VEGETATION SOIL RELATIONSHIPS AS AIDS TO SOIL SURVEY IN SEMI-ARID AREAS

BY

NEIL MANDINYENYA ZHOU
BSc (SIERRA LEONE), MSc (U.K.)

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Department of Soil Science and Agricultural Engineering
Faculty of Agriculture
University of Zimbabwe
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DEDICATION

This thesis is dedicated to my family.

ABSTRACT

The hypothesis that vegetation and woody species indicate soil type and land potential is very common in Zimbabwe and other similar countries. Research in vegetation – soil relationships to test this hypothesis in Zimbabwe is very limited. This thesis explores relationships between vegetation and soils along granite catenas found in semi arid areas of Zimbabwe. The main objective was to establish the relationship between the two, so that they could be used as a land quality indicators for increased agricultural production in these areas.

The study was conducted on granite in Mushandike Wildlife Sanctuary, Makoholi Research Station and Gutu Soti-Source Resettlement, all in Masvingo Province within agro ecological region III and IV and in Maruta village found in Wedza Communal land of Mashonaland East Province also in agro ecological region III. Satellite image and air photo interpretations, vegetation classification and mapping together with vegetation measurements and soil profile assessments were used as data collection methods. Laboratory analyses of soils were done using standard procedures followed by AREX. Vegetation identification and measurements were done during the rainy season between November and April 1999. Plant species and soils data collected were prepared in appropriate formats for statistical analyses with the aid of SPSS statistical package. Vegetation community data were analysed using multivariate ordination techniques that include Cluster analysis, Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA).

Results from the study revealed that there was a significant correlation (at $p < 0.05$ significance level) between species richness and soil characteristics that include drainage status ($r = -0.53$); % clay in the B horizon ($r = -0.28$); pH in the B horizon ($r = -0.32$); CEC in the B horizon ($r = 0.37$); Ca to Mg ratio in the A and B horizons ($r = 0.85$ and $r = 0.45$ respectively); ESP in the B horizon ($r = 0.71$) and soil erosion intensity ($r = -0.45$). There was no significant correlation between species richness and AWC of the soil. In addition, results also revealed that the differentiation of soils along the catena correspond with changes in vegetation physiognomy. Due to these vegetation and soil changes on the landscape, distinct patterns of land facets with different agricultural potential and land management requirements could be identified and delineated on imagery and maps. The DCA ordination analysis however showed that the major ecological gradients and the most important environmental factors that influence vegetation types and species composition along the catena were related to soil moisture, drainage status, available soil nutrients, excess sodium salts and soil erosion intensity. The CCA ordination analysis showed that of the soil variables used in the analysis, none of them except drainage status ($p = 0.03$) and erosion intensity ($p = 0.01$) were responsible for changes in the distribution and abundance of vegetation and species composition along the catena at $p < 0.05$ significance level.

It was concluded that vegetation physiognomic types and individual plant species are not influenced by particular soil types or characteristics such as soil depth, clay content, pH, CEC, ESP and organic matter content of the soil. They are influenced by a complex combination of environmental factors or land qualities such as drainage, soil erosion intensity, soil fertility and soil sodicity. Therefore vegetation types and plant species cannot be used as indicators of individual soil characteristics but as indicators of broad environmental attributes or land qualities which affect site potential and its management. Nevertheless, vegetation physiognomy, as a characteristic of vegetation structural significance, could be a promising tool for mapping soil patterns in detail along the catena on granite for the purpose of land use planning and management in semi arid areas.

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LIST OF ACRONYMS

%C	Percentage Carbon
AGRITEX	Agricultural Technical and Extension Services
ANOVA	Analysis of Variance
AREX	Agricultural Research and Extension
AWC	Available Water Capacity
BD	Bulk Density
BS	Bush Savanna
BS%	Base Saturation Percentage
BSI	British Standards Institute
CA	Correspondence
CANOCO	Canonical Correspondence software
CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
CV	Coefficient of Variation
DBH	Diameter at Breast Height
DCA	Detrended Correspondence Analysis
DGA	Direct Gradient Analysis
DNR	Department of Natural Resources
Dr	Soil drainage status

DRSS	Department of Research and Specialist Services
E/C	Cation Exchange Capacity per 100g of clay
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
FAO	Food and Agricultural Organisation
FAO - ISRIC	Food and Agriculture Organisation – International Soil Research Institute
FC	Field Capacity
GS	Grassland Savanna
GTZ	German Agency for Technical Co operation
IGA	Indirect Gradient Analysis
masl	Metres above sea level
MAST	Mean Annual Soil Temperature
MoLARR	Ministry of Lands Agriculture and Rural Resettlement
p	probability
PCA	Principal Component Analysis
PWP	Permanent Wilting Point
RA	Reciprocal Averaging
S/C	Total Exchangeable Bases per 100g of clay
SD	Standard Deviation
Se	Soil erosion intensity

spp	species
SPSS	Statistical Programme for Social Sciences
TBS	Tree Bush Savanna
TEB	Total Exchangeable Bases
TM	Thematic Mapper
TS	Tree Savanna
TWINSPAN	Two - Way Indicator Species Analysis
USDA	United States Department of Agriculture
UZ	University of Zimbabwe
VegRIS	Vegetation Resource Information System

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 BACKGROUND

About 60 to 65 % of soils in Zimbabwe are derived from rocks of igneous origin of which granite is one of the most widely distributed geological materials (Thompson and Purves, 1978). Authors for example Stagman (1978), Purves (1976) and Nyamapfene (1991) provide detailed descriptions of mineralogical composition of the granites in the Zimbabwean landscape. Similar to other geological landscapes within the granite are recurring topographical patterns with successions of soils along the landscape called catenas that are very common both in non-arid and arid areas. The fundamental variation of soils within the catena is attributable to differences in the composition of the granite, internal drainage and lateral transportation of both dissolved and suspended soil materials above and within the soil along a slope gradient.

The dominant vegetation structure on the granite geology in Zimbabwe is made up of miombo woodlands that are the most extensive tropical deciduous woodlands and dry forest formations. These areas cover about 2.8 million square kilometres in the regions in Africa receiving less than 700 mm of rainfall annually on nutrient poor soils that were originally classified as tropical and sub tropical semi arid (Trewartha, 1968: in Landon, 1984). This classification is equivalent to Agro-ecological regions III and IV (Vincent and Thomas 1960; Surveyor General, 1979). These areas cover more than 50 % of the country, encompassing a wide range of vegetation physiognomic types on granite soils. Despite the obvious differences between places due to land use, the physiognomy and species in miombo are instantly recognisable on the catena by the dominance of tree species in the genera *Brachystegia*, *Julbernardia* and *Isoberlinia* of the family *Fabaceae*, subfamily *Caesalpinioideae*. The key structure and functional features of the miombo woodland type and the factors that are thought to determine this vegetation type are discussed by many authors (Campbell *et. al*., 1994).

1.2 THE CATENA CONCEPT IN ZIMBABWE

The term 'catena' was derived from a Latin word meaning chain. It was originally intended to serve as a mnemonic for the succession of different soils corresponding to the links of a hanging chain (Milne, 1936) used to describe a regularly recurring toposequence of soils originally in East Africa from top land to lowland. Although originally in his description of the catena it was not essential for parent material to remain the same throughout the sequence, Milne nevertheless recognised a separate kind of catena that was confined to one parent material (Thompson and Purves, 1978). It is this concept that has received wide application in Zimbabwe today. Watson (1965) used this concept to describe these soils with "a regular repetition" on the landscape.

In Zimbabwe, Thompson (1957) defined the catena as: "a group of soil series within a climatic zone developed under similar vegetation and similar parent material but differing in characteristics of the solum owing to differences in relief and drainage". As a general rule, soils in the upper drier slopes have undergone less weathering and hence less differentiation than those found on lower moist, poorly drained topographic positions (Young, 1976). The differences in soil characteristics within the catena are greatly dependent on type of parent rock material and relief in combination with its indirect effects upon hydrology. For example, there are more pronounced soil colour and textural changes as well as chemical and mineralogical characteristics of soil in mafic than in granite catenas (Purves, 1976, Nyamapfene, 1991). The factors that influence soil types along the catena tend to be more pronounced in Zimbabwe due to the markedly seasonal rainfall pattern and its effects on water infiltration, denudation and weathering at different locations of the landscape. There is more differentiation of soils especially in areas receiving between 550mm and 940mm of rainfall (Nyamapfene, 1991) which generally fall within the semi arid natural regions III and IV (Vincent and Thomas, 1960).

The catena concept was introduced as a device for generalised mapping of complex soil associations on the landscape (Thompson and Purves, 1978). Its usefulness for this purpose has continued at different scales in many countries. The concept has gained wide recognition and application in the study of tropical vegetation (Young, 1976) and classification of soils in Zimbabwe and other countries within the tropics (Watson, 1965; Purves, 1976; Nyamapfene, 1991). Early ecologists who described tropical landscapes in Africa focused on the catena as a spatial variation of habitats on the land (Morrison *et al.*, 1948). Within these variations for example, they described the transitions of vegetation communities and soils from the top to the bottom of the landscape. In communal areas of Zimbabwe, which cover about 43% of the country, farmers have generally adapted to this variation by practising rain fed arable farming for subsistence on freely drained upper to middle parts of the catena. Specialised cultivation of high valued horticultural crops at valley floor margins and permanent grazing in valley floors and on granite hills. This arrangement of land use and potential can be applied in the specialisation of agricultural extension services to improve productivity of the land (Scoones, 1991). It is therefore the catena concept that forms a framework upon which the study of vegetation and soil relations on granite in this thesis is based.

1.3 RATIONALE OF THE STUDY

Soil survey is a prerequisite for all-agricultural development planning. However, in Zimbabwe and other developing countries, the present conventional soil survey techniques have proved to be both time consuming and costly especially when detailed information about soils is required for land use planning and management. While natural vegetation patterns have always been used in many soil surveys to confirm soil boundaries both on maps and in the field, the correlation between vegetation and soil characteristics has not been clearly defined or quantified in Zimbabwe.

Zimbabwe has a provisional soil map of the country together with other natural resources and survey information are readily available. The country has a complete coverage of soil maps at a scale of 1: 1 000 000 with some areas surveyed and mapped at more detailed scales, for example in high potential areas that are found in the central watershed zones of the country and in the eastern highlands. In arid and semi-arid areas, where granite soils are most widespread, detailed soil surveys have not been carried out on a large scale. The usefulness of the available soil maps is greatly limited due to the inaccuracies with which soil characteristics can be predicted. Since more information on soil and other relevant environmental characteristics in arid and or semi arid areas will be required, research is therefore necessary to establish appropriate means for identifying soils for development planning and for agricultural management.

In these areas, the use of soil survey and classification methods which require detailed schemes of soil profile descriptions means that workers other than soil scientists encounter many problems in trying to understand and extract relevant information from the soil map and memoir for land management and development. With the increasing need for simpler and low cost soil survey guidelines for land use planning, irrigation development and crop production in dry areas of Zimbabwe, understanding relationships between vegetation and soils will therefore both facilitate and result in a more cost effective way of carrying out soil surveys and assessment of suitability of land for agricultural development in these areas. At more detailed vegetation soil survey scale, individual plant species can indicate site potential for certain crops such as deep-rooted perennial as well as tree crops and forestry plantations when their growth requirements are known (Timberlake and Calvert, 1993).

Given that the majority of people in Zimbabwe generally rely on agriculture for their livelihood, it is essential to develop the agricultural sector so that production can be increased. To achieve this, either production on existing land needs to be increased or new land need to be put under cultivation, for example resettlement farms. In the later case, appropriate soil survey techniques for identifying soils and their potential for agriculture need to be developed.

1.4 OBJECTIVES OF THE STUDY

The major objective of this study is investigate relationships between vegetation composition and soil characteristics so as to establish a basis that could be used as an aid to mapping soil patterns at a detailed scale for land use planning and land management in semi arid areas. The specific objectives are as follows:

1.4.1 To investigate soils distribution and vegetation abundance in semi arid granite areas of Zimbabwe and quantify the relationships that exist between the two.

1.4.2 To determine the variance in vegetation abundance using multivariate techniques and investigate changes in vegetation physiognomy and species composition along environmental gradients on granite catenas in semi arid areas of Zimbabwe.

1.4.3 To identify soil characteristics which influence the distribution and abundance of vegetation types and plant species along the catena

1.4.4 To establish vegetation characteristics and indicator species for certain soil characteristics and land management problems

1.5 HYPOTHESES

1.5.1. Vegetation abundance in semi – arid granite areas of Zimbabwe are related to the distribution of soils

1.5.2. Variation in vegetation physiognomy and species composition can be used to predict environmental gradients along the catena in semi - arid areas.

1.5.3. The distribution pattern of vegetation communities and species along granitic catenas in semi-arid areas, is influenced by soil characteristics.

1.5.4 Certain individual woody plant species such as *Terminalia sericea*, *Colophospermum mopane*, *Diploryhnchus condylocarpon* and *Brachystegia spiciformis* can be used to indicate soil types in semiarid granitic areas.

1.6 ORGANISATION OF THESIS

This thesis is organised into six chapters. Chapter One is the introduction, which provides the general background about soils and occurrence of vegetation, the significance of the catena concept in Zimbabwe and the objectives of the research as well as framework of the thesis.

Chapter Two contains a general literature review of vegetation in Zimbabwe, vegetation soil relations and multivariate techniques that are commonly used in the analyses of vegetation and environmental data.

Chapter Three provides the description of the study areas and an outline of the materials and methods used for field surveys and sampling as well as laboratory analyses. Chapter Four describes the soils and vegetation along granite catenas in study areas, assesses variability and correlates important vegetation and soil characteristics.

Chapter Five determines the most appropriate vegetation data set to use for multivariate analyses. The ecological structure of vegetation data is summarised in this chapter. The influence of soil characteristics as environmental variables responsible for the variation of species along the catena is investigated. Also in this chapter, vegetation characteristics and indicator species that can be used to predict soil patterns along the catena are also identified. Multivariate ordination techniques called Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) that are available in the CANOCO computer program coupled with Cluster Analysis that is also available in the MINITAB computer program are used as analytical tools.

This thesis concludes with a general discussion (Chapter Six) in which the scientific achievements from the research are synthesised and their relevance for soil survey and land management discussed and evaluated. In the end, a summary of the major conclusions from the study is presented.

In order to avoid confusion with terms used in other similar vegetation classifications, a simple definition for the "Savanna"(S) used in this thesis is given. It is a tropical vegetation physiognomic type in which the ecological processes of primary production, hydrology and nutrient cycling are strongly influenced by woody and grass plants (Scholes and Walker, 1993). From this definition therefore, descriptive terms such as tree (T), bush (B) and grassland (G) have been adopted. These denote the predominant vegetation structure and type of plants at a site following the guidelines and procedures laid down by Pratt *et al*., (1966) and the Ministry of Agriculture, (1981) that were developed for livestock planning.

CHAPTER TWO

GENERAL LITERATURE REVIEW

2.1 INTRODUCTION

The vegetation or plant environment has been defined as the "sum of all external forces and substances affecting growth, structure and reproduction of plants species. It provides heat, light, water and nutrients in sufficient quantities at the right time to satisfy the growth and reproductive needs of plant species" (Billings, 1952).

Vegetation species tend to be most abundant around their particular environmental optima (ter Braak and Prentice, 1988) and that species composition tends to change along environmental gradients (Moore and Chapman, 1986). These environmental gradients do not necessarily have physical reality as continua in either space or time but are a useful abstraction for explaining the differences in vegetation types and the distribution of species in space and time (Austin, 1985).

2.2 VEGETATION IN ZIMBABWE

Vegetation types in Zimbabwe vary from place to place depending on climate, soils and geology. Many reports that have been produced, for example by the Departments of National Parks and Wildlife, Forestry Commission and National Herbarium and National Botanic Gardens describe the occurrence of vegetation types and species in small areas. Some of the early publications on vegetation of Southern Rhodesia, for example by Boughey (1961), Rattray (1961) and Rattray and Wild (1961) as well as on Agro-ecological survey of Southern Rhodesia, by Vincent and Thomas (1960), are major sources of information available relating to vegetation patterns and their distribution in Zimbabwe. Prior to these contributions, a number of other publications such as by Henkel (1931) and Boughey (1957) provided some information on distribution patterns of vegetation and broad ecological conditions governing these distributions. These studies indicate that generally, vegetation occurrence is related to topography, altitude and climate. Vincent and Thomas (1960) and Thompson (1965) found out that specific vegetation types, species composition and their general distribution in Zimbabwe were associated with climatic regions and stated that:

> "Zimbabwe is a meeting place for three major vegetation groups or floral regions. Irrespective of the region to which it belongs the vegetation formations are governed by climatic factors predominantly rainfall, but modified by temperature. These formations are Forest, Grassland, Woodland and Bushland….". (Thompson, 1965)

Generally, within each broad vegetation type, there are many variants of vegetation types or plant communities that occur in different localities depending on topography, soil type and soil moisture conditions. Good examples of such natural communities include those given by Ellis (1950) found on well-developed *Colophospermum mopane* and also on deep well-drained alluvial soils. In addition, species-rich thickets noted by Wild (1955) and Timberlake and Mapaure, (1992) commonly known as "jesse" found in the Zambezi Valley and in the south eastern lowveld in Sengwe communal lands are other examples found on sandy soils.

Similar biotic communities and species of botanical and pedological significance have been observed in various localities in Zimbabwe and described by many workers such as, Thompson (1965), Loxton and Associates (1971), Dye (1977), Calvert (1986), Wild and Barbosa (1968), Timberlake and Nobanda, (1992) and Nyamapfene (1991). Some examples of common soil indicator species for environmental conditions and soil properties are suggested by Thompson (1965) and a list of vegetation indicator species for soil types in Zimbabwe is given by Bennett (1985).

In communal areas of Zimbabwe, however, these natural biotic communities no longer exist due to the influence of humans through vegetation clearing, grazing and cultivation. In these areas, biotic communities that resemble those under natural conditions are only present in scattered relict communities, which lack continuity. This has lead to variable species richness and diversity of the woody vegetation component in these areas. However, it has been reported that although species richness is usually decreased by human influences, in some cases diversity is increased (Campbell and du Toit, 1994).

2.3 PREVIOUS STUDIES ON VEGETATION SOIL RELATIONSHIPS

To a very large extent, the foundations of vegetation-soil relationships were established long back as early as the later half of the nineteenth century by Vasilli Dokuchev and his co-workers who recognised associations between natural vegetation and soil in various geological – geographical surveys in different areas in Russia (Davidson, 1980). The results of the surveys led them to propose a conceptual framework whereby soils were interrelated to natural vegetation as well as to other environmental factors of climate, geology geomorphology, hydrological conditions and the activities of humans (Young, 1976; Davidson, 1980; Dent and Young, 1980).

Dokuchaev's hypothesis that the soil profile is the integrated expression of parent material, climate, topography, living organisms and age of the landscape led to the definition of soil as: "unconsolidated material on the surface of the earth that has been subjected to and influenced by the genetic and environmental factors of parent material, climate, organisms, topography, all acting over a period of time" (Foth, 1990).

The development of the soil with its associated vegetation must be considered as a complex pedogenic process that results in different soil types with variable physical and chemical properties (Brady, 1990). These properties of soils in combination with other environmental factors determine the type of vegetation that grows on it and in turn vegetation influences the development of the soils. Both physical and chemical soil properties such as soil depth, moisture, pH and cations would not be noticed on the ground Changes in these properties could possibly be realised from the variations in vegetation patterns and species composition on the landscape.

In studies of relations between vegetation and soils therefore, vegetation alone offers more opportunities for understanding soil variability because of two main reasons. Firstly it is the only reliable integrator of all environmental factors (Dent and Young, 1980; Timberlake *et al*., 1993) that are recognisable relatively easily in the field, on satellite images and on aerial photographs. Secondly, the shapes and the distribution patterns they make on imagery enable us to map them easily.

There is a greater element of a two-way interaction between vegetation and soil than is found with other soil forming factors (Eyre, 1968). Thus soil greatly influences the type of vegetation that becomes established in an area and vegetation in turn affects the formative process, as a result, the two evolve together (Thompson, 1957).

Research on the relationships between vegetation and soils in Zimbabwe and many other countries has been motivated by numerous observations on the associations between natural vegetation, climate, geology and soil type as well as other environmental factors. It has been noted that natural vegetation patterns generally coincide with geologic boundaries together with their associated soil types (Childes, 1984; Nyamapfene, 1988). Because of this, therefore, it could be possible to use natural vegetation communities and species as indicators of soil characteristics.

The vegetation communities are the only visual expression of the environmental factors and their interactions such as parent material, climate and topography, drainage and erosion that influence soils (Dent and Young, 1980). Campbell and du Toit (1994), in a study of vegetation patterns and their influence on small-scale farmers in a semi arid savanna area in the south east of Zimbabwe, concluded that the major environmental variables determining plant community floristics were soil type, topography and the activity of small-scale farmers.

In the Kalahari sands in Zimbabwe, the most important factor that was seen to influence vegetation physiognomy and floristic composition was topography through its influence on drainage and soil moisture availability. The occurrence of tree savanna vegetation dominated by *Brachystegia spiciformis* and *Baikea plurijuga* was found to be very common on well drained uplands and on crests with deep sandy soil of low water holding capacity whilst on middle slopes *Baikea plurijuga*, *Burkea africana* and *Pterocarpus angolensis* were more dominant. These were replaced by *Terminalia* species on lower slopes and *Combretum* species and in the vleis (Robinson, 1974). These findings were confirmed by research in similar parts of the Kalahari sands (for example Childes 1984) that topography in combination with other factors such as the depth of a hard pan layer, drainage and differences in texture and soil moisture seemed to influence changes in vegetation physiognomy and species composition.

In the south eastern lowveld of Zimbabwe, vegetation – soil catenary relationships were recognised Farrell (1968). He noted that shallow soils derived from coarse-grained alluvium support *Colophospermum mopane*, *Commiphora* species and *Kirkia acuminata* while the deeper and permeable soils of mixed lithology support *Acacia* tree species. These findings are similar to those reported by Campbell *et al.* (1994) along the Zambezi Valley but different in the species and soils.

Dye (1977, 1979) examined vegetation – environment relationships on Zimbabwean soils classified as sodic. The results of his work showed that on sodic soils, the occurrence and distribution of certain species such as *Colophospermum mopane* and *Acacia* species differed with depth of soil, texture, position on the landscape and the ratio between electrical conductivity (EC) and exchangeable sodium percentage (ESP). One of the conclusions he made was that plant communities were differentiated mainly on the basis of soil moisture regimes and soil texture suggesting that vegetation could be used as a reliable indicator of soil conditions.

McGregor (1994) studied the structure and distribution of woody plants in miombo woodland on different soil types derived from granite and dolerite. These geological materials differ in mineralogy and the types of soils that are derived from each of them. Results from this work indicated significant association of woody species such as *Brachystegia spiciformis* and *Julbernardia globiflora* in middle slopes and upslope positions of the catena with infertile sandy soils derived from granite. In other sites with well-drained red clay soils derived from dolerite, in the middle and upper positions of the catena, species such as *Brachystegia boehmii* were more common than on sandy soils.

Significant occurrences of ultra basic rocks that give rise to soil with a preponderance of magnesium to calcium is more common in soils that occur in areas along the Great Dyke (Thompson and Purves, 1978). In these areas, Proctor and Craig (1978) studied vegetation associated with nickel and copper bearing soils derived from serpentine (ultra basic) rocks. They found that these serpentine soils which have high calcium to magnesium ratio were associated with well developed woody vegetation dominated by *Brachystegia boehmii,* while those with inverted calcium to magnesium ratios (more magnesium than calcium) and toxic levels of heavy metal such as nickel, were associated with grassland vegetation dominated by *Hyparrhenia* and *Hyperthelia* species in combination with woody species such as *Diplorhynchus condylocarpon*.

Many workers showed the possibility of using vegetation as an indicator of soil types and potential for agriculture (Vincent and Thomas,1960; Thompson, 1965; Timberlake *et al.,* 1993). As stated earlier, they indicated that vegetation was an integrator of environmental factors such as climate, physiographic, edaphic and biotic factors of the area in which it was found. The indicator value of the vegetation could be used to provide a good insight into the agricultural and biological potential of the area. In addition, indigenous farmers in their localities have already made a number of observations through not documented. Results from these studies generally indicate that the variations in vegetation types and species composition that are found on the landscape do not occur at random but are closely related to changes in land qualities and characteristics; for example changes in soil nutrient availability and soil moisture and drainage. Land qualities are attributes of land which act in a distinct manner in its influence on the suitability of the land for a specific kind of use. The concept of land qualities: and characteristics (Dent and Young, 1981) is widely used in land suitability evaluation for agricultural production and is described in detail elsewhere (FAO, 1976; Dent and Young, 1980; Landon, 1984).

2.4 ENVIRONMENTAL GRADIENTS

An environmental gradient is a term that is used to describe a range in environmental conditions that affects distributions of species and communities in a particular habitat (Gauch 1982). Plant species occur in a limited range of habitats. They are usually most abundant where environmental conditions are optimum (ter Braak, 1996). Thus species composition changes along environmental gradients and the significance of these is realised in the explanation of the distribution of vegetation types and species in space and time (Austin, 1985). The study of vegetation-environmental relations along gradients have therefore formed an important basis for the development of the ecological theory (ter Braak and Prentice, 1988).

There are two basic types of environmental gradients that have been identified namely direct and indirect gradients (Moore and Chapman, 1986). Direct gradients are those that impose a direct influence on plant growth such as soil pH and nutrients, while indirect gradients include those factors, which do not impose a direct influence on plant growth such as altitude and slope. Thus, gradient analysis therefore includes both direct gradient analysis in which species abundance (or probability of occurrence) is described as a function of measured environmental variables; and indirect gradient analysis in which community samples are displayed along axes of variation in species composition that can subsequently be interpreted in terms of environmental gradients (ter Braak and Prentice, 1988).

2.5 MULTIVARIATE METHODS

Methods for vegetation and environmental gradient analyses are usually concerned about comparing plots in terms of plant species and environmental variables, relating vegetation variation to environmental factors and identifying control factors (Gauch, 1982). For this purpose, multivariate analyses have been used as tools to describe the vegetation variability and reveal the underlying relationships between vegetation and particular environmental factors.

There is no standard definition of multivariate analysis. However, the term “multivariate” analysis has commonly been used to include a group of statistical, mathematical and graphical techniques that attempt to examine more than one dependent variable simultaneously (Moore and Chapman, 1986). Standardised methods for analysis such as multiple regression analysis therefore cannot be considered as a multivariate analysis since only one dependent variable is studied at a time (ter Braak and Prentice, 1988). Two most common techniques that are available in multivariate analysis include ordination and classification.

2.5.1 Ordination

The origin of the term “ordination” is attributed to Goodall (1954) and the early attempts to order a group of objects, for example in time or along environmental gradients. Pielou (1984) defined ordination as the ordering of a set of data points with respect to one or more axes so as to make the relationships among the points in many dimensional space visible on inspection. Later, ter Braak (1987) defined ordination as a collective term that arranges sites along axes on the basis of data on species composition.

Community-environment relationships have often been explored by a two-step procedure namely indirect ordination followed by direct ordination analysis (Gauch,1982; ter Braak, 1996). Indirect ordination is first focused on the major patterns of variation in community composition. The main objective of indirect ordination is to help generate hypotheses about the relationship between species composition at a site and the underlying environmental gradients. Direct ordination enables further study of the variation in community composition that can be explainable by a set of measured environmental factors.

Nowadays, many researchers use the term more generally and it refers to the spatial arrangement of samples along abstracted environmental gradients such that their positions reflect similarity or association. It is widely used as a framework for comparing variability of species and environmental factors as a basis for identifying ordination (Moore and Chapman, 1986). Phytosociological ordination techniques are those that use all relationships between species and environmental variables to be able to formulate hypotheses about the cause and effect of the relationships (ter Braak and Prentice, 1988).

There are many ordination techniques that are being used for vegetation environmental relationships investigations such as Principal Component Analysis (PCA), Reciprocal Averaging (RA) and Correspondence Analysis (CA) including Canonical Correspondence Analysis (CCA). In Zimbabwe, these techniques have already been applied in vegetation studies for example PCA in vegetation environmental relations in sodic soils (Dye and Walker, 1980). In addition, recent studies in community – environmental relationships in a wetland (Mapaure and McCartney, 2001) have demonstrated the applicability of both indirect and direct ordination to summarise community patterns and compare them with environmental data in order to produce an environmental interpretation of the ordination results in a wetland. It is noted however that, some of standard multivariate statistical methods available that assume linear relationships among the variables in gradient analysis such as PCA and multiple regression analysis, have found only limited application in studies of vegetation and environmental relationships in many areas. This is because of the generally non-linear and non-monotone response of vegetation species to environmental variables (ter Braak, 1996).

Other techniques for studying vegetation environmental relations along environmental gradients have been developed based of unimodal (Gaussian) response models instead of linear ones (Gauch, 1982). Examples of these include the Detrended Correspondence Analysis (DCA) and the Canonical Correspondence Analyses (CCA) that are explained in detail in Chapter Five.

2.5.2 Classification

Classification involves a sorting procedure of objects into groups or classes that are defined by the possession of certain prescribed attributes (Moore and Chapman, 1986). Two basic approaches of classification known as divisive and agglomerative, have commonly been used.

Divisive approaches start with the entire sample and proceed by successive subdivisions of broad inclusive classes to provide a large number of exclusive classes or groups while agglomerative approaches start with a small group and proceed by recognising a large number of small exclusive units which are subsequently grouped together to form large clusters until the entire data are sampled (Pielou, 1984). The main objective for the two approaches, however, seeks to reflect the vegetation variability of large areas within a unitary framework. Examples of divisive and agglomerative methods include the Two-Way Indicator Species Analysis (TWINSPAN) and Average Linkage Method respectively. TWINSPAN (Hill, 1979b), a modification of the original indicator species analysis (Hill, 1974), has already been used in many vegetation studies in Zimbabwe, for example by the Vegetation Resource Information System (VegRIS) project in Forestry development (VegRIS, 1998). It was applied in the classification of vegetation and the identification of indicator species for soil types in Hwange National Park by Tafangenyasha (1988), Rogers (1992) and Timberlake *et al*. (1993).

It was also used in a vegetation survey in Lupane district (Nobanda, 1992) as part of a broader project on vegetation survey in communal lands of Zimbabwe.

2.5.3 Vegetation mapping

Various techniques in vegetation classification are amenable to vegetation mapping as a method of showing spatial variability. However, methods for vegetation mapping differ due to the purpose for which the map is required, the scale of the map and the units that can be represented on the map (Moore and Chapman, 1986). Usually, management based classifications such as of the type used by the Department of Agricultural Research and Extension (AREX) of the Ministry of Lands, Agriculture and Rural Resettlement follow simple schemes based for example on landform, topography and vegetation physiognomy together with vegetation community units and floristics. Small scale maps for example with a representative fraction of 1:500 000 and 1:100 000 can only show generalised features of vegetation variability while large scale maps for example with a representative scale of 1:10 000 and 1:25 000 allow more detailed information on vegetation variability including physiognomic structure and species composition. Although based on classes which are arbitrary, it is however noted that the use of criteria such as physiognomy and species composition for example as applied by Bennett (1985) gives an objective and realistic assessment of the vegetation resource by land use planners in the department of AREX in Zimbabwe.

2.6 SUMMARY

There is a general paucity of quantitative studies on vegetation-soil relationships in granitic soils in Zimbabwe. Purely descriptive classificatory work was done early for example by Vincent and Thomas (1960), Thompson (1965), and Wild and Barbosa (1968). Other recent research for example by Timberlake *et al* (1993) as already mentioned, outline general soil types and site characteristics for the various vegetation communities and species identified.

The concept of vegetation indicator species for certain environmental characteristics for example soil type is not new. In Zimbabwe, however, as already indicated above, very little conclusive information could be found concerning vegetation indicator species for soil types especially in arid areas apart from the vegetation indicator species for soil types suggested by, for example, Bennett (1985) and Nyamapfene (1992). The basic concept and the relationships as well as the methodology for identification of indicator species will be further investigated as part of this study.

A simple method for analysing vegetation species and community changes along environmental gradients in semi arid areas is to list all species present. While such a checklist is useful, it is rarely used alone because of its limited value. Quantitative data would be needed and for practical purposes, it would be impossible to conduct a quantitative analysis of the whole community because of the large size of areas involved. Representative samples or plots are often chosen from which measurements of appropriate vegetation and environmental characteristics are made to obtain species data sets for use in more detailed analyses.

In Zimbabwe, research in vegetation-soil relationships presently however, is being motivated by the numerous observations on these associations between natural vegetation communities and environmental characteristics. Before a detailed assessment and analysis of the environmental factors influencing the changes in vegetation and species distribution can be made, it is necessary to consider the natural variation in the distribution of species along the landscape. This enables one to gain an insight and understanding of the ecological structure and factors responsible for the changes in vegetation and soils.

The commonly used techniques in community – environmental relationships are ordination and classification as already indicated in section 2.5. These techniques are based on gradient analysis. Gradient analysis has limited applicability; only with evident environmental gradients is it applicable (Gauch, 1982).

Multivariate ordination techniques that are chosen in this study such as DCA (Indirect Gradient Analysis) and CCA (Direct Gradient Analyses) allow one to explore vegetation - soil relationships and compare community patterns with soils data. This is a means to produce an environmental interpretation of the results in semi arid areas of Zimbabwe. The Average Linkage clustering procedure that is chosen as classification technique is useful for providing research results expressed in terms of community types and for providing a workable number of ecological clusters for remembering and communicating results.

CHAPTER THREE

MATERIALS AND METHODS

3.1 INTRODUCTION

The general methodology used, was landscape guided based on satellite image and aerial photo interpretation coupled with field checking. This was followed by the identification of field sampling sites for vegetation and soils, field measurements as well as data collection and laboratory soil analysis. This methodology suited the determination of vegetation and soil characteristics that was carried out at a detailed level along catenas on granite.

This chapter outlines the general physical features of the study areas, methods and procedures that were followed in the vegetation and soil field surveys as well as soil laboratory analyses.

3.2 PHYSICAL DESCRIPTION OF STUDY AREAS

3.2.1 Location of study areas

The study was conducted in Masvingo Province along catenas namely Mutsungwe, Mushandike River, Navik Bay, Up Navik Bay, Airstrip North (a) and Airstrip North (b) found in Mushandike Wildlife Sanctuary, Chikungurugwi catena found in Makoholi Research Station and Agyle catena found in Soti Source resettlement of Gutu district. The province is situated between 30^0 to 32^0 E and 19^0 to 22^0 S in the South East of Zimbabwe (Figure 3.1), and covers an area of approximately 5 000 000 ha in the semi-arid zone (Vincent and Thomas, 1960).

An additional area namely Maruta catena found outside Masvingo province within the semi arid zone in Wedza communal land of Mashonaland East Province was included in the study for purposes of comparison. Details of location of catenas and study sites are summarised in Table 3.1 below.

Table 3.1 Location of catenas in the selected study areas found in Mushandike Wildlife Sanctuary, Makoholi, Soti Source Resettlement and Wedza.

Name of Catena	Catena symbol	Map Reference	Grid reference	Symbols for Vegetation plots / soil profiles
Mutsungwe	MU	Mushandike Dam, 1:50 000, 2030 B1	TN 482758	MU1 - MU6
Mushandike River	MR	Mushandike Dam, 1:50 000, 2030 B1	TN 497763	MR1 - MR4
Airstrip North (a)	ANa	Mushandike Dam, 1:50 000, 2030 B1	TN 486767	ANa1 - ANa4
Airstrip North (b)	ANb	Mushandike Dam, 1:50 000, 2030 B1	TN 491769	ANb1 - ANb4
Navik Bay	NB	Mushandike Dam, 1:50 000, 2030 B1	TN 542722	NB1 - NB5
Up Navik Bay	UN	Mushandike Dam, 1:50 000, 2030 B1	TN 548733	UN1 - UN4
Chikungurugwi	CH	Makoholi, 1:50 000, 1930 D4	TP 685066	CH1 - CH6
Agyle	AG	Soti Source, 1:50 000, 1931 A3	TP 958484	AG1 - AG4
Maruta	MA	Wedza, 1:50 000, 1831 D1	UQ 538382	MA1 - MA4

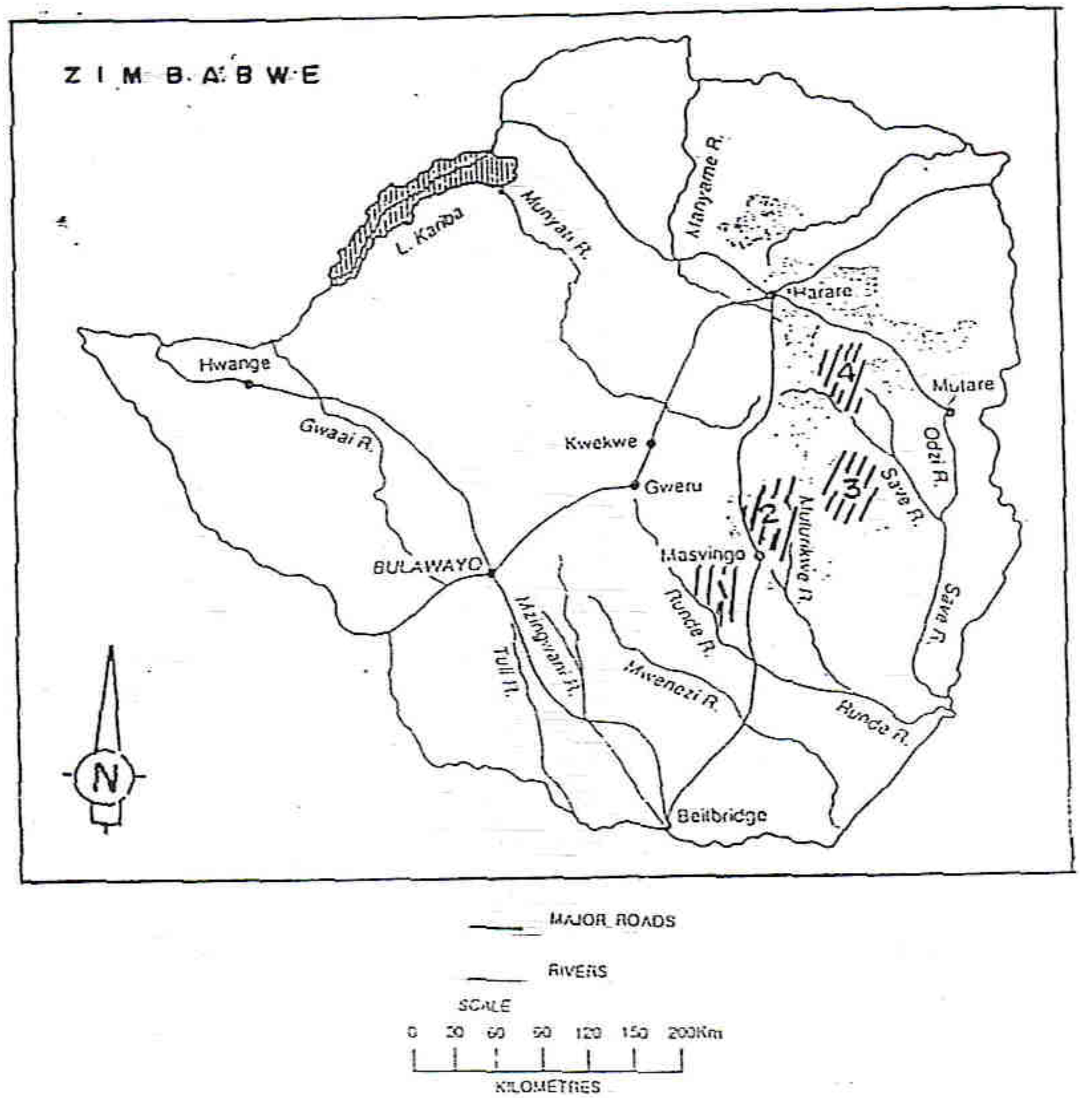
Notes: Vegetation plots and/or soil profiles have been numbered from the bottom to the top of the catena.

For example: 1 = Lowest catenal position.

6 = Highest catenal position

3.2.2 Climate

The selected study areas experience a sub tropical climate with distinct summer and winter seasons. The temperatures are generally high with averages of up to 22^{o}C. Generally, Masvingo Province has a tropical hot climate with modifying effects of altitude with



LEGEND

No.	Name	Remarks
1	Mushandike Wildlife Sanctuary	Masvingo District. Masvingo Province
2	Makoholi Research Station	Masvingo District. Masvingo Province
3	Soti Source Resettlement	Gutu District, Masvingo Province
4	Maruta Village	Wedza District. Mashonaland East Province

Figure 3.1 Location of study areas

temperatures ranging between 15^0 to 30^0C. In the hot months before the onset of the rainy season in November, temperatures can be as high as 35^o to 37^oC. The average rainfall ranges from 600 mm to 800 mm per annum. The annual rainfall pattern is very variable in amount and duration but reliability increases with elevation.

Most of the rain falls in summer between November and March. The average annual rainfall for the study areas is around 637mm per annum but the distribution is patchy (Figure 3.2). The winters are dry, occasionally with periods of 'guti', which are influxes of mist and drizzle brought in by the moist south easterly winds (Nyamapfene, 1991). Wind intensity is generally low but it increases especially during the months of August to October. For most times of the year, relative air humidity during the day is less than 50%. However during the rainy season between December and March the values for relative humidity can be as high as 70 to 80%. The morning humidity values are mostly above 80% to 90% with lowest values recorded in August, September and October between 65% and 75%.

Daily sunshine hours are high throughout the year with an average of about 8 hours. This figure increases especially between May and September. The study area can generally be placed into the iso-hyperthermic soil temperature moisture regime. The mean annual soil temperature (MAST) is about 22^oC or higher at 50cm depth and annual differences in soil temperatures are less than 5^oC (Anderson *et al.,* 1993).

Soil moisture in the study areas is within the aridic and ustic soil moisture regime indicating limited availability throughout the year (Anderson *et al*., 1993). At some localised sites such as along vleis or dambos and on shallow and compact soils, aquic and aridic soil moisture regimes can be encountered, respectively.

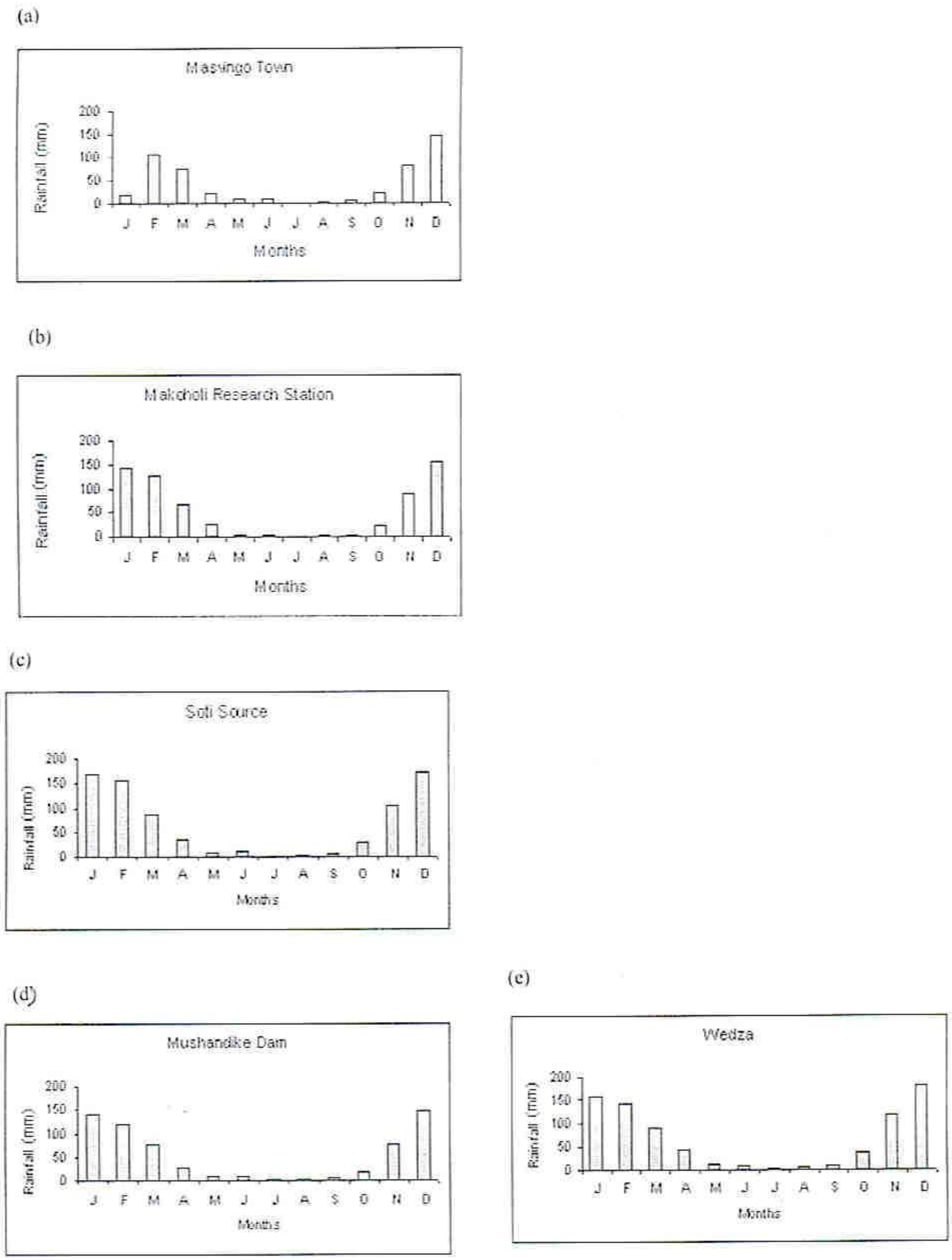


Figure 3.2 Rainfall patterns (monthly means) for (a) Masvingo town (b) Makoholi Research Station, (c) Soti Source Resettlement, (d) Mushandike Wildlife Sanctuary (e) Wedza and based on 30 years rainfall data from July 1941 to June 1971. Department of Meteorological Services, (1977).

3.2.3 Agro Ecological Regions

Masvingo Province falls within agro-ecological regions III and IV (Vincent and Thomas, 1960) (Appendix 3.1) with low and unreliable rainfall. The province is recommended for extensive farming systems based on fodder and limited food production with extensive livestock production. The province is also within agro climatologically zones III, IV, V, and VI where effective rainfall probability levels are very low (Bernardi and Madzudzo, 1990b). Wedza in Mashonaland East Province falls partly within agro ecological II and III where both intensive and extensive farming systems are practised. Agro-climatologically, Wedza falls within zone II where rainfall probability levels are higher than the other study areas in Masvingo Province (Bernardi and Madzudzo, 1990b).

According to this agro-climatological classification, all the study catenas found in Mushandike Wildlife Sanctuary and in Makoholi Research Station are located in agro-climatological zone IV whilst those catenas found in Wedza and in Soti Source Resettlement and are located in agro-climatological zones II and III respectively.

3.2.4 Landforms and Geology

The study areas fall within the southern highveld and the southeast middleveld with elevations between 900 m to 1200 m and 600 m to 900 m above sea level respectively. Topography is gently undulating to rolling with common rock outcrops and dissections. The major landform features in the study areas are a result of cycles of weathering and erosion (Anderson *et al.,* 1993) and fall within the Post-African Erosion Cycle (Lister, 1978). They are characterised by moderate slopes, steeper on the south east than the north-west and are dissected and weathered, producing inselbergs and castle kopjes. Extensive parts of the study areas found in

Mushandike wildlife Sanctuary, Makoholi and soti source resettlemennt in Gutu consist of the basement complex rocks containing predominantly granitic gneissic rocks, granites and other rocks including great dyke intrusions and Aeolian sands with highly variable mineralogy (Stagman, 1978).

In Mushandike, basement complex rocks comprise schists and granites consisting of banded gneisses, which have been reworked during successive cycles of folding, metamorphism and granitisation (Stagman, 1978). Banded gneisses consist of alternating dark and light coloured granitic rock layers which vary in thickness from a fraction of a centimetre to several centimetres with quartz and sodic plagioclase feldspar as dominant minerals. Within the main mass of the granite is the quartz monzonite, which occurs in and around Mushandike Wildlife Sanctuary. This includes some of the well-jointed rocks that give rise to impressive kopjes. This type of granite (Mushandike granite) exhibits gradational transition and sharp contacts; gradational transition from gneisses to massive granite with increase in microcline. Exposures within the transition zones are biotite-rich granodiorites, which appear to have formed from the re-crystallising of the gneisses (Stagman, 1978).

In Gutu, over 80% of the study area is underlain by basement complex rocks with numerous dolerite sills and micro-gabbros. These rocks have been extensively invaded and disrupted by various granitic rocks namely tonallites, granodiorites and adamellites (Loxton and Associates, 1971; Anderson *et al.,* 1993) giving rise to flatter topography. The adamellites that occur in this area are medium to coarse grained, well-jointed rocks and have led to prominent relief in the form of large rounded hillocks and castle kopjes.

In Wedza, the entire study area (Maruta) is underlain by gneiss and granites of the basement complex rocks (Stagman, 1978). In all the study areas, granites and gneisses are characterised by a mixture of predominantly quartz, feldspars and micas in variable proportions. A summary of the geological successions in Zimbabwe with dominant rock types is provided in Appendix 3.2.

3.2.5 Soils

The nature and distribution of soils is closely related to the geology, climatic regime and topography (Thompson and Purves, 1978). Hence granitic rocks which cover over 90% of the provinces form the major parent materials of the most dominant soils in the study areas. Soils are moderately shallow to moderately deep or deep, coarse textured sandy soils with sub soils that range between coarse sand and sandy clay. Soil texture is related to granitic rock mineralogy and topography of the site than to the amount of rainfall causing weathering (Purves, 1976).

According to the Zimbabwe Soil Classification System (Thompson and Purves, 1978), soils in the study areas are classified under Fersiallitic (5G) and Siallitic (4G) families of the Kaolinitic Order. The soils are by moderately to strongly leached with clay fractions that contain 1: 1 lattice clay minerals such as kaolinite and with variable amounts of free sesquioxides of iron and aluminium (Nyamapfene, 1991). A Zimbabwe soil classification summary and symbols used to denote parent material are provided in Appendices 3.3, 3.4 and 3.5.

3.2.6 Vegetation physiognomic types and dominant species

Savanna is the most dominant vegetation type in Zimbabwe (Wild and Barbosa, 1968) and the physiognomy and species composition are largely determined by rainfall pattern and soil type (Timberlake *et. al*., 1993). This vegetation type has also been classified as savanna woodland covering about 53 % of the total area of Zimbabwe (VegRIS, 1998). Although there seems to be little undisturbed natural vegetation that remains due to clearing for agriculture in many areas especially in communal areas, some relatively undisturbed natural vegetation communities can still be found in some commercial farm land, resettlement and designated wildlife areas.

In Makoholi the most dominant vegetation physiognomic type is Tree Bush Savanna (TBS) with a continuous or discontinuous grass cover depending on the soil moisture regime. The woody vegetation is dominated by *Brachystegia spiciformis* and *Julbernardia globiflora*, a type classified as miombo woodland (Campbell *et al.*, 1988). In addition, These species are mostly found on dry and well drained middle slopes and / or on upland soils derived from granitic rocks. In moist upland sites, invariably *Parinari curatellifolia* can be found either in pure stand or in combination with *Burkea africana* and *Terminalia sericea*. Vlei or dambo grassland forms an important component of the landscape as part of a well developed soil vegetation catena which extends from upland crests to vleis.

In Mushandike Wildlife Sanctuary the dominant vegetation type is similar to that of Makoholi in the uplands but different in species composition in the lower parts of the landscape where dryland species such as *Colophospermum mopane, Combretum adenogonium* and *Euclea divinorum* are common. Tall *Brachystegia boehmii* are found in association with shallow soils derived from dolerite, or with granitic soils that have evidence of dolerite intrusions.

In those study areas found in Gutu (Soti Source resettlement) and Wedza (Maruta village), vegetation types there are distinct vegetation patterns of TBS and Grassland Savanna (GS) physiognomic types between uplands and lowlands respectively mainly influenced by topography and soil moisture. In these areas, on uplands, vegetation is dominated by *Brachystegia* and *Julbernardia* savanna woodland with many variants as influenced mainly by topography, soil, climate and human disturbance. In the wet and poorly drained lowlands the vegetation physiognomic type is dominated by a continuous vlei Grassland Savanna (GS) with scattered woody species of *Syzigium* and *Ficus* with clumps of woody species on termitaria.

3.3 GENERAL RESEARCH METHODS

3.3.1 Materials used for vegetation and soil measurements

Existing geological, soil and vegetation maps at the scale of 1 : 1 000 000 as well as the most recent 1985 black and white air photographs for the respective study areas were obtained from the Department of Surveyor General department in Harare. In addition, other natural resources survey information such as previous soil reports for the proposed study areas were collected from the Department of Agricultural Research and Extension (AREX). Recent Landsat TM False colour satellite images for each study area were obtained from VegRIS Project of the Forestry Commission in Harare.

For vegetation sampling and measurements (Section 3.3.6), stereoscopes, measuring tapes, ranging rods, abney levels and pegs were used in the field. Other materials such as 1 x 1 square metre frames for assessing grass species and presses for preserving vegetation specimens in the field were also used. For soil assessments and sampling (Section 3.4), soil augers, picks, shovels, spades, pH meter, soil sample bags and other field equipment were used in the field.

3.3.2 Interpretation of satellite images and air photographs

Preliminary Landsat TM images in bands 4, 5 and 3 at a scale of 1:50 000 for each study area were ordered from Forestry Commission in Harare. These were analysed to give overview vegetation scenes of the study locations according to variability of the vegetation. These multi band false colour images were subjected to a series of visual interpretations based on differences in colour and in accordance with guidelines described by Landon (1984)

and VegRIS (1998). Thus, continuous patterns of bright red, dark red, dark reddish yellow indicative of woody vegetation cover types were initially marked off on the satellite image and confirmed in the field. The advantage of using satellite images was that an appreciation of spatial variation in land cover types for large catchments could be made visually and simply from image colour differences in the respective study areas thus making it a quick method of pre- selecting areas for more detailed investigations. Although visual assessment of satellite images had limited value due to the poor resolution, satellite images were very useful initially as a guide for assessing variability of vegetation cover in large areas at a glance during the reconnaissance survey phase.

Existing air photo coverage of the respective areas was obtained from the Departments of AREX and the Surveyor General for stereoscopic examination. Analysing stereo pairs with the aid of a portable mirror stereoscope enabled the identification of representative catenas and study catchments. For each catchment, the most recent (1985 coverage) low altitude, high resolution panchromatic aerial photographs at a scale of 1: 25 000 were used to identify vegetation structural patterns in physiognomic units or strata as viewed under a stereoscope. These physiognomic units were later delineated on air photographs and then perceived as different vegetation types or communities, the boundaries between which were drawn from the changes in tonal and textural patterns as described in Dent and Young (1980). Where the boundaries were difficult to identify, breaks in slopes, as perceived from the air photo analyses, were used as boundaries wherever possible. These boundaries were confirmed in the field making appropriate adjustments where necessary. In principle, preliminary air photo interpretation can usefully come before fieldwork. However, in this study, the two were carried out simultaneously or at least interactively in each study area to save time and costs. The fundamental vegetation characteristic of structural importance used as the mapping unit and as a basis for sampling along the catena was the vegetation physiognomic type.

3.3.3 Selection of study areas and representative catenas

With the aid of existing geology map of Zimbabwe at the scale of 1 : 1 000 000 (Stagman, 1978) and other geological reports specific to each site, study catenas were initially identified marked off on the maps and aerial photographs. They were then identified in the field within the granite. From all the study areas shown (Figure 3.1), a total of nine representative catenas were identified (Table 3.1).

All study areas constituted catchments or micro catchments where natural vegetation had been ostensibly unaltered by man. In addition, the selected areas showed wide ranges of vegetation physiognomic variation that could easily be identified as homogeneous vegetation types.

3.3.4 Mapping of vegetation physiognomic types

For each study site marked off on topocardastral Surveyor General (1980) maps at the scale of 1 : 50 000 and on air photographs at the scale of 1 : 25 000, more detailed stereo analysis of the air photo vegetation physiognomic types identified above was done. The analysis was then transferred on air photo double enlargements (x 2 magnification) at a scale of about 1 : 12 500 and finally on controlled photo mosaics at the same scale as double enlargements. These mosaics were then used to produce vegetation physiognomic classification maps on tracings or transparent paper overlays as done by AREX topographic section. Scale adjustments were done using a planevirograph with the aid of topographic base maps prepared from 1:50 000 topocardastral Surveyor General (1980) maps.

At this stage, all available secondary information on topography, geology, soils, vegetation and other relevant natural resources survey reports for the respective areas and similar adjacent areas were consulted. Vegetation maps at scales ranging from 1:6 250 and 1 ; 50 000 accompanied by detailed legends were produced from the air photo features inferred and confirmed ground characteristics for each study area.

3.3.5 Determining the minimum vegetation sampling area

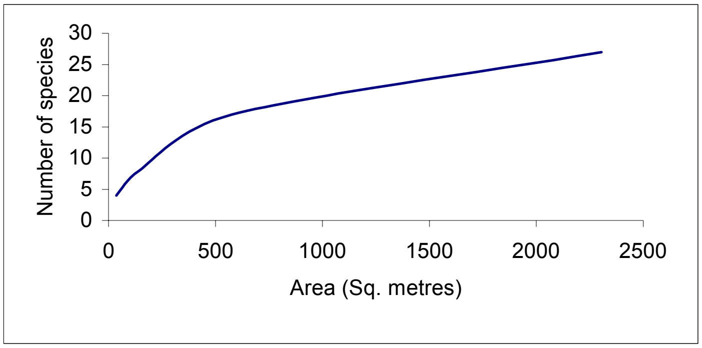
Before vegetation measurements were done in the field, important aspects of sample size needed to be considered first. Initially a small area of 5 m x 5 m was lined up at a site and all woody species that occurred within this area were enumerated and recorded as shown in Table 3.2. The sample area was enlarged to twice then successively increased until additional increments in the area did not yield additional increase in the total species. Additionally occurring species for each enlarged area were listed separately and the number of observed species was recorded as a cumulative total (Table 3.2).

The number of species was then plotted against the size of the sample area. The minimum sampling area was taken as that sample area at which initially the steeply increasing curve became almost horizontal (Figure 3.3). A full description of the procedures involved is provided by Mueller Dombois and Ellenberg (1974).

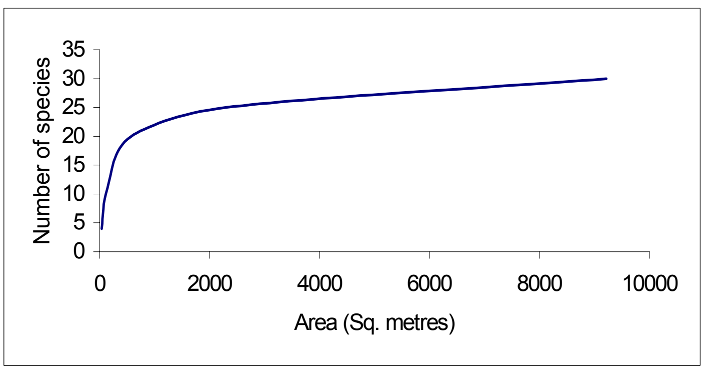
Table 3.2 Species - area data recorded in Chikungurugwi used for determining minimum sampling areas in study areas (Similar data from other sites is provided in Appendix 3.5 c)

Sample Plot No.	Size (Sq. metres)	Species in plot 1 and additionally occurring in other plots	Cumulative total
1	25	*Brachystegia spiciformis*	3
		Lannea disclor	
		Combretum molle	
2	100	*Monotes glaber*	7
		Peltophorum africanum	
		Acacia nilotica	
		Lecaniodiscus fraxinifolius	
3	225	*Terminalia serecea*	11
		Julbernardia globiflora	
		Maytenus senegalensis	
		Burkea africana	
4	400	*Grewia flavescens*	18
		Pterocarpus rotundifolius	
		Diospyros lycoides	
		Lannea stuhlimannii	
		Securinega virosa	
5	625	None	18

(a)



(b)



.(c)

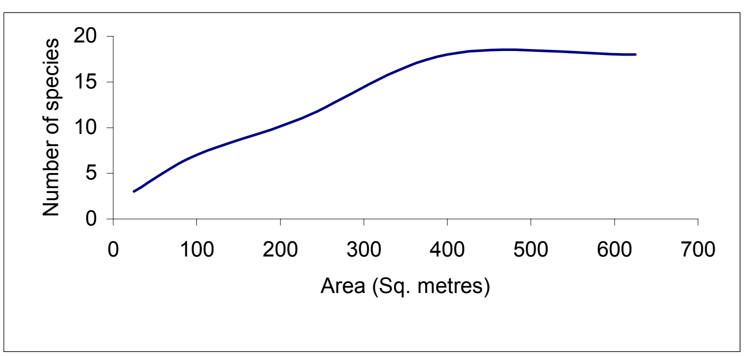


Figure 3.3 Graphs showing species area curves for sites at the (a) top (b) middle (c) bottom of Chikungurugwi catena in Makoholi Research Station. The minimum sample area was determined as that area at which initially the steeply increasing curve became horizontal (Mueller Dombois and Ellenberg, 1974).

3.3.6 Vegetation sampling

Homogeneous vegetation communities already recognised along the catenas in each study area and mapped as described in Section 3.3.4 were used as a framework for sampling. Sampling plots within each homogeneous community were identified with the aid of air photo interpretation coupled with field checking and then marked out on the mosaics and maps produced as already described in section 3.3.4.

An appropriate strategy of purposive sampling of vegetation in plots along the catena was followed. This initially involved the location of plots by visually assessing trees within a plotless area of up to 0.5 ha to obtain more representative sample plots. This was followed by lining up of plots in each vegetation physiognomic type along a catena using 50m tapes and surveying ranging rods as corner posts that were visible from a distance.

The sample plot size of 20 m x 20 m (0.04 ha) for woody species (Frost, 1995) was used. This area corresponded to the minimum sampling size (Figure 3.3) determined as described in Section 3.3.5. Vegetation characteristics that include species composition, species height, canopy cover, density, basal and breast height circumference were measured. One plot was assessed at each site with a homogeneous vegetation community along the catena. Only one plot was regarded as sufficiently representative for each vegetation type along the catena. All plots were purposively located where the vegetation community appeared to be most typically represented.

The identification of tree species was made with the aid of diagrams, pictures and descriptions as given by Palgrave (1988). Specimens of woody plant species that could not be identifiable in the field were collected, clearly labelled and preserved for identification at the National

Herbarium in Harare. In addition, local people were consulted to provide local names of the plant species.

Detailed vegetation enumeration and measurements were then done during the rainy season between November and March when all the vegetation was green and in flower thereby making plant species identification easier. Each plant species identified was recorded individually using its botanical name. The vegetation classification system and nomenclature used were that developed by Pratt *et al*., (1966) and Palgrave (1988) respectively.

The total number of individuals of each woody species were counted and recorded in the different height classes as follows: trees > 3 m, bushes 0.5 – 3 m and shrubs < 0.5 m as used by Nobanda (1992). Thereafter, the following measures of structural importance of vegetation species were assessed as already indicated above.

(i) Species maximum height

The maximum height of trees was measured using 5 metre graduated wooden poles and surveyor's vertical staff. In certain cases where this equipment was inadequate, an abney level and measuring tapes were used and the height of tree calculated using trigonometry.

(ii) Diameter at breast height (DBH)

The maximum circumference at breast height of the largest frequently occurring individual plant was measured using measuring tapes. DBH was then calculated from circumference at breast height.

(iii) Basal area

The circumference of the largest frequently occurring individual plant just above its stem base (0.2 m) was measured using measuring tapes and the basal cross-sectional stem area of the individual species was then calculated from the circumference measurements.

(iv) Canopy cover

Canopy cover is defined as the percentage of sample area beneath the canopy of a given species (Frost 1995).

Table 3.3: Braun Blanquet cover abundance scale

Percent (%) canopy cover	Abundance value
<1	0
1 – 10	1
10 –25	2
25 – 50	3
50 – 75	4
75 – 100	5

Notes: Modified from Mueller-Dombois and Ellenberg (1974).

The projected canopy cover of individual species was visually estimated using the Braun Blanquet scale (Mueller-Dombois and Ellenberg, 1974) shown in Table 3.3 as used by Nobanda (1982) in the three height classes already mentioned above. Starting with the most dominant woody species the percentage of the total sample area under canopy cover of the respective species was visually estimated and assigned an abundance value shown in Table 3.3.

These cover abundance estimates gave an indication of the structure as well as the relative abundance of plant species in the plot.

(v) Grass cover

Similar to woody vegetation, identification of grass species was also made with the aid of diagrams, pictures and descriptions as given by Biegel and Mavi, (1972) Specimens of grass species that could not be identifiable in the field were collected, clearly labelled and preserved for identification as for woody species.

Dominant grass species within 1 m x 1 m plot were also recorded. As already explained for woody species, each grass plant species identified was recorded individually using its botanical name during the same period for easy identification. Grass species richness for each community was determined as the number of occurring in the vegetation plots.

3.4 SOIL INVESTIGATIONS

3.4.1 Selection of soil profiles and their description

Following the air photo analyses and field confirmation of vegetation physiognomic types and the subsequent mapping units as described in Section 3.3.4, representative soil profile sites were chosen within the homogeneous vegetation types. To identify a representative soil profiles site, a series of soil auger holes were made within the vegetation type along a catena transect cutting across all vegetation types to assess differences in soil depth, texture and colour, and to identify and confirm soil boundaries. At least 15 soil auger holes were drilled depending on the change in the vegetation and the length of the catena. Care was taken in the selection of representative soil profiles by avoiding eroded areas, rock outcrops, animal tracks, termitaria and road edges. These profile sites were marked on the air photo mosaics, maps and on the ground using pegs for easy identification during digging. Soil profiles of at least 100 cm deep (where ever possible) and about 100 cm square were dug using a pick, mattock and shovel between February and September when the soil was sufficiently moist and therefore easy to work. The sides of the pit were smoothened with a spade and then cleaned to expose different soil horizons. A total of 41 representative soil profiles identified along the catena in the study areas were selected. These profiles were distributed according to changes in vegetation physiognomy and species composition along each catena. A diagrammatic representation of profiles along a catena in Mushandike Wildlife Sanctuary is shown in Figure 3.3. The soil profiles were described (Appendices 4.1 and 4.2) and sampled following guidelines by Bennett (1985). Site and soil characteristics including roots distribution were recorded in accordance with FAO – ISRIC soil database format (Appendices 3.6 to 3.7).

3.4.2 Measurement of land slope

The slope of the land was measured using an abney level following the procedure normally used by the AREX department of the Ministry of Lands Agriculture and Rural Resettlement. The slope of the land was described according to guidelines given in Table 3.6.

Table 3.4 Guidelines for assessing and classifying land slope.

Slope class	Percentage slope (%)	Description
A	0 < 2	Nearly flat
B	2 – 5	Gently sloping
C	5 – 12	Sloping
D	12 – 30	Moderately Steep
E	30 – 35	Steep
F	>35	Very steep

Notes: Modified from Bennett, 1985.

3.4.3 Assessment of drainage status and wetness regimes of the soil in the field

The drainage status and wetness regime of the soil were estimated at each site from soil morphology. With the aid of the Munsell soil colour charts, mottles down the profile were used as indicators. The classes and guidelines for assessing drainage and wetness regime in soils are given in Tables 3.5 and 3.6.

Table 3.5 Practical guidelines for assessing drainage status in the field.

Drainage class	Drainage status	Description
D1	Very poorly drained.	Wet for a large part of the year. Colours are neutral or pale greys, blues, olives and greens with little mottling due to almost total reduction or depletion of iron. Organic matter accumulates at the surface and iron staining may occur in root channels.
D2	Poorly drained	Regularly subject to alternating oxidising and reducing conditions, due usually to a fluctuating water table. The matrix is pale in colour with low chroma, and contrasts strongly with frequent, well-developed iron segregation mottles. Root channel staining may occur.
D3	Moderately poorly drained.	Subject to partial waterlogging irregularly for periods of short duration, more often because of poor permeability rather than a fluctuating water table. Iron segregation mottles are small, occupy a low surface area or do not contrast strongly with the matrix.
D4	Moderately well drained	Some colour variegation not definable in terms of mottling. Lower subsoil horizons may be slightly paler than those below.
D5	Well drained.	Most medium to fine soils with no colour changes indicative of wetness.
D6	Very well drained	Soil with permeability class 6 and no colour changes indicative of wetness.
D7	Excessively well drained.	Soil with permeability class 7 and no colour changes indicative of wetness.

Table 3.6. Practical guidelines for assessing soil moisture regimes used by AREX Department extension officers of the Ministry of Lands Agriculture and Rural Resettlement in the field.

Symbol and soil moisture regime	Description	Significance
W1	Wet for relatively short and infrequent periods	Choice of crop affected; some interference with farming operations
W2	Frequently wet for considerably long periods during the rainy season	Choice of crop limited; interference with farming operations
W3	Very wet for most of the season, vlei (dambo) area	Normal cropping operations precluded; sometimes suitable for rice or selected pastures

Ministry of Agriculture, (1981)

3.4.4 Assessment of erosion intensity of the soil in the field

Observable erosion was visually assessed at each site following procedures normally used by AREX officers if the field. Erosion intensity was estimated using the classes and guidelines given in Table 3.7.

Table 3.7 Practical guidelines for assessing soil erosion in the field resulting from man made or natural factors or a combination of the two used by AGRITEX Department extension officers of the Ministry of Lands Agriculture and Rural Resettlement in the field

Erosion class symbol	Description
E1	No apparent, slight erosion
E2	Moderate erosion: moderate loss of top soil generally and /or marked dissection by runoff channels or gullies
E3	Severe erosion: severe loss of top soil generally and/or marked dissections by runoff channels or gullies
E4	Very severe erosion: complete truncations of soil profile and exposure of subsoil (B horizon and/or deep intricate dissections by runoff channels or gullies

Ivy, (1977) p38.

3.4.5 Estimation of root abundance in soil profiles

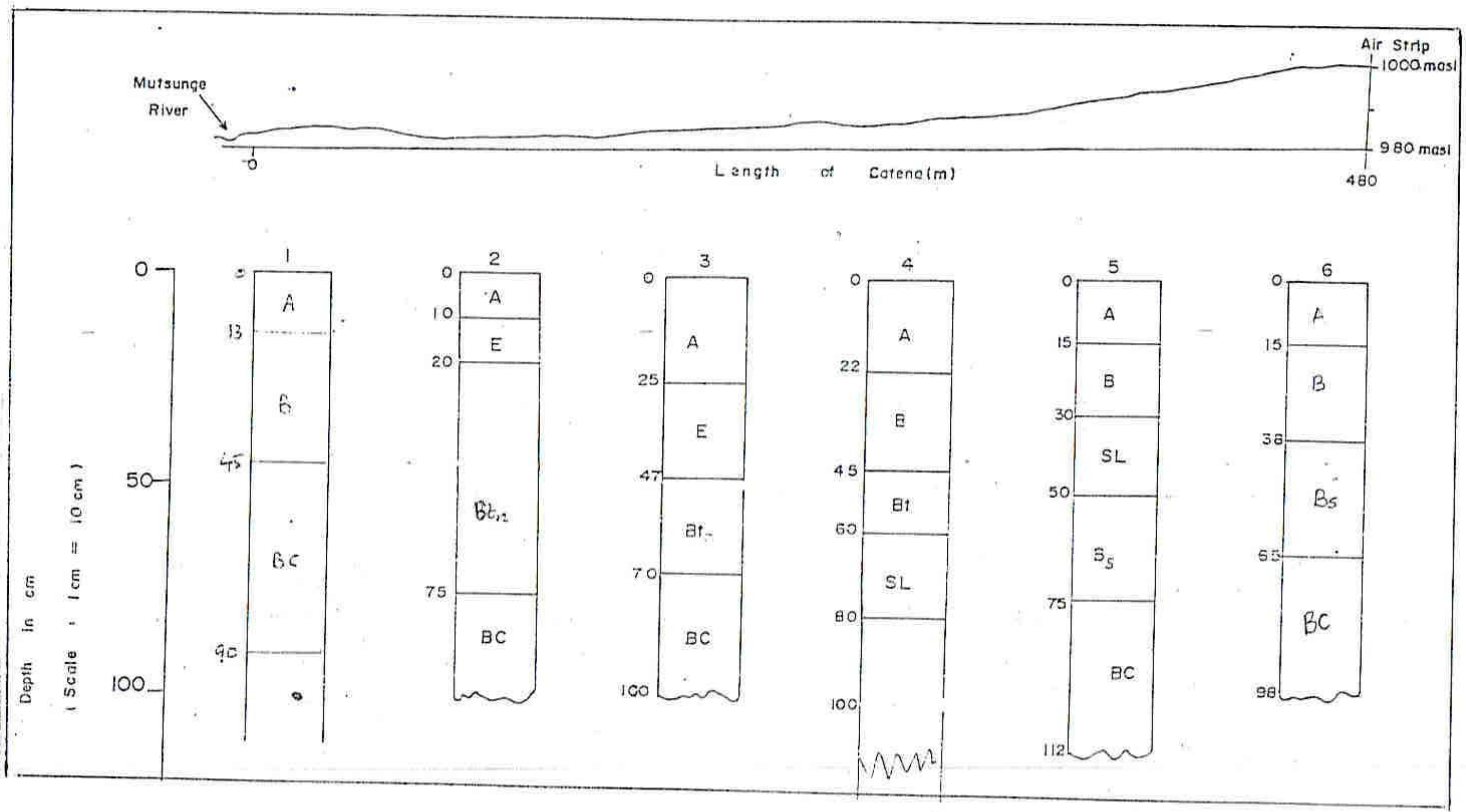
In all catenas, a general visual assessment of roots was made for the different size classes (Table 3.8) using the terms: nil, occasional (o), few (f), fairly numerous (fn), numerous (n) and very numerous (vn) as given in Bennett, (1985). In addition, detailed enumeration of roots were done in only two catenas namely Mutsungwe (MU) and Chikungurugwi (CH) which were regarded as representative catenas because they contained the three major soil groups (Siallitic, Fersiallitic and Sodic) and vegetation physiognomic types (TBS, BS, and GR) that were identified throughout the study area.

In these catenas, (MU and CH) roots populations were estimated using the vertical profile method. This involved identifying and marking off soil horizons on the vertical profile face followed by enumeration of roots according to their size classes (Table 3.8) in areas of about 10 cm square. This was achieved after carefully plucking back the profile about 5 mm with a knife to expose the roots. In addition, for comparison, root abundance was also estimated using the "Trench" profile method. This method initially involved cleaning up the top surface soil layer on the side of the soil profile with a spade to expose roots on the horizontal surface of the A horizon. There after, trenches in a step wise manner were successively dug to expose the top layers of horizons thereby exposing roots for enumeration.

Table 3.8 Root size classes in diameter (mm) used for the assessment of root size and abundance.

Diameter (mm)	Size description
<1	Very fine (vf)
1 - 2	Fine (f)
2 - 5	Medium (m)
>5	Coarse (c)

Source: Bennett, 1985.



Notes: A = Top soil; B = Subsoil; E = Albic horizon (bleached); Bt = Subsoil with clay accumulation; Btn = Subsoil with clay and sodium accumulation; Bs = Subsoil with sesquioxides of iron and aluminium accumulation; SL = Stone-Lime; BC = Saprolite

Figure 3.3 Diagrammatic representation of soil profiles along Mutsungwe (MU) catena in Mushandike Wildlife Sanctuary.

3.4.6 Soil sampling and preparation

Soil sampling was done by horizons, along the catenas, according to observed patterns of vegetation and soils. About 2kg mass of soil from each horizon was carefully collected from the middle of the horizon in clean and uncontaminated plastic bags using a geological hammer and a spade. On - site pH tests were made using an electronic soil pH meter to identify similarities so as to reduce number of profiles and soil samples requiring detailed analyses and study. This was also done as a routine check for apparent uniformity in soil chemical changes along the catena inferred from soil pH.

Two types of samples namely disturbed and undisturbed core samples were collected. Disturbed samples from the field were air dried at room temperature. Undisturbed soil samples were collected using core rings of 100 cm^3 and 250 cm^3 for soil moisture determinations and for bulk density measurements, respectively, in accordance with British Standards Institute (BSI) (1975). Two bulk density samples were collected from the middle of the B horizon of each profile. A total of 82 soil cores were collected and prepared for laboratory analysis.

3.4.7 Laboratory analysis of soil samples

For all soil laboratory tests, analysis of the fine earth passing through the 2mm sieve and expressed on an oven dry basis were done. The sand fractions namely fine, medium and coarse as well as the silt fraction were determined using the sieve method.

Clay content was determined using the hydrometer method (Gee and Bauder,1986). Bulk density was calculated from volume of soil cores and oven dry-mass of soil cores. The hanging water column technique was used to measure water tension (Hall, 1991). Water retention data were obtained by the pressure membrane extraction method (Klute, 1986). Available water capacity (AWC) was calculated as the difference in moisture at 0.1 bars (field capacity (FC)) and at 15.0 bars (permanent wilting point (PWP)).

Soil pH was determined using 1:5 0.01 M $CaCl_2$ soil suspension. Cation exchange capacity (CEC) by saturation of soil with 1 M CH_3COONH_3 buffered at pH 5.2. Organic carbon was determined by the modified Walkley and Black method (Houba *et al.,* 1989) with additional heat applied under reflux. Although this method has been noted (Nelson and Sommers, 1982; Nyamangara *et al*., 2001) to result in variable recovery of organic carbon, however, it is frequently used by many workers in Zimbabwe where soil organic carbon in most soils does not exceed 1% (Mugwira *et al*., 1992).

CHAPTER FOUR

SOILS AND VEGETATION PHYSIOGNOMY ALONG CATENAS ON GRANITE IN SEMI ARID AREAS OF ZIMBABWE

4.1. ABSTRACT

The aim of this chapter was to summarise the data and correlate important vegetation and soil characteristics in order to gain an understanding into the relationship between the two so as to improve prediction of soil type.

Vegetation was classified and mapped in terms of physiognomy and described in relation to four soil groups namely Siallitic (4G) Fersiallitic (5G) Fersiallitic (5GE) and Sodic (8N) that were identified. Data on soils and vegetation was analysed using the SPSS statistical Package. In addition the Least significant Difference (LSD) test at $p \leq 0.05$ was used to assess differences in soil characteristics between A, B and BC horizons in catenas when ANOVA indicated a significant F-value.

The results showed that soils of the study areas there were relatively small variations in % clay and pH and other related physical and chemical characteristics. Results from an ANOVA of %clay and soil pH in the majority of catenas in study areas did not show any significant difference between A, B, and BC horizons at $p \leq 0.05$ except for a few catenas. An inverted Ca to Mg ratio was observed in the sandy soils especially under leaching conditions in upland sites and lowland sites.

The results also showed that the most commonly occurring vegetation physiognomic types in the study areas were TBS and / or TS in middle slopes and upland hills associated with Fersiallitic (5G) and Siallitic (4G) soils. This was followed by BS in dry lowlands associated with Sodic (8N) soils and GS or BS or TBS in wet lowlands (dambos), flat areas or middle slopes associated with Fersiallitic (5G) soils and / or vertisols.

Of the vegetation characteristics assessed in the study areas, species richness was most significantly correlated to soil drainage ($r = -0.53$), soil erosion status ($r = -0.45$) as well as clay content ($r = 0.20$), CEC ($r = 0.37$), ESP ($r = 0.71$), all in the B-horizon at $p < 0.01$, and bulk density of the soil in the A-horizon and B-horizon at $p<0.05$ significance level. There was no significant correlation between species characteristics measured and soil moisture content as represented by available water capacity (AWC) of the soil.

4.2 INTRODUCTION

The most extensive soils occurring in Mushandike, Makoholi, Gutu and Wedza are derived from granite rocks. These rocks comprise a group of heterogeneous intrusive rocks of various ages (Appendix 3.2) and mineralogy (Stagman, 1978). The geological complexity of the rock (granite) has led to a high variability of soils found in the study areas (Nyamapfene, 1991).

Through different processes of weathering, some granite rocks have given rise to soils which are more prone to clay eluviation and water logging in low lying areas known as vleis or dambos. However, field experience has shown that granite soils are light to medium textured, characterised by significant amounts of coarse sand. The soils are usually yellowish to reddish brown in well-drained topo-positions and yellowish grey to greyish brown in poorly drained topo-positions.

The majority of the study areas on granite are covered by natural vegetation that is very diverse (Timberlake *et al.,* 1993) especially where the catena is well developed. The most common vegetation type has generally been referred to as miombo woodland. This is a savanna vegetation type dominated by *Brachystegia spiciformis, Julbernardia globiflora* and a mosaic of other species that include *Combretum, Monotes, Parinari, Terminalia* species and *Colophospermum mopane,* the later especially in lower topographic positions.

The interesting associations between granites and savanna vegetation types have attracted great attention and enthusiasm for further investigations by many workers on savanna vegetation (Cole, 1982; Timberlake *et. al*.,1993). This chapter forms a foundation upon which more detailed investigations of relationships between vegetation characteristics, land qualities and soil characteristics, in the selected study areas along catenas, were based.

4.3 OBJECTIVES

The major objectives of this chapter are as follows:

4.3.1. To assess changes in soil characteristics along the catena on granite and explain them in relation to the catena continuum concept.

4.3.2. To classify soils according to observed morphological, physical and chemical properties using the Zimbabwean Soil Classification System.

4.3.3. To assess, analyse and describe vegetation physiognomic structure and species composition along catena gradients in relation to important land qualities and soil characteristics.

4.3.4. To correlate woody vegetation species characteristics with land qualities and soil characteristics that are most important in sandy soils found in semi arid areas.

4.4 HYPOTHESES

4.4.1. Soils of the study areas do vary with vegetation along the catena.

4.4.2. There is a significant correlation between vegetation distribution, species abundance and soil % clay, soil pH, CEC, ESP, soil drainage and erosion status in the study areas on granite.

4.5 METHODS

4.5.1 Vegetation classification

For each study area vegetation was classified and mapped according to physiognomy and species composition using guidelines laid down by Pratt *et. al.,* (1966), Bennett, (1985) and the Ministry of Agriculture, (1981) as already described in Chapter Three under Section 3.3.4. Maps and tabulated legends were produced together with detailed descriptions of vegetation in relation to soils.

4.5.2 Soils

Methods for the preparation and analyses of soil samples in the laboratory have already been described in Chapter 3, Section 3.4.5.

For data analysis, the least significant difference (LSD) test at $p \leq 0.05$ was used to assess differences in soil characteristics between A, B and BC horizons in catenas when ANOVA indicated a significant F-value. As a measure of the variability in soil characteristics in catenas, the coefficient of variation (CV %) was calculated.

The Spearman Product Moment Correlation in SPSS statistical Package (SPSS Inc., 1988) was used to assess correlations among vegetation species abundance and site as well as soil characteristics. These included topography, slope, drainage status and erosion intensity % clay, roots abundance, pH, CEC, ESP and Ca to Mg ratio, bulk density and Available Water Capacity (AWC).

4.6 RESULTS

4.6.1 Soil morphology

Soil analytical data and profile descriptions are shown in Tables 4.13 to 4.16 and in Appendices 4.1 and 4.2.

At Navik Bay and Mutsungwe in Mushandike Wildlife Sanctuary for example, soils at the top of the catena were found to be shallow (40 -50 cm deep) to moderately shallow (50-100 cm deep), weakly developed loamy sandy soils. These soils are loose and granular in structure, non-plastic and non-sticky consistence over the whole of their depth. The colour (moist) of the soil ranges from dark yellowish brown (10YR 3 / 4) in the surface horizon to yellowish brown in the lowest horizon. In the B-horizon, they are few, fine to coarse gravel or small stones of sub- rounded quartz. The thickness of the gravel layer varies with position on the catena. The horizon boundaries are diffuse and broken and the soil has a horizon sequence of A-B-BC that is typical of Siallitic(4G) soils (Zimbabwe Soil Classification, after Thompson and Purves, 1978). or Luvisols (FAO/UNESCO Soil Classification, FAO,1988).

At the bottom of the catenas (in Mushandike Wildlife Sanctuary) are moderately deep (100-150 cm) well developed heavy clay soils with a sandy surface layer (0-15 cm). These soils have a granular structure and a moderate to strongly angular blocky structure in the Bt-horizon (with illuvial clay accumulation) that changes to columnar structure with depth. It has a high amount of fine pores and a colour (moist) ranging from yellowish brown (10 YR 5 / 5) in the surface to dark yellowish brown (10 YR 4 / 3) in the sub-soil horizons. Roots are few, fine to medium in the surface horizon becoming occasional and very fine in the subsoil.

The soil is plastic and sticky and this tends to increase with depth, with a horizon sequence of A-Btn-BC (Btn-horizon with illuvial clay and sodium accumulation) that is typical of a sodic soil (8N) using the Zimbabwe Soil Classification, (Thompson and Purves, 1978).

In Chikungurugwi (Makoholi Research Station), soils found at the top of the catena are moderately deep to deep (100-150 cm), weakly developed loamy sandy soils, which are soft and friable with a granular structure, and are non-sticky and non-plastic over the whole of its depth. Soil colour (moist) ranges from dark yellowish brown (10 YR 4 / 3) in the topsoil to yellowish brown (10 YR 5/ 5) in the sub soil. There are fairly numerous fine to medium roots in the surface soil which change to numerous but fine to very fine roots in the sub soil. The soil has a horizon sequence of A-B-BC that is classified under Fersiallitic (5G) soil (Zimbabwe Soil Classification, after Thompson and Purves, 1978), an Arenosol (FAO/UNESCO Soil Classification, FAO, 1988).

At the bottom of the catena are very deep (>150 cm) sandy clay soils with a granular structure in the surface horizon and sub angular blocky structure in the B-horizon. The soils are slightly sticky and plastic with depth. The colour (moist) of the soil is dark yellowish brown (10 YR 4/3) in the surface soil and changes to yellowish brown (7.5 YR 5/2) in the sub-soil. Roots are numerous very fine or fine to medium in the A-horizon but tend to be, few fine to medium iron II stained roots with depth. The soil has a horizon sequence A-B-BC of a Fersiallitic (5G) hydromorphic soil (Zimbabwe Soil Classification, after Thompson and Purves, 1978) or a Luvisol (FAO/UNESCO Soil Classification, FAO, 1988).

In Maruta (Wedza) and Agyle (Gutu Soti Source Resettlement) soil morphology at the top of catenas is similar, generally with moderately shallow to moderately deep sandy loams that are weakly to moderately developed, medium to coarse, sub angular blocky structure with a soft consistence (dry). The soils are slightly sticky and slightly plastic over the whole of their depths. Soil colour (moist) changes from light yellowish brown (10 YR 6 / 4) in the topsoil to brownish yellow (10 YR 6 / 6) in the subsoils. In the lower parts of the catenas, soil morphology changes with depth. The soils are moderate to strong, fine to medium with an angular blocky to sub-angular blocky structure that tends to be hard (dry), firm sticky and plastic with depth. Soil colour (moist) ranges between light-brownish grey (10 YR 6 / 2) to light grey or grey (10 YR 6 / 1). Similar to soils in Mushandike and Makoholi already described, horizon boundaries (in Maruta and Agyle) are diffuse and broken with a horizon sequence of A-Bt-C or A-Bt-BC that is typical of a Siallitic (4G) soil (Zimbabwe Soil Classification, after Thompson and Purves, 1978) or Luvisol (FAO/UNESCO Soil Classification, FAO, 1988).

4.6.2. Soil Texture

Generally, at the top of the catenas, surface soil texture varies from coarse sand to loamy sand in all study sites. At the bottom of the catena surface soil texture varies from sandy loam to loam. In the sub soil, texture varies from sandy loam to clay for example in Navik Bay, Mutsungwe and Up Navik Bay leading to poor permeability and drainage of the sub-soils. In other catenas however such as Chikungurugwi, Agyle and Maruta, soil texture in the sub soil is sandy loam or sandy clay loam where water-logging is common in vleis or dambos leading to poor soil aeration and plant rooting conditions.

For all catenas however, there appears to be a very narrow variation in topsoil texture (Tables 4.1 to 4.3) especially for the sand fraction.

Table 4.1 Soil depth, texture and particle size analysis of soils derived from granitic parent material along Navik bay catena (For abbreviations used see bottom of table for explanation).

Profile No.	Soil Depth (cm)	Texture	% Clay	% Silt	% Fine sand	% Medium sand	% Coarse sand
	0-15	cSaL	15	15	31	19	20
1	15-45	mSaCL	29	16	30	12	13
	45-75	mSaCL	33	15	27	13	12
	75-112	mSaCL	30	12	29	16	13
	0-12	cSaCL	9	10	34	25	22
2	12-30	cSaCL	22	10	32	16	20
	30-75	mSaCL	25	8	38	16	13
	75-100	mSaL	19	8	37	19	17
	0-10	mLS	8	6	44	24	18
3	10-18	mSaL	12	3	38	27	20
	18-80	cSaC	45	5	19	11	20
	80-120	cSaCL	28	7	22	21	22
	0-15	mLS	5	5	48	22	20
4	15-65	cLS	7	4	30	25	34
	65-100	cS	4	5	26	17	48
	0-10	mLS	4	8	51	18	19
5	10-45	cLS	5	6	36	16	37

Notes: i. cLS =coarse loamy sand; mLS=medium Loamy Sand; cSaL= coarse Sandy loam: cSaCL= coarse sandy clay loam; mSaL = medium Sandy loam; cSaC = coarse Sandy clay;
ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.2 Soil depth, texture and particle size analysis of soils derived from granitic parent material found along Chikungurugwi catena (For abbreviations used see bottom of table for explanation).

Profile	Soil Depth (cm)	Texture	% Clay	% Silt	% Fine Sand	% Medium Sand	% Coarse Sand
	0-25	cSaL	16	6	26	28	24
1	25-40	cSaL	20	8	18	25	29
	40-80	cSaCL	22	8	14	22	34
	80-102	cSaL	20	6	15	18	41
	0-26	cSaL	12	4	23	36	25
2	26-59	cSaL	12	6	22	29	31
	59-114	cSaL	14	6	22	26	32
	114-150	cSaL	12	6	18	30	24
	0-16	cSaL	12	6	22	28	32
3	16-89	cSaL	14	6	22	26	32
	0-26	cSaL	16	6	26	23	29
4	26-107	mSaL	16	6	22	28	28
	107-120	mSaL	18	4	22	23	33
	120-150	mSaCL	28	4	16	22	30
	0-12	mSaL	12	6	23	31	28
5	12-50	cSaL	14	6	22	28	30
	50-150	cSaL	10	8	23	27	32
	0-22	cSaL	12	6	18	30	34
6	22-45	cSaL	14	6	21	27	32
	45-75	cSaL	12	6	22	28	32
	75-100	cSaL	12	6	22	27	33

Notes: i. cLS=coarse loamy sand; mLS=medium Loamy Sand; cSaL= coarse Sandy loam: cSaCL= coarse sandy clay loam; mSaL = medium Sand loam; SaC = coarse Sandy clay;
ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.3 Soil depth, texture and particle size analysis of soils derived from granitic parent material found along Mutsungwe catena.

Profile	Soil Depth (cm)	Texture	% Clay	% Silt	% Fine Sand	% Medium Sand	% Coarse Sand
	0-13	cLS	5	8	13	34	40
1	13-45	cLS	8	6	12	34	40
	45-90	cLS	8	7	15	29	41
	0-10	cLS	7	10	27	26	30
2	10-20	cSaL	12	8	23	21	36
	20-75	cSaC	42	11	15	11	24
	75-100	cSaC	37	10	15	14	21
	0-25	cLS	5	9	32	30	24
3	25-47	cLS	5	7	24	17	47
	47-70	cSaCL	25	9	23	22	21
	70-100	cSaCL	25	9	23	22	21
	0-22	cLS	6	10	32	27	25
4	22-45	cLS	7	9	30	27	27
	45-80	cSaC	39	10	17	15	19
	80-150	cSaL	13	11	20	15	41
	0-15	cSa	3	7	38	28	24
5	15-50	cLS	5	10	30	25	30
	50-75	cLS	5	8	25	27	35
	75-112	cLS	4	8	21	23	44
	0-15	cS	3	8	32	27	30
6	15-38	cLS	5	9	27	26	33
	38-65	cLS	4	9	19	24	44
	65-98	cSaL	8	9	14	17	52

Notes: i. cLS =coarse loamy sand; mLS=medium Loamy Sand; cSaL= coarse Sandy loam: cSaCL= coarse sandy clay loam; mSaL = medium Sand loam; SaC = coarse Sandy clay; ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Clay content seems to increase with depth especially for soils found at the lower parts of the catena due to clay elluviation. This has lead to poor permeability and hydraulic conductivity of soils in the lowlands. In uplands for example in Makoholi, Soti Source and Maruta which receive relatively more annual rainfall than the other areas, soil texture tends to change, from medium to fine textured sandy loam or sandy clay loam with more clay content due to increased weathering intensity.

Results from an ANOVA of % clay in the study areas indicated that there were no significant difference between A, B and BC horizons in clay content for the soils at $p \leq 0.05$ except for catenas ANa and UN (Table 4.7a and 4.7b). However, in certain catenas such as those along Navik Bay catena results of ANOVA indicated that there were no significant differences in % clay at $p \leq 0.05$ between B and BC horizons but there were between A and B. (Tables 4.7a and 4.7b)

The differences in clay content of sub soils between crest and lower position of catenas have given rise to soils which exhibit a marked degree of ground water fluctuation for a considerable period during the rainy season (Tables 4.4 and 4.5). In the middle slope positions, sites with perched water table as a result of relatively restricted permeability due to increased clay content in the B-horizon and dense saprolite were observed.

Table 4.4 Clay content of soils derived from granite showing high clay content due to increased weathering from 5 profiles found in Chikungurugwi (CH), Agyle (AG) and Maruta (MA) catenas which receive more rainfall than other catenas.

Catena	Annual rainfall amount (mm)	Profile No.	%clay (B)	%clay (B)	%clay (BC)	Position of profile
Chikungurugwi	650.40	4	16	16	18	Middle slope
Chikungurugwi	650.40	6	12	14	12	Crest
Agyle	774.10	4	4	36	36	Crest
Chikungurugwi	650.40	5	12	14	10	Upper slope
Maruta	796.30	4	42	42	47	Crest

Notes: (i) % clay (A) = percentage of clay in A horizon; %clay (B) = percentage of clay in the B-horizon; % clay (BC) = percentage of clay in the BC horizon.

(ii) Annual rainfall, 30 years return period July 1941 – June 11971

Table 4.5 Soil texture description and clay content of selected soils from four catenas with poor drainage in vleis (dambo) that exhibit marked wetness for a considerable length of time in the wet season.

Catena	Soil profile symbol	Soil texture	%clayB	Soil permeability class and hydraulic conductivity	Soil drainage status
Chikungurugwi	AG1	cSaCL	22	P3 Moderately restricted permeability, 2-5 mm/hr hydraulic conductivity	D3 Moderately poorly drained
Maruta	MA1	mSaL	18	P3 Moderately restricted permeability 2-5 mm/hr hydraulic conductivity	D3 Moderately poorly drained
Agyle	AG1	cSaC	36	P2 severely restricted permeability, 0.2-2 mm/hr hydraulic conductivity	D2 poorly Drained
Mushandike River	MR1	cSaC	37	P2 severely restricted permeability, 0.2 - 2 mm/hr hydraulic conductivity	D2 poorly Drained

Notes: (i) cSaL= coarse Sandy loam: cSaCL= coarse Sandy clay loam; mSaL = medium Sand loam; cSaC = coarse Sandy clay; P = permeability; D = drainage class

(ii) For detailed description of soil drainage classes, see Appendix 4.9 to 4.11.

Table 4.6 Soil texture description and clay content of selected profiles from 6 catenas with perched water tables

Catena	Soil profile symbol	Soil texture	% clayB	Soil permeability class and hydraulic conductivity	Soil drainage status
Airstrip North a	ANa3	cSaCL	29	P3, Moderately restricted permeability, 2-5 mm/hr hydraulic conductivity	D3 Moderately poorly drained
Airstrip North b	ANb3	cSaC	48	P2, severely restricted permeability, 0.2 - 2 mm/hr hydraulic conductivity	D2 Poorly drained
Mutsungwe	MU4	cSaC	39	P2, severely restricted permeability, 0.2 - 2 mm/hr hydraulic conductivity	D3 Moderately poorly drained
Chikungurugwi	CH2	cSaL	14	P4, Slightly restricted permeability 5-9 mm/hr hydraulic conductivity	D4 Moderately well drained
Up Navik	UN3	cSaCL	30	P3, Moderately restricted permeability, 2-5 mm/hr hydraulic conductivity	D2 Poorly drained
Agyle	AG3	cSaL	14	P4, Slightly restricted permeability, 5-9 mm/hr hydraulic conductivity	D4 Moderately well drained

Notes: i. cSaL= coarse Sandy loam: cSaCL= coarse sandy clay loam; mSaL = medium Sand loam; cSaC = coarse Sandy clay; C = Clay; P = permeability; D = drainage class.

ii. For grid references of catenas see Table 3.1 and for detailed descriptions of soil drainage classes, see Appendix 4.11.

Table 4.7a ANOVA of % clay in soils found along Airstrip North a (ANa) catena in Makoholi Research Station

Source of variation	df	ss	ms	vr	F-prob
Reps stratum	3	687.00	229.00	5.88	
Reps.*units* stratum	2	547.17	273.58	7.03	0.027
Residual	6	233.50	38.92		
Total	11	1467.67			

Table of means

Grand mean	18.8		
Horizon	1.00	2.00	3.00
Mean	9.5	21.8	25.3

Table Standard errors of differences of means

Table	Horizon
Rep.	4
d.f.	6
l. .s. d.	4.41

Table Least significant differences (LSD) of means

Table	Horizon
Rep.	4
d.f.	6
l. .s. d.	10.79

Table Stratum standard errors and coefficients of variation

Stratum	d.f.	s.e.	cv %
Reps	3	8.74	46.4
Reps.*units*	6	6.24	33.1

Table 4.7b ANOVA of % clay in soils found along Up Navik Bay (UN) catena in Mushandike Wildlife Sanctuary.

Source of variation	df	ss	ms	vr	F-prob
Reps stratum	3	1972.25	657.42	12.54	
Reps.*units* stratum	2	721.50	360.75	6.88	0.028
Residual	6	314.50	52.42		
Total	11	3008.25			

Table of means

Grand mean	22.8		
Horizon	1.00	2.00	3.00
Mean	12.5	24.5	31.3

Table Standard errors of differences of means

Table	Horizon
Rep.	4
d.f.	6
l. .s. d.	5.12

Table Least significant differences (LSD) of means

Table	Horizon
Rep.	4
d.f.	6
l. .s. d.	12.53

Table Stratum standard errors and coefficients of variation

Stratum	d.f.	s.e.	cv %
Reps	3	14.80	65.1
Reps.*units*	6	7.24	31.8

4.6.3 Roots structure and abundance for all profiles

Results for root abundance and density are summarised in Table 4.8and 4. The total root density and distribution in the profiles obtained using the vertical method (Section 3.4.5) appears to increase with depth. This was observed from lower parts of the catena to the crest. This seems to be strongly governed by the differences in soil texture and structure that affect soil permeability as well as the internal and external drainage. Poorly drained soils that occurred in the lower parts of the catena had less root densities than the soils of the uplands.

When compared with results of root distribution (Table 4.9) obtained using the horizontal 'Trench profile' method (Section 3.4.5) for the same profiles, root densities in the sub - soils from bottom profiles of the catenas appeared to be different from those for vertical methods. The reason for this was attributed to the difficulty observed in the accurate assessment of different root sizes in the field.

Roots density in Chikungurugwi catena for both vertical and horizontal methods show higher root densities in the surface horizons than in the B-horizons, for example for profiles located in poorly drained parts of the catena. This suggests that most roots were concentrated in the surface layer that was better drained and aerated for good root respiration. A trend of increasing root density with improved drainage conditions from the bottom to the top for example in Mutsungwe catena was observed. For sandy catenas such as Chikungurugwi (CH) and Agyle (AG), this appeared to be very weak presumably due to relatively smaller differences in soil texture found in soils.

Table 4.8 Soil depth, root abundance (numbers) and density per 100 cm^2 assessed using the vertical profile method in soil profiles along Mutsungwe (MU) catena in Mushandike Wildlife Sanctuary.

Soil profile no.	Soil depth (cm)	V. fine (<1 mm dia.)	Fine (1 – 2 mm dia.)	Medium (2 – 5 mm dia.)	Coarse (>5 mm dia.)	Root density per 100-cm square
	0-13	18	41	12	0	71
1	13-45	48	44	23	8	123
	45-90	22	–	–	7	60
	0-10	20	67	50	1	138
2	10-20	10	10	22	12	54
	20-75	15	25	18	32	90
	75-100	20	0	3	1	24
	0-25	0	42	41	8	91
3	25-47	0	20	6	0	26
	47-70	0	30	24	44	98
	70-100	0	0	5	0	5
	0-22	19	29	53	0	101
4	22-45	35	8	14	19	76
	45-80	0	15	17	0	32
	80-150	0	3	1	0	4
	0-15	38	42	39	29	148
5	15-32	59	47	92	42	240
	32-100	52	59	49	46	206
	0-15	74	62	128	4	268
6	15-38	56	72	13	11	152
	38-98	50	73	99	10	232

Notes: Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.9 Soil depth, root abundance (numbers) and density per 100 cm^2 assessed using the 'Trench profile' method in soil profiles along Mutsungwe catena in Mushandike Wildlife Sanctuary. (Data for other areas is provided in Appendix 4.3 (j).

Soil profile no.	Soil depth (cm)	V. fine (<1 dia.)	Fine mm(1 – 2 dia)	Medium mm(2 – 5 dia)	Coarse mm(>5 dia.)	Root density mmper 100-cm square
	0-13	15	65	14	1	95
1	13-90	20	16	27	2	65
	0-10	0	72	120	0	192
2	10-20	20	34	45	12	111
	20-75	0	4	7	0	11
	75-100	0	0	0	4	4
	0-25	0	110	92	0	202
3	25-47	14	20	22	7	63
	47-100	0	67	82	3	152
	0-22	49	74	117	0	240
4	22-45	32	39	27	46	144
	45-150	0	15	55	0	70
	0-15	0	62	127	59	248
5	15-32	35	31	36	49	151
	32-100	15	22	35	39	111
	0-15	0	75	320	0	395
6	15-65	36	24	36	21	114
	65-98	50	42	61	19	172

Notes: Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

4.6.4 Bulk density of soils

Results for bulk density of soils obtained from all catenas in the study areas as described in section 3.4.6 are summarised in Table 4.10. Differences in soil texture and particle size distribution between and within catenas has resulted in a corresponding diversity in bulk density of soils.

Bulk density ranges between 1.30g/cm^3 to 1.82g/cm^3 in the topsoil and between 1.38g/cm^3 and 1.77 g/cm^3 in the subsoil (Table 4.10). There is a low variation of bulk density in the surface sandy layer (Table 4.10). These values of bulk density are typical of bulk density of sandy soils in Zimbabwe derived from granite (Nyamapfene, 1991). However in the sub soils, at some sites for example in Up-Navik and Navik Bay figures for bulk density were observed to be rather high, exceeding 1.70 g/cm^3. This was due to the high clay content in the soil that has resulted in the formation of a Bt horizon characterised by heavy texture and massive soil structure as already described under Section 4.6.1, that is always associated with compacted soils of poor drainage and plant rooting conditions.

Table 4.10 Bulk density (BD) for the top and sub-soils from all catenas in the study areas

Name of Catena	Soil Profile No.	Soil depth (cm)	BD (g/cm^3)	Soil depth (cm)	BD (g/cm^3)
Agyle (AG)	1	0-20	1.73	20-45	1.21
	2	0-12	1.61	12-45	1.65
	3	0-10	1.53	10-30	1-66
	4	0-17	1.45	17-30	1.65
Air Strip North a (ANa)	1	0-15	1.41	15-50	1.52
	2	0-12	1.56	12-45	1.65
	3	0-15	1.69	15-34	1.44
	4	0-13	1.67	13-45	1.74
Air Strip North b (ANb)	1	0-15	1.36	15-30	1.44
	2	0-12	1.52	12-30	1.74
	3	0-19	1.74	19-39	0.91
	4	0-10	1.47	10-150	1.47
Maruta (MA)	1	0-15	1.43	15-50	1.44
	2	0-12	1.61	10-47	1.66
	3	0-10	1.65	10-50	1.21
	4	0-15	1.69	15-45	1.29
Mushandike River (MR)	1	0-35	1.41	35-50	1.27
	2	0-15	1.66	15-45	1.66
	3	0-14	1.56	14-30	1.51
	4	0-15	1.50	15-90	1.66

Table 4.10 (Continued)

Name of catena	Soil Profile No.	Soil depth (cm)	BD (g/cm^3)	Soil depth (cm)	BD (g/cm^3)
Mutsungwe (MU)	1	0-13	1.55	13-45	1.77
	2	0-10	1.74	20-75	1.59
	3	0-25	1.73	25-47	1.51
	4	0-22	1.65	22-45	1.62
	5	0-15	1.61	15-30	1.66
	6	0-15	1.65	15-38	1.66
Chikungurugwi (CH)	1	0-25	1.54	25-80	1.56
	2	0-26	1.65	26-59	1.63
	3	0-16	1.73	16-89	1.62
	4	0-26	1.57	26-107	1.63
	5	0-12	1.80	12-50	1.70
	6	0-22	1.65	22-75	1.70
Navik Bay (NB)	1	0-15	1.30	15-75	1.58
	2	0-12	1.61	12-75	1.38
	3	0-10	1.36	10-80	1.53
	4	0-15	1.66	15-65	1.64
	5	0-10	1.65	10-45	1.45
Up Navik Bay (UN)	1	0-12	1.52	12-75	1.68
	2	0-20	1.57	20-75	1.77
	3	0-12	1.82	12.70	1.47
	4	0-13	1.73	13.75	1.66

Notes: Soil profiles were numbered from the bottom (low lands) to the top (uplands) of the catena

4.6.5 Soil moisture retention

Results of soil moisture retention of soils at all sites found in the study areas are summarised in Table 4.11.

In the surface soil of all sites found in the study areas, AWC ranges between 4% at MU6 in Mutsungwe catena to 24% at MR1 (and also at ANa1 found in Air Strip North a catena) found in Mushandike River catena. Figures for available water capacity (AWC) for sub-soils range between 2% at CH3 (and also CH4) in Chikungurugwi catena found in Makoholi to 22% at NB1 in Navik bay catena found in Mushandike.

The amount of available water capacity (AWC) in all soils is largely governed by % clay, which in turn influences the structure, hydraulic conductivity and drainage class of the soil. For soils found in lowland areas and in some middle slope sites such as NB1 and MR3, AWC of soils is higher than in upland sites due to increased clay content. It (AWC) ranges between 17% and 18% in the top - soil and 13% and 16% in the sub - soil.

In dry lowland sites associated with sodic soils for example at ANa1, ANa2, NB2, MU2, MU3, and ANb2 where drainage is poor and soil erosion intensity is high, in Mushandike Wildlife Sanctuary, AWC is higher than in Siallitic soils which are found on the well drained lowlands and middle slope sites.

In upland sites with Fersiallitic and Siallitic soils such as NB5, MU5, CH5, CH6 and MA4 (Fersiallitic soils) and NB4, ANa4, MU6, UN4, AG4 and CH4 (Siallitic soils) available water capacity (AWC) of soils is moderately small to moderately large. It ranges between about 6% to 17% in sandy soils found in Chikungurugwi catena. This is mainly due to the low clay content of soils found along this catena. In Navik Bay and Up Navik Bay catenas (which are both found in Mushandike Wildlife Sanctuary) with clay soils found at the bottom of the catenas and sandy soils at the top of the catenas, AWC ranges between 8% to 22% in the top and sub soils in clay soils.

Table 4.11 Summary of available water capacity of top and sub soils found in the study areas

Name of Catena	Soil Profile No.	Soil depth (cm)	Retained water at 0.1 bars (FC)	Retained water at 15.0 bars (PWP)	Percentage available water capacity (% AWC)	Soil depth (cm)	Retained water at 0.1 bars 0.2 (FC)	Retained water at 15.00 bars (PWP)	Percent Available water capacity (% AWC)
Agyle (AG)	AG 1	0-20	24.5	5.7	19	20-45	33.4	16.7	17
	AG 2	0-12	20.3	7.2	13	12-45	15.2	4.2	11
	AG 3	0-10	14.4	5.6	9	10-30	11.8	3.7	8
	AG 4	0-17	12.8	4.2	9	17-30	31.2	17.5	14
Air Strip North a (ANa)	ANa 1	0-15	32.8	9.1	24	15-50	34.5	17.4	17
	ANa 2	0-12	29.8	13.9	16	12-45	31.2	17.5	14
	ANa 3	0-15	26.8	7.9	19	15-34	29.2	12.1	17
	ANa 4	0-13	20.7	6.0	15	13-45	20.7	6.0	15
Air Strip North b (ANb)	ANb 1	0-15	24.0	8.4	16	15-30	34.0	18.7	15
	ANb 2	0-12	29.5	11.9	18	12-30	34.8	17.7	17
	ANb 3	0-19	23.8	8.2	16	19-39	42.0	26.2	16
	ANb 4	0-10	8.9	2.9	6	10-150	17.2	8.5	9
Maruta (MA)	MA 1	0-15	25.0	11.4	14	15-50	21.7	8.8	13
	MA 2	0-12	15.8	4.4	11	10-47	25.7	15.5	10
	MA 3	0-10	15.2	4.2	11	10-50	38.5	24.9	14
	MA 4	0-15	26.4	7.6	19	15-45	35.6	19.7	16
Mushandike River (MR)	MR 1	0-35	33.2	9.3	24	35-50	25.2	3.9	18
	MR 2	0-15	16.9	4.9	12	15-45	11.9	3.5	8
	MR 3	0-14	28.8	12.9	17	14-30	27.6	13.9	14
	MR 4	0-15	9.1	2.7	6	15-90	21.9	8.7	13

Table 4.11 (Continued)

Name of catena	Soil Profile No.	Soil depth (cm)	Retained water at 0.1 bars (FC)	Retained water at 15.0 bars (PWP)	Percentage available water capacity (% AWC)	Soil depth (cm)	Retained water at 0.3 bars 0.4 (FC)	Retained water at 15.00 bars (PWP)	Percent Available water capacity (% AWC)
Mutsungwe (MU)	MU 1	0-13	10.8	2.5	8	13.45	25.7	15.5	10
	MU 2	0-10	24.1	8.4	17	20-75	31.0	17.5	14
	MU 3	0-25	24.7	5.7	19	25-47	27.6	13.9	14
	MU 4	0-22	15.2	4.2	11	22-45	23.3	14.9	8
	MU 5	0-15	15.8	4.4	11	15-30	11.8	3.7	8
	MU 6	0-15	12.5	8.5	4	15-38	24.0	8.4	16
Navik Bay (NB)	NB 1	0-15	27.8	9.8	18	15-75	34.1	12.5	22
	NB 2	0-12	29.6	14.6	15	12-75	36.3	15.1	21
	NB 3	0-10	21.1	8.5	13	10-120	31.0	17.5	14
	NB 4	0-15	24.2	7.1	17	15-120	15.2	4.2	11
	NB 5	0-10	15.8	4.4	11	10-45	15.6	4.2	11
Up Navik Bay (UN)	UN 1	0-12	28.6	15.2	13	12-75	34.0	16.4	18
	UN 2	0-20	28.2	9.9	18	20-100	28.8	9.6	19
	UN 3	0-12	24.0	9.4	15	12-120	26.8	14.7	12
	UN 4	0-13	11.9	3.5	8	13-80	25.7	15.5	10
Chikungurugwi (CH)	CH 1	0-25	16.3	1.9	14	25-80	26.0	15.1	11
	CH 2	0-26	15.4	8.6	6	26-120	27.0	15.0	12
	CH 3	0-16	17.0	2.8	14	16-100	18.0	15.9	2
	CH 4	0-26	22.2	5.7	17	26-150	38.0	18.1	20
	CH 5	0-12	18.4	1.9	17	12-150	11.0	13.3	2
	CH 6	0-22	16.9	0.9	16	22-75	35.0	17.7	17

Notes: i. FC=Field Capacity; PWP=Permanent wilting point; %AWC=Percent available water capacity; NB=Navik Bay catena; UN+ Up Navik Bay catena; CH= Chikungurugwi catena.
ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

4.6.6 Soil erosion, wetness regimes and drainage status

Results for soil erosion, wetness and drainage assessments in the field are summarised in Table 4.12. The study areas are characterised by gently undulating to undulating uplands and crests. These (upland crests) are dry and well drained with slight erosion intensity, mainly sheet wash because of the high percent canopy cover that reduces raindrop impact and erosion on the soil surface. Assessment techniques and guidelines for land slope, drainage and wetness status as well as soil erosion intensity in the field are given in sections 3.4.2 to 3.4.4.

From the assessment of erosion intensity, about 39% of all the sites are slightly eroded whilst 34%, 22% and 5% of the sites are moderately eroded, severely eroded and very severely eroded respectively. The majority of the severely and very severely eroded sites are those mainly with Sodic and Fersiallitic soils found especially in lowland areas. These (lowland) areas are associated with BS and / GS vegetation physiognomic type dominated by *Acacia* and *Combretum* species, *Colophospermum mopane*, *Terminalia sericea* and *Syzigium* tree species. For drainage status of the soil, about 41% of the sites are well drained (Drainage class D5) with W1 to W2 (Table 3.7b) soil moisture regimes. About 24% and 12% of sites are moderately poorly drained and moderately well drained respectively. Very well drained sites on uplands on siallitic soils make up about 5% of the sites whilst about 17% are poorly drained sites mostly found in lowland areas.

Table 4.12 Summary description of site characteristics, drainage status, wetness regimes and erosion intensity along catenas found in the study areas on granite (Guidelines for the assessment of slope, drainage, wetness and erosion see sections 3.4.2 – 3.4.4 for explanation)

Name of Catena	Site symbol	Position of site	Topography	Slope %	Soil drainage status	Soil drainage class	Soil wetness regime	Soil erosion intensity	Soil erosion class
	MU 1	Lower slope	Gently undulating	2-5% convex slope	moderately well drained	D4	W1	Moderate erosion	E2
	MU 2	Lower slope	Gently undulating	2-5% concave slope	poorly drained	D2	W1	Severe erosion	E3
	MU 3	Lower slope	Almost flat	0.5-2% straight slope	poorly drained	D2	W1	Severe erosion	E3
Mutsungwe (MU)	MU 4	Middle slope	Gently undulating	2-5% concave slope	moderately poorly drained	D3	W2	Moderate erosion	E2
	MU 5	Upper middle slope	Undulating	5-8% convex slope	moderately well drained	D4	W1	Moderate erosion	E2
	MU 6	Crest	Almost flat	0.5-2% Convex slope	well drained	D5	W1	Slight erosion	E1

Notes: i. D = drainage class; W = wetness regime; E = erosion class

ii. Sites for soil profiles vegetation plots were numbered from the bottom (lowlands) to the top (uplands) of the catena

iii. For drainage, wetness and erosion classes see Appendix 4.9 to 4.11 for explanation

Table 4.12 (Continued)

	NB 1	Lower slope	Gently Undulating	0– 2 % Concave	Poorly drained	D2	W1	Severe erosion	E3
	NB 2	Lower slope	Scarp minor	5-8 % Rectilinear	Poorly drained	D2	W1	Very severe erosion	E4
Navik Bay (NB)	NB 3	Lower slope	Flat to gently sloping	2-5 % Concave	Poorly drained	D2	W1	Severe erosion	E3
	NB 4	Middle slope	Gently sloping	2-5 % Rectilinear	Well drained	D5	W1	Moderate erosion	E2
	NB 5	Crest	Gently sloping	2-5 % Concave	Well drained	D5	W1	Slight erosion	E1
	MR 1	Lower slope	Gently Slopping	2-5 % Concave	Well drained	D3	W2	Moderate erosion	E2
Mushandike River (MR)	MR 2	Middle slope	Gently Slopping	2-5 % Concave	Well drained	D5	W1	Moderate erosion	E2
	MR 3	Up slope	Nearly flat	2-5 % Concave	Well drained	D5	W1	Moderate erosion	E2
	MR 4	Up slope/crest	Flat to gently sloping	0-5 % Concave	Well drained	D5	W1	Slight erosion	E1

Notes: i. D = drainage class; W = wetness regime; E = erosion class
ii. Sites for soil profiles vegetation plots were numbered from the bottom (lowlands) to the top (uplands) of the catena
iii. For drainage, wetness and erosion classes see Appendix 4.9 to 4.11 for explanation

Table 4.12 (Continued)

Name of Catena	Site symbol	Position of site	Topography	Slope %	Soil drainage status	Soil drainage class	Soil wetness regime	Soil erosion intensity	Soil erosion class
Up Navik Bay (UN)	UN 1	Lower slope	Undulating slope	2-5 % Concave	Moderately poorly drained	D3	W2	Very severe erosion	E4
	UN 2	Middle slope	Gently slopping	2-5 % Concave	Well drained	D5	W1	Slight	E1
	UN3	Middle slope	Scarp slope	5-8 % Rectilinear	Moderately poorly drained	D3	W1	Severe erosion	E3
	UN 4	Crest	Flat	0-2 %	Well drained	D5	W1	Slight erosion	E1
Agyle (AG)	AG 1	Lower slope	Flat	0-2 % Concave	Moderately poorly drained	D3	W2	Moderate erosion	E3
	AG 2	Middle slope	Gently Slopping	2-5 % Concave	Moderately well drained	D4	W2	Severe erosion	E2
	AG 3	Middle slope	Gently undulating	2-5 % Concave	Moderately well drained	D4	W2	Moderate Erosion	E2
	AG 4	Upland slope	Flat to gently sloping	0-2 % Concave	Well drained	D5	W1	Moderate Erosion	E1

Notes: i. D = drainage class; W = wetness regime; E = erosion class

ii. Sites for soil profiles vegetation plots were numbered from the bottom (lowlands) to the top (uplands) of the catena

iii. For drainage, wetness and erosion classes see Appendix 4.9 to 4.11 for explanation

Table 4.12 (Continued)

Name of Catena	Site symbol	Position of site	Topography	Slope %	Soil drainage status	Soil drainage class	Soil wetness regime	Soil erosion intensity	Soil erosion class
	CH 1	Lower slope	Gently undulating	2 - 5 % Concave	Moderately poorly drained	D3	W3	Moderate erosion	E2
	CH 2	Middle slope	Flat	0 - 2 % Flat	Moderately well drained	D3	W2	Slight erosion	E1
Chikungurugwi (CH)	CH 3	Middle slope	Gently undulating	2-5 % Concave	Well drained	D5	W1	Slight erosion	E1
	CH 4	Middle slope	Nearly flat	0-2 % Flat	Well drained	D5	W1	Slight erosion	E1
	CH 5	Middle slope	Gently undulating	2 – 5% Concave	Well drained	D5	W1	Slight	E1
	CH 6	Up slope	Flat to gently undulating	0 – 2% concave	Well drained	D5	W1	Slight	E1
	MA 1	Lower slope	Flat to gently undulating	0 - 2 % Concave	Poorly drained	D2	W3	Moderate erosion	E2
	MA 2	Middle slope	Gently undulating	2 - 5 % Convex	Well drained	D5	W1	Slight erosion	E1
Maruta (MA)	MA 3	Middle slope	Gently undulating	2-5 % Concave	Well drained	D5	W1	Slight erosion	E1
	MA 4	Crest	Flat to gently undulating	0-2 % Convex	Well drained	D5	W1	Slight erosion	E1

Notes: i. D = drainage class; W = wetness regime; E = erosion class
ii. Sites for soil profiles vegetation plots were numbered from the bottom (lowlands) to the top (uplands) of the catena
iii. For drainage, wetness and erosion classes see Appendix 4.9 to 4.11 for explanation

Table 4.12 (Continued)

Name of Catena	Site symbol	Position of site	Topography	Slope %	Soil drainage status	Soil drainage class	Soil wetness regime	Soil erosion intensity	Soil erosion class
	AN(a) 1	Lower slope	Gently undulating	0 - 5 % Concave	Poorly drained	D2	W2	Moderate erosion	E2
Airstrip North a	AN(a) 2	Lower slope	Nearly flat	0 - 2 % Concave	Moderately poorly drained	D3	W1	Severe erosion	E3
	AN(a) 3	Middle slope	Gently undulating	2-5 % Concave	Moderately poorly drained	D5	W2	Slight erosion	E1
	AN(a) 4	Crest	Nearly flat	0-2 % Concave	Very well drained	D6	W1	Slight erosion	E1
	AN(b) 1	Lower slope	Flat plain	0 - 2 % Concave	Moderately poorly drained	D3	W1	Severe erosion	E3
Airstrip North b	AN(b) 2	Lower slope	Nearly flat	0 - 2 % Concave	Moderately poorly drained	D3	W1	Severe erosion	E3
	AN(b) 3	Middle slope	Gently undulating	2-5 % Concave	Moderately well drained	D4	W2	Moderate erosion	E2
	AN(b) 4	Upper slope	Undulating	5 - 8 % Rectilinear	Very well drained	D6	W1	Moderate erosion	E2

Notes:
i. D = drainage class; W = wetness regime; E = erosion class
ii. Sites for soil profiles vegetation plots were numbered from the bottom (lowlands) to the top (uplands) of the catena
iii. For drainage, wetness and erosion classes see Appendix 4.9 to 4.11 for explanation

4.6.7 Soil chemical properties

Soil chemical results for soil profiles found in the study areas are presented in Tables 4.13 to 4.16 and in Appendices 4.1 and 4.2.

These results indicate that soils of the study areas are characterised by low pH values that range between 4.0 and 6.2. Similar to texture and its related mechanical properties, the pH of soils in the study areas is not very variable (Tables 4.13 to 4.16 and Appendices 4.1 and 4.2).

From an ANOVA, for profiles found in the study areas there were not any significant differences in pH (Table 4.17) between A, B and BC horizons. The variation that appeared to occur in the soil exchange properties, presumably, is brought about as a result of clay illuviation within and between soil profiles along the catena (See Section 4.6.2).

The chemical properties of soils in the study areas as shown by TEB and CEC of the soil vary with position along the catena and also depth of the soil. High values of TEB and CEC are found in the lower parts of the catenas and in the sub soils where clay content is higher and drainage is poorer than in the top parts of the catenas. TEB ranges between 0.50 c mol c/kg to 10.40 c mol c/kg in the A horizon. In the B and BC horizons, TEB ranges between 0.24 to 20.90 c mol c/kg and 0.12 to 25.00 c mol c/kg respectively.

In the A horizon CEC ranges between 0.8 to 45.00 c mol c/kg. In the B and BC horizons, CEC ranges between 0.40 to 33.50 c mol c/kg and 0.38 to 46.20 c mol c/kg respectively implying that the soils are generally acidic and infertile.

In most sites in the study areas, soils have generally more exchangeable calcium than magnesium in the topsoil. However, in certain sites, the ratio of Ca to Mg especially in the sub soils is inverted suggesting that there is more exchangeable magnesium than calcium in the soil, a situation that is unusual for sandy soils derived from granite. This anomaly appears to be highest in the B-horizon. A possible explanation to this anomaly could be related to the mechanism involved in the weathering and movement of the two major nutrients: calcium and magnesium in granite soils down the profile under conditions of low rainfall and leaching.

There appears to be a similar trend of inverted calcium to magnesium ratios in individual catenas. This is evident especially in those soils that show sharp differences in percent clay, pH and CEC in the subsoil in both uplands and lowland parts of catenas. Examples of such soils are found in MU, NB and UN catenas in Mushandike Wildlife Sanctuary.

Most soils in the study areas are not sodic. However, about 17% of the sites studied can be classified under the sodic category (See section 4.6.9). These include sites found in the lower parts of the catenas such as MU, ANa, ANb and NB in Mushandike Wildlife Sanctuary and AG in Soti Source Resettlement in Gutu. High values of ESP of up to 25.0 at MU2, 29.1 at NB2, 38.4 at ANb2 and 49.1 at MU3 were encountered in the sub soils associated with high % clay and the inverted calcium to magnesium ratios already indicated above.

Exchangeable potassium (K) in the surface soil horizons ranges between 0.08 and 11.0 c mol c/kg. This appears to increase with depth in the Bhorizon presumably due to high percent clay associated with a high proportion of bases that are found there including potassium.

Similar to TEB and CEC, base saturation percentage (BSa%), E/C and S/C values of soils found in the study areas also vary with position of site and % clay in the soil. The BSa% in the lower parts of the catenas with high % clay for example at MU2, MU3, UN1, NB2 and ANa1 (in Mushandike Wildlife Sanctuary) ranges between 59.0 to 75.0 in the A horizon. In the B and BC horizons, BSa% ranges between 80 to 100 and 98 to 100 respectively. In sandy catenas for example at CH1, CH2, CH6, MR4 and AG4 BSa% ranges between 45 to 99 in the A horizon and between 53 and 100 in both the B and BC horizons (Appendix 4.7).

For all sites, the E/C and S/C values (see Section 4.6.9) which are important chemical criteria for classifying soils in Zimbabwe (Thompson and Purves, 1978) range between about15.0 to 90.0 and 12 .0 to 70.0 in the surface soil respectively. In the sub soil, the equivalent figures are 9.5 to 82.5 and 9.5 to 87.8 respectively. Presumably, these figures indicate the presence of small amounts of 2:1 clay minerals in soils found in the study areas and the dominance of 1:1 clay minerals with appreciable amounts of sesquioxides.

Table 4.13 Results of chemical analyses and exchange properties of soil found along Mutsungwe catena in Mushandike Wildlife Sanctuary. (For abbreviations used and numbering of soil profiles see bottom of table for explanation).

Profile Symbol	Soil depth (cm)	Soil pH ($CaCl_2$)	Exchange Cations (c mol c/kg)					Exchange Properties (cmol c/kg)		
			Ca	Mg	K	Na	Ca / Mg Ratio	CEC	ESP	EKP
MU1	0-13	5.5	0.7	0.7	0.09	0.02	1.00	2.5	0.90	3.5
	13-45	4.3	0.9	1.3	0.06	0.06	0.69	4.2	1.50	1.5
	45-90	4.1	1.2	1.3	0.03	0.15	0.92	3.5	4.20	0.8
MU2	0-10	4.5	1.1	1.1	0.10	0.10	1.00	3.7	2.6	2.6
	10-20	4.9	0.4	1.8	0.02	0.28	0.22	3.1	9.2	0.8
	20-75	6.4	2.5	9.0	0.10	3.89	0.28	15.4	25.3	0.6
	75-100	8.4	14.7	13.2	0.09	0.60	1.11	25.0	2.4	0.4
MU3	0-25	5.0	0.9	0.7	0.09	0.02	1.29	3.0	0.8	3.0
	25-47	4.9	0.2	0.6	0.02	0.11	0.33	2.2	5.0	1.1
	47-100	6.3	0.5	0.8	0.02	1.19	0.63	2.4	49.1	1.1
MU4	0-22	4.4	1.0	0.3	0.06	0.06	3.33	2.10	3.0	3.0
	22-45	5.0	0.4	0.8	0.03	0.08	0.5	1.90	4.3	1.4
	45-80	7.0	3.0	4.6	0.07	0.50	0.65	17.50	2.8	0.4
	80-150	7.8	3.2	5.0	0.07	0.98	0.64	16.50	5.9	0.4
MU5	0-15	4.3	0.6	0.1	0.2	0.4	6.00	1.70	2.4	1.2
	15-30	3.9	0.6	0.2	0.03	0.08	3.00	2.20	3.6	1.2
	30-50	4.2	0.7	0.4	0.03	0.05	1.75	1.80	2.8	1.4
	50-112	4.8	0.6	0.5	0.03	0.11	1.20	1.70	6.6	1.7
MU6	0-15	4.9	0.5	0.3	0.07	0.07	1.67	1.2	5.5	5.5
	15-38	4.0	0.4	0.4	0.06	0.06	1.00	1.9	2.9	2.9
	38-65	4.3	0.7	0.6	0.04	0.09	1.17	2.5	3.4	1.7
	65-98	4.4	0.4	1.5	0.08	0.05	0.27	3.3	1.6	2.4

Notes: i. MU=Mutsungwe catena ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.14 Results of chemical analyses and exchange properties of soil found along Navik Bay catena in Mushandike Wildlife Sanctuary. (For abbreviations used and numbering of soil profiles, see bottom of table for explanation).

Profile Symbol	Soil depth (cm)	Soil pH ($CaCl_2$)	Exchange Cations (c mol c/kg)					Exchange Properties (cmol c/kg)		
			Ca	Mg	K	Na	Ca / Mg Ratio	CEC	ESP	EKP
NB1	0-15	5.7	3.5	6.6	0.09	0.18	0.53	12.2	1.5	0.7
	15-45	7.2	6.9	12.8	0.10	0.20	0.54	22.9	0.9	0.4
	45-75	8.4	21.0	19.1	0.09	0.24	1.10	20.9	1.1	0.4
	75-112	8.4	20.4	17.4	0.09	0.30	1.17	20.3	1.5	0.4
NB2	0-12	5.9	3.3	3.9	0.09	0.34	0.85	9.3	3.7	0.9
	12-30	8.7	18.7	9.2	0.08	2.96	2.03	17.2	17.2	0.4
	40-75	9.2	14.2	13.9	0.09	6.02	1.02	20.7	29.1	0.4
	75-100	9.4	7.5	13.0	0.08	11.9	0.58	22.5	51.9	0.3
NB3	0-10	4.3	1.0	1.9	0.08	0.11	0.53	3.8	2.9	2.2
	10-18	4.1	0.7	1.5	0.05	0.15	0.47	4.1	3.8	1.3
	18-80	4.9	2.0	8.9	0.09	0.54	0.22	13.0	4.2	0.7
	80-120	5.1	2.2	2.0	0.46	0.07	5.60	5.6	0.7	8.3
NB4	0-15	4.2	0.7	0.4	0.11	0.06	1.75	2.1	2.6	5.3
	15-65	4.3	0.6	0.9	0.08	0.11	0.67	2.6	4.3	3.2
	65-100	4.7	0.6	1.8	0.05	0.08	0.33	2.6	3.2	2.1
NB5	0-10	5.0	1.1	1.3	0.12	0.09	0.85	4.3	2.2	2.9
	10-45	4.8	0.04	1.7	0.13	0.06	0.01	2.8	2.3	4.6

Notes: i. NB=Navik bay catena ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.15 Results of chemical analyses and exchange properties of soil found along Agyle in Soti Source Resettlement Scheme of Gutu District. (For abbreviations used and numbering of soil profiles see bottom of table for explanation).

Profile Symbol	Soil depth (cm)	Soil pH ($CaCl_2$)	Exchange Cations (c mol c/kg)					Exchange Properties (cmol c/kg)		
			Ca	Mg	K	Na	Ca/mg Ratio	CEC	ESP	EKP
	0-20	4.5	1.2	1.1	0.06	0.11	1.09	2.5	4.5	2.3
	20-45	4.6	1.0	0.6	0.02	0.10	1.67	1.5	6.7	1.3
AG 1	45-75	5.3	0.6	0.5	0.02	0.10	1.2	1.0	9.4	2.4
	75-1000	6.0	5.3	1.2	0.03	0.35	4.42	8.1	4.4	0.4
	0-12	4.4	0.1	0.9	0.08	0.08	0.11	0.8	11.0	11.0
	12-45	4.2	0.1	0.4	0.03	0.06	0.25	0.5	12.4	6.2
AG2	45-90	4.1	0.1	0.2	0.03	0.07	0.50	0.4	18.0	9.0
	90-120	4.6	0.2	0.4	0.01	0.07	0.50	0.6	11.5	2.3
	0-10	4.3	0.5	0.6	0.12	0.09	0.83	1.6	5.9	7.4
	10-30	4.1	0.1	0.3	0.04	0.06	7.5	0.5	11.9	7.9
AG3	30-50	4.1	0.4	0.3	0.06	0.06	1.3	0.4	15.7	15.7
	50-80	4.2		0.5	0.11	0.11	1.0	0.8	14.2	14.2
	0-17	4.7	0.6	0.8	0.11	0.11	0.75	1.3	8.4	8.4
AG4	17-30	4.1	0.2	0.8	0.13	0.13	0.25	1.0	12.4	12.4
	30-65	4.0	0.1	0.5	0.09	0.09	0.20	0.5	16.5	16.5
	65-100	4.4	0.6	0.8	0.09	0.09	0.75	0.9	10.2	10.2

Note: i. AG=Agyle catena ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.16 Results of chemical analyses and exchange properties of soil found along Up Navik Bay catena in Mushandike Wildlife Sanctuary. (For abbreviations used and numbering of soil profiles see bottom of table for explanation).

Profile Symbol	Soil depth (cm)	Soil pH ($CaCl_2$)	Exchange Cations (c mol c/kg)					Exchange Properties (cmol c/kg)		
			Ca	Mg	K	Na	Ca/mg Ratio	CEC	ESP	EKP
UN1	0-35	5.1	5.1	3.3	0.24	0.02	1.03	9.3	0.3	2.6
	35-45	4.9	4.9	3.9	0.08	0.03	1.10	11.8	0.2	0.7
	45-75	5.1	5.1	6.4	0.06	0.03	0.75	14.1	0.2	0.4
	75-112	5.7	5.7	4.9	0.07	0.11	1.14	11.0	1.0	0.6
UN2	0-20	5.1	3.6	5.3	0.23	0.05	0.68	9.8	0.5	2.3
	20-75	5.0	6.4	8.6	0.10	0.13	0.74	18.4	0.7	0.6
	75-100	5.1	7.5	9.9	0.10	0.13	0.75	22.2	0.6	0.4
	100-120	5.6	9.2	8.3	0.07	0.14	1.11	21.5	0.7	0.3
UN3	0-12	5.0	1.0	1.1	0.10	0.03	0.91	3.5	0.7	3.0
	12-70	4.6	0.6	1.8	0.03	0.08	0.33	4.2	1.9	0.6
	70-100	5.1	0.6	2.3	0.02	0.21	0.26	4.8	4.3	0.4
	100-120	5.6	2.8	7.0	0.06	0.44	0.40	11.6	3.8	0.5
UN4	0-13	5.2	1.0	0.6	0.10	0.05	1.67	3.0	1.7	3.3
	13-35	4.2	1.4	0.9	0.06	0.10	1.55	3.3	2.9	1.9
	35-80	4.3	1.4	1.7	0.03	0.10	0.82	4.6	2.2	0.7
	80-120	4.3	1.4	1.7	0.03	0.10	0.82	4.6	2.2	0.7

Note: i. UN=Up Navik catena ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Table 4.17 Summary of ANOVA results of soil pH for all catenas found in the study areas

Name of catena	Total d.f.	Grand mean	s.e.d.	s.s.	F. prob.
Airstrip North a (ANa)	11	6.24	1.252	45.469	0.523
Airstrip North b (ANb)	11	6.32	0.805	35.302	0.121
Mushandike River (MR)	11	5.17	0.554	6.422	0.514
Agyle (AG)	11	4.77	0.586	7.507	0.970
Maruta (MA)	11	4.55	.0384	2.130	0.678
Up Navik BAY (UN)	11	5.09	0.267	2.329	0.348
Chikungurugwi (CH)	17	5.09	0.220	3.368	0.530
Mutsungwe (MU)	17	5.47	0.650	35.256	0.111
Navik Bay (NB)	14	5.87	0.578	48.289	0.082

4.6.8 Percent carbon (%C) in soils

Results of organic matter of the surface soil for all study areas are shown in Table 4.18. Organic carbon content for all sites varies between 0.01% and 2.80%. This figure is low and therefore typical of sands soils derived from granite (Nyamapfene; 1991). However, some catenas for example AG and MA appear to have higher % C comparable to those for other catenas such as UN, MU and NB.

Table 4.18 Results of percent carbon (% C) of surface soil horizon for soils found in all catenas of the study areas.

Name of catena	***Profile Number***	Soil Depth (cm)	% C
	UN 1	0 – 12	0.03
UP Navik Bay (UN)	UN 2	0 – 20	0.32
	UN 3	0 – 12	0.46
	UN 4	0 - 13	0.15
	MR 1	0 – 35	1.55
Mushandike River (MR)	MR 2	0 – 15	0.60
	MR 3	0 – 14	1.34
	MR 4	0 – 15	1.42
	MU1	0 – 13	0.80
	MU 2	0 – 10	0.03
Mutsungwe (MU)	MU 3	0 – 25	0.03
	MU 4	0 – 22	1.06
	MU 5	0 – 15	0.71
	MU 6	0 – 15	0.83
	MU 6	0 – 15	0.83
	AG 1	0 – 20	2.8
Agyle (AG)	AG 2	0 – 12	1.26
	AG 3	0 – 10	1.19
	AG 4	0 – 17	1.15
	ANa 1	0 – 15	0.4
Air Strip North (ANa)	ANa 2	0 – 12	0.01
	ANa 3	0 – 15	1.35
	ANa 4	0 – 13	0.86

Table 4.18 (Continued)

Name of catena	Profile Number	Soil Depth (cm)	% C
	ANb 1	0 – 15	0.07
Air Strip North b (ANb)	ANb 2	0 – 12	0.01
	ANb 3	0 – 19	1.16
	ANb 4	0 – 10	0.68
	CH 1	0 - 25	0.09
	CH 2	0 - 26	0.86
	CH 3	0 - 16	1.01
Chikungurugwi (CH)	CH 4	0 - 26	0.95
	CH 5	0 - 12	0.72
	CH 6	0 - 22	0.66
	NB 1	0 – 15	0.58
	NB 2	0 – 12	0.06
Navik Bay (NB)	NB 3	0 – 10	0.09
	NB 4	0 – 15	0.72
	NB 5	0 – 10	1.12
	MA 1	0 – 15	1.40
Maruta (MA)	MA 2	0 – 12	0.43
	MA 3	0 – 10	1.68
	MA 4	0 – 15	1.04

4.6.9 Classification of soils of the study areas

Soils of the study areas have been classified according to the Zimbabwe soil classification system (after Thompson and Purves, 1978) into Siallitic (4G), Fersiallitic (5G), Fersiallitic (5GE) Sodic (8nG) and Sodic (8NG) respectively (Table 4.19). Similar soils have been identified elsewhere on granite in Zimbabwe by Nyamapfene (1991) and Anderson *et. al*. (1993) the latter in a physical resource inventory of the communal lands of Zimbabwe. For all soils identified in the study areas, a correlation between the Zimbabwe soil classification system (Thompson and Purves, 1978) and the FAO/UNESCO soil classification system (FAO, 1988) is provided in Table 4.19.

Table 4.19 A summary of soil classification for all catenas according to the Zimbabwe soil classification system (Thompson and Purves, 1978) and the FAO/UNESCO soil classification system (FAO, 1988).For abbreviations used see end of table for explanation..

Name of catena	Soil profile symbol	Clay %	BSa%	E/C value	S/C value	ESP	*Soil classification (Soil family)	**FAO/UNESCO soil classification system
Mutsungwe (MU)	MU1	8	75	50	34.0	4.2	Siallitic (4 G)	Arenosol
	MU2	42	100	66	37.0	25.0	Sodic (8 NG)	Solonetz
	MU3	25	100	61	36.0	49.1	Sodic (8 N)	Solonetz
	MU4	39	70	45	22.0	2.8	Fersiallitic (5 G)	Luvisol
	MU5	5	67	57	27.0	2.8	Fersiallitic (5 G)	Arenosol
	MU6	8	80	60	32.6	3.5	Siallitic (4 G)	Arenosol
Up Navik Bay (UN)	UN1	37	80	51.8	38.9	0.3	Siallitic (4 G)	Luvisol
	UN2	50	93	45.2	42.1	0.7	Siallitic (4 G)	Luvisol
	UN3	11	63	63.0	39.9	4.3	Siallitic (4 G)	Lixisol
	UN4	8	74	69.9	40.3	3.3	Siallitic (4 G)	Arenosol
Mushandike River R)	MR1	43	81	53.7	34.7	5.8	Siallitic (4 G)	Luvisol
	MR2	6	75	39.2	29.3	5.2	Fersiallitic (5 G)	Arenosol
	MR3	32	72	86.7	61.8	0.5	Fersiallitic (5GE)	Luvisol
	MR4	7	77	60.2	39.8	2.6	Siallitic (4 G)	Arenosol

*Zimbabwean soil classification system after Thompson and Purves (1978).
**FAO/UNESCO Soil classification system after FAO, (1988).

Table 4.19 (Continued)

Name of catena	Soil profile symbol	Clay %	BSa%	E/C value	S/C value	ESP	*Zimbabwe soil classification (Soil family)	**FAO/UNESCO Soil classification system
Air Strip North b (ANb)	ANb1	23	91	79.6	58.1	8.8	Siallitic (4 G)	Solonetz
	ANb2	32	100	73.9	53.5	38.4	Sodic (8NG)	Solonetz
	ANb3	48	84	86.3	53.2	5.5	Siallitic (4 G)	Luvisol
	ANb4	6	74	39.1	27.2	2.9	Siallitic (4 G)	Arenosol
Agyle (AG)	AG1	36	98	41.1	40.3	9.4	Sodic (8NG)	Solonetz
	AG2	3	100	18.8	18.8	8.0	Fersiallitic (5G)	Arenosol
	AG3	7	100	56.6	46.9	4.2	Siallitic (4 G)	Arenosol
	AG4	16	100	35.9	35.9	6.5	Siallitic (4 G)	Lixisol
Maruta (MA)	MA1	18	99	24.3	11.0	4.1	Fersiallitic (5 G)	Luvisol
	MA2	5	100	20.7	20.7	0.6	Fersiallitic (5 G)	Arenosol
	MA3	43	100	20.7	20.7	0.6	Fersiallitic (5 G)	Luvisol
	MA4	42	100	9.5	9.5	2.4	Fersiallitic (5 G)	Luvisol
Navik Bay (NB)	NB1	33	100	80.4	68.8	1.5	Siallitic (4G)	Luvisol
	NB2	25	100	82.0	87.8	29.1	Sodic (8NG)	Solonetz
	NB3	45	89	46.4	38.0	4.2	Siallitic (4 G)	Luvisol
	NB4	7	74	57.2	42.3	4.3	Siallitic (4 G)	Arenosol
	NB5	5	70	51.7	28.4	2.3	Fersiallitic (5G)	Arenosol

*Zimbabwean soil classification system after Thompson and Purves (1978).
**FAO/UNESCO Soil classification system after FAO, (1988).

Table 4.19 (Continued)

Name of catena	Soil profile symbol	Clay %	BSa%	E/C value	S/C value	ESP	*Zimbabwean soil classification (Soil family)	**FAO/UNESCO soil classification system
Air Strip North a (ANa)	ANa1	33	100	75.2	65.3	28.7	Sodic (8NG)	Solonetz
	ANa2	26	75	46.2	33.8	13.9	Sodic (8nG)	Solonetz
	ANa3	35	71	55.4	37.8	3.2	Siallitic (4 G)	Luvisol
	ANa4	8	75	54.7	34.0	4.2	Siallitic (4 G)	Arenosol
Chikungurugwi (CH)	CH1	22	82	43	35	0.0	Siallitic (4 G)	Arenosol
	CH2	14	90	46.8	42.1	3.1	Siallitic (4 G)	Arenosol
	CH3	14	97	52.8	51.4	0.0	Siallitic (4 G)	Arenosol
	CH4	28	79	63.9	50.3	2.1	Siallitic (4 G)	Luvisol
	CH5	14	89	20.0	17.7	4.5	Fersiallitic (5G)	Arenosol
	CH6	14	99	21	16	4.0	Fersiallitic (5G)	Arenosol

*Zimbabwean soil classification system after Thompson and Purves (1978) .

**FAO/UNESCO Soil classification system after FAO, (1988).

Notes: . BSa=Base saturation; E/C=Cation exchange capacity per 100g of clay; S/C=Total exchangeable bases per 100g of clay; ESP=Exchangeable sodium percentage; 5G=Fersiallitic soil derived from granite; 4G=Siallitic soil derived from granite; 8N=Sodic soil. .Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena. Only the B – horizon data was used for this classification.

4.6.10 Vegetation physiognomic types along the catenas

Results for the classification of vegetation in the study areas produced as described in section 3.3.4 are shown in Figures 4.1 to 4.3 and Appendix 4.7. Descriptive legends for each figure are provided in Tables 4.21 to 4.24.

Three different vegetation physiognomic types that indicate the general structure of the vegetation were identified from 41 sites along nine catenas (Table 3.1) in the study areas following guidelines and procedures laid down by Bennett (1985) and the Ministry of

Agriculture (1981). These vegetation physiognomic types are Tree Bush Savanna (TBS), Bush Savanna (BS) and Grassland (GR) as shown in the table below.

Table 4.20: A summary of vegetation physiognomic types found in the study areas

Vegetation physiognomic type	Description	No. of sites	Percent of total
Tree Bush Savanna (TBS)	A fairly dense stand of deciduous trees with under storey of bushes. Trees are up to 6m or more in height with a well developed grass cover.	22	54
Bush Savanna (BS)	An open stand of bushes from 3m to 6m in height with a well developed grass cover. Trees are occasional and scattered..	12	29
Grassland (GR)	Land covered by grasses and herbs sometimes with scattered trees. These include vleis and secondary grasslands resulting from removal of trees	7	17
Total		41	100

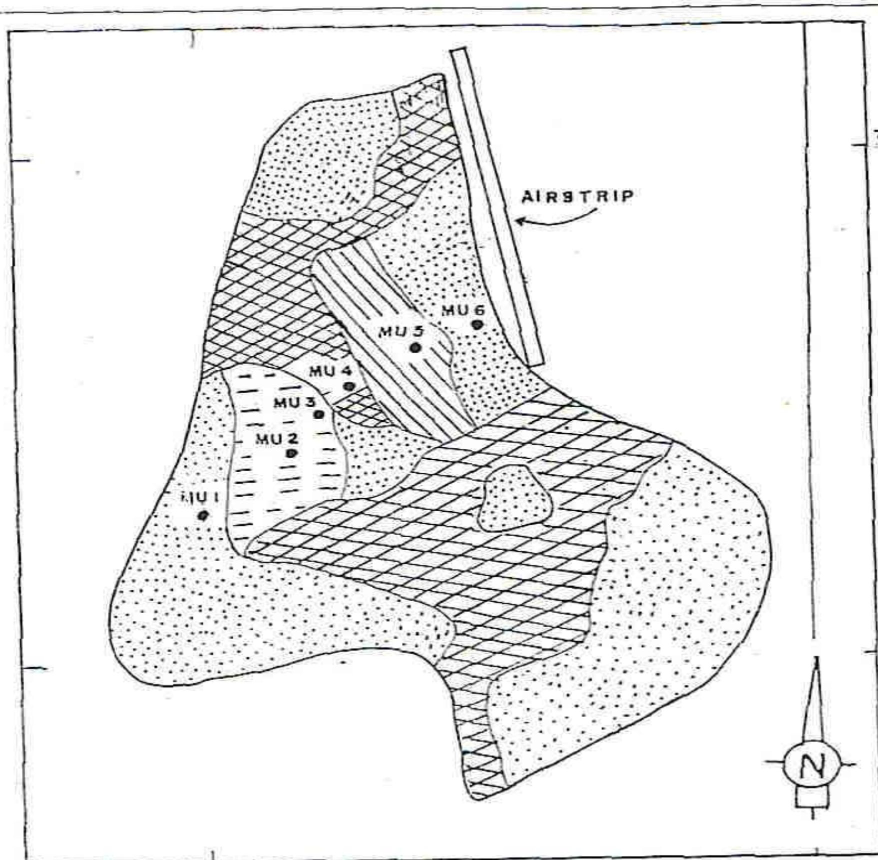
Tree Bush Savanna (TBS) is the most commonly distributed vegetation type in the study areas whilst Grassland (GR) is the least (Table 4.20). GR included vlei and secondary grassland resulting from the removal of trees along stream banks, vlei margins and anthills, for example in Maruta, Agyle and Chikungurugwi catenas. Bush savanna (BS) was mostly encountered in dry middle or lower slopes associated with clay soil that tended to be sodic, compact and shallow for example in Mutsungwe (MU) and Navik Bay (NB) catenas.

In Chikungurugwi (Figure 4.2) out of the total mapped area (40.02 ha), TBS covers about 51.42% of the area on well drained uplands with Siallitic (4G) soils. Bush and Grassland Savanna respectively cover about 28.28% and 21.99% on middle slopes and wet lowland areas with Fersiallitc (5G) that are hydromorphic. This vegetation distribution pattern of is similar to other study areas such as AG, MA and MR.

In Mutsungwe, (Figure 4.1), TBS covers about 58.37% of the total area (21.21 ha) on uplands with Siallitic (4G) soils similar to Chikungurugwi. This is followed by GR (and vlei) with about 37.67% in the middle slopes on Fersiallitic soils. Bush Savanna occupies localised areas towards dry lowlands mostly dominated by *Acacia* and *Colophospermum mopane* on Vertisols (3E / 3M) and Sodic soils (8N)

The vegetation distribution patterns found in ANa and ANb in Mushandike Wildlife Sanctuary are similar to those found in Mutsungwe. In these areas, TBS covers at least 50% of the area with *Colophospermum mopane, Acacia* species being the most common especially in the dry lowland areas although these species occur mainly bushes and shrubs.

Similar to other study areas, BS covers about 54.20% of the area in uplands NB and UN leaving the remainder BS on dry and eroded lowlands and also along waterways dominated by C. mopane *Acacia* and *Combretum* bushes and shrubs.



Scale 1:12500

Map Reference: 1:50000 Mushandike Dam 2031 B1

Vegetation symbol	Vegetation physiognomic type	Area (Ha)	% of Total	Remarks
	Tree Bush Savanna (TBS)	11.16	52.60	Upland Forest
	Tree Savanna (TS)	1.22	5.75	Open stand
	Bush Savanna (BS)	1.41	6.65	Mopane bush and shrub
	Grassland Savanna (GS)	7.41	35.00	Dry lowland
Total		21.20	100	

Notes: i. A dot, and number e.g. MU5 = soil profile location
ii. For detailed description of mapping units see tabular legend next page

Figure 4.1 Vegetation classification map along Mutsungwe catena in Mushandike Wildlife Sanctuary.

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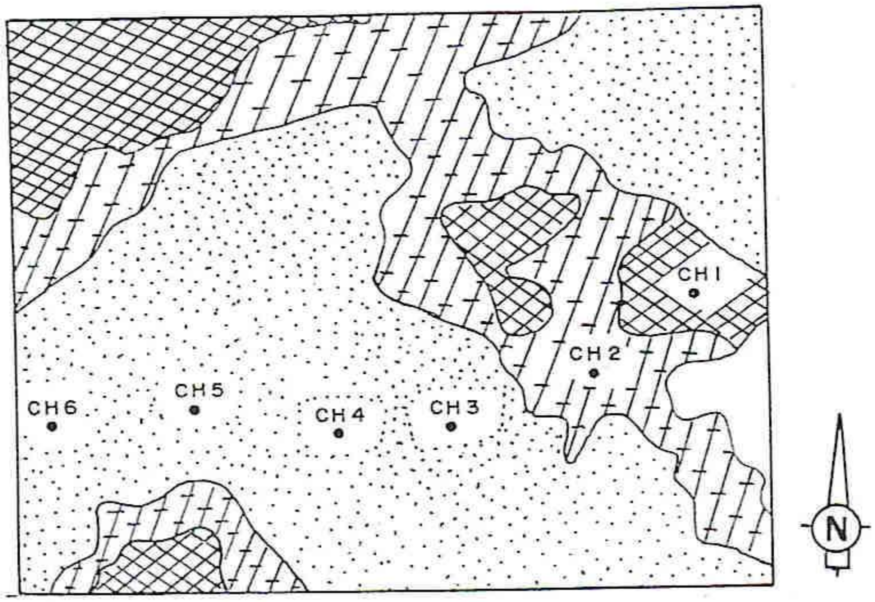
Table 4.21 Legend for vegetation classification along Mutsungwe (MU) catena in Mushandike Wildlife Sanctuary.

Vegetation physiognomic structure	Topography and landform	Geology	Soils	Vegetation description and dominant woody species
TreeBush Savanna (TBS)	Undulating ridge crests and low hills, 5 – 8% convex slope, dotted with small rocky outcrops	Granite	Shalow to moderately shallow, gravelly, freely draining coarse loamy sand or sand loam, Siallitic (4G) soils	Well established deciduous forest of open to closed stands with an understorey cover of bushes and shrubs, dominated by *Brachystegia spiciormis, Burkea africana, Ozoroa reticulata*
Bush Savanna	Gently undulating footslopes, 2 – 5% slopes with concave upper and lower margins, localized areas	Gniess and Granite	Moderately shallow to modreately deep, coarse loamy sand or sand clay loam over coarse, sandy clay loam or sand clay, compact, sodic impermeable, highly erodible, Sodic (8N) soils	Open poorly established stand of bushes and scrub with scattered trees and poor grass cover, open ground patches, dominated by *Colophospermum mopane, Acacia nilotica, Euclea divinorum,*
Grassland Savanna	Gently undulating middle slopes, 2 – 5% slopes, straight and concaves, dotted with some quartz outcrops towards the upper sope	Gneiss and Granite	Moderately shallow, coarse loamy sand over coarse sandy clay loam or sand clay, imperfectly drained, fluctuating water table, Fersiallitic (5G) soils	Wooded vlei grassland, intermediate between wet and dry vlei dominated by *Acacia spp, Terminalia sericea, Maytenus senegalensis*



Scale 1:12500
Map Reference: 1:50000 Makoholi 1930 D4

Vegetation symbol	Vegetation physiognomic type	Area (Ha)	% of Total	Remarks
	Tree Bush Savanna (TBS)	20.58	51.30	Upland Forest
	Bush Savanna (BS)	11.52	28.71	Vlei / Forest margins
	Grassland Savanna (GS)	8.02	19.99	Wet vleis
Total		40.12	100	

Notes: i. A dot and number e.g.•CH2 = soil profile location
ii. For detailed description of mapping units see tabular legend next page

Figure 4.2 Vegetation classification map along Chikungurugwi (CH) catena in Makoholi Research Station.

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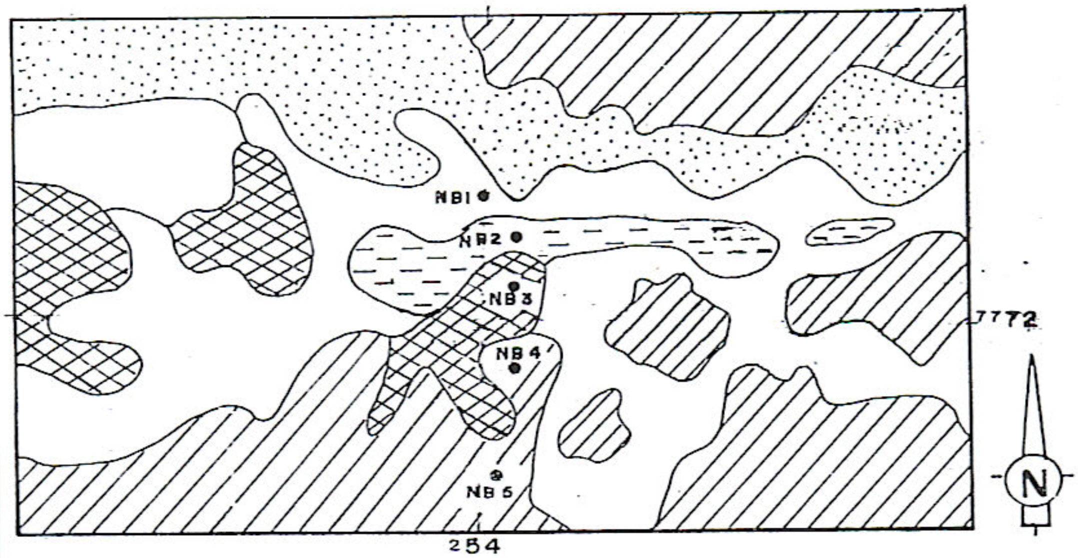
Table 4.22 Legend for vegetation classification map along Chikungurugwi (CH) catena in Makoholi Research Station.

Vegetation physiognomic structure	Topograghy and landform	Geology	Soils	Vegetation description and dominant woody species
Tree Bush Savanna (TBS)	Gently undulating ridges, crests and midddle slope plains with flat areas and pediments, 2 - 5% slope	Granite	Moderately shallow to moderately deep, coarse loamy sand or coarse sandy loam or medium sandy clay loam, reddish brown, Fersiallitic (5G) soil and Siallitic (4G), well drained	Fairly dense stand of deciduous trees with an understorey of bushes and shrubs dominated by *Monotes engleri, Julbernardia globiflora,Combretum molle, Brachystegia spiciformis*
Bush Savanna (BS)	Almost flat, 0 – 2 % slopes, concave at margins, middle slope plain, vlei or forest margins	Granite	Moderately deep to deep coarse loamy sand or coarse sand loam, acidic, greyish, iron II mottled at shallow depth; periodic high ground water, perched water table, moderately poorly drained Fersiallitic (5G) soils	Mixed forest and vlei , transitional stands on sites with perched watertables composed of an open stand of bushes and scattered trees with a good grass cover, dominated by *Terminalia sericea, Julbernardia globiflora Monotes engleri*

Table 4.22 (C0ntined)

Vegetation physiognomic structure	Topography and landform	Geology	Soils	Vegetation description and dominant woody species
Grassland Savanna (GS)	Almost flat and broad, gently undulating , concave slopes 0 – 2% or 2 – 5% slope, Foot slopes and valley bottoms, adjacent to main tributary streams and drainage lines	Alluvium, Granite	Moderately deep to deep, greyish brown coarse loamy sand or sandy loam over sandy clay loam, iron II mottled, Fersiallitic (5G) hydrormophic soils	Wet vlei or dambo grassland vegetation with scattered trees dominated by *Terminalia sericea and Monotes engleri*



Scale 1;16700

Map Reference: 1:50000 Mushandike Dam 2030 B1

Vegetation symbol	Vegetation physiognomic type	Area (Ha)	% of Total	Remarks
	Tree Bush Savanna 1 (TBS)	6.51	17.46	Upland Forest
	Tree Bush Savanna 2 (TBS)	13.70	36.74	Open stand
	Bush Savanna (BS) 1	1.97	5.28	Slope break
	Bush Savanna (BS) 2	3.53	9.47	Bush scrub, eroded, sodic
	Grassland Savanna (GS)	11.58	31.05	Dry riverine, scrub
Total		37.29	100	

Notes: i. A dot and number e.g. NB5 = soil profile location
ii. For detailed description of mapping units see tabular legend next page

Figure 4.3 Vegetation classification map along Navik Bay (NB) catena in Mushandike Wildlife Sanctuary.

Table 4.23 Legend for vegetation classification map along Navik Bay catena in Mushandike Wildlife Sanctuary.

Vegetation physiognomic structure	Topograghy and landform	Geology	Soils	Vegetation description and dominant woody species
Tree Bush Savanna (TBS)	Ridge crests and low hills, Undulating to rolling, irregular slopes, 5-8 % or 8 – 12% slopes, locally dotted with rock outcrops	Granite	Very shallow to moderately shallow, acidic coarse loamy sand, reddish, freely drained Siallitic (4G) soils on quartz gravel, weathering granite	Open to closed well established deciduous forest with under storey bushes, shrubs and grass cover dominated by *Brachystegia spiciformis, Pavetta schumaniana* and *Ozoroa reticulata*
Bush Savanna (BS)	Gently undulating middle and lower plains, rugged and eroded terrain, 2 – 5% slope adjacent to tributary streams and valleys	Gneiss and Granite	Moderately shallow to moderately deep, coarse loamy sands over compact, alkaline (sodic), poorly drained coarse sand clay loam or sand clay with iron II mottles at about 15 to 20 cm depth, Fersiallitic (5G) / Sodic (8N) soils	An open stand of bushes and scrub with scattered trees, sparse grass cover, dominated by *Colophospermum mopane, Combretum adenogonium, Euclea divinorum*, and *Diospyros lycoides*
Grassland Savanna (GS)	Lowland dry plains, tributary valleys and dry vleis Flat to gently sloping areas, 0 – 2% or 2 – 5% slopes	Gneiss and Granite	Moderately shallow to moderately deep medium sandy loam over compact, impermiable, alkaline, medium sandy clay loam soil that is poorly drained, iron II mottles at very shallow depth. Fersiallitic (5G) soil	Dense stand of bushes and scruby plants with a sparse understory grass cover dominated by *Acacia nilotica, Colophospermum mopane, Combretum hereroense* and *Bauhinia thonnigii*

4.6.11 Occurrence and distribution of plant species in the study areas

A total of 134 plant species made up of 81 woody species were identified together with 40 and 13 under-storey grass and herb species respectively. All species were recorded in all study areas and their characteristics measured as already described in section 3.3.6. The results are displayed in Tables 4.24 to 4.31 and Figures 4.4 and 4.5.

The highest species richness for woody species is found in catenas NB, UN and MR and the lowest figures were found in AG and MA (Table 4.24). With individual catenas species richness and density for woody species increase from bottom to top where drainage and aeration are improved in sandy catenas such as Chikungurugwi (Table 4.25). For clayey catenas such as Navik Bay and Mutsungwe (Table 4.26 and Table 4.27) this is the opposite.

For common grass and herb species, the highest species richness was observed in the sandy catenas such as CH and AG. The lowest figures were observed in the clayey catenas such as MU, ANa and MR (Table 4.28). In both sandy and clay catenas, grass species richness appeared to decrease from the bottom of the catenas where soils are more fertile and also more water retentive than the top parts of the catenas.

Occurrence of herb species in sandy catenas such as CH and AG catenas was higher than in the clayey catenas such as MU and UN. This appears to be more associated with leached acidic and base poor soils in the upland sites than with base rich soils in the lowland sites.

Table 4.24 A summary of total individual woody plants (trees, bushes and shrubs) and species richness in plots of 20m x 20m (0.04 ha) from the nine catenas studied on granite.

Name of catena	No of plots	Total individuals	Total No. of Species	Percent of total species
Agyle (AG) Soti Source, Gutu	4	90	21	26
Air Strip North (a) (ANa) Mushandike	4	555	40	49
Air Strip North (b) (ANb) Mushandike	4	484	30	37
Chikungurugwi (CH) Makoholi	6	600	30	37
Maruta (MA) Wedza	4	149	25	31
Mushandike River (MR) Sanctuary	4	479	44	54
Mutsungwe River, (MU) Mushandike	6	822	36	44
Navik Bay (NB) Mushandike	5	1174	47	58
Up Navik Bay (UN) Mushandike	4	327	44	54
Total	41	4680	81	–

Notes: Plots were numbered from the bottom (lowlands) to the top (uplands) of the catena. The total number of plots was 41.

Table 4.25: Species richness and density of woody plants in 0.04 ha representative plots identified along Chikungurugwi (CH) catena in Makoholi Research Station.

Plot No.	Species Richness (no. of individuals)	Total population (no. of individuals)	Species density (plants/ha)
1	9	29	725
2	9	32	800
3	11	95	2375
4	12	53	1325
5	13	136	3400
6	15	251	6275

Notes: Plots were numbered from the bottom (lowlands) to the top (uplands) of the catena. The total number of plots was 41. Minimum sampling area was 20m x 20m (0.04 ha) see section 3.3.6.

Table 4.26: Species richness and density of woody plants in 0.04 ha representative plots identified along Navik Bay (NB) catena in Mushandike Wildlife Sanctuary.

Plot No.	Species Richness (no. of individuals)	Total population (no. of individuals)	Species density (plants/ha)
1	19	292	7300
2	21	440	1100
3	17	207	5175
4	12	63	1575
5	11	172	4300

Notes: Plots were numbered from the bottom (lowlands) to the top (uplands) of the catena. Minimum sampling area was 20m x 20m (0.04 ha) see section 3.3.6.

Table 4.27: Species richness and density in 0.04 ha representative plots identified along Mutsungwe (MU) catena in Mushandike wildlife Sanctuary

Plot No.	Species richness (no. of individuals)	Total population (no. of individuals)	Species density (plants/ha)
1	17	49	1225
2	17	270	6750
3	11	274	6850
4	18	94	2350
5	6	55	1375
6	17	79	1975

Notes: Plots were numbered from the bottom (lowlands) to the top (uplands) of the catena. Minimum sampling area was 20m x 20m (0.04 ha) see section 3.3.6.

Table 4.28: Species richness of common grasses and herbs occurring in 1.0 m^2 plots and in 0.04 ha plots respectively along catenas.

Catena	Grass Species richness (no. of individuals)	Herb Species richness (no. of individuals)
Navik Bay (NB)	14	5
Mushandike River (MR)	11	3
Chikungurugwi (CH)	16	7
Up Navik Bay (UN)	13	3
Mutsungwe Airstrip (MU)	11	3
Agyle (AG)	15	6
Air Strip North (a) (ANa)	14	2
Air Strip North (b) (ANb)	11	3
Maruta - Wedza (MA)	14	4

Notes: The total number of plots was 41. Minimum sampling area was 20m x 20m (0.04 ha) see section 3.3.6.

From Figure 4.4, catenas MU, ANa, ANb and NB have the highest species densities of about 3425, 3568, 3025 and 5870 plants per ha respectively but a very large proportion of this abundance is contributed by percentage of shrubs. These figures confirm the BS vegetation physiognomic type that was identified in these catenas especially in the lower positions. The same catenas have the lowest percentage of trees for example ANa (9.51%); ANb (7.23%) and MU (10.37%) (Figure 4.5). These are catenas with high % clay, TEB and CEC as well as higher AWC but with alkaline (sodic) soils at the bottom that are associated with poor drainage and poor plant rooting conditions, high physical degradation hazard through surface crusting and erosion.

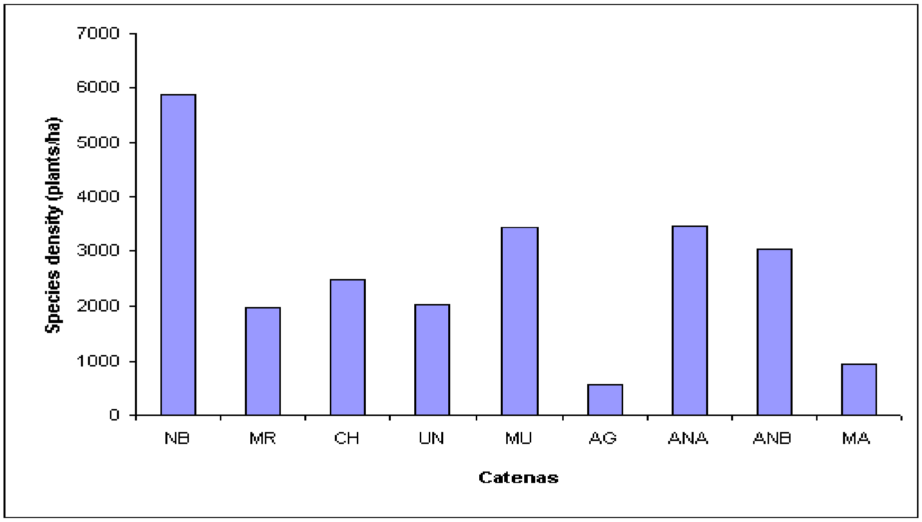


Figure 4.4 Species density in woody plants per ha measured from 0.04 ha plots along the catenas found in the study areas. (NB = Navik Bay; MR = Mushandike River; CH = Chikungurugwi; UN = Up Navik Bay; MU = Mutsungwe; AG = Agyle; ANA = Airstrip North A; ANB = Airstrip North B; MA = Maruta)

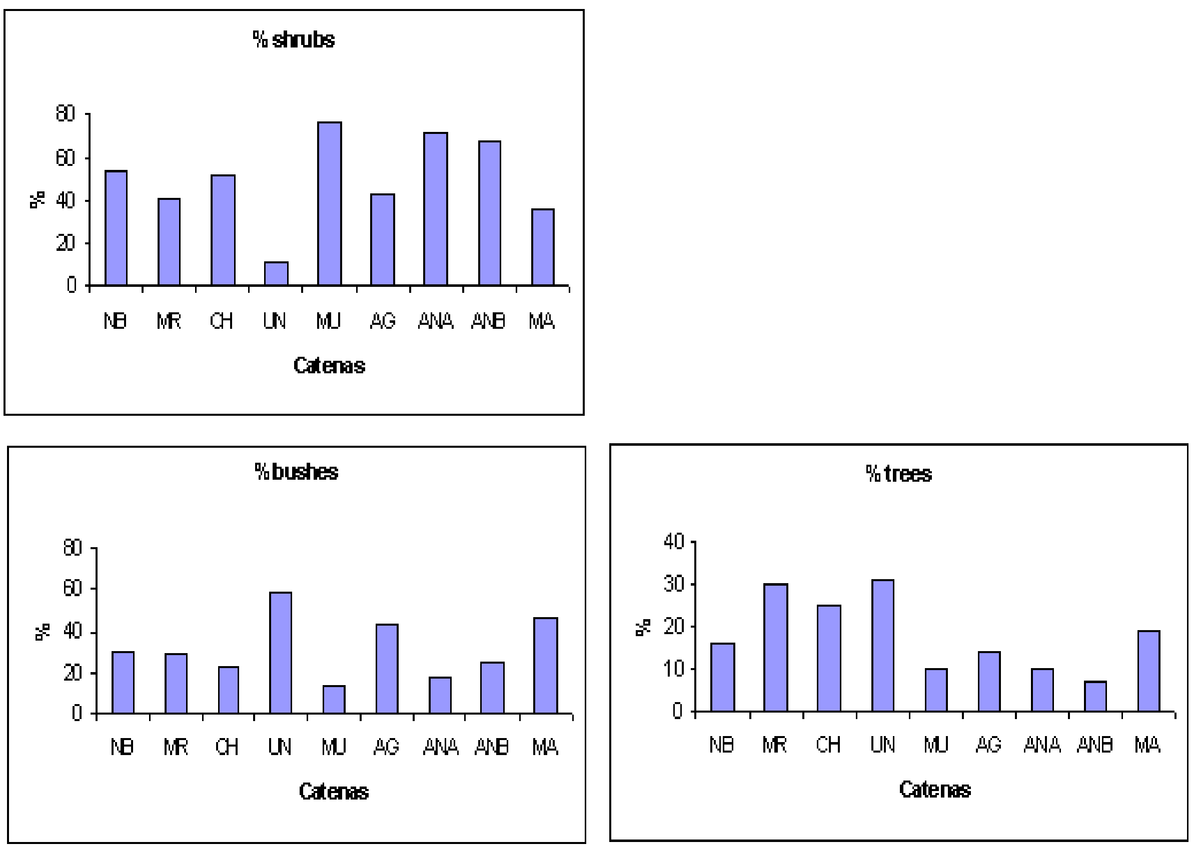


Figure 4.5 Percentage of (a) shrubs (b) bushes and (c) trees and along different catenas. (NB = Navik Bay; MR = Mushandike River; CH = Chikungurugwi; UN = Up Navik Bay; MU = Mutsungwe; AG = Agyle; ANA = Airstrip North A; ANB = Airstrip North B; MA = Maruta).

4.6.12 Characteristics of dominant plant species found in study areas

Details for total individuals and characteristics of the most dominant species found in each catena are summarised in Tables 4.29 to 4.31. The highest species frequency and diversity as measured by the Simpson index but low relative abundance were observed for *Brachystegia spiciformis* in MR, followed by *Colophospermum mopane* in NB catena where it was most abundant but less diverse.

Table 4.29: Population density, relative abundance and diversity of the most dominant woody species on catenas.

Catena symbol	Species name	Total individuals	Frequency %	Species density (plants/ha)	Relative abundance %	Simpson's diversity index (x
ANa	Colophospermum mopane	265	75.00	1637.50	47.38	22 446.69
ANb	Combretum adenogonium	98	25.00	612.50	27.61	7 620.71
MU	Colophospermum mopane	412	50.00	1716.67	50.12	25 121.80
NB	Colophospermum mopane	522	60.00	2610.00	49.95	24 952.18
MR	Brachystegia spiciformis	62	75.00	387.50	14.87	2 210.61
UN	Brachystegia spiciformis	77	75.00	481.25	22.92	5 251.74
CH	Monotes engleri	143	66.67	595.83	23.99	5 756.78
AG	Syzigium huillense	20	25.00	125.00	22.47	5 049.87
MA	Brachystegia spiciformis	51	75.00	318.75	34.23	110715.69

Notes: For full names of catenas refer to Table 3.1

Plant species in different plots along the catena varied in their canopy cover, height and circumference characteristics depending on species density and relative abundance. These were related to the position of the plot along the catena with high species density tending to give low values of percentage tree canopy cover and circumference measurements and low species density giving high percentage tree canopy cover and circumference characteristics but low species maximum height. Tables 4.30 and 4.31 contain some measurements of canopy cover, height and area characteristics of dominant species in Navik Bay catena

Table 4.30: Canopy cover %, maximum height, circumference and area characteristics of dominant species along Navik Bay (NB) catena

Plot	Species Name	Canopy cover %	Species maximum height (m)	Max DBH (cm)	Max basal Circum. (cm)	Max basal area (cm2)
1	Colophospermum mopane	50	5.5	7.0	28.0	62.39
2	Colophospermum mopane	60	10.4	16.55	63.0	315.84
3	Colophospermum mopane	50	4.0	7.32	42.0	140.37
4	Brachystegia spiciformis	80	9.8	26.42	150.0	1790.49
5	Brachystegia spiciformis	80	7.8	54.75	180.0	2578.31

Table 4.31: Canopy cover %, maximum height, circumference and area characteristics of co-dominant species along Navik Bay (NB) catena.

Plot	Woody species name	Canopy cover %	Species maximum height (m)	Max DBH (cm)	Max Basal Circum (cm)	Max Basal Area (cm2)
1	Acacia nilotica	60	4.2	8.91	43.0	147.14
1	Combretum hereroense	60	8.5	21.01	83.0	548.21
2	Euclea divinorum	30	4.0	18.46	12.0	877.34
3	Catunaregum spinosa	10	0.4	0.00	0.00	0.00
4	Julbernardia globiflora	80	7.8	26.42	130.00	1790.49
5	Pavetta schumanniana	10	0.4	0.00	0.00	0.00

4.6.13. Correlation between vegetation and soil characteristics in the study areas

Of the site qualities assessed (Table 4.32), drainage appeared to be the most significantly correlated factor to woody vegetation species richness, the most important vegetation characteristic, followed by position along the catena, slope and soil erosion hazard at $p < 0.05$ significance level. Other correlations in vegetation and soil characteristics are summarised in Tables 4.32 to 4.34.

Table 4.32: Correlation between vegetation and site characteristics in the study areas

Vegetation Characteristic	Topography	Position on catena	Drainage class	Slope %	Erosion intensity
Species richness	-0.54**	0.51**	-0.53**	-0.31**	-0.45**
% bushes	-0.09	0.06	-0.27**	-0.25**	0.16*
% shrubs	0.04	-0.04	0.25**	0.12	-0.15
% canopy cover	-0.05	-0.03	0.15**	0.04	-0.08
DBH	-0.02	-0.06	0.12*	-0.01	-0.03

Table 4.33: Correlation between vegetation and soil characteristics in the study areas

Vegetation Characteristic	%Clay in B horizon	%Clay in BC horizon	Roots abundance in A horizon	Roots abundance in B horizon	Roots abundance in BC horizon
Species richness	0.28**	0.27	0.25	0.16	0.20**
% trees	-0.13*	-0.12*	0.01	0.01	0.03
% bushes	0.10	0.15**	-0.07	0.08	0.03
Species density	0.08	0.06	-0.12*	-0.06	-0.00
Species % canopy cover	-0.15**	-0.16	-0.04	-0.06	0.01
Species maximum height	0.13*	0.13*	-0.08	-0.06	0.03
Species DBH	0.12*	0.12*	-0.05	-0.04	0.02

Notes: * = significance level at $p < 0.05$; ** = significance level at $p < 0.01$.

Table 4.34: Correlation between species characteristics, soil pH and exchange properties of the soil.

Vegetation Characteristic	pH in B horizon	pH in BC horizon	CEC in B horizon	ESP in B horizon	ESP in BC horizon	Ca/Mg in A horizon	Ca/Mg in BC horizon
Species richness	-0.21	-0.32**	-0.37**	0.71**	0.01	0.85**	0.45**
Population	0.17*	0.17*	0.13	0.15	0.17*	0.00	-0.69**
% trees	0.15	0.17*	-0.10	-0.06	0.09	0.04	-0.20
% bushes	0.17*	0.17*	0.18*	0.03	0.11	-0.17	0.25
% shrubs	-0.05	-0.02	-0.09	0.07	-0.04	0.20	-0.20
Species density	0.17	0.17*	0.13	0.15	0.16*	0.00	0.09
Species % canopy cover	-0.11*	-0.15**	0.09	0.00	0.00	0.00	0.00
Species maximum Height	0.09	-0.11*	-0.03	0.00	0.02	0.00	0.00
Species maximum DBH	-0.13*	-0.14**	-0.07	0.00	0.01	0.00	0.00

Notes: * = significance level at $p < 0.05$; ** = significance level at $p < 0.01$.

There are negative and significant correlations between drainage and species richness, (r = – 0.53) and between drainage and percentage of bushes (r = – 0.27) but positive correlation between drainage with percentage of shrubs and percent canopy cover. This implies that species richness and the percentage of bushes decrease as drainage class improves while canopy and shrubs increase (Table 4.32). This was observed in Navik Bay and Mutsungwe catenas. Species richness is negatively correlated with topography (r = – 0.54), position (r = – 0.51), slope (r = – 0.3) and erosion hazard (r = – 0.45). Percent bushes is negatively and significantly correlated with slope of the land (r = – 0.25) but also positively correlated with erosion hazard (r = 0.16) (Table 4.33a).

For clay content of the soils (Table 4.33b), species richness is negatively and significantly correlated with % clay in the B-horizon (r = – 0.28). Percentage of trees appears to be negatively and significantly correlated to % clay in the B-horizon (r= – 0.13). Percentage of bushes is positively correlated with clay content in the B-horizon (r = 0.15). The maximum species height and diameter at breast height (DBH) are positively correlated with clay content both in the B and BC horizons. As expected, there are however no significant correlations between woody (excluding grasses) species characteristics and roots abundance (Table 4.33) except for species richness in the BC horizon (r = 0.20) and species density in the A-horizon (r = – 0.11).

For pH and exchange properties of the soil (Table 4.34), species richness is negatively and significantly correlated with soil pH in the B and BC horizons and CEC in the B-horizon. There is a positive and highly significant correlations between species richness and ESP in B horizon (r = 0.71) as well as calcium to magnesium ratio in the A and BC horizons with r-values of 0.85 and 0.45 respectively suggesting that there is high association of species with sodicity and inverted calcium to magnesium ratios as observed in Mutsungwe (MU), Navik Bay (NB) and Airstrip North (ANa) catenas. Plant population is positively and significantly correlated with soil pH in the B and BC horizons and with ESP in the BC horizon while % trees, % bushes, species density and other vegetation characteristics are also significantly correlated with pH, CEC and ESP in the A and B horizons.

Bulk density of the soil in the A and B-horizons is negatively and significantly correlated with species richness with r-values of – 0.35 and – 0.80 respectively. There is a positive and significant correlation between species richness and available water capacity of the soil in the A and B horizons with r-values of 0.50 and 0.92 respectively but a negative and significant correlation between species richness and permanent wilting point (PWP) in the B horizon with r-value of 0.33. This result seems to suggest that species richness is highly associated with clay and base-rich soils of higher AWC but of poor permeability and drainage.

4.7 DISCUSSION

4.7.1 Soils of the study areas

The main soil types that were identified in the study areas are siallitic (4G), fersiallitic (5G), sodic (8N) and Fersiallitic (5GE). These soils do reflect diverse physical, chemical and biotic properties but the scale is small. It was observed that variability of soil properties was systematic and persistent along the catena showing the influence of site drainage, erosion and soil fertility. It reflected physiognomy and species composition in the upland sandy soils that were acidic, leached and generally infertile but well drained. These soils were associated with Tree Bush Savanna (TBS) the most widely distributed vegetation type dominated by deep-rooted *Brachystegia spiciformis* and *Julbernardia globiflora*. In the dry lowlands more fertile base-richer clay soils that were affected by excess sodium salts identified as Sodic (8N) were associated with BS dominated by *Colophospermum mopane*, and *Acacia* bush and scrub. On the other hand in wet lowland areas, clay loamy soils that are more fertile but more susceptible to water logging identified as Fersiallitic (5G) hydromorphic soils were associated with GS characterised by scattered trees mainly *Syzigium guineense* subspecies *guineense* and *Ficus* species. Between the uplands and the lowlands were Fersiallitic (5G) and/or Siallitic (4G) soils depending on the intensity of weathering and leaching and also the degree to fluctuating ground water caused by perched water tables due to impeded drainage of the sub soil and/or saprolite. In this transitional zone is a mixture of tree vegetation composed of a mixed mosaic of TBS; BS and GS dominated by *Terminalia sericea* and *Parinari curatellifolia* and *Monotes engleri* commonly occurs. This pattern of variability was very common in all catenas and can be described as macro variability. Its trends and magnitude can be predictable and related to already known factors for example the influence of slope and soil moisture regimes and processes such as weathering taking place along the catena.

In addition to macro variability, there is evidence of micro variability for example due to clay elluviation and illuviation, and sodicity in the soils that was observed at single soil profiles on the catena. Perhaps a most intriguing feature that was noted from the soils was the extremely low or inverted calcium to magnesium ratios that tended to occur in all the three soil types: Siallitic (6G), Fersiallitic (5G) and Sodic (8N) especially in the sub soils irrespective of position along the catena. This situation is very unusual for sandy soils derived from granite. It is a situation that is associated with heavy metal toxicity in red clay soils derived from ultramafic rocks that are found along the main Zimbabwe Great Dyke (Wild, 1965). The values for Ca/Mg ratio encountered in the study areas that are less than 1.00 are anomalous and therefore difficult to explain considering that there was no evidence of ultramafic intrusions observed in the study areas which could be attributed to this occurrence although there are some minor occurrences of certain known ultramafic related vegetation species in localised sites such as *Brachystegia boehmii* and *Diplorhynchus condylocarpon* especially in Mushandike Wildlife Sanctuary. Similar results showing inverted Ca/Mg ratios in sandy soils were also observed elsewhere by earlier workers such as Purves (1976) working in granite soils in Zimbabwe although no explanation was given by this author.

Previous literature has already established that in soils derived from acid igneous rocks such as granite, similar to those found in the study area, the bivalent calcium and magnesium ions are provided by primary minerals (Brady, 1990). In this study, from what has been observed on uplands granite sites, the Ca and Mg contents were very low and less than 5.0 c mol c / kg as expected from these soils in Zimbabwe (Nyamapfene, 1990). Therefore, following a small input of bases from weathering under low rainfall and high leaching conditions in these areas tends to produce high acidity in sandy soils certainly because of the deficit in base saturation of the adsorption complex by these two major elements.

Under these circumstances, it has already been established that magnesium is leached faster than calcium and then will accumulate more in the lower heavier horizons, more so in poorly drained soils where it contributes to magnesium saturation of clays and a rise in pH (Brady, 1990). It is therefore possible to have higher magnesium than calcium in soils derived from granite especially in leached and poorly drained conditions. On lowland sites with soils affected by excess sodium inverted calcium to magnesium ratios are associated with high exchangeable sodium percentage in the sub soils.

4.7.2 Relating vegetation physiognomy and species composition to soils found in study areas

Previous vegetation survey on granitic sandy soils lacked spot or site observations with emphasis on local topography and soil type. Available soil survey reports by AREX officers from the Ministry of Agriculture and Rural Resettlement are based on interpretations of existing natural resources survey information at exploratory scales such as the Soil Map of Zimbabwe at a scale of 1: 000000.

In this study, distinct changes in vegetation physiognomy and species composition could be observed along catenas on granite in the study areas. It was possible to separate the different vegetation physiognomic types along the catena using aerial photo interpretation based on the recognition of differences in tones, texture, patterns and shapes as well as relief (Dent and Young, 1980). In this study, three vegetation physiognomic types namely Tree Bush Savanna (TBS), Bush Savanna (BS) and Grassland (GR) were recognised. These were described in terms of local topography, landform, soils and species composition. These physiognomic types and most dominant species appeared to have a bearing on soil type and land potential and overall land use in the different study areas.

Observations from this show that in drier parts of the study areas, a tree bush savanna (TBS) – bush savanna (BS) vegetation pattern was common along catenas dominated by a *Brachystegia* - *mopane* savanna mosaic the separating topographic and soil characteristics being related to altitude, soil pH, % clay and drainage. *Brachystegia* species occurred on acidic soils in the uplands and *Colophospermum mopane* occurred on alkaline and sodium enriched soils at the lower parts as a bush savanna (BS). This is the vegetation type described by Timberlake *et al*. (1993) as a miombo – mopane mosaic that earlier workers, such as Wild and Barbosa (1968), had broadly classified under mopane woodland.

On the other hand, in moist semi arid conditions on granite, a TBS – GS vegetation pattern was common along the catena dominated by a *Brachystegia* – *Syzigium* savanna mosaic. These vegetation types occur on poorly drained soils. They are separated from each other by catena gradients related to soil moisture and drainage, clay content and CEC in the sub soil leading to high water logging and poor plant rooting conditions.

Most of the upland soils under TBS on granite are acidic in chemical reaction with measured pH values ranging between 4.3 and 5.8 confirming typical weathered granite soils commonly found in Zimbabwe under miombo vegetation. Their coarse texture has given rise to good drainage and aeration conditions for good root respiration for most plants and grasses as evidenced by the presence of few mottles that were observed throughout the soil profiles. Plant species such as *Brachystegia*, *Julbernardia* and *Combretum* are commonly found in these soils because of their deep root systems capable of mining water and nutrients from deeper layers of the soil throughout the year. These species can also encountered in combination with a mosaic of other species such as *Combretum* species*, Burkea africana, Peltophorum africanum and Terminalia* species. The last two are found in transitional sites such as forest or vlei margins where there is a marked increase in available soil moisture due to a fluctuating water table during the wet season.

The most important site quality and soil characteristics that appeared to determine the occurrence and distribution of woody vegetation physiognomic types and species composition in the granite catenas were related to drainage, nutrient availability and retention, excess salts, and their associated effects on soil erosion.

4.8 CONCLUSIONS

The following conclusions were made:

4.8.1 Granitic soils found in the study areas do vary with vegetation physiognomic types and species composition along the catena. The results of this study indicate that at the bottom of the catena on Sodic soils under BS or GS vegetation types in semi arid *Bolasanthes speciosus*, *Acacia*, *Combretum*, *Euclea* and *Colophospermum mopane* together with a range of other eutrophic species are most abundant. In wet areas these lower parts of the catena with Fersiallitic soils on GS vegetation type will be dominated by species such as *Syzigium* and *Ficus.* In the middle slopes on Fersiallitic or Siallitic soils under TBS or TS are species such as *Diploryhncus condylocarpon*, *Terminalia sericea*, *Monotes engleri* and *Parinari curatellifolia* on grassland margins. At the top of the catena with deep sandy or sandy loam soil classified as Siallitic are TBS vegetation types dominated by species such as *Brachystegia spiciformis*, *Ormacarpum kirkii* and *Julbernardia globiflora* and other similar dystrophic vegetation species of uplands.

4.8.2 Percentage of clay in the B-horizon is the most variable soil physical characteristic in the granite soil. Of the chemical characteristics measured, soil pH is the least variable characteristic of the granite soils. Cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) in the A and B-horizons are the most variable characteristics.

4.8.3 It is possible to have higher exchangeable magnesium than exchangeable calcium in granite sandy soils especially in leached and poorly drained areas. On lowland sites, and in sites affected by excess salts of sodium, inverted calcium to magnesium ratios are commonly associated with high exchangeable sodium percentage in the sub soils.

4.8.4 Under moist conditions, species richness increases with slope, drainage and soil type from the base-rich soils found in poorly drained lower parts of the catena to the base-poor soils found in well drained uplands, hills and the crests. Fertility in these soils seemed to be maintained by the efficient cycling of nutrients between litter from the vegetation (and other biota) and the soil (Scholes and Walker, 1993; Schulte, 1998). This undoubtedly is strongly believed to contribute to the nutrient functioning of the vegetation stands in the upland parts of the catena. Under drier conditions along the catena such as lowlands with compact soils, higher species richness is closely associated with eutrophic sites characterised by heavy textured soils with high exchangeable sodium percentage in the B-horizons that results in poor rooting conditions. But the majority of the plant species were mopane bush and scrub.

4.8.5 There is no significant correlation between species characteristics measured and soil moisture represented by the available water capacity (AWC) of the soil, but there is a significant correlation between species richness and soil drainage, erosion, clay content, pH, CEC, ESP and bulk density of the soils at 5% significance level.

CHAPTER FIVE

VEGETATION-ENVIRONMENTAL RELATIONSHIPS AND THE INFLUENCE OF SOIL CHARACTERISTICS ON VEGETATION IN SEMI-ARID AREAS.

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5.1 ABSTRACT

A study was conducted on granitic soils comprising moderately shallow, to deep Siallitic (4G) Fersiallitic (5G), Siallitic (4G) and Sodic (8N) soils in semi-arid areas of Zimbabwe. Study areas were located in Mushandike, Makoholi and Gutu all in Masvingo Province and in Maruta village, Wedza in Mashonaland East Province. Forty-one vegetation sites with a total of 81 woody plant species were studied.

The objectives of the study were to identify environmental gradients that are responsible for the variation in vegetation patterns and species along the catena in semi arid areas in Zimbabwe, investigate soil characteristics as main factors influencing this variation and identify vegetation indicator for certain soil characteristics.

A cluster analysis was conducted to identify groups of vegetation sites that were found in the study areas. In addition, Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) ordination techniques were carried out. The purpose of these were to investigate variance in vegetation and relate community composition to known characteristics of soils, and to identify indicator species for certain soil characteristics and land management problems.

Results from the cluster analysis for the species density data used showed that, at 60% similarity level, vegetation sites from the study areas could be grouped according to changes in environmental factors, mainly soil moisture, topography, drainage, soil fertility, sodicity and erosion. The DCA ordination revealed that the strongest environmental gradients that could be explainable were more apparent from the density data set than from other data sets (canopy cover and maximum height) used. Definite ecological patterns of sites and species based on known characteristics were more recognisable from the ordination diagrams obtained using species density data set than from those obtained using percent canopy cover and maximum height data sets. The major ecological gradients and most important land qualities that distinguished upland from lowland vegetation were associated with environmental factors that include ESP, CEC, soil erosion and drainage status of the soil. These factors corresponded to land qualities – attributes of land that act in a distinct manner in their influence on suitability of land for a specified kind of land use and management (Dent and Young, 1980).

Results from the CCA analyses showed that the coefficient of variation (CV) of most soil variables was >25% except for pH_A, AWC_A and AWC_B. Each variable explained a unique characteristic of the species abundance in the study areas except for CEC_B. The weighted correlation (n=41) of these variables was most significant between CEC_B and $\%clay_B$ (r=0.72); CEC_B and pH_B (r = -0.74), and drainage together with erosion (r=0.76).

About 67% of the variation in species abundance could be explained by changes along axis 1, which represented the most important environmental gradient. The cumulative figures for percent variance of species abundance and species environmental relationships in the study areas were 10.5% and 35.9% respectively. nce water-holding capacity of the soil.

It was concluded that although the three vegetation characteristics: species density, canopy cover and height were alternative measures of vegetation structural importance they differed in their sensitivity for measurement. Density was the most sensitive and accurate measure that reflected more meaningful ecological patterns closely related to known environmental factors. It was also concluded that vegetation types and species composition in the areas studied were neither influenced by individual soil types nor single soil characteristics such as percentage clay, pH, ESP and CEC. Rather they were influenced by a combination of factors such as drainage, erosion and soil fertility. These (factors) are important land qualities that determine the agricultural potential of a site as well as related land management problems that need to be addressed for sustainable production.

5.2 INTRODUCTION

Changes in the distribution of vegetation communities, species composition and abundance that are observed on the landscape are a natural property of ecological systems. These ecological systems cannot only be studied for the purpose of establishing how things are, in this case vegetation, but also to understand how and why the vegetation changes the way it does in space and time (Anderson and Gribble, 1988).

Before a detailed assessment and analysis of the environmental factors influencing the changes in vegetation and species distribution can be made, it is necessary to consider the natural variation in the distribution of species along the landscape. This will enable one to be able to gain an insight and understanding of the ecological structure and factors responsible for the changes in vegetation.

Classification and ordination have often been used as multivariate techniques in vegetation analysis to identify vegetation groups or clusters and also to compare species data and environmental factors. This is achieved by interpreting the axes of variation constructed from the vegetation data in terms of possible ecological gradients as well as environmental factors that can be used to explain the variation.

The purpose of the cluster analysis was to identify groups of sites from the study areas that formed homogenous vegetation communities and relate them to environmental gradients identified from the DCA analysis. The CCA provided an opportunity to elucidate variations in vegetation and species distribution patterns.

5.3 OBJECTIVES

The major objectives of this chapter are threefold:

5.3.1 To explore vegetation community structure and composition and explain changes in vegetation according to known ecological gradients along the catena on granite in semi arid areas

5.3.2 To investigate the variance of vegetation types and species along the catena in study areas and detect which of the soil variables measured influence this variation on granitic soils.

5.3.4 To investigate which vegetation characteristics and species are consistently associated with the soil characteristics in granitic soils found in arid areas.

5.4 HYPOTHESES

5.4.1 Vegetation and plant species along the catena are dependent upon environmental gradients related to soil moisture, drainage, soil texture, soil fertility, sodicity and soil erosion.

5.4.2 Soil variables influence vegetation abundance and distribution along the catena in semi-arid areas on granite.

5.4.3 Plant species can be used as indicators of soil type in semi arid areas.

5.5 MATERIALS AND METHODS

5.5.1 Preparation of species data matrices for multivariate analyses

Plant species abundance data sets based on species density, species percent canopy cover and species maximum height, for 81 woody plant species encountered in 41 plots were used to design data matrices for the multivariate analyses. Vegetation data matrices for species by sites and environmental variables by sites were designed for the purpose of multivariate analyses. A computer program called CANOCO (ter Braak, 1987) was used as an aid for analysis.

All site variables such as erosion, wetness and drainage which were originally measured and recorded as categorical variables (Table 4.12) were converted into dummy variables (presence or absence data). The conversion from categorical to dummy variables was done by assigning the value 1 for the presence and 0 for absence of the variable which are compatible with the CANOCO program (ter Braak, 1996). Data for the actual species abundance were preferred to standardised values, as the objective was to represent the actual situation in the field.

5.5.3 Multivariate Cluster Analysis

Sites by species data matrices made up of 41 plots and 81 woody plants species were constructed using the vegetation species abundance data for species density, height and canopy cover.

The cluster analysis was done using a hierarchical clustering procedure following a divisive methods called the Average Linkage Clustering Technique in the MINITAB computer statistical program (Gauch, 1982). This technique is based on the fusion of single or individual clusters that closely resemble one another into large groups or classes. This technique has been described as the average similarity or dissimilarity between all possible pairs of members and is described in detail by Jongman *et al*., (1987).

The evaluation of cluster dendrograms was done visually by examining the clusters and relating them to environmental gradients perceived in the DCA described in section 5.5.2. In addition, field knowledge and experience of the observed environmental characteristics of different sites were used to interpret dendrograms. Three broad clusters of vegetation sample sites were identified from the density data set and then compared with the results from the DCA analyses.

5.5.3 Detrended Correspondence Analysis (DCA)

An ordination technique called Detrended Correspondence Analysis DCA by Hill (1979) was used with the aid of the computer program CANOCO (ter Braak, 1986). The purpose of the DCA was to define the ecological data structure and identify key site and soil variables that could best characterise the identified structure.

This method of analysis is a further development from Correspondence Analysis (CA) developed by Hill (1974). However the CA suffers two major setbacks of the "arch effect" and compression of the ends of gradients. It is for this reason, in this study, that DCA was therefore chosen to overcome the problems by detrending and re-scaling (Gauch, 1982). The DCA is often referred to as the Reciprocal Averaging (RA) method. It assumes that plant species have unimodal species response curves rather than linear and that a species is located in the position where it is most abundant. However the CA suffers two major setbacks of the "arch effect" and compression used to overcome these two problems by detrending and re-scaling. The actual processes involved in the methods which were developed by Gauch and Hill (1980) are fully described in detail by Gauch (1982).

For this DCA analysis, vegetation data matrices for all the 81 plant species from 41 plots found in Mushandike Wildlife Sanctuary, Makoholi Research Station and Soti Source Resettlement of Gutu in Masvingo Province and from 4 plots found in Maruta village of Wedza communal land were used.

5.5.4 Preparation of vegetation and soils data for Canonical Correspondence Analysis (CCA).

Based on the environmental gradients already identified, ten most important soil characteristics defining these gradients were selected (Table 5.10) leaving the rest, to improve the analytical power of the CCA. Plant species abundance defined by density (Section 5.5.1) for all the 81 woody vegetation species encountered in 41 plots were used to establish data matrices (environmental variables x vegetation sites) for the CCA with the aid of the CANOCO computer program. From all site variables measured, two most important variables namely soil erosion intensity, and drainage status of the soil were then converted to dummy variables that are compatible with the CANOCO program. These variables were originally measured and recorded as categorical variables (Table 4.12) following guidelines by Bennett (1985) and Stocking *et al*., (1988)

The selected soil variables were subjected to a forward selection procedure in the CANOCO computer program. This procedure enables the selection of significant variables by performing a testing process which reduces the inflation of unexplained variation by elimination of redundant variables that cause variation by chance (ter Braak, 1987; Anderson and Gribble, 1998). This process uses The Monte Carlo significance test at 95% confidence level ($p = 0.05$).

5.5.4 Canonical Correspondence Analysis (CCA)

To be able to obtain a combination of explanatory soil variables maximizing the separation or distribution of vegetation sites and plant species along the catenas, Canonical Correspondence Analysis (CCA) was chosen. This (CCA) is a multivariate ordination method developed to relate vegetation composition and other biological communities to known variation in the environment (ter Braak, 1996). It extracts axes of variation from species occurrence or abundance data which (axes) are interpreted with the help of external knowledge of data on environmental variables.

The CCA method is a constrained ordination that was developed from the original Correspondence Analysis (CA) (Hill, 1974) and DCA (Hill 1979a; Hill and Gauch, 1980). It differs from CA and DCA in that, rather than looking for implicit relationships between ordination of biological data and environmental characteristics, which CA and DCA do, it looks for explicit relationships and therefore it is a direct gradient analysis ordination method (Jongman *et al*., 1995).

A detailed description of the CCA ordination method is given by ter Braak, (1996).

5.6 RESULTS

5.6.1 Classification of vegetation sites

The cluster analysis (Figure 5.1) classified sites into different groups on the basis of similarities and abundance of species. Three dendrograms (Figures 5.1 – 5.3) were produced using species density, canopy cover and height data matrices.

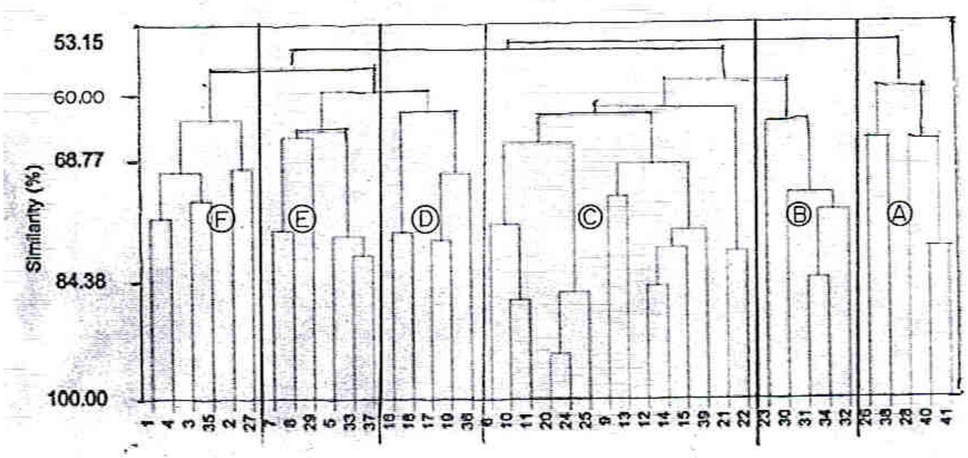

Figure 5.1 Dendrograms of 41 vegetation plots obtained using the Average Linkage Technique with species density data set for all vegetation sites selected in study areas. Symbols A to F shown indicate clusters of sites or plots. A key to the plot numbers is provided in Appendix 5.2.

Six different woody plant communities (A - F) were distinguished by the cluster analysis (Figure 5.1) at about 60% similarity level on the bases of vegetation physiognomy and soil type as well as erosion intensity and drainage status.

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Cluster A is made up of Grassland (GS) and Bush Savanna (BS) vegetation physiognomic types on Siallitic and Feriallitic soils found in middle and lower slope positions of the catena. The most dominant grasses are *Hyperrhernia filipendula* in combination with scattered tree species mainly *Syzigium* species, *Combretum molle*, *Brachystegia spiciformis* and *Diospyros lycoides* the later on termitaria.

Cluster B comprise BS and GS vegetation physiognomic types on Siallitic and Sodic soils found mostly on lower slope positions of the catena. The dominant woody species found in this cluster include *Combretum species*, *Colophospermum mopane*, and *Euclea divinorum*. These species are found in combination with *Heteropogon contortus* and *Hyperrhernia* grass species.

In cluster C, the most common vegetation physiognomic type is TBS found on crests and other upland positions of the catena with well drained Siallitic and Fersiallitic soils dominated by *Brachystegia spiciformis*, *Julbernardia globiflora*, *Parinari curatellifolia* and *Monotes engleri*. In this cluster, the co-dominant grass species are *Eragrostis* and *Aristida* species. Bush Savanna and Grassland can also be found in lower positions with *Colophospermum mopane* and *Terminalia sericea* on Siallitic and Sodic soils. These species occur in combination with *Hyperrhenia*, and *Heteropogon contortus*

In cluster D , the most common vegetation physiognomic type is TBS. This type is found on middle slopes and crests. This type of vegetaion is dominated by *Terminalia sericea* and *Brachystegia spiciformis* on Siallitic soils.

In cluster E, TBS is very common on upland positions and crests with well drained Siallitic and Fersialitic soils. The most dominant woody vegetation species are *Brachystegia spiciformis* and *Julbernardia globiflora*. Vertisols are also found in localised places associated with mixtures of thick under storey cover of grasses and herbs.

A mixture of TBS, BS and GS occurs as cluster F on Siallitic, Sodic and Fersiallitic soils respectively. The most dominant woody species are *Brachystegia spiciformis*, *Colophospermum mopane* and *Syzigium* species. In BS vegetation type on lower catena slopes, vertisols can also be encountered. In these areas, *Colophospermum mopane* as bushes and shrubs is very common.

Dendrogams obtained from canopy cover and maximum height data are represented in Figures 5.2 and 5.3 respectively. From Figure 5.2, five clusters were identified at about 60% similarity level and labelled as P, Q, R, S and T. Clusters P and Q are small Grassland Savanna vegetation physiognomic types on middle and lower slope positions with Fersiallitic and Sodic soils. These sites are hydromorphous and are dominated by *Syzigium* and *Diospyros lycoides* tree species. Cluster R comprise mainly of BS found in dry lowland areas associated with poorly drained Sodic, Siallitic and Fersiallitic soils. The most dominant woody vegetation species include *Colophospermum mopane*, *Terminalia sericea*, *Acacia nilotica* and *Combretum* species. In uplands along crestlines are Siallitic soils under TBS dominated by *Brachystegia spiciformis*. Cluster S is a mosaic of TBS, BS, and GS vegetation physiognomic types on Fersiallitic soils dominated by *Brachystegia and Syzigium* species.

The remaining group of sites (Cluster T) is a broad formation that comprises well drained upland (ANa_4, NB_4, MU_6), middle slope (MR_3, AG_3, UN_3, ANa_3) and lowland sites (CH_1, CH_2, MR_1) that are non-sodic. The major vegetation physiognomic type in this cluster is TBS. This vegetation type is found on well drained Siallitic and Fersiallitic soils, on middle and crest positions of the catena. Ocassional grassland vlei and bush can be encountered in localised sites along the catena. At 70% to 80% similarity levels, more upland clusters that are well drained, dominated by *Brachystegia spiciformis* on Siallitic soils tend to appear but these are rather small.

The ecological interpretation of Figure 5.3 appears to be similar to that of Figure 5.1 in that six broad clusters (U, V, W, X, Y and Z) were identified at about 60% similarity level. Clusters U, V and X are small groups of sites comprising TBS, BS and GS on Siallitic, Fersiallitic and Sodic soils. The most dominant species are *Brachystegia spiciformis*, *Euclea divinorum* and *Syzigium* species on Siallitic and Fersiallitic soils.

Cluster W is a large mixed group of upland and middle slope sites that range from moderately well drained to well drained Fersiallitic and Siallitic soils. The major vegetation physiognomic type is TBS found on both middle and upland sites with minor occurences of BS in localised areas. In this cluster, the most dominant tree species are *Brachystegia spiciformis*, *Euclea divinorum*, *Parinari curatellifolia* and *Monotes engleri*. At higher similarity levels (70-90%) clusters for upland sites become more apparent as for cluster T (Figure 5.2). The last two clusters namely Y and Z represent wet lowlands with perched water tables and dry lowlands with more erodible Sodic soils respectively.

These results show that there is variation in groups of vegetation sites found in the study areas. At about 60% similarity level and above, it was possible to find groups of sites that could be related to certain environmental factors such as soil fertility, sodicity, soil drainage status and soil erosion that are known to influence site conditions, vegetation and species abundance on the landscape.

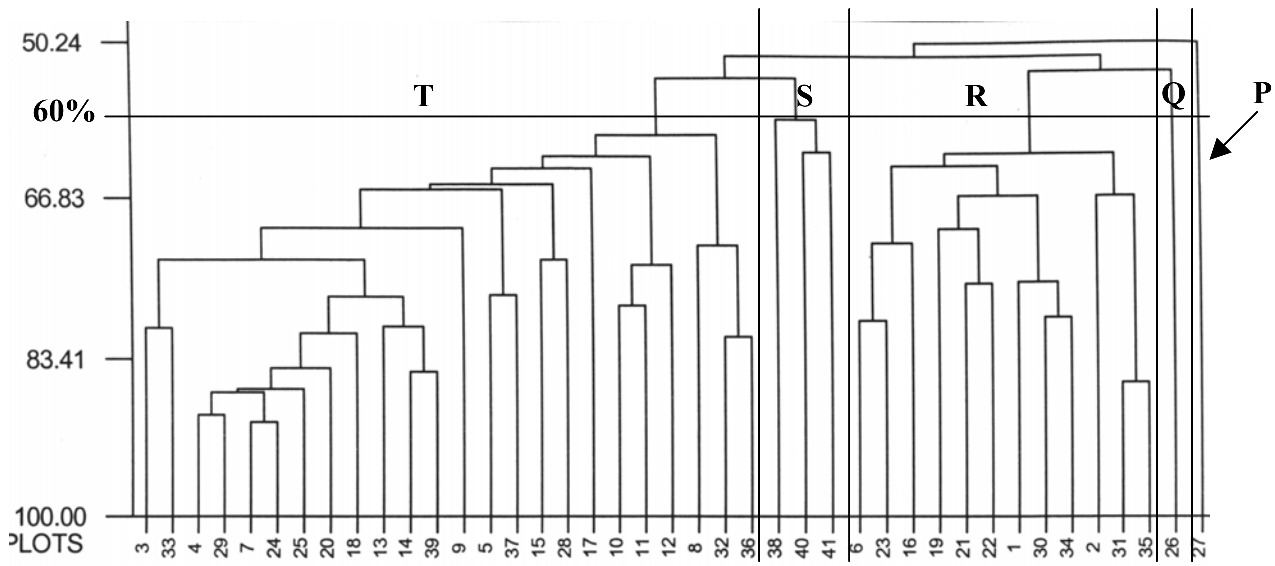


Figure 5.2: Dendrograms of 41 vegetation plots using the Average Linkage Technique with species percent canopy cover data set for all vegetation sites selected in study areas. Symbols U to Z shown indicate clusters of sites or plots. A key to the plot numbers is provided in Appendix 5.2.

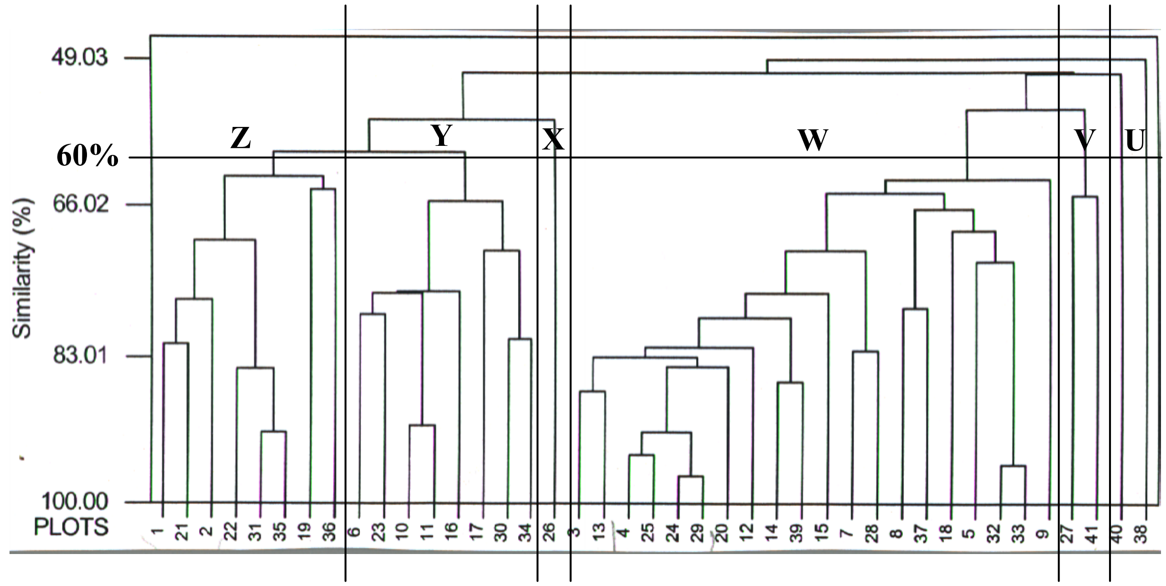


Figure 5.3: Dendrograms of 41 vegetation plots using the Average Linkage Technique with species maximum height data set for all vegetation sites selected in study areas. Symbols U to Z shown indicate clusters of sites or plots. A key to the plot numbers is provided in Appendix 5.2.

For individual vegetation species, the interpretation of species dendrograms has not been attempted because the ecological meaning of the cluster divisions was difficult to establish. This was possibly due to the wide range of species tolerances to many ecological conditions as already mentioned under the sections on ordination.

5.6.1 Variance in species data from the study areas

Results for the variance of both species and sites ordination derived from the three data matrices are summarised in Table 5.1. The total number of detrended segments used in the ordination biplots is 26 and that of axis is 2. The amount of variation accounted for along 4 axes of the ordination is given by the summary of eigenvalues.

From the DCA ordination, high eigenvalues for the first axis indicate that environmental gradients that are represented by this axis are stronger and more interpretable than those represented by other axes. For the density data set, the eigenvalue for axis 1, the most important axis is 0.79 with an ecological gradient of about 4.89 standard deviation (SD) units. This represents therefore the strongest gradient followed by axis 2 with an eigenvalue of 0.44 (Table 5.1) and a gradient length of about 3.07 SD units. The remaining axes have smaller eigenvalues and hence shorter gradients. For all the data sets, the percentage variance of species data accounted for along axis 1 is about 78%, 65% and 51% respectively for the species density, height and canopy data sets**.** From the three data sets, the variance accounted for along the remaining axes 2, 3 and 4 is much lower.

Table 5.1 Variance of plant species data accounted for by the first four ordination axes of DCA using three different data sets. Axis 1 accounts for the largest amount of variation of species data

Plant species data set	Axis 1	Axis 2	Axis 3	Axis 4
Density	0.778	0.445	0.269	0.191
Height	0.650	0.605	0.423	0.235
Canopy	0.509	0.351	0.225	0.172

Notes: DCA = Detrended Correspondence Analysis.

The values for total inertia or variance of species data using the three data sets: density, height and canopy are 6.384, 6.115 and 4.940 respectively. From the density data set axis 1 accounts for 12.3% (Table 5.2) of the total variation of species data. Furthermore, from the density data for the DCA ordination results, it is shown that the first two most important axes cumulatively account for 19.3% of the variation of species data. From height and canopy cover data sets axis 1 accounts for 10.6% and 10.3% respectively. The first two ordination axes cumulatively account for 20.5% and 17.4% respectively for the height and canopy cover data sets.

Table 5.2: Cumulative % variance of species data and species environmental relations from DCA and CCA ordination using three different data sets.

Vegetation species data set	Axis 1	Axis 2	Axis 3	Axis 4
Density	12.3	19.3	23.5	26.6
Height	10.6	20.5	27.4	31.3
Canopy	10.3	17.4	22.0	25.5

Notes: DCA = Detrended Correspondence Analysis

These results therefore indicate that the strongest environmental gradients that can be explained are found in the density data set rather than from the other two data sets. In addition, they emphasise the point that there is a greater separation of both sample sites and species along axis 1 than along axes II, III and IV. This confirms that the distribution of sites and species in the areas studied is influenced much more by the gradients along axis 1 namely soil moisture, drainage, soil texture and fertility.

5.6.2 Interpretation of DCA ordination of species data and distribution of plant species along environmental gradients in granitic areas.

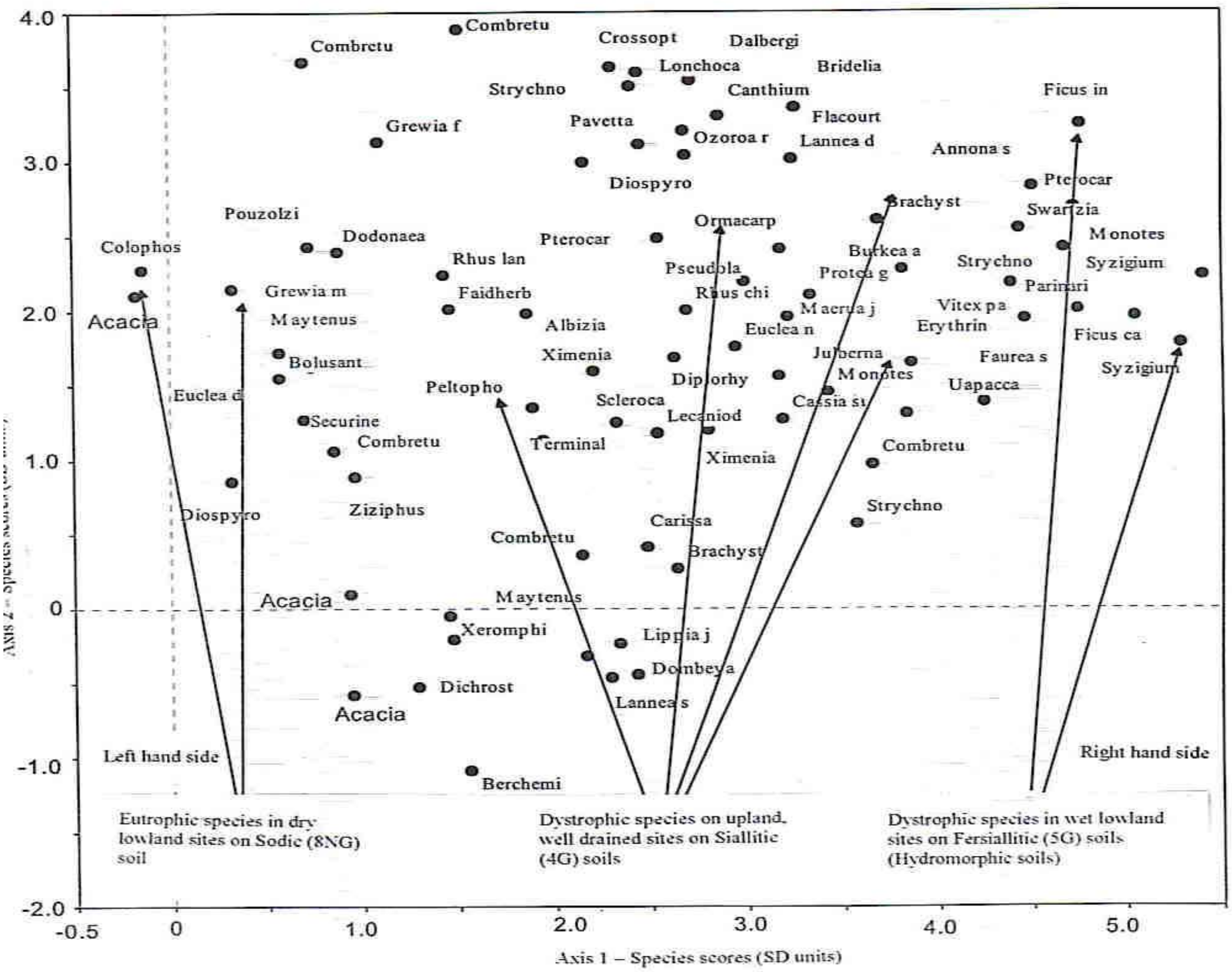
As one of the objectives of the study was to identify gradients that were significantly influencing the distribution patterns of vegetation sample sites and species, the purpose of the DCA as described in Section 5.5.3 was to help define the underlying ecological structure of the vegetation. The DCA ordination represented vegetation community data from the study areas on two-dimensional diagrams (Figures 5.4 to 5.9) which were easy to construct and inspect.

The ordination diagram for all species using the density data set (Figure 5.4) reveals grassland vleis (dambos), upland vegetation and sodium affected and eroded areas. These constitute three broad ecological formations that can be found in the study areas although this was distinctly not due to the presence of species that seemed to tolerate a wide range of habitat conditions in the study areas.

There is generally lack of a clear distribution pattern of species from the ordination of species density, canopy cover and maximum height data (Figures 5.4 - 5.6). It can be seen (Figure 5.4 and 5.5) that the scatter of species points is more to the upper portion of the ordination diagram with many species tending to occur in or near the centre of the scatter diagram. However on the left and right extremes of the ordination diagram (Figure 5.4), species such as *Syzigium* and *Ficus,* on one hand, and *Colophospermum mopane* and *Acacia,* on the other hand, tend to occur. These two groups of tree species are most dominant in lowland area with, *Ficus* and *Syzigium* species dominant in wet poorly drained fertile lowlands on Fersiallitic soils and *Colophospermum mopane* and *Acacia* species dominant in dry, poorly drained lowlands on Fersiallitic, Sodic soils and sometimes Siallitic soils.

In the middle of the ordination diagrams (Figures 5.4 and 5.5) many tree species such as *Brachystegia spiciformis*, *Ximenia americana*, *Albizia amara*, *Monotes engleri*, *Pterocarpus angolensis*, *Ormacarpum kirkii* and *Combretum* species that are usually encountered on Siallitic and Fersiallitic soils in uplands and other well drained sites can be identified.

This confirms the presence of two major gradients that can be identified along axis 1, the most important axis here more related to moisture, texture and soil fertility and soil drainage. Environmental gradients along axis 2 were not easy to interpret because the distribution patterns of species in the ordination diagrams did not give any ecological meaning.



Key to species ordination diagram (Figure 5.4) showing the environmental gradients identified along Axis 1 (Gradients along axes 2 were not easily identifiable and therefore were left out).

Left hand side of diagram	Environmental gradient	Right hand side of diagram
Low	Available soil moisture	High
High	Soil Fertility	High
High	Excess sodium salts	Low, Nil
Poor	Soil drainage	Poor, water logging
High	Soil erosion hazard	Low
Poor	Plant rooting conditions	Poor

Figure 5.4 Distribution of vegetation species relative to the first two DCA axes for the species density data obtained from the study areas along granite catenas. (The first eight letters of a species name are shown in the ordination diagram. A list of full species names is presented in Appendix 5.1)

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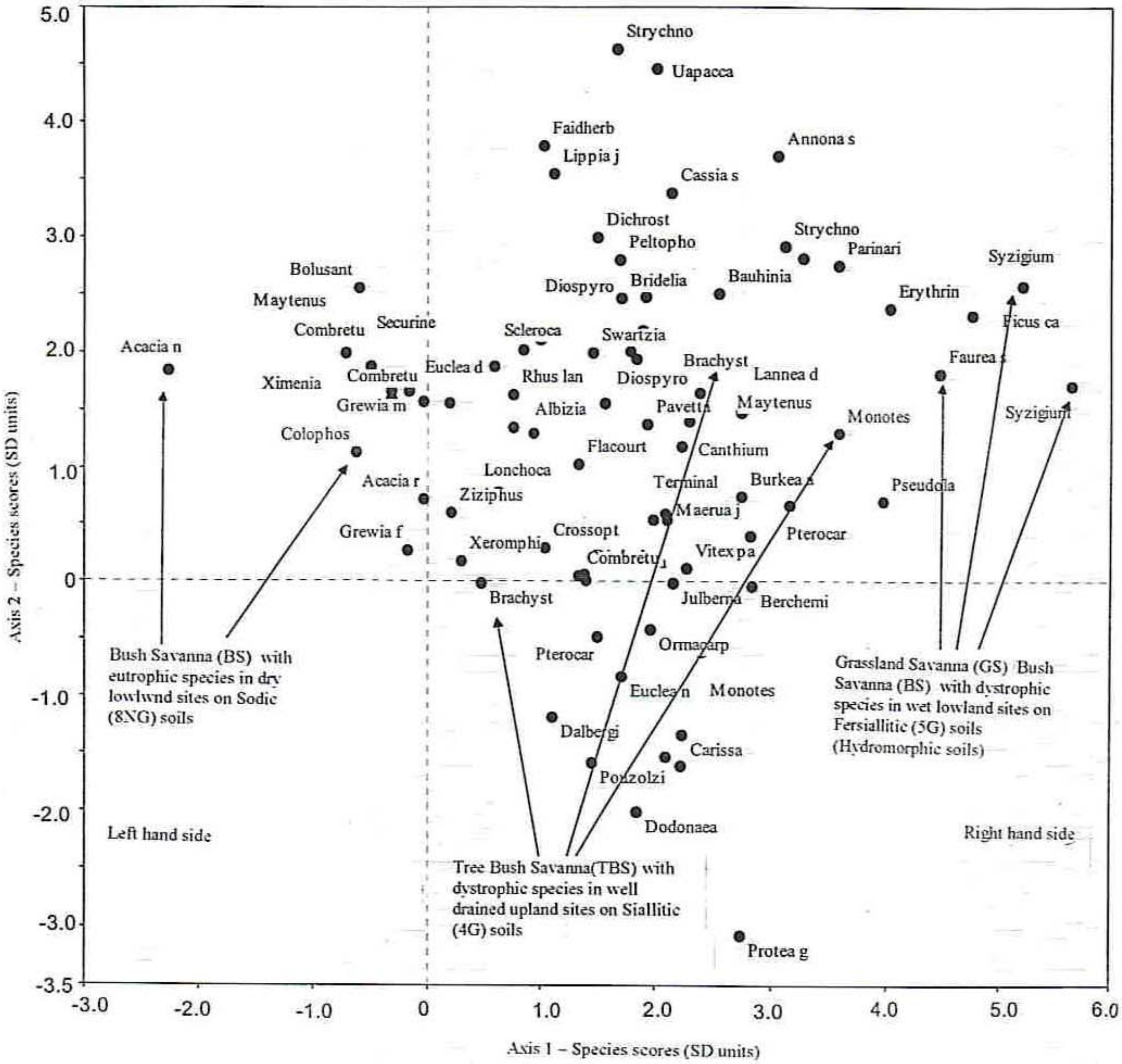
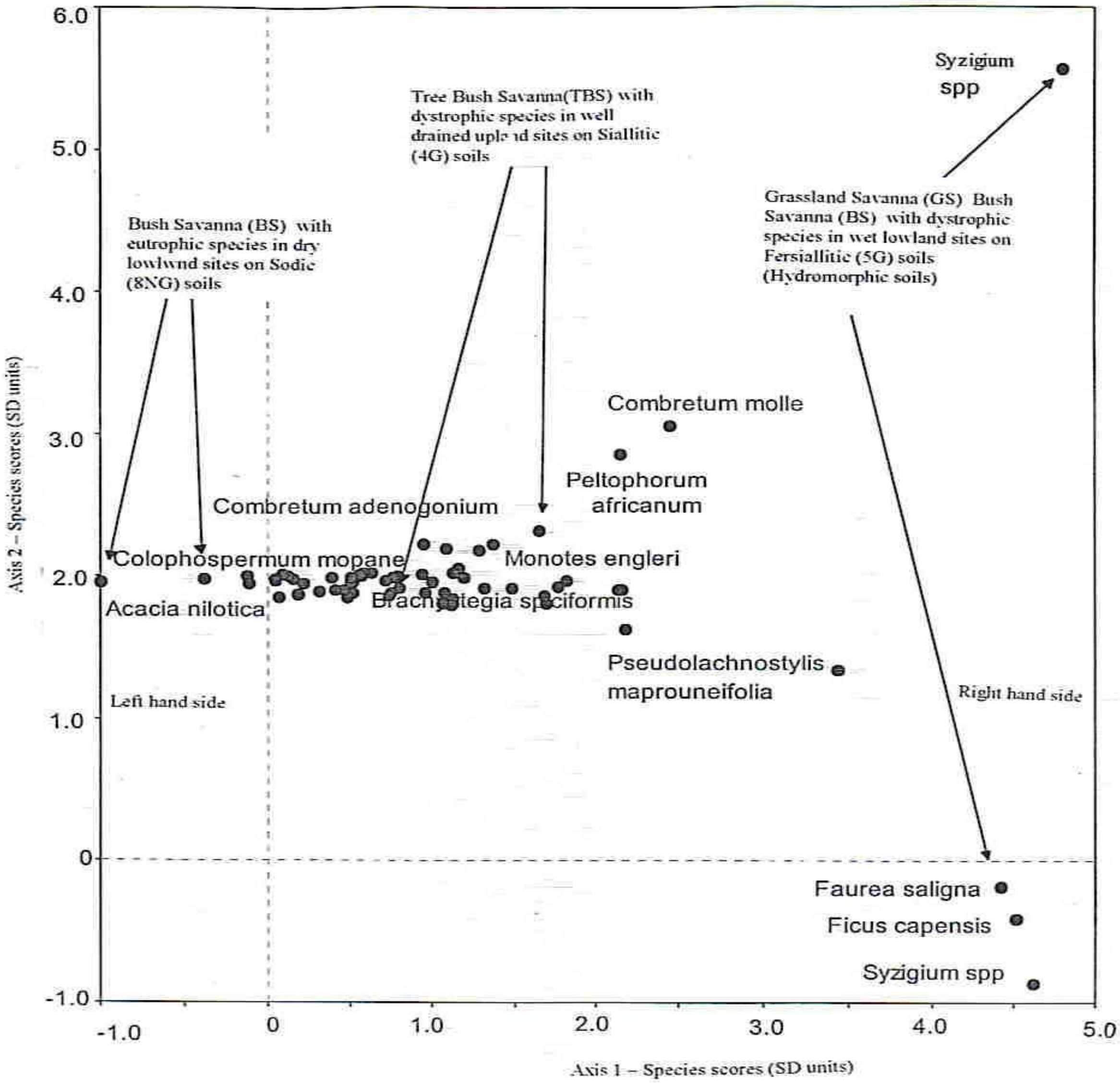


Key to species ordination diagram (Figure 5.5) showing the environmental gradients identified along Axis 1 (Gradients along axes 2 were not easily identifiable and therefore were left out).

Left hand side of diagram	Environmental gradient	Right hand side of diagram
Low	Available soil moisture	High
High	Soil Fertility	High
High	Excess sodium salts	Low, Nil
Poor	Soil drainage	Poor, water logging
High	Soil erosion hazard	Low
Poor	Plant rooting conditions	Poor

Figure 5.5 Distribution of vegetation species relative to the first two DCA axes for the species canopy cover data obtained from the study areas along granite catenas. (The first eight letters of a species name are shown in the ordination diagram. A list of full species names is presented in Appendix 5.1)



Key to species ordination diagram (Figure 5.6) showing the environmental gradients identified along Axis 1 (Gradients along axes 2 were not easily identifiable and therefore were left out).

Left hand side of diagram	Environmental gradient	Right hand side of diagram
Low	Available soil moisture	High
High	Soil Fertility	High
High	Excess sodium salts	Low. Nil
Poor	Soil drainage	Poor. water logging
High	Soil erosion hazard	Low
Poor	Plant rooting conditions	Poor

Figure 5.6 Distribution of vegetation species relative to the first two DCA axes for the species maximum height data obtained from the study areas along granite catenas.

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These results (Figures 5.4 to 5.6) however, do not indicate recognisably restricted distribution pattern of species data in the study areas. This reflects small changes in the ecological behaviour of plant species, an indication of the little separation and high correspondence between plant species. However, gradational differences can be noted in Figure 5.7 to 5.9 where in sample sites ANa2, ANb2, NB1 and MU3 on one side and AG2 and MA1 on the other side, by virtue of their isolation can be considered to differ in ecological conditions from the others.

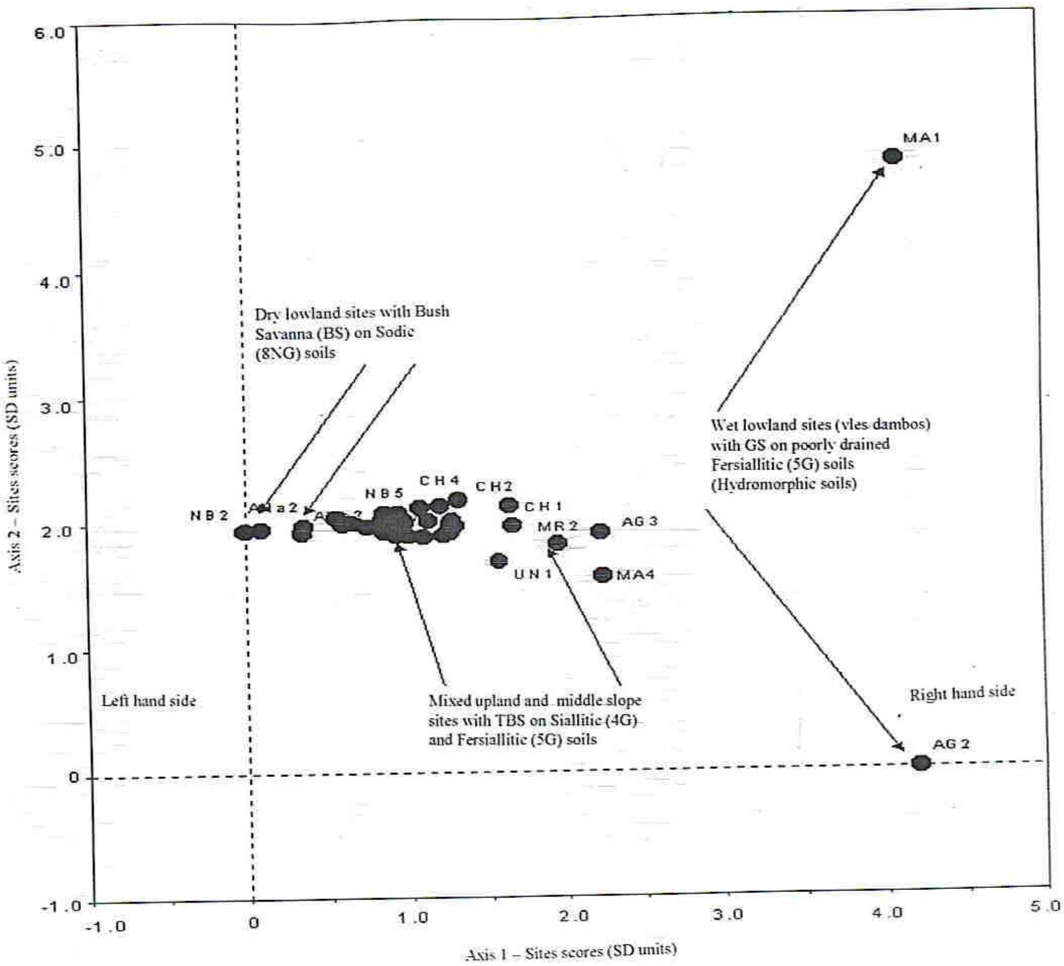
From the ordination of vegetation species, it can therefore be seen that the degree of separation of individual species and hence the environmental gradients separating them are much more observable and interpretable along DCA axis 1 than along axis II. The gradients along axis II are difficult to interpret. It therefore means that, ecological conditions related to available soil moisture and drainage, excess sodium salts and soil fertility as defined by pH and CEC, along axis 1 rather than axis II (Figures 5.4) can be used to explain the variation of species occurrence and distribution along the catenas in the study areas.

5.6.3 Interpretation of DCA ordination of vegetation sites and the identification of ecological patterns along the catena.

DCA ordination diagrams (Figures 5.7 to 5.9) were obtained using three different species data sets namely species maximum height, species percent canopy and species density. The DCA ordination diagram obtained from the height data (Figure 5.7) shows very high compression of sites scores towards the left-hand side of the gradient with an apparent arch effect towards the right hand side of the gradient. The minimum site score on both axes is zero and the maximum site score is about 4.2 with no similar sites or species found at both ends of the gradient. There appears to be no ecological distinction between the seemingly high separation of sites for example in MA1 and AG2 along axis 2 (Figure 5.7) which contain woody vegetation species such as *Faurea saligna* and *Syzigium guineense sub species huilense* which are known to commonly occur in waterlogged sites.

Using the species canopy data, the DCA ordination (Figure 5.8) was nearly similar to the one produced using density data (Figure 5.9) though more compressed towards the centre. The diagram shows a better separation of sites that appears to increase outwards along both axes 1 and 2 compared with the ordination using the height data set shown in Figure 5. 7.

Definite ecological patterns of sites and species based on known characteristics of sites and species, for example wetness, drainage and other environmental factors can be identified along axis 1, more so from the ordination diagram produced using species density data (Figure 5.9) than those from canopy and height data. Similar to the height and density data, the minimum site score for canopy data is zero along both axes and the maximum score is about 4.7 (Table 5.3). No similar sites appeared to be shared at both ends of the gradient. Despite the separation of sites along axis 2, however, there were no clear and meaningful ecological distinctions between sites separated along the Axis 2. Hence environmental gradients along this axis are not easily recognisable and interpretable.



Key to ordination diagram (Figure 5.7) showing the environmental gradients identified along Axis 1 (Gradients along axes 2 were not easily identifiable and therefore were left out).

Left hand side of diagram	Environmental gradient	Right hand side of diagram
Low	Available soil moisture	High
High	Soil Fertility	High
High	Excess sodium salts	Low. Nil
Poor	Soil drainage	Poor. waterlogging
High	Soil erosion hazard	Low
Poor	Plant rooting conditions	Poor

Figure 5.7 DCA ordination diagram obtained using species height data set for 41 vegetation sites showing a distribution of vegetation sites in the ordination plane with a tendency of compression of sites towards the left hand side of the diagram. (Full names of sites and catenas given in Appendix 5.2).

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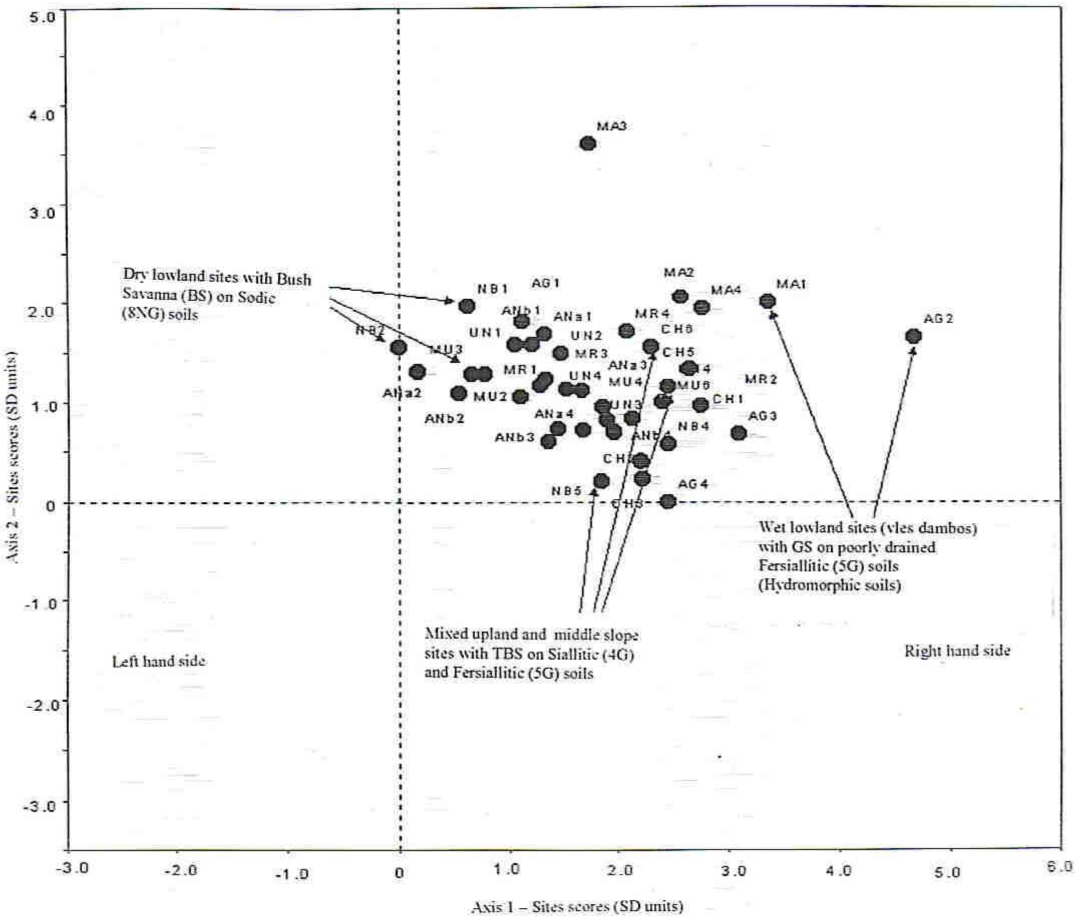
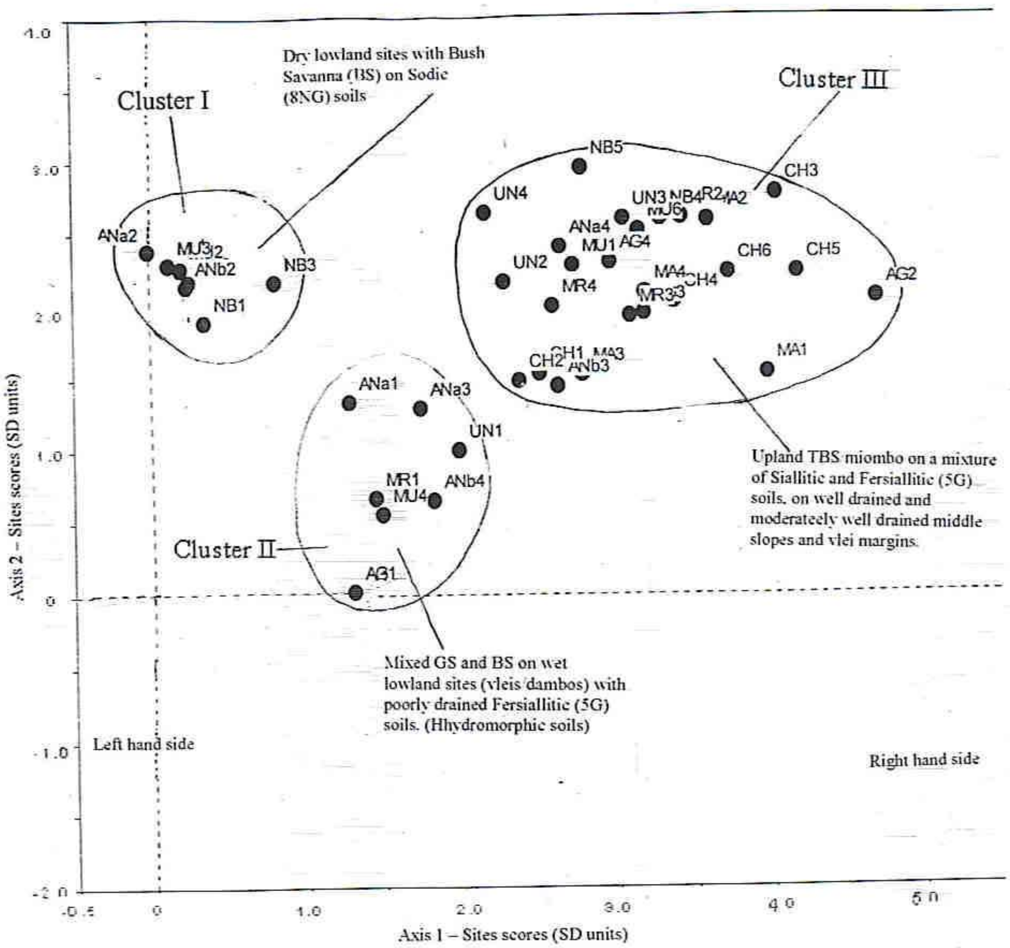


Key to ordination diagram (Figure 5.8) showing the environmental gradients identified along Axis 1 (Gradients along axes 2 were not easily identifiable and therefore were left out).

Left hand side of diagram	Environmental gradient	Right hand side of diagram
Low	Available soil moisture	High
High	Soil Fertility	High
High	Excess sodium salts	Low, Nil
Poor	Soil drainage	Poor, waterlogging
High	Soil erosion hazard	Low
Poor	Plant rooting conditions	Poor

Figure 5.8: DCA ordination diagram obtained using species canopy cover data set for 41 vegetation sites showing a poor separation of points without any meaningful ecological patterns (For example the separation of MA1, CH1 and AG1 along axis 1 gradient has no meaningful ecological basis since the three sites were all lowland, waterlogged sites found at the bottom of the catena. (Full names of sites and catenas given in Appendix 5.2).



Key to ordination diagram (Figure 5.9) showing the environmental gradients identified along Axis 1 (Gradients along axes 2 were not easily identifiable and therefore were left out).

Left hand side of diagram	Environmental gradient	Right hand side of diagram
Low	Available soil moisture	High
High	Soil Fertility	High
High	Excess sodium salts	Low. Nil
Poor	Soil drainage	Poor. waterlogging
High	Soil erosion hazard	Low
Poor	Plant rooting conditions	Poor

Figure 5.9: DCA ordination diagram obtained using species density data matrix for 41 vegetation sites showing a distribution pattern of points that forms more meaningful ecological patterns along axis 1. the most important axis. based for example on certain known environmental factors such as drainage. (Groups or clusters of points can be identified easily by eye. (Full names of sites and catenas are given in Appendix 5.2).

A summary of lengths of environmental gradients in SD units that were obtained from the DCA ordination of species data using the three data sets; density, height and percent canopy cover is shown in Table 5.3. These environmental gradient lengths give an indication of vegetation species turnover or beta diversity in the study areas. The longest environmental gradients for all data sets except for height data set are associated with the first ordination axis; the only interpretable axis. This result confirms the fact that a large proportion of the dispersed species data can be better explained by changes along axis 1 than other three axes. The shorter and weaker gradient length for the height data set seems to confirm the rather poor separation of species and uninterpretable environmental gradients observed along axis 1 than axis 2 as seen in Figure 5.7. The highest gradient length of 4.9 standard deviation units (SD units) is obtained from the density data set (Table 5.3), the strongest environmental gradients that are revealed by this data set. Higher beta diversity and species turnover are therefore expected from this density data set than from the other two.

Table 5.3: Length of environmental gradients (SD units) obtained from species data from the DCA ordination using three data sets

Vegetation species data set	Axis 1	Axis 2	Axis 3	Axis 4
Density	4.895	3.067	3.486	3.191
Height	4.199	4.816	4.229	2.275
Canopy	4.681	3.589	2.720	2.388

5.6.4 Vegetation clusters and their environmental characteristics.

From the ordination diagram (Figure 5.9) obtained using the density data set, the formations of more distinctly recognised groups or clusters of sites than in the species ordination (Figure 5.7) is revealed. Three main clusters (Table 5.4) each made up of sites with similar vegetation types, land qualities and site characteristics assessed in the field, can therefore be identified and drawn by eye (Figure 5.9).

Table 5.4: A summary description of three main vegetation clusters and their environmental characteristics identified from the DCA ordination of all vegetation sites shown in Figure 5.9.

Cluster	General description of vegetation and soil types	Important land qualities and site characteristics	Dominant woody species
I Eutrophic	Open community stands of BS mainly on eroded and surface crusted sodic (8NG) soils composed of dry eutrophic bushes and scrub	Excess sodium salts, poor drainage, high erosion and land degradation hazard, compact soils and poor plant rooting conditions	*Colophospermum mopane*
II Wet dystrophic	Open dry savanna grassland or vleis and bushes with scattered trees, mainly on Fersiallitic (5G) soils inter spaced with poorly drained sodic (8NG) soils.	Poor drainage and periodic water logging, sodic locally and compact sub soil, poor rooting conditions	*Terminalia sericea, Acacia nilotica, Combretum hereroense, Euclea divinorum and Diospyros lycoides*
III Dry dystrophic	A mixture of open to fairly dense community stands of TBS on Fersiallitic (5G) and Siallitic (4G) soils composed of dry and wet dystrophic species	Soil infertile and acidic, poor soil moisture retention in uplands	*Brachystegia spiciformis, Julbernardia globiflora, Monotes engleri, Terminalia sericea,*

Cluster 1 (Table 5.4) is composed of sites with Bush Savanna (BS) vegetation physiognomic types on highly erodible, compact and poorly drained and impermeable soils (Table 5.5) classified under sodic (8N) soils (Thompson and Purves, 1978) with variable species richness but dominated by a single eutrophic species, *Colophospermum mopane*. The major ecological gradients and most important land qualities that distinguish this cluster from others are high ESP (Table 5.6), high soil erosion hazard, poor drainage as a result of surface crusted and compact soils with high clay content in the B - horizon that leads to poor plant rooting conditions.

Table 5.5: A summary of depth properties and permeability of some selected sodium affected sites (Cluster I) in the study areas. (For abbreviation used, see bottom of table for explanation).

Site symbol	Depth to compact clay (cm)	Depth to columnar structure (cm)	*Permeability
MU2	20.0	20.0	Relatively impermeable
MU3	47.0	47.0	Relatively impermeable
ANb2	32.0	78.0	Relatively impermeable
ANb1	23.0	70.0	Severely restricted
Ana2	45.0	45.0	Relatively impermeable
NB1	45.0	45.0	Relatively impermeable
NB2	40.0	40.0	Relatively impermeable
ANa1	33.0	55.0	Relatively impermeable

* (after Bennett, 1985) Notes: MU=Mutsungwe; Ana=Airstrip North a; ANb=Airstrip North b; NB=Navik Bay.

Table 5.6: A summary of important soil characteristics of sodium affected sites (Cluster I) found in study areas. (For abbreviations used, see bottom of table for explanation)

Site symbol	Clay in B horizon (%)	AWC (%)	Depth to mottles (cm)	pH	CEC (c mol c/kg)	ESP (%)
MU2	42.0	18.9	20.0	6.4	15.4	25.3
MU3	25.0	16.9	47.0	6.3	20.4	49.1
ANb2	32.0	19.9	32.0	9.0	17.3	38.4
ANb1	23.0	18.9	23.0	7.7	14.5	9.9
ANa2	26.0	17.3	-	7.8	12.2	13.9
NB1	33.0	20.3	45.0	8.4	22.9	15.0
NB2	25.0	19.7	40.0	9.2	20.7	29.1
ANa1	33.0	19.5	33.0	8.7	14.9	28.7

Notes: MU= Mutsungwe; CH=Chikungurugwi; ANa=Airstrip North a; NB=Navik Bay; ANb= Air Strip North b.

Cluster II (Table 5.4) comprises sites with vlei Grassland Savanna (GS) vegetation physiognomic types on poorly drained but wet lowland sites which differ from those of cluster I in that there are waterlogged with poorly aerated soils of low ESP (Table 5.7), less surface crusting and erosion. Soils are clayey and more fertile with higher CEC (Table 5.8) than for sites found in cluster I. The soils have been classified under Fersiallitic (5G) soils that exhibit a considerable degree of hydromorphy for the larger part of the wet season. In this cluster, species richness appears to be lower (Figure 5.10) but more diverse than in cluster I. The most frequent woody vegetation species in cluster II are mainly wet dystrophic species dominated by *Terminalia sericea* and also *Brachystegia spiciformis* on better-drained catena positions.

Table 5.7: Some important characteristics of waterlogged vlei sub-soils of three selected sites found in study areas. (For abbreviations used, see bottom of table for explanation)

Site symbol	AWC (%)	Depth to mottles (cm)	PH ($CaCl_2$)	ESP (%)
AG2	14.90	10.0	4.40	12.4
MA1	21.40	15.0	4.00	1.6
CH1	29.50	22.0	5.01	-
AG1	15.33	20.0	4.50	4.4

Notes: AG= Agyle; MA= Maruta; CH= Chikungurugwi

Cluster III is a broad ecological division made up of sites with similar Tree Bush Savanna (TBS) vegetation physiognomic types on the uplands, crests and interfluves with high species richness and densities. *Brachystegia* species are most abundant. Associated with the TBS are well drained and non – sodic soils that have been classified under Siallitic (4G) soils (Thompson and Purves, 1978) with variable clay content, major nutrients and calcium to magnesium ratios (Table 5.8) depending on the catena position.

Table 5.8: A summary of some important soil characteristics in the B-horizon for soils in upland sites (Cluster III) under miombo vegetation. (For abbreviation used see bottom of table for explanation).

Site symbol	AWC (%)	pH	CEC (c mol c/kg)	ESP (%)
MU5	24.6	4.3	2.2	3.6
MU6	24.9	4.9	1.9	2.9
CH6	15.9	4.7	0.6	2.0
MR3	19.2	5.8	11.9	0.4
ANa4	21.0	4.3	2.4	5.6
NB4	21.0	4.3	4.2	3.5

Notes: MU= Mutsungwe; CH= Chikungurugwi; MR= Mushandike River; ANa= Airstrip North a; NB= Navik Bay.

Table 5.9 Clay content, major nutrients and calcium magnesium ratios in sub-soils of some selected upland forest sites (Cluster III) in study areas. (For abbreviation used see bottom of table for explanation)

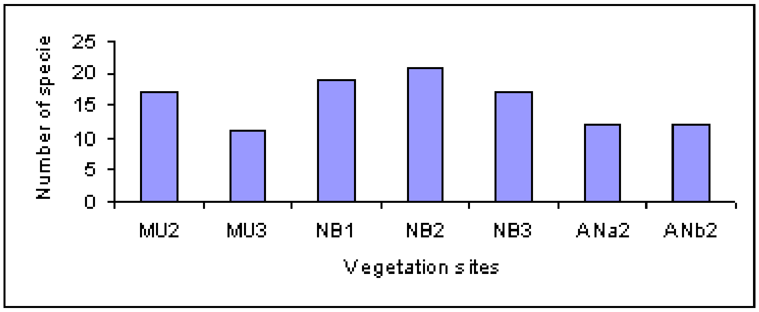
Site symbol	Clay (%)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	Ca/Mg
MU5	5.0	0.60	0.50	0.03	0.11	1.20
MU6	5.0	0.04	1.50	0.08	0.05	0.03
CH6	12.0	0.05	0.11	0.05	0.03	0.45
MR3	24.0	3.90	4.10	0.05	0.05	0.95
MR4	7.0	0.70	1.00	0.15	0.08	0.70
NB5	5.0	0.10	1.70	0.13	0.06	0.06
ANb4	4.0	0.70	0.90	0.07	0.07	0.78
ANa4	5.0	0.90	1.30	0.06	0.06	0.69
NB4	7.0	0.60	0.90	0.05	0.08	0.33

Notes: MU= Mutsungwe; CH= Chikungurugwi; MR= Mushandike River; ANa= Airstrip North a ; NB= Navik Bay; ANb= Air Strip North b.

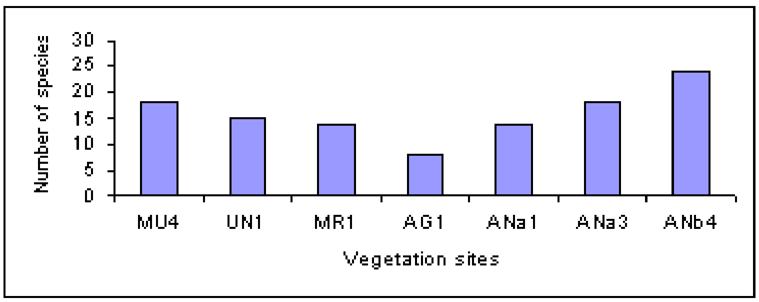
The major ecological gradients and associated land qualities that separate this cluster and species from the rest are related to both soil nutrient availability and retention, available water capacity, ESP and calcium to magnesium ratios in the soil.

Surrounding cluster III (Figure 5.9) are a variety of sites for example ANb1, CH1 and AG2 (Table 5.7) that appear to be intermediate between uplands and lowlands. These sites, singly or in association with other similar ones appear to form transitional vegetation ecological zones of BS and/or TBS on Fersiallitic (5G) and/or Siallitic (4G) soils. These sites tend to exhibit less wetness characteristics for shorter periods during the wet season than for cluster II due to perched water-tables. The most important environmental characteristics separating these vlei margin sites (Table 5.7) from the others are soil moisture and fertility related, much similar to cluster III but with more fertility and soil moisture. The main species encountered within these transitional clusters are *Terminalia sericea* and *Parinari curatellifolia*.

a) Cluster I (Eutrophic sites)



Cluster II (Wet dystrophic sites)



Cluster III (Dry dystrophic sites)

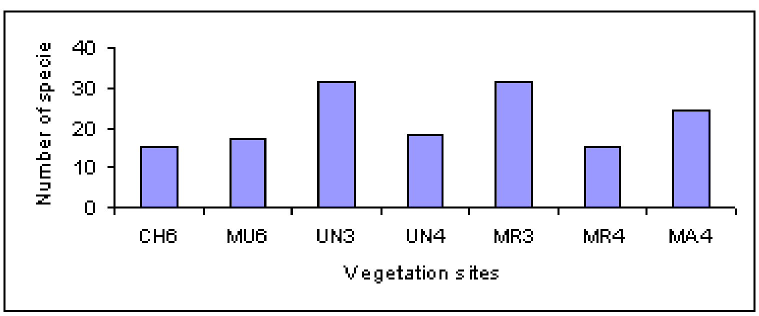


Figure 5.10: Graphs for three clusters showing comparisons of species richness in the respective vegetation sites along the catena. It can be observed that species increase with drainage with more species in better drained upland sites (cluster III) than in poorly drained lowland sites (clusters I and II).

5.6.6 Environmental variables used in the CCA and their significance.

Soil characteristics assessed in the field and in the laboratory that are known to be most important for plant growth and development were chosen from results of soil investigation presented in Chapter 4. Table 5.10 provides a summary of the soil characteristics which were used for the CCA analysis. An explanatory key to the abbreviations used for the variables is given in Table 5.11.

Most variables showed high variability as shown by their coefficients of variation (CV) (Table 5.11). The majority of the variables have CV > 25% except for pH_A, % AWC_A and % AWC_B where CV are 11%, 18% and 19% respectively. The low CVs confirm the small differences in the texture in the A horizons and not in the B-horizons. The inflation values however are small suggesting that each variable explains a unique characteristic of the species data except for CEC_B where the inflation factor (10.45) is rather high. This indicates that some aspects of this variable are contained in other variables, possibly % $clay_B$ and pH_B.

The weighted correlations of environmental variables are rather weak (Table 5.10). More variables appear to be positively or negatively correlated with pH_B. The most significant correlations however are obtained between CEC_B and % $clay_B$ (r = 0.72): CEC_B and pH_B (r= 0.74), drainage and soil erosion (r = – 0.76). There appear to be no correlations between those variables that have seemingly high coefficients of variation, such as $Ca.Mg_B$ (CV=57%) and ESP_B (CV=117).

Table 5.10: Weighted means (n=41), standard deviations and inflation factors for 10 environmental variables used in the CCA ordination. (For abbreviations used, see Table 5.11 for explanation)

Environmental variable	Mean (weighted)	Standard deviation	Coefficient of variation %	Inflation factor
$\%clay_B$	23.28	13.41	58	4.42
PH_A	5.07	0.57	11	2.92
PH_B	6.06	1.66	27	5.63
$Ca{:}Mg_B$	0.68	0.38	57	1.83
CEC_B	9.97	7.17	72	10.45
ESP_B	12.16	14.23	117	2.37
AWC_A	22.56	4.08	18	1.74
AWC_B	20.40	3.86	19	1.35
S_e	0.57	0.49	86	3.85
D_r	0.35	0.48	137	3.34

Table 5.11: Key to abbreviations used for environmental variables in the CCA ordination analysis.

Abbreviation used	Name of environmental variable
$\%clay_A$	Percentage of clay in A horizon
$\%clay_B$	Percentage of clay in the B horizon
PH_A	Soil pH in the A horizon
PH_B	Soil pH in the B horizon
AWC_A	Available water capacity in the A horizon
AWC_B	Available water capacity in the B horizon
$Ca.Mg_A$	Calcium to magnesium ratio in the A horizon
$Ca.Mg_B$	Calcium to magnesium ratio in the B horizon
CEC_A	Cation exchange capacity in the A horizon
CEC_B	Cation exchange capacity in the B horizon
ESP_A	Exchangeable sodium percentage in the A horizon
ESP_B	Exchangeable sodium percentage in the B horizon
S_e	Soil erosion hazard
D_r	Drainage status of soil

Soil erosion and drainage appear to be the most important variables contributing to the variation of species composition data followed by soil pH in the B horizon. The two variables: soil erosion and drainage respectively explain 53% and 52% of the variation in the species data (Table 5.12) implying that these are the most important variables influencing vegetation in the study areas.

Table 5.12: A summary of results from automatic forward selection of environmental variables using the Monte Carlo permutation test showing the order of importance of each variable as indicated by the percentage variance each explains independently in the ordination (For abbreviations and symbol used, see Table 5.11 for explanation).

Environmental Variable symbol	Variance explained (independently)	F-ratio	P-value
S_e	0.53	3.52	0.01
D_r	0.52	1.60	0.03
PH_B	0.39	1.38	0.10
ESP_B	0.33	1.14	0.25
CEC_B	0.31	0.99	0.42
AWC_B	0.29	0.92	0.51
AWC_A	0.25	0.86	0.52
$\%clay_B$	0.23	0.85	0.70
$Ca:Mg_B$	0.17	0.68	0.84
pH_A	0.17	0.61	0.95

From the Monte Carlo tests results the two variables, namely surface erosion ($P = 0.01$) and site drainage status ($P = 0.035$), appear to be contributing significantly to differences in species composition data in the ordination. None of the soil chemical variables selected as explanatory variables appear to have any significant influence on species composition.

Such results from significance tests in forward selection, however, have often been regarded as too liberal (ter Braak and Smilauer, 1998). This suggests that if none out of a large number of variables has a significant effect, the reported p–value of the best variables in the forward selection may be well below the conventional 95% confidence level, just because of the selection'. In view of this, therefore, and in consideration with the environmental gradients and land qualities identified all the selected soil variables that had not performed well in the Monte Carlo permutation test were included in the ordination analyses.

5.6.7 Variance of vegetation species data and species environmental relationships along the catena.

The results for the analysis of eigenvalues using the species density data set indicate that axis 1 of the CCA ordination represents a strong environmental gradient (Table 5.13) as shown by the high eigenvalue (0.67). This means that about 67% of the variation in species data along the catenas can be explained by the changes along axis 1 (Figure 5.11) that represent the main environmental gradients of available soil moisture and drainage, soil fertility and pH, sodicity and erosion.

Table 5.13: A summary of the CCA ordination results from species density data for the first 4 ordination axes, for 81 woody vegetation species identified from 41 sites in the selected study areas.

Ordination axes	1	2	3	4	Total Variance
Eigenvalues	0.67	0.24	0.21	0.16	8.38
Species–environmental correlations	0.94	0.77	0.74	0.73	–
Cumulative % variance of species data	10.50	14.10	17.40	20.00	–
Cumulative % variance of species-environmental relationships	35.90	48.6	59.7	68.6	–
Sum of unconstrained eigenvalues					6.38
Sum of canonical eigenvalues					1.86

The cumulative figures for percent variance of species data with respect to axes 1 and 2; the two axes that are easily interpretable in the two-dimensional ordination diagram are 10.5% and 14.1% respectively (Table 5.13). The equivalent figures for the species environmental relationships are about 36% and 49%.

Comparative results for eigenvalues, cumulative variance and variance explained by axis 1 for the six clusters (Table 5.15) identified indicate that higher variance in species data is obtained from the upland clusters rather than from the lowland clusters.

5.6.8 Species-environmental correlations

All the environmental axes show high correlation with species axes (Table 5.14), and the highest correlation is obtained between environmental axis 1 and species axis 1 ($r = 0.94$) suggesting that the two axes represent strong gradients. Environmental axis 1 shows a positive correlation with AWC_B ($r = 0.51$) and with the drainage status of the sites ($r = 0.84$) together with species axis 1 ($r = 0.79$). In addition, axis 1 shows negative correlations with soil pH_B ($r = -0.69$), ESP_B ($r = -0.62$) and CEC_B ($r = -0.59$) together with species axis 1. The equivalent figures for the r – values for species axis 1 are – 0.64; – 0.56 and – 0.58 respectively. A strong negative correlation occurs between environmental axis 1 and surface erosion ($r = -0.86$) together with species axis 1 ($r = -0.81$).

It is noted (Table 5.14) that soil erosion, being a one of the key variables that showed significant influence on species composition and abundance has the strongest negative correlation with both environmental axis 1 and species axis 1, with $r = -0.86$ and $r = -0.81$ respectively.

Table 5.14: A summary of weighted correlation matrix (n= 41) for vegetation sample sites, species (Spp) and environmental (Env) data as shown by species and environmental axes and ten selected environmental variables to be used for the ordination analyses. (For abbreviation of environmental variables used, see Table 5.11 for explanation).

Variable	Species Axis 1	Species Axis 2	Species Axis 3	Species Axis 4
Spp Axis 1	1.0000			
Spp Axis 2	0.0047	1.0000		
Spp Axis 3	0.0605	0.0937	1.0000	
Spp Axis 4	0.0011	0.0730	0.0512	1.0000
Env Axis 1	0.9381	0.0000	0.0000	0.0000
Env Axis 2	0.0000	0.7675	0.0000	0.0000
Env Axis 3	0.0000	0.0000	0.7417	0.0000
Env Axis 4	0.0000	0.0000	0.0000	0.7275
% $Clay_B$	0.4099	0.2384	0.0815	0.3837
pH_A	0.1087	0.2786	0.1600	0.2670
pH_B	0.6445	0.2220	0.0159	0.1422
$Ca{:}Mg_B$	0.1390	0.2955	0.4547	0.1272
CEC_B	0.5574	0.2403	0.0547	0.2987
ESP_B	0.5821	0.1155	0.0763	0.2736
AWC_A	0.4275	0.3778	0.1312	0.0095
AWC_B	0.4785	0.3872	0.0247	0.1744
Se	0.8114	0.1079	0.0777	0.1439
Dr	0.7912	0.2366	0.1927	0.0443
Env Axis 1	1.0000			
Env Axis 2	0.0000	1.0000		
Env Axis 3	0.0000	0.0000	1.0000	
Env Axis 4	0.0000	0.0000	0.0000	1.0000
% $Clay_B$	0.4369	0.3106	0.1099	0.5287
pH_A	0.1158	0.3630	0.2158	0.3680
pH_B	0.6871	0.2892	0.0214	0.1960
$Ca{:}Mg_B$	0.1481	0.3851	0.6131	0.1753
CEC_B	0.5942	0.3131	0.0737	0.4117
ESP_B	0.6205	0.1505	0.1029	0.3770
AWC_A	0.4557	0.4922	0.1770	0.0130
AWC_B	0.5101	0.5045	0.0333	0.2404
Se	0.8650	0.1406	0.1047	0.1983
Dr	0.8435	0.3083	0.2599	0.0611

5.6.8 Interpretation of CCA ordination diagrams and the identification of possible vegetation indicator species.

Figure 5.11 displays the variation of vegetation sites and environmental variables using density data set. The labelled shaded rings represent vegetation sites. The arrows that run from the origin to an arrowhead represent environmental variables. Each arrow "points in the direction of maximum change in the value of the associated variable, and the co-ordinates of the arrow show correlations between the variable and the axes. In the perpendicular direction the variable does not change in value (ter Braak, 1987; ter Braak and Verdomschot, 1995).

In comparison with the interpretation of environmental gradients in the DCA ordination (Figures 5.4 to 5.9), the CCA ordination of sites (Figure 5.11) revealed a more distinct pattern of vegetation sites. These can easily be separated by eye into six main clusters related to specific positions along the catena (Table 5.15). One can infer the distribution of the species in the field by applying the centroid principle for interpreting the location of species and sites: 'that vegetation sites which contain a particular species are scattered around the point of that species in the ordination' (ter Braak and Verdonschot, 1995).

Thus, in Figure 5.12, *Brachystegia spiciformis (11)* together with *Monotes engleri (50*) in combination with many other dystrophic species were found to be distributed on leached upland sandy soils which are acidic, infertile and well drained Siallitic (4G) soils on sites such as CH4, CH6, MA4, MR4 and MU6. The position of *Colophospermum mopane (17)* in the ordination (Figure 5.12) shows that the distribution of the species is largely confined to those areas found in the lower and poorly drained parts of dry sites on Fersiallitic (5G) soils. Highest abundance was observed in MU2 and MU3 where erosion hazard risk was highest.

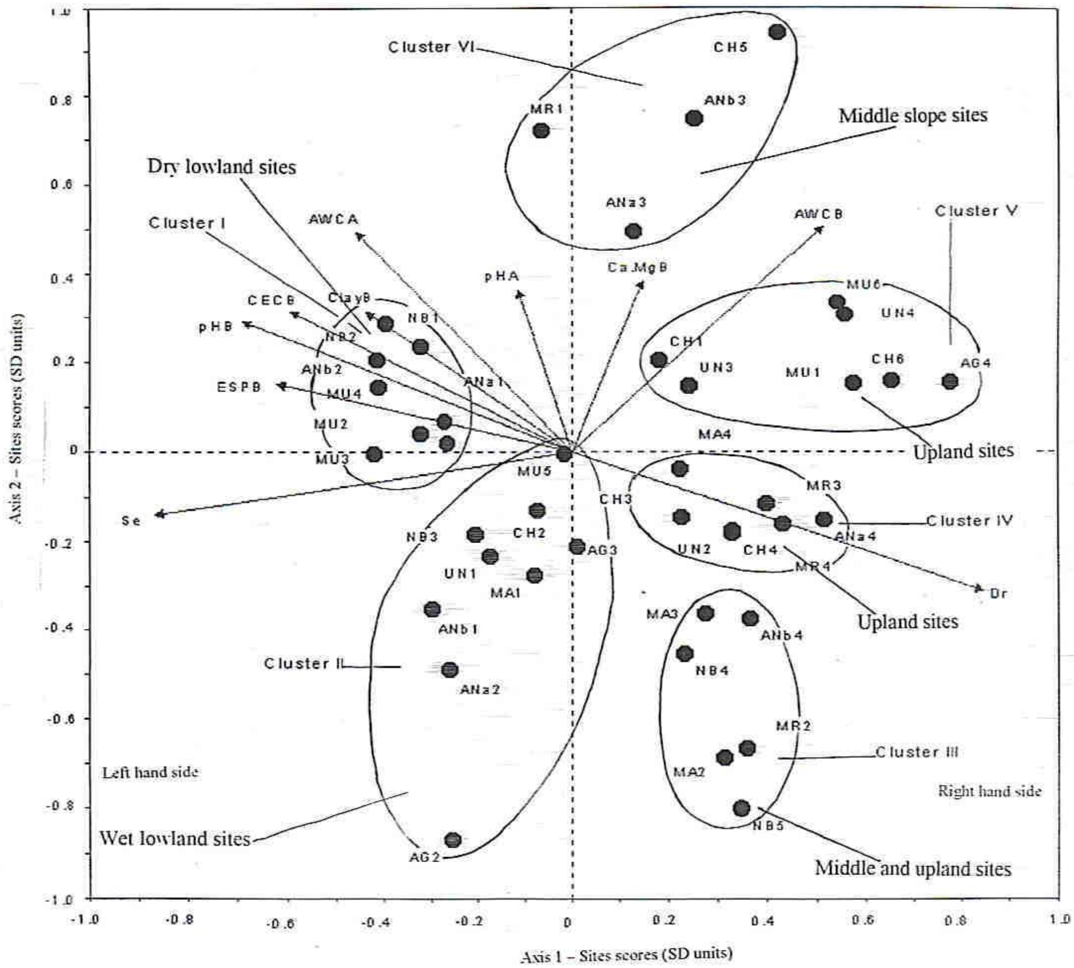


Figure 5.11: CCA ordination diagram showing vegetation sites from study areas represented by labelled and shaded dots constrained by 10 selected environmental variables (Table 5.10) shown by labelled arrows. Clusters of similar sites were identified by eye in the ordination diagram. For a summary description of environmental characteristics and dominant vegetation species see Table 5.15. (Full names of sites and catenas are given in Appendix 5.2).

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Table 5.15: A summary description of vegetation clusters delineated by eye from the CCA ordination diagram (Figure 5.11) of species density data from all study areas constrained by ten environmental variables shown in Table 5.10.

Cluster Number	Dominant vegetation physiognomic type	Important land qualities and site characteristics	Soil type	Dominant species mnemonics
I	Open Bush Savanna (BS)	Dry lowlands, gently sloping, poorly drained compact soils, heavily eroded	Fersiallitic (5G) and Sodic (8NG) soils	*C. mopane* *A. nilotica*
II	Open Grasslands (GS) and Bush Savanna (BS)	Gently sloping lowlands and vleis, moderately eroded, water logged sites.	Fersiallitic (5G) with localized patches of sodic (8NG) soils	*T. sericea* *C. adenogonium* *S. guinense* *C. mopane*
III	Open Tree Bush Savanna (TBS)	Gently undulating dry middle and upland slopes, well drained slopes, well drained and slight erosion	Siallitic (4G) soils	*B. spiciformis*
IV	Dense Tree Bush Savanna (TBS)	Gently undulating dry, well drained upland sites, slight erosion	Fersiallitic (5G) and Siallitic (4G) soils	*B. spiciformis* *J. globiflora* *M. engleri*
V	Open to fairly dense Tree Bush Savanna (TBS)	Almost flat, to gently sloping, dry, well drained upland crests and interfluves	Siallitic (4G) soils	*B. spiciformis*
VI	Open, mixed Tree Bush Savanna (TBS), Bush Savanna (BS) and Grassland vleis (GS)	Gently undulating middle slopes with fluctuating water table	Fersiallitic (5G) soils hydrormophic	*T. sericea* *P. curatellifolia* *C. molle* *E. divinorum*

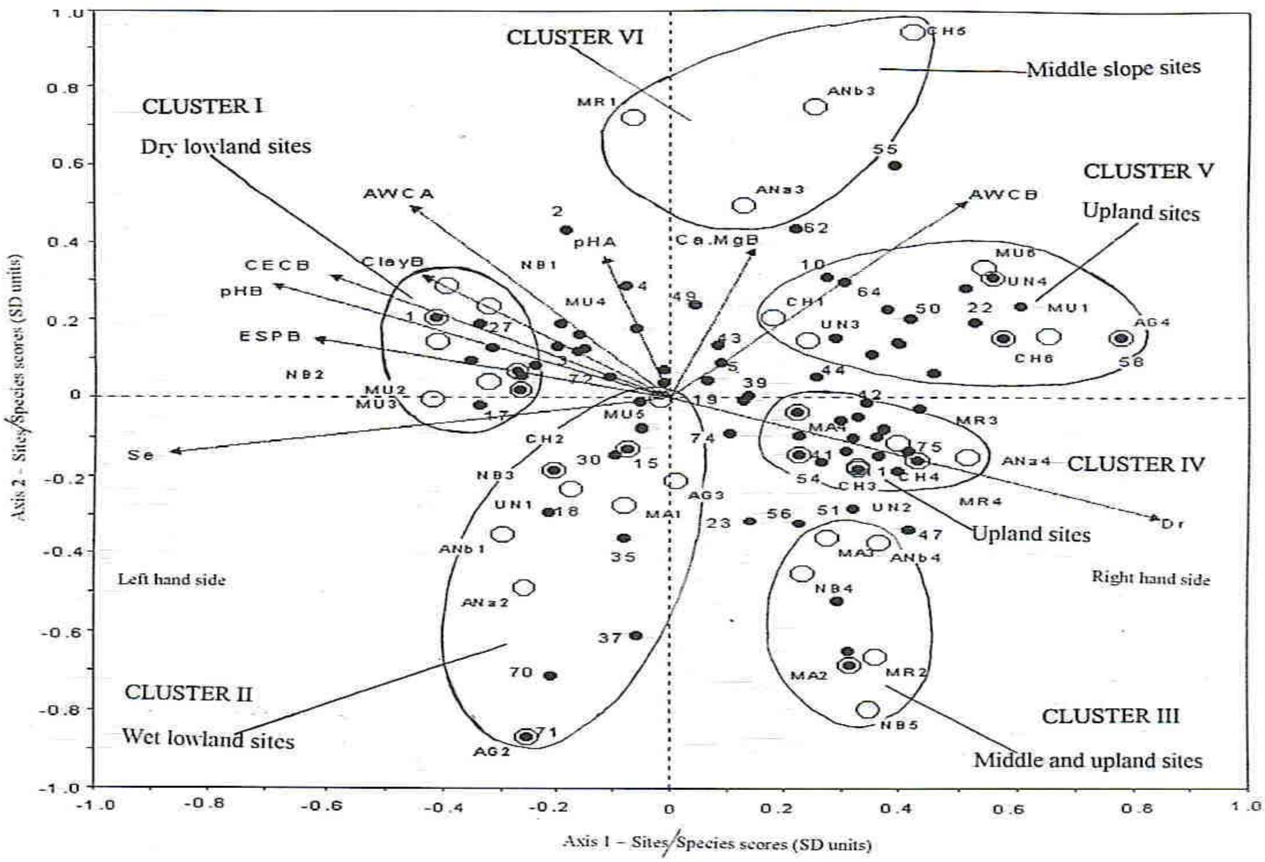

Figure 5.12: CCA Ordination diagram showing 81 woody species points represented by small shaded dots. 41 vegetation sites represented by labelled rings and environmental variables shown by arrows. Points for most dominant species are labelled with numbers to avoid congestion. Notes: A shaded dot inside a ring shows a species and a site together. Six clusters of vegetation sites are shown and labeled in the diagram. (For abbreviations of environmental variables used see Table 5.11 for explanation. Full names of sites and catenas are given in Appendix 5.2).

With *Combretum adenogonium (18)* (Figure 5.12), the distribution is centred in those sites found on poorly drained lower parts that are dry vleis occasionally on Fersiallitic (5G) soils that have compact sub soils that makes them resemble soils classified under those commonly known as 'sodic' soils.

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Unlike other species, *Syzigium guineense* sub species *huilense (71)* is the only species whose distribution as expected was limited to waterlogged sites with Fersiallitic (5G) soils which exhibit a marked degree of hydromorphy for example at AG2 and MA1 found in Soti Source resettlement in Gutu and in Maruta village in Wedza communal land respectively which receive more rainfall than most sites in the study areas.

From both Figures 5.11 and 5.12 erosion and drainage represent the strongest environmental gradients and appear to be most influential variables responsible for significant changes in species composition and abundance in the study areas because of the length of their arrows compared with the others. To avoid congestion of species points that makes interpretation difficult, a limited number of species including five most abundant ones have been selected for the purposes of interpretation.

By projecting the species points on the arrow (see ter Braak, 1987b and ter Braak and Verdonschot, 1995) for erosion as shown in Figure 5.12 *Colophospermum mopane* (17) has the highest weighted average for erosion compared to ESP_B, pH_B, CEC_B and other soil characteristics used in the CCA. *C. mopane* therefore occurs in sites with highly eroded soils than any other species displayed close to it such as *Combretum adenogonium (18), Dodonea viscosa (30), Carissa bispinosa (15) and Piliostigma thonningii(34)*.

Similarly, *Acacia nilotica (01)*, a species that has been reported to occur in a wide range of habitats, in nutrient-rich sites as a small shrub in mopane woodland (Timberlake *et al*., 1999). This species appears to be the only species with the highest weighted average for the four main B horizon soil chemical and physical characteristics namely ESP_B, pH_B, CEC_B and % $clay_B$ than any other displayed variables within the poorly drained compact soils at the bottom of catenas. Hence *A. nilotica* (01) was encountered on sodic soils with heavy sub-soils (42% clay) associated with 'shrink-swell' behaviour, high ESP (25.30); high CEC (15.40 c mol c/kg) and inverted Ca/Mg ratio (0.27). It is presumably the structure and strength of the root system similar to that observed in *C. mopane (17),* which allows *Acacia nilotica (01)* to survive on these cracking soils where most woody species would suffer from repeated root shearing throughout the year and die (Timberlake *et al*., 1999).

In well-drained sites of the uplands parts of the catena with Siallitic (4G) soils, *Brachystegia spiciformis (11)* occurs at high weighted average for drainage status of the soil in a mixture with a variety of other species such as *Strychnos cocculoides (66)*, *Ximenia americana (75)* and *Ozoroa reticulata (53)*. When ranked with these species within the uplands (Figure 5.12), *B. spiciformis (11)* appears to occur at better-drained sites than *Julbernardia globiflora (41)*, *Azanza garckeana (31*), *Burkea africana (13)* and *Grewia flavescens (39)*. There are however other species that appear to occur in better-drained areas than *B. spiciformis (11)* and these include*, (07), X. americana (75)*, and *S. cocculoides (66)* (Figure 5.12). This seems to suggest that among these, one could indicate good drainage in Siallitic (4G) with *B. spiciformis (11),* a species that was found to be most dominant in these soils.

Parinari curatellifolia (55) and *Acacia nilotica (01*) are two species that appeared to occur at higher Ca/Mg_B ratios and higher pH_A values respectively both on Fersiallitic (5G) soils with a fluctuating water table suggesting that the two species are possibly favoured by slightly alkaline and poorly drained conditions.

Monotes engleri (50), *Diospyros mespiliformis (28)* and *Sclerocarya birrea (64)* tend to occur at higher $\%AWC_B$ than other species such as *Brachystegia boehmii (10)*, *Combretum molle (22)*, *Pterocarpus angolensis (59), Senna singueana (16)* and *Pterocarpus rotundifolius (60)*

These species were observed to frequently occur in transitional sites with fluctuating water tables as revealed by the mottled soil profiles at shallow depth between the upland and lowland sites as described in Chapter Four.

5.7 DISCUSSION

5.7.1 Vegetation characteristics and their appropriateness for the analyses of vegetation–environmental relationships in semi-arid areas.

Among the vegetation features of structural importance measured, three most representative characteristics namely species density, height and canopy cover were selected for designing data sets for multivariate analyses. This was because they were more objectively measured by use of plots and more significantly correlated with important site and soil physical, morphological and chemical characteristics (Chapter Four).

From the ordination analyses of species data using three different data sets, similar results reflected ecologically recognisable patterns in the areas studied. In addition, all the data sets containing the three vegetation characteristics seemed to have agreed that environmental gradients along the first ordination axis were the most important in explaining the dispersion of species data. Although the three characteristics are alternative measures of vegetation structural importance, they differ in their appropriateness and sensitivity for measurement. Species density is a more sensitive parameter than height and canopy cover for collecting representative and accurate field data that reflects meaningful ecological patterns related to environmental factors.

From a number of ecological studies in Zimbabwe such as by Campbell *et al*. (1988), Campbell and du Toit (1994) and Frost (1995) it appears that percent canopy cover has conventionally been used as a measure of the species competitive performance. In addition, it was also used as an indicator of species dominance within a vegetation community. Presumably, this is because canopy cover is easier and less strenuous and time consuming to assess in the field as compared for example to species density and mean height measurements though the later would not necessarily indicate dominance.

Experience from this study has shown that a phytosociological technique such as the Braun Blanquet method (Mueller-Dombois and Ellenberg, 1974) that is normally used to give an indication of the abundance of different plant species cannot be used without modifications even for the same species in different sites and times. The problems encountered in estimation of percent cover of different species in different sites found in arid areas leads to rather arbitrary types of estimates. These estimates can ultimately result in poor and unrepresentative measures of species abundance at a site even with the same vegetation physiognomic types (Pratt *et.al,*1966) and species composition. These problems of measurement of species percent canopy cover are similar to those for species height in that both tend to provide indirect and subjective estimates for species abundance for a given site. This is probably the main reason why the ordination of species data based on species canopy cover and maximum height data sets showed poor ecological patterns with relatively lower environmental gradient lengths (Table 5.3) and species environmental axes correlation as compared with density. What appears therefore to be most important are actual abundance methods that give relatively more accurate indications of species density defined as the number of rooted individuals of a given species per unit area (Frost, 1995). It is noted that although it is labour intensive and time consuming, analysis of floristic data based on density data measurements rather than height and canopy can reveal the actual ecological pattern to be able to investigate how these patterns relate to given soil conditions.

5.7.2 Vegetation patterns and ecological gradients along the catena on granite

From the results of the ordination analysis, there are clear differences in vegetation species composition and their distribution particularly between dystrophic vegetation species of the upland areas and vleis as well as the eutrophic species of the dry lowland areas. It appears that soil texture and sodicity together with their effects on the availability of soil moisture, drainage, pH and availability of nutrients are mainly responsible for the changes in the distribution of vegetation patterns that have been identified in the study areas. The results from ordination analyses demonstrate that the major ecological gradients identified from the study are related to these factors.

5.7.3 Upland 'miombo' vegetation patterns in granitic areas

In this study, miombo sites were found on coarse or medium textured soils on upland positions of the catenas. From a summary of their most important characteristics (Table 5.8 and 5.9), these soils are well drained with available water capacity (AWC) ranging between 16% to 25% in the B-horizons. Due to low % clay in both the A and the B horizons, the soils have poor fertility as shown by their low CEC values ranging between 0.6 to 11.9 c mol c/kg. The soils are non-sodic with exchangeable sodium percentage (ESP) value ranging between 0.04% to 4.0%. The levels of bases in these soils is very low but an interesting feature observed was the inverted Calcium to Magnesium ratios especially in sub-soils (Table 5.9) which is unusual for sandy soils derived from granite as already indicated in section 4.7.1 (Chapter Four).

Most of these soils are acidic in chemical reaction with measured pH values ranging between 4.3 and 5.8 confirming typical weathered granite soils commonly found in Zimbabwe under miombo vegetation. Their coarse texture has given rise to good drainage and aeration conditions for good root respiration for most plants and grasses. Plant species such as

Brachystegia, *Julbernardia* and *Combretum* are commonly found in these soils because of their deep root systems capable of mining water and nutrients from deeper layers of the soil throughout the year.

The most dominant tree species that are encountered in these sites therefore is *Brachystegia spiciformis* in combination with *Julbernardia globiflora* and a mosaic of other dry land species such as *Combretum* species*, Burkea africana, Peltophorum africanum and Terminalia* species. The last two namely *Peltophorum africanum and Terminalia* species are found in transitional sites such as forest or vlei margins. In these sites, there is a marked increase in available soil moisture due to a fluctuating water table during the wet season that leads to poor site drainage problems (Nyamapfene, 1990). The major problem of these soils (associated with miombo sites) generally is related to acidity due to leaching of bases released from weathering leading to low pH, low CEC and consequently poor soil fertility.

Clearing of natural vegetation indiscriminately exposes the loose top-soil to direct raindrop impact in these areas for purpose of cultivation. Without proper conservation measures this can lead to serious soil erosion because the sandy soils are very unstable due to low clay content the property that makes them more prone to accelerated erosion through bad land use practice. Soil losses of up to 10 t/ha have been known to have occurred in similar soils elsewhere in Zimbabwe from croplands under a light drizzle locally known as “guti” rainfall (Stocking, 1972). Continuous cultivation therefore in these soil without replenishment of nutrients through fertiliser application, crop rotations and land management can therefore lead to low crop yields.

5.7.4 Sodium affected (Sodic) sites in granitic areas

Lowland *C. mopane* dominated areas are termed “sodic soils” in Zimbabwe due to the often high exchangeable sodium percentage (ESP) within the first 80 cm of the soil profile (Thompson and Purves, 1978) This was originally greater than ESP 15 but was later revised to ESP 9 (Nyamapfene, 1991).

In this study, *C. mopane* dominated sites were found to be in direct contrast with upland forests which were identified mostly at higher altitude. These mopane sites, as expected, were found to occur in the lower, drier and degraded parts of the catena usually associated with medium to coarse grained shallow or deep loamy sand or sandy loam soils. These soils have been altered due to compacted clayey and alkaline subsoil with moderately high to high cation exchange capacity (CEC) and ESP.

Presumably, the granite parent material found in the study areas especially in Mushandike Wild Life Sanctuary (where all mopane sites were identified). This granite that is relatively rich in plagioclase feldspar containing a sodium releasing mineral, albite (Thompson, 1965; Thompson and Purves, 1978), could be the main factor responsible for the formation of mopane sites in the lower parts of catenas of the study areas. This is where the sodic sites were identified. It is therefore presumed that these sites were formed under conditions of low rainfall of less than 650 mm per annum and high temperature of 35^{o}C to 37^{o}C in Agro-Ecological Region IV (Vincent and Thomas, 1960). In addition, the formation of the soils have also been a result of poor drainage, deposition of clay and salts by diffuse runoff from higher ground and erosion of the surface soil layer leading to bare ground where most plants cannot grow (Ellis, 1950).

The most dominant tree species in sites with a marked sodicity gradient were C*olophospermum mopane* with *Combretum hereroense* and *Combretum adenogonium* sometimes in combination with *Acacia nilotica.* These species occur because of their shallow rooting systems which coincide with the zone of maximum moisture retention of many soils. In addition, they are able to survive in most degraded conditions where other woody species find it difficulty to grow. The most common management problems in sodium affected soils are sodicity and alkalinity which have lead to the formation of compact sub-soils that cause poor root penetration by plants, poor water infiltration and drainage through the soil resulting in periodic water logging, excessive runoff and erosion. For their management, the reduction or removal of exchangeable sodium can be achieved by the addition of a beneficial ion such as calcium to replace the sodium through the application of gypsum and to reduce clay dispersion, thereby maintaining good soil structure. Other practicable methods have involved the establishment of salt tolerant perennial plants on the sodic affected areas such as *Atriplex* species with deep-rooted systems that will assist in providing water management ground cover to reduce runoff and erosion.

5.7.5 Lowland vleis (Dambos) in granitic areas

Available soil moisture resulting in the identification of vleis (dambos) appears to be the most prominent and easily identifiable environmental gradient responsible for the major vegetation patterns of vegetation along the granite catenas throughout the study areas. In Zimbabwe these seasonally waterlogged bottomlands (vleis) cover approximately 1.28 million ha of which about 25% are found in communal areas (Owen *et al*, 1995). The vleis are mostly used for grazing livestock after harvest and for small-scale vegetable production during winter using residual moisture and water from shallow wells recharged by water that infiltrates from uplands and laterally flows down the catena to the vlei.

The formation of these vleis is still not clear. However, it is asserted that vleis have formed under conditions of clay and organic matter elluviation with the subsequent formation of a surface soil relatively richer in organic matter and nutrients (than soils found in the uplands). An impervious clay layer is also formed which reduces infiltration and drainage resulting in seasonal water logging and anaerobic conditions in the soil rooting zones where most trees cannot survive (Timberlake *et al.*, 1993).

Their poor drainage conditions are confirmed by the high clay content in the subsoil for most sites, the existence of iron (II) mottles at very shallow depths about 10 to 20 cm and the low assessed drainage classes of the sites. Due to the existence of an impervious clay layer, root abundance in lower horizons is bound to be low as these conditions would not be favourable for most woody plants and grasses.

Recent research conducted by Chiredzi Research Station has shown that among many other environmental factors, vleis vary considerably in fertility and hydrology that influence the utilisation capacity and land management in these lowlands (Owen *et al*, 1995). There are indications that a locally developed technology called "broad-bed and broad-furrow" that is being initiated and tried through research and demonstration (Mharapara pers.com.) can prove so far to be the only appropriate utilisation and management technique for these areas in Zimbabwe. This is because the technique was found to hold runoff from catchment, limit or prevent erosion within the wetland and increase yields up to 3 t/ha of rice and 7 t/ha of maize in summer (Owen *et al*, 1995). However, the existing legislation in Zimbabwe: the Water Act and the Natural Resources Act do not provide an adequate framework for effective and sustainable use of vleis.

5.7.6 Variation in vegetation and species composition on the catena and factors responsible for the variation

There is a very large residual variation of about 4.5 as shown by difference between the sum of all unconstrained eigenvalues and the sum of all canonical eigenvalues (Table 5.13). This implies that the dispersion of species scores in the ordination could not be adequately explained by the measured environmental variables used in the study. It could be partly due to the fact that the study areas are located within the same region (Vincent and Thomas, 1960) and granite geology. In these areas, small variations in soil characteristics especially texture can be expected. This is due the nature of the granite parent material from which the soils are derived (Purves, 1976).

But from a closer inspection of environmental gradients it appears that the differences in soil texture between sites though not significant especially in the sub soils seem to be exerting rather large and observable influence on vegetation and species composition. This influence is indirect along the catena through drainage and erosion: the two site factors which in this study were found to be the most significant vegetation control variables (Table 5.12)

Over the years, observations by many farmers, land use planners and agricultural extension officers in AGRITEX in Zimbabwe, indicate strongly that there are vegetation physiognomic zones across the catena on granite. These include a zone of vlei (dambo) Grassland Savanna (GS) in wet bottom parts of the catena or Bush Savanna (BS) in the dry parts; Tree Bush Savanna (TBS), Tree Savanna (TS) or Woodland Savanna (WS) in the top parts of the catena suggesting that the physiognomic structure changes in response to soil moisture differences.

Sometimes a transitional zone of TBS dominated for example by species such as *Terminalia sericea (72)* between the bottom and the top physiognomic types can occur especially on Fersiallitic (5G) soils with a fluctuating water table.

Recent research in Zimbabwe on vegetation environmental relations in a catchment with a wetland (dambo) on granite by Mapaure and McCarthy (2001) considered the depth to the water table as the major determinant factor for the variations in species composition within the catchment. They concluded that both available moisture and the extent to water logging are the most overriding factors in distinguishing florist composition between wetlands and dry uplands. In this study, moisture availability was implied in the environmental gradients identified from the DCA ordination but in the CCA ordination. The Monte Carlo permutation tests did not show any significant difference in the species composition in relation to available soil moisture. It showed significant difference in species data in relation to the drainage status of the soil (Table 5.12).

Possibly, the absence of significant differences in the vegetation and species composition along the catenas in relation to soil moisture could be explained by the close similarity of available moisture figures from the study areas given that soil particle size distribution for most sites was similar especially in the A horizons. Alternatively, and probably more importantly is that this could have a bearing on the fact that the influence of soil moisture on vegetation and species composition similar to that of temperature and altitude, tends to operate at a broader scale unlike soil characteristics (Alejandro, 1994).

This is similar to the argument presented by Scholes (1990) that, moisture availability and fertility gradients are correlated to a large degree at a continental scale: areas of high rainfall have leached, infertile soils; while areas of low rainfall tend to have relatively fertile soils.

Although at a small scale water availability is a more important determinant than nutrient availability, for differentiating between the savannas at a more detailed scale, however, in it is more useful to distinguish between fertile and infertile areas rather than between wet and dry areas as an initial step. This is because changes in vegetation physiognomy and species composition caused by soil fertility are more discrete and more fundamental than changes caused by water availability (Scholes and Walker 1993).

Given that all the study areas were located within the same granite geology, with soils of similar surface texture that have low soil moisture retention capacity (Chapter Four) it is more relevant to distinguish between ecological groups or clusters according to soil fertility and pH, soil sodicity, drainage and erosion. These are the most important factors which characterise the main environmental gradients that are identified in this study (Figure 5.11).

5.7.7 Soil fertility, drainage and erosion as key determinants for distinguishing between vegetation communities and species on the catena.

The differences in soil pH between the top and bottom parts of the catenas have been observed (Chapter Four) and these are strongly implied in the gradients identified as shown from the interpretation in Figure 5.11.

In the well drained granitic soils at the top of the catena, where higher abundance of woody species was observed, soil pH has been found to be acidic and fertility poor due to leaching of bases as already explained in Chapter Four. However, it appears that the magnitude of leaching is small in some sites as indicated by the relatively higher pH in the A horizons than B-horizons for most sites.

In the poorly drained Fersiallitic (5G) soils found in the lower parts of the catena where, few woody species have been encountered, high levels of clay that leads to poor drainage of the sites have been noted especially in the sub-soils due to clay eluviation. As a result, CEC values for the sub soils are relatively higher, indicating that these soils are more fertile than upland Siallitic (4G) soils but support fewer woody species such as *Syzigium guineense* sub species *huilense* and *Ficus capensis* which appear to tolerate water logging. The major cause for high pH in these lower parts of the catenas, in vleis or dambos appears to be related to transportation and deposition of basic cations in the vleis. In addition to this, as drainage in these vleis is continuously impeded, oxygen supply in the soil for respiration by plant roots and micro-organisms will be reduced. A shortage of oxygen would lead to anaerobic conditions associated with reduced oxidation and increased reduction reactions in the soil that contributes to pH increase (Foth, 1990).

In the lowland dry sites where very high densities of *C. mopane* have been encountered, for example in Mushandike Wildlife Sanctuary, the sites were characterised mainly by severely eroded soils. This was due to poor permeability and drainage resulting in numerous bare patches with shallow top soil completely devoid of natural vegetation cover. The soils are alkaline, compact, clayey , relatively impermeable especially in the B-horizons and 'sodic' soils. In these sites, there appeared to be a higher proportion of bushes and shrubs than trees. Presumably, the high proportion of bushes and shrubs found in these sites is an indication of repeated pruning of root systems of the species on extreme drying of the heavy sub soils which appear to exhibit 'shrink-swell' behaviour leading to stunted and poor growth of plants (Nyamapfene, 1991). It seems that the relatively poor permeability and drainage of the soils has led to increased surface runoff and constant removal of vegetation litter and biomass from the ground surface. This results in repeated sheet wash of the exposed topsoil layer during the rainy seasons. A rapid appraisal of degradation in similar areas found in the eastern part of Zimbabwe in *C. mopane* dominated woodland indicates that natural accelerated soil erosion was relatively common in undisturbed mopane woodland due to surface capping (Barret *et al.,* 1991).

The contrast in soil pH and soil fertility between the upper and lower parts of the catenas (Chapter Four) is closely associated with vegetation and species composition found in the different areas. This is evident from a comparison of species richness and abundance between uplands and vleis. Higher woody species densities and abundance especially of trees have been more encountered in uplands than in wet vleis or dambos and other dry lowland parts of the catena. Contrary to this, in other sites such as in Navik Bay (NB) found in Mushandike Wildlife Sanctuary, higher densities of woody species were observed in the dry and lower parts of the catena on shallow and compact soils. The majority of these species were however a mixture of shrubs mainly of *C. mopane*, *Acacia and Combretum species*.

There are many studies of vegetation on granite in Zimbabwe such as by Rogers (1992); and Timberlake *et al*. (1993). These studies confirm that there are higher diversity and densities of vegetation species in the upland sandy soils that are infertile but better drained than in the more fertile base-rich clayey lowland soils. This is attributed to better soil drainage and more efficient root systems of species found in the uplands that are capable of obtaining water and nutrients from deeper layers of the soil profile than the species found at lower altitude.

It would appear that the pH and soil fertility contrast between uplands and lowlands in the granite catenas, is a microcosm of a pattern that is very common in most parts of the granite country in semi-arid areas of Zimbabwe (Anderson *et al*., 1993). Because of this contrast, it has been observed in communal lands in Zimbabwe that farmers have generally adapted this contrast by promoting more rain–fed arable farming in summer in uplands and small scale informal irrigation of high valued vegetable crops in the more fertile vleis or dambos. The infertile sandy areas at the top of the catenas have been left out mainly for summer grazing (Owen *et al*., 1995).

5.7.8 Sources of acidity and alkalinity in catenas on granite

Acidic soils found in the uplands presumably have developed under a tree vegetation and slightly more rainfall especially for CHI, AG1, and MA4 from Makoholi, Gutu and Wedza respectively (Chapter Four) which receive more rainfall than other areas leading to high rates of weathering and leaching in the sandy soil derived from granite (Purves, 1976). The leaching of bases coupled with more additions of H^+ ions to the soil through aerobic respiration, organic mineralisation and formation of carbonic acid through natural precipitation increases soil acidity (Foth, 1990).

In those sites that appeared to have undergone more intense weathering and leaching of bases such as those found along Maruta catena in Wedza, soil pH in both A and B horizons tends to be acidic. By contrast, in some sites found in Mutsungwe and Navik Bay catenas in Mushandike Wildlife Sanctuary for example which appear to have undergone less intense weathering and leaching, soils tend to have acidic A horizons but with neutral or alkaline B and / or BC horizons.

Generally, for all upland sites on Siallitic (4G) soils, soil pH is below 5.0 hence the sites have been classified as acidic. CEC ranges were between 1.2 and 8.9 c mol c/kg, because of low content of bases, an indication that the soils are infertile. Such low levels of CEC are associated with calcium and magnesium deficiencies as well as aluminium toxicity (Landon, 1984).

5.7.9 Vegetation indicator species on granite in study areas.

Results from this study (Figures 5.11 and 5.12) indicate that it is possible to identify vegetation species associated with certain soil characteristics and land management problems. However, it was observed that many of vegetation species such as *B. spiciformis, C. mopane, A. nilotica, D. condylocarpon* and many others that are reported to have some indicator value for certain soil characteristics (Bennett, 1985) do not appear to indicate single and specific soil characteristics in the study areas. Instead, they appear to be associated with many of soil characteristics and land management problems. This makes the vegetation species poor indicators for soil characteristics.

Research on the issue of indicator value of vegetation species in is lacking. Previous work done in Zimbabwe by Timberlake *et al.* (1993), Timberlake (1995) seems to suggest that, the indicator value of species and what they indicate is site specific and therefore cannot be extrapolated to other areas without taking consideration of confounding differences for example in soil depth, soil texture and incident rainfall.

In this study, the most abundant woody species is *C. mopane* found mainly as a shrub or bush in poorly drained and eroded lower parts of catenas on Fersiallitic (5G) soils derived from granite. These soils resemble those classified under the Natric Order in Zimbabwe as ‘sodic’ soils with ESP greater than 9 (Thompson and Purves, 1978). The soils where *C. mopane* was frequently observed differ considerably from sodic soils in their morphological and chemical characteristics. In fact, many soils where this species commonly occur could have important agricultural significance especially in the drier areas of Zimbabwe for example, in Mwenezi, Chiredzi and Triangle where commercial production of high valued export crops such as cane sugar and cotton so far have proved to be most profitable under irrigation.

Timberlake (1995) gives a detailed bibliography and review of *Colophospermum mopane*. Other available literature on this species (Ellis, 1950) show that although it mainly occurs in the lower and drier parts of the catena with compacted clayey, strongly alkaline sub soils and moderately high content of ESP it is by no means confined to these areas alone. The species is also found on both soils that are deep and alluvial and on soils that are shallow owing to shallow weathering or accelerated erosion or both (Nyamapfene, 1988; Timberlake et al., 1993). It is probably for this reason why mopane tree in Zimbabwe and other neighbouring countries where it frequently occurs, is commonly and sometimes regarded as an indicator of shallow, infertile and sodic soils.

In this study, results confirm that *Colophospermum mopane* is the most dominant vegetation species in lower parts of the catena in dry areas with compact, poorly drained clayey soils on granite. The distribution of this species in these parts of the catena appears to be controlled by clay content in combination with high levels of exchangeable magnesium in the soil than other exchangeable bases. Of all sites dominated by *C. mopane* about 82% of them show a preponderance of exchangeable magnesium over other exchangeable cations. About 45% to 60% of these sites were sodic. These findings appear to be similar to those by Henning (1976) from laboratory experiments with *C. mopane*. He found out that there was a correlation between plant performance as indicated by breast height diameter (DBH) x Density in *C. mopane* with subsoil moisture and exchangeable soil magnesium and concluded that the species was dependent on high rates of exchangeable magnesium than calcium and other nutrients because magnesium improved its rate of soil moisture uptake.

These findings are further supported by those from Timberlake (1995); Dye and Walker (1980); Dye (1977) that the association of mopane with sodic soils in certain parts of the central Zimbabwe watershed with similar arid conditions is due to its shallow rooting system and the ability to survive in places where other species have difficulties.

5.8 CONCLUSION

The following conclusions were made:

5.8.1 As one of the measures of vegetation abundance, species density appears to be the most appropriate characteristic for explaining the distribution patterns of vegetation along the catena in semi-arid areas. Density data set gave the largest separation of sites and species in the ordination plane along the first ordination axes that were associated with the most important gradients in the vegetation data.

5.8.2 Soil drainage status in combination with soil fertility and erosion are key factors for identifying diagnostic environmental gradients along the catena that influence variation in vegetation and species composition in arid areas on granite.

5.8.3 Four main ecological patterns that are interconnected through the movement of water and materials vertically down the profile and laterally on the surface and/or below can be identified along the catena slope from the upland to the lowland on granite in semi-arid areas. At the top of the catena which is characterised by deep, sandy, well drained and infertile soils is Tree Bush Savanna (TBS) with *Brachystegia, Combretum, Monotes and Julbernardia* as the most abundant woody species. At the bottom of the catena and on waterlogged sites is Grassland (GS) vlei with few scattered tree species made up of *Ficus* and *Syzigium* species. In the other poorly drained lower but drier part of the catena is Bush Savanna (BS) or Bush Scrub Savanna (BSS) associated with high physical degradation and erosion hazard that was observed from surface crusting and sheet erosion. In these sites, more fertile and high water holding clayey soils that are sometimes sodic are common. In such areas, the most commonly occurring tree species are *Colophospermum mopane, Acacia nilotica, Euclea divinorum* and *Grewia flavescens*. In the middle slopes and along forest and/or vlei margins, TBS, GS or a mixture of the two can be encountered. The most common species in these areas with perched water table include *Terminalia sericea, Parinari curatellifolia* and *Diplorhynchus condylocarpon*.

5.8.4 Vegetation physiognomy and species composition can be used as a land quality indicator and not as an indicator of specific soil types and/or characteristics. For example *Syzigium guineense* sub species *huilense* would indicate poorly drained sites associated with soils that exhibit a high degree of hydromorphy. The environmental factors that were found that, were found to influence vegetation along catena gradients correspond with major 'land qualities' a concept that has received wide applicability in soil survey and land evaluation for sustainable agriculture and land management in many countries (Dent and Young 1980; FAO, 1983). These land qualities: "attributes of the land which act in a distinct manner in their influence on suitability of the land for a specified kind of use" appeared to exert the most distinct influence on vegetation distribution along the catena. The most important land qualities that were involved include soil moisture availability and drainage, soil nutrient availability and retention (fertility), excess salts, plant rooting conditions, physical land degradation and erosion hazard.

5.8.5 The assertion that *C. mopane* as an indicator of sodic soils appears largely to be a misnomer because evidence shows that it has been found both on sodic soils and on non sodic soils. In this study, *C. mopane* as a bush and / or shrub is the only species encountered in closer association with compact and severely eroded clay soils than with sodic soils. Although no conclusive evidence has been established yet, results from this study show that *C. Mopane* could be a possible indicator of poorly structured soils that are not only associated with sodicity problems alone but also, with inverted calcium to magnesium ratios in the sub-soil. This situation is rather unusual in sandy soil derived from granite and this is of important land management significance for agricultural production. It is noted that, other vegetation species such as *Acacia nilotica and Combretum species* appear to be more promising indicators for sodicity than *C. mopane* and its companion species.

5.8.6 It is possible to establish important soil factors that influence vegetation through soil fertility, drainage and erosion with the aid of multivariate techniques. These factors appear to be a result of subtle differences in soil characteristics especially texture, which otherwise could probably be overlooked. This is important for distinguishing between areas with certain vegetation communities and species according to land qualities that are already known. This is needed for farming in semi arid areas of Zimbabwe where formal soil surveys to identify site potential for agriculture would probably be difficult because of the time and cost implications involved in conducting them.

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSIONS

6.1 SUMMARY

The purpose behind finding relationships between vegetation and soils is to provide a more reliable means for predicting soil patterns using vegetation that we can see and that many farmers and land managers already know. The philosophy this thesis has expounded on is that the most effective and efficient means of investigating the relationships is to assess vegetation and soils in the field, analyse, interpret and integrate this with existing scientific knowledge on vegetation, soils and land management in semi arid areas of Zimbabwe.

The objectives of this study were fully achieved. It is acknowledged that the methods for studying ecological relationships that include multivariate ordination and classification are extremely complex and quite subjective and to some extent, they rely on subjective interpretation of patterns using experience and existing scientific knowledge of soils and vegetation. However, it is submitted that, presently, in the absence of other more appropriate analytical techniques, the challenge is to distil from the simplest and essentially sound and commonly known relationships revealed through ordination methods such as correspondence analyses of vegetation and environmental data. This will make it possible to make useful predictions for soils and land management using vegetation in semi arid areas of Zimbabwe where agricultural production must be improved to meet the food and income requirements of the population.

This chapter consolidates the findings of the research and draws useful conclusions on the relationships of vegetation and soils that farmers, researchers and all other land users including decision makers require, to develop more appropriate technologies for soil survey and land management in semi arid areas of Zimbabwe.

6.2 CORRELATIONS BETWEEN PLANT SPECIES ABUNDANCE AND SOIL CHARACTERISTICS IN GRANITIC CATENAS IN SEMI-ARID AREAS

There was no significant correlation between vegetation characteristics and soil characteristics but with site qualities (Chapter Four) implying that individual vegetation characteristics such as species richness, canopy, density and height were not associated with soil characteristics but a complex combination of site conditions. Presumably, this is a result of the already known interactions of many soil variables and environmental factors (Dent and Young, 1980). This is confirmed by the results from the CCA ordination (Chapter Five) which show highly significant correlation between species and environmental characteristics especially for the ordination axis 1. This axis represents the most important gradients of soil moisture and drainage, fertility and erosion that explain the largest amount of variation of species along the catena.

6.3 SIGNIFICANCE OF VEGETATION PHYSIOGNOMY IN REVEALING SOIL PATTERNS ON THE CATENA

Vegetation physiognomy has been an important theme of research in soil survey and land management in many countries because it is an integrator of many environmental factors (Dent and Young, 1980). Though it cannot explain soil patterns alone, however, it has so far been used as a more representative and meaningful measure of vegetation structural importance in both species and community characteristics than other attributes. This is because, it has a high reflective capability of the ecological variability of a site and as defined by the plant species in association with site qualities such as water availability and drainage and soil characteristics for example pH and AWC.

In this thesis, the four vegetation physiognomic types namely Tree Bush Savanna (TBS), Tree Savanna (TS), Bush Savanna (BS) and Grassland Savanna (GS) were encountered within the savanna. Their distributions appeared to coincide with the occurrence of localised soil conditions and characteristics along the catena in the uplands, middle slopes, dry lowlands and wetlands (vleis) (Chapters Four and Five). The delineation of vegetation zones then (Chapter Four) based on the distribution patterns of physiognomic structure at each site appeared to have provided an objective way of representing variability along the catena. There was a very strong relationship between these vegetation physiognomic types shown on maps and the results produced from the ordinations of the physiognomic types (Chapter Five) that tended to form clusters of sites with similar physiognomy along environmental gradients of soil moisture and drainage, alkalinity, fertility and erosion.

For example, in the hot dry lower parts of the catenas BS was the most common physiognomic type on clay soils dominated by *Colophospermum mopane*. This is a very distinctive species most found in hot lowland areas familiar to many people in Zimbabwe, Zambia and/or Botswana where it is widely reported to dominate many soil types with its finest specimens obtained in deep fertile and well drained sites (Timberlake *et al*, 1993). Results from vegetation data indicate that, *C. mopane*, mainly as a bush and/or shrub was much more confined to clay soils than its companion species in the lowland sites. In these sites, soils were found to have high levels of ESP in their sub-soils. The clay soils in these sites are heavy and impervious thereby making them poorly aerated resulting in very poor plant rooting conditions and thus unfavourable to the growth of most plants (Timberlake *et al*, 1993). These soils unlike those under miombo do not conserve water due to their poor structure and low permeability, which promotes surface runoff and erosion. In all the sites, erosion was high and hence indications from CCA ordination (Chapter Five) were that the species could indicate sodic soils that are highly susceptible to erosion more than any other species found there.

Results from morphological, physical and chemical analyses on soils (Chapter Four) potentially allow us to differentiate both physiognomically and floristically distinct areas or sites along the catena and relate them to the main soil types and characteristics that are found there. Because the ultimate objective is to reveal soil patterns from vegetation, therefore physiognomy and species composition play a central role in that they are visual expressions of changes in environmental factors and soil types (Dent and Young, 1980). This is the only opportunity where vegetation–soil patterns are apparent and where one of the most important application of vegetation mapping for soil survey and land management can be realised.

6.4 VEGETATION-ENVIRONMENTAL RELATIONS ALONG CATENAS ON GRANITE IN SEMI-ARID AREAS

There has been a general debate regarding vegetation and environmental gradients in terms of their causes, significance and methods for their assessment (Moore and Chapman, 1986). The main disparity of opinion was between researchers who emphasised on homogeneity of vegetation (Moore and Chapman, 1986). This view plays down the importance of the continuity concept (Whittaker, 1967) by considering that classification of vegetation is the most appropriate way of representing vegetation variability on the landscape.

Results from gradient analysis (Chapters Five) demonstrate the ecological principle used in ordination that no two sample sites and/or species have exactly the same ecological amplitude (Mueller-Dombois and Ellenberg, 1974). However, from inspection of ordination diagrams, there was a clear indication for certain vegetation sites and or species that were similar to form groups or clusters that could be easily delineated by eye. This suggests that some species were so similar in their distribution patterns due to the effect of environmental gradients that they could be combined into ecological groups or communities. In these vegetation communities therefore, soil patterns appeared to coincide with certain vegetation physiognomic units or types and species composition (Chapter Four) as already discussed under Section 6.4. This implies that while vegetation communities were observed to integrate continuously as shown by the scattered sites and species, along soil moisture and drainage, and soil fertility and erosion gradients, they also tended to form distinct groups especially towards both ends of gradients as a result of the extreme effects of site and soil characteristics between the top and the bottom of the catena. This confirms the point that plant communities are not only organisms that can only be treated as wholes, but as combinations of species whose composition is dependent upon local environment (Amiri, 1999).

6.5 VEGETATION INDICATOR VALUE FOR PREDICTING SOIL CHARACTERISTICS AND SITE CONDITION.

Certain plant communities will inevitably occur in particular types of environments because the physical, chemical and biotic and abiotic characteristics of the environment have a strong effect on the distribution of plant communities (Mueller-Dombois and Ellenberg, 1974).

Results from the CCA analysis (Chapter Six) indicate that the only two environmental factors that significantly influence vegetation and species composition in the study area were soil drainage status and erosion hazard. Drainage and soil erosion are some of the broad site attributes resulting from combined influence of many variables such as pH, texture, permeability, vegetation cover and position on the catena. These factors operate together as a single dynamic system to influence vegetation physiognomy and species composition at a site, for example water logging by producing certain rooting conditions in the soil such as anaerobic conditions that are unfavourable to certain plants (Brady, 1990). It is therefore impossible to predict the effects of one factor in isolation from all the others. This is the reason why drainage and erosion, the two already known products of environmental interaction appeared to have the most significant influence on the dispersion of vegetation and species composition along the catenas data than individual soil characteristic such as soil pH, clay content and CEC. This therefore means that vegetation would not be able to tell us about specific soil characteristics. Instead, it would indicate broad site or land qualities that have either positive or negative effects on land that influence land potential for specific kinds of land uses (FAO, 1976; Dent and Young, 1980).

6.6 IMPORTANCE OF THE STUDY FOR SOIL SURVEY AND LAND MANAGEMENT IN SEMI ARID AREAS OF ZIMBABWE

Opportunities have emerged to our existing knowledge of vegetation-soil relationships and the assessment of land potential for land use planning in Zimbabwe. The results of this study provide a starting point for the development of models for various areas based on vegetation and soils data and their application in detailed assessment and evaluation of land potential. These models will be needed by many people including farmers and policy makers involved in land capability classification, land quality zonation, land use and management in communal, commercial as well as in resettlement areas found in different agro-ecological regions. The results of this study complement the already available exploratory and reconnaissance information on natural resources surveys (in Zimbabwe) such as the Agro-Ecological Classification (Appendix 3.1). This was originally produced by Vincent and Thomas (1960) and the Soil Classification of Zimbabwe by Thompson and Purves (1978) (Appendix 3.4) that are currently in use today.

The use of vegetation as a land quality indicator would contribute towards improvement of technology for soil survey and land management in Zimbabwe where the economy remains largely agriculturally based. The results of this study also create opportunities for closer collaboration among stakeholders that include pedologists, ecologists, land use planners and farmers to address vegetation and soil relations in a holistic way. This is necessary to gain a deeper understanding in vegetation-soil relationships and increase practical knowledge and skills for the assessment of land potential for agriculture.

6.7 SUMMARY OF CONCLUSIONS

The major conclusions from this study are summarised below:

6.7.1 Granitic soils are very variable in texture and chemical exchange properties especially CEC, ESP and calcium to magnesium ratios. This variability was observed in soil profiles along the catenas. Soils with inverted calcium to magnesium ratios can possibly be encountered in granitic soils under conditions of leaching in upland areas and poor drainage in lowland areas that have been invaded by excess salts of sodium. Due to this soil variability, therefore, distinct patterns of land facets along the catena with different agricultural potential and land management requirements could be identified.

6.7.2 Variation in vegetation and species composition along the catena cannot be used to predict soil types. In this study, vegetation and species composition along catenas did not appear to have been influenced by particular soil types or individual soil characteristics such as percentage clay in the soil, pH, CEC and ESP. They appeared to be influenced by land qualities. These (land qualities) are a result of complex interaction of environmental factors that determine the agricultural potential of a site thereby providing an indication of the possible land management problems, which would need to be addressed for sustained use of the land. It is, therefore, impossible to isolate the discrete influence of single soil variables on vegetation abundance and species composition.

6.7.3 The distribution patterns of vegetation communities and plant species along the catena are not random but systematic in response to the influence of factors of the environment that include soil moisture, drainage, availability and supply of nutrients, excess salts (sodium) and soil erosion. These factors correspond to land qualities (Dent and Young, 1980), which are important attributes of land that act in a distinct way in their influence on land suitability for a specific kind of land use.

6.7.4 Among many vegetation characteristics of structural significance that can be used as guides in soil survey and land management, physiognomy and species composition appears to be the only characteristic that was closely associated with soil patterns and land qualities along the catena in the granitic areas.

6.7.5 Individual plant species do not appear to indicate soil types and/or characteristics. They do indicate broad environmental or land attributes such as poor drainage in the vleis (dambos) with *Ficus, Syzigium, Terminalia* species, high sodicity and erosion in dry lowlands for example with *Colophospermum mopane, Acacia* and *Combretum* species and poor soil fertility in upland soils for example with *Brachystegia spiciformis, Julbernardia globiflora and Ximenia americana.*

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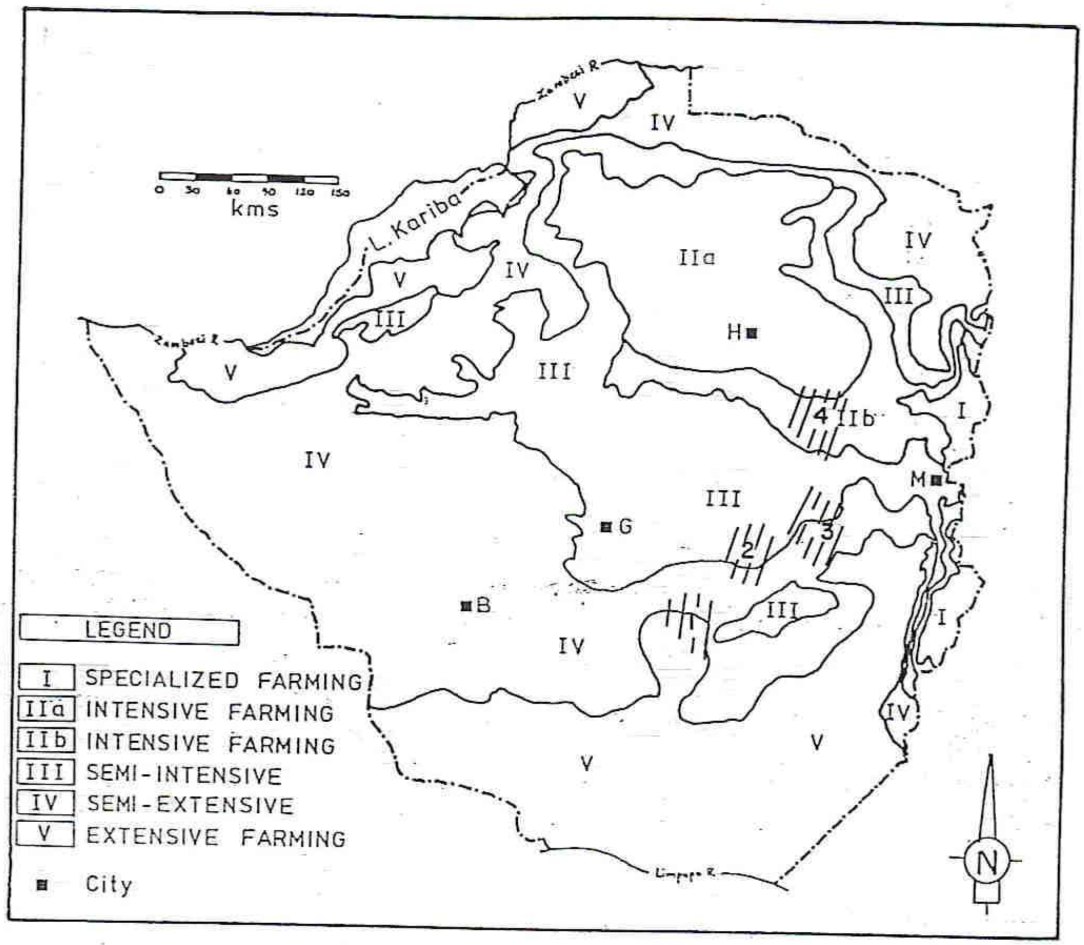
APPENDICES

Appendix 3.1 Agro-ecological regions of Zimbabwe



(Based on Vincent and Thomas, 1960)

Number	Name of area
1	Mushandike Wild life Sanctuary, Masvingo Province
2	Makoholi Research Station, Masvingo Province
3	Agyle, Soti Source Resettlement, Masvingo Province
4	Maruta, Wedza, Mashonaland East Province

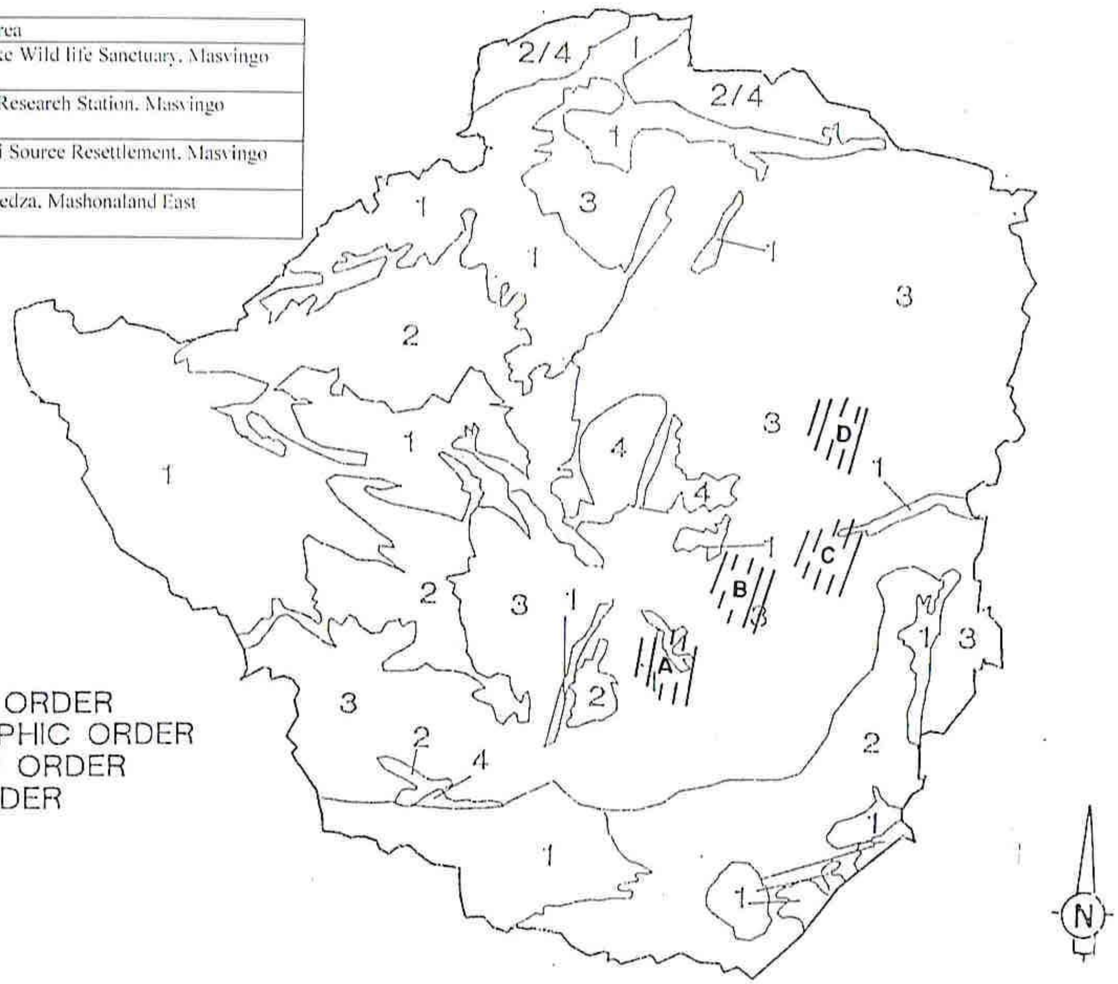
Appendix 3.2 Geological successions in Zimbabwe

Age	Classification	Dominant Rock Types
Quaternary and Tertiary	Kalahari System	Alluvium and other superficial deposits Aeolian sands
Cretaceous and Upper Jurassic	Malvernia Beads, Kadzi Beds, Gokwe Formation	Sandstone, siltstone, conglomerate and limestone
Lower jurassic to Upper Carboniferous	Upper and Lower Karoo including Batoka Basalt, Forest Sandstone, Pepply Arkose, Escarpment Grit, Madumabisa Mudstone, Sandstone and Wankie Maine Coal Seam	Basalt, sand stone, arkose, grit, mudstone and coal
Late Precambrian	Sijarira Group	Sandstone, shale, grit, arkose and conglomerate
	Tengwe River Group	Limestone, dolomite and quartzite
	Makuti-Rushinga Groups	Paragneiss, meta-arkose, schist, dolomite marble
Mid Precambrian	Umkondo Group	Quartzite, arkose, shale, phyllite, schist and andesite
	Lomagundi Group	Slate, dolomite and quartzite
	Deweras Group	Grit, metaarkose, conglomerate and basic metavavolcanics
	Piriwiri Group	Phyllite and quartzite
Early Precambrian	Beitbridge Group	Paragneiss and anorthositic gneiss
	Shamvaian-Bulawayan-Sebakwian Groups (Greenstone Schist or Gold Belts)	Metasediments and felsic to ultramafic metavolcanics
	Zambezi and Limpopo mobile belts	Gneiss, migmatite and granulite
		INTRUSIVE IGNEOUS ROCKS
Late jurassic		Granophyre, granite, syenite and gabbro
		Dolerite and epidiorite
Various ages	Mashonaland-Umkondo Dolerite suites	Norite, gabbro, serpentinite and pyroxenite
	Great Dyker	Gneiss, granodiorite, adamellite, tonalite and granite
	Cratonic Basement	

Appendix 3.3 Distribution of Soil Orders in Zimbabwe

Location of study areas

Symbol	Name of area
A	Mushandike Wild life Sanctuary, Masvingo Province
B	Makoholi Research Station, Masvingo Province
C	Agyle, Soti Source Resettlement, Masvingo Province
D	Maruta, Wedza, Mashonaland East Province



1. AMORPHIC ORDER
2. CALCIMORPHIC ORDER
3. KAOLINITIC ORDER
4. NATRIC ORDER

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Appendix 3.4 Outline of the Zimbabwean soil classification system

Order	**Group**	**Some typical soil families**	**Some typical soil series**
I. Amorphic	1. Regosol 2. Lithosol	1K (Regosols formed on Kalahari sands, Karoo sandstones). etc 2P (Lithosols on siliceous gneisses) 21: (on mafic rocks).	 Nyamandlovu 1K. 2 Triangle 2P.O Matopos 2I.O
II. Calcimorphic	3. Vertisol 4. Siallitic	3B (Vertisols derived from basalt) 3X (from ultra mafic rocks) 3I: (from mafic rocks) etc. 4PI: (Siallitic soils derived from mafic gneisses) 4U (from alluvium) 4I: (from mafic rocks) etc.	 Chisumbanje 3B.2 Selous 3X.2 Harare 3I.4 Triangle 4PI:2 Sabi 4U.2 Kwekwe 4I:2
III. Kaolinitic	5. Fersiallitic 6. Paraferrallitic 7. Orthoferrallitic	5F: (Fersiallitic red clays derived from mafic rocks) 5A (relatively silty soils derived from arenaceous metasediments) 5G (coarse grained sandy soils derived from granite) 6G (Paraferrallitic soils with a coarse grained sand fraction, derived from granite) 7E (Orthoferrallitic red clays derived from mafic rocks) 7M (fine grained sandy loams derived from sandstones and quantities. 7G (soils with a coarse grained sand fraction, derived from granite)	Harare 51:2 Raffingora 5A.2 Harare 5G.3 Makoholi 5G.2 Harare 6G.2 Chipinge 7E.2 Chipinge 7M.2 Marondera 7G.2
IV. Natric	8. Sodic	8n (weakly sodic soils) 8N (strongly sodic soils) 8h (saline sodic soils)	Matopos 8n G.5 Matopos 8NG.5 Tuli 8h G.2 Sabi 8NU.5

Source: Thompson and Purves, (1978)

Appendix 3.5 Symbols used to denote parent material at family level in the Zimbabwean soil classification system

A	Siliceous sediments, volcanics, metasediments and metavolcanies that give rise to light to medium textured soils, but in which silt content is significantly high.
B	Basalt. This parent rock is differentiated from other mafic rocks in that, in Zimbabwe, it invariably gives rise to dark clayey soils even in areas of high rainfall.
C	Colluvium.
E	Igneous and metamorphic mafic rocks other basalt that give rise to soils of high clay content.
F	Parent materials that give rise to highly micaceous, light to medium textured soils.
G	Granites and gneissic granites that give rise to soils in which the sand fraction is coarse grained. Clay content varies according to degree of weathering and catenal position.
I	Ferruginous metasediments that give rise to medium to heavy textured soils in which the silt content is not significantly high.
K	Unconsolidated fine to medium grainde sands without weatherable minerals. Most of these are Kalahari sands.
M	Sandstones and quartzites that give rise to predominantly sandy soils in which silt content is not significantly high.
P	Siliceous gneisses that give rise to light textured soils in which the sand fraction is fine to medium grained.
S	Combined argillaceous sediments and metasediments with volcanics and metavolcanics that all give rise to heavy textured soils in which silt content is significantly high.
U	Alluvium.
X	Ultramafic rocks. These invariably give rise to clayey soils in which exchangeable magnesium is greater than exhangeable calcium, i.e., the the calcium/magnessium ratio is inverse. In these soils the presence of heavy metals, such as nickel and/or chromimum, in toxic amountsis common.

Source: Thompson and Purves, 1978

Appendix 3.6 FAO-ISRIC soil data recording guidelines in the filed.

STATUS
1 reference pit
2 routine pit
3 pit; incomplete
4 augering
5 other
6 mapping units

TOPOGRAPHY
F flat 0-0.5%
A almost flat 0.5-2%
G gently undul. 2-5%
U undulating 5-8%
R rolling 8-12%
H hilly 12-30%
S steeply dissec.>30%
M mountainous >30%

LANDFORM
PL plain
PT plateau
ES escarpment
HI hill
VA valley
AP alluvial plain
LP lacustrine plain
RI ridge
FD fossil dunefield
MO mountain

LAND ELEMENT
FA fan
FL flood plain
FT flat area
PE pediment
SC scarp minor
SL slope
TE terrace
VL vlei
IF interfluve
DU dune
ID interdune
PA pan
DE depression
RI ridge
BA backswamp
CH channel
LE levee
VA valley
VF valley floor
HI hill

POSITION OF SITE
undul./mountain.
CR crest
US upper slope
MS middle slope
LS lower slope
flat
HI higher part
IN intermediate
LO lower part
BO bottom part

SLOPE – class
FL flat 0-0.5%
NL nearly level 0.5-2%
GS gently sloping 2-5%
SL sloping 5-8%
SS strong 8-12%
MS mod. steep 12-30%
ST steep 30-60%
VS very steep >60%
slope form
S straight
C concave
V convex
T terraced
X complex

MICRO TOPOGRAPHY
N nil
UE uneven
LE level
AT animal tracks
AB animal burrows
GI gilgai (unspec.)
GL low gilgai
GH high gilgai
GM medium gilgai
HU hummocks
RI ripples
SS shifting sand
TS terracettes
TU termite mount
TL low <20cm
TM medium 20-100cm
TH high 1-2m
TV very high 2-4m
TE extrem. high >4m

LAND USE TYPE
Cropping
CUN cropping unsp.
CAR annual rainfed
CAI annual irrig.
CPR perennial rainfed
CPI perennial irrig.
CRP pasture rainfed
CIP pasture irrig.
CFA fallow
CSH shifting cultiv.
COR orchard rainfed
COI orchard irrig.
CPD paddy (rice)
CMK market gardening
CGR green houses
CPE permaculture
Grazing
GUN grazing unspec.
GCF communal free
GCP communal paddock
GRC commercial beef
GRD commercial dairy
GRS commercial sheep
GRG commercial game
Forestry
FUN forestry unsp.
FNU forestry virgin
FNS virgin, cleared
FPU plantation
FPC plantation cleared
FWU woodlot
FWI woodlot indigen.
FWE woodlot exotic
FWC woodlot cleared
Others
HUN hunting, gather.
MID mine dump
MIT mine tailing
PUN preservation
PAU preser.archaeol.
PGU preser. game

CROPS
NK not known
SO sorghum
MA maize
MF finger millet
MP pearl millet
PE peas
BE beans
GR groundnuts
SU sunflower
CP cowpeas
FO fodder crops
VE vegetables
FR fruits
CT cotton
BA barley
BN banana
CA cassava
CF coffee
CH cashew
CI citrus
CS castor
CY chicory
FL flowers
WH wheat
LU lucerne
MG mango
OA oats
PA papaya
PI pineapple
PO potato
RP rice paddy
RU rice upland
SC sugarcane
SI sisal
SP sweet potato
TE tea
TO tobacco
YA yams
PP pigeon pea

HUMAN INFLUENCE
N nil
NK not known
BP burrow pit
BR burning
BU bunding
CL clearing
CR contour ridging
DR drainage
IR irrigation
MT min. tillage
PL ploughing
PO pollution
RB raised beds
RI ridging
RT tied ridging
SC surface compaction
SL sludge application
TE terracing
TR trampling
VU vegetation distur.

VEGETATION TYPE
forest
EU evergreen unspec.
EM evergreen moist
ED evergreen dry
RU riparian unspec.
RE riparian deciduous
RD riparian evergreen
DU deciduous (dry)
woodland
WU unspecified
WC closed (>80%)
WD dense (50-80%)
WO open (20-50%)
WT woodland thicket
shrubs
BU bushland unspec.
BT bushland thicket
BS bushland scrub
GU grassland unspec.
GT grassland & trees
GY grassl tree & bush
GB grassland & bushes
GC grassl & treeclump
GV grassland vlei
GD grassland dry
SU swamp
BL barren
CU cleared

GRASS COVER
0 0-15%
1 15-40%
2 40-80%
3 >80%

PARENT MATERIAL
UU unconsolidated
UA alluvial
UE aeolian
UO organic
UL lacustrine
UC colluvial
WU weathered in situ

ROCK TYPES
AU acid
BU basic (mafic)
UU ultrabasic
AD adamalite
AN andesite
BA basalt
BO olivine-basalt
BR breccia
CL claystone
CO conglomerate
DI diorite
DO dolerite
DL dolomite
GA gabbro
GE greenstone
GI granodiorite
GN gneiss
GR granite
GY greywacke
LI limestone
MA marble
ML marl
MU mudstone
NO norite
PA paragneiss
PH phyllite
PI inter. paragneiss
PM mafic paragneiss
PS silic.paragneiss
PY pyroxene
RY rhyolite
SA sandstone
SC schist
SE serpentine
SH shale
SI siltstone
SL slate
TO tonalite
QU quartzite

EFF. SOIL DEPTH (cm)
V very shallow 0-25
S shallow 25-40
X moder.shallow 40-50
M moder.deep 50-100
D deep 100-150
E very deep >150

ROCK OUTCROPS
abundance
N none
V very few 0-2%
F few 2-5%
C common 5-15%
M many 15-40%
A abundant 40-80%
D dominant >80%
distance
1 >50m
2 20-50m
3 5-20m
4 2-5m
5 <2m

SURFACE STONES
abundance
see rock outcrops
size (cm)
F very small 0.2-0.6
S small 0.6-2
M medium 2-6
L large stones 6-20
V v.large stones 20-60
B boulders >60

EROSION/ACCUM.
intensity
N nil
SL slight
MO moderate
SE severe
EX extreme
type
WS sheet erosion
WR rill erosion
WG gulley erosion
WT tunnel (piping)
WD water deposition
WA water & wind eros.
WB streambank erosion
AD wind deposition
AM wind eros./depos.
AS shifting sand
area affected
1 rare <5%
2 local 5-10%
3 common 10-25%
4 very common 25-50%
5 dominant >50%

SEALING/CRUSTING
thickness (mm)
N none
F thin <2
M medium 2-5
C thick 5-20
V v. thick >20
consistence
see consistency dry

SURFACE SALTS (%)
N none
LO low 0-15
MO moder. 15-40
HI high 40-80
DO dominant >80

SURFACE CRACKS
width (cm)
N none
F fine <1
M medium 1-2
W wide 2-5
V v.wide 5-10
E extr.wide >10

DRAINAGE
V very poor
P poor
I imperfect
M moderately well
W well
S somewhat excessive
E excessive
internal drainage cm/h
RI relat.imperm. <0.06
SE sever.restr.0.06-0.2
MO moder.restr.0.2-0.6
SL sligh.restr. 0.6-2
GO good 2-6
RA rapid 6-20
EX excessiv.rapid >20

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external drainage
R rapid runoff
M mod. rapid runoff
S slow runoff
N runoff=run on
L run on > runoff
P ponding
Y spring
X seepage, sponge

FLOOD/INUNDATION
frequency
N nil
NK not known
AM annually, several
AO annually, one
FR frequent 2-4yrs
OC occasional 5-10 yrs
RA rarely >10 yrs
duration (days)
ES extrem.short <1 d
VS very short 1-15d
SH short 15-30d
ML moderately 30-90d
LO long 90-180d
VL very long 180-270d
EL extrem. long >270d

WATER TABLE DEPTH
N not observed
V v. shallow <25cm
S shallow 25-50cm
M mod.deep 50-100cm
D deep 100-150cm
E v. deep >150cm

MOISTURE CONDITIONS
D dry
S slightly moist
M moist
W wet

NATURAL REGION
I specialised
IIA intensive
IIB intensive
III semi-intensive
IV semi-extensive
V extensive
VI as V, but drier

HORIZON VARIABLES

BOUNDARY
width
A abrupt (0-2 cm)
C clear (2-5 cm)
G gradual (5-15 cm)
D diffuse (> 15 cm)
topography
S smooth
W wavy
I irregular
B broken

COLOUR MODIFIER
MO moist
DR dry
VM variegated moist
VD variegated dry

MOTTLES
abundance
N nil
V very few (0-2%)
F few (2-5%)
C common (5-15%)
M many (15-40 %)

size (mm)
V very fine <2
F fine 2-6
M medium 6-20
C coarse >20
contrast
F faint
D distinct
P prominent
boundary
S sharp 0-0.5 mm
C clear 0.5-2 mm
D diffuse >2 mm
colour
WH white
DR dark red
RE red
RS reddish
YR yellowish red
BR brown
BS brownish
SB strong brown
RB reddish brown
YB yellowish brown
YE yellow
RY reddish yellow
GE greenish,green
GR grey
GS greyish
BU blue
BB bluish-black
BL black

TEXTURE (< 2 mm)
S sand
C clay
L loam
LS loamy sand
SL sandy loam
SCL sandy clay loam
SC sandy clay
CL clay
SIL silty loam
SICL silty clay loam
SIC silty clay
VFS very fine sand
FS fine sand
MS medium sand
CS coarse sand
LVFS loamy v.f. sand
LFS loamy fine sand
LCS loamy coarse sand
CSL coarse sandy loam
OM organic matter

ROCK FRAGMENTS
abundance
N none
V very few (0-2%)
F few (2-5%)
C common (5-15%)
M many (15-40%)
A abundant (40-80%)
D dominant (>80%)
size cm
F fine gravel 0.2-0.6
C coarse gravel 0.6-2
S small stones 2-6
L large stones 6-20
B small boulders 20-60
V large boulders > 60
shape
F flat
A angular
S subangular
O subrounded
R rounded
weathering
F fresh or slightly
W weathered
S strongly

nature
Q quartz
L laterite
M quartz & rock
P parent rock

STRUCTURE
grade
SG single grain
MA massive
VW very weak
WE weak
MO moderate
ST strong
V very strong
WM weak to moderate
MS moder. to strong
size
VF very fine
FI fine
ME medium
CO coarse
VC very coarse
FM fine to medium
MC medium to coarse
CV coarse to v.coarse
type
GR granular
CR crumb
PR prismatic
CO columnar
AB angular blocky
SB subangular blocky
AS ang. & subang bl.
AW ang.blocky wedges
SN nutty subang.bl.
PL platy
RS rock structure
SS stratified structure
compoundrelationships
+ and
/ to
> falls apart into

CONSISTENCE
dry
LO loose
SO soft
SH slightly hard
HA hard
VH very hard
EH extremely hard
moist
LO loose
VF very friable
FR friable
FI firm
VI very firm
EF extrem. firm
stickiness
NS non sticky
SS slightly sticky
ST sticky
VS very sticky
plasticity
NP non plastic
SP slightly plastic
PL plastic
VP very plastic

VOIDS (PORES)
type
I interstitial
B vesicles
V vughs
C channels
P planes
abundance
N none
V very few
F few
C common

M many
A abundant
size
V v. fine <0.5mm
F fine 0.5- 2mm
M medium 2 - 5mm
C coarse > 5mm
FF fine & v.fine
MC medium & coarse
porosity
1 very low
2 low
3 medium
4 high
5 very high

CUTANS
abundance
N none
V very few (0- 2%)
F few (2- 5%)
C common (5-15%)
M many (15-40%)
A abundant (40-80%)
D dominant (> 80%)
contrast
F faint
D distinct
P prominent
nature
CL clay
CS clay & sesquiox.
CH clay & humus
PF pressure faces
SL slickensides, non-intersecting
SI slickens.,intersect.
SP slickensides, partly intersecting
location
PD pedifaces
PV vertical pedifaces
PH horizont. pedifaces
CF coarse fragments
LA lamellae bands
VO voids
BR bridging sand
RC root channels
CR cracks
NS non specific

CEMENTAT./COMPACT.
continuity
N nil
B broken
D discontinuous
C continuous
structure
P platy
V vesicular
P pisolithic
N nodular
M massive
grade (degree)
Y compacted, non-cem.
W weakly cemented
M moder. cemented
C strongly cemented
nature
K carbonates
Q silica
C carbonates-silica
F iron
O iron-organic matter
G gypsum
S sesquioxides
P ploughing
T traffic

MINERAL NODULES
abundance
N nil

V very few (0-2%)
F few (2-5%)
C common (5-15%)
M many (15-40%)
A abundant (40-80%)
D dominant (>80%)
kind
T crystals
C concretions
S soft segregations
N nodules
size
V very fine (<2mm)
F fine (2-6mm)
M medium (6-20mm)
C coarse (>20 mm)
shape
R rounded
E elongated
F flat
I irregular
A angular
M mycelia
hardness
H hard
S soft
B hard and soft
nature
K carbonates
C clay
G gypsum
X soluble salts
Y sulphur
Q silica
F ferrugeneous
S iron-manganese
M manganese
N not known
colour
see mottles

ROOTS
abundance & size
as voids

BIOLOGICAL FEATURES
abundance
N none
F few
C common
M many
kind
AR artefacts
BU burrows unsp.
BO burrows open
BI burrows insect
BM burrows millipede
BS burrows spider
BF burrows infilled
CH charcoal
EA earthworm channels
IN insect activity
PE pedotubules
TE termite channels
TO term.channels, open
TI term.channels,filled
TF termite fungal

CARBONATES
N nil
SL slight (audible)
MO moder. (visible)
ST strong
EX extremely (foam)

PERMEABILITY cm/h
see perm. site var.

Appendix 3.7 FAO-ISRIC soil description form.

SOIL DESCRIPTION FORM - FAO-ISRIC SOIL DATABASE PROFILE CODE

status date author unit

loc elev

sheet grid lat lon

FAO 89 phase USDA

grp subg txt mi re

soil moisture/temperature regime Local

topography landform land element position

slope clss form micro topo

land use type crops human

vegetation type species grass cover

parent material over derived from eff.soil depth

rock type

rockoutcrops stones erosion/dep

ab di ab si int type area

sealing/crust Surface ash surface cracks

th co wi di

drainage flood freq/dur watertable

clss int ext obs mi ma

moist cond

dpt dpt dpt

Nat. Region

Remarks

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Appendix 3.7 (continued)

DESIGN	DPT up/lo	BND w t	COLOUR hue val chr mo	MOTTLES a s c h co	TEXTURE % >2mm C	ROCK FRAGM a si s w na	STRUCTURE.. gr si ty >

CONS... dry moi sti pla	VOIDS t ab si p	CUTANS a c na lo	CEM/COM c s g n	NODULES a k s s h n co	ROOT a si	BIOL a ki	CA	PH	SAMPLES

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Appendix 4.1. Soil profile description for an upland site in Mushandike River (MR) Catena found in Mushandike Wildlife Sanctuary.

Soil Profile Number: MR 4

Location: Mushandike River in Mushandike Wildlife Sanctuary, Masvingo Province.

Site**:** Up slope position, 0-2% slope, concave slope.

Parent material**:** Granite Rainfall: 650 mm Elevation: 950 masl

Vegetation Type**:** Tree Bush Savanna dominated by *Brachystegia* and *Combretum* tree species with a mixture of various grasses.

Soil Classification: Siallitic 4G (Zimbabwe)
Arenosol (FAO/UNESCO)

Depth (CM)	Description
0 – 15	Light brownish grey (10YR 6/2 moist) to light grey (10YR 6/1 moist), fine to medium grained sand to loamy sand; granular to sub-angular structure; non-stick, loose consistence, numerous roots, gradual boundary.
15 – 90	Pale brown (10YR 6/3 moist) to light yellowish brown (10YR 6/4 moist), medium sand to loamy sand, loose granular structure; non-sticky, weak, loose consistence, numerous fine to medium size roots, diffuse boundary..
90 - 120	Yellowish brown (10YR 5/4 moist), medium grained loamy sand, weak granular to sub angular structure; non-sticky, loose consistence, very few roots, soft weathering granite.

Soil analytical data (Appendix 4.1 continued)

Depth (cm)	0-15	15-90	90-120
Lab No.	M101	M102	M103
DM %	99.6	99.8	99.8
Texture	fS	mS	mLS
Clay %	4	5	7
Silt %	5	3	5
Fine Sand %	64	48	43
Medium Sand %	13	24	23
Coarse Sand %	14	20	22
pH (CA $C1_2$)	4.8	4.5	4.5
Ex. Ca (c mol c/kg)	0.4	0.7	0.7
Ex. Mg (c mol c/kg)	0.9	1.0	1.0
Ex. NA (c mol c/kg)	0.03	0.07	0.08
Ex. K (c mol c/kg)	0.08	0.10	0.15
TEB (c mol c/kg)	1.4	1.9	1.9
CEC (c mol c/kg)	2.1	2.4	2.9
Base Saturation (%)	66.6	77	66
E/C = Cec Clay	60.2	46.2	41.3
S/C	39.8	35.5	27.3
ESP	1.3	2.8	2.6
EKP	4.0	4.2	5.3

Appendix 4.2 (a): Soil Profile description for a dry lowland site along Air Strip North (a) Catena found in Mushandike Wildlife Sanctuary.

Soil Profile Number: AN(a) 1

Location: Eland Section in Mushandike Wildlife Sanctuary, Masvingo Province.

Site: Lower part of Catena 2-5% slope, concave, North of Air Strip.

Parent Material: Granite Rainfall: 650 mm Elevation: About 950 masl

Vegetation Type: Grassland Savanna dominated by *Hyparrhenia* and *Heteropogon* grass species with scattered *Acacia* and *Combretum* bushes.

Soil Classification: Sodic 8 NG (Zimbabwe)
Solonetz (FAO/UNESCO)

Depth (cm)	Description
0 – 15	Greyish Brown (10YR 5/2 moist) coarse sandy loam, granular to moderate, medium granular structure; soft consistence, non-sticky, non-plastic, numerous fine to medium size roots; abrupt wavy boundary.
15- 50	Light to pale grey (10YR 6/1 moist) to greyish brown (10YR 5/2 moist) ; coarse loamy sand, granular structure, soft, non-sticky, non plastic very fine to medium size roots,
50 – 75	Dark greyish brown (10YR 4/2 moist) medium sand clay loam; strong angular blocky to columnar structure; very hard, firm, very sticky, very plastic, few fine tubular roots; few rounded carbonate nodules, gradual wavy boundary.
75- 100	Yellowish brown (10YR 5/3 moist) to brown (10YR 4/3 moist) with depth; coarse sandy clay loam; columnar structure, extremely hard, very firm, very sticky, very plastic, very few fine to medium roots, compact weathered gneissic granite, difficult to dig with a spade.

Soil analytical data (Appendix 4.2 a continued)

Depth (cm)	0-15	15-55	55-75	75-100
Lab No.	H1042	H1043	H1044	H1045
DM %	99.3	99.7	98.4	98.2
Texture	cSaL	cLS	mSaCL	cSaL
Clay %	8	5	33	33
Silt %	11	11	9	11
Fine Sand %	24	29	25	12
Medium Sand %	28	32	19	22
Coarse Sand %	29	22	14	22
pH (CA $C1_2$)	5.6	7.1	8.7	9.4
Ex. Ca (c mol c/kg)	2.8	2.1	3.8	3.2
Ex. Mg (c mol c/kg)	1.3	1.1	8.3	10.4
Ex. NA (c mol c/kg)	0.12	0.31	4.28	5.52
Ex. K (c mol c/kg)	0.06	0.02	0.11	0.11
TEB (c mol c/kg)	4.2	3.6	14.9	16.4
CEC (c mol c/kg)	6.3	3.8	14.9	16.4
Base Saturation (%)	67	94	100	100
E/C = CEC Clay	75.2	69.8	45.3	49.9
S/C = TEB Clay	50.1	65.3	45.3	49.9
ESP	1.9	8.1	28.7	33.7
EKP	1.0	0.6	0.7	0.7

Appendix 4.2 b : Soil profile description for a dry lowland site along Up Navik Bay (UN) Catena found in Mushandike Wildlife Sanctuary.

Soil Profile Number: UN 1

Location: Up North of Navik Bay, Mushandike Dam in Mushandike Wildlife Sanctuary, Masvingo Province.

Site: Lower slope position of catena, 2-5% slope concave.

Parent Material: Granite Rainfall: 650 mm Elevation: About 900 masl

Vegetation Type: Bush Savanna dominated by *Bolasathnes speciosus* and C*ombretum* in combination with *Hyperrhenia* and *Heteropogon* grass species.

Soil Classification: Siallitic 4G Zimbabwe)
Luvisol (FAO/UNESCO)

Depth (cm)	Description
0 – 35	Dark greyish brown (10YR 4/2 moist) sandy loam; weak fine and medium sub- angular blocky structure, hard, friable slightly sticky, slightly plastic; common fine to medium tabular roots; abrupt wavy boundary.
35 – 45	Brown (10YR 5/3 moist) to yellowish brown (10YR 5/4 moist), medium sandy clay loam; sub-angular blocky structure hard, friable, sticky, plastic, few very fine roots few medium rounded carbonate nodules, gradual wavy boundary.
45 – 75	Yellowish brown (10YR 5/6 moist) medium to coarse sandy clay, angular blocky structure, firm, sticky plastic very few fine tabular roots, distinct clay films on ped faces, few medium rounded carbonate nodules; gradual wavy boundary.
75 - 112	Yellowish brown (10YR 5/5 moist) medium to coarse sandy clay loam, medium sub-angular block structure, firm, sticky, plastic; very few fine tabular roots; few medium rounded carbonate nodules; weathering gneissic granite, hard to dig with a spade.

Soil Analytical Data. Soil analytical data (Appendix 4.2 b continued)

Depth (cm)	0 – 35	35 – 45	45 – 75	75 - 112
Lab No.	H 1015	H 1016	H 1017	H 1018
DM %	98.7	98.0	97.5	98.3
Texture	mSaL	mSaCL	cSaC	mSaCL
Clay %	18	29	37	23
Silt %	12	11	10	11
Fine Sand %	40	33	28	38
Medium Sand %	16	13	10	12
Coarse Sand %	14	14	15	16
pH ($CaC/_2$)	51	4.9	5.1	5.7
Ex. Ca (c mol c/kg)	3.4	4.3	4.8	5.6
Ex.Mg (c mol c/kg)	3.3	3.9	6.4	4.9
Ex. Na (c mol c/kg)	0.02	0.03	0.03	0.11
Ex. K (c mol c/kg)	0.24	0.08	0.06	0.07
TEB (c mol c/kg)	7.0	8.3	11.3	10.7
CEC (c mol c/kg)	9.3	11.8	14.1	11.0
BSa %	75	70	80	98
E/C	51.8	40.5	38.4	47.5
S/C	38.9	28.5	30.7	46.2
ESP	0.3	0.2	0.2	1.0
EKP	2.6	0.7	0.4	0.6

Appendix 4.2 c: Soil Profile description of a wet lowland site in Chikungurugwi Catena found in Makoholi Research Station.

Profile Number	: CH 1
Location	: Lower Catena Slope
Site	: Edge of Vlei
Slope	: 5% slope
Parent Material	: Granite Rainfall:850 mm Elevation: About 1150 masl
Vegetation Species	: *Terminalia* and *Hyperrhenia* grass species
Soil Classification	: Siallitic 4G (Zimbabwe) Arenosol (FAO/UNESCO)

Depth (cm)	Description
0 – 25	Darkish grey (10YR 5/1 moist) and dark greyish brown, medium grained sand loam, granular to sub-angular structure, soft and non-sticky, many tubular roots, clear boundary.
25 – 40	Yellowish Brown (10YR 5/4 moist), medium grained sand or loamy sand, weak, medium granular structure, soft consistence, non-sticky, few roots, gradual boundary.
40 – 80	Light yellowish brown (5YR 6/6 moist), fine to medium grained sandy loam, weak granular structure, non-sticky, non plastic, soft consistence, numerous yellow (10YR 7/8 moist) mottles, very few roots, very weak diffuse boundary.
80 – 100	Very pale brown (10YR 7/4 moist); weak granular structure, non-sticky, weathered granite with very prominent reddish yellow (7.5 YR 5/6, 5/8 moist); mottles, no roots, weathered granite becoming less weathered with depth.

Soil analytical data. Soil analytical data (Appendix 4.2 b continued)

DEPTH (CM)	0 - 25	25 – 40	40 – 80	80 - 102
Lab No.	1536	1537	1538	1539
DM %	99.7	99.7	99.8	99.6
TEXTURE	cSaL	cSaL	cSaCL	cSaL
Clay %	16	20	22	20
Silt %	6	8	8	6
Fine Sand %	26	18	14	15
Medium sand %	28	25	22	18
Coarse sand %	24	29	34	37
pH ($CaC/_2$)	5.01	4.95	4.93	5.05
Ex. Ca (c mol c/kg)	0.4	1.5	0.08	0.8
Ex. Mg (c mol c/kg)	0.7	0.8	0.6	0.9
Ex. Na (c mol c/kg)	0.07	0.08	0.03	0.06
Ex. K (c mol c/kg)	0.04	0.11	0.02	0.06
TEB (c mol c/kg)	1.2	2.4	0.4	1.8
CEC (c mol c/kg)	1.4	2.7	0.4	3.4
BSa %	86	90.0	100	53.0
E/C	32.8	46.8	11.1	71.8
S/C	28.3	42.1	11.1	38.2
ESP	4.9	3.1	7.3	1.8

Appendix 4.2 d Soil Profile description of a middle slope site along Mushandike River (MR) catena found in Mushandike Wildlife Sanctuary

Profile Number: MR 3
Location: Middle slope position along Mushandike River catena, near turn - off to Eland Section.

Site: Well drained

Slope: 2 – 5% slope, concave

Parent Material: Gneissic granite Rainfall 650 mm Elevation: About 950 masl

Vegetation Type: Tree Bush Savanna dominated by *Brachystegia* and *Combretum* tree species

Soil Classification: Fersiallitic 5GE (Zimbabwe)
Luvisol (FAO/UNESCO)

Depth (cm)	Description
0 – 14	Brown (10 YR 4/3 moist), medium sandy loam, weak medium granular structure; soft, friable non sticky, non plastic many fine roots; abrupt wavy boundary
14 – 40	Dark reddish brown (5 YR 3 / 4moist; coarse sandy clay loam, weak sub angular blocky structure, hard, friable, sticky, plastic; many fine roots; gradual wavy boundary
40 – 75	Reddish brown(5YR 5/4 moist; coarse sandy clay loam, hard very sticky, very plastic; common very fine roots, many fine discontinuous tubular roots, diffuse boundary
75 - 98	Yellowish red (5YR 4/6 moist); coarse sandy clay loam, sub angular blocky structure, hard friable, sticky, plastic; few fine roots; weathering gneissic granite

Soil analytical data. Soil analytical data (Appendix 4.2 d continued)

DEPTH (CM)	0 - 14	14 - 40	40 - 75	75 - 98
Lab No.	H1038			
DM %	98.8	98.2	97.5	98.7
TEXTURE	mSaL	cSaCL	cSaCL	cSaCL
Clay %	15	24	32	21
Silt %	26	16	14	17
Fine Sand %	31	30	16	18
Medium sand %	13	15	10	12
Coarse sand %	14	16	28	32
pH ($CaC/_2$)	5.8	5.1	5.4	5.3
Ex. Ca (c mol c/kg)	4.9	3.9	5.9	4.0
Ex. Mg (c mol c/kg)	4.2	4.1	5.8	3.3
Ex. Na (c mol c/kg)	0.06	0.05	0.05	0.03
Ex. K (c mol c/kg)	0.35	0.12	0.10	0.06
TEB (c mol c/kg)	9.5	8.2	11.8	7.4
CEC (c mol c/kg)	13.3	11.9	16.5	211.0
BSa %	71	69	72	67
E/C	86.7	50.2	51.9	53.4
S/C	61.8	34.7	37.3	35.8
ESP	0.5	0.4	0.3	0.3
EKP	2.6	1.0	0.6	0.5

Appendix 4.2 e Soil Profile description of a middle slope site along Chikungurugwi (CH) catena found at Makoholi Research. Station.

Profile Number:	CH 4
Location:	Middle slope position along Chikungurugwi catena in Makoholi Drewton Farm.
Site:	Undulating, well drained, few scattered termitatia
Slope:	0 – 2% slope nearly flat
Parent Material:	Granite Rainfall: 850 mm Elevation: About 1050 masl
Vegetation Type:	Tree Bush Savanna dominated by *Brachystegia spiciformis* and *Julbernardia globiflora* with a continuos or a discontinuous under storey cover of various grass species and herbs.
Soil Classification:	Siallitic 4G (Zimbabwe) Luvisol (FAO/UNESCO)

Depth (cm)	Description
0 – 26	Light brownish gray (10 YR 6/2 moist), medium to coarse grained sandy loam, medium sub angular structure; non sticky, non plastic, soft consistence; numerous roots; clear and wavy boundary.
26 – 107	Yellowish brown (10 YR 5/4 moist), fine to medium grained sandy loam to sandy clay loam, medium sub angular structure,; soft consistence, slightly sticky, slightly plastic, faint reddish brown (5 YR 4/4 moist) mottles, few tubular roots, diffuse boundary.
107 - 150	Yellowish brown (10 YR 5/6 moist); medium to coarse sandy clay loam, weak to sub angular blocky structure, sticky, plastic; more reddish brown (5 YR 4/4) moist) mottles which increase with depth; soft saprolite.

. Soil analytical data (Appendix 4.2 e continued)

Depth (cm)	0 - 26	26 - 107	107 - 150
Lab No.	H1540	H1541	H1542
DM %	99.7	99.7	99.8
Texture	cSaL	mSaL	mSaCL
Clay %	16	18	28
Silt %	6	4	4
Fine Sand %	26	22	16
Medium sand %	23	23	22
Coarse sand %	29	32	34
pH ($CaC/_2$)	4.45	4.45	4.51
Ex. Ca (c mol c/kg)	1.1	0.8	1.9
Ex. Mg (c mol c/kg)	0.9	0.5	4.6
Ex. Na (c mol c/kg)	0.05	0.07	2.55
Ex. K (c mol c/kg)	0..15	0.04	0.08
TEB (c mol c/kg)	2.2	1.1	9.1
CEC (c mol c/kg)	2.8	1.1	11.5
BSa %	80	100	79
E/C	35.4	31.0	63.9
S/C	28.4	31.0	50.3
ESP	1.8	6.4	2.1

Appendix 4.3a ANOVA of Ca : Mg ratio in soils found along Navik Bay catena

Source of variation	df	ss	ms	vr	F-prob
Reps stratum	4	1.6591	0.4148	1.34	
Reps.*units* stratum	2	0.5849	0.2925	0.95	0.428
Residual	8	2.4747	0.3093		
Total	14	4.7188			

Table of means

Grand mean	0.74		
Horizon	1	2	3
Mean	0.90	0.86	0.46

Table Least significant differences (LSD) of means

Table	Horizon
Rep.	5
d.f.	8
l. .s. d.	0.811

Table Stratum standard errors and coefficients of variation

Stratum	d.f.	s.e.	cv %
Reps	4	0.372	50.2
Reps.*units*	8	0.556	75.0

Appendix 4.3b Coefficient of variation (CV) of particle size classes for different catenas in the study areas.

Soil horizon	Particle size	NB CV%	MR CV%	CH CV%	UN CV%	MU CV%	AG CV%	ANb CV%	ANa CV%	MA CV%
	Sand	8.78	17.61	3.08	10.28	2.80	2.94	8.45	5.12	7.32
A	Silt	38.48	73.10	12.34	11.55	11.69	29.70	26.52	18.12	35.39
	Clay	45.23	63.02	13.98	74.76	28.81	25.04	32.57	37.93	56.59
	Sand	24.52	31.01	4.24	23.75	25.42	5.86	18.59	26.75	20.56
B	Silt	50.67	72.46	10.77	8.82	18.86	13.14	13.31	11.91	23.57
	Clay	43.46	82.71	17.38	81.27	72.05	60.13	31.14	56.08	20.21
	Sand	17.11	23.40	7.44	23.85	43.18	18.27	26.83	19.15	28.17
BC	Silt	25.12	55.55	21.76	76.48	15.96	11.74	18.08	13.95	27.61
	Clay	57.44	7.053	42.87	50.81	77.90	88.62	72.44	52.25	18.29

Notes: NB = Navik Bay: MR = Mushandike River; CH = Chikungurugwi; UN = Up Navik Bay; MU = Mutsungwe; AG = Agyle; ANb = Airstrip North b; ANa = Airstrip North a; MA = Maruta.

Appendix 4.4: Comparison of total root densities (roots per 100-sq. cm) for A and B-horizons using the vertical and the horizontal methods of assessing roots in soil profiles along Chikungurugwi catena.

Profile symbol	Soil depth (cm) A horizon	Vertical root density	Horizontal roots density	Profile symbol	Soil depth (cm) B-horizon	Vertical root density	Horizontal roots density
CH 1	0-25	107	171	CH 1	25-102	59	53
CH 2	0-25	7	52	CH 2	26-114	15	67
CH 3	0-16	41	69	CH 3	16-89	62	84
CH 4	0-26	25	38	CH 4	26-120	25	26
CH 5	0-12	9	18	CH 5	12-100	34	49
CH 6	0-22	33	242	CH 6	22-100	7	31

Notes: i. CH=Chikungurugwi catena ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Appendix 4.5 Comparison of total root densities (roots per 100-sq. cm) for A and B-horizons using the vertical and the horizontal methods of assessing roots in soil profiles along Mutsungwe catena. (For the abbreviations used see notes under Table).

Soil profile symbol	Soil depth (cm) A horizon	Vertical root density	Horizontal roots density	Soil profile symbol	Soil depth (cm) B-horizon	Vertical root density	Horizontal roots density
MU 1	0-13	71	95	MU 1	13-90	183	65
MU 2	0-10	138	192	MU 2	20-100	168	126
MU 3	0-25	91	202	MU 3	25-100	129	215
MU 4	0-22	101	240	MU 4	22-150	112	214
MU 5	0-15	148	248	MU 5	32-100	446	262
MU 6	0-15	268	384	MU 6	15-98	384	286

Notes: i. MU= Mutsungwe catena ii. Soil profiles were numbered from the bottom (lowlands) to the top (uplands) of the catena

Appendix 4.6 Explanations of some physical soil moisture retention parameters for soils

Physical parameter	Explanation
Bulk Density (g/cm3)	
<0.2	Very low
0.2-0.8	Low
0.8-1.3	Moderate
1.3-1.8	High
>1.8	Very high
Retained Water Capacity (%V/V)	
<9.9	Very small
10-19.9	Small
20-29.9	Moderately small
30-39.9	Moderately large
4.-49.9	Large
>50	Very large
Available Water Capacity (%V/V)	
<0.5	Very small
5.0-9.9	Small
10.0-14.9	Moderately small
15.0-19.9	Moderately large
20.0-24.9	Large
>25	Very large

Source: Landon (1984)

Appendix 4.7 BSa%, E/C and S/C values of upper and lower parts of some catenas.

(i) Sites found in the upper parts of the catena

Horizon	A			B			BC		
Catena	BSa%	E/C	S/C	BSa%	E/C	S/C	BSa%	E/C	S/C
CH1	90.0	46.8	42.1	53.0	71.8	38.2	53.0	71.8	38.2
CH2	82.0	43.0	35.0	71.0	14.0	10.0	32.0	10.0	3.0
UN1	75.0	51.8	38.9	80	38.4	30.7	98	47.3	46.2
ANa1	60.0	79.6	47.4	91	64.1	58.1	100	59.5	59.5
ANb1	67.0	75.2	50.1	100	69.8	65.3	100	49.9	49.9
MU2	66.0	49.4	32.8	100	66.0	37.0	100	66.9	66.9
MU3	59.0	61.5	36.5	100	61.5	36.0	100	18.3	18.3

(ii) Sites found in the lower parts of the catena

Horizon	A			B			BC		
Catena	BSa%	E/C	S/C	BSa%	E/C	S/C	BSa%	E/C	S/C
CH6	99	21	16	99	21	16	99	19	7
MR3	71	86.7	61.8	72.0	51.9	37.3	67	53.4	35.8
MR4	66	60.2	39.8	77	46.2	35.5	66	41.3	27.3
AG4	98	41.1	40.3	100	41.1	40.3	100	23.8	23.8
MU6	45	38.4	30.7	80	60.0	32.6	63	41.7	26.2

Appendix 5.1 Woody species density data sets.

Species density data set

Plot	MU1	MU2	MU3	MU4	MU5	MU6
Acacia karroo	0	0	0	0	0	0
Acacia nigrescens	0	0	0	0	0	0
Acacia nilotica	0	375	175	775	0	25
Acacia rehmanniana	0	0	0	0	0	0
Albizia amara	25	0	25	25	25	25
Unknown 1	0	0	0	0	0	0
Bauhinia spp	0	0	0	0	0	0
Berchemia zeyheri	0	0	0	25	0	0
Bolusanthus speciosus	0	0	0	0	0	0
Brachystegia boehmii	0	0	0	0	0	0
Brachystegia spiciformis	450	25	0	0	800	1275
Bridelia mollis	0	0	0	0	0	0
Burkea africana	25	0	0	0	125	125
Canthium huillense	25	0	0	0	0	0
Carissa bispinosa	0	0	0	0	0	0
Cassia singueana	0	0	0	0	0	0
Colophospermum mopane	0	5000	5250	50	0	0
Combretum adenogonium	0	175	50	0	0	0
Combretum apiculatum	0	0	0	50	0	25
Combretum imberbe	0	0	0	0	0	0
Combretum hereroense	25	0	0	0	0	0
Combretum molle	50	0	0	50	0	0
Crossopteryx febrifuga	0	0	0	0	0	0
Dalbergia melanoxylon	0	25	0	0	0	0
Unknown 2	0	0	0	0	0	0
Dichrostachys cinerea	0	100	75	225	0	0
Diospyros lycioides	25	0	0	0	0	0
Diospyros mespiliformis	0	0	0	25	0	0
Diplorhynchus condylocarpon	50	0	0	25	0	25
Dodonaea viscosa	0	0	0	0	0	0
Dombeya kirki/Azanza garkeana	0	0	0	0	0	0
Euclea divinorum	0	125	375	25	0	25
Euclea natalensis	25	0	0	0	0	0
Faidherbia thonningii	0	0	0	25	0	0
Faurea saligna	0	0	0	0	0	0
Ficus capensis	0	0	0	0	0	0
Ficus ingens	0	0	0	0	0	0
Flacourtia indica	0	0	0	0	0	0
Grewia flavescens	25	25	0	0	0	0

Grewia monticola	0	125	375	0	0	0
Julbernardia globiflora	75	0	0	0	50	50
Lannea discolor	0	0	0	0	0	25
Lannea stuhlmannii	0	0	0	0	0	0
Lecaniodiscus fraxinifolius	50	50	0	25	0	0
Lippia javanica	0	0	0	0	0	25
Lonchocarpus capassa	0	0	0	0	0	0
Maerua juncea	0	0	0	0	0	0
Maytenus heterophylla	0	0	0	0	0	0
Maytenus senegalensis	0	0	0	375	0	50
Monotes engleri	0	0	0	0	200	0
Monotes glaber	0	0	0	0	0	0
Ormacarpum kirkii	0	0	0	0	0	0
Ozoroa reticulata	175	25	0	25	25	75
Pseudolachynostylis maprouneifolia	0	0	0	0	0	0
Parinari curatellifolia	0	0	0	0	0	0
Pavetta schumanniana	0	0	0	0	0	0
Peltophorum africanum	0	50	200	75	0	25
Protea gaguedi	0	0	0	0	0	0
Pterocarpus angolensis	0	0	0	0	0	0
Pterocarpus rotundifolius	25	0	0	0	0	0
Pouzolzia hypoleuca	0	0	0	0	0	0
Rhus chirindensis	0	0	0	0	0	0
Rhus lancea	0	125	0	0	0	25
Sclerocarya birrea	0	0	0	0	0	75
Securinega virosa	0	200	75	25	0	0
Strychnos cocculoides	0	0	0	0	0	0
Strychnos madagascariensis	0	0	0	0	0	0
Strychnos spinosa	0	0	0	0	0	0
Swartzia madagascariensis	0	0	0	0	0	0
Syzigium guineense	0	0	0	0	0	0
Syzigium huilense	0	0	0	0	0	0
Terminalia sericea	25	50	125	375	175	50
Vitex payos	0	0	0	0	0	0
Xeromphis obovata	125	125	125	0	0	0
Ximenia americana	0	0	0	0	0	0
Ximenia caffra	0	0	0	0	0	0
Ziziphus micronata	25	150	0	150	0	25
Unknown 3	0	0	0	0	0	0
Uapacca kirkiana	0	0	0	0	0	0
Annona stenophylla	0	0	0	0	0	0
Erythrina abyssinica	0	0	0	0	0	0

NB1	NB2	NB3	NB4	NB5	MR1	MR2	MR3	MR4
0	375	0	0	0	0	0	0	0
25	0	0	0	0	125	0	0	0
950	0	25	0	0	0	0	25	75
25	0	0	0	0	100	0	25	0
0	0	0	0	0	0	0	125	50
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	25	25
0	0	0	0	0	0	0	0	0
250	125	0	0	0	0	0	0	0
0	0	0	0	0	0	0	475	0
0	0	475	1000	1550	0	925	1900	150
0	0	0	0	0	0	0	0	0
0	0	0	25	0	0	50	0	0
0	0	25	0	0	0	0	0	25
0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	75	50
4100	6025	2928	0	0	0	0	0	0
0	0	25	0	125	0	0	0	0
0	0	75	50	175	200	0	50	0
50	75	0	0	0	0	0	0	0
950	225	25	0	0	600	0	0	50
0	0	75	50	0	0	0	1250	0
0	0	0	0	125	0	0	0	0
0	0	0	0	275	0	0	0	0
0	0	0	0	0	0	0	0	0
25	25	0	0	0	275	0	50	50
175	950	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	25
0	0	0	0	300	50	0	50	25
0	0	400	0	0	0	0	0	0
0	0	0	0	0	0	0	0	25
50	2100	0	0	75	0	0	0	75
0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	75
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	25
0	0	0	0	0	0	0	0	0
0	25	0	0	50	0	0	0	25
0	0	0	0	0	0	0	0	0
25	125	0	0	0	0	0	0	25
0	0	50	175	100	0	25	75	700
0	0	0	50	75	0	0	125	50
0	0	0	25	0	25	0	0	0

0	25	0	0	0	0	0	50	25
0	0	0	0	0	0	0	125	0
0	0	0	0	0	0	0	0	0
0	0	0	0	50	0	0	50	0
0	75	0	0	0	0	0	0	0
25	0	50	0	0	0	0	0	50
0	0	0	0	0	0	0	0	0
0	0	0	25	0	0	125	100	0
0	0	0	0	25	0	0	675	0
0	0	25	75	175	0	0	0	50
0	0	75	25	100	0	125	125	50
0	0	0	0	0	0	50	0	75
0	225	125	50	1125	0	0	0	100
100	0	0	0	0	0	0	75	25
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	25	0	0	0	0	0	0
0	25	0	0	0	0	0	0	0
175	225	0	0	0	0	0	75	100
0	25	0	0	0	25	0	0	25
25	25	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	25
0	0	0	0	0	0	0	0	75
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
125	25	125	25	0	725	75	0	50
0	0	0	0	0	0	0	0	0
0	125	650	0	75	375	0	125	0
0	0	0	0	0	0	0	0	25
0	25	0	0	0	0	0	50	0
0	150	0	0	0	75	0	25	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	0	0	0	0	0

UN1	UN2	UN3	UN4	AG1	AG2	AG3	AG4	CH1
0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
75	50	0	25	0	0	0	0	0
25	0	0	0	0	0	0	0	0
0	0	25	100	0	0	0	0	0
0	0	0	0	125	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
75	775	775	300	0	0	25	25	0
0	0	0	25	0	0	0	0	0
0	0	75	25	0	0	50	50	25
0	0	0	275	0	0	0	25	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	75	0	0	0	0	0	0	0
25	0	0	150	0	0	0	0	0
75	75	75	50	0	0	0	0	0
0	0	0	0	0	0	0	0	0
100	275	0	275	0	0	0	0	0
0	0	50	25	25	0	75	50	25
0	0	0	0	0	0	0	0	0
0	0	0	25	0	0	0	0	0
0	0	0	0	0	0	0	0	0
25	25	0	50	0	0	0	0	25
0	25	0	0	100	0	0	0	0
0	0	0	200	0	0	0	0	0
0	75	100	50	0	0	0	0	0
0	0	0	0	0	0	0	50	0
0	0	0	0	25,00	0	0	0	0
0	75	25	175	50	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
175	0	0	0	0	125	0	0	0
0	0	0	0	0	100	0	0	0
0	0	0	0	0	0	0	0	0
0	0	25	25	0	0	0	0	0
0	0	0	25	0	0	0	0	0
0	0	0	25	0	0	0	0	0
0	0	25	0	0	0	0	25	0

0	0	325	125	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	50	25	50
250	0	0	0	100	0	0	0	0
0	0	0	75	0	0	0	0	0
0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
100	25	0	0	0	0	0	0	25
0	0	0	0	0	0	0	25	125
0	0	25	0	0	0	0	0	0
0	0	0	225	0	0	0	0	0
0	0	25	225	0	0	0	0	0
0	25	25	25	0	25	75	0	25
0	0	0	0	0	0	0	0	0
0	50	25	25	0	0	0	0	0
25	75	0	50	0	0	0	0	50
0	0	0	0	0	0	0	25	0
0	0	0	0	0	0	0	0	0
0	0	0	25	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	125	25	25	0	0	0	0	0
0	0	0	25	0	0	0	0	0
0	0	0	75	25	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	75	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	200	0	0	0
0	0	0	0	0	500	0	0	0
725	0	25	0	25	75	0	0	375
0	0	0	0	0	0	0	0	0
0	0	25	75	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	50	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	0
0	0	0	0	0	0	0	0	0

CH2	CH3	CH4	CH5	CH6	MA1	MA2	MA3	MA4
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	0	0	0	0
0	0	0	0	25	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	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	800	25	100	2225	0	500	125	650
0	0	0	0	25	0	0	0	0
25	25	25	25	0	0	125	0	0
0	0	25	50	100	0	0	0	0
25	0	0	0	0	0	0	0	0
0	0	0	100	25	0	25	50	50
0	0	0	0	0	0	0	0	0
0	25	25	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	0
25	0	75	0	1975	200	0	0	125
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	75	0	0	25	75
0	0	0	0	0	0	0	0	25
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	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	75	0
0	0	0	0	0	0	0	0	125
0	0	0	0	0	0	0	0	25
0	25	0	0	0	0	0	0	0
0	0	0	25	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
200	75	750	20	0	0	75	0	0

0	0	0	0	0	0	0	0	25
0	0	0	0	0	0	0	0	0
0	0	25	0	75	0	0	0	0
0	0	0	0	0	0	0	75	0
0	0	0	0	0	0	0	0	0
0	0	0	0	25	0	0	0	0
0	0	0	0	0	0	0	0	0
25	0	0	225	0	0	0	0	75
0	1250	0	700	1500	0	0	0	0
0	0	0	0	0	0	0	0	125
0	0	0	0	0	0	0	0	0
0	0	25	0	0	0	25	0	0
0	0	50	50	25	0	0	0	0
0	0	250	1525	0	0	100	0	125
0	0	0	0	0	0	25	0	75
0	0	0	0	0	50	0	25	150
0	0	0	0	0	0	0	0	0
0	75	0	25	50	0	0	0	0
25	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	25	25	0	0	0	0
25	25	0	0	0	0	25	0	50
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	25	0	0	50	0
0	0	0	0	0	0	0	0	0
0	25	25	50	0	0	75	0	0
0	0	25	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	175	0	0	0
425	25	0	0	0	0	0	0	0
25	25	0	0	100	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	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	75	75	0
0	0	0	0	0	0	25	0	0
0	0	0	0	0	0	0	0	25

ANa1	ANa2	ANa3	ANa4	ANb1	ANb2	ANb3	ANb4
0	0	0	0	0	0	0	0
0	0	0	0	0	50	0	0
100	0	300	25	100	150	150	250
0	25	0	0	0	0	0	0
0	25	0	25	0	250	25	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	0
0	0	325	50	0	25	375	0
0	0	0	450	0	0	0	25
0	0	0	0	0	0	0	0
0	0	25	0	0	0	0	25
0	0	0	0	0	0	25	0
0	0	0	0	0	0	0	0
0	0	25	0	0	0	0	0
250	6325	50	0	0	3225	25	0
50	0	0	50	2450	0	0	0
175	0	100	50	25	0	0	0
0	0	0	25	25	0	0	0
500	525	125	0	150	350	50	0
25	0	550	50	0	0	550	50
50	0	0	25	25	0	25	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
25	25	50	25	25	175	0	0
0	0	25	0	0	0	0	0
0	0	25	25	0	0	0	0
0	0	100	25	0	0	25	25
0	0	0	0	0	0	0	0
0	0	0	25	0	0	0	0
0	75	900	50	75	75	0	0
0	0	0	0	0	0	0	0
25	0	0	0	25	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	50	0	0	0	0
0	25	0	0	0	0	0	0
0	50	75	25	0	0	0	0
0	0	0	100	0	0	350	250

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	25	25	0	0	0	0
125	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	25
0	0	0	0	0	0	0	0
25	0	150	25	25	0	25	0
0	0	0	0	0	0	25	0
0	0	0	0	0	0	0	75
0	0	0	0	0	0	0	0
25	0	0	50	0	0	0	0
0	0	75	100	0	25	0	0
0	0	0	0	0	0	0	0
0	0	75	100	25	0	250	75
50	0	50	0	25	0	25	25
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
0	0	0	0	0	0	0	0
0	25	100	25	25	25	25	0
0	0	0	0	0	0	0	0
0	25	75	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	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
325	50	50	0	450	50	100	175
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1125
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
50	25	0	0	50	25	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	0	0

Appendix 5.2 Key to plot numbers used in the cluster analyses.

Catena Name	Vegetation sample site symbol	Plot number used in the dendrogram	Catena Name	Vegetation sample site symbol	Plot number used in the dendrogram
Navik Bay	NB_1	1	Mutsungwe	MU_4	23
	NB_2	2		MU_5	24
	NB_3	3		MU_6	25
	NB_4	4	Agyle	AG_1	26
	NB_5	5		AG_2	27
Mushandike River	MR_1	6		AG_3	28
	MR_2	7		AG_4	29
	MR_3	8	Air Strip North B	ANb_1	30
	MR_4	9		ANb_2	31
Chikungurugwi	CH_1	10		ANb_3	32
	CH_2	11		ANb_4	33
	CH_3	12	Air Strip North A	ANa_1	34
	CH_4	13		ANa_2	35
	CH_5	14		ANa_3	36
	CH_6	15		ANa_4	37
Up Navik Bay	UN_1	16	Maruta	MA_1	38
	UN_2	17		MA_2	39
	UN_3	18		MA_3	40
	UN_4	19		MA_4	41
Mutsungwe	MU_1	20	Total number of sites		41
	MU_2	21			
	MU [illegible]	22			