legacy of the past but the present distribution is also closely related to current climatic and edaphic conditions as well as being continuously reshaped by man's interference through his various cultural practices.

Despite the lack of long-term records, there is ample evidence suggesting that the *entire* region has been subjected to marked ecological changes. Recurring major perturbations such as droughts, floods, fire, overgrazing, and the excessive removal of the woody vegetation are cases in point. Although these incidences appear to have been occurring over centuries, grasses and trees with varying combinations continued to exist there, and to re-establish themselves after virtual elimination in many localities, thus, showing a high degree of resilience in the region. However, this resilience, as shall be substantiated in this chapter and the next one, proves to be not indefinite and there are many examples where the bounds seem to have been exceeded. The so-called *desertification* in the region is a case to be mentioned.

In this chapter, the different natural factors or processes that cause or induce changes in the vegetative-cover of the study area will be identified and assessed. The emphasis here will be made on the natural processes that disturb habitats and lead to the local extinction of plant species. Relationships between the various processes to be discussed will be scrutinized and evaluated on the assumption that, the prevailing vegetation reflects the interactions between the several factors that make up the habitat. These natural processes include a number of physical factors which together or separately cause a wide range of changes in the vegetation character of the area. Although these factors occur and often operate together in an interactive way, they are here studied under separate headings only for the purpose of explaining the magnitude and the extent of the role each plays.

5.2 Climatic factors

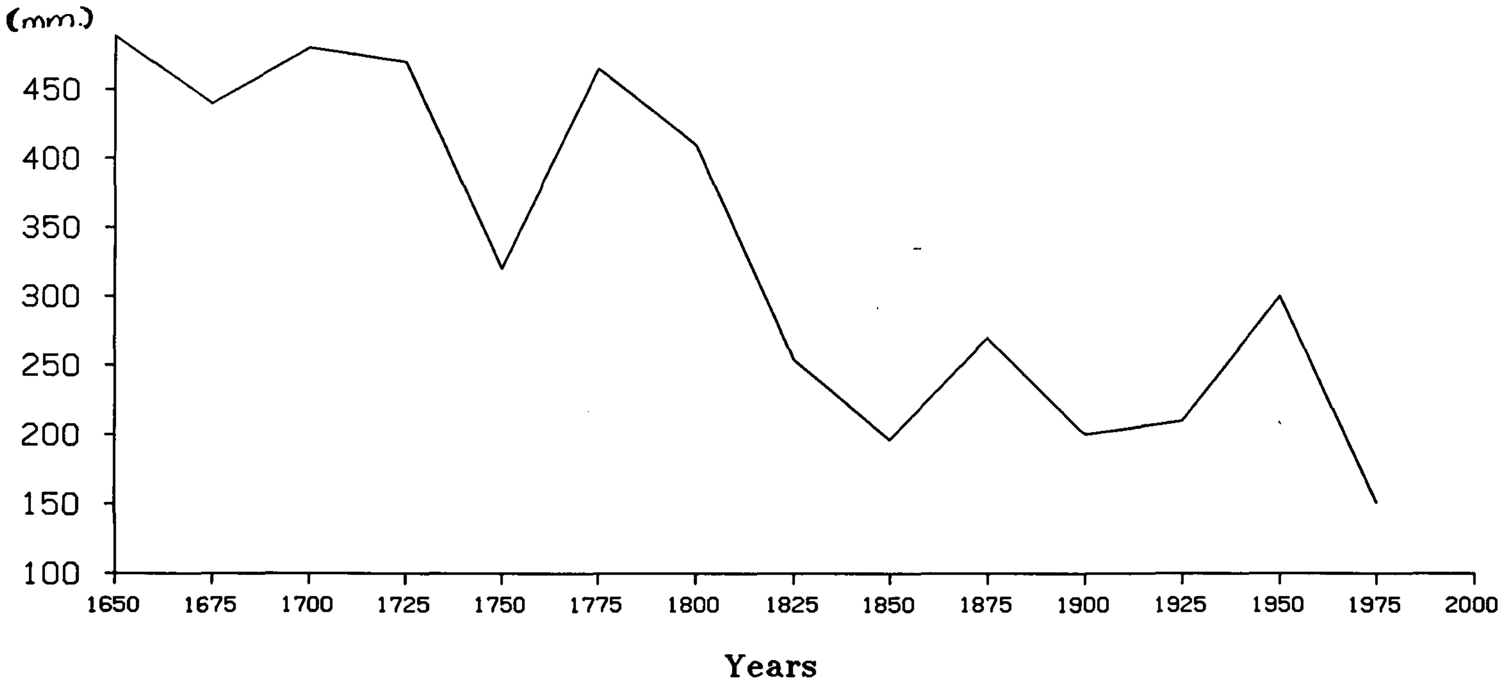
Among all of the physical factors, climate stands as the major one affecting and continuously reshaping the vegetation of the earth surface through its various elements of moisture, temperature, sunlight and wind. It is the moisture, in the form of rainfall, which plays the vital role in the arid parts of the African tropical environments and, accordingly, any change in its variability is bound to have direct consequences on the area's vegetative-cover.

Meteorological records suggests that the *Sahel* and other parts of tropical Africa had experienced marked changes in rainfall in terms of amount and distribution. It has been demonstrated that, large scale rainfall variability is an inherent feature of the region and deviation from the *average* conditions can persist over long period of time (Nicholson 1976). Available climatic records indicate that several significant climatic fluctuations occurred in the region during the last four centuries.

Major droughts of 6-15 years duration occurred in 1681-7, 1738-54, 1828-39, 1904-18, and since 1968, Fig (5.1). Minor and more localized droughts occured in the 1640's, 1770's, 1790's, and the 1940's (Nicholson 1978, NRC 1983). However,

Figure 5.1

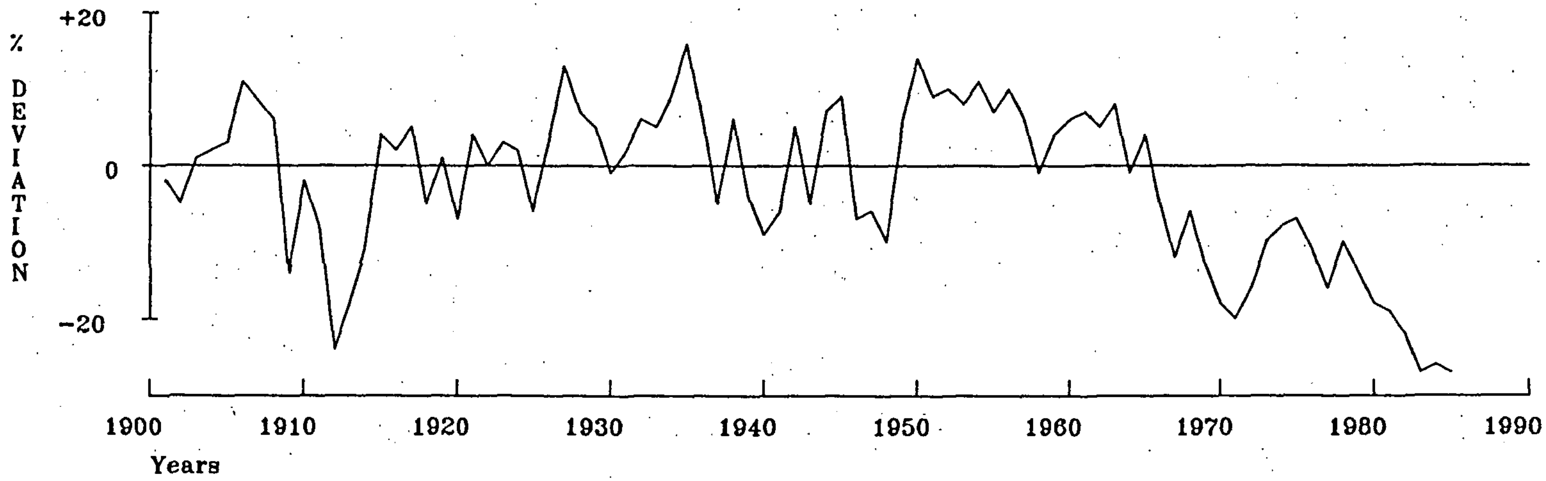
Probable Long–Term Rainfall Trend in the Sahel & the Sudan



Source: National Research Council of USA, 1983

Figure 5.2

The Percentage Deviation of Annual Rainfall around the Mean in the Sudanian Zone (1901–1985)



Source: Modified from Nicholson 1976

relatively wet periods occurred in 1760-69, 1789-98, and during the 1950's. By the end of the 19th century, however, a marked change towards aridity began throughout the African tropics. Rivers and depressions were reported to have dried out and rainfall in the region progressively diminished. The desiccation culminated in a severe drought which reached a climax around 1907 and persisted for about a decade. This appears to have been the climax of a dry period which plagued much of tropical Africa and the sahel. Nicholson (1976) reported Chad and the western parts of Sudan as the most badly affected areas, and locally the devastation made by this drought is still being remembered by the inhabitants which had become part of their heritage. A less intensive and less widespread drought occured in the 1940's. Following a period of greater rainfall in the 1950's, drier conditions prevailed again in the early 1960's. By 1968 the impact of drought was felt again throughout the region. This drought continued with some ameliorations in 1974-76 into the 1980's.

Rainfall was consistently high in the 1950's and stood as much as 20-30% above the mean in the region, Fig (5.2). Conditions changed abruptly around the year 1960 when rains started to decline sharply to reach its lowest in 1973. During this year, rainfall was about 40% below the mean. Thus, rainfall during the 1950's may be more than twice that for the period 1968-73. The years 1974-76 were relatively better than the preceding ones. From 1977 through to the 1980's, there were consistently dry conditions, with the seasons 1982-1983 apparently matching the worst years that were experienced earlier in this century, Fig (5.2).

Due to the sparse distribution of meteorological stations in Kordofan in general and their absence in the study area †,data from the neighbouring Elobied and

† There is a rainfall gauging station in Khuwei but readings were said not to done accurately and

EnNahud meteorological stations were used to monitor short-term variations in rainfall in the area during the period 1950-87, Fig (5.3). The manipulation of the data for these years showed the following summary for the two stations.

Table 5.1: Rainfall characteristics in Elobied and EnNahud

Station	Latit.	Long.	Mean	STD	CV
Elobied	13 12 N	30 13 E	317mm.	119	37
EnNahud	12 34 N	28 12 E	350mm.	113	34

Source: Meteorological Office, El Obied

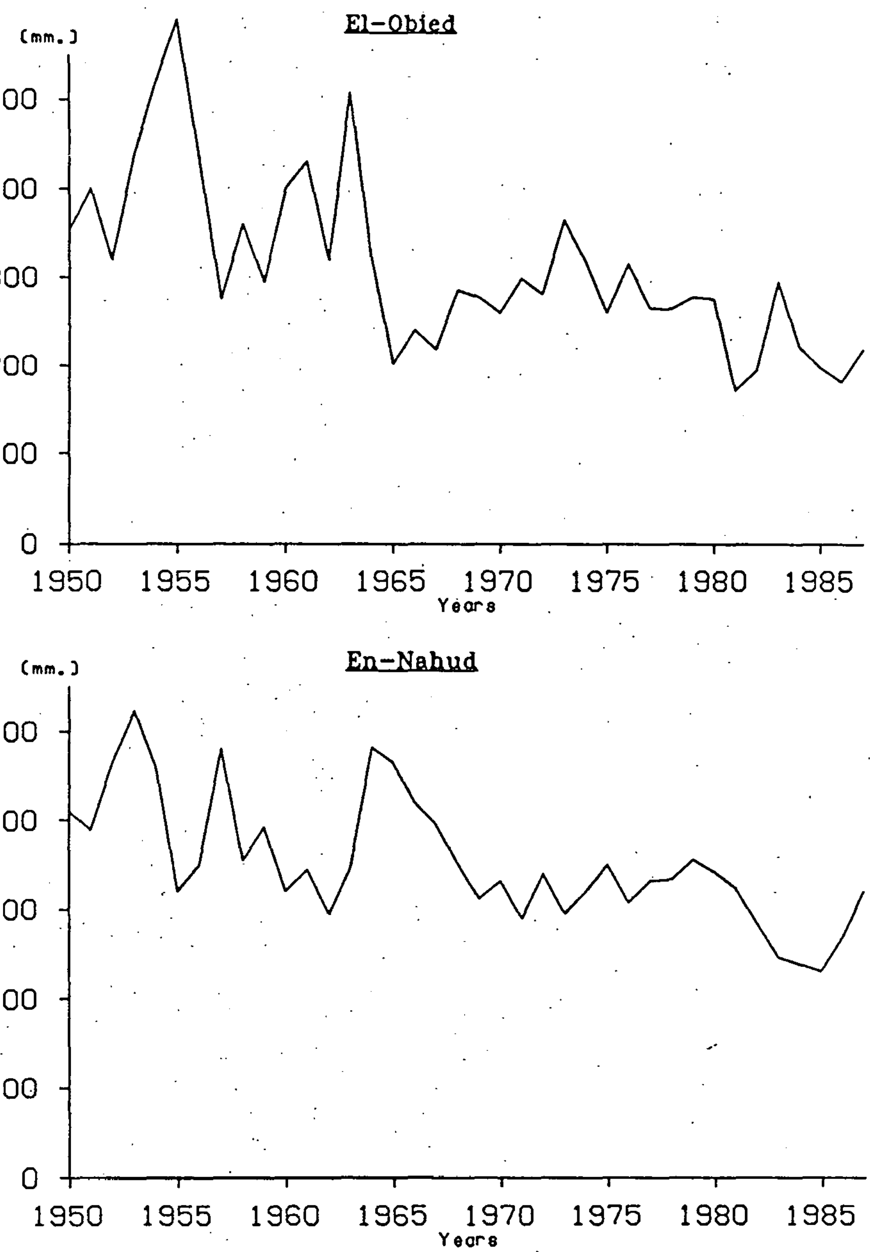
The degree of variability is indicated by the standard deviation and the coefficient of variations. The results show a high degree of variability with a mean annual coefficient of variation as high as 37%.

Obviously, rainfall plays a vital role in vegetation growth and, accordingly, the types of vegetation developed in the area are assumed to reflect a close correlation with rainfall amount and distribution. As shown in the last chapter, the overall distribution of vegetation in the southern parts of the study area, where conditions are relatively wet, shows a near regular pattern, whereas in the more arid areas of the north, the distribution shows a more contagious pattern with greater densities found only in hollows where moisture conditions are relatively better. The ecological amplitute of most species in the region are rather striking. There are species that range from the borders of the desert with rainfall as low as 100 mm. into savanna with rainfall exceeding 700 mm.. However, the ecological niches throughout this distribution range are very unequal. While in the dry areas of the north,

most times based on personal estimate and for this reason it was excluded

Figure 5.3

Rainfall in En-Nahud & El-Obied



Source: Meteorological Office, El-Obied

plant species cluster in dunes and water retaining sites, they occur in the wetter parts of their range on the sandy plain. With more rainfall to the south, again they become restricted but this time to dry lands as they become less capable of tolerating competition against other species on the plain. Along this climatic gradient, the sequence recognized is that, the drier the climate the more the species become restricted to the damper sites and the damper the the climate the more they become restricted to the drier lands. Within this geographical range, where the distribution of a species or group of species is near to a random pattern or where the departure from randomness is small such a site assumes the best niche for the species in question.

However, the frequent shift towards less rainfall, can by itself transform the ecological equilibrium described above, for the increase in aridity index, theoretically, is bound to shake up these biotopes and gradually to confine species' geographical ranges. To quantify such changes, a long-term vegetation measurement along this climatic gradient is required to monitor habitat and species behaviour, a task which is beyond the time scope of this research. However, the evidence obtained at this level suggests that there are quite a number of species showing different signs of struggle and inability to draw in sufficient moisture, while yet others appear to have been favoured by the situation.

In a hundred 10 × 10 metre samples on species abundance taken from the different vegetation stands surveyed, the results showed that for certain species there were far less seedlings and younger age classes than mature ones, Table (5.2). The distribution of these seedling show a more contagious pattern than the parent trees which exhibit a near regular pattern over the sandy plain. However, for another group of trees the sequence seems to be reversed with more seedlings and younger age classes than mature ones and, surprisingly, the distribution of seedlings shows an inclination towards randomness†.

Although this is not a conclusive proof, the suggestion to be made here is that, the first group of species are water demanding which had become increasingly incapable of competing under such arid conditions and consequently are driven to damper sites. On the other hand, the second group represents drought-enduring species which are well equipped to stand such conditions and accordingly have widened their habitats and bridged over areas previously occupied by the first group of species. The decrease in rainfall apparently had resulted in a great reduction in forage production. Again the impact is selective, for species like *Tribulus terrestris* and *Sida cordifolia* were observed to optimize little rains and to gregariously grow in areas extremely unfavourable from soil moisture point-of-view. To compensate for the lack of adequate soil-moisture, these two species were noticed to complete their life cycle during the very short rainy period. For other grasses, especially those requiring a large amount of water, the consequences of of the decline in moisture was found to be a critical one. Cells at the leaf tips were noticed to start dying out, and with little incoming moisture to relieve the situation, this spread to the base of the grass which eventually turns yellowish within a short time. The idea obtained here is that, increasing aridity has transformed the geographical ranges of these grasses and has favoured the growth and spread of faster growing and drought-enduring ones at the expense of others which remain unchanged only in damper places where they can successfully draw in sufficient water. The most significant thing here is that, these grasses are killed before completing their life

† The classes, mature, young and seedling are used here in a literal manner to indicate different stages of the growth cycle. Mature comprizes species that had reached the stage of reproduction, seedlings means newly emerged shoots while young species covers species that are half-way

Table 5.2 :The trend of species frquency based on age-classes (%)

(A) Decreasing trend

Species	Frequency of mature trees	Frequency of young trees	Frequency of seedlings
Sylerostachys birrea	78.3	21.5	0.20
Albizzia amara	69.4	05.6	25.0
Terminalia laxiflora	70.4	22.2	07.4
Terminalia brownii	62.1	10.3	27.6
Dichrostachys glomerata	95.5	05.0	00.0
Lannea kertingii	84.2	15.8	00.0
Combretum harmannianum	57.8	17.8	24.4
Combretum aculeatum	62.8	32.7	04.5
Balanites aegyptiaca	64.7	11.8	23.5
Maeura crassifolia	80.0	10.0	10.0
Combretum glutinosum	85.7	00.0	14.3

(B) Increasing trend

Species	Frequency of mature species	Frequency of young species	Frequency of seedlings
Guiera senegalensis	29.5	39.3	31.2
Lannea humilis	29.8	21.4	48.4
Boscia senegalensis	27.2	32.0	40.8
Acacia nubica	31.0	32.8	36.2

Source: Fieldwork measurements 1987

cycles, and in doing so, seeds are rarely produced which greatly reduces the chance of regeneration and ultimately eliminates the species in question. A grass species like *Blepharis linariifolia* which was mentioned by Smith (1949) and Harrison and Jackson (1958) as widely spread over this area, at present it is almost absent except in a depression to the north of Megeisim. In the Sahelian Zone of Senegal, a study was carried out to assess the impact of drought on rangelands in a four year project during a period where the average rainfall declined from 575 mm. to 392 mm. The main findings were that, the effect is selective, and some species have endured the drought, but the dominant grass species *Andropogon gaganus* disappeared and was replaced by the weed *Loudete bogoenus*, Walter (1971).

However, the dramatic damage of drought seems to be associated with the contrasting sequence of relatively wet and extremely dry episodes. Certainly, consecutive years of reasonably good rainfall, as occurred in the 1950's, encourages the growth of forage, herds, and promotes the use of marginal lands which were more safely left under grass. False confidence about carrying capacity of land in such times often grows. When rains finally fail, animals eat every available bite of grass and trees leaving behind wooden skeletons and consequently a desertified land will be created. Moderate rainy seasons immediately following a severe drought can again bring the bogus optimism about land potentiality and eventually the same deadly cycle will be repeated. More elaboration on these aspects will be made in the next chapter.

5.3 Edaphic factors

While moisture is the main climatic element which determines and reshapes the general character of vegetation, variations often arises as a result of particular edaphic or soil parameters of the area. These are namely connected with certain mechanical and chemical properties of soil.

As outlined in chapter two, six major soil types have been recognized in the area, Fig (2.7). The mechanical and chemical characteristics of these soils are shown in Tables (5.3 to 5.8). The following diagrams (boxplots) have been produced to compare the six soil types for several of the most important variables. An explanation of these boxplots is given below. In a normal distribution, the box tails will lie symmetrically on either sides of the median, whereas in skewed distribution, the tails are elongated either way. The boxplot therefore identifies the *core* of the distribution with the upper and lower thresholds indicating extremes encountered from time to time. Values above these thresholds would be interpreted as exceptional and due to odd circumstances.

Relative to their significance to the vegetation of the area, the following conclusions can be drawn from the analysis of the physical and chemical properties of these soils.

5.3.1 Physical characteristics of soils

These characteristics comprise the proportion of sand, silt, and clay in the soil which is particularly significant in determining the quantity of moisture available to plants. Sandy soils drain most of the rain water,thus, allowing only little moisture accumulation, whereas soils with higher clay contents retain part of that water for plant uptake.

As shown in Fig (5.4), Umm Bum, Wad Gerad and El Qubba soils have particularly higher proportions of fine and coarse sand which is explained by their aeolian

Table 5.3: Physical and chemical characteristics of El Qubba soil type

Variable	Median	Mean	STD	Coeff. of variation	Minimum value	Maximum value
C (%)	9	9.0	4.2	11	6	17
S (%)	2	6.5	10.6	42	0	32
FS (%)	30	28.6	3.8	43	14	45
CS (%)	57	49.9	3.1	46	25	76
OC (%)	0.27	0.25	4.3	23	0.18	0.34
N (%)	.015	.016	9.2	19	0.01	0.03
K me/100g	0.5	0.46	8.3	28	0.1	0.7
M me/100g	1.2	1.7	3.8	24	0.2	3.5
C me/100g	2.4	3.0	4.6	37	1.0	7.3
pH	7.8	7.8	5.7	11	6.1	8.7
TEB me/100g	4.2	5.37	3.4	21	1.8	8.4
P pmg/100g	2.25	1.74	2.4	61	0.2	2.6

Table 5.4: Physical and chemical characteristics of Shemeila soil type

Variable	Median	Mean	STD	Coeff. of variation	Minimum value	Maximum value
C (%)	15	15.8	2.0	16	5	23
S (%)	6	7.8	4.8	22	1	16
FS (%)	50	50.8	2.4	31	41	56
CS (%)	25	26.2	3.6	24	21	38
OC (%)	0.54	0.54	7.3	39	0.39	0.66
N (%)	0.03	0.03	1.8	11	0.03	0.04
K me/100g	0.4	0.4	0.2	2	0.1	1.0
M me/100g	4.6	5.7	6.6	61	1.3	10.3
C me/100g	5.0	7.17	11.4	81	1.0	14.3
pH	7.9	7.72	2.7	48	6.0	9.0
TEB me/100g	11.8	14.91	6.1	42	6.2	19.2
P pmg/100g	16.9	16.5	9.1	61	12.5	19.2

Source: Fieldwork data 1987

Table 5.5: Physical and chemical characteristics of Markib soil type

Variable	Median	Mean	STD	Coeff. of variation	Minimum value	Maximum value
C (%)	13	13.3	6.4	21	4	26
S (%)	2	2.3	1.4	61	0	7
FS (%)	43	40.1	3.1	44	19	64
CS (%)	45	44.5	5.4	45	23	64
OC (%)	0.31	0.37	3.6	35	0.2	1.1
N (%)	0.02	0.02	2.1	23	0.02	0.05
K me/100g	0.2	0.17	1.8	39	0.1	0.4
M me/100g	1.1	1.17	2.5	63	0.3	2.6
C me/100g	0.0	0.48	4.1	81	0.0	1.6
pH	5.4	5.7	2.4	46	4.7	7.7
TEB me/100g	1.4	1.70	0.81	22	1.12	2.01
P pmg/100g	2.2	11.9	1.8	37	0.8	18.8

Table 5.6: Physical and chemical characteristics of Umm Bum soil type

Variable	Median	Mean	STD	Coeff. of variation	Minimum value	Maximum value
C (%)	4	7.5	6.2	24	2	17
S (%)	1.2	7.8	13.4	146	0	31
FS (%)	36.5	38.4	5.1	13	18	50
CS (%)	54.5	47.2	8.2	61	8	63
OC (%)	0.37	0.38	1.2	54	0.15	0.78
N (%)	0.02	0.02	3.5	35	2.02	0.04
K me/100g	0.1	0.13	0.3	41	0.1	0.3
M me/100g	1.45	2.05	8.4	128	0.0	6.9
C me/100g	2.55	2.96	4.7	36	0.4	6.0
pH	8.4	7.9	2.1	28	6.8	8.8
TEB me/100g	4.18	5.36	1.7	24	3.27	6.99
P pmg/100g	13.7	14.5	2.4	27	10.4	25

Source: Fieldwork data 1987

Table 5.7: Physical and chemical characteristics of Wad Gerad soil type

Variable	Median	Mean	STD	Coeff. of variation	Minimum value	Maximum value
C (%)	10	10.9	4.6	88	6	24
S (%)	1	1.3	3.5	53	0	11
FS (%)	24	23.8	2.4	44	12	36
CS (%)	66	67	3.2	41	41	80
OC (%)	0.25	0.26	2.8	31	0.06	0.43
N (%)	0.02	0.02	1.6	38	0.01	0.03
K me/100g	0.2	0.26	3.5	22	0.1	0.7
M me/100g	1.4	1.8	0.6	52	0.4	6.1
C me/100g	1.6	2.8	10.2	121	0.8	12.8
pH	7.55	7.47	3.5	24	6.5	8.4
TEB me/100g	4.0	5.8	4.8	61	2.2	7.98
P pmg/100g	1.1	2.2	2.4	42	1.1	6.2

Table 5.8: Physical and chemical characteristics of Wad Sharef soil type

Variable	Median	Mean	STD	Coeff. of variation	Minimum value	Maximum value
C (%)	21	23.8	7.7	129	9	45
S (%)	9.5	13.3	8.6	98	1	35
FS (%)	21.5	24.5	10.2	53	15	49
CS (%)	43	39.5	6.4	66	6	74
OC (%)	0.75	0.76	3.1	8	0.52	0.98
N (%)	0.04	0.04	0.6	19	0.02	0.06
K me/100g	0.6	0.7	1.5	18	0.2	1.8
M me/100g	0.6	2.3	4.9	61	0.2	11.5
C me/100g	6.9	7.7	2.7	64	2.8	14.6
pH	8.6	8.6	1.3	14	8.1	9.1
TEB me/100g	8.3	12.6	4.5	64	3.9	28.2
P pmg/100g	7.9	10.4	6.8	144	2.0	33.8

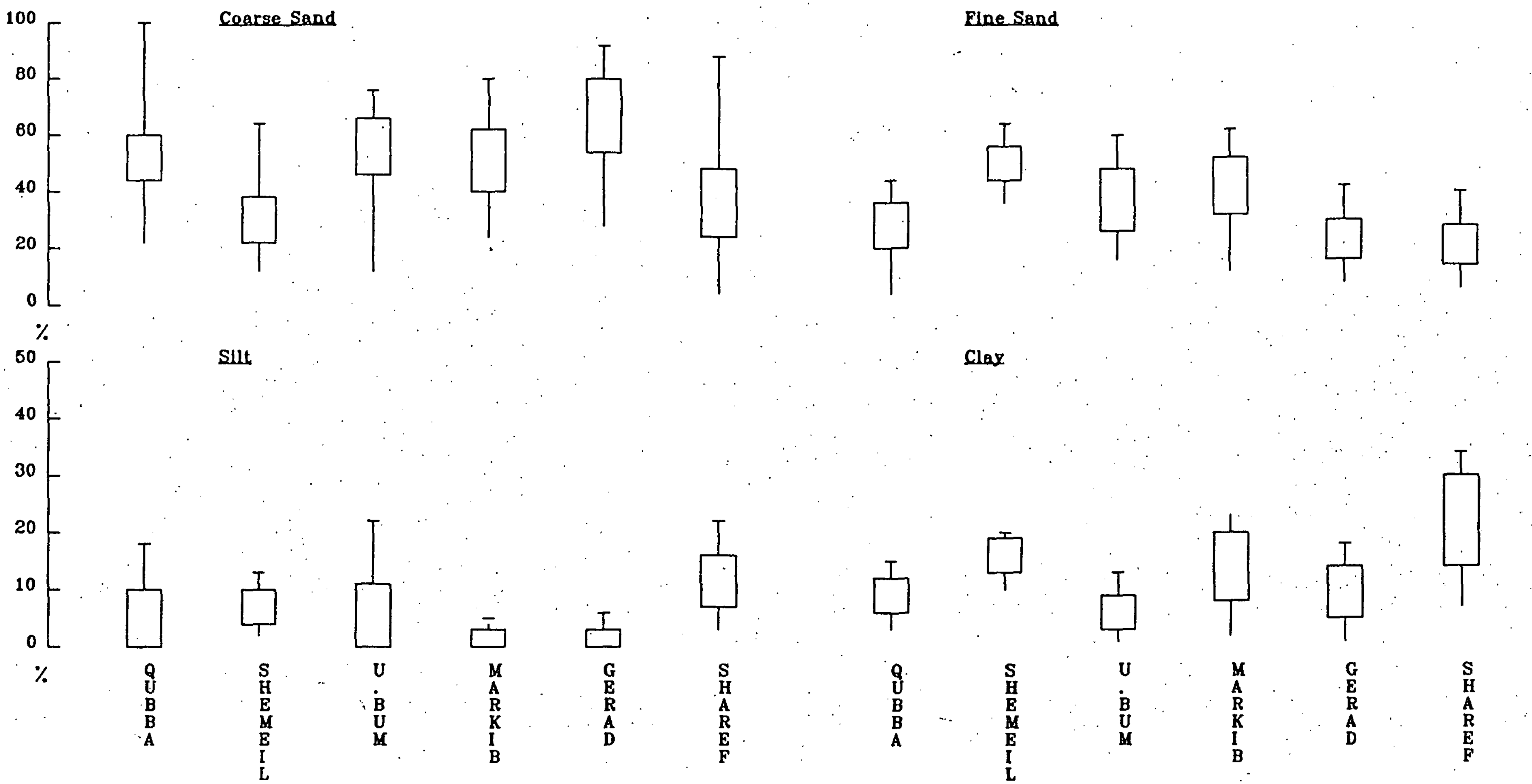
Source : Fieldwork data 1987

origins, while the relative high silt and clay contents of Wad Sharef indicates its alluvial-colluvial mode of origin which is found mainly along seasonal watercourses and in low lying water retaining sites. The general low level of clay contents in the area as a whole is partially due to the very low rate of chemical weathering. Throughout the area, plants suffer from lack of water due to low rainfall, but the shortage in Umm Bum, Wad Gerad and El Qubba is particularly extreme. Because of their coarse-textured soils, the availability of moisture becomes so reduced that artificial droughts frequently occur giving sometimes the wrong impression that the average rainfall has decreased even during fairly wet seasons. These droughty conditions have favoured the development of a particular edaphically climax vegetation made primarly of sparsely distributed drought-resisting trees with extensive tap root systems which can reach moisture well below surface levels. The grass-cover is mainly of short life cycle species. With more sands being blown in, the situation gets more acute especially for seedlings which are relatively shallow-rooted and,therefore, more sensitive to drought.

It is only in the inter-dune hollows where a fairly well stocked cover of vegetation grows which is mainly attributed to better soil-moisture conditions. In these areas if we assume that an annual amount of 200 mm. rainfall is to be received and a hollow may collect 20% of the rain water from an area 20 times as large, the plants growing in the hollows would have water available corresponding to a rainfall of 800 mm. This excess in moisture has resulted in a strip-like arrangement of vegetation where a dense cover in the inter-dune hollows alternate with strips that are almost barren of vegetation on these dune crests..

However, Wad Sharef soils, with a relatively higher content of clay, holds more rain water for longer times than the others do which eventually results in a savanna-

Figure 5.4 Mechanical Characteristics of the Six Soil Types



Source: Fieldwork data 1987

like landscape, i.e. trees with grasses in various combinations. As the sandy soil becomes shallow, grasses were noticed to dominate over trees and conversely with the increase in the sandy layer, trees become more abundant while the grass-cover becomes partially confined to higher grounds.

On the other hand, areas with extreme clay contents, as southwest of Ankosh where clay exceeds 60%, remain flooded for considerable months. However, the same areas dry up very markedly during the dry season resulting in an extreme alternations in soil moisture. However, only trees can cope with such a situation and therefore edaphically conditioned tree vegetation develops proportional to the clay content of the soil and the quantity of soil moisture.

5.3.2 Chemical characteristics of soils

This covers a wide range of substances in the soil which are of vital significance to plant growth. The most important ones for plant nutrition will be discussed here and for convenience, variables that have, more or less, similar effect on vegetation will be here dealt with together.

(1) Organic carbon and nitrogen

These are essential for plant growth and are constituents of all proteins. Wad Sharef soil particularly displays relatively high levels for both these variables, which is possibly due to the higher clay content and perhaps other inherent soil qualities, Table (5.8). On this soil, plants grow vigorously in terms of height and luxuriance. *Balanites aegyptiaca*, *Sylerocarya birrea*, *Albizzia amara* and *Acacia tortilis* were found to add respectively 21%, 18%, 27% and 15% more height on this soil when compared to the other soils. Moreover, *Cassia absus* was observed to develop an exceptionally large leaf surface area on this soil and in one instance a ratio of 3:1 was obtained when compared with Wad Gerad soil. These observations, however, seem to be in line with the concept put by Russell (1973) that the amount of leaf area available for photosynthesis is roughly proportional to the amount of nitrogen in the soil.

Regarding the other types of soils, there is an overall similarity of very low values, whereas organic carbon is marginally higher in Markib and Umm Bum soils. Generally, it was noticeable that fine-textured soils tend to contain more organic carbon and nitrogen than the coarse-textured ones, Fig (5.5).

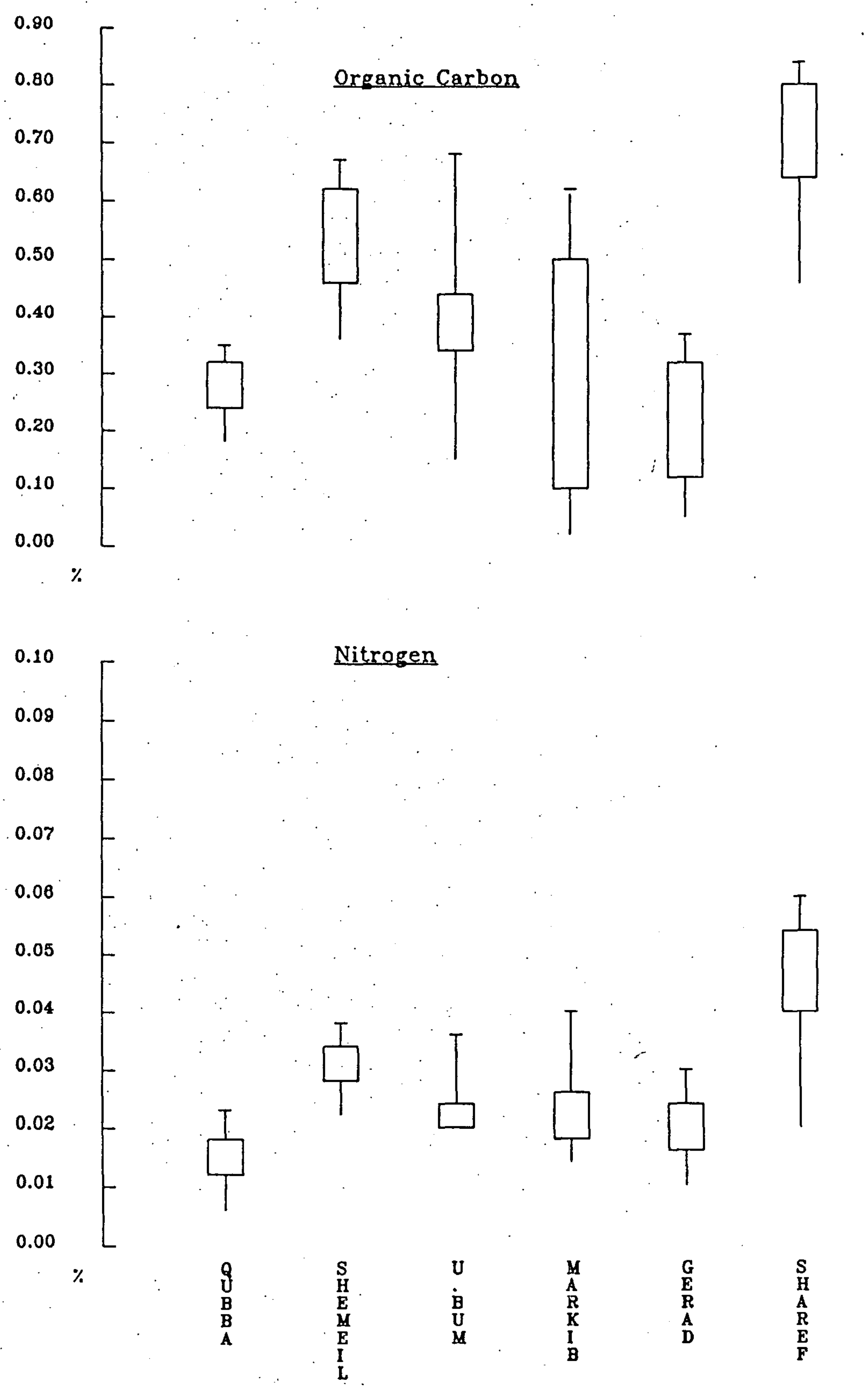
(2) Phosphorus and potassium

Again these are essential elements in the nutrition of plants. Phosphorus values in all six soils are very low and neither show a clear pattern of distribution nor a relationship to clay or organic carbon. Shemeila and Umm Bum soils have the highest content of phosphorus with the lowest values encountered in Wad Gerad soils.

Regarding potassium, it is generally held that, tropical soils with content above 0.3 meq are considered well-endowed. Accordingly, while Wad Sharef and El-Qubba soils meet that limit, Umm Bum soil has only 0.1 meq. Potassium distribution shows a marked relationship with clay as it increases proportionally with the increase in the clay content. Regarding its importance for plants, Russell(1973) wrote that "*when nitrogen and potassium are simultaneously in short supply, the plants are stunted, their leaves are small and rather ashy-grey in colour, dying prematurely, first at the tips and then along the outer edges*". This, however, possibly explain part of the extremely depleted plant cover on Umm Bum soil which has

Figure 5.5

Organic Carbon & Nitrogen Contents in the Six Soil Types



Source: Fieldwork data 1987

low nitrogen and exceptionally very low potassium content, Fig (5.6).

(3) Magnesium and calcium

While these two elements are not major plant nutrients, they are important soil cations which affect other soil properties. Magnesium is found to increase progressively with clay, Umm Bum has the least and Shemeila has the most. Calcium shows a similar pattern to magnesium with Wad Sharef having relatively higher values which is reflected in its pH. The high calcium and pH figures for Wad Sharef could explain its relative poverty of phosphorus for, as explained by Bradly(1983), phosphorus form relatively insoluble compound with calcium, Fig (5.7).

(4) Total exchangeable bases (TEB)

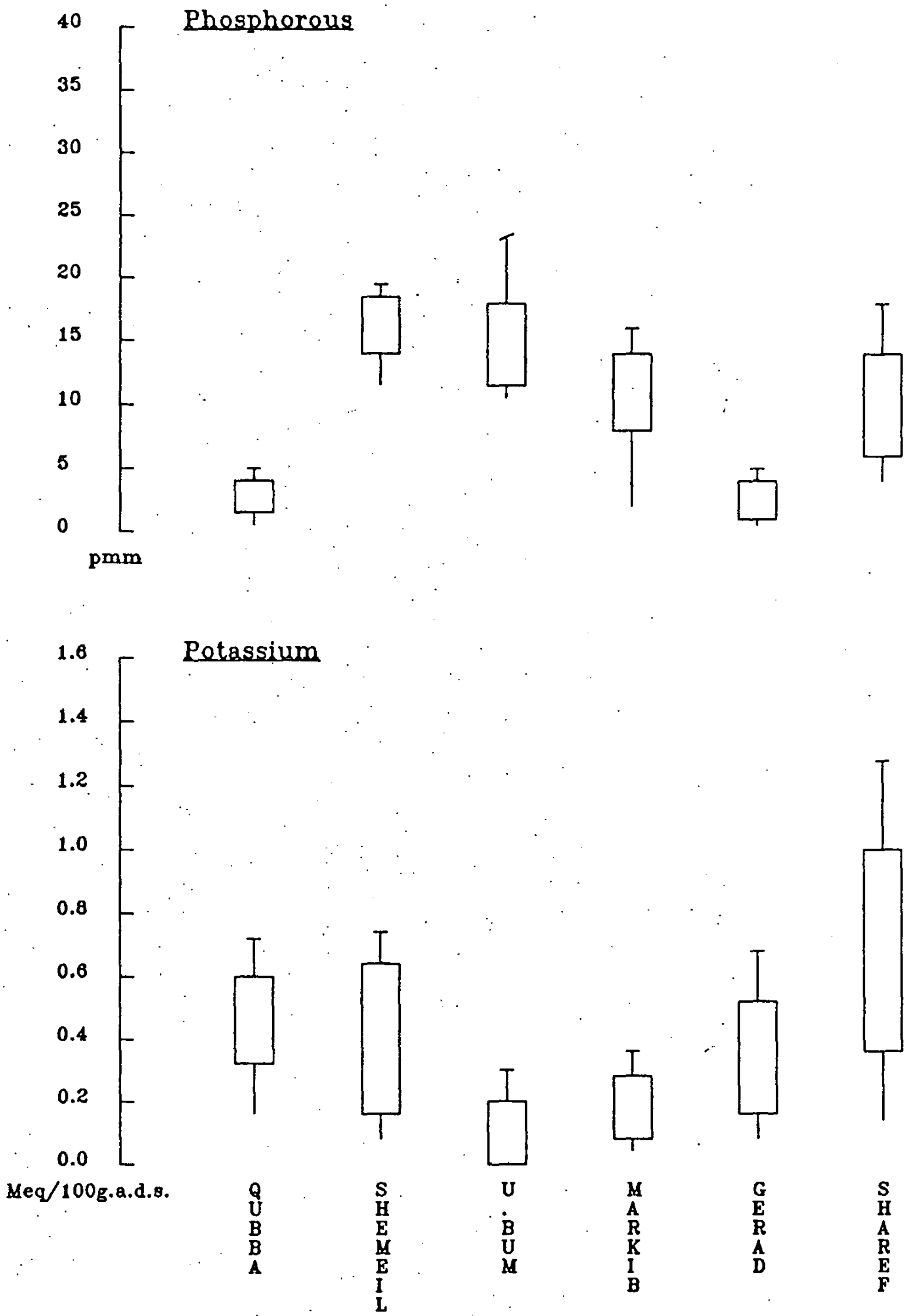
This is the sum of potassium, sodium, magnesium and calcium cations which represents the stock of these important plant nutrients. All soils display very low TEB † content. Markib has remarkably low values (1.7 me/100g), while Wad Sharef with pH=8.6 has only a TEB value of 12.62 me/100g. Shemeila soils, however, have the highest TEB values (14.91 me/100g). There is an overall similarity between TEB and calcium among the six soils. Also there is a trend of increasing in TEB with the exception of Markib soil, Fig (5.8).

The assessment of the actual effects that each individual nutrient exerts on the vegetative-cover of the study area needs extensive soil sampling across various gradients as different plants take up different amount and proportion of nutrients and, therefore, exhibit different reactions to nutritional deficiencies. However, at this level it would be safe to say that the lack of certain nutrients in certain soils is

† TEB is normally measured in the laboratory under conditions of neutral soil reaction (pH=7.0). So where soil is acidic (pH$<$ 7.0), TEB is overestimated, conversely when soil is alkaline (pH$>$ 7.0), measures are underestimated

Figure 5.6

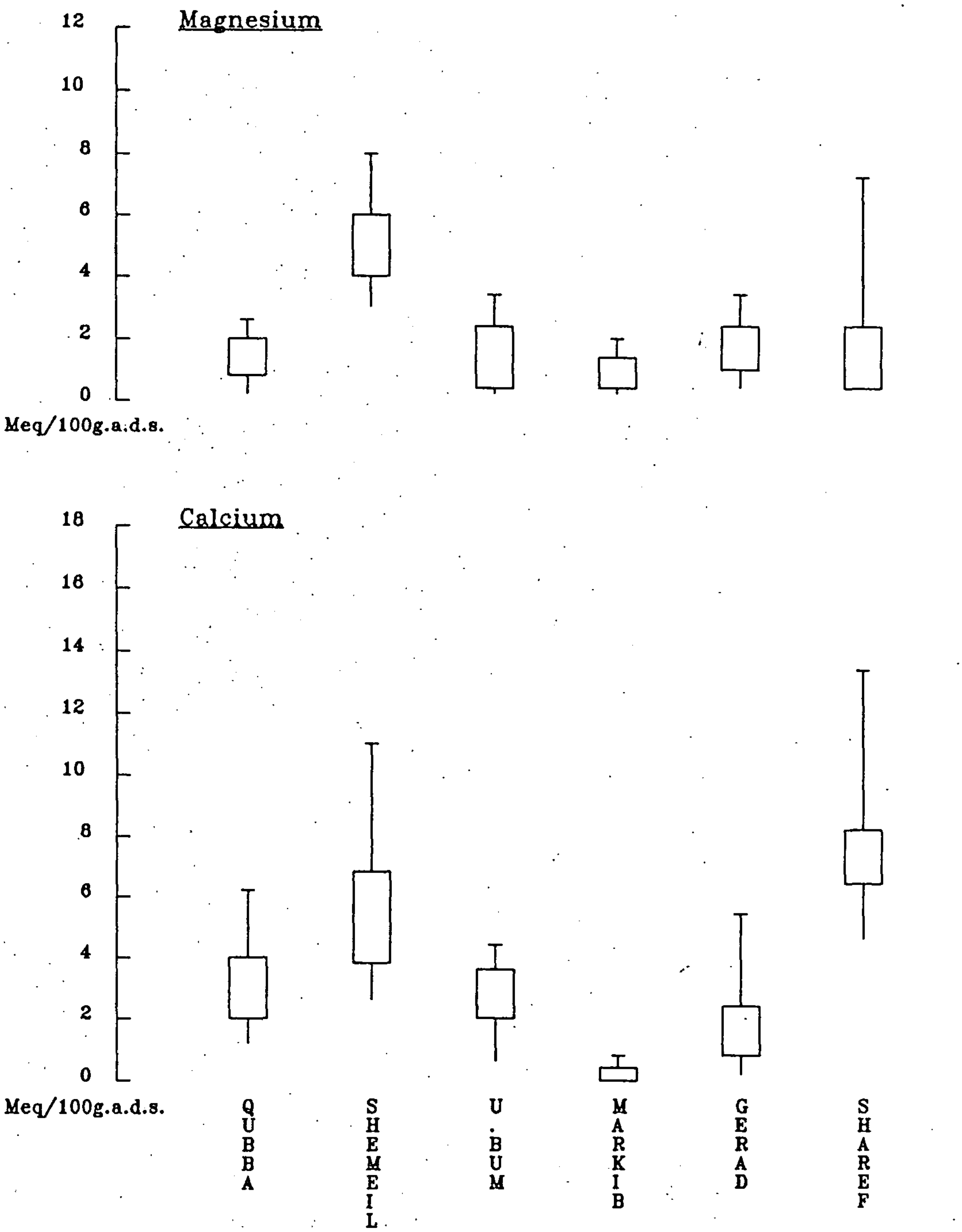
Phosphorous & Potassium Contents in the Six Soil Types



Source: Fieldwork data 1987

Figure 5.7

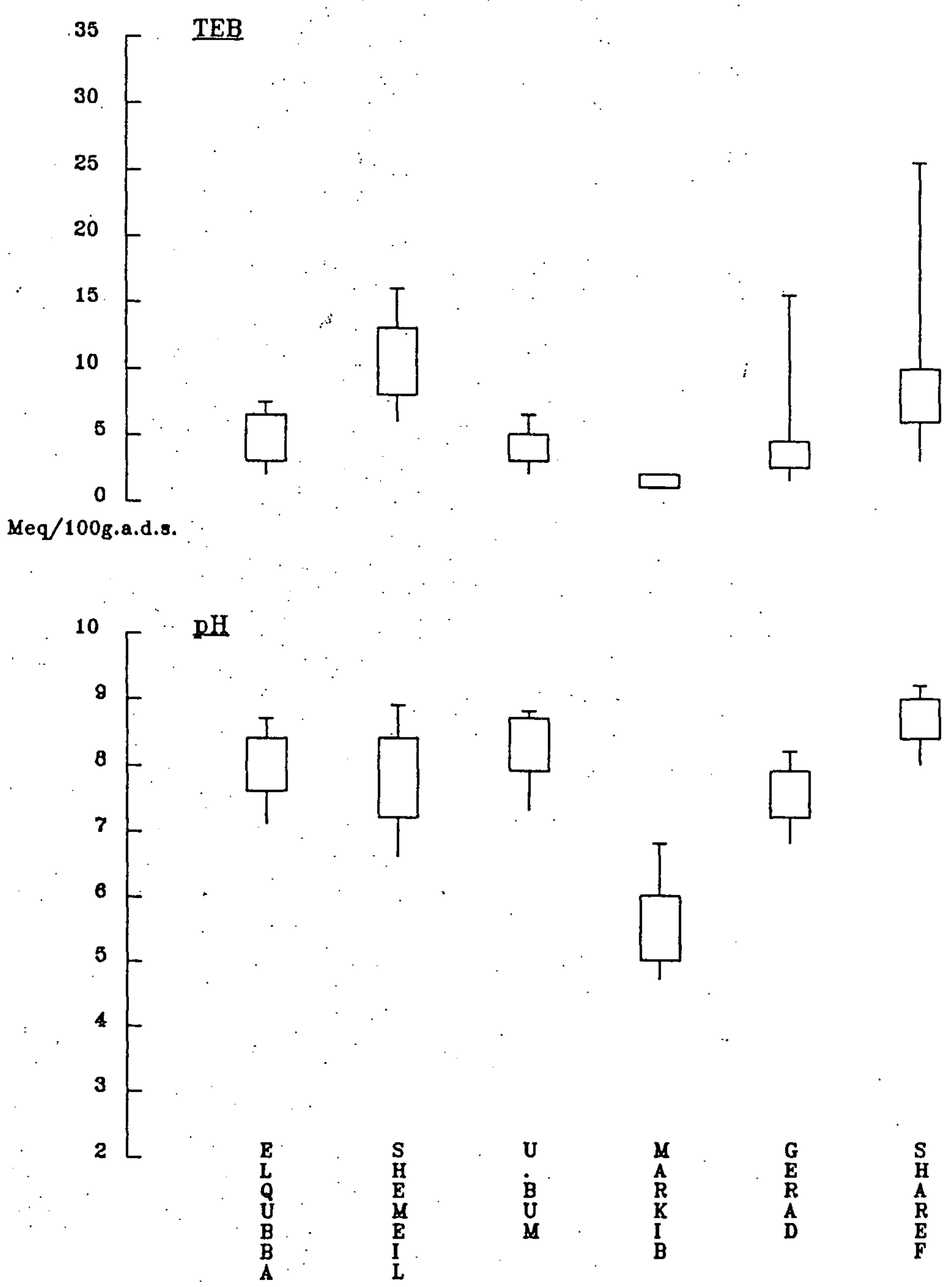
Calcium & Magnesium Contents
in the Six Soil Types



Source: Fieldwork data 1987

Figure 5.8

Total Exchangeable Bases (TEB) & pH Contents in the Six Soil Types



Source: Fieldwork data 1987

the deciding factor in determining the type of plant to grow, though some species seemingly have adapted to such deficiencies. Also the natural slow growth of species like *Boscia senegalensis* and *Balanites aegyptiaca* may be an adaptation to these nutrients deficiencies especially nitrogen and phosphorus.

As a summation to all the properties of soils mentioned above Table (5.9) offers a comparison of the six soil types based on a ranking from one to six across the variables.

Table 5.9: Ranked values for 12 variables across 6 soil types

Soil type	C	FS	S	C	OC	N	K	Mg	Ca	pH	TEB	P
El Qubba	2	4	4	5	5	6	2	4	4	4	3	5
Shemeila	6	1	2	2	2	2	3	1	2	3	1	1
Umm Bum	3	3	5	6	3	3	6	2	3	2	4	2
Markib	4	2	3	3	4	5	4	5	6	6	6	3
Wad Gerad	1	5	6	4	6	4	5	3	5	5	5	6
Wad Sharef	5	6	1	1	1	1	1	6	1	1	2	4

Source: Fieldwork data 1987

If the above ranking is confined to variables that efficiently contribute to fertility (clay, organic carbon, nitrogen, potassium, and TEB), these soils can be ordered in terms of their general quality as in Table (5.10). Figures shown indicate the fertility magnitude of each soil relative to the others.

This overall ranking provides a crude guide to the level of fertility of each soil type relative to the others. Thus Wad Sharef, which is the most fertile soil among the six types, with a fertility index of 156 has a fertility degree as much as twice

Table 5.10: Relative Fertility of the Six Soil Types of the Area

Soil Types	Percentage of variables contributing to fertility						Index of Comparative Fertility
	C	OC	N	K	TEB	P	
Wad Sharef	29.6	30.1	30	30	23.9	12.4	156.0
Shemeila	19.7	21.7	20.1	20	33.6	30.8	145.9
Umm Bum	9.3	14.8	13.3	5	13.5	25.2	81.1
Markib	16.6	12.6	13.3	10	4.4	22.5	79.4
El Qubba	11.2	10.8	10.0	25	13.8	4.6	75.4
Wad Gerad	13.6	10.0	13.3	10	10.8	4.5	62.2

Source: Fieldwork data 1987

as that of El Qubba which has 75.4. On the other hand, Wad Gerad is the least fertile soil in the area with just an index of 62.2.

5.3.3 Biotic factors

These comprise the part played by living organisms in the vegetation character which is as significant as the climatic and edaphic ones. Biotic processes, likewise, appear to have affected vegetation in the area in various ways. The effect of grazing animals is perhaps the most significant as animal husbandary is one of the major human activities in the area. Aspect related to animal grazing will be dealt with in the next chapter in connection with the other anthropogenic processes that operate in the area.

(A) Pests and diseases

It was found that quite a large number of species in the area have suffered greatly from attacks by pests and other diseases. Walter(1971) believes that most species in the tropics are susceptible to such attacks and if the pressure is great enough many species could suffer extinction.

Lannea humilis was noted as the mostly affected species. 10 kms north of Khuwei, a mass death of the species was noticed over an area of approximately 5 square kilometres while other species remained unharmed there. The same observation was also made south of Nasharbu and east of Umm Bum. *Dichrostrays glomerata* was also observed to suffer from pests and diseases especially young age classes, a trend which had eliminated the species from certain communities as shall be shown in chapter seven.

In a study conducted in the gum belt, Saeed (1983) wrote that, ..*Pachemrus spp. and Pruchus cinearis, which are serious pest species, were found in Acacia seeds collected from 15 different sites. These pests immediately destroy the pods and, therefore, inhibit the regeneration of seeds..* 15-25% of the sample seeds collected in that study were found to have been attacked by pests and diseases.

Termite mounds form a common feature in the area. The mounds are usually built around tree trunks and ultimately the tree perishes leaving behind the mound body. However, in the southern parts of the study area, most of the mounds are found around living trees, while further north, the mounds encircle dead trees. Regarding termites feeding habits, Sammani (1983) observed that, they depend on grasses in richer cover areas, but they turn to trees when the grass-cover is seriously denuded. Based on these observations, the appearance of termite mounds around trees in the southern portion of the study area indicates a trend of degradation on the grass-cover spreading from north to south, and that many trees found dead without other obvious reasons could well be attributed to the effect of termites.

The species found most liable to damage by termites is *Sylerocarya birrea* which in the area northeast of Khuwei has started to die out in noticeable quantities as a result. *Dalbergia melanoxylon* is also affected and many tree skeletons were found left behind. Thus the effect is selective and it appears that some species, like *Boscia senegalensis*, may have developed some adaptive characters which enable them to survive the damage as they often found amid termites colonies with no signs of apparent damage.

(B) Competition among plants

This is another aspect of a biotic significance which, as mentioned in the last chapter, had resulted from the coming together of plants in the process of migration and aggregation, Weaver and Clements (1938). Plants compete among each other for water, nutrients, sunlight, and other resources. The lack of adequate soil-moisture coupled with the great deficiencies in nutrients, however, have provided rooms for strong competition between species which varies from site to site following the availability of these resources.

On the sandier soils, where soil-moisture conditions are extremely unfavourable, plants with shallow lateral roots and no tapping system, have no means of obtaining any water from the soil once the top layer has dried out. The length of the period when water is lacking is, therefore, critical for these plants, and the result is that these plants are progressively pushed to the damper sites by deep-tapper species which ultimately get foothold over these sites. *Balanites aegyptiaca* and

Acacia senegal are examples of these deeply rooted species which can endure dry conditions. However, another group of species, despite their lack of deep roots, have similarly favoured the dry conditions and are found vigorously growing there such as *Boscia senegalensis* and *Calotropis procera.* Competition also occurs between grasses and tree seedlings. Under normal conditions, tree seedlings hardly successfully compete with grass roots and thus, only few survive with the result that the woody cover always occurs scattered. However, whenever the competitors, i.e. the grasses, become destroyed by grazing or fire, quite a large number of seedlings survive with a result a dense thicket develops within a short time.

Competition between plants for nutrients have a similar consequences to that described for water. Extreme deficiency in vital nutrients such as nitrogen and organic carbon have apparently reduced the number of many species, while others which can survive such situations have been promoted and their habitat widened following the shrinkage of sensitive ones. Species like *Boscia senegalensis* and *Guiera senegalensis* were noticed to grow in relatively dense thickets under extremely low nutient conditions without showing any signs of struggle. Such an observation possibly indicate the greater resilience of these species.

Chapter VI

Anthropogenic or Land Management Factors Affecting Vegetation in the Study Area

6.1 Introduction

This set of factors involves the impact of human activities on vegetation. Such activities may be destructive as when trees are felled or when grasses are over-grazed. On the other hand, human activities may be constructive such as when they help in establishing a new kind of vegetation as in tree plantations. In this sense, the anthropogenic processes have greatly modified vegetation in most parts of the world and wherever man got a foothold.

The anthropogenic processes that operate in the study area, as previously outlined, and which induce varying degrees of changes in its vegetative-cover will be assessed here under the following two headings:

(1) Processes related to types of land management.

(2) The uncontrolled biomass harvesting.

6.2 Processes Related to Land Management

The main types of land use found in the study area that directly involve the natural vegetation, as it is elsewhere in tropical Africa, are crop production in a traditional system of shifting cultivation, forestry with particular emphasis on gum production and livestock raising.

6.2.1 Agro-Forestry Practices

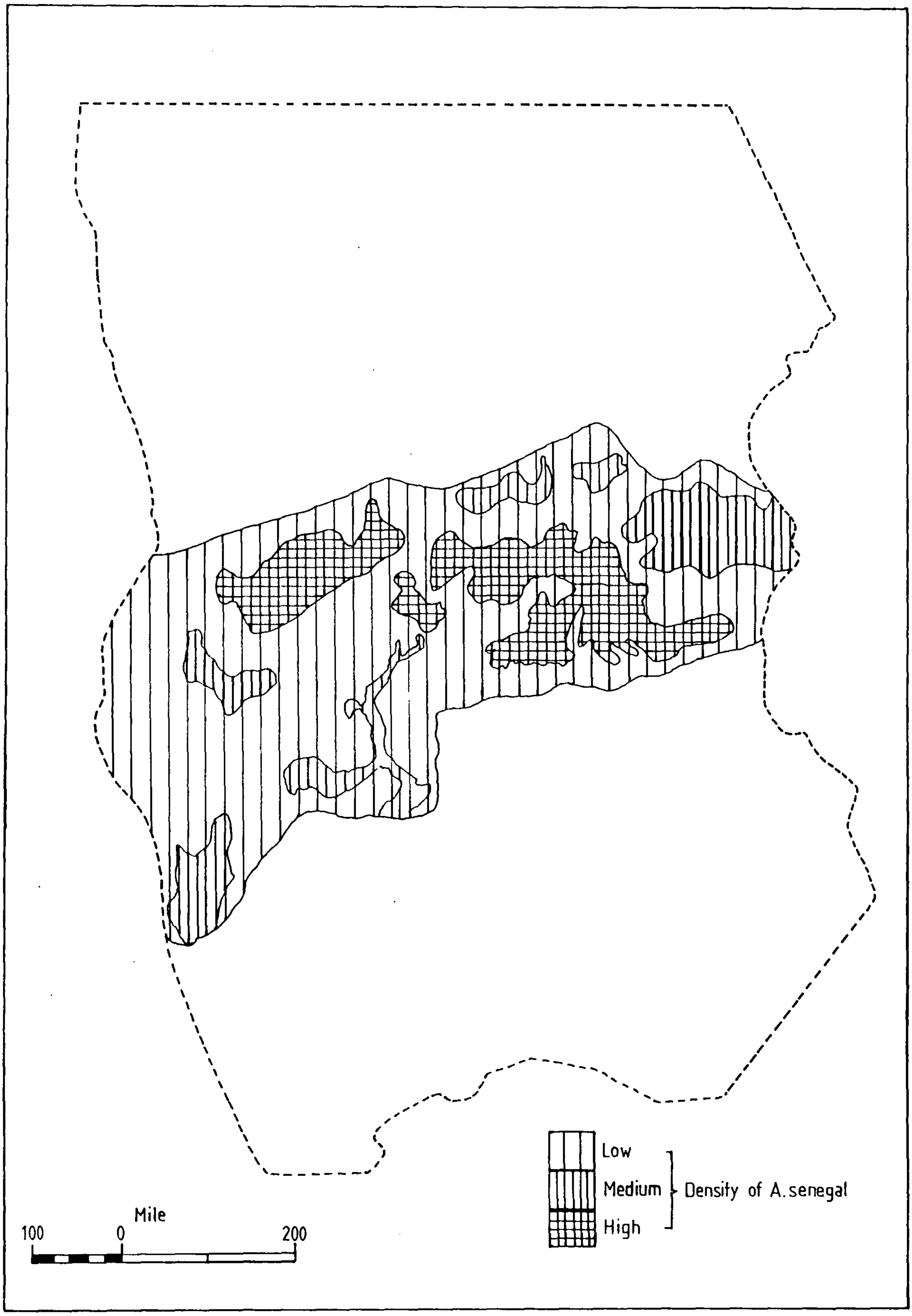
This type of land use involves a standard pattern developed by farmers through which some tree species are being incorporated within the local farming system. These species are mainly of certain economic value for which they are being retained and promoted in this widespread practice.

(1) Gum production

Sudan, in general, is a major producer of gum with *Acacia senegal* as the best producing species. This species has a wide distribution in tropical Africa. It occurs in Nigeria, Senegal, Chad, Mauretania, Somalia, Kenya, Tanzania and Uganda. It was reported by Wickens (1966) to be found as far east as India. Smith (1949) recognises *Acacia senegal* as a component of a continental vegetation belt with a rainfall requirement lying between those of *Acacia mellifera* in the north and *Acacia seyal* in the south. The sandy soil prevailing in this zone is unsuitable for the growth of *Acacia seyal* while the moisture stored is in excess of that required by *Acacia mellifera*. Within these limits, *Acacia senegal* becomes the dominant species. This zone is frequently mentioned as the *gum-belt* crossing the whole Sudan east-west with a width estimated by HTS (1963) as 560 kms. The boundaries were said by Blunt (1926) to be 11°-15° N, with the main concentration between 12°-13° N. However, Vidal-Hall (1961) gave the limits as 10°-15° N, Fig (6.1).

The density of stocking of *Acacia senegal* in the the study area is generally low as compared to other parts of the gum-belt. It is in the northeastern corner of the area that the best stocking is found where regeneration is plentiful. The best of these density classes were measured to be 65 trees per feddan and the average is about 28 trees. Elsewhere, the highest density is as low as 10 trees

Figure (6.1) The Gum Belt in Kordofan



Adapted from HTS (1963), Booth (1966) and Olsson (1985) per feddan†. *Acacia senegal* does not appear to show a marked preference to a particular type of soil other than a deep sandy one, and neither does it seem to prefer a particular contour on the dunes. The present state of distribution indicates that the densest stocking is in the deep light sandy soils with particular concentration in the interdune hollows while the crests have more widely spaced trees. This is certainly due to the fact that, the interdune hollows are preferred for cropping through which the species is being encouraged and maintained. As land provision had become short, this has brought about a change and crests also are now being used with the result that new gum gardens are being established on dune crests. This had particularly happened in areas north and northeast of El Qubba.

Data obtained from farmer interviews showed that gum production is practiced by almost over 90% of the farmers of the study area in a traditional rotational cycle. It consists of a shifting cultivation system where a plot of land is allowed to rest for a number of years under gum trees after being depleted in the processes of cropping. The first report traced on gum cultivation in Kordofan is that of Bond (1918). He described the period of cultivation as 4-10 years after which the land would be abandoned and rest under *Acacia senegal* fallow.

Basically, gum tapping starts when trees are 3-4 years old and continues 6-10 years after which trees would begin to die out after having been heavily tapped. Subsequently, fires destroy the remaining trees and the land is then reverted to undifferentiated bush fallow. In this standard agro-forestry practice, the land is kept under cultivation while the old stumps of *Acacias* keep producing by coppice shoots and cut back during the weeding period. Besides, seeds from trees growing

† A 10 trees density per feddan is the equivalent of an average of 20 metres distance between species

on the adjoining land will thus keep falling on the cultivated plot year after year. The cultivated plot being kept clear from weeds will form favourable sites for the regeneration of *Acacia senegal*. By the end of the cropping period the plot will be fairly stocked with gum trees which eventually forms a gum garden. Cultivation will then be repeated on another plot which had been under fallow.

In this sense, the ideal gum-cultivation cycle is one in which the rotation with cropping is so arranged that a normal series of age-classes is established in the gum. Theoretically, the logical share of land requirement for this is 60 feddans, on the basis that a 15 feddans area is allocated for cropping and a rotation of 4 years, where one quarter of land would be producing food, one quarter under gum of 0-4 years and one half under productive gum aged 5-12 years. This ensures that an adequate period of rest is being allowed to land for restoring fertility and protecting soil against excessive wind erosion. Besides, such a cycle would ensures that a high proportion of the land is continuously under trees from which farmers could get their minor forest needs in addition to gum.

In the past and particularly before the 1960's, farmers used to frequently move their village sites from one locality to another as their farmlands would be nearing the stage of exhaustion in 4-6 years. This, along with the fact that there were better sites to which villages could move into, motivated farmers to continuously change their village sites. The new sites would have been fallow for a long time and would have regained some fertility. The governing factors in these movements were the need to improve crop production and establish a reasonable series of age classes in the gum fallow.

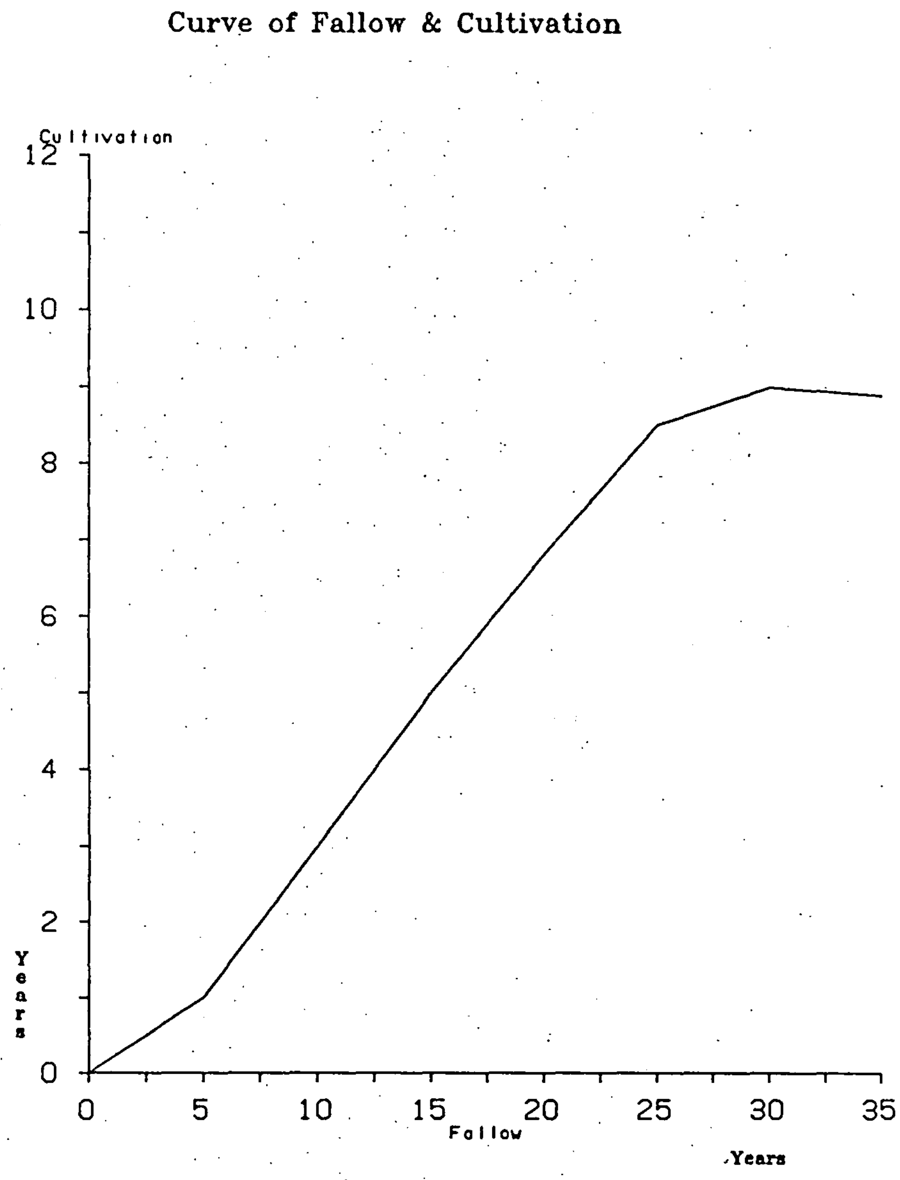
The change to permanent sites of villages, section (6.2.4), made it increasingly difficult and in some places even impossible for the once maintained cycle to be kept working in its ideal form. The value of land for cultivation is becoming high and can not be left fallow for that long period necessary for the establishment of gum gardens, Fig (6.2). Consequently, young gum is being cut very soon while old trees are left out of the rejuvenation cycle.

In the villages surveyed, data obtained showed that, land allotment is unevenly distributed among farmers. The majority of farmers do not have enough share of land to maintain the ideal cycle. Of the 185 farmers interviewed, 177 were found to have less than the 60 feddans required. Accordingly, the old system of 4-5 years cropping followed by 8-12 years under gum, has been replaced by a multitude of systems designed by each farmer to meet his own needs. In areas like Mahboub and Megeisim, where cultivation pressure has not reached that stage, the natural regeneration of *Acacia senegal* is sufficient to maintain a fair stocking.

The most significant ecological aspect that is related to this agro-forestry practice lies in the colonization of an exhausted soil by *Acacia senegal* which ultimately helps in restoring its fertility. The part played by *Acacia senegal* in improving soil conditions could well be documented by the simple example that, after 30 years under *Acacia senegal*, crop production could be maintained up to 9 years to produce what to be considered locally as a reasonable yield, whereas a similar area where the rest period falls below 10 years, a satisfactory cropping would rarely go beyond 4-5 years, Fig (6.3).

To assess the part played by *Acacia senegal* in restoring soil fertility, 10 soil samples of similar mechanical composition were examined in an area west of Umm Bum. 5 of these samples represent land being under cultivation for a period of more

Figure 6.2

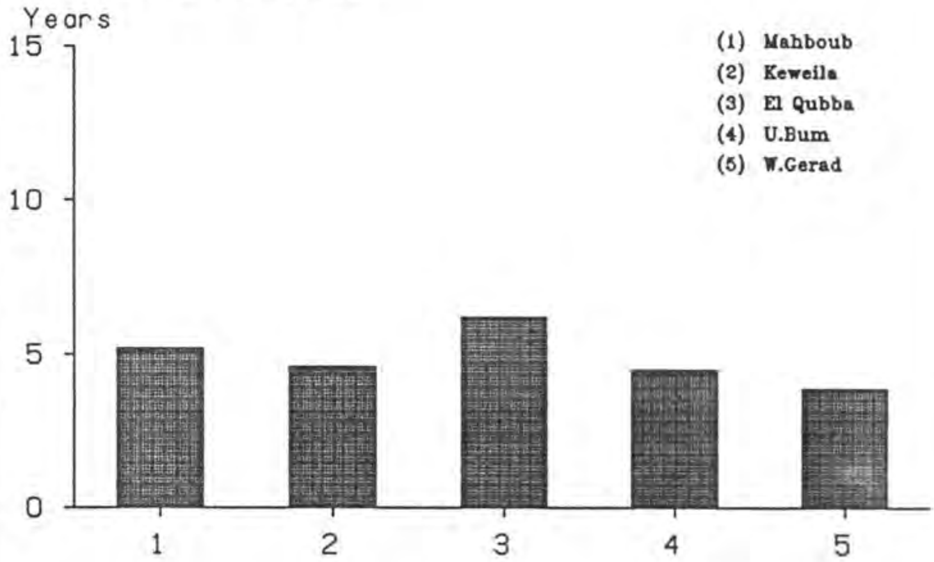


Source: Fieldwork Data 1987

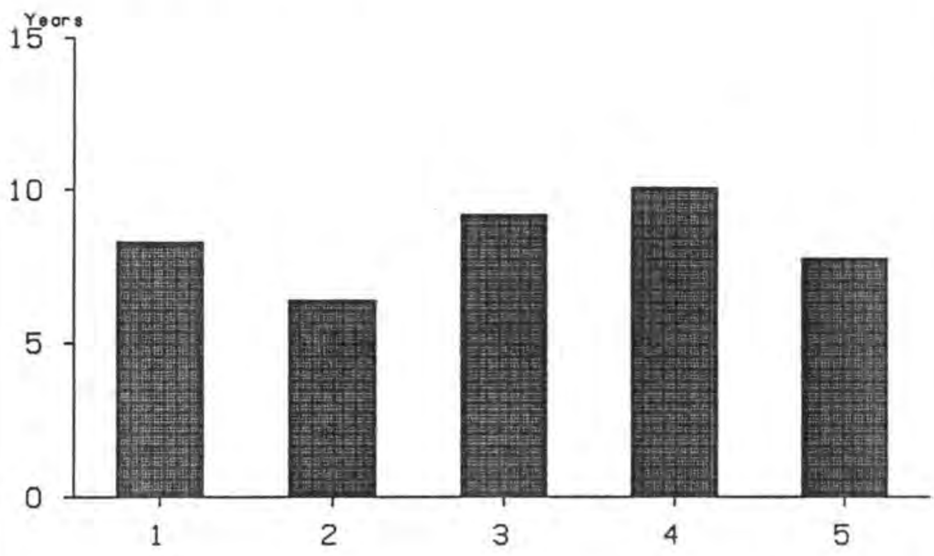
Figure 6.3

Cultivation Under Bush Fallow & Under A.senegal in selected Villages

(A) Under Bush Fallow



(B) Under Acacia senegal



Source: Fieldwork Data 1987

than 20 years, the other 5 from a nearby land which has been under *Acacia senegal* for approximately a similar period. Chemical analysis indicated a considerable increase in the nitrogen content under *Acacia senegal*. It could be assumed here that, this species being leguminous, helps in fixing nitrogen. Another difference was detected in a marked improvement in the very low base status under *Acacia senegal*. This is shown by the increase in pH and exchangeable calcium, Table (6.1).

Table 6.1 : Chemical characteristics of soils under *Acacia senegal* and soils under cultivation (Umm Bum)

Variable	Under *A. senegal*	Under Cultivation
Nitrogen	0.52	0.21
Potassium	0.73	0.34
Calcium	4.61	2.76
Organic carbon	0.43	0.24
pH	8.92	5.15
Phosphorus	4.10	4.00
Magnesium	1.22	0.71

Source: Fieldwork data 1987

A similar comparison was made between another two sets of samples near Shemeila, one is under *Acacia senegal* and the other under weed fallow. The results showed that, the nitrogen content is again higher round the tree, 0.93% as opposed to 0.14% under the weed fallow. Organic carbon increased from 0.18 near the trees to 0.23 at a distance of 7 metres from the tree compared with 10%

for the weed. The increase of organic carbon away from the tree is probably due to the dry leaves being blown away. Potassium also showed a noticeable increase under *Acacia senegal*, 60 mg./100 compared to 20 mg./100 in the weed fallow. Phosphorus showed no significant difference between the two sites, Table (6.2).

Table 6.2: Chemical characteristics of soils under *Acacia senegal* **and similar soils under fallow (Shemeila)**

Variable	Under *A. senegal*	Under cultivation
Nitrogen	0.93	0.14
Potassium	0.60	0.20
Calcium	5.11	4.72
Organic carbon	0.23	0.10
pH	8.32	6.98
Phosphorus	3.90	3.89
Magnesium	1.35	1.34

Source : Fieldwork data 1987

Beside playing a major role in soil fertility, *Acacia senegal* was also found to play an important part in soil conservation and in protecting soil against erosion. The value of *Acacia senegal* is that it is not killed by the repeated cutting back of the shoots during cropping. Coppice shoots grow vigorously as soon as cultivation is abandoned giving protection against excessive wind erosion which lasts for the life of the gum. In the less intensively cultivated areas of Wad Gerad and Keweila *Acacia senegal* is still strongly maintained there with no observed signs of soil erosion. Because of the lack of drinking water both cultivation and grazing are minor, which provided an adequate environment for the growth of a dense grass-cover. The chief causes of serious erosion are, therefore, absent in this area and the fact that the relatively lower trees density does little to reduce wind speed is, under these circumstances, of no significance.

By contrast, in the intensively cultivated areas, a varying degree of soil loss is noticeable which is the inevitable result of exposing the sandy soils to cultivation. Although the degree of this soil loss was not measured, it was estimated that some of the soils are in movement over restricted areas. The sand is trapped by thorn fences around cultivation and the eventual result is the creation of sandy ridges. It was noted that soil from cultivated plots are blown through gaps in the thorn fences and spills out in a delta shape whereas in adjacent gum gardens no such traces were found.

(2) The use of multipurpose trees

A second aspect of agro-forestry nature which affects the vegetation of the area is that, like *Acacia senegal*, another group of trees of particular value are left standing on farms instead of being cut down as done to others. Farmers do not only keep these desirable trees, but were also found to take care of the seedlings. This practice of retaining trees on farms and inside villages is an old tradition which seems to have a strong background. Each individual species retained has its definite values which it is protected for, here are some of the most significant ones;

(a) *Acacia albida.* The National Academy of Science(1975) recognized *Acacia albida* as the fastest growing savanna tree in Africa reaching a height of 3-10 m. in just 3 years. This species has a long lifespan which was estimated by Wickens (1969) as 70-90 years though he mention the species to live as long as 150 years in

Zambia. *Acacia albida* has an extensive tap root which develops rapidly to reach an adequate moisture layer making the species relatively drought resistent. The most unusual phenological characteristic of the species is its ability to retain the green leaves throughout the dry season and to shed them only when the rainy season has started. No other species was found in the study area to possess this reverse deciduous cycle.

Extensive research on the soil enriching properties of *Acacia albida* has been carried out in Senegal and Nigeria. Kirms and Norton (1984) found that all important soil properties improve by the presence of the species. Nitrogen, available phosphorus and exchangeable calcium contents were mentioned to increase from 20% to 100%. In a study by Dougain (1960) in Niger, he wrote that .. *on a 10 cm. depth basis which represents about 1500 tonnes of soil per hectare, the nutrients increase due to the presence of Acacia albida were found to be the equivalent of 300 kg nitrogen, 31 kg phosphorus and 24 kg magnesium amount of fertilizers amendments annually.*

In the study area, *Acacia albida* occurs on bush fallow of cultivated land and is rarely found in areas that have not been exploited by man. Being completely leafless during the rainy season, *Acacia albida* allows crops to be grown underneath without necessarily felling the tree. Leaves growing in the dry season, however, provides a comfortable working environment for farmers during harvest period which incidently coincides with the hot summer. Moreover, the ripening of pods in the middle of the dry season provides livestock with highly nutritious feeds which are readily consumed by all domestic animals. According to Charreau (1974), a dense stands of the tree can provide forage, from pods alone, greater than any local forage on a per hectare basis. Giffard (1964) found that, a wood savanna in which *Acacia albida* is noticeably present, is capable of stocking 20 animal units per square kilometres as compared to 10 units when it is absent.

To sum up some of the beneficial qualities of *Acacia albida*, it improves local soil conditions and increases productivity without the use of expensive fertilizers, it provides fodder of high quality during summer, it provides shade during the hottest period of the year and in the end, *Acacia albida* provides farmers with hard wood which is highly valued locally. It is for these considerations or at least part of them, that *Acacia albida* is being strictly protected and promoted by local farmers. In this context, Gasim (1984) regarded *Acacia albida* as the best species known for agro-silvo-pastoral land use practice, and earlier recognized by Weber (1978) as a focal point for a land management in tropical savanna.

(b) *Adansonia digitata* (the Boabab). This is the second most valued species in the area. The boabab is leafless during the dry season when only its large elongated fruits hang suspended from the branches. With most other species cleared out, *Adansonia digitata* remain to form a characteristic vegetative landmark throughout the region. This species has been used over the centuries as a source of food and fibre, its leaves are harvested and cooked. In some areas the tree is completely stripped of the foliage leaving only a small proportion to keep it alive. The shade is thus reduced to allow for cultivation. The bark contains fibres for making ropes while the fruits are eaten throughout the Sudan which are also highly valued for some local medicinal purposes. But the major usage of the boabab is for storing water in its huge hollowed soft trunk during the rainy season to be consumed later during the dry season. The quantity of water stored was estimated in one instance to be as high as 100,000 litres. By the establishment of more wateryards in the area, there comes a time when the boabab became less valued as water reservoirs and consequently, the damage inflicted upon this species had increased ever since. In the northern parts of the study area, away from these boreholes, the need for water storing facilities made the local inhabitants to continue preserving the species.

There are also additional tree species of particular importance to the livelihood of the people are equally retained on farms. Some are valued for some medicinal properties as *Acacia nilotica* and *Guiera senegalensis*. *Balanites aegyptiaca*, *Ziziphus-spina-christi* and some other few genera are preserved for their fruits. *Boscia senegalensis* which is a drought-enduring shrub, is particularly valued for its fruits during severe drought and starvation. *Acacia tortilis*, as the only tree species growing to a large extent in the drier northern parts, provides the main fodder source for animals which is an enough reason for it to be protected.

6.2.2 Agricultural practices

Shifting cultivation, as earlier mentioned, is the most ideal system for such a dry land environment. Land is allowed to rest under fallow for a number of years in order to regain fertility. Cultivation, done manually, is relatively shallow, the re-burial of some of the weeds improves soil fertility and the light tilling prevents serious erosion. However, there comes a time when several events promote the allotment of more land for cropping with an eventual shortening of the fallow period.

Over extensive areas cultivation has become almost continuous and the fallow is being taken under grass. Although there is lack of tree plantation schemes in this area, self-sown trees of economic value, however, have been intentionally allowed to remain giving the landscape a park-like appearance. On cultivated soils, the woodland has been heavily degraded and locally replaced by secondary thickets and shrubs. Thus the harmful effects of cultivation started when farmers failed to maintain their traditional shifting cultivation system as practiced centuries ago.

(1) Overcultivation

As mentioned in the preceding chapter, rainfall in this area is unreliable and not sufficient for permanent agriculture based on rainfed cropping. Nonetheless, where water supply permits permanent or even seasonal settlement, rainfed crops are grown even where rains are as low as 200 mm. Success, however, is intermittent and even in the wetter phases of the climatic cycle, crops were found to fail at least once every 3 years. In the drier phases they fail completely.

The increase in the number of agricultural population of this area at a rate of 2.8% annually †, has brought additional land into use. Data obtained from the satellite image showed that, about 65% of the study area is in use at present in the fallow-cultivation rotational process compared to 40% for all Kordofan as reported by Sammani (1983). The proportions of land reported by Sammani (1983) that had been under cultivation for the years 1972, 1976, 1979, 1982 was 18%, 16%, 22% and 24% respectively. In 1987 the figure obtained from satellite data is approximately 28%. This shows that, the land under cultivation in the study area has increased from 147,120 feddans in 1972 to 228,720 feddans* in 1987. In addition to that, more lands have also been brought into cultivation by nomads who increasingly adopted the practice of combining farming with their migration.

The frequent failure of the rainy season has forced farmers to increase their

† Population National Census 1983.

* Feddan =0.42 hectare = 1.04 acre.

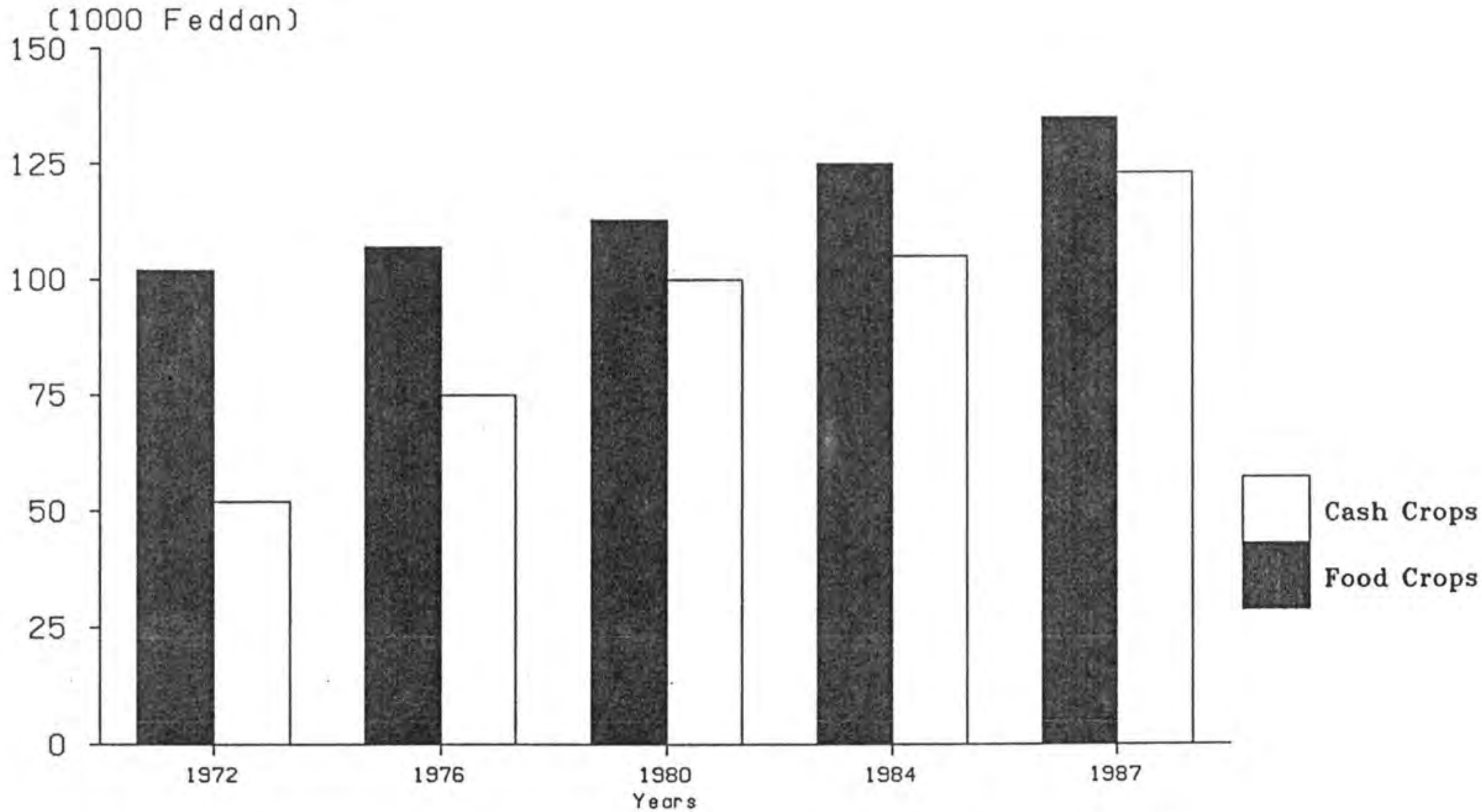
cultivated plots and to distribute them in different directions in the hope of ensuring a reasonable yield. This, however, explains why some farmers often succeed in keeping up food production fairly well in spite of the declining productivity. Meanwhile, as the demand for cash arises and prices increase, farmers are often tempted to focus on growing cash crops rather than meeting their food needs. Figures (6.4), (6.5) and (6.6) show a diagramatic representation of this significant trend based on discussion with older farmers in the area.

An indirect consequence of this agricultural expansion is that it has increased the pressure on the surrounding rangelands as the conversion of more productive forage areas to agricultural production forces animals to overgraze the remaining land-base.

Thus, the damage caused by cultivation on the area's vegetative-cover follows from the degree of pressure exerted on the available arable land. With the fallow period being progressively shortened, land is allowed little chance to revert to its previous state, hence the partially recovered land is brought back into cultivation again before tree growth has a chance to become re-established and eventually a secondary grassland conditions dominate, Fig (6.5), (6.6). The regular alternation of cultivation with too short period of fallow weakens and destroys coppice regrowth and prevents the possible regeneration from seeds. Re-establishment of trees from seeds naturally requires the presence of seed-bearing trees, and since large areas have been devoted to cultivation, there are actually few trees left to produce seeds for germination. Under these conditions, the land is sapped of the natural resilience with which it can maintain its natural rejuvenation cycle. The results, depending on local circumstance, have involved the complete eradication of trees from some areas to major changes in species composition in others. Those areas where the

Figure 6.4

Area Allocated to Food & Cash Crops (1972-1987)



Source: Fieldwork Data 1987

pressure of cultivation has not yet reached this stage, Fig (6.7), have adequate cover of vegetation provided that they escaped other physical and human perturbations.

(2) Fires

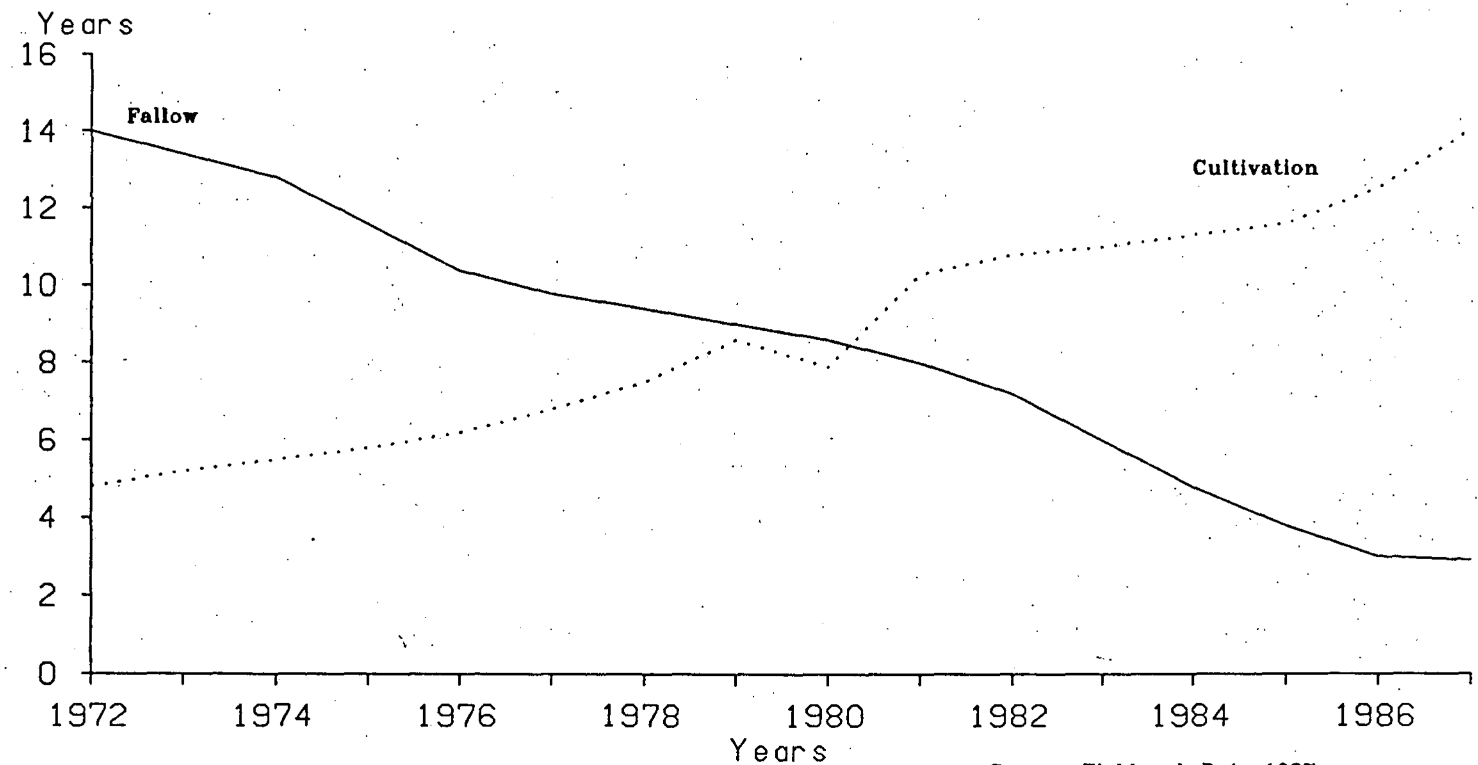
Fire has long been used by farmers as a tool to clear up land from dry grasses for cultivation. This practice has resulted in considerable damage to both soil and vegetation of the area even in the remote and less populated parts of the area.

To examine the damage inflicted on the soil, a number of soil samples from repeatedly burnt and unburnt sites in El Qubba soil type were investigated. The results ,Table (6.3), show that the nitrogen and organic carbon contents of the burnt soils have dropped by 46% and 33% respectively. No significant change was found in phosphorus and potassium, but a decrease of 15% was observed in the TEB content. Thus continuous burning results in excessive soil depletion and nutrient deficiencies and, eventually in a critical breakdown in soil ecology. In this connection, Russell (1973) wrote that *burning volatilizes organic nitrogen compounds, and the excessive leaching of tropical soils during the rainy season results in the loss of salt from ashes of the burned grasses.*

Regarding vegetation, fire has a selective effect particularly on woody plants. Only those species that can either survive a grass fire by having thick bark or those that regenerate from their below ground parts endure fires without serious damage. Old trees are particularly susceptible to damage for often they are already half dead from attack by wood cutters and the dry branches burn easily. The path of fire through middle and younger ages classes does not destroy large blocks of trees, but picks up trees at random burning some completely and leaving others unharmed. Species found to be most vulnerable to damage by fire are *Acacia senegal* and

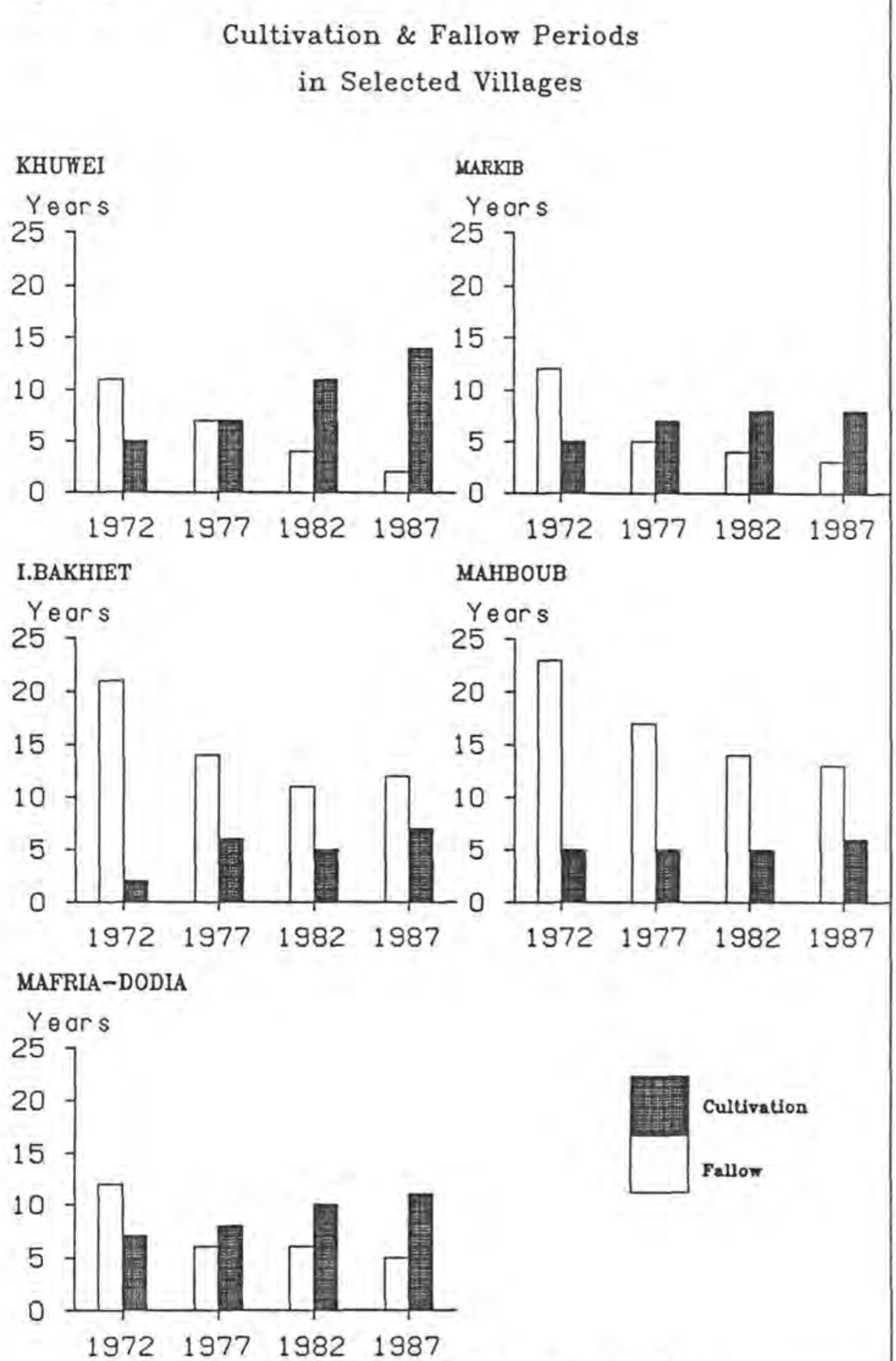
Figure 6.5

The Changing Pattern of Fallow & Cultivation



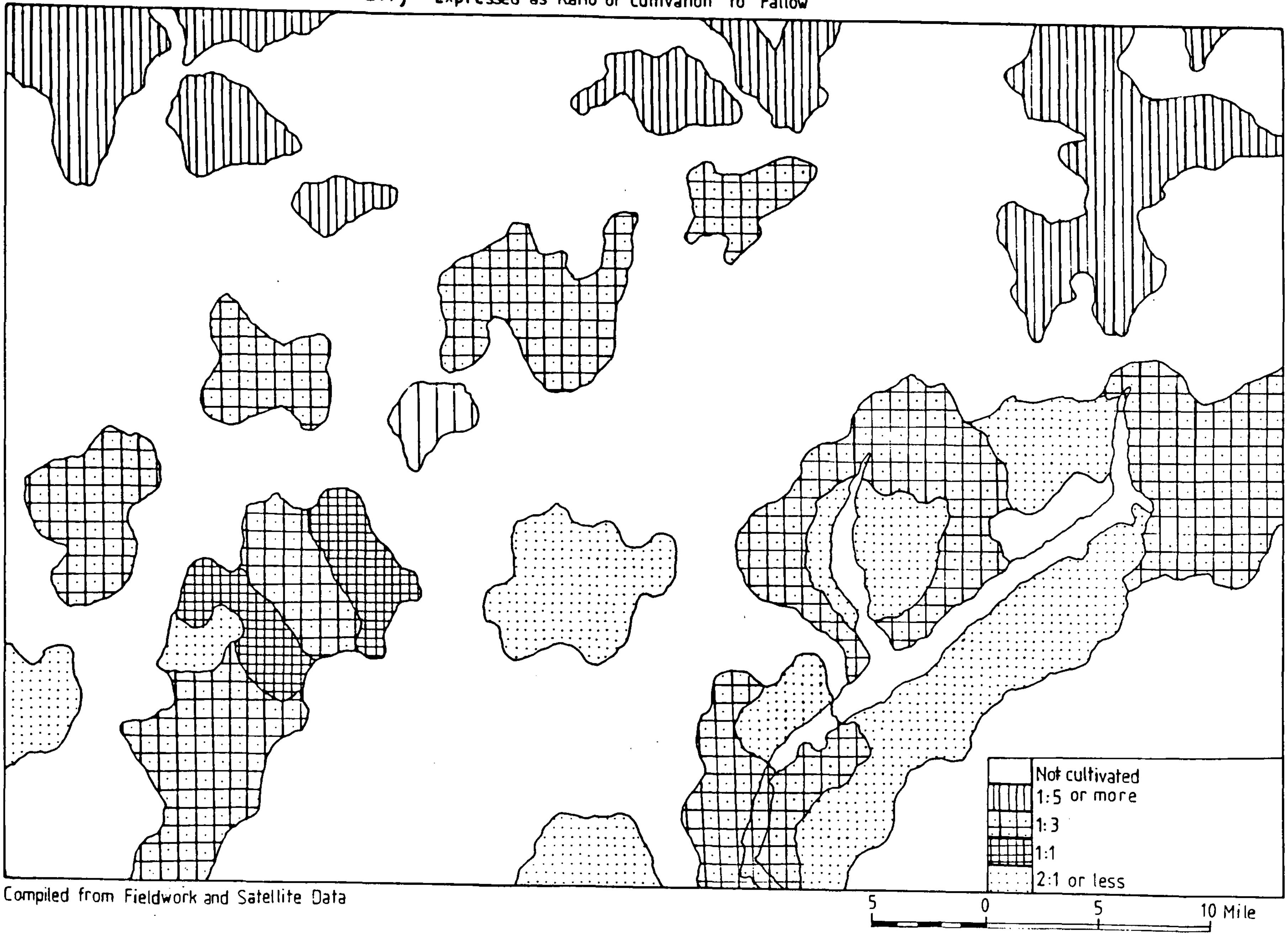
Source: Fieldwork Data 1987

Figure 6.6



Source: Fieldwork Data, 1987

Figure (6.7) Cultivation Intensity: Expressed as Ratio of Cultivation to Fallow



Compiled from Fieldwork and Satellite Data

Table 6.3: Chemical characteristics of burnt and unburnt soils in El Qubba

Variable	Unburnt soil	burnt soil
Nitrogen	0.026	0.014
Potassium	0.46	0.47
Calcium	2.4	2.2
Organic carbon	0.27	0.18
Phosphorus	2.25	2.23
Magnesium	1.2	1.21
TEB	5.83	4.64

Sourse: Fieldwork data 1987

Combretum cordofanum. Repeated fires east and south east of Iyal Bakheit had removed these species and resulted in the reduction of large areas to the conditions of almost grassland with scattered fire-resistent trees. This area is particularly susceptible to fire damage because it is only lightly grazed, whereas elsewhere, the damage of fire is partially reduced due to the removal of grasses by heavy grazing. The main trees found to withstand fires include, *Balanites aegyptiaca, Acacia nubica* and *Maeura crassifolia* which are frequently found scattered over the dense grass-cover. Repeated burning, therefore, results in vegetation equilibrium with a close cover of grasses and a scattered fire-resistent trees. Around Humeir Jabir, where burning was reported to have been abandoned about 20 years ago due to a partial village desertion, shrubs show better development and some forest species remained around in protected areas have started to re-invade.

Regarding the impact of fire on grasses, it was found that fire alone does little damage to them. Perennials are partially liable to be affected as they stay dormant during the long dry season, whereas the seeds of the annuals do survive in the soil to resume another cycle of growth by the start of the next rains. In this sense, fires favour the development of a secondary annual grassland which, as a replacement community, has resulted from the destruction of forests and perennial grasses. Once this grass-cover has become established, repeated burning will cause its spread into neighbouring areas.

The destruction made by fire was found to increase in areas where grazing animals are driven onto burned lands. It was observed that, animals prefer burned over areas where the new grass shoots appear. Consequently, the better fodder grasses in particular are so heavily exploited that the poor species eventually become dominant. This had especially happened round Markib which is among the major grazing lands. As a result, an overgrazed, secondary vegetation composed of thorny short shrubs and annual grasses has become established round such areas.

6.2.3 Animal pasturing practices

The gross effects of domestic livestock on rangelands are almost entirely due to overstocking, i.e. when livestock requirements exceed the productive output of the range. Because animals are primarily consumers, high number of livestock eventually leads to noticeable changes in the structure and composition of vegetation. These changes are nearly always in the direction of reduced phytomass, low production and more xeric conditions.

The general feature of grazing in the study area is that, there are far more animals on the poor grazing land than the latter can safely carry. This is linked to a number of socio-economic factors. For the nomads, animals provide most of the food consumed and for them and for others, animals represent capital and a form of insurance against adverse conditions like drought. For settled subsistance farmers, animals are a source of cash particularly in the light of frequent crop failures. Labour working for cash salaries in other regions and abroad, often invest their earnings in buying more animals.

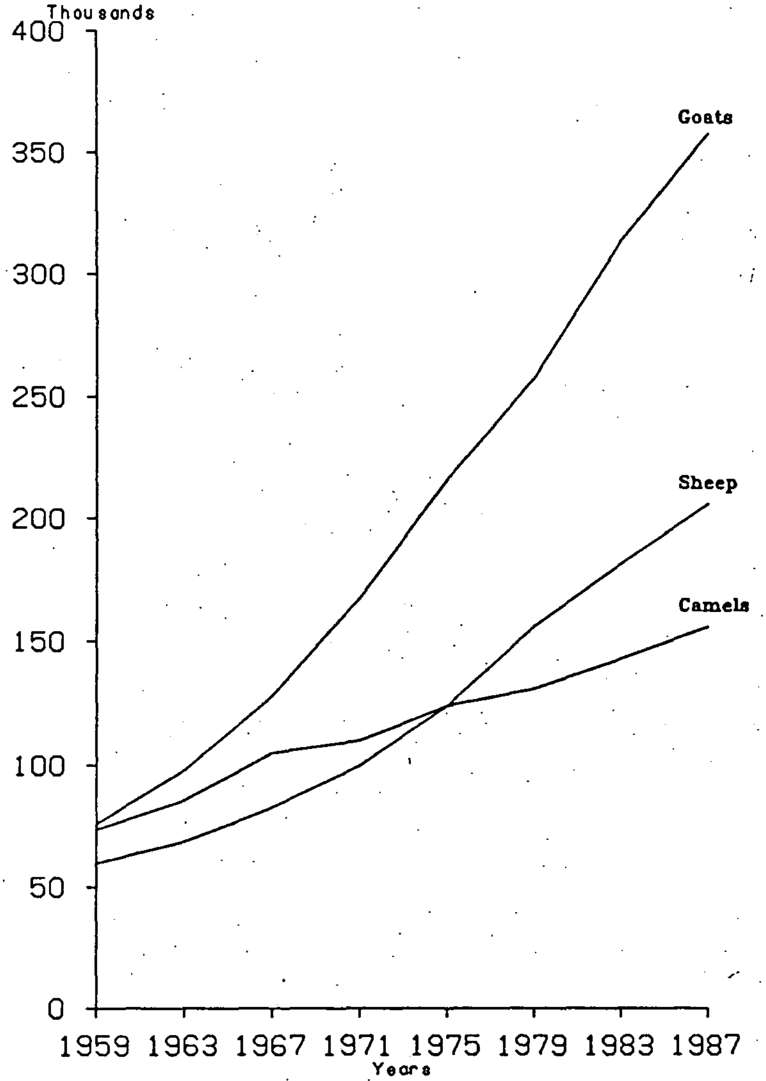
The many efforts made in this area to improve the livelihood of people had greatly upset the traditional grazing pattern which had been working over centuries. For instance, the introduction of veterinary services and vaccination have lead to a tremendous increase in animal population which is estimated to have grown by at least four times during the last three decades, Fig (6.8). Moreover in the attempt to improve the situation, the government had provided quite a number of artificial water supply centres in the area. This step has allowed animals to survive in areas that are otherwise too arid at times to support them, and ultimately the spread of the impact of intensive grazing had reached areas that would be only lightly grazed. Besides, animals began to concentrate during the dry season in densities much higher than the normal permissible stocking rate.

Various animals, because of their variety in size and diet preference, were found to differ in the pressure they exert and in the patchiness they cause to vegetation. In order of the number of animals in terms of grazing units are, camels, goats and sheep. Camels are primarily browsers, feeding on tall thorny shrubs and trees. Goats are both browsers and grazers and exist on anything that is not absolute desert. Fisher (1944) recognizes goats as the most destructive animal in Western Sudan. Sheeps are essentially grazers, they are, however, handicapped by their inability to stand upright on their hind legs like goats, but they were noticed to do so when it is needed to survive.

Depending on their pressure, animals affect vegetation of the area at varying

Figure 6.8

The Growth of Livestock in the Area
(1959–1987)



Source: Animal Resources Dept., El-Obied.

levels from destruction to barely discernible interaction between the two. It is within reach plants and the juiciest ones that are most liable to attack. The effect of grazing is, thus, to tip the balance in favour of those species which are little relished or favouring the growth of other species by curtailing their serious competitors.

The pattern of grazing prevailed in the past appeared, more or less, rational as grazing animals spread across the whole area as far as drinking water exists which was mainly found in depressions and water retaining sites (fulas). This has resulted in a continuous mobility of animals and ultimately in a cyclical pattern of grazing. This cycle, as schematically represented in Fig (6.9), appears to have been an *ideal* formula of grazing in such arid lands. It was ideal because it allows plants the time necessary to grow and flourish after having been grazed.

This ideal pattern of grazing has been disrupted and replaced by permanent and semi-permanent grazing especially near artifical water supply centres. This had lead to an all-year-round concentration of animals which could not but reduce the potential output of grasses and trees.

Based on the number of animal units present and the distance they can travel to look for pasture, it was found that, the pattern of grazing intensity round these areas, Fig (6.10), declines from 8 animal units per feddan at the outskirts of the water source to under 2 units at about 20 kms. Palatable grasses are depleted and so too are the perennials with a noticeable increase in resistent and avoidable ones. Grazing was also found to cause a greater variety in the flora, as many species and even rare ones like Khara hausa†. are able to maintain themselves where otherwise

† This is a local name, its Latin equivalent is not known and it seems not to have been previously identified in the entire western Sudan region

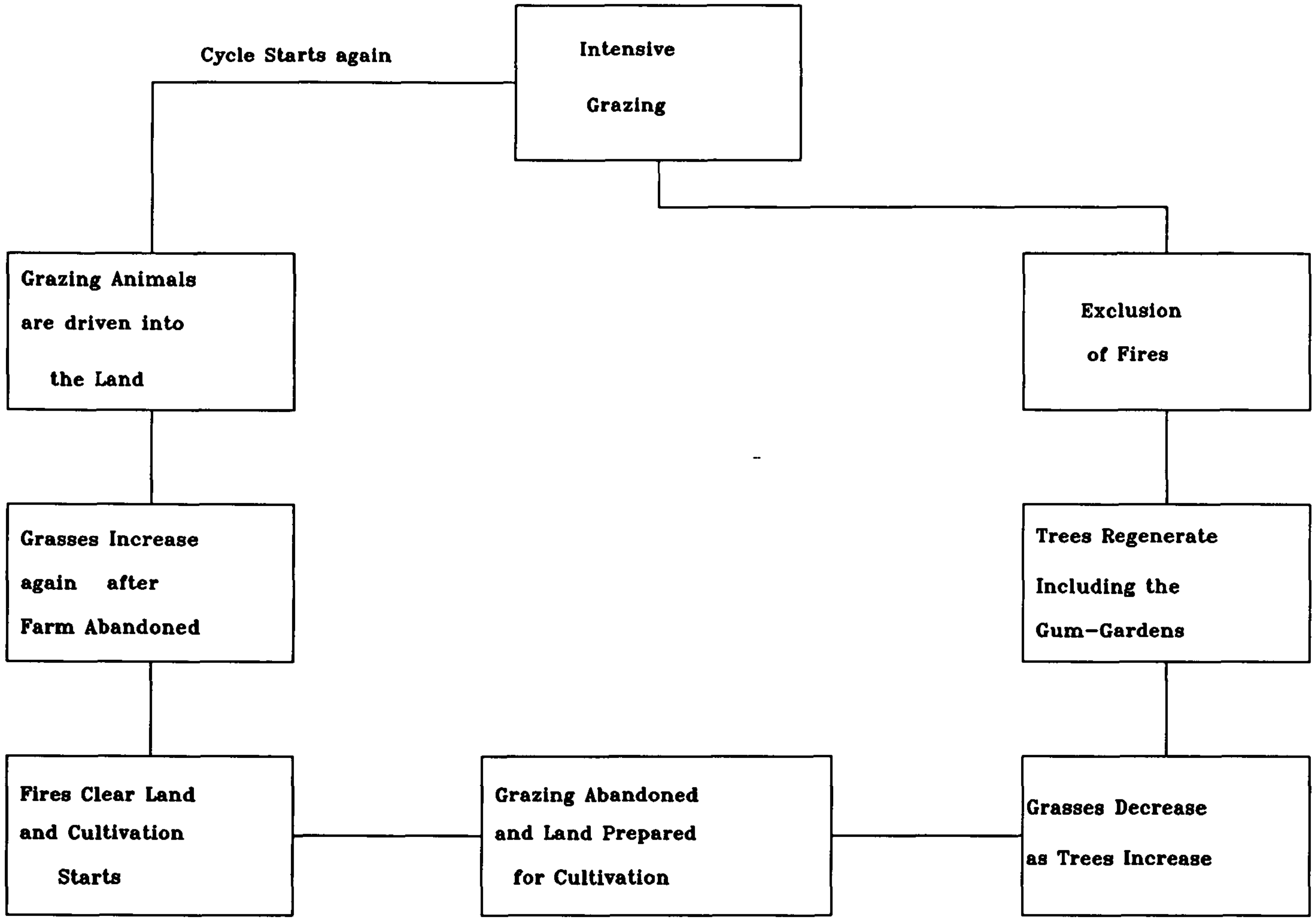


Figure 6.9 A Schematic Model of Land Use in the Past

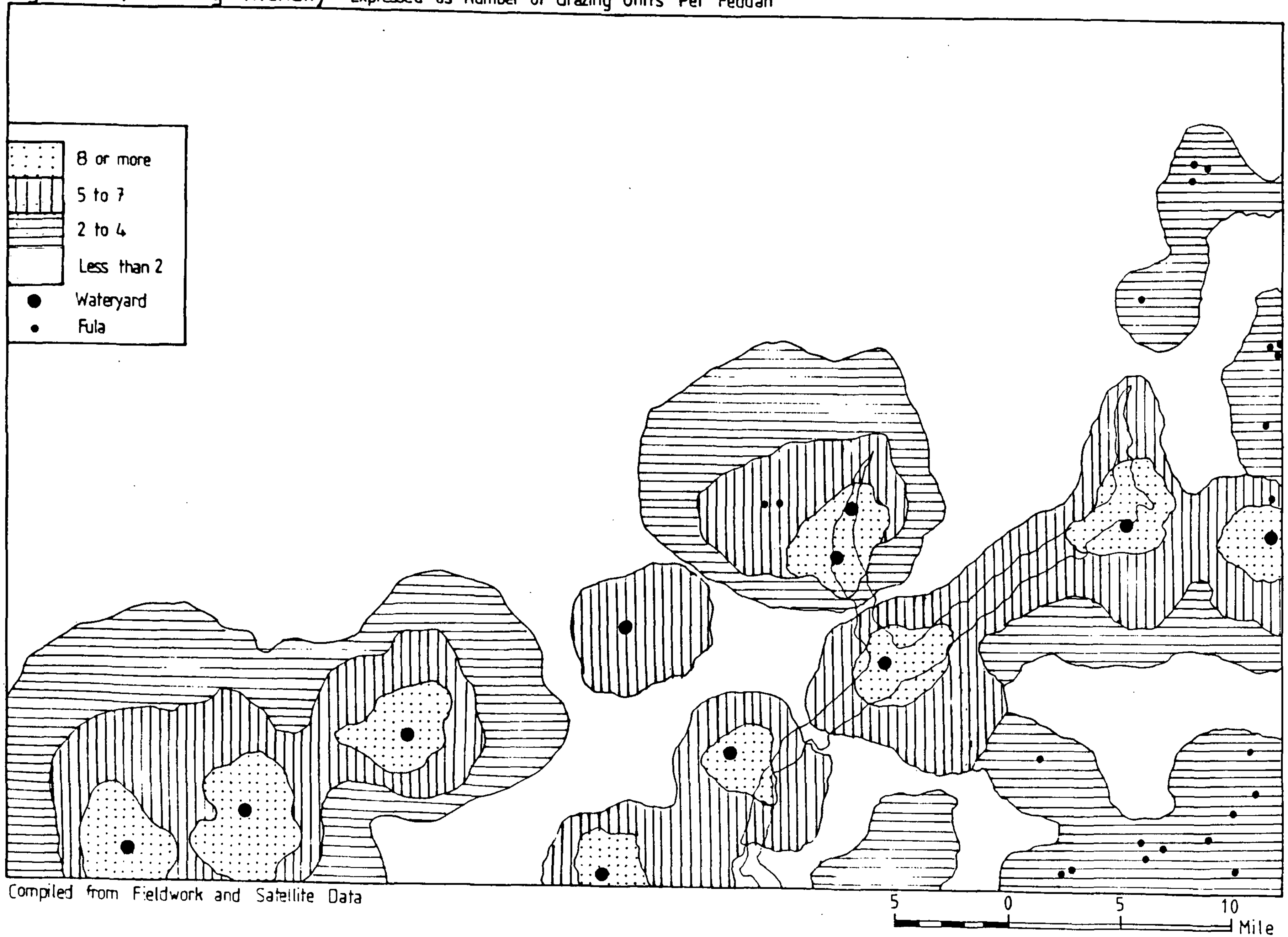
Source: Fieldwork data 1987

they would have been swamped by a dominant species if not checked by grazing. One of the aspects of rangeland deterioration could be explained by the fact that the depletion of palatable grasses had forced grazing animals to widen their dietry acceptance range. According to animal herders, grasses like *Waltheria indica* and *Cassia italica* were formerly never touched by animals, but currently these species constitute their main food consumption. The fact that the dry climate and the short rainy season do not allow the regeneration of plants once they are grazed worsens the damage by grazing even more.

Regarding the woody cover, grazing to a lesser extent affects the number of standing trees and shrubs, but much of the damage merely retards the growth without killing them. *Acacias* are the most liable to damage by goats as they are relatively within reach. The *Capparidaceae*, however are more palatable than the *Acacias* because when the two occur together near villages, the former are often reduced in size and found straggling under shrubs while the latter appear much less affected. Even tall trees like *Sylerocarya birrea* and *Combretum hartmannianum* did not escape the effect of grazing as nomads often cut down their branches to feed the animals.

It is the common pasturing of animals on grass growing under trees and shrubs that causes the real damage to the woody cover. Because young seedlings and saplings will often be consumed instead of growing and later replacing older trees. In this sense, intensive grazing could be considered in the long run as harmful and damaging as the woodman's axe. Experimental work in a secondary grassland in Uganda had shown that, animals play a decisive role in preventing the regeneration of woodland, (Spence and Angus 1971, Harrington and ross 1974, and Lock 1977). Seif & Obied (1971), in an experimentally simulated grazing of *Acacia senegal*

Figure (6.10) Grazing Intensity: Expressed as Number of Grazing Units Per Feddan



Compiled from Fieldwork and Satellite Data seedlings found that, maximum seed mortality due to grazing occurred when the species is below 40 days old, beyond this they recognized that the seedlings develop strong root systems that facilitate recovery and new shoots sprout from the base of the stem.

Away from water centres, the damage by grazing animals is greatly reduced and even in places had promoted a better tree-cover, because the removal of a dense grass-cover alleviates the damage of fire and the moisture available will consequently be in full use by trees.

The destruction of vegetation by grazing had caused extensive damage to the soil which ultimately paves the way for the physical process of soil degradation of varying severity. The vegetal litter covering the soil surface becomes scarce and this in turn exposes the soil to trampling by animal hooves. Loose soil particles are carried away by wind which in the end result in a desertified landscape round these water centres. A layer of 10 cm. deep wind blown sand particles was estimated to have been deposited in different sand accumulation forms in the area round Markib. Moreover, wind erosion exposes plants to abrasion by sand particles which often damage or even kill some plants. *Boscia senegalensis* and *Calotropis procera* were the only species found to stand undamaged. Regarding the impact of grazing on soils, USDA(1988) asserts that livestock grazing is only outranked by farming (which intentionally manipulates the soil) as a cause of soil loss and damage to vegetation. Possibly, even more destructive to vegetation than the feeding itself, is the trampling that comes with the search for food. Most grasses are ill-equipped to survive intensive pressure by hooves which exceeds 30 pounds per square inch for camels. Trampling, particularly round water centres, had transformed large areas to bare dirt as the frequency of animals in motion is very high.

During the rainy season, this bare ground transforms into pools which dry out as a crust with no chances for seed germination. For a distance of 2 kms., only *Tribulus terrestris* and *Cassia absuss* were the chief grasses found. The dramatic change caused by trampling on woody species lies in the fact that it destroys young seedlings and sapplings and, therefore, reduces the chances for trees to continue their natural cycle of growth. However, only *Boscia senegalensis* and *Acacia nubica* were noticed to escape this effect

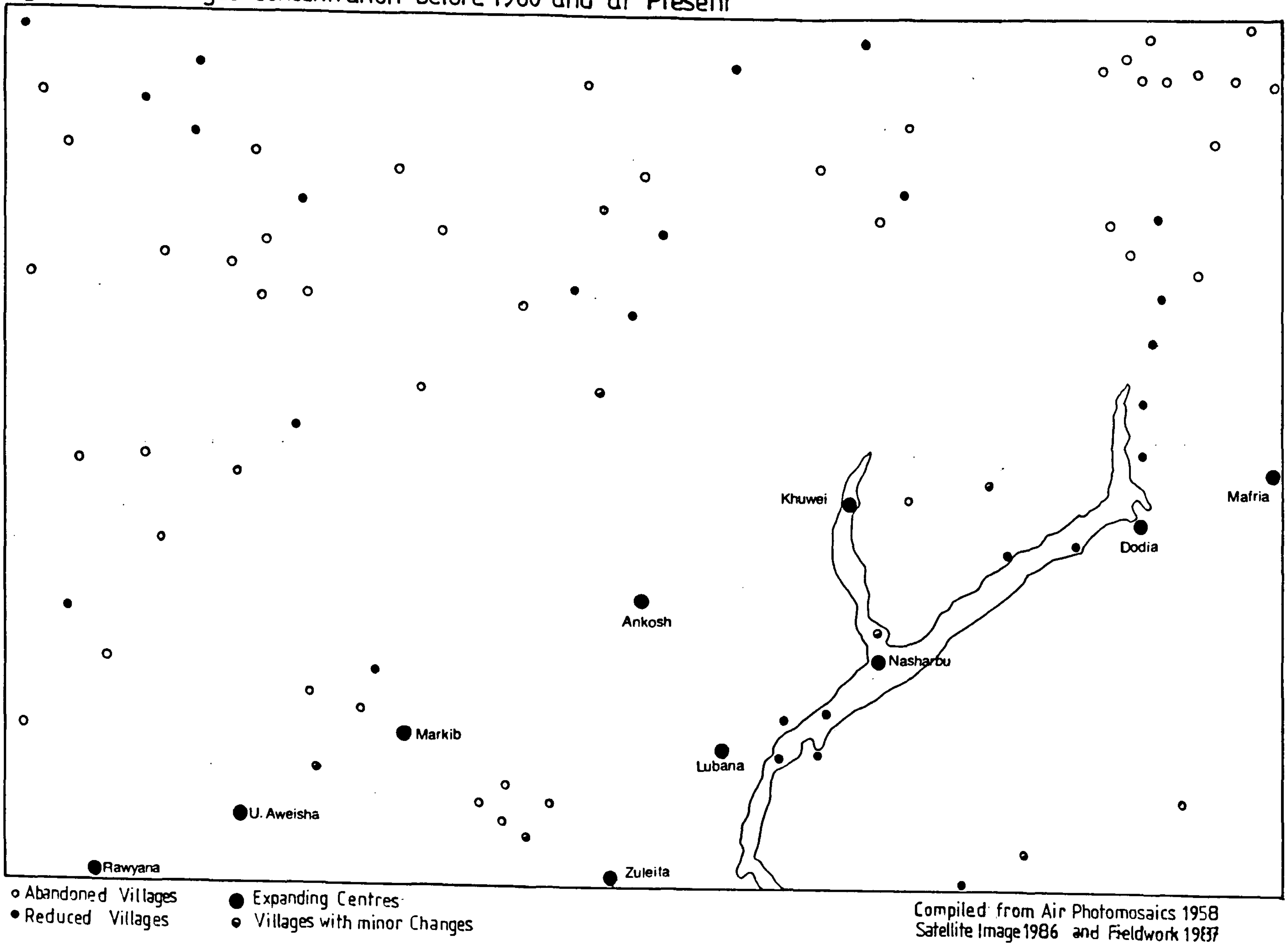
6.2.4 Establishment of concentrated activities centres

In the past, villagers of the area used to move from one site to another as soon as the land they cultivate approached the stage of exhaustion. These villages, often not exceeding 30 households each, were widely scattered over the sandy plain, Fig (6.11). Prout (1877) noted the numerous and wide distribution of villages in this part of Kordofan, and in that connection he wrote that ... *the traveller is seldom an hour out of sight of villages*†. Nomads were likewise in constant movement following good pastures and where drinking water is available. Both farmers and nomads, through this chain of mobility, maintained a cyclical land use pattern which was in complete harmony with the local natural resource-base.

The intrusion of modern factors and the incorporation of the area into a market economy has, probably, upset this harmony and brought about a new pattern of land use. This seems to be the crucial turning point in man/land relationship in this area which had set into train an exploitive systems of land uses. The most important factor was the bringing together of these wanderers into permanent settlements without the necessary readjustment. This had been promoted mainly

† The time distance which Prout specified was based on a travelling distance by animals.

Figure(6.11) Villages Concentration before 1960 and at Present



Compiled from Air Photomosaics 1958
Satellite Image 1986 and Fieldwork 1987

by the establishment of artificial water supply centres (boreholes) which had attracted neighbouring villages and led to the partial settlement of nomads. The limited resource-base round these settlements had left the inhabitants with the choice between starvation or actions of whatever consequences to increase their food production. Accordingly, the degree of cultivation, as shown in Fig (6.7), has reached an unprecedented stage round these settlements to the extent that such settlements could well be spotted on aerial photographs. In fact, a water point demonstrates the culmination of the combined effects of all of the man-made processes that more than ever can operate in a single locality.

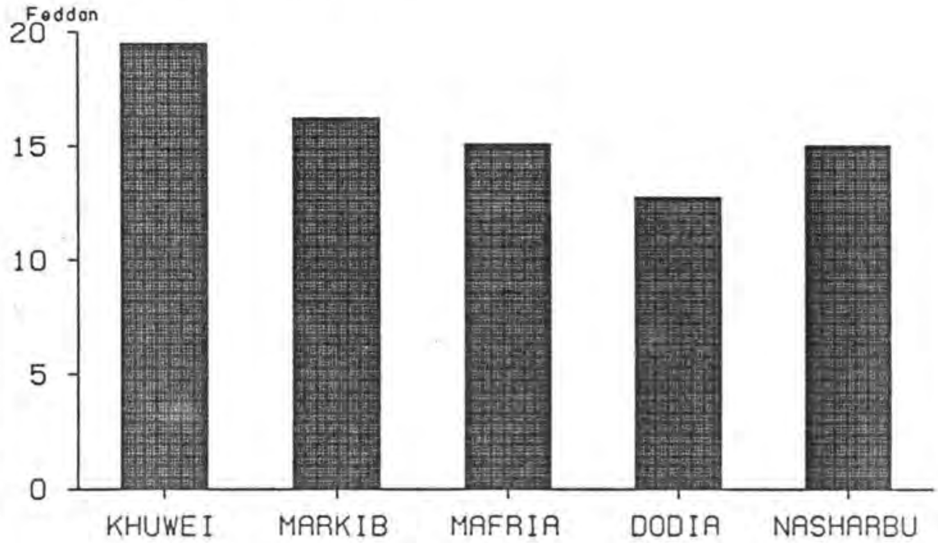
In contrast to pastoral nomadism, sedentary animal husbandary damages practically the same area all-the-year round. It does not give plants even a short break to grow undisturbed so that seeds for the preservation of kind could be produced and grown. Whereas in the past, animal movement, whether by regular migration or through fragmented distribution, had kept animal biomass in the area well below the mean carrying capacity

Settled people around these water centres were found to cultivate more land than their other counterparts, Fig (6.12). This is probably due to the fact that, here people have additional time not being consumed in searching for water. The area cultivated by each farmer, therefore, will continue to increase to a limit imposed by the availability of arable land and family labour. Also the need for cash had, apparently, tempted most farmers to increase the area they allocate for cash crops without affecting their food production. This, eventually, has widened the area under cultivation and brought marginal lands into cultivation. For instance, farmers from Khuwei were found to go as far north as Iyal Bakheit to grow cash crops like *Colocynthis* (watermelon) and peanuts.

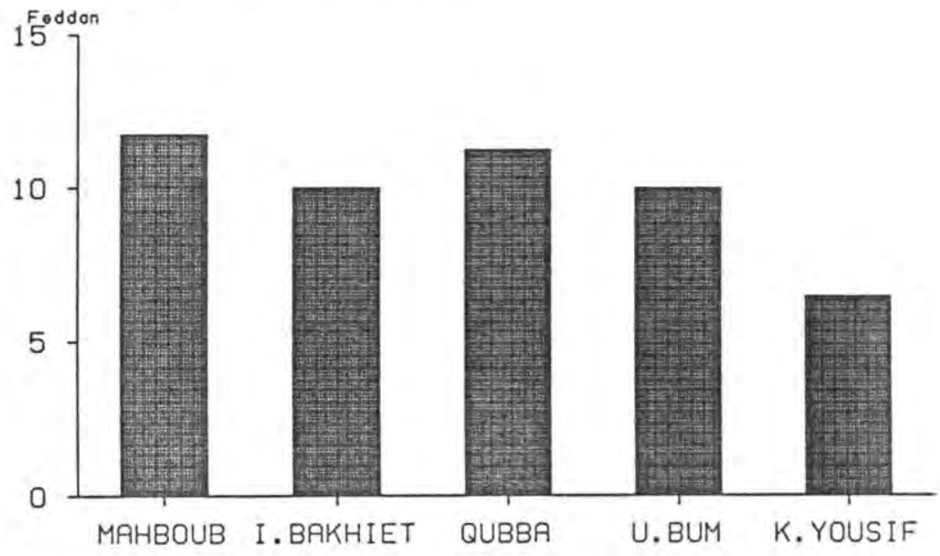
Figure 6.12

Average Cultivated Area by a Farmer in Selected Villages

(1) Round water supply centres



(2) Away from water supply centres



Source: Fieldwork Data 1987

Moreover, the introduction of heavy vehicles and trucks onto the area has a similar consequence. The impact of rural roads on the area's vegetative-cover could easily be appreciated as one sees the transportation network connecting the different parts of the study area. In fact the busiest road throughout western Sudan, which connects the two biggest commercial towns (El Obied and En Nahud), runs east-west across the area. In addition, these trucks often follow separate routes in order to avoid being stuck in the sands. This, however, produces with an added weight the results that have been described for animal trampling.

Recently, because of the excessive use of underground water, water level in a number of wells had dropped to the extent that deeper drilling became necessary in order to reach the water table. It was reported to have dropped 3 metres in Markib, 2.5 metres in Ankosh and 1.5 metres in Khuwei†. It is most likely that the construction of too many deep boreholes in recent times, coupled with the decrease in rainfall, have lead to a lower ground water level. This could have its direct bearing on water available to trees and, in the long run, may affect the surrounding tree-cover vegetation.

6.3 Excessive Biomass Harvesting

In recent years, the excessive and uncontrolled felling of timber and clearance of grasses to prepare land for cultivation and to meet the domestic demand of the growing population for firewood, charcoal and wood products for house construction, has caused an alarming loss in the vegetative-cover of the area. It was found that, the number of trees cleared per household in the less populated parts of the north is greater than in the crowded villages of the south. This is explained by

† Unpublished figures obtained from the Regional Rural Water Authority in Elobied.

the fact that, in the north, few trees have been cleared in the past and still there are plenty standing, whereas the strong impact on vegetation in the south had left but few trees dotting the landscape.

Throughout the area, fire and axe are used to fell and clear out scrub. Felling by axe is much less damaging since trees are found to produce new shoots after having been partially cut like *Sylerocarya birrea, Balanites aegyptiaca* and *Acacia senegal*, whereas the less energy consuming and quicker method of simply burning the base of the tree cause complete eradication of that tree as the chances for the burnt base to coppice are greatly reduced.

6.3.1 Felling of trees for firewood and charcoal

Biomass is the oldest and most widely used source of energy in Sudan in general and in Kordofan in particular. It includes, firewood, charcoal and agricultural residue. Fuelwood and charcoal are the basic sources of energy in the area which are both utilized in a rather wasteful way.

Firewood is burnt in open fires and, as found by Whitney (1981), only 6% of the actual energy stored in the wood is actually being effectively used while the 94% is totally lost. Charcoal production and use is an even more wasteful type of energy. The local traditional way of manufacturing charcoal, as estimated by CARE (1979), leaves only 10% of the energy originally stored in the wood to be used in traditional stoves which operate at a rate of 14% efficiency. This implies that just under 1.5% of the original energy in the tree is effectively being used as charcoal. This can not not but increase the per capita consumption of energy to an unnecessary stage.

To estimate the consumption of fuelwood in the area, a total 54 households were selected each with 6-7 members (the average family size in the area) and each household was allocated two stacked cubic metres of wood to see how long this quota lasted. The results obtained showed an average of 18 days. Based on this finding, a total of approximately 675,500 cubic metres of wood is used annually for fuel in this area. Saini (1964), however, made similar estimate for the whole Kordofan Region and gave the figure 2,849,000 cubic metres as his forcasted consumption in 1981. The figure given by Saini seems to be very low and if we are to extend our estimate to cover Saini's area, our figure would be in the region between 10,000,000 to 12,000,000 cubic metres.

As used to be, firewood consumed in the area is largely obtained from branches and trunks of dead trees which, of course, reduces the per capita impact that a rural consumer makes on the surrounding tree-cover. However, the integration of the local people into market economy, and particularly in the light of the frequent crop failure and the desperate need of cash, have paved the way for the commercial felling of timber and production of charcoal. The local produce was found to be transported to markets as far east as Elobied and west as En Nahud. There is some demand for firewood, but the bulk of domestic supplies is in the form of charcoal. For quality reasons, both firewood and charcoal produce delivered to these markets involves the felling of live trees.

Species most favoured by wood cutters are *Dichrostachys glomerata* with a calorific value of 24,6000 B.th.u., *Acacia senegal* 17,600 B.th.u.,and *Combretum hartmannianum* 16,400 B.th.u†. The high quality of *Dichrostachys glomerata* has

† These calorific values were obtained from an unpublished data prepared by the Energy Department in Khartoum

ultimately resulted in its virtual elimination from most parts of the study area except for a few traces found south of Nasharbu. The other species have likewise been greatly depleted but not yet eliminated. This, apparently, has forced the local people to use species of very low quality like *Calotropis procera* with just 8,200 B.th.u. and *Boscia senegalensis* with 10,000 B.th.u. The main tree species now used for charcoal production is *Albizzia amara*, its calorific value is not known but is believed not to be particularly high, Table (6.4).

6.3.2 Felling of trees for house construction

Building materials used for house construction, i.e., huts, enclosures, and fences are of great significance in the destruction of the tree-cover of the area as the majority of houses here and even in neighbouring towns are primarily built-up of wood products. Terrain, soil type, climate, cheap or free wood and the standard of living have altogether led to this situation.

The selective use of specific tree species according to type of building, Table (6.4), has put more pressure on these species which in places have been completely eradicated as a result. An indicator to that is the use of *Azardica indica* for building although it is never favoured for particular quality reasons.

Wood products used to be gathered from village surroundings at a minimum efforts and cheap expenses. Increase in population and expansion in settlements have increased demand for timber and, consequently, people have to get their supplies from far distances. In rural areas the main needs are poles of small dimensions between 2-3 metres long for the framework of the thatched grass huts besides thorny branches for enclosure and fences. In urban centres by contrast, in addition to the small building poles, the improved housing standard there have

Table 6.4: Main Tree species felled for different purposes expressed as percentage of the total

Species	Charcoal	firewood	House construction
A.mellifera	3	3	4
A.nubica	0	1	2
A.senegal	4	6	11
A.nilotica	3	0	2
A.digitata	0	0	2
A.amara	27	14	10
B.aegyptiaca	11	0	8
C.aculeatum	0	2	2
C.cordofanum	18	5	6
C.hartmannianum	3	4	9
D.melanoxylon	1	13	2
D.glomerata	2	11	2
G.senegalensis	0	9	5
L.humilis	0	0	3
L.pyrotehnica	0	0	2
s.birrea	4	13	10
T.brownii	19	5	8
Z.christi	5	4	7
C.procera	0	7	3
Others	0	3	2
Total	100	100	100

Source: Fieldwork data 1987

created a market for better quality poles up to 4-5 metres long. Added to this, the demand on poles is always kept high due to the tendency of frequently renewing the houses which, as reported by the inhabitants, have an average durability not exceeding 10 years.

Chapter VII

Vegetation Response to Major Disturbances & the Resultant Successional Changes

7.1 Introduction

In this chapter the response of vegetation to the major disturbances in the local environment of the study area, as identified in the last two chapters, will be discussed and evaluated. Weaver & Clements (1938) regard such responses to vary from one which keeps the same overall appearance of vegetation to another that markedly alters its characteristics such that it can be considered to have changed into a different type. Weaver & Clements termed the first as *fluctuation* and the second as *succession.* As fluctuation changes are less detectable and usually require extensive and long-term observations, the emphasis here shall be made to reveal significant successional changes that have followed major disturbances in the area.

Early views caused succession to be defined as a community or species replacement driven exclusively by autogenic environmental modifications, (Weaver & Clements 1938). Subsequent theories, however, had related succession to tolerance and inhibition factors, species life-history characteristics and population processes, (Grime 1971, Horn 1974, Connell & Slatyer 1977, Van Hulst 1978, Peet & Christensen 1980, and Noble & Slatyer 1981). However, the current established view of succession is that, following a disturbance several assembleges of species progressively occupy a site each giving way to its successor until finally a community develops which is able to continue reproducing itself. It is this community which is at equilibrium with the prevailing environment, (Noble & Slatyer 1981, Hopkins 1983, and Bornkamm 1988).

Drury & Nisbet (1973) and Miles (1979) rejected the analysis of succession at the community level for they claim that it often leads to biologically unrealistic and ineffective results. Bazzaz (1971), Noble & Slatyer (1981) and Van Hulst (1987), on the other hand, have recommended a population level of investigation which, according to them, increases our understanding of the processes involved and the ability to predict future vegetation trends.

Thus, succession here is being taken as the pattern of changes in species composition and in community structure following radical disturbances and the opening of a new patch in the physical environment for colonization by plants. The emphasis shall be made to reveal changes leading from one stage of vegetation to the next based on data on populations in different communities. The analysis will incorporate the effect of the interactions between individual plant species and the environment. Implicit in this view is the impact of man through his various activities.

As there is a serious lack in quantitative data in a time-series format, an inference from size-age structure and known life-history characteristics will be used to detect population response to particular events of disturbance and to predict the magnitude of such responses. To adequately assess vegetational replacement, comparisons will be made between density of sapling and mature species, between stands of a particular population in varying site characteristics and density of these populations in different communities.

7.2 Evidence of Vegetation Changes in the Study Area

In the literature, numerous indicators of change in the vegetation of the area were mentioned by different authors who wrote about related subjects in Kordofan in general and this area in particular. These indicators have included the following:

1. There is a clear written evidence that the ecosystems in this area have drastically changed since the turn of this century. Prout (1877) gave a long description of the region in which he frequently used the words *forest*, *rich grasses* and *heavy rains*. He added, the rains at that time were very heavy and in one instance his team had to abandon part of the tour until the end of the rainy season. The Intelligence Department (1912) described the region's fauna and flora and had indicated a much richer type of ecosystem. The report contained some wild animals and birds that virtually do not exist at present. During interviews, the local inhabitants confirmed these observations and emphasized that most of these animals had migrated southwards following the successive droughts in the 1950's and the 1960's and never returned

2. One opinion found in literature is that the northern boundary of the distribution of *Acacia senegal* and other species is progressively shifting southwards, (Vidal-Hall 1961, Booth 1966, Lampery 1975 and GITEC 1981). In a review made by Jackson & Shawki (1950) on shifting cultivation, they believe that *Acacia senegal* began to die as a result of excessive cultivation and pressure on land. HTS (1963) recognized that widespread felling of trees and continuous cultivation have transformed the savanna vegetation into a semi-desert grassland. The report claims that much of the area classified, by HTS, as belonging to the *Acacia senegal* Association, probably once had belonged to the

Acacia senegal-Combretum cordofanum Association which is a slightly more mesophytic type of vegetation. These opinions, however, are not in agreement with Olsson (1984) who argues that no woody species has been eliminated from the area, no ecological zone has shifted southwards, and the boundaries between vegetation types appear to be the same as they were described 80 years ago. Nevertheless, Olsson (1984) couldn't resist mentioning a gradual move towards what he described as *useless* species especially around heavily populated areas.

3. DECARP (1976), Digernes (1977) Hellden *et al* (1983), Ibrahim (1983) and Olsson (1984), among many others, have emphasized the role of man in transforming land into waste in Kordofan. Ibrahim (1978) and Whitney (1981) recognized a recession in town and village perimeters which they attributed to uncontrolled felling of trees and to overgrazing. They found that, these processes through time had lead to the creation of desert-like patches in the vicinity of settlements. Stebbing (1958), Lampery (1975), DECARP (1976) and Ibrahim (1983) have gone beyond this to claim that, these human activities have caused the southern boundary of the desert to spread annually at a rate of 4-5 kms. Helldon (1984) and Olsson (1984), however, rejected the idea that the desert is creeping southward, but recognized that the area was transformed into more xerophytic types of vegetation. According to Harrison (1955) and Booth (1966) the damage caused by the primitive methods of farming, annual burning of trees and grasses and at a later stage by overgrazing, had transformed the land into what Harrison described as *Kordofan graveyard* and Booth as *desert past-recovery*.

4. In his interesting work on Arabic plant names, Hassan (1978) found that, many

villages carrying names of plants such as *Umm Sunta, Laota, Talha, Hashaba*†, are today lying in areas where such species are non-existent. It is clear that these villages had obtained their names from the species formerly prevelant in their surroundings. Abdel-Bari (1977) believes that "Jebel" vegetation in northern and central Sudan shows evidence of a southward shift in vegetation belts. From surveying 16 sites, Abdel-Bari found many species that are almost absent in the vicinity, find refuge in these hilly areas. She termed these species as *relic* vegetation and emphasized that they usually correspond to species commonly dominating the neighbouring southern belt.

7.3 Assessment of Successional Changes in the Study Area

In the following part, the assessment of successional changes in the vegetation of the study area will be made with emphasis on the actual trends of change that have been measured or observed in the field. A comparison between results obtained and similar observations cited in literature will be made. An earlier attempt was made to adapt historical vegetation and land use data previously reported to the pattern of today, but because different criteria were often adopted and extensive limits were employed, such a task was made very difficult, if not impossible, to achieve.

To avoid unnecessary repetition, the discussion here shall be based on the five vegetation formations that were previously identified and mapped in the study area, Fig (7.1). This criteria was selected because at the formation level, vegetation units possess similar floristic and physiognomic characteristics and a similar range of environment, to which that physiognomy is a response. Thus, formations provide

† Vernacular names for the species *Acacia nilotica, Acacia nubica, Acacia seyal, Acacia senegal* respectively.

a fairly adequate platform for the analysis of the different aspects of succession. These formations are:

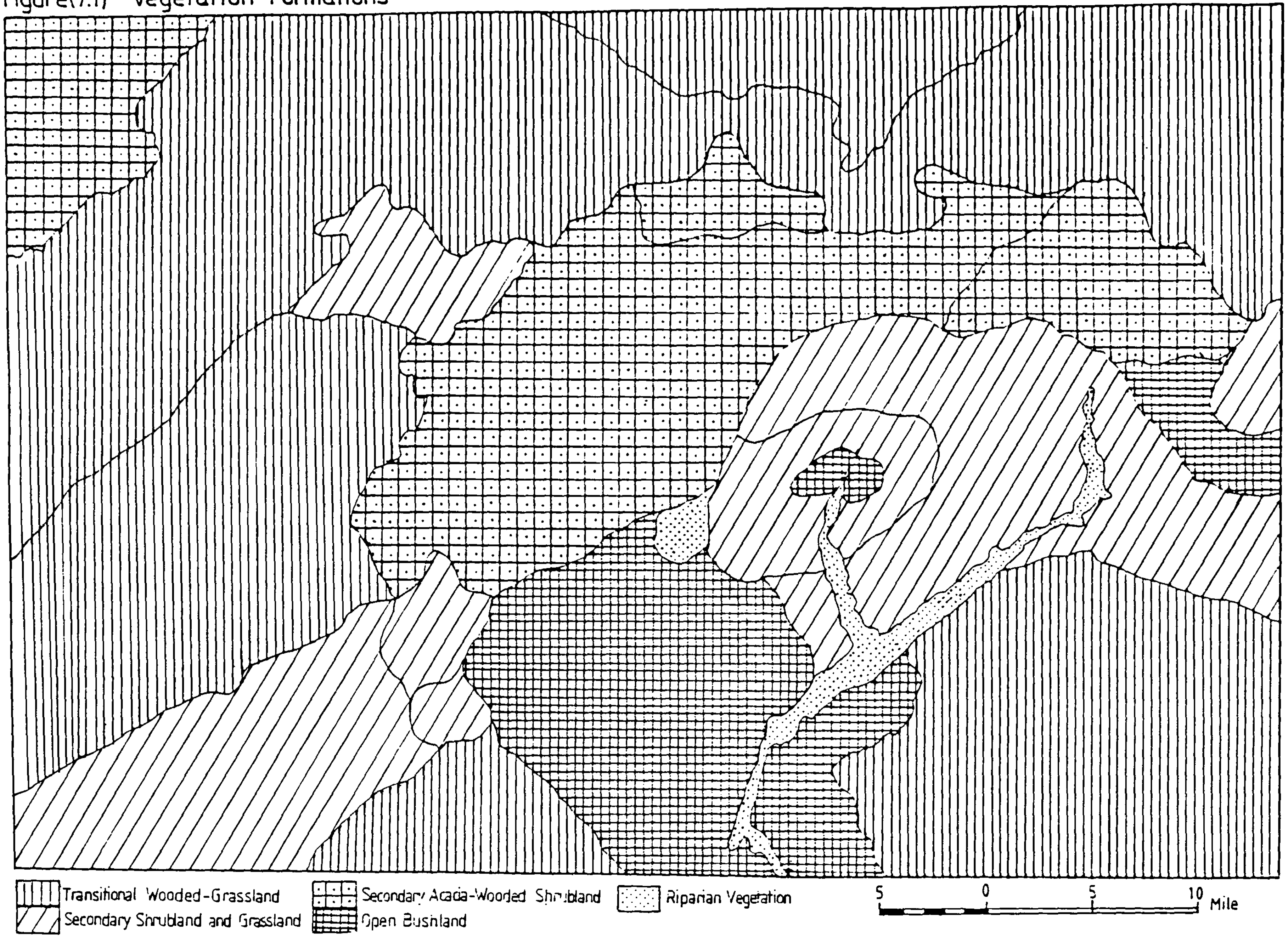
- Secondary Acacia-Wooded Shrubland.
- Open Bushland.
- Secondary Shrubland and Grassland
- Transitional Wooded Grassland.
- Riparian Vegetation.

7.3.1 Successional changes in Secondary Acacia-Wooded Shrubland

This formation consists of three associations namely, *A.senegal-Balanites Sylerocarya*, *A.senegal-Albizzia-Sylerocarya* and *A.senegal-Boscia- A.nubica* Association, Fig (3.2). These associations were found to contain the vegetation types which are being least affected by the recurrent disturbances in the area. Grazing is very rare, cultivation, with the exception of few patches, is very light, and the landscape, more or less, present a natural-like appearance. Only after closer inspection the secondary nature of the vegetation was revealed.

In the *Acacia senegal-Balanites-Sylerocarya* association, due to the lack of drinking water, the area in general and the most extreme northwestern parts in particular, had suffered little from human interference. There is still much semi-natural woody cover, as described long ago by the Intelligence Dept (1912). The natural regeneration has left many of the same species as those mentioned by Harrison & Jackson (1958), for still there are *Acacia senegal, Combretum cordofanum, Acacia mellifera, Balanites aegyptiaca* and *Sylerocarya birrea.* The most striking

Figure(7.1) Vegetation Formations



feature found in this association is the natural re-establishment of *Sylerocarya birrea* which was frequently noticed to develop stands of multiple age-classes, whereas elsewhere it failed to do so. The suggestion to be made here is that, this species is very sensitive to disturbances which ultimately make the habitat less suitable for its germination and reproduction.

In the southern and eastern parts of this association, burning is annually practiced by farmers to prepare their lands for the cropping season. The general observation made on these burned sites suggested that, fire favours the development and maintenance of a predominantly grassland vegetation by destroying the juvenile trees and shrubs and, therefore, preventing the development of more mature plants to a taller fire-resistence stage. This implies that, the type of vegetation present under these conditions is nearer to a transitional grassland than a secondary wooded shrubland. So with repeated burning, a characteristic equilibrium was eventually achieved, that is vegetation with a close cover of grasses and a scattered few trees that managed to escape the effects of fire.

However, contrary to a widely held opinion, the majority of trees and shrubs found in this area were noticed not to be particularly resistent to fire. Where there was repeated burning, traces of burnt-out stands of *Combretum cordofanum, Acacia senegal, Albizzia amara* and *Acacia mellifera* were found. *Balanites aegyptiaca* appeared to be the most tolerant species to fire as mature stands were found widely spaced in the same places where the above mentioned species had perished, though dead seedlings of *Balanites aegyptiaca* too were found. So, while *Balanites aegyptiaca* tolerates fire, burning does not increase its establishment, whereas the fire-sensitive ones, unlike *Balanites aegyptiaca* increase in density with the exclusion of fire. In areas where fire was discontinued, especially in the northern areas of the association, a relatively dense cover of *Acacia senegal, Acacia nubica, Acacia mellifera, Maeura crassifolia* besides *Balanites aegyptiaca* has developed. Apparently these woody plants consisted of those species which remained in moist ravines during fire, and then re-invaded when fire was abandoned. As these bushes have become established, grasses are becoming increasingly suppressed and, therefore, subsequent fires will no longer be effective as there is not enough grass-cover to fuel and support a sufficiently intensive fire. This could partially explain why farmers had decided to abandon cultivation in these areas.

Trollope (1982) believes that, burning when practiced before the rains commence would result in an earlier and greater seedling establishment than when practiced after the first rains which, according to him, prevents a large number of seeds from reproducing and ultimately drives some grasses to extinction. Although both these regimes of burning were found to be practiced here, the consequences of each regime could not be adequately assessed under such uncontrolled field conditions. Moreover, such a sharp division does not exist between areas covered by each regime and often they are practiced simultaneously or sequentially on the same plot of land.

The area to the southeast of Humier Jabir, which is classified here as *Albizzia-Acacia senegal* community, has been mapped by HTS (1963) as *Albizzia-Boscia* and was described as being caused by overgrazing and other disturbances. This community is not particularly found around villages or a densely populated area, neither near grazing posts and observations did not suggest that it has been heavily grazed during the past few years. Surprisingly, HTS (1963) did not mention *Acacia senegal* which at present represent the second most abundant woody plant. This could partially be explained by cultivation through which this species was encouraged and protected. In the neighbouring communities, and where grazing animals were allowed, clumps of *Boscia senegalensis* often dominate the shrub layer. This may indicate that, the *Boscia* vegetation described by HTS (1963) probably had been caused by ancient disturbances, possibly grazing which resulted in a secondary vegetation that was less suitable for grazing animals as *Boscia senegalensis* is often avoided by stock. Soon grazing was abandoned and subsequent cultivation had brought about a retreat in *Boscia senegalensis* and eventually the community has reverted into *Albizzia- Acacia senegal.*

Acacia senegal-Boscia-Acacia nubica association was found to be the mostly affected vegetation type of this formation by human interference, particularly through cultivation. To reveal the secondary successional changes following these disturbances, four sites with four vegetation stages were studied in the area to the southeast of Umm Bum. These sites will be referred to as A, B, C, and D, where they represent:

(A) Areas where cultivation has recently been abandoned, about 1-3 years.

(B) Areas of 8-10 years of fallow.

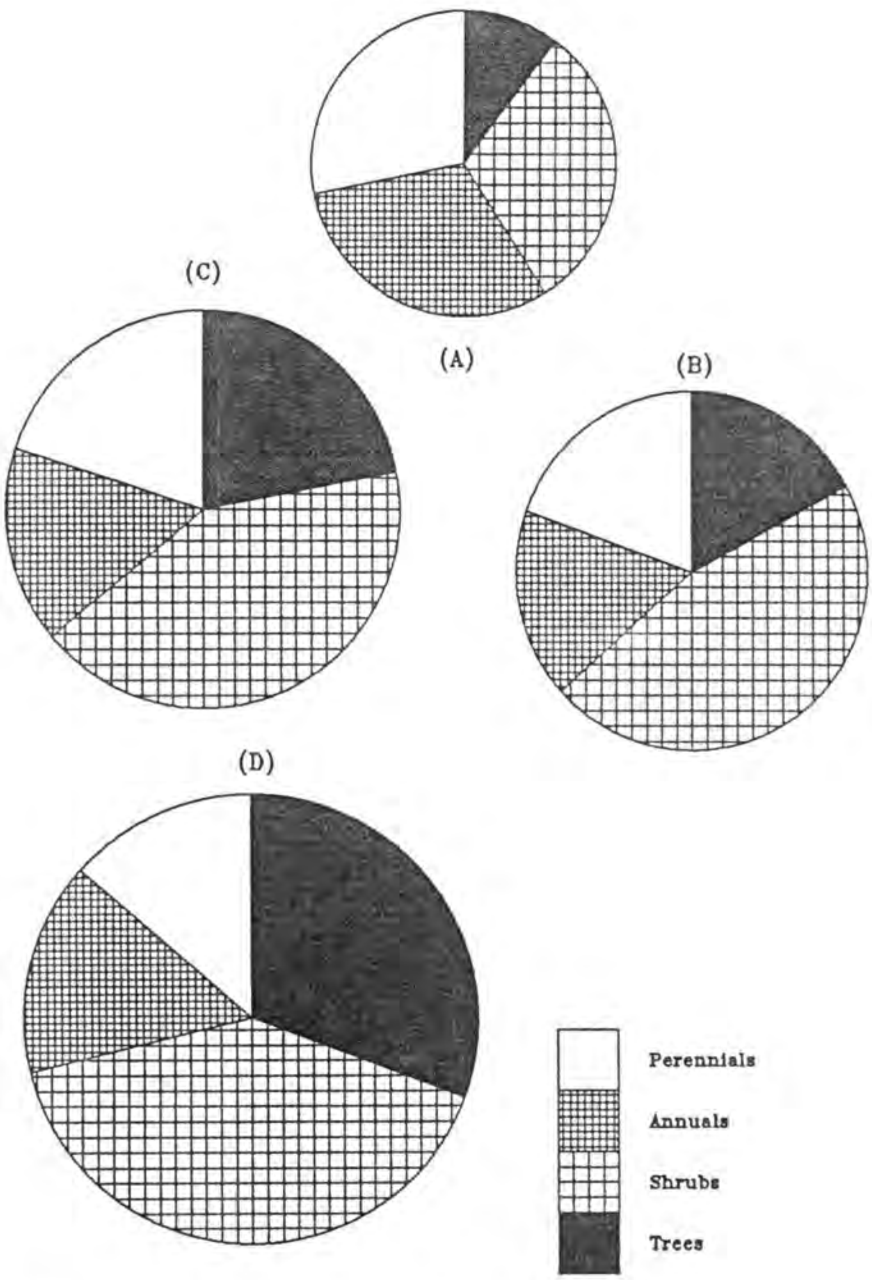
(C) Areas under fallow for 14-16 years.

(D) Areas where the fallow periods had exceeded 20 years.

The results obtained, Fig (7.2), show the steady increase in the abundance of woody species overtime with shrubs being the most frequent category in the three early successional stages and some trees in the (D) stage. The obvious trend is the increase in the population of tree species with increasing age of vegetation, shrubs also show the same trend. Grasses, however, show a progressively decreasing trend

Figure 7.2

Proportion of Different Growth Forms in Different Fallow-Classes in A.senegal-Boscia-A.nubica Association*



*Pie area proportional to cover

Source: Fieldwork data 1987

with the age of vegetation.

Immediately after field abandonment, the vegetation becomes dominated by grasses, both annuals and perennials, and shrubs with very few trees. At the next stage, the total cover increases and shrubs dominate over grasses. At stage (C), grasses become increasingly confined while shrub and tree seedlings increase, and by stage (D), the woody plants constitute more than 70% of the total vegetation cover.

Considering the sequence of species establishment, it was found that, of the total species listed in stage (D) which is regarded here as a "climax vegetation" (32 species in total), one sixth of these species were present at stage (A) and a third at stage (B), Table (7.1). Considering the high frequency climax species (those with > 50% frequency), two third were present in stage (C) or younger vegetation stands. When the eight most dominant species alone were considered, 12% are present from stage (A), 50% from stage (B), while 75% were found in stage (C) onwards, Table (7.1).

Table 7.1: Climax Species and their Presence in each Successional Stage (% in brackets)

Vegetation Stage	All Species	Species with > 50% Frequency	Eight most Frequent Species
A	5 (16)	5 (27)	1 (12)
B	11 (33)	8 (44)	4 (50)
C	17 (53)	12 (66)	6 (75)
D	32 (100)	18 (100)	8 (100)

Source: Fieldwork Data 1987

As shown in Table (7.2), a separation between species emerged when they were grouped into growth forms with emphasis on species unique to stage (D). The species of grasses were found to be unique in the woodland while about half of the climax trees and shrubs are common to (D) and younger stages. When climax trees and shrubs were grouped together into leaf-size† categories, species with smaller leaf sizes appeared earlier in the succession process than those with larger leaf sizes, Table (7.2).

Table 7.2: Growth Forms and Leaf Size of the Climax Species

Type	% of Species only in Stage (D)	% of Species in all Stages
Trees	51.4	48.6
Shrubs	60.0	40.0
Grasses	98.0	02.0
Nanophyll	02.0	98.0
Microphyll	38.0	62.0
Mesophyll	79.0	21.0

Source: Fieldwork Data 1987.

The conclusion to be drawn from these observations is that, abandoned fields are first invaded by annual grasses with few perennials. The shrub and tree layers develop significantly by the second stage, starting with species that tolerate disturbances and those adapted to such impoverished soil conditions. As the land approaches stability, more trees and shrubs grow and become established and more species at the shrub layer are being promoted to the tree layer. The development

† Leaf-size category fallow Raunkiaer (1934). Nanophyll $>$ 2025 mm.,

of more woody plants gradually weakens annual grasses because of their inability to compete and are soon succeeded by the better adapted perennials.

7.3.2 Successional changes in Open Bushland

This formation comprises the associations, *Boscia-Guiera-Albizzia*, *Boscia-Calotropis* and *Guiera-Boscia-A.senegal* which represents the most degraded type of vegetation in the study area.

In all three associations, evidence obtained suggested that, various types of woodland were formerly more extensive and that they have been replaced by secondary bushland following cultivation and the uncontrolled felling of trees. Meanwhile, grazing had removed much of the grasses which in turn favoured the establishment of these bushes by reducing the competitive vigour of the former.

The area occupied by *Boscia-Calotropis* association was described by Andrews (1948), Harrison & Jackson (1958) and HTS (1963) as being dominated by the species, *Combretum cordofanum, Combretum aculeatum, Combretum hartmannianum, Terminalia brownii* and *Sylerocarya birrea.* At present, none of these species makes any impression on the landscape, instead a secondary bushland appears to have developed. *Boscia senegalensis, Guiera senegalensis* and *Albizzia amara* in that order are the dominant type of vegetation with frequent occurrence of *Calotropis procera.* The herbaceous cover, owing to intensive grazing in this area, is reduced to a sparse unpalatable species like *Tribulus terristris* and *Cenchrus biflorus.* At the foot of Khuwei, scattered stands of *Boscia senegalensis* represent the sole cover of vegetation, otherwise, the landscape is dominated by the yellowish colour of the sand. Furtherout, widely spaced *Albizzia amara, Guiera senegalensis* and *Lannea humilis* begin to take part.

Booth (1966), investigating the distribution of *Acacia senegal* in Kordofan, pointed out its absence in the vicinity of Khuwei. The same observation was earlier made by Smith (1937). However our data indicate that *Acacia senegal* does grow in this association but with very low density as compared to other areas. The local farmers asserted that the productivity of *Acacia senegal* is extremely low and that the species needs a comparatively longer time to produce what they consider as a reasonable yield of gum. These aspects, coupled with the high demand for land around Khuwei, probably had left these farmers with no choice but to exclude this species from the fallow. Abandoned fields, instead, are dominated by *Boscia senegalensis, Calotropis procera* and *Acacia nubica.* Moreover, unlike these species, *Acacia senegal* appears not to have developed necessary defensive modifications that offer some sort of protection against browsing animals in such heavily grazed areas (Seif & Obied 1971) and the result is that, dead grazed seedlings were frequently encountered. Even those seedlings which have managed to survive were noticed to emerge very weak and apparently ill-equipped to stand competition against such aggressive species as *Boscia senegalensis.*

In *Guiera-Boscia-A.senegal* association, a long persistence of adult *Sylerocarya birrea* in the absence of regeneration has been observed in the different communities, while near villages, adult species started to die out due to excessive cutting. *Sylerocarya birrea* was noticed to have a predominantly long juvenile period which possibly had reduced its growth rate and allowed species like *Guiera senegalensis* and *Boscia senegalensis*, which have a relatively shorter juvenile period, to succeed. The same observation applies to *Adansonia digitata* which has an exceptionally long life-span, mentioned by Own (1974) to be in excess of 4,000 years. Although this species was never found reproducing in any part of the study area, its long duration probably slows the retreat of range boundary and, unlike *Sylerocarya birrea*, most adults will remain in the vegetation several centuries after habitat deterioration before being eliminated.

Booth (1966) described the vegetation of the area occupied by *Boscia- Albizzia-Guiera* association as being dominated by *Acacia senegal, Albizzia amara, Terminalia brownii, Dalbergia melanoxylon* and *Lannea humilis*, while regarded the grass-cover as forming a continuous carpet dominated by *Schoenefeldia gracilis.* It is interesting here to note that, after 21 years a drastic shift had occurred in the vegetation that was described by Booth. Regarding the woody plants, *Dalbergia melanoxylon* is not there, *Terminalia brownii* is very rare, *Albizzia amara* grows only in moister ravines while *Lannea humilis* was noticed to occupy a larger area than that described by Booth and often grows in dense thickets together with *Boscia senegalensis* and *Guiera senegalensis.* These two last species represent the successional stage that followed the destruction of the original vegetation. The only species which managed to persist from the list given by Booth (1966) is the *Acacia senegal*, Table (7.3). The grass-cover was not as continuous as described by Booth, but still *Schoenefeldia gracilis* had managed to keep its dominance with *Aristida pallida, Panicum turgidum* and *Belpharis linariifolia.*

Analysis of aerial photographs showed that this area has been heavily cultivated in the past and that most of the area is now being abandoned. The maintenance of *Acacia senegal* is explained by the cultivation cycle, the depletion of *Albizzia amara* and *Terminalia brownii* by land clearance and wood harvesting especially for charcoal making. Although no traces of *Dalbergia melanoxylon* were found in this area, in the neighbouring *A.senegal Albizzia Sylerocarya* association, signs of mortality of *Dalbergia melanoxylon* seedlings were frequently noticed where they hardly survive the first stage of growth. Close inspections revealed that termite attacks were the cause of death. This possibly could account for the disappearance of *Dalbergia melanoxylon* from this association.

Table 7.3: The Density of the Main Species in *Boscia Guiera Albizzia* Association.

Trees	
Species	Density (%)
A.senegal	15
A.amara	9
L.humilis	34
G.senegalensis	14
B.senegalensis	13
T.Brownii	2
Others	10
Total	100

Grasses	
Species	Density (%)
S.gracilis	27
A.pallida	21
P.turgidum	18
B.linariifolia	11
C.italica	9
B.xantholeuca	5
Others	9
Total	100

Source: Fieldwork Data 1987.

Investigating the successional pattern of grasses on abandoned farmlands in *Boscia-Guiera-Albizzia* association in the area south of Tor Imara, the following results were obtained, Table (7.4).

Among the seven species listed in Table (7.4), the first four species were found to reflect particular successional pattern. *Schoenefeldia gracilis* was noticed to spread rapidly during the first years once the land is abandoned, fastly doing so on sandier soils. The reason, probably, because initially it has not been removed

Table 7.4: Percentage Frequency of the main grasses in Different Age of Fallow in *Boscia Guiera Albizzia* Association.

Species	0-4	5-9	10-14	15-19	20 & Over
S.gracilis	11.6	44.6	71.8	84.2	92.1
A.pallida	37.5	64.3	61.3	72.3	65.9
P. turgidum	16.9	18.2	19.6	33.5	69.7
C.sesamoioes	01.8	00.0	19.6	53.1	91.3
D.ciliaris	02.6	06.3	01.2	11.7	04.7
B.linariifolia	08.6	04.3	12.4	07.6	10.2
B.xantholeuca	07.3	06.1	04.3	08.4	07.3

Source: Fieldwork Data 1987.

completely as grazing pressure is negligible in this area. After 20 years of abandonment this species was found to form in places closed stands. *Aristida pallida*, however, spread much slower, but again is faster on sandy soils, and although its frequency at the climax stage was less than *Schoenefeldia gracilis*, it was able to become established after 10 years of abandonment. *Panicum turgidum* started later with very few seedlings colonizing further sites, thus, spreading very slowly. It was found to spread much faster on soils with more clayey properties. *Panicum turgidum* reaches all sites only after 20 years. *Certatotheca sesamoioes*, however, invades very late and spread very rapidly like an infestation, no differentiation between any type of soil has been detected, and after 15 years, nearly all sites had been reached with a frequency exceding 50%.

These findings show that the invasion of grasses on abandoned farmlands takes place continuously throughout the succession observed so far. However, not every invasion was successful and not every successful invasion results in a consequent dominance. For instance, *Panicum turgidum* invaded very early but never spread continuously until 20 years later. On the other hand, *Aristida pallida* started to decline in the final stage after reaching a peak at the fallow class 15-19 years.

7.3.3 Successional changes in secondary shrubland & grassland

Interpretation of aerial photographs had shown that, a far larger area had been under cultivation in this formation than there at present. *Albizzia amara* was found surviving in faint rows marking the outlines of former farmlands, while on the abandoned exhausted fields, secondary clumps of *Boscia senegalensis* and *Guiera senegalensis* grow under conditions of low fertility and probably less available soil moisture due to increased runoff from these denuded surfaces. No other woody species would have successfully tolerated and become established under such site characteristics. This, however, corresponds to the "tolerance" successional model proposed by Connell & Slatyer (1977). The herbaceous cover is essentially secondary dominated by annual grasses which, as a replacement community, has resulted from the destruction of woodlands. The unpalatable *Cenchrus biflorous* increases under cultivation and, as suggested by HTS (1963), it may had been introduced in this area by grazing animals, while elsewhere *Aristida pallida* is the dominant grass species.

Andrews (1948), in his "Acacia Short Grass Scrub" vegetation division that wholly covers this formation, mentioned the wide occurrence of *Terminalia brownii* and *Dalbergia melanoxylon* and recognized them as outliers to the next division. HTS (1963), on the other hand, regarded these two species alongside with *Albizzia* *amara* as the characteristic woody plants of the area. At present, *Terminalia brownii* and *Dalbergia melanoxylon* are to be found in isolated mature stands away from villages and without signs of young age classes. Though both species satisfactorily grow in water retaining sites which may, to some extent, confirm their former widespread occurrence.

Hutchinson & Dalziel (1954) gave the distribution of these two species as being from northern Nigeria extending eastwards to Ethiopia and the Red Sea. This broad ecotone, however, suggests a higher rainfall than the 350mm. received at the most extreme southern parts of this formation. Based on these observations, it may be said that, the favourable moisture conditions prevailed in the past had probably favoured the growth and establishment of *Terminalia brownii* and *Dalbergia melanoxylon* in this formation, and that successive droughts and the removal of the sandy soil may had reduced their chances of regeneration at this range. Moreover, overcultivation, overgrazing and particularly wood harvesting would make conditions become even more difficult for natural regeneration as these two species were especially valued for their timber and aromatic qualities. Such a combination of disadvantageous factors had certainly brought a retreat in the distribution of *Terminalia brownii* and *Dalbergia melanoxylon*, and observations indicated that they have been succeeded by specimens of the drought-resistent *Albizzia amara* and by clumps of *Boscia senegalensis* and *Guiera senegalensis.*

The *A.senegal-Boscia* association in the area around Rawyana provided an interesting site for studying successional changes following the destruction of the original vegetation particularly through grazing animals. Four sites were selected here to cover situations of varying degrees of grazing pressure, these sites will be referred to as 1, 2, 3, and 4, where:

(1) Consists of areas of no grazing (nil).

(2) Comprises areas with light grazing (light).

(3) Covers areas with moderate use (moderate).

(4) Consists of areas where intensive grazing is practiced (intensive).

Efforts were made to choose sites of similar soil characteristics in terms of depth, structure and texture. The only variables found particularly varying to cause differences in plant growth between stands were N and P, which indirectly are related to grazing pressure itself.

The trees *Acacia senegal, Albizzia amara, Combretum cordofanum* and the shrub *Boscia senegalensis* were present at all sites. *Albizzia amara* dominated the tree and the shrub layers except at site (4) where *Boscia senegalensis* was dominant in the shrub layer. The most diverse populations were found in intensive and moderate grazing areas. *Guiera senegalensis* occurred in all sites except areas with nil grazing, thus, increasing in abundance following grazing pressure, Table (7.5). Casual observations and interviews with animal herders had, to some extent, explained the degree of abundance of the main grass species in these four sites, Table (7.6). Owing to heavy grazing, perennial and palatable grasses diminish by approximately 65% in the moderate and intensive grazing where being replaced by annuals and unpalatable ones which were found to increase by more than two fold. However, in nil and light grazing areas, the pattern is different, instead, perennial and palatable grasses grow and occupy large areas while annuals and unpalatable were never found to make the same impression they did in the first two categories, Fig (7.3).

Table 7.5: Percentage Frequency of some Woody Species at Different Grazing Pressure in *Albizzia A.senegal* Association.

Species	Nil	Light	Moderate	Intensive
A.senegal	22	14	08	10
A.amara	36	18	10	14
G.senegalensis	00	14	38	46
B.senegalensis	12	28	54	68
L.humilis	08	06	24	18
C.cordofanum	10	18	18	22
C.hartmannianum	16	06	00	02
T.brownii	08	00	04	00
B.aegyptiaca	04	06	00	08

Source: Fieldwork Data 1987.

From these observations made on both the woody and the herbaceous cover, the most important findings could be summarized as follows:

- In areas of nil and light grazing, the herbaceous cover is mostly dominated by late successional perennial grasses, shrubs are kept at minimum while trees are noticeably present.

- In areas of moderate and heavy grazing, there is a shift towards annuals over perennials, a selection of prostrate rather than erect forms of growth, and unpalatable and resistent grasses over palatable and sensitive ones. Regarding the woody cover, trees are reduced to a shrub level which becomes the prominant feature of the vegetation. In the most extreme cases, woody vegetation in the form of thickets of *Boscia senegalensis* and *Guiera senegalensis* dominate the

Table 7.6: Percentage Frequency of some Grass Species at Different Grazing Pressure in *Albizzia A.senegal* Association.

Species	Nil	Light	Moderate	Intensive
E.aspera	65	42	44	21
A.pallida	34	08	14	00
E.colonum	44	15	22	08
A.gaganus	45	24	12	14
P.anaboptistum	64	16	00	04
H.hirta	35	38	10	02
D.ciliaris	42	20	22	18
A.lanceolatum	36	18	20	08
S.festivus	14	00	06	04
C.biflorous	24	22	32	64
A.adscensionis	18	10	26	22
A.sesamoioes	24	38	42	18
C.abssus	46	76	60	64
C.italica	48	65	48	54
P.turgidum	18	24	38	42

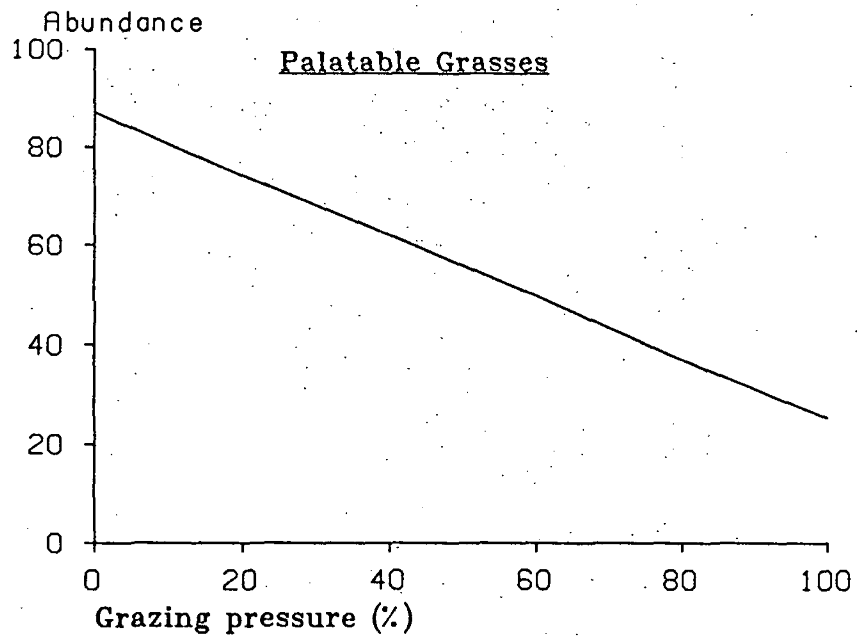
Source: Fieldwork measurements 1987.

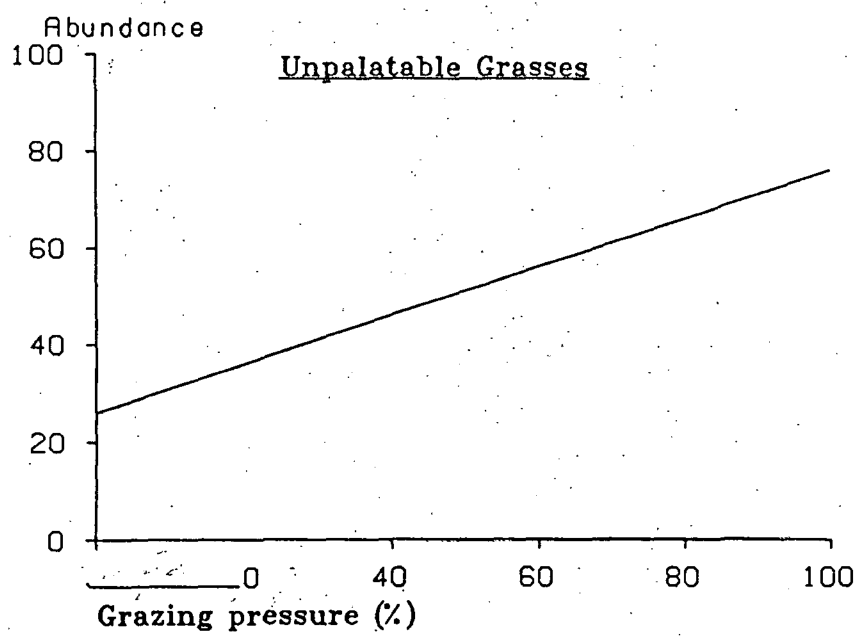
final state nearly excluding grasses.

An important aspect which accompanies the disappearance of perennial grasses is the increase in bare soil surfaces in intensively grazed areas. Here the annuals, unlike perennial grasses, are consumed on the spot and only a very small proportion is left to become litter, thus, providing little protection to the soil. From this

Figure 7.3

Regression Lines Showing Relationship Between Palatable & Unpalatable Grasses and Grazing Pressure





Source: Fieldwork data 1987

ecological point-of-view, the most stable herbaceous cover are the swards dominated by perennial grasses in areas lightly or not utilized which probably represent the type of vegetation that had existed before such grazing animals were introduced in large numbers. Instability, therefore increases with intensity of grazing as exhibited by the domination of annuals and the increasing trend of heterogeneity and diversity. Moreover, there is a clear evidence that, areas intensively grazed appear to be in an early stage of succession. This is attributed to two main reasons. First, the predominance of annual grasses and especially early successional species which are known indicators of site disturbances like *Cassia absus* and *Cenchrus biflorous*. Second, the absence of late successional perennial grasses like *Digitaria ciliaris* which is quite common in neighbouring associations, besides the overall lack of other perennials like *Sporobolus festivus* and *Hyparrhenia hirta*.

The *Boscia-A.senegal* association carries another type of vegetation which has developed through decades of cultivation and grazing. The area around Dodia is essentially dominated by shrubs and unpalatable grasses. Shrubs listed have included *Acacia nubica, Guiera senegalensis* and *Boscia senegalensis* with scattered trees of *Albizzia amara* and *Balanites aegyptiaca* which near the village were strongly deformed by browsing animals. Inside the village, the picture is incredibly different where the shade and fruit-bearing trees like *Acacia albida, Acacia tortilis, Balanites aegyptiaca, Acacia nilotica* and *Adansonia digitata* grow untouched. The suggestion offered here is that, these dense stands of tree-cover represents relic vegetation that once dominated this area.

To assess successional changes in the herbaceous cover in the above area, three sites each consisting of grazed and ungrazed components were studied, Fig (7.4). The most noticeable change is the increase in *Eragrostis aspera* and *Panicum an-*

aboptistum in grazing-free areas, *Sporobilus festivus* in grazed areas, while *Cenchrus biflorous*, which was never recorded on ungrazed areas, was constantly present on grazed sites. Earlier accounts made on this area by Harrison & Jackson (1958) made little mention of *Sporobilus festivus* which here was identified to increase with grazing pressure. This partly could be explained by the fact that, this area had become a permanent grazing post after Harrison &Jackson made that observation†. Casual observations suggested that the growth form of *Sporobilus festivus* allows its domination in grazed areas where competition against taller grasses is minimal. This species grows with dense bases and well-protected meristems which makes it at a considerable advantage.

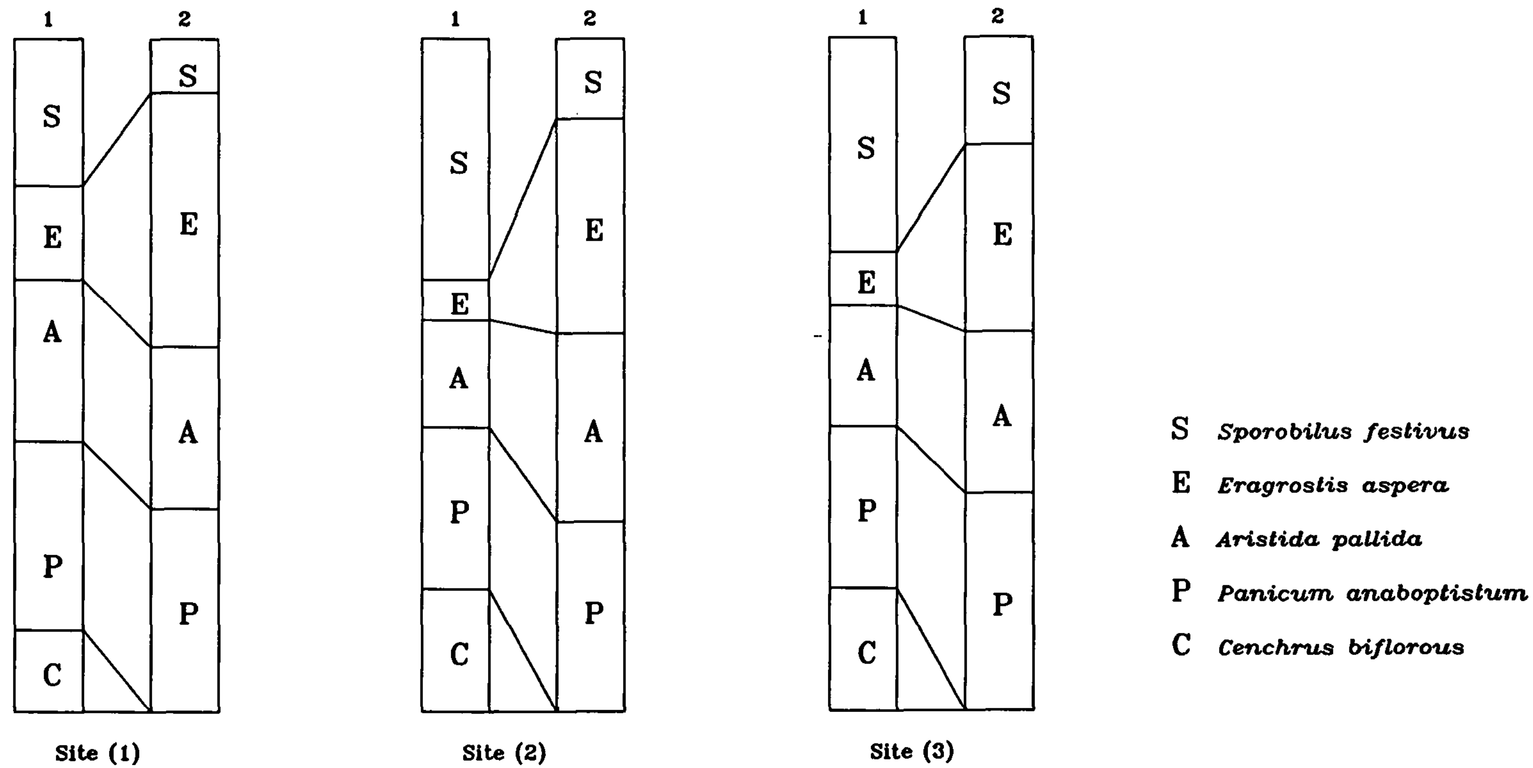
Regarding secondary succession on abandoned farmlands, it was found to consist of regeneration of the woody plants which have survived the period of cropping either as protected trees like *Acacia senegal, Balanites aegyptiaca, Acacia albida* or more usually as underground rootstocks as *Guiera senegalensis* and *Acacia nubica.* As shown in Fig (7.5), the initial stage of succession consists of a fairly dense shrub layer with scattered, previously protected trees and a rather heterogeneous herb layer consisting largely of agricultural weeds, (*Strigga spp.*), and annual grasses. Considerable variations in this generalized scheme were noticed which probably related to available moisture and intensity of land utilization.

The pattern of secondary succession, where grazing animals are excluded, commences with the domination of annual grasses, primarily agricultural weeds, with shrubs 1.2 to 1.5 metre tall. After 10 years of abandonment, perennial grasses increase, annuals remarkably decrease with the appearance of scattered 4-5 metre tall trees. Five years later, the woody plants increase with a noticeable domination

† The wateryard in Dodia was constructed early in the 1960's

Figure 7.4

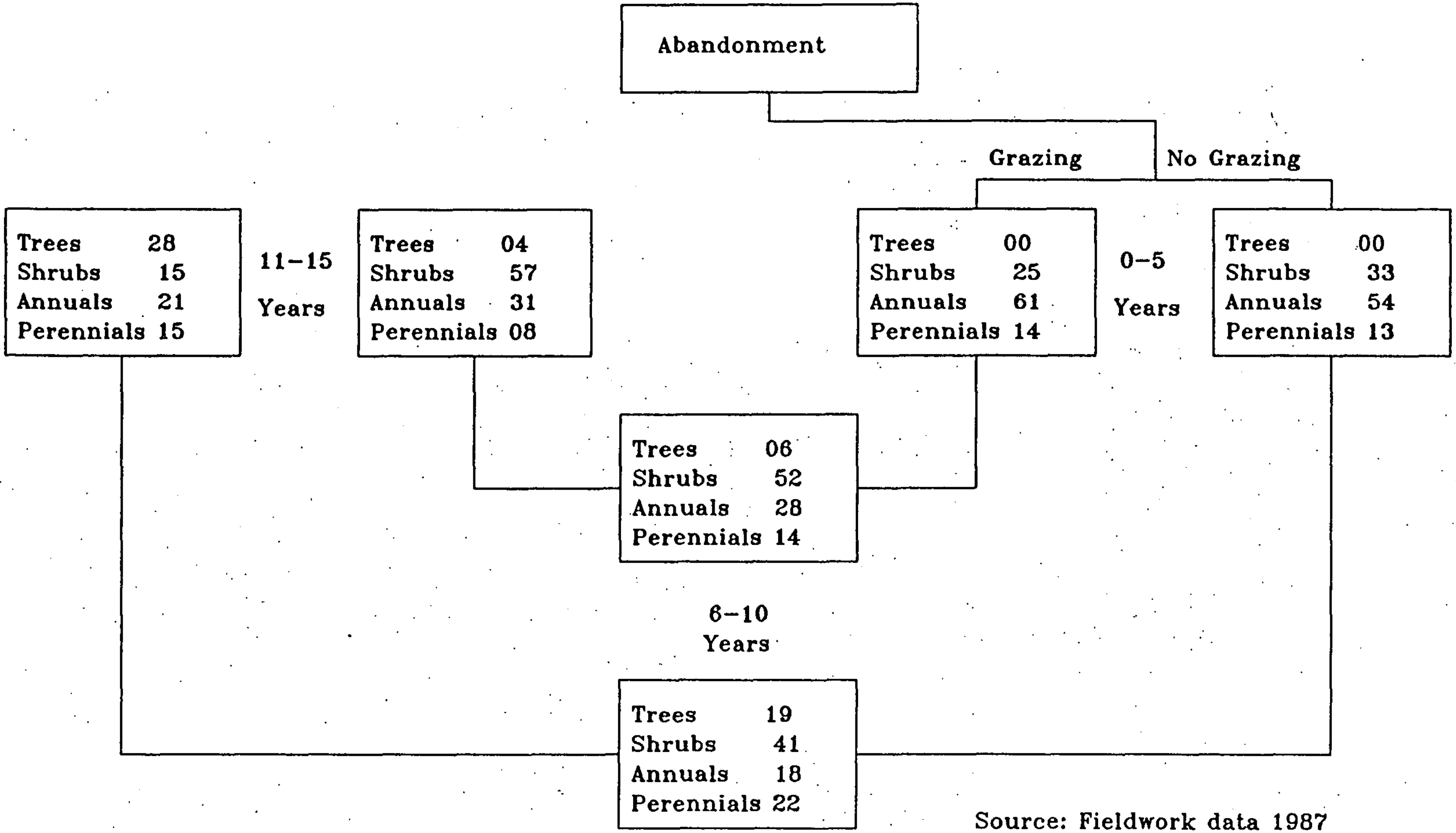
Relative Abundance of Five Grass Species in (1) Grazed (2) Ungrazed Areas in Boscia–A.senegal Association



Source: Fieldwork data 1987

Figure 7.5

Schematic Representation of Different Life-Forms at Various Fallow Ages in Boscia-A.senegal Association, (% of Total Cover)



Source: Fieldwork data 1987

of trees over shrubs. However, these abandoned farms were observed to have at the first two stages abundant *Combretaecae*, largely *Guiera senegalensis*, and little *Acacia spp.*, while in the next stages these two taxa are reversed. On the other hand, where grazing animals were allowed, the pattern of secondary succession was found to be different. Here shrubs increase over trees while annual grasses greatly suppress perennial ones, Fig (7.5).

Thickets of shrubs, previously not recognized, were observed to have emerged in different parts of the study area in general and in this formation in particular which in places have resulted in a thorn-scrub vegetation. This phenomenon has been recognized and analyzed by many authors in similar habitats in African Tropical Savanna, (Walter 1971, Kelly & Walker 1976, Hopkins 1983, Van Vegten 1983 and Gibson & Brown 1985). Close inspection indicated that these invasive shrubs often occur on old farms with large number of grazing animals or near water posts where perennial grasses have been much suppressed or destroyed by overgrazing. In terms of habitat charactersistics, *Boscia-Lannea* association had provided the most ideal suite for the development of this phenomenon and, therefore, conclusions drawn here will be largely based on observations made on this vegetation type.

To assess shrub encroachment, the canopy cover of the main woody vegetation stands in *Boscia-Lannea* association was mapped from the aerial photographs taken in 1958 and from the 1987 satellite data. Using these two sources, it was possible to distinguish five cover classes, namely $< 5\%$, 6-10%, 11-30%, 31-50% and $> 50\%$, Table (7.7).

Between 1958 and 1987 the surface area with little woody biomass, as represented by the first three canopy classes, has decreased by at least 50%, while the

Table 7.7: Surface Area Covered by Different Canopy Classes in *Boscia-Lannea* Association in 1958 and 1987

Class (%)	1958	1987
< 5	18.6	04.1
6-10	26.7	17.3
11-30	35.7	20.6
31-50	15.2	41.8
> 50	03.8	16.2

Source: Compiled from aerial photographs and satellite data

area with dense stands, as shown by the last two classes, increased by two fold. Table (7.8) presents ground data on percentage of woody plants stratification collected from three sites in the same area. Site (1) at the outskirt of Lubana with site (2) and (3) situated at a distance of 5 and 10 kms respectively. Assuming that land use intensity increases form site (1) towards site (3), the figures obtained clearly indicate an increasing trend of shrub populations, represented by the first three categories, following pressure on land. These shrubs, namely *Boscia senegalensis, Guiera senegalensis* and *Lannea humilis*, comprised 57.2%, 69.4% and 85.9% of the total woody cover in sites (3), (2) and (1) respectively. Thus they increase by 21% and 50% in sites (2) and (1) from that recorded in site (3), Table (7.8).

In the attempt to seek explanation for this shrub encroachment phenomenon, habitat factors were found to be the main cause. Under heavy grazing and cultivation, the shallow root mat is weakened leaving more unused water and probably leached nutrients to reach deep layers of the soil. This obviously favours the growth

Table 7.8: Percentage Frequency of Woody Cover Strata with Respect to Intensity of Land Use in *Boscia Lannea* Association

Stratum (m)	Site 1	Site 2	Site 3
< 2	17.0	09.5	11.2
2.1-3	36.7	25.7	19.6
3.1-4	32.2	34.2	26.4
4.1-5	08.8	11.4	17.3
5.1-6	03.6	12.9	16.4
> 6	01.7	06.3	09.1

Source: Fieldwork Data 1987.

of deep-rooted woody plants because of their increased access to water underneath (Walter 1971, Gibson & Brown 1985). So the chances for grasses to become re-established is greatly being reduced while young woody plants, particularly the inedible ones, can manage to burst past the grazing level and eventually survive to develop thickets. Moreover, when the grass shoots become scarce, animals feed on the pods of the woody plants with seeds passing unharmed through their intestines and finally finding a good seed bed in the deposited dung. Walter (1971), investigating the efficiency of Acacias seed germination from ripe pods and from cow dropping, found that the first seeds germinate after 9 and 5 days with a germination efficiency of 78% and 92% respectively indicating an increased efficiency.

By contrast, in *Acacia-senegal-Albizzia Sylerocarya* association, where grazing presure is comparatively lower, an extensive and dense grass-cover develops which had effectively suppressed most shrub seedlings allowing a very few to survive to maturity stage. A similar observation was also made in *Acacia senegal Balanites Sylerocarya* association where the gregarious *Boscia senegalensis* is successfully being controlled by the exclusion of grazing and the long fallow.

Shrub invasion has, therefore, changed in places the zonal vegetation into a type that characterizes more humid areas. The question that naturally arises is, could this shift be considered as permanent or as a successional stage towards a higher or lower equilibrium?.

The idea of Gibson & Brown (1985) is that, once these thickets are established, they will remain until the system is broken by artificial removal of the shrubs, (woodcutting, cultivation...etc), combined with the exclusion of grazing animals. On the other hand, Walter (1971) believes that, with further growth of shrubs, water use in time will no longer be balanced by rainfall and gradually the thickets will open up and more grasses will become established with no further regeneration of woody plants. He added, when the shrubs attain their age limit and begin to die out, a grass cover has already been established which can then close up allowing only few bushes to remain in between.

Our view in this respect is that, shrub establishment will continue to add to these thickets until water in the soil becomes a limiting factor and, therefore, further establishment will be balanced by dying-off of shaded-out species. The grass-cover will have a very little or no chance to become successfully re-established so long as land is kept under the same pattern of management. From this point the succession will become thinning process which lasts either until a subsequent disturbance or until natural thinning opens the shrub layer and a balance is achieved between patches which are thinning and patches at the stage of establishment.

7.3.4 Successional changes in transitional wooded grassland

This formation is the most widespread type of vegetation and, like secondary Acacia-wooded shrubland, among the least affected by human interference. It includes, *Aristida grassland*, *Acacia senegal Boscia*, *Combretum Lannea* and *Guiera Boscia* associations.

In *Acacia senegal-Boscia* association, major successional changes were found to be controlled by cultivation more than by grazing. As shown in Table (7.9), abandoned fields initially become dominated by the annual grasses *Aristida pallida, Sporobilus festivus* and *Digitaria ciliaris.* The perennials *Andropogon gaganus, Panicum turgidum* and *Cymobopogon nervatus* become established during the following 5-9 years. Gradually *Panicum turgidum* and *Cymobopogon nervatus* decline and become succeeded by *Andropogon gaganus.* This is locally sometimes taken as an indication that the land is ready to be farmed again. The re-establishment of woody plants was very variable depending on the number of rootstocks removed or killed during the clearance of land and the period of farming afterwards. *Boscia senegalensis* was found to be an early colonizer, followed at a later stage by *Acacia senegal, Lannea humilis* and *Maeura crassifolia* in that order, Table (7.9). Although *Acacia senegal* has been taken as a typical tree species in this association, it should be regarded as a secondary species associated with the system of cultivation through which it has been protected and encouraged for its economic value.

The area between Umm Kherein and Wad Gerad is essentially a secondary grassland and is mapped as *Aristida* grassland. This area seems to have been formed fairly recently by cultivation and the removal of firewood from the relatively richer woodland types of vegetation that was described by Harrison &

Table 7.9: Percentage Frequency of the Main Plant Species in Different Age of Fallow in *Acacia senegal Boscia* Association

Species	0-4	5-9	10-14	15-19	¿20
B.senegalensis	44	51	58	61	79
A.senegal	08	32	65	59	65
M.crassifolia	06	13	12	22	28
A.nubica	11	14	28	36	45
A.amara	08	15	11	09	18
C.aculeatum	03	14	07	08	02
Z.christi	02	07	06	11	15
L.humilis	10	08	21	28	35
A.pallida	34	48	48	65	31
S.festivus	41	61	28	42	18
C.biflorous	22	82	34	65	42
A.gaganus	00	36	47	80	84
P.turgidum	05	14	36	41	23
D.ciliaris	45	32	45	26	18
C.nervatus	04	21	56	56	48
E.aspera	08	10	18	21	18

Source: Fieldwork Data 1987.

Jackson (1958) and by HTS (1963). These two studies gave a long list of trees in this area, Table (7.10), which except for *Acacia senegal* they were hardly traced. Again *Acacia senegal* managed to escape elimination by virtue of being maintained through the gum-cultivation cycle. The dominance of *Calotropis procera* and the abundance of *Ziziphus spina-christi*, growing on mounds of wind blown sands together with the sparseness of the herbaceous cover indicate a successional stage towards a more arid type of vegetation.

Table 7.10: Frequency of the Main Woody species in *Aristida* Grassland Compared to those of Harrison & Jackson (1958) and HTS (1963)

Species	Frequency (%)	H & J	HTS
A.senegal	45	Dominant	Abundant
M.crassifolia	00	Frequent	Abundant
B.aegyptiaca	15	Abundant	Frequent
C.cordofanum	07	Frequent	Frequent
A.mellifera	00	Abundant	
Z.christi	32		Rare
C.procera	42	Rare	Frequent
B.senegalensis	18	Frequent	Rare

Source: Fieldwork Data 1987.

Balannites aegyptiaca was noticed to grow in this formation only as coppice regrowth, while seed germination was virtually absent. Mortality during seed germination and establishment was found to be high. In many cases no seedling had survived the first growing season. By contrast, *Balanites aegyptiaca*'s seedling establishment under the optimum conditions in Khuwei nursery was reported to be comparatively higher, an unreliable source at the nursery gave a figure in the region of 80-90%. The conclusion to be drawn from these observations is that, *Balanites aegyptiaca* can survive long dry periods in these areas in the reproductive phase of its life cycle but seedling establishment is being greatly curtailed.

The lacustrine depressions south of Abu Haya were recognized by Harrison & Jackson (1958) as being dominated by *Acacia mellifera* with frequent *Acacia nu-*

bica. HTS (1963) showed an increase in *Acacia nubica* either more extensive in its natural habitat along depression margins or as a secondary species following cultivation of depressions formerly dominated by *Acacia mellifera.* Observarions made on these depressions showed that, abandoned fields either remain open or become fairly dominated by *Acacia nubica.* Further colonization by *Acacia mellifera* was found to be very rare.

When farmlands are abandoned in these depressions, colonization of the bare sand commences in the hollows. It is here that the vegetation litter collects which provides shelter and possibly a moister micro-climate for seed germination. In many cases it was observed that only a few individuals belonging to one species is the sole initial colonizer of the dune hollows. *Cenchrus biflorous* is often a primary colonizer. *Aristida pallida* and *Panicum turgidum,* which have fluted tap roots and vigorous prostrate habits, appear to be well adapted for survival in the shifting sands. These two species soon dominate the hollows and offer protection to subsequent grasses. This replacement pattern, however, seems to be in line with the "facilitation" model of succession proposed by Connell & Slatyer (1977).

7.3.5 Successional changes in the riparian vegetation

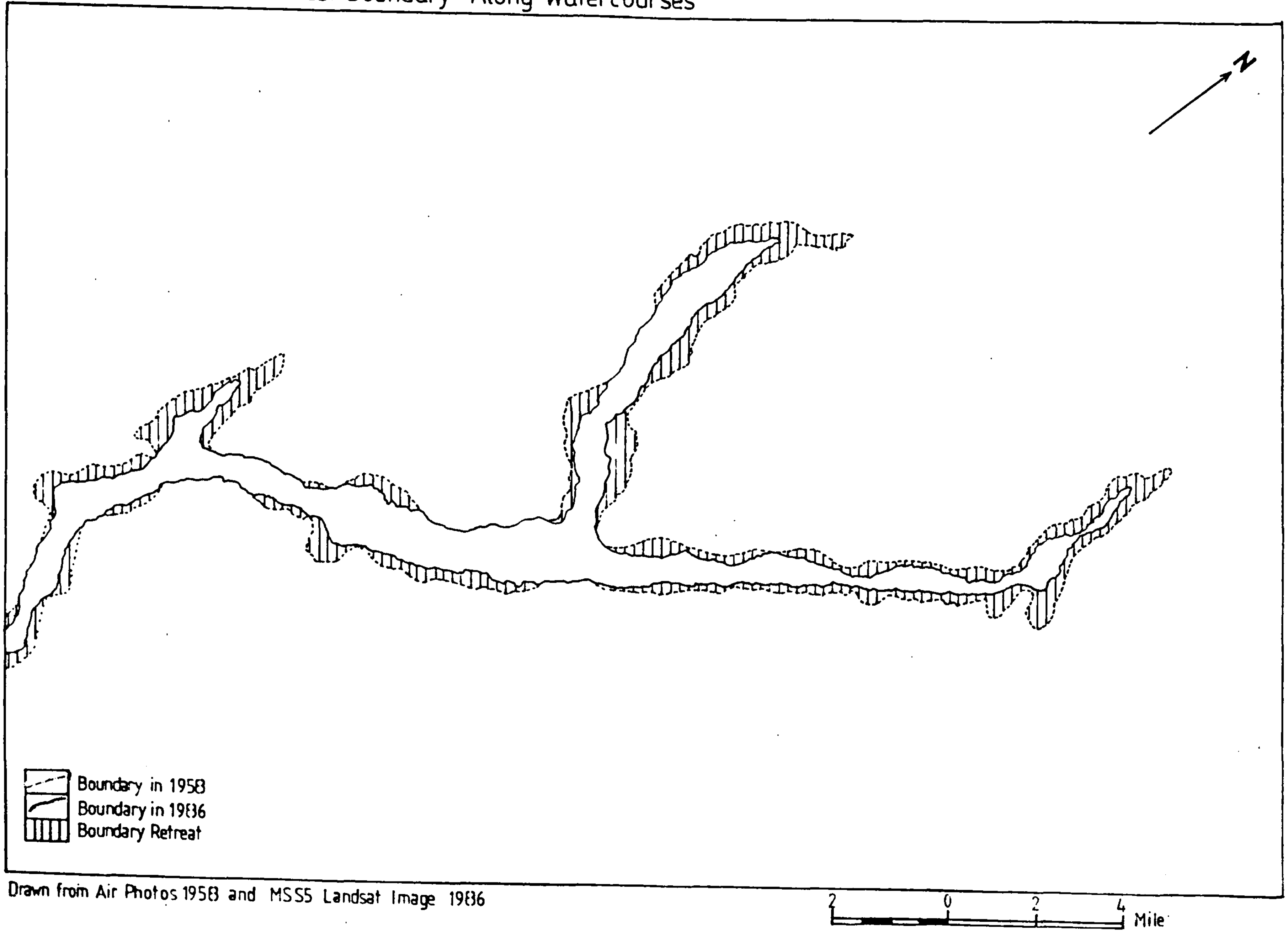
As mentioned in chapter three, this type of vegetation consists of the rich flora developed along the main watercourses and in the water retaining sites. Although these areas basically carry reserve forests where grazing animals are excluded and other types of land use are extremely prohibited, close inspection had revealed positive signs of successional trends in the composition and structure of the vegetation present.

1. Successional changes along watercourses

The relatively wet climatic conditions prevailed in the past apparently had allowed these courses to flow water on a wider area on both sides which through time had promoted the growth and development of a closed forest canopy. Recurrent droughts and the frequent shortage of rains, however, had seriously reduced the flow of water in these courses and as a result, a large part of the these forests, especially near the margins were denied the amount of water necessary for maintaining the canopy cover. The comparison made between these forests in 1958 and 1987, using aerial photographs and satellite data, showed a remarkable retreat in the forest boundary, Fig (7.6). In certain areas this ecotone is reduced to a tiny remnant as in the area near Arak and north of Khuwei. Regarding the situation in the latter area, the Forestry Department (1984) wrote that .. *the administration had decided to abandon two reserve forests as there are no longer forests that worth preserving.* At the margins of these forests, the canopy is gradually becoming open and species like *Tamarindus indica* which is a characteristic species of these forests, was never found reproducing. On the other hand, this shift in habitat has favoured the spread of savanna woodland species like *Acacia nubica, Acacia nilotica, Balanites aegyptiaca, Albizzia amara* and *Acacia mellifera.* Many species of neighbouring vegetation types were noticed to have started to encroach agressively towards the margins of these forests. The pioneers have included *Boscia senegalensis, Lannea humilis* and *Guiera senegalensis.* Altogether, indicating a successional trend towards a more open savanna woodland as the habitat is becoming increasingly less favourable to maintain a closed forest.

Moreover, the relaxation in the implementation of forestry laws has encouraged some farmers and animal herders to use large parts of these forests, and if this trend

Figure(7.6) Retreat of Forest Boundary Along Watercourses



Drawn from Air Photos 1958 and MSS5 Landsat Image 1986 is to be allowed to continue without check, the same general pattern described for the other four formations would soon repeat itself here no matter how much water is being channeled by these courses.

2. Successional changes in water retaining sites

Evidence on secondary succession in these sites was found to be largely compositional as no structural signs of succession have been detected. The discussion here will be based on the observations made on the riparian type of vegetation to the west of Ankosh.

In this area, seedlings of Acacias, especially *Acacia nilotica* were found almost exclusively in areas with no woody cover with very few individuals at the outer edges of the canopies. In contrast, the distribution of seeds and seedling establishment of other trees especially *Terminali brownii* and *Albizzia amara* was noticed to increase beneath the canopy as well as in the open. These observations can be interpreted as representing a successional sequence from Acacia vegetation to stands dominated by *Terminalia brownii* and *Albizzia amara*. The absence of *Acacia nilotica* in under canopy environment is most likely due to competition for below ground resources and the reduced light under canopy. There were generally higher rates of Acacia seedling germination below tree canopy, but in the same time, there was also a higher mortality of seedlings. This successional trend, however, corresponds to the "inhibition" model of succession proposed by Connell & Slatyer (1977). Gibson & Brown (1985) regard early successional species to require more open soil patches. This in principle could explain the above identified successional pattern. For Acacias are regarded here as early successional species while *Terminalia brownii* and *Albizzia amara* as late successors

With the senescence of *Acacia nilotica*, the stands gradually change from one of large regularly dispersed Acacias to stands dominated by patches of *Terminalia brownii*. It may be suggested here that, in the past, grazing animals have acted as a factor restricting these two species from being established and in turn increasing the turnover rate of *Acacia spp.*. Acacias are relatively less affected by grazing when present among other species. However, the elimination of grazing animals in this site probably had been followed by an increase in the establishment of *Terminali brownii* and *Albizzia amara*. If this assumption is correct, then the removal of grazing animals may well had acted as a disturbance to the *Acacia spp.* in these ecotones.

7.4 Concluding Remarks

The different vegetation types in the study area were shown to represent various secondary successional stages following either excessive cultivation, grazing or both. However, purely climatically conditioned natural vegetation are virtually absent in the area as the effect is almost entirely masked by man. Evidence suggested that, if the vegetation is protected and the climatic and edaphic conditions are favourable, it will eventually be succeeded by a richer vegetation type. Alternatively, either the soil, climatic conditions or disturbances by man will limit growth and so that it is unlikely to be succeeded by the ecologically higher formations.

The vegetation in cultivated areas had suffered less than that intensively grazed. Except in areas where cultivation is continuous, as around settlements, the vegetation is allowed enough time to become re-established. Always valuable trees are protected and left untouched giving sometimes a false impression of a wooded landscape.

Many communities reflect and have been explained through their history of grazing pressure. Animals were found to interrput the process of succession and to radically change its dynamics and to set plants on a wide variety of paths depending largely on pressure exerted. Because animals are merely consumers, these changes are always in the direction of reduced phytomass, lower production and more xeric conditions. Comparisons made between heavily grazed and areas not utilized had shown how animals played a decisive role in preventing the germination of major plants. Resistent species became more abundant in the grazed plots and many grazing-sensitive or palatable species absent in that plot became re-established in the ungrazed areas. The impact on the tree cover was more dramatic than on the herbaceous cover. Overstocking had resulted in a decrease in woody plants and increased the density of the shrub layer. Although many of these areas are in a dynamic equilibrium, a decrease or the exclusion of grazing animals, as exemplified by the riparian vegetation, often results in a more close woody vegetation. Although these changes were considered as a succession, the climax vegetation was by no means always clear except in areas abandoned a long time ago.

Many authors claim that the vegetation zones of Kordofan are constantly shifting southwards as a result of overgrazing, overcultivation and accelerated soil erosion. Although such a claim could not be totally rejected, so far no evidence has been found to support it. Our view in this connection will be presented through findings obtained from the analysis of successional changes in the different formations. These successional changes were found to range from those of multiple equilibria with mere changes to high or low levels of populations to a complete change from one set of populations to another. The latter implies the extinction of the first set (or at least some dominant species in that set) and that it has been followed by the development of a different set. In this context, it is difficult to determine whether or not the second state, although in most cases exhibiting a more xeric form of vegetation, is truely an equilibrium condition or merely representing a lower successional stage, let alone to claim a southward shift in the vegetation zones. Such a judgement, in our opinion, probably requires long-term observations, the use of more plant vital attributes and the systematic incorporation of life-history characteristics in the modeling of temporal and spatial aspects of succession, a task certainly beyond the achievement of this work.

Chapter VIII

Summary and Conclusion

Investigating different aspects of vegetation change, floristically and structurally as well as temporally and spatially, in relation to major environmental disturbances and discontinuities in Kordofan region had constituted the theme of this research-work. The work, however, has started with the classification of the area's vegetation cover through which similar stands were grouped together for further analysis.

The first subsequent step was made to investigate different aspects of the spatial arrangement of species or their pattern of distribution. The purpose here was mainly to present data on species abundance recorded in quadrats and transects in a way which is suggestive of their underlying structure. It was found that most species are not randomly distributed and no indication of the postulated regularity of distribution was found as only very few species at very local levels did fall below the random expectation. In fact at all stands identified, contagious distribution was recognized to be the common pattern. Such a distributional pattern of species was explained through the pattern of surface properties. Extremely minor variations in environmental factors were shown to produce a corresponding variation in the structure and composition of the area's vegetation.

Association analysis and departure from randomness in species distribution were the two methods used. Association analysis was used to reveal the degree of the interaction between different species as reflected in the positive and negative correlation between species. Presentation of the results was made through the differential requirements of species, competition and the pattern of association created by modification in the micro-environment whether by plants themselves or by other external factors like climate man or animals. On the other hand, analysis of non-randomness was largely used to detect scales of pattern that resulted from the interaction of vegetation with the major environmental discontinuities.

Rainfall in the study area was shown to be insufficient to allow for a continuous vegetational cover with the result that vegetation often occurs in patches on the most favourable sites. Plant growth is vigorous and dense on sites where water accumulates while bare surfaces become increasingly extensive northwards. The shift towards less rainfall was shown to have transformed the ecological equilibrium between species and confined their geographical range. Water demanding species become incapable of competing under such arid conditions and consequently were driven to damper sites. On the other hand, drought-enduring species, which are better equipped to stand such arid conditions, have widened their habitats and bridged over areas previously occupied by the first group of species. The effect of rain failure on grasses was shown to be more dramatic than that on trees. They are often killed before completing their life-cycle which means that seeds are rarely produced. Through this process many grasses had disappeared from many localities. Other type of grasses seemingly have optimized little rains, growing fairly densely in areas extremely unfavourable from the soil-moisture point-of-view. These species were found to compensate for the lack of adequate water supplies by completing their life-cycles during the very short rainy period.

Soil charactersitics, in terms of structure, texture and levels of fertility, were found to have a measurable impact on vegetation. It was shown that on sandy soils, trees and shrubs are the dominant type of vegetation while the grass cover significantly increases on clayey soils. As drainage is more free on sands, water penetration is deeper with the upper layer being frequently dry. On clays, however, there is more water available in the top layer during and shortly after the rains. So on sands water is available to deep-rooted species, thus favouring the development of a particular edaphic climax vegetation made of sparsely distributed drought resisting trees with extensive tap roots that can reach moisture well below surface levels. With more sand being blown in, the situation gets more acute and only in the dune hollows does a fairly well stocked cover of vegetation grow. On soils with higher clay contents, a savanna-like type of vegetation grows. As the sandy layer becomes shallow, grasses replace trees and conversely with the increase in the sandy layer, trees become more abundant with grasses becoming confined to higher grounds. Species with strong lateral and deep root systems were found to have a wider pattern of distribution on both soils as they are able to make use of water at the surface as well as from lower depths.

Other measured soil properties were shown to vary from place to place exerting varying degrees of pressure on vegetation. While the effect in some vegetation stands was clear and significantly indicative, in others it was hardly detectable. Similarly, the reaction by species was shown to vary from those being strongly affected by these soil parameters to those barely reflecting any significant response.

Variation in the micro-topography was shown to have greatly modified the pattern of association between species and have created series of patterns that differ from the surrounding both floristically and physiognomically. These patterns were shown to have resulted from the inter-related factors of soil moisture, nutrient supply, pH, drainage and leaching which together reflect non-uniformity in the soil surface. In all cases investigated, water availability was found to be the governing factor which controls the nature and magnitude of these patterns.

In dune areas, dense stands of vegetation grow in the inter-dune hollows and increasingly doing so towards the north where moisture progressively becomes a limiting factor. A catena effect was shown to have developed across these topographical features with certain species becoming associated with particular position of the slope. A similar pattern was found to have developed in low lying areas where water accumulates during the short rainy season. In these areas, a mosaic-like pattern of vegetation even stronger than that produced by the sequence of dune tops and bottoms was recognized. These mosaic were found to be structurally and physiognomically isolated from the dry surroundings.

Patterns produced by seedling/performance interaction was investigated as this is significant in shaping future vegetation stands. Aspects of propagation through vegetative spread and seed germination were particularly emphasized. Species germinating by seeds were found to produce a noticeable open pattern of adult populations which was explained through the process of random seedling mortality. Seedlings are particularly vulnerable and have to compete among other species for available water before reaching deep to permanent supplies with the result that mortality of seedlings becomes very high. Grazing was rejected as a factor because dead but ungrazed seedlings were frequently encountered. Some seed-bearing species were mentioned to lack regular reproduction and this was explained by the nature of seeds and tolerance of seedlings. On the other hand, species germinating by vegetative means were found to have better chances of establishment as shown by their less drastic differences between various age-classes. This mode of propagation was recognized to have caused these species to become clumped together and grow in homogeneous colonies. Such a strong pattern was shown to have driven other species into secondary aggregations more often in unfavourable localities.

The assessment of the impact of man on the area's vegetation was made through investigating land management and types of land use practices and through the assessment of the uncontrolled harvesting of biomass. It was found that not all human activities practiced were harmful to vegetation as the pressure exerted differs from place to place and from one type of land use to the next. In fact some of these practices were found to play an important constructive part in the maintenance and conservation of the area's soils and vegetation. These have consisted of the different agro-forestry activities through which several plant species are locally protected and encouraged for certain economic and related values.

The harmful effect of cultivation was shown to have started when farmers failed to maintain their traditional shifting cultivation system as practiced in the past. Most farmers were found not to have enough land necessary to keep that cycle and with the frequent failure of rains, these farmers opted for increasing cultivated lands in the hope of securing their food and cash needs. This, however, took place at the expense of the fallow period and the result has been a continuous opening of new areas for permanent cultivation. The risk of crop failure increases from south to north and so too the tendency to put more land under cultivation. An indirect consequence of the expansion in cultivation is that it has increased the pressure on the surrounding rangelands as the conversion of more productive forage areas to agricultural production forces animals to overgraze the remaining land-base.

Fire which is locally used to prepare land for cultivation was shown to have resulted in excessive soil depletion and nutrient loss and eventually in a critical breakdown in the soil ecology. Repeated burning had resulted in the reduction of large areas to the condition of almost secondary grassland with scattered fire-resistant trees. Areas lightly grazed were mentioned to be particularly susceptible to fire damage. Therefore, fires have resulted in a vegetation equilibrium with a close cover of grasses and scattered fire-resistant trees. In areas where burning was discontinued, signs of vegetative recovery were recognized.

Regarding the impact of grazing animals, it was found that there are far more animals on the poor grazing land than the latter can safely support. The many interventions made in this area had greatly upset the traditional grazing pattern that had been working over centuries. Population mobility in the past kept a cyclical land use pattern. The establishment of permanent activity centres and the increase in animal population have brought about a change in that pattern and instead a permanent type of grazing has replaced the cyclical one. Grazing animals were allowed to survive on areas that were otherwise too dry at times to support them. Palatable species have become depleted with a noticeable increase in the resistent and avoidable ones. Grazing was found to have caused a greater variety in the flora as many species and sometimes rare ones have maintained themselves where otherwise they would have been swamped by a dominant species if not checked by grazing. For woody species, it was found that pasturing of animals on grasses growing underneath causes the real damage. Because seedlings will often be grazed instead of growing to maturity.

Uncontrolled felling of timber to meet the increased demand on fuelwood, charcoal, house construction and other types of commercial utilization was shown to have caused a dramatic loss in the woody vegetation of the area. The mechanized transportation network has facilitated this process for it permitted man to reach remote areas and to transport products over longer distances. The result is a massive intrusion of external demands on the local meagre resources which in turn has widened the scale of destruction.

The different types of vegetation identified in the study area were shown to represent various successional stages following either excessive cultivation, grazing or both. Climatically conditioned natural vegetation is virtually absent in the area as the effect is almost entirely masked by man. Comparisons made between field data and the available reports on this area had revealed significant floristic and physiognomic changes in the area's vegetation.

Human activities had explained parts of these changes. Evidence presented showed that various types of woodland were formerly more extensive and that they have been replaced by secondary shrubland and bushland following cultivation and excessive felling of trees. With more grazing animals present, most of the grass-cover had been removed which in turn favoured the establishment of these shrubs and bushes.

Abandoned farmlands were found to be invaded first by annual grasses with few perennials. With more time, shrubs and trees gradually develop starting with species that tolerate disturbance and those adapted to such impoverished soil conditions. They are often those species which have survived the period of cropping either as protected trees or more usually as underground rootstocks. As the land approaches stability, more trees and shrubs grow and become established and more species at the shrub layer become promoted to the tree layer. The development of more woody plants weakens annual grasses because of their inability to compete successfully and they are succeeded by the better adapted perennials. Where fires are used to clear land, mainly a secondary grassland vegetation develops and where they are discontinued a dense woody cover emerges. This includes those species which remained in moist ravines during burning.

Most of plant communities investigated have been explained by their history of grazing pressure. Grazing animals were found to interrupt the process of succession, to radically change its dynamics and to set plant species on a wide variety of paths which is largely controlled by the pressure exerted. In light grazing areas, vegetation was less affected, the herbaceous cover is dominated by late successional species, shrubs are kept at minimum while trees are noticeably present. However, in heavily grazed areas a significant shift was recognized towards annuals over perennials, a selection of prostrate rather than erect forms of growth and towards unpalatable and resistent species over palatable and sensitive ones. Trees were reduced to a shrub layer with the latter becoming a vegetal feature of these areas. In the most extreme cases, thickets of shrubs were shown to have dominated the final stage nearly excluding grasses.

The emergence of such thickets has not been previously reported in this region and close inspection showed that these invasive shrubs often develop on old farmlands with large number of grazing animals. Habitat factors were used to interpret part of this phenomenon. By contrast, in areas of minor grazing and long fallow periods, most shrub seedlings were found suppressed and only few can successfully manage to survive to maturity. The conclusion drawn on this phenomenon is that these thickets will continue to exist there as long as these lands are kept under the same pattern of management.

Along watercourses, significant compositional and structural changes were detected and have been attributed to the severe rain shortage, and at a later stage, to the overuse by man. Signs of encroachment of savanna species from neighbouring regions were recognized and shown to indicate a successional trend towards a more open woodland as the habitat is increasingly becoming less favourable to maintain a closed type of forest. In water-retaining sites the change was shown to be compositional as no structural signs of change were detected.

The claim often found in literature that the vegetation zones in Kordofan are constantly shifting southwards as a result of overgrazing, overcultivation and accelerated soil erosion could be neither proved nor rejected. Such a conclusion was shown to require an extensive and a long-term project in order to reach a meaningfull assessment. The findings we presented in this respect have included the recognition of a continuous process of successional change which vary from one place to another in terms of nature and intensity largely depending on site charactersitics. Although part of this change was shown moving towards a more xeric type of vegetation, it was not possible to determine whether such a shift is a true equilibrium or merely represents a transitional stage towards another type of vegetation. So in the light of the available range of data, there is no ground what so ever to make any sound judgement concerning a southward shift of vegetation zones, neither could those previous studies, in the absence of long-term records, have adequately and scientifically proved it.

Whatever the results of climatic researches, an inescapable central lesson to be drawn from the experience of this area is that, drought is an unavoidable natural phenomenon in the entire zone. The real calamity, however, arises fom the failure of these societies to mould their habits to fit environmental reality. Incidences of successive and severe drought have continued to hit the region. Nevertheless, grasses and trees in varying combinations have persisted and re-established themselves after virtual elimination. Such an aspect could only point to the high resilience of the system. This is perhaps its prominent feature which enables it to adapt and survive such temporal variations.

Ample evidence was shown that if the vegetation is protected and the climatic and edaphic conditions are favourable, it will eventually be succeeded by a richer vegetative-cover. In areas where fires were discontinued, deciduous woodlands had emerged on what used to be a secondary grassland. Successional changes on farmlands when allowed the full length of time to rest were shown to result in a more dense vegetation. The decrease or exclusion of grazing animals was shown to result in a more close woody cover.

Therefore, with a transformation of farming and grazing techniques towards a less self-destructive pattern, these activities can have a far reaching consequence on environment. Human cultural patterns in these regions must be remodeled to survive the driest years, not to push the system to its limits in years of favourable rains.

Land use planning involving the integration of agriculture, animal husbandry and useful trees appears to be a sound tool. However, the traditional values governing the way the land is used and owned may impose the first obstacle to this intervention. Changing the land into purely resources management basis is unacceptable to most of the people where the first priority is centred around their survival. Considering such constraints, we believe that adopting or beginning with low risk small-scale demonstration projects seems to be the most appropriate approach. Attempts in this connection may begin with agro-forestry projects which cover a variety of land use practices in which vegetation is directly associated with agricultural crops and/or livestock. This type of land management has been traditionally practiced in the region and has shown ample evidence of success.

Other measures may include establishing well identified grazing areas with the necessary vegetation and water supplies to help maintain small well-managed herds. The employment of rotational grazing based on field carrying capacity is bound to exclude the harmful effect of overgrazing. In this respect it appears that a margin still exists between the actual and the potential production capacities and that locally appropriate grazing management options can be pursued.

Regarding the dramatic loss of timber resources, other cheap sources of energy can be introduced to reduce the total dependency on biomass. By increasing the effeciency of fuelwood utilization rates as well as charcoal production and consumption extensive woodlands will be saved at a relatively modest cost. In this connection a call is required for more forest conservation and for an integrated and proper management programme that allows the local people to participate in the formulation and the execution of such plans. Preparation of forest inventories, policies for potecting forests, forest utilization and future research all require adequate and sound planning.

Perhaps with opportunities of long-term projects combined with thorough ecological investigations, detection of significant relationships between vegetation and habitat can be made. Firm findings can only be arrived at after ecological, experimentally based, stations have been established where they could provide a basis for prolonged observations. This will eventually develop and help in the application of a sound methodology for studying and monitoring vegetation dynamics and change in the region as well as throughout the entire zone. In this respect, enormous progress in the realm of vegetation science could be achieved if there is a continental collaboration and, most importantly, agreement on the terminologies and definitions of vegetation stands and status as this would help in comparing vegetation types on a continental as well as a world-wide scale in a more communicable forms.

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Appendix A

TWINSPAN Clusters Output

A.1 First Level of Divisions

Table (A.1) is a tabular arrangement produced by TWINSPAN which clearly distiguishes between species according to their preferentialities to either groups in order to make this dichotomy. The top 18 species are more abundant on the left side and accordingly they are preferential to that side forming a defined category than the rest of species which are somewhat indifferent, widely ocuring in both sides. *B. xantholeua* occurs in all samples in the negative group and in non in the positive group. Thus, this species is taken as the finest differential species and it's presence exactly demarcates the group of samples to the left of the dichotomy and strongly indicates the conditions in which the other 17 species are likely to be found. By contrast, species like *B.senegalensis* and *T.terrestris* are poor differential species, not sharing any particular affinity with either group of samples indifferently occuring in both.

The classification of species and samples are indicated along the right and bottom margins respectively. The main dichotomy for the species is indicated by a horizontal line, and for the samples by a vertical line. Values indicate a scale of abundance with absence of species represented by the symbol "–"

A.1.1 Division (1)

TWINSPAN has selected *B.xantholeua* as the single indicator for deriving this dichotomy and was given the sign (–) to denote it as a negative indicator as it does not occur outside the negative group. The samples that contain this species are assigned to the negative group, whereas the rest are designated as a positive group. As there is only one indicator species for making this first dichotomy, the maximum indicator score assigned to the negative group is -1 while zero is the minimum

(continue.....)

	Samples Clustered																																	Divisions					
Species	17	18	16	05	07	24	23	12	19	14	20	21	22	25	28	27	26	30	32	33	02	09	29	04	06	03	08	10	11	15	01	13	31	1	2	3	4	5	6
B.aeygyp.	2	-	1	1	1	2	2	1	1	2	2	2	2	2	2	1	1	2	1	1	1	1	2	2	-	2	2	2	1	2	1	-	1	1	0	1	1	0	0
A.nubica	-	-	-	1	-	1	1	1	1	2	2	1	2	1	2	1	1	2	1	1	3	1	2	2	3	-	-	1	-	3	1	2	2	1	0	1	1	0	0
B.senegal.	2	-	2	2	2	-	2	2	2	3	2	3	3	2	3	2	2	2	3	3	2	2	2	4	2	2	2	3	2	2	3	2	2	1	0	1	1	0	0
S.birrea	1	-	1	1	1	2	1	1	1	2	2	1	2	1	1	1	1	1	1	1	2	1	1	2	2	3	2	2	2	1	1	-	-	1	0	1	1	0	1
C.sesmam.	2	-	2	1	2	1	2	1	1	3	2	1	2	1	2	3	3	2	2	2	3	1	3	2	4	3	2	-	2	-	2	3	1	1	0	1	1	1	
G.senegal.	-	-	1	1	1	2	2	2	2	3	2	2	2	2	2	1	1	2	1	2	2	1	1	2	1	1	1	3	2	3	2	2	-	1	1	0	0	0	
A.amara	1	-	1	2	1	1	2	2	2	2	3	2	2	2	2	1	-	1	1	1	2	1	-	2	1	2	-	2	2	2	2	-	1	1	1	0	0	1	
C.hartmann.	1	-	1	1	1	2	2	1	2	1	2	2	1	1	1	1	-	-	1	-	-	1	1	-	2	2	1	2	2	2	1	1	-	1	1	0	1	0	0
D.glomera.	1	-	-	1	-	2	-	1	1	-	2	2	-	-	1	1	-	-	-	-	-	-	-	1	1	-	-	1	1	-	-	1	-	1	1	0	1	0	0
W.indica	1	-	2	2	2	1	2	1	1	2	1	1	2	1	1	1	1	1	2	1	2	-	2	-	2	2	2	3	2	2	2	1	1	1	1	0	1	0	1
D.melanox.	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	0	1	1	
A.nilotica	-	-	1	1	1	1	1	1	1	-	1	-	1	-	1	-	-	-	-	-	1	1	-	2	2	-	-	1	-	1	2	1	-	1	1	1	0	0	0
T.brownii	-	-	1	-	-	2	1	1	2	1	2	2	1	1	-	-	-	-	-	-	-	-	-	2	2	1	-	2	2	-	-	-	-	1	1	1	0	0	1
A.digitata	-	-	-	-	-	-	1	1	-	1	1	-	-	1	-	-	-	-	-	-	1	-	-	1	2	-	-	-	-	-	-	1	1	1	1	1	0	0	1
A.gayanus	-	1	-	1	-	-	-	-	1	-	1	1	1	2	-	-	-	-	-	1	-	-	-	-	-	1	1	-	-	-	-	-	1	1	1	1	0	1	
Divisions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1						
	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1						
	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	1						
	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1		0	0	0	1	1							
			0	1	1		0	1	1		0	0	1	1	1	0	0	0	0	0	1	1						0	1	1									
													0	0	1	0	1	1	1	1																			

(Continue....)

Species	Samples Clustered																																Divisions					
	17	18	16	05	07	24	23	12	19	14	20	21	22	25	28	27	26	30	32	33	02	09	29	04	06	03	08	10	11	15	01	13	31	1	2	3	4	5	6
A.albida	1	-	1	1	-	1	1	1	1	-	1	1	1	1	1	-	1	-	-	1	-	-	1	1	1	-	-	-	-	-	-	-	1	1	0	0	1	1	0
M.crassifolia	1	-	1	-	1	1	1	1	2	2	1	1	1	1	1	1	-	1	-	-	1	-	1	-	2	1	-	1	1	2	-	-	-	1	0	0	1	1	0
C.procera	1	-	2	2	1	2	1	2	2	1	1	1	-	2	2	-	2	2	2	2	2	2	2	2	-	2	-	2	1	-	-	-	3	1	0	0	1	1	0
L.humilis	2	-	1	2	2	2	2	2	2	2	1	2	2	2	2	-	1	2	1	2	2	2	2	-	2	3	2	-	2	1	-	-	-	1	0	0	1	1	0
T.terrestris	3	-	1	1	1	2	2	1	1	1	2	2	1	2	2	2	1	2	2	2	1	2	3	-	2	2	1	-	2	1	-	1	3	1	0	0	1	1	0
C.bifolorus	2	-	2	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	2	2	2	2	2	4	2	2	2	2	-	1	-	-	1	0	0	1	1	0
C.obtusifolorus	-	-	2	2	1	1	2	1	-	-	-	-	1	1	2	1	-	1	1	1	1	-	1	-	1	-	-	2	-	-	-	-	2	1	0	0	1	1	0
C.italica	3	-	3	1	1	2	3	1	3	2	3	3	2	3	2	2	2	3	3	3	2	1	4	2	2	3	2	2	2	3	1	1	3	1	0	0	1	1	0
D.ciliaris	1	-	2	3	2	1	2	1	1	2	1	2	1	1	2	2	2	1	1	1	1	1	3	2	3	2	2	-	1	-	-	2	-	1	0	0	1	1	0
A.acanthus	3	-	2	1	1	2	3	2	2	2	2	2	2	3	3	2	1	1	-	1	2	2	2	2	-	2	-	-	2	-	2	2	1	1	0	0	1	1	0
C.obilorius	2	-	2	-	-	3	2	-	1	2	2	2	2	2	1	2	3	2	1	2	-	-	2	-	-	2	2	-	1	-	-	1	1	1	0	0	1	1	0
G.tenax	-	-	1	-	-	-	-	1	1	-	-	1	-	-	1	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	0	0	1	1	0
A.tortilis	1	-	-	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	1	-	2	-	1	1	-	-	-	-	-	1	0	0	1	1	1
A.lanceolatum	1	-	1	2	1	1	1	1	1	1	1	-	1	1	1	1	1	1	-	-	1	1	1	2	-	2	-	-	-	-	2	1	-	1	0	0	1	1	1
S.gracilis	1	-	2	1	1	1	2	2	2	2	1	1	2	1	1	1	-	1	-	-	2	1	1	2	2	2	-	-	-	-	1	2	-	1	0	0	1	1	1
P.anabapt.	3	-	2	2	2	2	2	2	2	1	1	1	1	1	2	1	1	1	1	1	1	2	1	2	3	2	2	-	-	-	-	-	1	1	0	0	1	1	1
L.pyrotech.	2	-	2	1	1	2	1	1	1	1	-	1	1	1	1	1	-	1	1	1	1	2	1	3	-	1	2	2	1	-	-	1	-	1	0	1	0	0	
E.aspera	2	-	3	1	1	2	3	1	2	2	2	2	2	2	1	1	1	-	1	1	1	1	1	3	3	2	2	2	-	-	1	1	-	1	0	1	0	0	
P.oleracea	2	-	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	1	2	2	2	2	2	-	3	3	2	-	2	3	2	3	-	1	0	1	0	1	
A.senegal	2	-	2	2	2	2	2	2	3	2	2	3	3	3	4	3	2	2	2	2	3	2	2	2	4	3	3	2	2	2	1	2	2	1	0	1	1	0	0

Table A.1: Two-Way Table Ordered & Classified by TWINSPAN

	Samples Clustered																																	Divisions					
Species	17	18	16	05	07	24	23	12	19	14	20	21	22	25	28	27	26	30	32	33	02	09	29	04	06	03	08	10	11	15	01	13	31	1	2	3	4	5	6
Z.christi	1	1	-	-	1	1	1	-	2	1	2	1	1	1	1	-	-	1	1	1	1	1	1	-	-	-	-	-	-	-	-	1	-	0	0	0	0		
A.pallida	2	2	1	2	-	2	2	2	1	1	2	1	1	1	1	2	1	1	-	1	1	1	2	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	
B.xantholeua	2	2	2	1	1	1	2	2	1	1	2	2	1	1	2	2	1	1	1	1	1	2	1	-	-	-	-	-	-	-	-	-	-	0	0	0	1	0	
A.adscensionis	2	2	2	1	1	3	2	1	2	1	2	2	2	2	1	1	1	1	-	1	1	-	2	-	-	-	-	-	-	-	-	1	-	0	0	0	1	1	
T.laxiflora	-	-	-	-	-	1	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1			
T.portulacastum	-	-	-	-	2	2	2	2	1	1	2	2	2	2	2	1	1	1	1	2	2	2	2	2	-	-	-	-	-	-	-	-	-	0	0	1			
C.glutinosum	-	-	1	1	-	1	1	1	2	1	1	2	2	1	1	1	-	-	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	0	1	0	0	0	
L.kerstingii	1	-	-	-	1	1	1	1	1	1	1	1	1	-	-	-	-	-	1	1	-	-	1	-	-	-	-	1	-	-	-	1	-	0	1	0	0	1	0
C.aculeatum	-	-	2	1	-	2	1	-	1	-	1	1	1	1	1	1	-	1	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	0	1	0	0	1	1
C.sativus	2	-	2	1	2	2	2	1	2	-	2	1	2	2	2	2	2	1	1	2	1	1	3	-	-	2	-	-	-	-	-	-	-	0	1	0	0	1	1
E.colonum	-	-	2	2	1	1	2	1	2	2	1	1	2	2	2	1	1	1	1	1	1	1	2	2	-	-	-	2	-	-	-	-	-	0	1	0	0	1	1
S.festivus	2	-	2	2	1	3	2	1	1	1	2	2	2	1	2	1	2	1	1	2	1	-	2	2	-	-	2	-	-	-	-	-	-	0	1	0	0	1	1
C.africana	1	-	-	1	1	1	1	1	1	1	1	1	2	1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	0	1	0	1		
P.turgidum	2	-	2	1	1	1	-	1	1	-	-	-	1	1	-	-	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-	0	1	0	1		
C.tuberosum	2	-	2	2	2	2	2	-	2	2	1	1	1	1	2	2	1	2	1	2	2	2	2	-	2	1	-	-	1	-	1	1	-	0	1	0	1		
A.anthelmin.	-	-	1	1	-	-	1	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-	0	1	1	1		
S.cordifolia	-	-	-	-	-	1	1	-	1	1	2	2	1	2	1	-	1	2	2	1	1	1	3	-	-	-	-	2	-	-	2	1	1	1	0	0	0	0	
C.absus	-	-	1	1	-	1	1	-	2	1	1	1	1	1	1	-	-	1	1	1	2	-	3	-	-	2	-	2	2	-	-	1	-	1	0	0	0	1	1
B.linarifolia	1	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	1	0	0	1	0	

(continue....)

score for the positive group, Table (A.2). Scores assigned to the positive group are separated from those assigned to the negative group by the solid horizontal line. The zone of indifference (comprising segments 5-8) is indicated by columns of solid verical lines. Values in the table indicate numbers of the samples in each category. Thus the value 6 appears at the bottom left of the scatter table corresponds to the six samples that occur in segment 1 and have indicator score of -1.

Table A.2: Scatter table for division (1)

Indicators together with signs:

*B.xantholeua*1 (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	1	0	1	0	0	1	1	4	2	0
6	10	4	2	1	0	0	0	0	0	0	0	0	0	0	0	−1

23 samples were assigned to the negative group according to their indicator scores (−), these samples are 2,5,7,9,12,14,16,17,18,19,20,21,22,23,24,25,26, 27,28,29,30,32,and 33. Sample 14 was designated as "borderline negative" because it lies in the zone of indifference. On the other hand, 10 samples were assigned to the positive group with a zero indicator score, these are 1,3,4,6,8,10,11,13,15, and sample 31 which was also designated as a borderline positive.

TWINSPAN also classifies species that are at least twice as likely to occur in any side of the dichotomy than in the other "negative preferential", "positive preferential" and species with no particular fidelity to both sides "non-preferentials" and lists them according to their degree of preferentialities, Table (A.3). Values given infront of each species represent the number of occurrences indicated in the first bracket while the second one represents the times that the mentioned species is likely to be found in that group than in the other. Thus the entry *C.africana*1 (14-1)(6) signifies that this species occurs with abundance 1 or more in 14 samples in the negative side of the dichotomy and in one sample in the poisitive side and it is six times as likely to occur on the negative side as on the positive one, and therefore was assigned as negative preferential.

Since the split at this level is uneven (23 to 10), an entry like *M.crassifolia2* (2-2) is designated as positive preferential for it has 20% frequency on the positive side as compared to 8.6% on the negative one and, therefore, more than twice as likely to occur in that group.

Again the best negative preferential species is *B.xantholeua* with an entry of (23-0) followed by *A.pallida* (21-0) with *A.nilotica1* (15-3) as the least negative preferential. On the other hand, *A.nilotica2* (0-3) is the best positive preferential while *M.crassifolia* (2-2) *T.brownii* (4-4) *C.absus* (3-3) and *S.birrea* (6-6) are the least ones, Table (A.3). Species that are less than twice as likely to occur on any group than on the other are designated as non-preferentials. These can be checked by referring to the two-way table.

Table A.3: Preferential species of division one

(A) Negative preferentials:

No	Species	Degree	No	Species	Degree
1	*B.xanthol.*1	(23-0)(100)	11	*A.anthelm.*1	(11-1)(4.8)
2	*A.pallida*1	(21-0)(91)	12	*S.festivus*1	(22-2)(4.8)
3	*C.sativus*1	(22-1)(9.5)	13	*E.colonum*1	(22-2)(4.8)
4	*A.adscens.*1	(22-1)(9.5)	14	*C.obilor.*1	(15-2)(3.3)
5	*T.portul.*1	(19-1)(8.3)	15	*L.kerstin.*1	(14-2)(3)
6	*Z.christi*1	(18-1)(7.8)	16	*P.anabapt.*1	(22-4)(2.4)
7	*C.tuberos.*1	(16-1)(7)	17	*C.obtusif.*1	(16-3)(2.3)
8	*C.glutios.*1	(15-1)(6.5)	18	*A.albida*1	(16-3)(2.3)
9	*C.africana*1	(14-1)(6)	19	*A.lanceol.*1	(20-4)(2.2)
10	*C.aculeat.*1	(13-1)(5.6)	20	*A.tortilis*1	(15-3)(2.2)

(B) Positive preferentials:

No	Species	Degree	No	Species	Degree
1	*A.nilotica*2	(0-3)(100)	6	*S.birrea*2	(6-6)(2.3)
2	*P.oleracea*3	(1-4)(9.2)	7	*M.crassifolia*2	(2-2)(2.3)
3	*A.nubica*3	(1-2)(4.6)	8	*T.brownii*2	(4-4)(2.3)
4	*G.senegalensis*3	(1-2)(4.6)	9	*C.absus*2	(3-3)(2.3)
5	*A.lanceolatum*2	(2-3)(3.5)			

(C) Non-preferentials species:

Species	Dgree	Species	Degree	species	Degree
*A.amara*1	(21-8)	*G.tenax*1	(7-2)	*C.hartman.*1	(19-8)
*G.senegal.*1	(22-9)	*A.senegal*	(23-10)	*D.glomer.*1	(9-5)
*B.aegypt.*1	(22-8)	*S.birrea*1	(23-8)	*T.brownii*1	(10-5)
*M.crassif.*1	(18-5)	*A.nubica*1	(20-7)	*B.senegal.*1	(22-10)
*A.nilotica*1	(13-6)	*A.digitata*1	(6-4)	*L.pyrotech.*1	(21-6)
*C.procera*1	(12-5)	*L.humilis*1	(22-5)	*C.tuberos.*1	(22-5)
*P.olerac.*1	(23-7)	*T.terrest.*1	(23-7)	*E.aspera*1	(22-7)
*S.gracilis*1	(20-5)	*C.bifolous*1	(23-7)	*W.indica*1	(22-9)
*C.semam.*1	(23-8)	*D.ciliaris*1	(23-6)	*C.absus*1	(16-4)
*C.obilor.*1	(18-5)	*C.italica*	(23-10)	*A.acanth.*1	(22-6)
*S.cordif.*1	(16-4)				

A.2 Second Level of Divisions

At this level, four clusters of samples are produced by splitting up each of the above two groups into further tow sub-divisions.

A.2.1 Division (2)

This division corresponds to the negative group of level one having 23 samples in total. Five indicator species were used to derive this division and they are listed in Table (A.4) in an approximate order of effectiveness. Thus *P.turgidum* (negative) is a better indiactor than *S.cordifolia* (positive). As there are four negative and one positive indicator species, the maximum indicator score to be asigned to the negative group will be -2 and the minimum the score for the positive group will be -1.

Table A.4: Scatter table for division two

Indicators together with signs:

(1) *P.anabaptistum2* (−)

(2) *P.turgidum2* (−)

(3) *S.cordifolia1* (+)

(4) *A.pallida2* (−)

(5) *A.nilotica1* (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	−1
0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	−2
2	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	−3
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	−4

Nine samples were found to have an indicator score of -2 or less thus assigned to the negative group, these are 5,7,12,16,17,18,19,23 and 24. While 14 samples have an indicator score of -1 or more and thereby assigned to the positive arm of the dichotomy. These are 2,9,14,20,21,22,25,26,27,28,29,30,32, and 33. There is no case in both groups that lie in the zone of indifference. Species preferential to each side are listed in table (A.5). The rest of species are non-preferential to either sides and, therefore, have been excluded. Values given in brackets are the actual number of occurrences.

Table A.6: Scatter table for division (3)
Indicators together with signs:
*P.anabaptistum*1 (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	4	0
1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	−1

Table A.5: Preferential species of division two
(A) Negative preferentials:

Species	Occurrence	Species	Occurrence
*C.africana*1	(8-6)	*G.tenax*1	(4-3)
*A.nilotica*1	(8-5)	*B.linarif.*1	(4-0)
*P.turgidum*1	(8-3)	*C.hartman.*2	(4-2)
*C.aculeat.*2	(2-0)	*L.pyrotech.*2	(4-1)
*B.linarif.*2	(3-0)	*A.lanceol.*2	(2-0)
*A.pallida*2	(6-3)	*A.adscens.*2	(7-5)
*C.obtusifol.*2	(3-1)	*S.gracil.*2	(5-3)
*P.anabapit.*2	(8-2)	*E.aspera*3	(3-0)

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence
*S.cordif.*1	(3-13)	*A.nubica*2	(0-7)
*S.cordif.*2	(0-7)	*B.senegal.*3	(0-6)
*A.senegal*3	(1-6)	*C.sesmam.*3	(0-5)

A.2.2 Division (3)

This division coresponds to the positive group identified at the first level with a total of 10 samples. *P.anabaptistum*1 (−) is the indicator species used to sort out this group into further positive and negative sub-divisions. Therefore −1 is the maximum score assigned to the negative group while 0 is the minimum score for the positive arm, Table (A.6).

Among these 10 samples, 4 were found to have an indicator score of −1 and thus assigned to the negative group, these are 3, 4, 6, and 8. While the other 6 samples have a zero score which puts them in the positive group, these are 1, 10, 11, and 31 with the last one as a borderline case. Table (A.7) lists preferential species to each side.

Table A.7: Preferential species of division (3)

(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*A.albida*1	(2-1)	*A.tortilis*1	(2-1)	*T.brownii*1	(3-3)
*E.aspera*1	(4-3)	*L.humilis*1	(3-2)	*S.gracilis*1	(3-2)
*C.biflorous*1	(4-3)	*P.anabapt.*1	(4-0)	*D.ciliaris*1	(4-2)
*S.festivus*1	(2-0)	*B.aegypt.*2	(3-2)	*A.nubica*2	(2-1)
*A.lanceol.*2	(2-1)	*S.birrea*2	(4-2)	*L.humilis*2	(3-1)
*S.gracilis*2	(3-1)	*L.pyrotech.*2	(2-1)	*E.aspera*1	(4-1)
*P.anabapt.*2	(4-0)	*C.biflorous*2	(4-2)	*C.obilorius*2	(2-0)
*D.ciliaris*2	(4-1)	*C.sesmam.*2	(4-3)	*S.festivus*2	(2-0)
*A.senegal*3	(3-0)	*E.aspera*3	(2-0)	*C.sesmam.*3	(2-1)

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*L.kerstin.*1	(0-2)	*C.absus*1	(1-3)	*S.cordif.*1	(0-4)
*C.obtusif.*2	(0-2)	*S.cordif.*2	(0-2)	*G.senegal.*2	(1-5)
*G.senegal.*3	(0-2)				

The rest of species were grouped as non-preferentials as they show no marked affinities to either sides and, therefore, has been excluded.

A.3 Second Levels of Divisions

Each of the four clusters sorted out at the previous level are further sudivided here to produce 8 divisions (4-7).

A.3.1 division (4)

This corresponds to the negative sub-group of division (2) which has 9 samples. *G.senegalensis2* (+) is the indicator species used to split this group of samples. Thus the maximum indicator score assigned to negative group is zero while 1 is minimum score for the positive group, Table (A.8).

Table A.8: Scatter table for division (4)

Indicators together with signs:

G.senegalensis2 (+)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	2	1
4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Five samples have an indicator score of zero which assigns them to the negative group, these are 5,7,16,17, with sample 7 as a borderline case. Whereas samples 12,19,23 and 24 have a score of 1 and therefore clustered in the positive side. Preferential species to each side are listed in Table (A.9).

Table A.9: Preferential species of division (4)

(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*B.linarif.*1	(4-0)	*L.pyrotech.*2	(3-1)	*W.indica*2	(4-1)
*B.linarif.*2	(3-0)	*A.lanceol.*2	(2-0)	*D.ciliaris*2	(3-1)
*C.sesmam.*2	(4-1)				

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*A.nubica*1	(2-4)	*T.brownii*1	(1-4)	*A.digitata*1	(0-2)
*T.portul.*1	(1-4)	*S.cordif.*1	(0-3)	*G.senegal.*2	(0-4)
*A.amara*2	(1-3)	*T.brownii*2	(0-2)	*C.harmann.*2	(1-3)
*B.aegypt.*2	(0-2)	*T.portul.*2	(1-3)	*A.acanth.*2	(2-4)

A.3.2 Division (5)

This division splits the 14 samples clustered in the positive side of division (2) into further a positive and a negative sub-group using using *A.tortilis*1 (−) and *A.anthelminthica*1 (−) indicator species. The maximum indicator score assigned to the negative group is, thus, −2 while −1 is the minimum score assigned to the positive group, Table (A.10)

Table A.10: Scatter table for division (5)

Indicators together with signs:

(1) *A.tortilis*1 (−)

(2) *A.anthelminthica*1 (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	1	0	1	0	0	0	2	3	1	0
0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	−1
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	−2

Samples 14,20,21,22,25 and 28 have a −2 indicator score which assigns them to the negative group while, on the other hand, samples 2,9,26,27,29,30,32 and 33 have a score of −1 or more which clusters them in the positive group. Species preferential to each side are listed below in table (A.11).

Table A.11: preferential species of division (5)
(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*T.laxifl.*1	(2-0)	*C.africana*1	(5-1)	*G.tenax*1	(2-1)
*C.hartman.*1	(6-4)	*A.albida*1	(5-3)	*D.glomer.*1	(3-1)
*M.crassif.*1	(6-4)	*A.tortilis*1	(6-1)	*A.anthelm.*1	(6-1)
*T.brownii*1	(5-0)	*A.nilotica*1	(3-2)	*A.digitata*1	(3-1)
*C.glutin.*1	(6-2)	*C.aculeat.*1	(5-2)	*A.amara*2	(6-1)
*G.senegal.*2	(6-3)	*B.aegypt.*2	(6-2)	*S.birrea*2	(3-1)
*E.aspera*2	(6-2)	*E.colonum*2	(4-1)	*A.adscens.*2	(4-1)
*B.xanthol.*2	(3-2)	*S.gracil.*2	(2-1)	*A.acanth.*2	(6-4)
*A.senegal*3	(4-2)	*B.senegal.*3	(4-2)		

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence
*C.procera*2	(2-7)	*C.tuberosum*2	(2-6)
*C.absus*2	(0-2)	*C.semamoioes*3	(1-4)

A.3.3 Division (6)

This division further sub-divides the negative cluster of division (3) at the second level which has four samples into two more negative and positive groups. *A.amara*1 is here used as a negative indicator species to make the split, thus, assigning −1 as a maximum score to the negative group and zero as a minimum score to the positive side, Table (A.12).

Table A.12: Scatter table for division (6)
Indicators together with signs:
*A.amara*1 (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−1

Within this dichotomy, samples 3,4 and 6 are assigned to the negative side as they have a score of -1, while only sample 8 scored 0 thus forming the positive arm of this division by it's own. Further dichotomization will not be carried out on this side as there are insufficient samples. Species preferential to each side are listed below in table (B.12).

Table A.13: Preferential species of division (6)

(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*A.amara*1	(3-0)	*A.albida*1	(2-0)	*D.glomer.*1	(2-0)
*A.nubica*1	(2-0)	*M.crassif.*1	(2-0)	*T.brownii*1	(3-0)
*A.nilotica*1	(2-0)	*A.digitata*1	(2-0)	*C.procera*1	(2-0)
*A.lanceol.*1	(2-0)	*C.tuberos.*1	(2-0)	*S.gracil.*1	(3-0)
*A.acanth.*1	(2-0)	*C.hartman.*2	(2-0)	*T.terrest.*2	(2-0)
*E.aspera*3	(2-0)	*P.oleracea*3	(2-0)	*C.semamoioes*3	(2-0)

(B) Positive preferentials:

Species	occurrence	Species	occurrence
*A.tortilis*1	(1-1)	*C.obilorius*1	(1-1)
*S.festivus*1	(1-1)	*L.pyrotechnica*2	(1-1)

A.3.4 Division (7)

This is the last division produced at this level and it corresponds to the negative group of division (3) at the second level. Again *A.amara*1 is here used as a negative indicator for sub-dividing up the six samples of this group. Therefore, -1 is the maximum and 0 is the minimum indicator score assigned to the negative and the positive groups respectively, Table (A.14)

Table A.14: Scatter table for division (7)
Indicators together with signs:
*Amara*l (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Samples 1,10,11,13 and 15 have a score of −1 which assigns them to the negative side,whereas, the sixth sample, 16, scored 0 which assigns it in the positive arm of the dichotomy. Again no further sub-divisions is being carried out on this group as is no sufficient samples. Preferential species to each side are listed in Table (A.15).

Table A.15: Preferential species of division (7)
(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*A.amara*l	(5-0)	*G.senegal.*1	(5-0)	*C.hartman.*1	(5-0)
*S.birrea*l	(4-0)	*D.glomer.*1	(3-0)	*M.crassif.*1	(3-0)
*A.nilotica*l	(4-0)	*L.pyrotech.*1	(3-0)	*E.aspera*l	(3-0)
*C.tuberos.*1	(3-0)	*C.biflorous*l	(3-0)	*C.absus*l	(3-0)
*P.olercea*l	(4-0)	*W.indica*2	(4-0)	*A.acanth.*2	(3-0)
*C.sesmam.*2	(3-0)				

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence
*A.acanthus*l	(3-1)	*S.cordifolia*l	(3-1)
*C.semamoioes*l	(3-1)	*C.italica*l	(3-1)
*T.terrestris*l	(3-1)		

A.4 Fourth Level of Divisions

Theoretically, TWINSPAN should produce 16 clusters of samples at this level by splitting up each of the eight groups identified at the third level into tow further sub-groups. But, mentioned before, there are tow groups out of these eight contain very few samples to be sub-divided and so only those remaining 6 clusters which have the minimum required number of samples will be dealt with at this level to produce 12 sub-divisions.

A.4.1 Division (8)

This comprises the negative group of division (4). Four indicator species are used to make up this split. These are listed below in Table (A.16) together with their signs in an approximate order of effectiveness. Thus the maximum indicator score assigned to the negative group is zero while 1 is the minimum score for the positive one.

Table A.16: Scatter table for division (7)

Indicators together with signs:

(1) *A.adscensionis2* (−)

(2) *T.terrestris2* (−)

(3) *D.ciliaris2* (+)

(4) *Z.christi1* (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
1	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	−1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−2
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−3

Samples 17 and 18 have scores of 0 and −3 respectively which asigns them to the negative group while samples 7,15 and 16 have a score of 1 which puts them in the positive arm of this dichotomy. Species preferential to each side are listed in Table (A.17).

table A.17: Preferential species to division (8)

(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*Z.christi*1	(2-1)	*L.kersting.*1	(2-1)	*C.obilor.*1	(2-1)
*L.pyrotech.*2	(2-1)	*E.aspera*2	(2-1)	*T.terrest.*2	(2-0)
*A.pallida*2	(2-1)	*A.adscens.*2	(3-1)	*B.xanth.*2	(2-1)
*C.italica*2	(2-1)	*P.turgidum*2	(2-1)		

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence	Species	Ocurrence
*G.senegal.*1	(1-3)	*B.aegypt.*1	(1-3)	*A.anthelm.*1	(0-2)
*A.nilotica*1	(1-3)	*E.colonum*1	(1-3)	*C.absus*1	(0-2)
*C.obtusif.*1	(1-3)	*P.anabapt.*1	(1-3)	*W.indica*2	(1-3)
*D.ciliaris*2	(0-3)				

A.4.2 Division (9)

This splits the four samples in the positive group of division (4) into a further positive and negative sub-groups. *T.laxiflora*1 is used as a negative indicator to derive this division. Thus -1 will be the maximum score for the negative group and zero the minimum one for the positive side, Table (A.18).

Table A.18: Scatter table for division (9)

Indicators together with signs:

*T.laxiflora*1 $(-)$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1

Among these 4 samples, only 24 has a score of -1 which assigns it to the negative group while the other three, 12,19 and 23 have a zero score which puts them in the positive group. Species preferential to each side are listed in Table (A.19).

Table A.19: Preferential species of division (9)
(A) Negative preferentials:

Species	Occurrence	Species	Occurrence
*T.laxiflora*1	(1-0)	*S.birrea*2	(1-0)
*D.glomerata*2	(1-0)	*C.aculeatum*1	(1-0)
*L.pyrotechnica*2	(1-0)	*A.adscensionis*2	(1-0)
*C.obilorius*2	(1-0)	*S.festivus*2	(1-0)

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*G.tenax*1	(0-2)	*A.anthelm.*1	(0-2)	*A.digit.*1	(0-2)
*B.senegal.*1	(0-3)	*A.amara*2	(0-3)	*E.colon.*2	(0-2)
*B.xanthol.*2	(0-2)	*S.gracilis*2	(0-3)	*C.italica*3	(0-2)

A.4.3 Division (10)

Involved here are the six samples comprized the negative group of division (5). *A.albida*1 is used here as the a positive indicator species for further sub-dividing this this group. Thus, zero will be the maximum score to be assigned to the negative group while 1 as a minimum score for the positive side, Table (A.20).

Table A.20: Scatter table for division (10)
Indicators together with signs:
*A.albida*1 (+)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Out of these 6 samples, only sample 14 has an indicator score below 1 which assigns it to the negative side, whereas the other five samples, 20,21,22,25 and 26 have scores of 1 which clusters them in the negative side of the division. Species preferential to each side are listed in Table (A.21).

Table A.21: Preferential species of division (10)

(A) Negative preferentials:

Species	Occurrence	species	Occurrence
M.crassifolia2	(1-0)	*C.tuberosum2*	(1-1)
W.indica2	(1-1)	*S.gracilis2*	(1-1)
G.senegalensis3	(1-0)	*P.oleracea3*	(1-0)
C.semamoioes3	(1-0)		

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
A.albida1	(0-5)	*D.glomer.1*	(0-3)	*A.nilotica1*	(0-3)
C.aculeat.1	(0-5)	*C.sativus1*	(0-5)	*C.obtusif.1*	(0-3)
T.terrest.2	(0-4)	*T.portul.2*	(0-5)	*A.adscens.2*	(0-4)
B.xanthol.2	(0-3)	*S.cordif.2*	(0-3)	*S.festivus2*	(0-4)
A.senegal3	(0-4)	*C.italica3*	(0-3)		

A.4.4 Division (11)

This division splits the 8 samples clustered in the positive side of division (5) into a positive and a negative groups using *A.tortilis1* as a positive indicator. Thus assigning zero as a maximum score for the negative group and 1 as a minimum score for the positive group, Table (A.22).

Of these 8 samples, 7 have have a zero score which clusters them in the negative group, these are samples 2,9,26,27,30,32 and 33. On the other hand, only sample 29 has a score of 1 which puts it separately in the positive arm. Species preferential to each side are listed in Table (A.23).

Table A.22: Scatter table for division (11)

Indicators together with signs:

*A.tortilis*1 (+)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.23: Preferential species of division (11)

(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*A.amara*1	(6-0)	*A.nilotica*1	(2-0)	*C.glutin.*1	(2-0)
*C.aculeat.*1	(2-0)	*G.senegal.*2	(3-0)	*B.xanth.*2	(2-0)
*A.senegal*3	(2-0)	*G.senegal.*3	(2-0)		

(B) Positive preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*A.albida*1	(2-1)	*A.tortilis*1	(0-1)	*L.kersting.*1	(2-1)
*A.anthelm.*1	(0-1)	*P.turgidum*1	(0-1)	*B.aegypt.*2	(1-1)
*A.nubica*2	(2-1)	*E.colonum*2	(0-1)	*W.indica*2	(2-1)
*A.pallida*2	(1-1)	*A.adscens.*2	(0-1)	*C.absus*2	(1-1)
*D.ciliaris*2	(2-1)	*S.cordifolia*2	(2-1)	*S.festivus*2	(2-1)
*C.sativus*3	(0-1)	*T.terrestris*3	(0-1)	*C.absus*3	(0-1)
*D.ciliaris*3	(0-1)	*S.cordifolia*3	(0-1)	*C.italica*4	(0-1)

A.4.5 Division (12)

This division splits the 3 samples clustered in the negative group of division (6) into two sub-groups. *G.tenax*1 is here used as a positive inbdicator to derive this division. Thus, assigning a zero score to the negative group and one to the positive group, Table (A.24).

Table A.24: Scatter diagram for division (12)
Indicators together with signs:
*G.tenax*1 (+)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Samples 4 and 6 have an indicator score of zero which clusters them in the negative side while on the other hand, sample 3 has a score of 1 which assigns it to the positive arm. Species preferential to each side are listed in Table (A.25).

Table A.25: Preferential species of division (12)
(A) Negative preferentials:

Species	Occurrence	Species	Occurrence
*A.albida*1	(2-0)	*D.glomerata*1	(2-0)
*A.nubica*1	(2-0)	*A.nilotica*1	(2-0)
*A.digitata*1	(2-0)	*T.brownii*2	(2-1)
*E.aspera*2	(2-0)		

(B) Positive preferentials—

Species	Occurrence	Species	Occurrence
*G.tenax*1	(0-1)	*C.aculeatum*1	(0-1)
*C.sativus*1	(0-1)	*B.linarifolia*1	(0-1)
*C.absus*2	(0-1)	*C.obilorius*1	(0-1)
*C.italica*3	(0-1)		

A.4.6 Division (14)

This division, which is last cluster produced, splits the 5 samples in the negative group of division (7) using *M.crassifolia*1 as a negative indicator species. Thus, −1 will be the minimum score to be assigned to the negative group while zero the minimum score for the positive group, Table (A.26).

Table A.26: Scatter diagram for division (14)
Indicators together with signs:
*M.crassifolia*1 (−)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	−1

Among these five samples, 10,11 and 15 have scores of −1 which cluster them in the negative side of this dichotomy, while on the other hand, samples 1 and 13 have zero scores which put them in the positive side. Species preferential to each side are listed in Table (A.27).

Table A.27: Preferential species of division (14)
(A) Negative preferentials:

Species	Occurrence	Species	Occurrence	Species	Occurrence
*B.aegypt.*1	(3-1)	*S.birrea*1	(3-1)	*M.crassif.*1	(3-0)
*T.brownii*1	(2-0)	*C.procera*1	(2-0)	*L.humilis*1	(2-0)
*C.hartman.*2	(3-0)	*A.senegal*2	(3-1)	*E.colonum*2	(3-1)
*C.biflorous*2	(2-0)	*C.absus*2	(2-0)	*C.italica*2	(3-0)
*G.senegal.*3	(2-0)				

(B) Positive preferential:

Species	Occurrence	Species	Occurrence
*E.aspera*1	(1-2)	*A.lanceolatum*1	(0-2)
*C.tuberosum*1	(1-2)	*S.gracilis*1	(0-2)
*A.acanthus*1	(1-2)	*S.cordifolia*1	(1-2)
*C.semamoioes*1	(1-2)		

Appendix B

Classified Soil Data

B.1 Wad Gerad Soils

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
01	0.24	0.02	7.0	1.6	20	0.6	0.2	1.4	1.2		70	21	2	7
02	0.14	0.01	7.4	1.5	21	0.6	0.3	1.0	1.2		66	27	0	7
03	0.31	0.03	7.4	1.4	17	1.1	0.3	2.0	2.0		69	18	2	11
04	0.06	0.03	7.4	1.3	19	0.6	0.2	2.8	0.4		65	20	1	14
05	0.40	0.02	7.9	1.6	20	0.7	0.2	2.3	1.0		73	16	1	10
06	0.23	0.03	8.4	2.1	27	0.6	0.2	1.8	1.4		72	20	2	6
07	0.42	0.03	7.6	6.2	39	0.7	0.7	3.2	3.2		68	22	1	9
08	0.36	0.03	7.6	4.7	31	0.7	0.4	2.8	2.0		63	28	2	7
09	0.28	0.02	7.6	6.1	38	0.9	0.7	11.6	6.1		41	24	11	24
10	0.32	0.02	8.0	6.1	37	1.1	0.5	12.7	2.1		47	38	3	12
11	0.39	0.03	8.0	5.9	40	1.1	0.5	11.5	3.4		51	29	2	18
12	0.23	0.03	7.3	1.9	49	1.6	0.6	2.1	1.9		54	32	2	12
13	0.26	0.02	7.6	1.8	47	1.6	0.4	2.7	1.4		56	24	4	16
14	0.21	0.03	7.6	2.1	51	1.8	0.1	3.7	2.3		55	26	1	18
15	0.22	0.03	7.8	1.9	55	1.9	0.3	1.8	3.8		57	23	3	17
16	0.38	0.01	8.1	1.2	31	0.7	0.3	1.4	1.4		78	14	2	6
17	0.37	0.02	7.7	1.1	29	0.8	0.2	1.5	0.6		76	19	1	4

(continue....)

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
18	0.39	0.02	7.9	1.7	28	0.9	0.3	1.2	1.7		61	28	3	8
19	0.37	0.01	8.1	1.2	34	0.9	0.2	1.1	1.0		59	33	1	7
20	0.38	0.03	7.1	2.5	41	1.0	0.1	2.0	3.1		64	23	2	11
21	0.21	0.01	7.9	1.0	21	0.6	0.1	1.1	1.3		62	28	1	9
22	0.31	0.02	6.9	1.3	31	1.2	0.2	0.8	1.4		64	25	2	9
23	0.20	0.01	7.3	1.9	23	0.6	0.2	1.2	2.8		71	22	1	6
24	0.17	0.01	7.2	1.8	20	0.8	0.1	1.2	1.0		72	20	2	6
25	0.16	0.01	6.8	1.7	21	0.6	0.1	1.2	1.0		70	22	1	7
26	0.18	0.01	6.4	1.9	25	0.8	0.1	1.4	1.0		66	25	1	8
27	0.21	0.02	6.5	1.9	20	0.7	0.1	0.8	1.2		68	21	3	8
28	0.17	0.02	6.9	1.7	27	1.2	0.2	1.6	0.9		54	31	5	10

B.2 Umm Bum Soils

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
01	0.17	0.02	6.7	13.2	68	0.0	0.1	1.8	0.7	0.1	51	46	1	2
02	0.21	0.02	6.9	15.8	72	0.0	0.1	1.6	1.4	0.1	54	43	1	2
03	0.21	0.03	7.1	16.3	79	0.0	0.1	1.0	1.5	0.2	54	41	1	4
04	0.16	0.02	6.9	12.3	54	0.3	0.1	0.3	1.1	0.2	56	42	0	2
05	0.25	0.02	7.1	11.9	92	0.1	0.2	2.1	1.2	0.2	56	41	1	2
06	0.27	0.03	8.3	12.7	105	0.1	0.1	2.8	0.5	0.5	52	44	1	3
07	0.21	0.02	8.4	15.6	105	0.3	0.2	3.8	0.1	0.4	36	58	2	4
08	0.26	0.03	8.7	15.9	116	1.2	0.2	2.1	3.1	0.9	57	38	2	4
09	0.31	0.03	8.5	19	113	0.3	0.2	5.1	0.7	0.2	63	24	4	9
10	0.41	0.03	8.4	21	116	0.3	0.2	4.1	2.7	0.5	59	25	8	8
11	0.42	0.03	8.5	24	108	0.1	0.1	5.3	2.9	0.4	46	33	8	13
12	0.51	0.04	8.6	25	124	0.0	0.1	5.1	1.7	0.5	24	33	25	18
13	0.61	0.04	8.8	21	122	0.1	0.1	3.4	6.1	1.5	38	18	21	23
14	0.52	0.03	8.4	21	102	0.3	0.1	1.8	4.1	0.3	0	51	32	17

B.3 Markib Soils

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
01	0.32	0.02	7.7	0.8	25	0.1	0.2	1.6	0.8	0.8	52	37	2	9
02	0.28	0.02	6.9	0.7	28	0.1	0.4	1.6	0.6	0.5	56	29	2	13
03	0.31	0.03	5.2	0.9	21	0.0	0.2	1.4	0.4	0.3	63	21	2	14
04	0.26	0.01	5.3	0.8	24	0.0	0.1	1.5	0.5	0.2	65	18	3	14
05	0.30	0.02	5.3	0.7	26	0.1	0.2	1.3	0.6	0.4	51	29	4	16
06	0.31	0.01	5.3	0.8	25	0.1	0.2	1.6	0.4	0.3	58	25	3	14
07	0.70	0.04	6.6	16.4	59	0.1	0.2	1.1	1.6	0.7	52	29	7	12
08	0.04	0.03	5.6	11.2	34	0.0	0.1	0.1	2.4	0.4	31	47	3	11
09	0.80	0.04	5.1	12.3	48	0.2	0.1	0.6	2.1	0.7	26	45	3	26
10	0.20	0.02	6.8	14.3	57	0.2	0.1	1.0	2.0	0.5	41	16	4	9
11	0.35	0.03	5.7	14.7	48	0.2	0.2	0.1	0.9	0.4	51	31	1	17
12	0.31	0.02	5.3	18.5	61	0.3	0.2	0.2	1.8	0.6	47	27	7	19
13	0.27	0.02	6.5	11.3	46	0.2	0.2	0.1	0.3	0.4	51	42	4	3
14	0.31	0.01	5.5	2.9	34	0.0	0.1	0.2	1.4	0.4	23	63	3	11
15	0.25	0.02	5.3	5.8	37	0.1	0.1	0.0	1.3	0.5	38	47	2	13
16	0.29	0.02	5.3	12.7	58	0.0	0.1	0.0	1.6	0.8	35	49	3	13
17	0.28	0.01	5.1	4.7	41	0.0	0.1	0.0	1.7	1.2	37	48	3	12
18	0.26	0.02	5.4	11.3	68	0.0	0.1	0.0	1.3	0.4	36	58	2	5
19	0.29	0.03	5.1	6.2	49	0.0	0.1	0.0	1.8	0.3	36	55	0	9
20	0.21	0.01	4.7	1.2	27	0.0	0.1	0.0	0.1	0.2	45	45	3	7
21	0.21	0.01	5.1	3.9	25	0.0	0.1	0.0	1.0	0.4	46	40	4	10

B.4 Wad Sharef Soils

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
01	0.87	0.05	8.4	32.4	321	0.3	1.6	12.1	4.5	1.7	28	27	21	24
02	0.91	0.06	9.0	32.7	216	2.5	0.6	13.2	4.4	7.1	6	36	19	39
03	0.96	0.06	9.1	34.6	424	6.4	0.6	11.3	11.5	41.7	8	31	16	45
04	0.97	0.05	8.7	32.8	391	9.3	1.1	2.1	3.7	51.7	5	31	21	43
05	0.63	0.04	8.1	16.2	61	0.1	0.9	6.8	1.8	2.3	63	27	2	8
06	0.50	0.03	8.3	5.3	53	0.1	0.3	6.5	1.2	2.2	73	17	2	8
07	0.48	0.04	8.4	3.2	61	0.1	0.7	7.1	1.4	2.5	66	15	4	15
08	0.53	0.03	8.3	2.4	50	0.1	0.7	5.8	1.0	2.4	59	18	5	18
09	0.52	0.04	8.5	2.1	48	0.2	0.6	4.8	0.7	2.6	25	16	33	26
10	0.49	0.03	8.5	2.0	48	0.1	0.7	4.1	0.8	3.4	63	14	3	20

B.5 Shemiela Soils

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
01	0.56	0.03	6.3	16.4	88	0.1	0.4	3.1	1.5	1.6	37	58	1	4
02	0.62	0.03	7.1	18.2	91	1.2	0.2	5.1	2.4	4.6	27	51	5	16
03	0.66	0.04	8.3	23.1	87	2.4	0.2	3.9	1.4	6.8	25	58	9	8
04	0.52	0.04	8.9	19.5	101	2.3	0.2	3.1	1.6	11.6	31	55	5	9
05	0.46	0.03	6.5	14.2	116	0.1	0.4	1.0	3.5	0.6	21	69	1	9
06	0.41	0.02	6.7	11.7	135	0.6	0.3	1.8	3.8	2.7	28	59	2	11
07	0.36	0.03	6.8	12.8	140	1.6	0.4	5.6	6.8	6.3	23	51	4	22
08	0.39	0.03	8.4	15.7	121	1.8	0.6	11.2	7.9	4.6	21	47	9	23
09	0.52	0.03	7.7	16.7	245	1.6	1.1	12.8	9.8	2.7	26	38	9	27
10	0.61	0.03	8.2	19.7	275	2.7	0.6	15.3	9.7	7.4	23	42	9	26
11	0.65	0.04	8.7	20.3	211	3.6	0.6	16.8	7.8	12.7	24	42	12	22

B.6 El Qubba Soils

Sample No.	%C	%N	pH	P Pmg/100	K Kmg/100	Exchangeable Cations me/100g Na	K	Ca	Mg	Na me/l	Mechanical Analysis C.S.%	F.S.%	S%	C%
01	0.18	0.01	7.5	0.4	19	0.3	0.1	2.6	0.2	0.8	63	28	1	8
02	0.20	0.01	7.4	1.1	27	0.3	0.5	1.7	1.3	0.9	56	34	4	6
03	0.21	0.02	6.5	0.3	28	0.3	0.4	1.5	0.6	0.6	63	28	1	8
04	0.19	0.01	6.0	0.4	20	0.6	0.2	1.0	0.5	0.6	73	16	4	7
05	0.21	0.01	7.6	2.1	38	0.1	0.3	2.1	1.2	0.5	77	13	2	8
06	0.20	0.02	7.9	2.0	41	0.2	0.3	1.7	0.9	0.7	77	12	0	13
07	0.24	0.02	7.9	2.8	39	0.2	0.8	2.7	0.5	0.7	47	45	0	8
08	0.25	0.01	7.5	2.0	40	0.1	0.7	2.1	1.3	0.7	68	24	1	7
09	0.26	0.01	8.3	2.4	48	0.1	0.6	4.7	2.6	1.1	46	38	4	12
10	0.27	0.01	8.2	2.2	48	0.1	0.5	4.1	2.3	0.7	47	37	6	10
11	0.23	0.02	8.4	2.1	51	0.1	0.6	4.2	3.0	0.7	43	38	2	17
12	0.26	0.01	8.4	2.4	41	0.1	0.6	4.2	3.6	0.9	36	32	14	18
13	0.28	0.02	8.6	2.8	59	0.1	0.6	6.7	3.4	1.2	26	35	34	5
14	0.29	0.02	8.6	2.5	48	0.2	0.7	6.7	2.6	1.1	46	24	21	9

(continue Appendix B)

Methods of Laboratory Soil Analysis

(1) Mechanical analysis by Bouyoucos hydrometer method:-

50g of soil were soaked with 300ml of water and 12ml of sodium hexametaphosphate solution, dispersed in an electric stirrer for 15 minutes, transferred to a cylinder, shaken and hydrometer readings taken after 5 minutes, 3 hours and 8 hours. The temperature was recorded at every reading and corrections made for the temperature and dispersing agent content.

(2) pH:-

Potentiometric determination using the glass electrode on a 1:5 soil water suspension.

(3) Nitrogen:-

Kjeldahi digestion, followed by distillation of the liberated ammonia into boric acid solution and titration with 0.05 N. H CI.

(4) Organic Carbon:-

The wet oxidation of organic matter by the Walkley-Black rapid method was used.

(5) Available Phosphorus:-

Soil extraction using 0.3% W/V ammonium sulphate in 0.002N. sulphuric acid.

(6) Available Potassium:-

Soil extraction using N. nitric acid.

(7) Exchangeable Calcium & Magnesium:-

5g of soil are taken and leached twice with 250ml of normal sodium chloride.

(8) Exchangeable Sodium & Potassium:-

50ml of normal ammonium were added to 12.5g of soil and after 5 hours leached four times by decantation. The soil then transferred to a filter funnel allowed to dry and then leached with successive portions of normal ammonium chloride. Leaching was continued until 250ml of filtrate were collected. 5ml of filtrate was diluted to 100ml and the sodium was read off on a flamephotometer against a 10 p.p.m. sodium standard containing the same amount of ammonium chloride as the filtrate. In another portion of diluted filtrate the potassium was determined photometrically against potassium standard containing the same amount of ammonium chloride as the filtrate.

Appendix C

The Vernacular & Latin Names of Plant Species

The vernacular (Local) plants names listed below have been collected in the field by guestioning farmers and herders, though the majority were obtained from published literature. The Latin (Botanical) equivalent names were obtained from, Andrews (1953), Harrison & Jackson (1958) and HTS (1963). Life-form type of each species is listed as well with T for Trees, S for Shrubs, H for Herbs, and G for Grasses.

Local Name	Botanical Name	Habit
Abu-mrakhees	*Andropogon gayanus*	G
Ajur	*Cucumis sativus*	H
Arad	*Albizzia amara*	T
Aradeib	*Tamarindus indica*	T
Babanus	*Dalbergia melanoxylon*	T
Binnu	*Eragrostis aspera*	G
Betikh	*Citrullus vulgaris*	H
Bigheil	*Blepharis linariifolia*	H
Beiaid	*Aneilema lanceolatum*	H
Burreid	*Chlorophytum tuberosum*	H
Darot	*Terminalia laxiflora*	T
Dereisa	*Tribulus terrestris*	H
Agig Elbagar	*Trianthema portulacastrum*	H
Difra	*Echinochloa colonum*	G
Irg-anar	*Waltheria indica*	H

(continue....)

Local Name	Botanical Name	Habit
Gafal	*Commifora africana*	T
Gaw	*Aristida pallida*	G
Gideim	*Grewia tenax*	S
Ghubeish	*Guiera senegalensis*	S
Habil	*Combretum hartmannianum*	T/S
Hantot	*Digitaria ciliaris*	G
Haraz	*Acacia albida*	T
Hashab	*Acacia senegal*	T/S
Haskaneet	*Cenchrus biflorus*	G
Higleeg	*Balanites aegyptiaca*	T
Humeid	*Sylerocarya birrea*	T
Humra	*Aristida adscensionis*	G
Hureish	*Sporobolus festivus*	G
Injada	*Sida cordifolia*	H
Kadad	*Dichrostachys glomerata*	T/S
Kawal	*Cassia absus*	H
Khudra	*Corchoras olitorius*	G
Kitir	*Acacia mellifera*	S
Koreib	*Brachiaria xantholeuca*	G
Laot	*Acacia nubica*	S
Layon	*Lannea humilis*	S
Mahareib	*Cymbopogon nervatus*	G
Mukheit	*Boscia senegalensis*	S
Nabak	*Ziziphus-spina-christi*	T/S
Neem	*Azardirachta indica*	T

(continue....)

Local Name	Botanical Name	Habit
Rijla	*Portulaca oleracea*	H
Seied	*Cyperus obtusiflorus*	H
Sena sena	*Cassia italica*	H
Sarih	*Cadaba farinosa*	S
Sereih	*Maeura crassifolia*	S
Seyal	*Acacia tortilis*	T/S
Shadara beida	*Lannea kerstingii*	T
Shoheit	*Comretum aculeatum*	S
Sismsim elafrit	*Certatotheca sesamoioes*	H
Sobagh	*Terminalia brownii*	T
Sunut	*Acacia nilotica*	T
Talih	*Acacia seyal*	T
Tamrelfil	*Andropogon acanthus*	H
Tabaldi	*Adansonia digitata*	T
Tundub	*Capparis decidua*	T
Um fereedt	*Schoenefeldia gracilis*	G
Um habilo	*Combretum glutinsom*	T/S
Um semeima	*Panicum anabaptistum*	G
Ushar	*Calotropis procera*	S

Appendix D

Questionnaire

Survey of Ecological & Socio-Economic Indicators of Vegetation Change in Kordofan Region-Sudan

1. IDENTIFICATIONS:-

1.1 Questionnaire number ( )
1.2 Date ( )
1.3 Name of area ( )
1.4 Name of village ( )
1.5 Name of tribe ( )
1.6 Occupation of respondant
   1. Farmer.....................( )
   2. Nomad.......................( )
   3. Merchant....................( )
   4. Government employee........( )
   5. Others (Specify)..................

1.7 Age of respondant
   1. 15-19 ( )
   2. 20-24 ( )
   3. 25-29 ( )
   4. 30-34 ( )
   5. 35-39 ( )
   6. 40-44 ( )
   7. 45 + ( )

2. Ecological Aspects:-

(A) Rainfall:

2.1 Did you observe any chang in rainfall during the last 10 years?

Yes ( ) No ( )

2.2 If "Yes", how do you describe the nature of these changes?
   1. Increasing......................................( )
   2. Decreasing in amount...........................( )
   3. Decreasing in duration.........................( )
   4. Decreasing in amount and duration..............( )

   5. How do you rate the amount of rainfall in relation to grazing in each of the following years?

Year	Adequate	Inadequate
1987	( )	( )
1986	( )	( )
1985	( )	( )
1984	( )	( )
1983	( )	( )
1982	( )	( )

2.4 How do you rate the amount of rainfall in relation to cultivation in each of the following years?

Years	Adequate	Inadequate
1987	( )	( )
1986	( )	( )
1985	( )	( )
1984	( )	( )
1983	( )	( )
1982	( )	( )

2.5 How was rainfall 10 years ago?

1. Sufficient for cultivation and grazing........( )
2. Insufficient but still better than these days.( )
3. The same as these days.......................( )
4. Even worse than these.......................( )

2.6 In your opinion, what are the main consequences of inadequate rainfall in this area?
1. Crop failure................................( )
2. Insufficient pasture........................( )
3. Death of trees..............................( )
4. Livestock mortality.........................( )
5. Migration of livestock......................( )
6. Population migration........................( )
7. Others (Specifiy)...............................

2.7 If rainfall has decreased round here over the last 10 years, What do you think the effects have been on the vegetation?
1. Elimination of some species ( )...............
2. Decrease in some species ( )...............
3. Increase in some species ( )...............
4. Appearance of new species ( )...............

2.8 What changes have you made during the last 10 years to cope with the new rains situations?
1. Expanding cultivated area...........( )
2. Restoring to quick maturing crops...( )
3. Extending grazing area..............( )
4. Giving up cultivation...............( )
5. Giving up livestock rearing.........( )
6. Others (Specify)........................

(B) Soils:

2.9 Which of the following types of soils are prevalent in this area?
Goz ( ) Hamaraia ( ) Jurraba ( ) Wadi ( )

2.10 Which of these soils have dense grass-cover?
Qoz ( ) Hamaraia ( ) Jurraba ( ) Wadi ( )

2.11 Which of these soils you prefer to cultivate?
Qoz ( ) Hamaraia ( ) Jurraba ( ) Wadi ( )

2.12 Which of these soils do you think is most affected by cultivation and/or grazing?

Goz (   ) Hamaraia (   ) Jurraba (   ) Wadi (   )

2.13 Have you observed any new problems in local soils during the last 10 years?

Yes (   ) No (   )

2.14 If yes, do you have these problems?

1. Decrease of productivity.............(   )
2. Decrease in the vegetation cover.....(   )
3. More frequent windstorms.............(   )
4. Enchroachment of dunes...............(   )
5. Increase in areas of bare lands......(   )
6. Extensive attacks of termites........(   )
7. Others (Specify).........................

2.15 Have you noticed any changes in the plants in the areas where you mentioned these soil problems?

Yes (   ) No (   )

2.16 If "yes", how do you describe these changes?

1. Elimination of some species (   )...............
2. Decrease in some species (   )...............
3. Increase in some species (   )...............
4. Appearance of new species (   )...............

2.17 Which type of soil has been mostly affected?

Goz (   ) Mamaraia (   ) Jurraba (   ) Wadi (   )

2.18 At what time back did you first noticed these problems?

1. More than 10 years ago............(   )
2. 10-5 years........................(   )
3. Recently..........................(   )

2.19 What do you think are the causes of these soil problems?

1. Continuous cultivation............(   )
2. Too many grazing animals..........(   )
3. Drought...........................(   )
4. Removal of vegetation cover.......(   )
5. Others (Specify)......................

2.20 What are the most serious effects of these soil problems on the livelihood of the local people?

1. Decrease in crop production.........(   )
2. Decrease in grazing areas...........(   )
3. Increase in sand movement...........(   )
4. Destruction of the vegetation cover.(   )

(C) Vegetation:

2.21 What are the main plant species existing at present in each of these soils?

Goz	Hamaraia	Jurraba	Wadi
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

2.22 What do you think are the main decreasing species in each soil type?

Goz	Hamaraia	Jurraba	Wadi
....	....	....	....
....	....	....	....
....	....	....	....

2.23 What are the species once prevailed but no longer existing at present in any of these soil types

Goz	Hamaraia	Jurraba	Wadi
....	....	....	....
....	....	....	....
....	....	....	....

2.24 Can you state time when you first noticed the decrease and/or the disappearance of these species?
...............years

2.25 In your opinion, what are the main reasons behind the decrease or disaapearance of these species?
1...
2...
3...
4...

2.26 Where was the concentration of vegetation 10 years ago in to settlement?
1. Less than one hour walk............( )
2. Within 1-2 hours walk.............( )
3. Within 3-4 hours walk.............( )
4. Within 5-6 hours walk.............( )
5. More than 7 hours walk............( )

2.27 Where is the concentration of vegetation at present in relation to settlement?
1. Less than one hour walk............( )
2. Within 1-2 hours walk.............( )
3..Within 3-4 hours walk.............( )
4. Within 5-6 hours walk.............( )
5. More than 7 hours walk............( )

2.28 Have you in common plant disappeared?
Yes ( ) No ( )

2.29 If "yes", was this because of:
1. Drought conditions.......................( )
2. Expansion of cultivated areas.............( )
3. Concentration of more animals.............( )

4. Felling of trees and clearance og grasses.( )
5. Pests and diseases........................( )
6. Fires.....................................( )
7. Others (Specify)..............................

2.30 Did you observe any increase in any particular species?
1. I did not observe any such increase........( )
2. I Observed the following species................
....

2.31 Did you observe any particular new species in this area?
1. I did not observe any new species..........( )
2. I Observed the following species................
....

2.32 How do you rate the new species as compared to the once prevalent ones?
Better ( ) Same ( ) Inferior ( )

2.33 Have you oberved any change in the overall tree vegetation of this area?
1. Increased.....................( )
2. Decreased.....................( )
3. The same......................( )

2.34 Have you oberved any change in the overall grass-cover of this area?
1. Increased.....................( )
2. Decreased.....................( )
3. The same......................( )

3. Socio-economic Aspects:-

(A) Cultivation:

3.1 Have you practiced cultivation in any of the following years?

Year	Yes	No
1987	( )	( )
1986	( )	( )
1985	( )	( )
1984	( )	( )
1983	( )	( )
1982	( )	( )

3.2 If you have not practiced cultivation in any of these years, please state reasons?
....
....
....

3.3 If you practiced, how many Mukhama you cultivated in each of the following years?

Year	No of Mukhamas
1987	....
1986	....
1985	....
1984	....
1983	....
1982	....

3.4 Were the areas cultivated in one consolidated plot or dispersed?
1. Consolidated plot...................( )
2. Dispersed...........................( )

3.5 If dispersed, give number of plots and average area of each?

....

3.6 For how many seasons did you used to leave a plot of land to rest in the past?

...............years

3.7 For how many seasons do you continuously cultivate a plot of land at present?

...............years

3.8 For how many seasons do you leave a plot of land to rest at present?

...............years

3.9 For how many seasons did ypu used to continuously cultivate a plot of land in the past?

...............years

If there is any change in land management strategies:

3.10 What are the reasons behind changing the old farming system?
1. No more available land to cultivate.....( )
2. Continuous decrease of productiin.......( )
3. To ensure more production...............( )
4. For commercializing the buisness........( )
5. Others (Specify)............................

3.11 What crops did you cultivate during the last five years?

Crop	1987	1986	1985	1984	1983	1982
Millet	( )	( )	( )	( )	( )	( )
Sorghum	( )	( )	( )	( )	( )	( )
Peanuts	( )	( )	( )	( )	( )	( )
Sesame	( )	( )	( )	( )	( )	( )
W.mellon	( )	( )	( )	( )	( )	( )
Okra	( )	( )	( )	( )	( )	( )

Other (Specify)

....

....

3.12 What area did you allocate to each crop you cultivated in and how much area did you allocate?

Crop	Area in Mukhamas	Yield in sacks
Millet	( )	( )
Sorghum	( )	( )
Sesame	( )	( )
Peanuts	( )	( )
W.mellon	( )	( )
Okra	( )	( )
Other	( )	( )
	( )	( )

3.13 How do you compare 1986 yields to previous years?
1. Higher......................( )
2. Same........................( )
3. Lower.......................( )

3.14 Was your production of stable food crops in 1986 enough to sustain your family?

Yes ( ) No ( )

If "NO",
3.15 How did you meet the shortage?
....
....
....

3.16 Was your production of stable cash crops in 1986 enough to meet the cash needs of the family?
Yes ( ) No ( )
If "NO",
3.17 How did you augment your cash resources?
....
....
....

3.18 In your opinion, what are the reasons behind good yields?
....
....
....

3.19 In your opinion, what are the reasons behind bad yields?
....
....
....

(B) Gum Production:

3.20 Do you have gum gardens (trees)?
Yes ( ) No ( )

If "Yes",

3.21 How many Mukhamas of gum do you own at presen and five years ago?

At present	5 years ago
....	....

If the area has changed

3.22 What are the reasons?

....
....

3.23 Estimate your yield per Mukhamas in the following years?

Year	Yield in sacks
1986	....
1985	....
1984	....
1983	....
1982	....

3.24 If the yield has changed, what do you think are the reasons?

....
....
....
....

3.25 Do you possess young gum-producing trees?

Yes (   )   No (   )

If "Yes",

3.26 What area in Mukhamas do you own?

..................Mukhamas

If "No",

3.27 Why you do not possess young gum-producing trees?

....
....
....

(C) Animal Husbandry:

3.28 Do you own livestock?

Yes (   )   No (   )

If "Yes",

3.29 What of the following types do you own and how many?

Cattle....................(   )
Sheep.....................(   )
Goats.....................(   )
Camels....................(   )
Donkeys...................(   )
Horses....................(   )

3.30 Have your animals increased or decreased in number during the last five years?

Animal	Increased	Decreased
Cattle	( )	( )
Sheep	( )	( )
Goats	( )	( )
Camels	( )	( )
Donkeys	( )	( )
Horses	( )	( )

3.31 If numer inceased, what were your sources of obtaining more animals?

....
....
....

3.32 If number decreased, what were the reasons?

....
....
....

3.33 Where do you graze your animals in the following periods?

Period	Near village	Distant land
Kharif	( )	( )
Darat	( )	( )
Seif	( )	( )
Shitta	( )	( )
Rushash	( )	( )

3.34 What are the reasons for distant grazing?

1. Inadequate grazing round village........( )
2. Large ize of herds......................( )
3. Fear of damaging crops..................( )
4. Scarcity of drinking water for animals near village............................( )
5. Others (Specify).............................

3.35 What are the main grasses available for your animals now?

....

3.36 Please list grasses preferred by animals but are not available in the surroundings?

....

3.37 When did these species disappeared from the area?

1. 4-5 years ago..........................( )
2. 6-10 years ago.........................( )
3. 11-15 years ago........................( )
4. More than 15 years ago.................( )

3.38 In your opinion what are the main reasons behind the disappearance of these species?

....
....
....

....

3.39 What are the most critical months for fodder shortage in this area?

....

3.40 How do you feed your animals during this critical period?

1. Moving animals to distant grazing areas..( )
2. By felling trees........................( )
3. Cutting branches of green trees..........( )
4. Collecting fallen leaves.................( )
5. Stored crop residues....................( )
6. Others

4.<u>Household Biomass Consumption</u>:-

(A) House Construction:

4.1 What tree and other plant species do you use now for each of the following construction purposes?

1. Kao..
2. Gazzaz.....................................
3. Stands.....................................
4. Matarig....................................
5. Tieing.....................................
6. Thatching..................................
7. Fencing....................................

4.2 For any of the above purposes, were there any species that you used to use in the past but no longer existing now?

1. Kao..
2. Gazzaz.....................................
3. Stands.....................................
4. Matarig....................................
5. Tieing.....................................
6. Thatching..................................
7. Fencing....................................

4.3 From where do you obtain the above wood materials at present?

	Village surrounding	Distant areas
1. Kao	( )	( )
2. Gazzaz	( )	( )
3. Stands	( )	( )
4. Matarig	( )	( )
5. Tieing	( )	( )
6. Thatching	( )	( )
7. Fencing	( )	( )

4.4 From where did you use to obtain these materials 10 years ago?

	Village surrounding	Distant areas

1. Kao	( )	( )
2. Gazzaz	( )	( )
3. Stands	( )	( )
4. Matarig	( )	( )
5. Tieing	( )	( )
6. Thatching	( )	( )
7. Fencing	( )	( )

4.5 How often do you renew the followings? Years

1. Hut......................( )
2. Rakuba...................( )
3. Fence....................( )

(B) Fuel:

4.6 Which of the following fuel materials do you use at home?

1. Firewood...................( )
2. Charcoal...................( )
3. Petrol products............( )
4. Crop residues & grasses.....( )
5. Others (Specify).................

If "1,2 and/or 4:

4.7 How do you obtain these materials?

	Collect	Purchase
1. Firewood	( )	( )
2. Charcoal	( )	( )
3. Crop residues & grasses	( )	( )

4.8 What tree species do you use at present for fuel?

Firewood.......................................

Charcoal.......................................

4.9 What tree species did you used to use in the past that no no longer available in the surroundings?

Firewood.......................................

Charcoal.......................................

4.10 From where do you obtain fuel at present?

	Village surrounding	Distant areas
Firewood	( )	( )
Charcoal	( )	( )

4.11 From where did you use to obtain them 10 years ago?

	Village surrounding	Distant areas
Firewood	( )	( )
Charcoal	( )	( )

4.12 What type of aromatic firewood used by women?

....

5.<u>Perception</u>:-

5.1 Do you think that any degradation has recently taken place in the vegetation cover of this area?

Yes (   )   No (   )

If "Yes",

5.2 How do you describe this trend of degradation?

....

....

....

5.3 What do you think are the main causes behind this trend?

1. Severe drought conditions.................(   )
2. Expansion in cultivated area..............(   )
3. Increase in animal population.............(   )
4. Establishment of more wateryards..........(   )
5. Impact of nomads..........................(   )
6. Commercial harvesting of biomass..........(   )
7. Pests ans diseases........................(   )
8. Others (Specify)...............................

5.4 Do you think man is involved in any way in this degradation trend?

Yes (   )   No (   )

If "Yes",

5.5 How would you describe this involvement?

....

....

....

....

5.6 In your own power, how would you contribute towards the restoration of the vegetation of this area?

....

....

....

Appendix E

Quadrat and Transect Data

In the following part the data recorded from the 33 quadrat and the 34 transect sample sites are presented. Values given indicate the number each species occurred as calculated from the 20 sample plots made in each site. For the identification of these quadrats and transects a map is attached to show the location of these sample sites, Figure (E.1).

Appendix (E)

(A) Quadrat Data†

Site	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
A.albida				1	1	1						1				1	1		1	1	1	1	1	1	1	1		1	1		1		1
M.crassifolia		1	1			2	1			1	1	1		2	2	1	1		2	1	1	1	1	1	1		1	1	1	1			
C.procera		2	2	2	2		1		2	2	1	2		1		2	1		2	1	1		1	2	2	2		2	2	2	3	2	2
L.humilis		2	3		2	2	2	2	2		2	2		2	1	1	2		2	1	2	2	2	2	2	1		2	2	2		1	2
T.terrestris		1	2		1	2	1	1	2		2	1	1	1	1	1	3		1	2	2	1	2	2	2	1	2	2	3	2	3	2	2
C.bifolorus	1	2	2	2	1	4	2	2	2	2	2	2		2		2	2		2	2	2	2	2	2	2	1	1	1	2	1		1	2
C.obtusiflorous		1			2	1	1			2		1				2						1	2	1	1		1	2	1	1	2	1	1
C.italica	1	2	3	2	1	2	1	2	1	2	2	1	1	2	3	3	3		3	3	3	2	3	2	3	2	2	2	4	3	3	3	3
D.ciliaris		1	2	2	3	3	2	2	1		1	1	2	2		2	1		1	1	2	1	2	1	1	2	2	2	3	1		1	1
A.acanthus	2	2	2	2	1		1		2		2	2	2	2		2	3		2	2	2	2	3	2	3	1	2	3	2	1	1		1
C.obilorius			2					2			1		1	2		2	2		1	2	2	2	2	3	2	3	2	1	2	2	1	1	2
G.tenax			1									1	1			1			1		1							1		1			
A.tortilis					1	2	1	1		1		1		1			1		1	1	1	1	1	1	1			1	1				
A.lanceolatum	2	1	2	2	2		1		1			1	1	1		1	1		1	1		1	1	1	1	1	1	1	1	1			
S.gracilis	1	2	2	2	1	2	1		1			2	2	2		2	1		2	1	1	2	2	1	1		1	1	1	1			
P.anabapt.		1	2	2	2	3	2	2	2			2		1		2	3		2	1	1	1	2	2	1	1	1	2	1	1	1	1	1
A.senegal	1	3	3	2	2	4	2	3	2	2	2	2	2	2	2	2	2		3	2	3	3	2	2	3	2	3	4	2	2	2	2	2

(Continue.........)

(Continue.........)

Site	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
B.aeygpt.	1	1	2	2	1		1	2	1	2	1	1		2	2	1	2		1	2	2	2	2	2	2	1	1	2	2	2	1	1	1
L.pyrotech.		1	1	3	1		1	2	2	2	1	1	1	1		2	2		1		1	1	1	2	1		1	1	1	1		1	1
E.aspera	1	1	2	3	1	3	1	2	1	2		1	1	2		3	2		2	2	2	2	3	2	2	1	1	1	1			1	1
P.oleracea	2	2	3		2	3	2	2	2		2	2	3	3	3	2	2		2	2	2	2	2	2	2	2	2	2	2	1		1	1
A.nubica	1	3		2	1	3			1	1		1	2	2	3				1	2	1	2	1	1	1	1	1	2	2	2	2	1	1
B.senegal.	3	2	2	4	2	2	2	2	2	3	2	2	2	3	2	2	2		2	2	3	3	2		2	2	2	3	2	2	2	3	3
S.birrea	1	2	3	2	1	2	1	2	1	2	2	1		2	1	1	1		1	2	1	2	1	2	1	1	1	1	1	1		1	1
C.sesmam.	2	3	3	2	1	4	2	2	1		2	1	3	3		2	2		1	2	1	2	2	1	1	3	3	2	3	2	1	2	2
G.senegal.	2	2	1	2	1	1	1	1	1	3	2	2	2	3	3	1			2	2	2	2	2	2	2	1	1	2	1	2		1	2
A.amara	2	2	2	2	2	1	1		1	2	2	2		2	2	1	1		2	3	2	2	2	1	2		1	2		1	1	1	1
C.hartmann.	1		2		1	2	1	1	1	2	2	1	1	1	2	1	1		2	2	2	1	2	2	1		1	1	1			1	
D.glomerata				1	1	1				1	1	1	1				1		1	2	2			2			1	1					
W.indica	2	2	2		2	2	2	2		3	2	1	1	2	2	2	1		1	1	1	2	2	1	1	1	1	1	2	1	1	2	1
D.melanox.	1																				1		1										
A.nilotica	2	1		2	1	2	1		1	1		1	1		1	1			1	1		1	1	1				1					
T.brownii			1	2		2				2	2	1		1		1			2	2	2	1	1	2	1								
A.digitata		1		1		2						1	1	1						1			1		1						1		
A.gayanus			1		1			1										1	1	1	1	1			2						1		1

(Continue.........)

Site	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Z.christi		1					1		1				1	1			1	1	2	2	1	1	1	1	1			1	1	1		1	1
A.pallida		1							1			2		1		1	2	2	1	2	1	1	2	2	1	1	2	1	2	1			1
B.xantholeua		1					1		2			2		1		2	2	2	1	2	2	1	2	1	1	1	2	2	1	1		1	1
A.adscensionis		1					1					1	1	1		2	2	2	2	2	2	2	2	3	2	1	1	1	2	1			1
T.laxiflora																					1			1	1								
T.portulacastum		2		2			2		2			2		1					1	2	2	2	2	2	2	1	1	2	2	1		1	2
C.glutinosum									1	2		1		1		1			2	1	2	2	1	1	1		1	1					
L.kerstingii							1			1		1	1	1			1		1	1	1	1	1	1					1			1	1
C.aculeatum			2													2			1	1	1	1	1	2	1		1	1		1			
C.sativus		1	2				2		1			1				2	2		2	2	1	2	2	2	2	2	2	2	3	1		1	2
E.colonum		1		2			1		1	2		1		2		2			2	1	1	2	2	1	2	1	1	2	2	1		1	1
S.festivus		1		2			1	2				1		1		2	2		1	2	2	2	2	3	1	2	1	2	2	1		1	2
C.africana						1	1					1		1			1		1	1	1	2	1	1	1		1						
P.turgidum						2	1					1				2	2		1			1		1	1				1				
C.tuberosum	1	2	1			2	2		2		1		1	2		2	2		2	1	1	1	2	2	1	1	2	2	2	2		1	2
A.anthelmin.						2								1		1			1	1	1	1	1		1			1	1				
S.cordifolia	2	1							1	2			1	1					1	2	2	1	1	1	2	1		1	3	2	1	2	1
C.absus		2	2							2	2		1	1		1			2	1	1	1	1	1	1			1	3	1		1	1
B.linarifolia			2													2	1																

(B) Transect Data†

Site	01	02	03	04	05	06	07	08	09	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
A.albida		1							1			1						1					1				1		1	1	1		1	
T.terrestris	2		1	1	1	2		2	1	1	1	2	2		2	1	1	3	2	1	1	2	2	3	1	2	1	1	2	1	1	1	3	
C.bifolorus	2	1	3	4	2	1	4	2	1	1	3		1	3	1	3	2	1	1	2	3	1	4	3	2	3	2	1	3			2	1	2
C.obtusiflorous	1		2	2	1	3	3	2	1		2	1	2	1	4	1	1	1		2	4	2	1	2	3	1	2	1	2	1	1	2	3	1
C.italica	2	1	2	3	1		2	1	2	1	3	1	2	3	1	3	4	1	4	2	3	1	1	3	2	1	2		3	2	1	3	3	4
D.ciliaris	3	2	1	1	3	4	2	1	2	3		3	2	1	1	3	2	1			2	3	2	2	3		4	2	2	2		2	3	
A.acanthus	3	1	2	4	2	5	3	2		3	4	1	1	2	3	2	4	1	3	2	3	3	3	4	2		3	4	1	2	2		2	2
C.obilorius	1	2		2	1	3		3	2	1	2	3		2	1	3	2	1	2	3	3	1	1	2	3		1	2	1	1	2		3	1
G.tenax		1							1					1			2					1	1				1				1	1		1
A.tortilis	1	2	1			1			1		2	1	1					1			1				2	1			1	1	1		1	1
A.lanceolatum	1	2	3	1		1		1	1	1		2	2	1				2	1	2	1	2	1	2	2	1	2	3	1	2	1	2	1	
S.gracilis	2	2	3	3	4	1	2	3	2		2	1	1	2	2		3			2	3	2	1			2	2		2	3	2		2	1
P.anabapt.	1	2	3	1		2	3	2	3	3	2		1	2	3	2		2	3			3	2	1	2	2	2	3			2	2	3	1
L.pyrotech.				1	1					1								1						1		1				1				
E.aspera	2	3	2	1	1	2	1	3	2	1	1			2	1	2		1	1	1	3	1	2	1	3	3	1	2	2	2	3	1	2	1
P.oleracea	1	1	2	1			1	1	3	1	3	3	1	2	4	2	3	1			2	1	1	2	3	3	2	1			4	2	2	2
A.senegal	2	2	4	4	5	2	1		2	1	2	4	3	3	2	1	1	1	3	1	1	4	2	3	2	1	4	3	2	1	1	2	3	3

(Continue......)

(Continue.......)

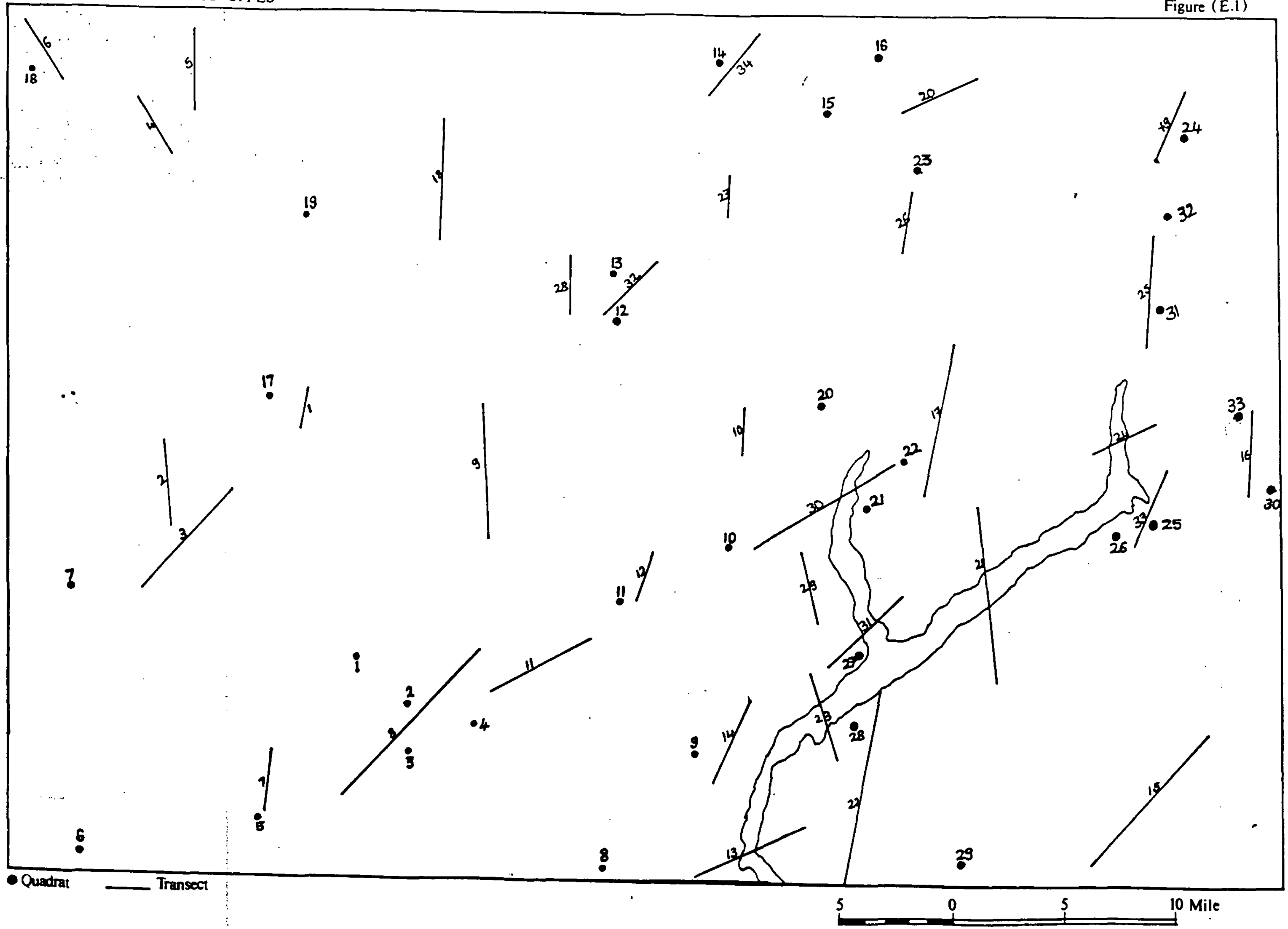
Site	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Z.christi	1	1	1							1	1				1	1				2	1					1	1	2	2	2		2	3	1
A.pallida	2	1	2	2	2	2	3	1		1		3	4	1	1	1		3	2	1			2	3	1	2	2	2	2	2	2	2	3	1
B.xantholeua	1				1	1		1	2	1	1		1		2	1	1	1			2	3		2	1		1	3	1			2		1
A.adscensionis	1	1	2	2	1	1		1	2	1		2	2		2	2	1	1		2	3	1		2	3	1		2	3		2	1	2	1
T.laxiflora											1			2														1						
T.portulacastum	3	1	1	3		1	1	1		2	1	1	2		1	1	1	2	2	1	1	2	3		1	3	2		1	3	1	1		1
C.glutinosum										1					2			1		1	1		2			1			1	2		1	1	2
L.kerstingii	1	1			1						1		1		1	1		1				1		1		2	1			1		1		
C.aculeatum		1		1	1	1						2			1			1		2		1	2	1	2	1				2	1	1	1	
C.sativus	1	2	2	1	1	1	2	2	2	3	3	1	2	1	1	2	1	1	2	1	2	2	3	3	2			1			1	1	2	2
E.colonum	1	1	1	1	2	1		1			2	2	2	1	1	1		1		1	2	2		1	3	3	2	1	1		2	2	2	3
S.festivus	1	1				1			2	2	2		2	1	1	1	3	1	2		2	1	3	2	3		2	3	2		2	2		1
C.africana	1							2	1				1	1		1				1		1	1						1	1	1			
P.turgidum	1	1	2	2	3	1	1	2	2			2	1	1	1		1	2	1	1		2	1	2	1	1	3	1		1	1		1	1
C.tuberosum	3	1	2	2	2	1	1	3	2	4	2	1				1	1	2	1	2	1	2	1	1	1		1	1		3		1	3	1
A.anthelmin.	1	1	2	2		1	1		1	1	2	2	1	2	1	1	1		2	2	1	1	2	3	1	3	3	1	2	3		1	2	
S.cordifolia	1	2	1	1	1	1	2	2	1		1	1	2	2	1	1	1	2	2	1	3	2	1		1	2	2	3	2	1	2	1	1	1
C.absus	3	1	2	3	3	2	1	3		2	3	2	1	2	2		3	2			2	1	1	2	2	1	1			2	1	2	3	2
B.linarifolia																		1										1					1	

(Continue....)

Site	01	02	03	04	05	06	07	08	09	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
B.aeygpt.	2	2	1		2	3		2	3	1	2	2	3			4	2	1	2	3	1	2		3	3	2	3	1			2	1	2	2
M.crassifolia		2		1			1	2					3		1		1			2		1	1					1		2				
C.procera	3	2	1	2	1	1	3	4			2	1	4		1	1	1	3	2	1		1	2		4	2	1	1	2	1	1	1	1	
L.humilis	2	3	2		1	2	4	2	3	1		2	2			1	1		2	1	1			2	1	2	2		1	1	1	2	1	1
A.nubica	3	2	3	2	1		1	1	2	3	4	3	1	1	1	2	4	2	2	1	3	4		2	1	2	3	4	3	3		2	2	1
B.senegal.	4	3	6	4	5	4	3	2	2	1	1	3	4	3	4	4	2	2	1		2	3	3	2	2	3	3	1	1	4	5	3	4	3
S.birrea			2	1	1		1	1	1	1		2	2	1		1	1	1		1	2	2	3	2	1			2	2	3	2	2	2	1
C.sesmam.	4	4	5	2	1	2	3	4		3	3		2	4	3	2	1	1	2	2	2	3	3	5	4	2	3	2	1	1	2	1	1	3
G.senegal.	3	3	2	1	2	2	3	3	3	2	3	1	1	2	4	3	3	3	2	2	1	1	1	2	3	4	3	3	2	3	2	2	1	2
A.amara	3	2	1	1			1	2		1	2	1			1	1	2	1	2	2	1	2	1		3	2	2	1	1		2		3	2
C.hartmann.				1	2		2	1				2		1	1	2		1	1	1	2	3	2	1	2	1	1	2		1		2		
D.glomerata	1	1	1						1					1	1							1	1	1	1				1	1		1	1	
W.indica	1	3	2	3	2	1	1	1	2	3	4	1	3	2	1	1	2	3	2	1			1	2	2		2	3		2	1		2	1
D.melanox.														1													1				1			
A.nilotica		2	1		1	1	2	1				1		1	2	2		1	1	1						1			1	1	1			
T.brownii	1	1	2		1	1	2	1		1	1	2	1	2						1	1	2	1	1	2	1	1							
A.digitata	1			1		1				1				2		1	1	1			1		1	1				1	1					1
A.gayanus	1	1		1	2	1	1		1	1	1	2	2			2	1	1	2		1		1	1	1		2	2	1			1	1	1

QUADRATS & TRANSECTS SITES

Figure (E.1)



QUADRATS & TRANSECTS SITES

Figure (E.1)