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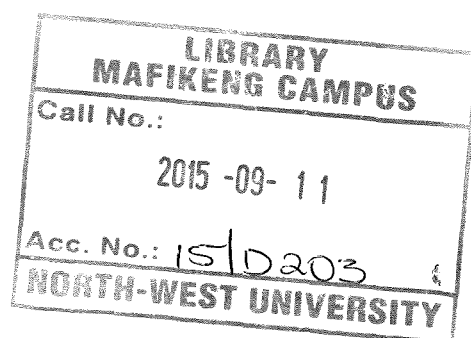
ANALYSING MULTITEMPORAL VEGETATION DENSITY IN THE UPPER MOLOPO RIVER CATCHMENT USING REMOTE SENSING TECHNIQUES

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Thesis submitted in fulfilment of the requirements for the degree of Master of Science in
Environmental Science

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DECLARATION

I, Agnes Kyomukama Turyahikayo, hereby declare that the dissertation for the Master of Science in Environmental Sciences at the North West University, hereby submitted has not previously been submitted by me in its entirety or in part for any degree at this or any other University, that it is my own work in design and execution and that all material contained herein has been duly acknowledged.

SIGNED: ATIQ.

Agnes Kyomukama Turyahikayo

DATE: 16/04/2015

DEDICATION

I dedicate this dissertation to my late father, Peter Rwenzigye, my late mother, Fidelis Kinkuhaire Rwenzigye and my late husband, Dr. Bernard Turyahikayo. May their souls rest in eternal peace.

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My sincere and heartfelt gratitude to my daughters (Claire, Cynthia and Charlotte) for their understanding and patience during the time of conducting the thesis, when they practically took over all household chores. Thank you so much for your support, prayers, and encouragement without which I would have given up.

I would also like to express my appreciation to all my course mates for their friendship and for the wonderful events we shared together. Finally yet importantly, thanks to the Almighty God for making this study a success.

ABSTRACT

In arid and semi-arid environments like most of South Africa, the state of vegetation density in catchments is an important indicator of the state of the environment, particularly because vegetation influences water availability by encouraging groundwater recharge. Because of the scarcity of water and consequent limits in abundance of vegetation in healthy green condition, in addition to climatic pressure, vegetation density in semi-arid environments are under human use pressure. The upper Molopo river catchment area (UMRCA) in the North West Province of South Africa is under this combined human use and rainfall pressure. This study aimed at assessing long-term changes in vegetation density in the upper Molopo river catchment area, resulting from anthropogenic and rainfall pressures. Four Landsat images were utilized in analyzing the vegetation density change. For purposes of interpreting the changes identified, ancillary long-term data on anthropogenic factors (human population, number of houses, household use of wood as energy source, livestock populations) and rainfall were obtained from state sources.

Vegetation density on the images was enhanced using the Normalized Difference Vegetation Index (NDVI). The training data was then used for supervised maximum likelihood classification of the images into separate LULC as well as vegetation density (low, medium, high) maps for each date. Assessment of accuracy indicated high classification accuracy of over 80%. The errors in classification were mainly due to spectral signature confusion for the LULC classes. Change detection was then performed using the post-classification comparisons technique. Results indicated a growth in built up area from 3% in 1989 to 16% in 2013. The main indication of disturbance to the vegetation was a sustained decline in medium vegetation density and its replacement by low vegetation density, particularly within 5km of human settlements. Hence, the study concluded that anthropogenic factors were the main cause of the decline in vegetation density in the UMRCA.

Rainfall showed a cyclical pattern, with low seasonal rains (and high, negative Standardized Precipitation Index (SPI) values in the mid-1980s and positive SPI values thereafter, indicating that in the image period of analysis had wet conditions in general. Differences in rainfall prior to image date accounted for most of the inter-date variation in the vegetated LULC classes as well as water bodies. Long-term rainfall pattern did not have direct impact in the decline of medium vegetation density class in the UMRCA. However, there was a statistically significant negative correlation between human population and area of cover by

medium vegetation density ($r = -0.960$, $P < 0.01$), implying that as human population increases, the medium vegetation density declines in area of cover.

The decline in medium vegetation density in the Upper Molopo River Catchment is of ecological concern. There is a need for short term and long term strategies to ensure sustainable land management in the catchment area, and in order to preserve vegetation density and biodiversity in their natural state.

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LIST OF ACRONYMS

CBD	Convention on Biological Diversity
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environmental Affairs and Tourism
DN	Digital Number
ENSO	El Nino Southern Oscillation
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetation Index
GCP's	Ground Control Points
GHG	Green House Gases
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
LULC	Land Use - Land Cover
MAR	Mean Average Rainfall
MEA	Millennium Ecosystem Assessment
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager
PCA	Principal Component Analysis
RAI	Rainfall Anomaly Index
SPI	Standardized Precipitation Index
TM	Thematic Mapper
UMRCA	Upper Molopo River Catchment Area
UTM	Universal Transverse Mercator
VI's	Vegetation Indices
WMO	World Meteorology Organization

INTRODUCTION

This research examines multi-temporal vegetation density in the Upper Molopo River catchment area of South Africa using remotely sensed imagery. The purpose of this chapter is to introduce anthropogenic and climatic factors affecting vegetation density in the study area. A background section puts the subject matter of the research followed by statement of the problem together with the aim and objectives of this research. The rationale provides the reason why the research of this magnitude should be conducted while the hypotheses provide the guiding framework of the research.

1.1 Background

Over the past century, significant changes at global and regional levels have been observed in climate as well as in vegetation cover. Under such conditions, more attention has been paid over the past decades to climate related studies. However, it is evident that vegetation is closely interrelated with its surrounding environments. Changes in temperature and rainfall coupled with different anthropogenic activities (wood gathering, agriculture, and urbanisation) could affect vegetation cover at varying levels. The effects can be severe and even detrimental on some forms of vegetation and minor on some others. Hence, an equal attention has to be paid to the vegetation density (Cicely, 2011). Climatic factors such as rainfall and surface temperature determine the availability of moisture for physical, biological and chemical activities that occur in plants which ultimately lead to healthy plant growth. The impacts of climate change on plant life are of key concern to humankind because plants, apart from their inherent interest, play a vital role in ecosystem function and in food production and security. They also have implication for other groups of organisms which depend on them for habitat and shelter. Unlike some other groups of organisms, plants are sessile and only able to move through dispersal of pollen, seeds, which slows migration, and this makes them less able to respond to climate change.

Recent studies in the Southern African region have revealed climatic and land cover changes that threaten to undermine the integrity of riverine habitat, the availability and quality of water, and agricultural productivity (IPCC, 2008). In South Africa, the unsustainable use of natural resources for rural livelihood and overgrazing has led to serious vegetation degradation (Moleele et al., 2002). Rangeland degradation, especially bush encroachment and soil erosion, are particularly acute in the North West Province where all districts show signs

of desertification and loss of biodiversity resulting in bush encroachment. The modifications of natural vegetation cover and soil conditions usually lead to changes in rainfall runoff characteristics of the catchment area, which consequently change river flow regimes (Palamuleni et al., 2011).

Increased temperature can increase plant growth up to a limit, beyond which death occurs. Increased temperatures can also cause plant respiration rates to increase relative to photosynthesis, resulting in no net gain in biomass production and to plants even becoming a potential source of CO₂. Although the causes of vegetation density change are not fully understood, several natural and human factors, including fire, livestock grazing, human population, cultivation and constant droughts are primary causes (Moleele et al., 2002) among many other possible causes (Kraaij and Ward 2006; Ward 2005).

In the Upper Molopo Sub-Management Area, like most other catchment areas in South Africa and the North West Province in particular, vegetation density is continually decreasing. This trend could be attributed to both climatic and anthropogenic factors such as climate variability, deforestation, erosion due to overgrazing and urbanisation (Taylor et al., 2009). According to Wessels et al. (2007), most of the impoverished people live in semi-arid mixed farming regions and depend on natural resources for their survival. Households living in these areas face severe constraints that stem from marginal conditions for most forms of agriculture. Therefore, changes in vegetation cover and structure occur through agricultural practices, urbanization, deforestation, fire wood harvesting and mining.

In spite of the vegetation changes taking place, especially in the upper and central parts of the catchment area, there is a general lack of quantification of the extent of vegetation density change within the catchment area (DWAF, 2003). Hence, there is a need for research on the trends and implications of vegetation density change in the study area. This study focuses primarily on the vegetation abundance of the Upper Molopo River catchment Area (UMRCA) of the North West Province of South Africa, Which is situated on the Molopo River.

1.2 Statement of the problem

This study looks at the socio-economic activities (deforestation, mining, urbanisation and agricultural) which are taking place in the UMRCA and its environs, how they affect the local climate which in turn will affect the vegetation of the area. The Upper Molopo River Catchment is a Transboundary catchment with diverse plant life.

Plant diversity is fundamental to all terrestrial ecosystems and provides the life-support systems upon which all forms of life depend. In spite of the extraordinary complexity and diversity of the catchment; patterns of the catchments' vegetation density have never been adequately quantified or documented. The natural woodland and forest cover are cleared away for settlement expansion, mining, provision of energy from wood and agricultural practices (Department of environmental affairs and tourism, 2004). Removal of forest and woodland is of ecological concern in the context of among others; biodiversity conservation ground water recharge and carbon stock provision in buffering the build-up of CO₂ as greenhouse gas (Bucini and Hanan, 2007). It is therefore, the study of vegetation density trends in the study area that will indicate the relationship and the interaction between plants and climatic conditions. Understanding the extent to which anthropogenic activities and climate variability affect vegetation will go a long way in identifying cause and effects which will lead to developing mitigation and adaptation strategies.

1.3 Aim and objectives

The primary aim of this study was to assess changes in vegetation density in the in the Upper Molopo River Catchment Area for the periods 1989, 1996, 2005 and 2013.

The specific objectives are:

1. To identify and map various land use types in the study area.
2. To quantify vegetation density change per unit area in a semi-arid environment like the North West Province using remote sensing techniques.
3. To analyse the effects of rainfall variability on vegetation density on the basis of spectral response of vegetation.
4. To establish land use pressure induced trends in vegetation density using multi-temporal Landsat imagery.

1.4 Hypotheses

The research had the following hypotheses:

- **hypothesis 1:** Climate variability and anthropogenic activities affect vegetation density in the Upper Molopo River catchment area.
- **hypothesis 2:** There has been a statistically significant change in the vegetation density in the study area during the period 1989 -2013

1.5 Rationale

There are quite a number of compelling reasons why the vegetation density of this catchment should be studied amongst which are the following:

Quantification of the change trends can enhance understanding of the way that ecosystems are structured and function in this area. It may also be possible to extrapolate this knowledge to other catchment ecosystems in Southern Africa. In addition, the area is also home to various rural communities who were previously under the old Bophuthatswana homeland whose livelihood depend on the catchments resources in form of eco-tourism, fishing, fire wood harvesting, commercial and subsistence agriculture. It is an area of extraordinary complexity and diversity encompassing dolomite eyes (Molopo and Molemane), wetlands of international importance (Ramsar Sites), conserved areas and areas of cultural heritage (Lotlamoeng cultural village), pans and a rich mixture of floristic elements.

This provides an ideal natural laboratory which should be taken advantage of for understanding trends of change in vegetation density within the Upper Molopo River Catchment area (UMRCA). An understanding of change patterns within the vegetation of the area can lead to an understanding of the ecosystem structure and function, resulting in better management of the area, especially with respect to riparian vegetation and rangeland conservation planning. The area has vast potential from the perspectives of eco-tourism and agriculture (commercial and subsistence).

These reasons therefore, make it crucial to establish the effect of anthropogenic activities and climate variability on the vegetation density of UMRCA, since vegetation is a crucial link in understanding the interaction between plants and climatic conditions of any area.

1.6 Description of the study area

1.6.1 Location setting

The Molopo River catchment area lies in the North West Province, South Africa. Molopo River is a tributary of the Orange River (DWAF, 2003). The catchment area of the basin is 367,201 km² and is divided into upper and lower sections with the upper Molopo River being part of the Crocodile (West) and Marico water management area while Lower Molopo is included in the lower Vaal water management area. Molopo River is an ephemeral river, 960km long and acts as the border between South Africa and Botswana in the north- western part of South Africa. It runs usually west for approximately 966km to flow into the Orange

River close to the South eastern boundary of Namibia (Shand and Basson, 2003). The river, being an ephemeral type, ceases as surface run off in Mafikeng and discharges into pans in Botswana before flowing south and emerging as surface flow before it reaches the Orange River. The area is almost flat with an average elevation of about 1480 m above mean sea level, and a total perimeter of 341 km and a total area of 7189.49 km² (DWAF, 2004a).

The study area constitutes the upper Molopo River catchment area, located in eastern part of the Molopo catchment in the North West Province of South Africa. The area of interest is between the Molopo Eye on the East of Mafikeng Town and the Disaneng dam on the West of Mafikeng and the area covering the Botsalano game reserve on the North where the Molopo River forms the border between the North West Province and Botswana covering a distance of 93km. It is located between 25°38' S, 26°10' S and 25°10' E, 26°10'E (Figure 1). The catchment area is one of the very few sustainable sources of water in a semi-arid environment. The source of the Molopo River is the main supplier of water to the town of Mafikeng and its environs. Irrigation is also a dominant water demand in this sub-management area. Major dams include Disaneng, Modimola (Setumo), Letlamoreng and Cooke's Lake whose flora and fauna form a major tourism industry (Figure 1).

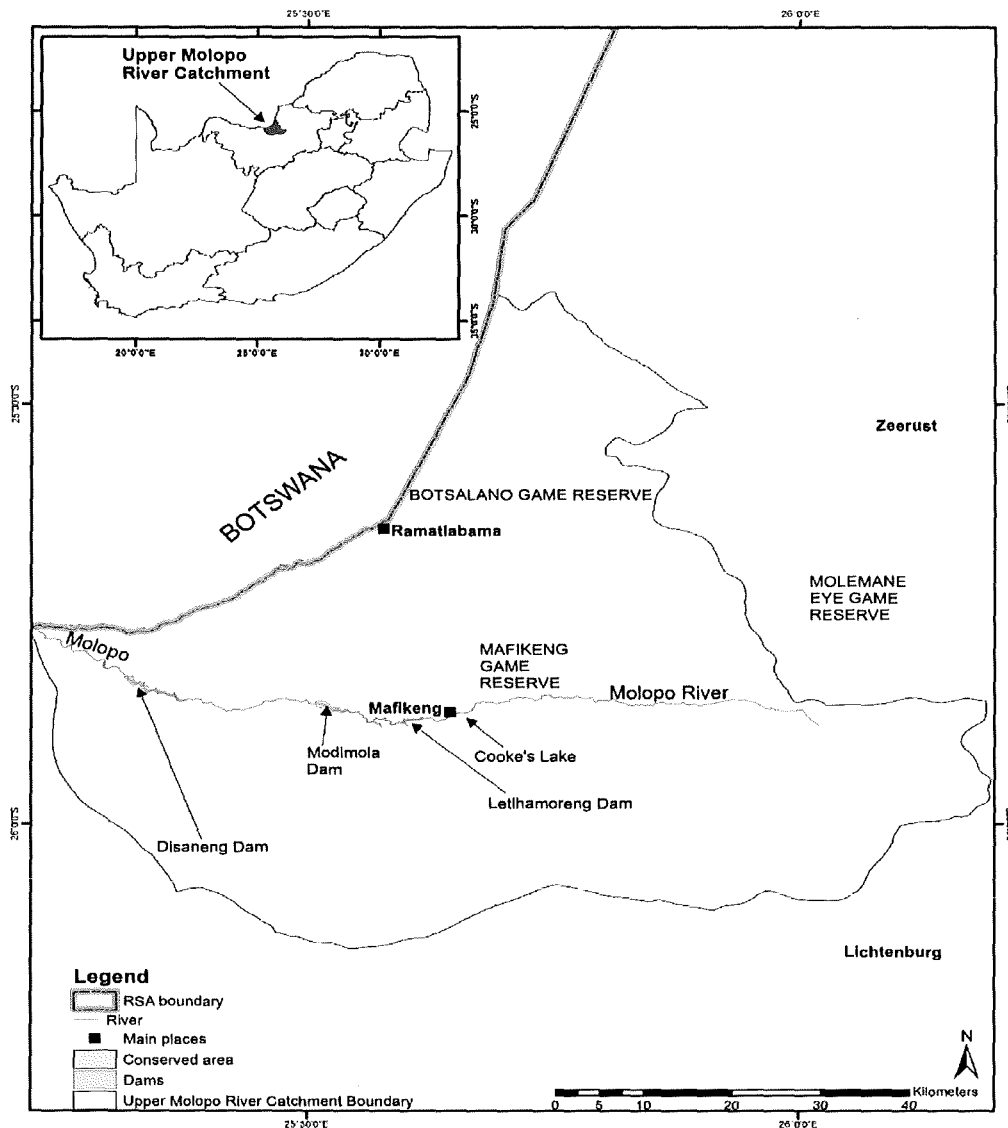


Figure 1 Location setting of the study area in the North West Province and South Africa

1.6.2 Climate

1.6.2.1 Rainfall

The semi-arid parts of southern Africa are characterized by low and highly variable rainfall in space and time (Freeland, 2001). Rainfall is seasonal, with most rain occurring as thunderstorms during the summer period of October to April. The mean annual precipitation ranges between 400 and 600 mm per year in the study area.

1.6.2.2 Temperature

Maximum temperatures are experienced in January while minimum temperatures usually occur in July, sometimes accompanied by frost. During winter months, mean temperatures of about 10°C are recorded while in summer the mean temperature ranges between 22.5°C and 25°C (DWAF, 2003).

1.6.2.3 Evapotranspiration

The Mean Annual Evaporation (MAE) for the Upper Molopo is very high. It is estimated to be as high as 2800mm, with the highest occurring in December (Shand and Basson, 2003). Soil moisture management in this arid and semi-arid area is faced with limited and variable rainfall and high evapo-transpiration rate determining ephemerality of rivers. Because of limited water flow, salts build up and the only types of vegetation that survive around these springs and wetlands are salt tolerant species.

1.6.3 Vegetation

The most dominant vegetation types in the upper Molopo River catchment area are the Open *Acacia tortilis* woodland, open grass plains, thicket closed woodlands, *Acacia Karoo*, vleis and floodplain (Mafikeng Spatial Development Framework, 2005). According to Mucina and Rutherford (2006), the Upper Molopo River Catchment has six main types of vegetation. The characteristics of these vegetation types are as follows:

Carltonville Dolomite Grassland – It occurs in the eastern part of the catchment and is associated with slightly undulating plains dissected by prominent rocky chert ridges. It consists of species-rich grasslands forming a complex mosaic pattern, dominated by graminoids such as *Aristida congesta*, *Digitaria tricholaenoides*, *Diheteropogon amplexans*, *Eragrostis chloromelas*, *Loudetia simplex*, *Heteropogon contortus*, *Schizachyrium sanguineum*, etc. and herbs such as *Acalypha angustata*, *Barleria marcrostegia*, *Chamaecrista mimosoides*, *Chamaesyce inaequilatera*, etc. and scattered shrubs including *Euclea undulata*, *Rhus magalismontanum*, *Zanthoxylum capense* and *Diospyros lycioides*. The geology and soils are dolomite and chert of the Molemane Supergroup (Transvaal Supergroup) supporting mostly shallow Mispah and Glenrosa soil forms. It occurs in rainfall of average 593mm.

Dwarsberg-Swartruggens Mountain Bushveld – It occurs in isolated stands on hills and ridges to the north of Mafikeng. It is characterized by tall trees such as *Acacia*

robusta and small trees like *Acacia caffra*, *Acacia e rubescens*, *Burkea Africana*, *Combretum apiculatum*, *Protea caffra*, *Ziziphus mucronata*, etc; succulent trees such as *Aloe marlotii* and tall shrubs such as *Dichrostachys cinerea*; low shrubs such as *Athrixia elata*, *Pavonia burchellii*, *Rhus magalismontana*; woody climbers such as *Asparagus africanus*. Its geology and soils are shales, quartzites of the Pretoria Group (Transvaal Supergroup) with stony shallow soils of the Glenrosa and Mispah soil forms. It occurs in rainfall of 550-650mm.

Highveld Salt Pans – These are found in isolated pockets east of Mafikeng. They occur in arid to semi-arid elevated regions of the Highveld, as depressions in plateau landscape containing temporary water bodies. Central parts of the pans often seasonally inundated and sometimes with floating macrophyte vegetation or the vegetation cover develops on drained bottoms of the pans and forms typical concentration patterns. Low shrubs include *Atriplex vestita*, *Felicia filifolia*, *Felicia muricata*, *Nenax microphylla*, *Nestlera conferta*, *Pentzia globosa*, etc; succulent shrubs include *Salsola glabrescens*, *Lycium cinereum*, *Malephora herrei*, *Suaeda fruticosa*, *Titanopsis hugoschlechteri*, etc; Megagraminoids include *Cyperus congestus*, *Phragmites australis*, etc; Graminoids include *Chloris virgate*, *Cynodon dactylon*, etc. The bottoms of the pans are unusually formed by shales of the Ecca Group giving rise to vertic clays. Occurs in areas with rainfall less than 500mm.

Klerksdorp Thornveld - Occurs in Botsalano Game Reserve to the north of Mafikeng, around Mafikeng, as well as in vicinity of Madibogo to the South of Mafikeng (2.5% is conserved in the Mafikeng Game Reserve and in the Botsalano Game Reserve). It has plains or slightly irregular undulating plains with open to dense short *Acacia karroo* bush clumps in dry grassland. Other dominant trees include *Acacia caffra*, *Celtis Africana*, *Rhus lancea*, *Ziziphus mucronata*. Tall shrubs include: *Acacia hebeclada*, *Diospyros lycioides*, *Grewia flava*, *Gymnosporia buxifolia*, *Rhus pyroides*, etc. Woody climbers include: *Asparagus Africanus* and low shrubs include *Asparagus laricinus*, *Felicia muricata*, *Anthospermum hispidulum*, etc. Geology and soils are made up of shale, slate and quartzite of the Pretoria Group with interlaid diabase sills and Hekpoort lava supporting relatively shallow and rocky soils. Occurs in areas with average rainfall of 533mm.

Mafikeng Bushveld - It occurs west of Mafikeng and south of the Botswana border

around Vergelee, southwards to Piet Plessis and Setlagole. It is characterized by well-developed tree and shrub layers, dense stands of *Terminalia sericea*, *Acacia luederitzii*, and *Acacia erioloba* in certain areas. Shrubs include *Acacia karroo*, *Acacia mellifera*, *Acacia hebeclada*, *Dichrostachyas cinerea*, *Grewia flava*, *Grewia retinervis*, *Rhus tenuinervis*, *Ziziphus mucronata*, etc. The geology and soils is composed of Aeolian Kalahari sand of Tertiary to Recent age on flat sandy plains, soil deep > 1.2m. Occurs in places with average rainfall of 520mm.

Western Highveld Sandy Grassland - It occurs south-west of Mafikeng. It is characterized by flat to gently undulating plains with short, dry grassland, with some woody species occurring in bush clumps. Grass species include, among others, *Antheophora pubescens*, *Aristida congesta*, *Cymbopogon pospischilii*, *Cynodon dactylon*, *Eragrostis lehmanniana*, *Sporobolus africanus*, *Aristida adscensionis*, *Themeda triandra*, *Aristida canescens*, *Digitaria argyrograpt*, etc. It is also characterized by high shrubs such as *Gazania krebsiana*, *Dicoma anomala*, etc. and low shrubs such as *Anthospermum rigidum*, *Felicia muricata*, etc. Its geology and soils are made up of basaltic lavas of the Klipriversberg Group and adensitic lavas of the Allanridge Formation covered by Aeolian sand or calcrete, with the eutrophic plinthic soils, which are mainly yellow apedals. Occurs in places with average rainfall of 520mm.

1.6.4 Soil types and distribution

The type of soils and their distribution in the catchment area are determined by geology, topography and rainfall. Major soil types are moderate deep clayed loam soil types, highly suitable for commercial agriculture when sufficient water is provided (Taylor et al., 2009). Soils in most ephemeral rivers are relatively poor and thin and have little potential for irrigated agricultural production. However, these soils support dense stands of trees and other woody vegetation, which provide essential fodder for livestock and wildlife (Mucina and Rutherford, 2006).

1.6.5 Land use pattern

The land use pattern is mainly grazing and dry land subsistence agriculture, with Mafikeng as the major urban and industrial town. Commercial irrigated agriculture occurs in the northern and western portions of the catchment area where the dolomites traverse the Upper Molopo catchment area. The emerging population growth and status of settlements in and around the

UMRCA is leading to changes in the land use pattern with demand for more land for agriculture and habitats. Different land-use practices have an effect on species composition and thus diversity which makes it very important to understand this relationship so that one can predict the effect of climate and anthropogenic activities on vegetation patterns.

1.7 Outline of the thesis

This study is divided into five chapters. The first chapter provides the general introduction of the study covering background to the research, the research problem, objectives, hypothesis and the significance of the study. It also presents a profile of the physical environment and the land use of the UMRCA. The second chapter provides an examination of current literature relating to characteristics of vegetation density, role of vegetation in ephemeral rivers and remote sensing of the vegetation characteristics. It also presents parts of the findings of aspects of vegetation density trends, rainfall variability, anthropogenic activities and their impact on vegetation density change elsewhere in the world and similar studies in South Africa. Chapter three consists of research design and the methods of data collection, procedures of data analysis and the materials that have been used in the study. It further shows the procedures used to determine the extent of vegetation change in each plot using remotely sensed images. Chapter four presents the findings of the study with emphasis placed on the extent and magnitude of vegetation density change in relation to problem and aims of the study. The results are in form of maps, tables, graphs, pie charts and histograms. Chapter five presents the conclusion of the study as well as suggestions on mitigation measures for vegetation density preservation in the study area and propose future research directions.

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter a review of literature on characteristics of vegetation density, climatic and anthropogenic impacts on vegetation density, consequences of these impacts on biodiversity conservation, role of vegetation density in ephemeral rivers, remote sensing and vegetation characteristics, and their uses in studying this variability have been addressed. The research aims at illustrating the impact of various activities on the vegetation density of Upper Molopo River catchment area and the importance of incorporating climate variability into the policy and management of indigenous vegetation.

2.2 Key concepts about vegetation

Vegetation density is defined as all plant life in a given area (Thackway and Lesslie 2005, 2006). In this study, vegetation density shall mean the number of trees per transect or plot of 90x90m. More generally, it is referred to as distribution, abundance and condition of vegetation. The meaning of 'condition' is less clear, despite the concept of vegetation condition becoming more prevalent in recent land management policies worldwide. Keith and Gorrod (2006) define condition as a state of being or health. In biological terms, condition at an individual scale refers to the fitness of that individual (Keith and Gorrod, 2006), or rather a measure of the individual's reproductive success (Pinter et al., 1996). At higher biological scales, for example communities, ecosystems and landscapes, the concept of density/condition becomes less clear (Keith and Gorrod 2006).

Different types of vegetation communities that exist on earth could be explained in terms of biomes. A biome is a large geographical area of distinctive plant and animal groups, which is adapted to that particular environment (Mucina and Rutherford, 2006). The type of a biome that could exist in a region is determined by the climate and geography of that particular region. Major biomes on earth include deserts, forests, grasslands, tundra, and several types of aquatic environments.

South Africa has a unique natural environment and biological diversity recognised at an international level to be outstanding. There are considered to be nine separate biomes represented in the country the second largest of which is the grassland biome. The grassland

biome is characterised by high overall species richness and often very high local richness (Mucina and Rutherford, 2006). Highveld grasslands are home to almost 4000 species overall (Scott, 2006), and a single 100m² plot may contain anywhere from 8 to 60 species. The extent of the grassland biome in South Africa can be reasonably well defined on the basis of vegetation structure in combination with environmental factors. However, moisture availability, minimum temperature and rainfall seasonality are three factors considered to be important in defining the distribution of the grassland biome and distinguishing it from surrounding biomes (Rutherford et al., 2006a), and vegetation types that reflect differences in environmental conditions within the biome. Vegetation cover is part of the ecosystem and as such is affected by any change in the environment depending on zone and species, which might lead to their loss in productivity (Gurnell and Petts, 2006).

2.3 Climate variability and vegetation density characteristics

Over the past decades precipitation regimes have become more variable, with longer dry periods and an increase in the number of extreme rainfall events (Min et al. 2011; Smith 2011). These trends are projected to intensify as atmospheric carbon dioxide concentrations continue to rise (Karl et al. 2009). Worldwide, grasslands are experiencing more prolonged droughts and fewer but more intense rainfall events within seasons (IPCC 2012). Because grasslands and savannas cover 40% of the terrestrial surface (Chapin et al. 2001), their responses to changes in rainfall will have significant consequences for global patterns of productivity and diversity under future climate scenarios (Fay et al. 2003)

Climate has a strong influence on dry land vegetation type, biomass and diversity. Climatic factors such as precipitation, radiation and temperature are key determinants for the distribution and productivity (Huxman et al., 2004) of vegetation around the world. Climatic characteristics control world biomes and hence regional climate will determine what plants will grow where, and what animals will inhabit it. All three components, climate, plants and animals are interwoven to create a biome. Plant communities that ultimately give rise to different terrestrial ecosystems evolve and exist stably in regions where the combination of local climatic parameters, particularly, temperature and precipitation are conducive for a particular vegetation community. As the terrestrial ecosystems and climate are closely coupled, any change in one or more of the climatic variables will be reflected by vegetation.

Studies based on global, regional and local scales have been used extensively to explore the potential effect of diurnal and annual rainfall variability. For example, Knapp et al., (2002)

studied the effects of rainfall variability using an intact eco-system in USA. At regional scale, Harper et al., (2005) studied such variability over Kansas, USA. Dewar (2003), over southern Asia and western Pacific used ground based rainfall data to investigate the impacts of rainfall variability on the ecological diversification of grain crops and root and tree crops. Reason et al., (2002) studied rainfall variability in relation to El Niño Southern Oscillation (ENSO) over southern Africa using ground based and remotely sensed data. The sensitivity of global and regional climates to projected changes in vegetation density was tested using the Simple Biosphere Model (SiB2) coupled to a general circulation model (GCM) (Bounoua et al., 2002). The major findings of the simulations are that increases in vegetation density cause corresponding increases in evapotranspiration and precipitation. Increased vegetation causes an annual mean cooling of up to 0.8 kelvins (K) in tropical regions. Furthermore, precipitation was modelled to increase more than evapotranspiration reflecting more water stored in the atmosphere, as transferred from soil moisture. In addition, vegetation-rainfall dynamics have been studied mostly in semi-arid and agricultural regions of the world such as the Sahel and the Great Plains of the United States (Mendoza et al., 2003, and Jimenez et al., 2009).

Using a simplified coupled atmosphere-vegetation model, Zeng et al., (2000) found that rainfall and vegetation are reduced by climate variability in high rainfall regions but increased in low rainfall regions. The study revealed that positive upward feedbacks of vegetation on rainfall are more distinct in intermediate precipitation regions although climate variability reduces this gradient in the semi-arid regions (Zeng et al., 2000). In contrast, Zeng and Neelin (2000) suggested that without external climate variability, positive feedbacks from vegetation would enhance the gradient between desert and forest regions at the expense of the savannah, but in drier regions, climate variability would act to weaken this gradient.

Vegetation modelling studies have focused on the physiological impacts of vegetation on the climate particularly in deforestation and desertification studies. Advances in numerical modelling have not only included simulating vegetation response to climate variability, but also atmospheric response to vegetation change (Wang, 2004). The coupling of dynamic vegetation (biosphere) models to atmospheric models in climate studies have increased in recent years (Delire et al., 2004). Using a dynamic vegetation model, Ni et al., (2006) determined that variability in the temperature of the coldest month can induce evergreen mortality. However, changes in rainfall amount and increased rainfall variability minimally impact mesic grassland composition and diversity (Knapp et al., 2002), which are primarily

controlled by long-term regional climate (Collins et al., 2012), as well as fire frequency and grazing (Spasojevic et al. 2010; Collins and Calabrese 2012).

Woody and non-woody vegetation have unique advantages and disadvantages when competing for variable resources of water, nutrients, and light (Notaro, 2008). Plot-scale studies have suggested that woody or forest vegetation is less sensitive to drought than grasslands (Scott et al., 2006). Due to their shallow roots, grasses are highly responsive to interannual precipitation fluctuations (Schlesinger, 1996; Knapp et al., 2002). The grass growth is dependent on upper-soil water resources (Scanlon et al., 2005), so increased precipitation variability results in reduced grass growth in grasslands (Knapp et al., 2002) and drylands (Williams and Albertson, 2006). Therefore, climate does influence the distribution and abundance of plant and animal species through changes in resource availability, fecundity, and survivorship (Bugmann et al., 2001).

Previous studies of climate variability impacts on vegetation have been regionally focused and vastly differ in their conclusions. For example, in a study by Grau and Veblen, (2000), higher precipitation variability favoured tree establishment in the Argentina's ecotones while Ni et al., (2006) showed that an increase in precipitation variability in China and in North Africa favoured grasses over trees. Yiran et al., (2012) observed that the long dry seasons coupled with high temperatures and bushfires make the trees suffer for water, resulting in poor re-growth or stunted growth and death. Equally, Fadhil (2009) concluded that most of the sites studied in Iraq are exposed to a serious risk of land degradation and drought. The results showed a clear deterioration in vegetative cover (2 620.4 km²), an increase of sand dunes accumulation and a decrease in soil/vegetation wetness. Similarly, studies by Nichol森 (2008) and Wessels et al., (2008) showed that the perceived decline in vegetative cover in arid and semi-arid lands could largely be attributed to variation in rainfall. Thus, the many different kinds of unmanaged vegetation are adapted to today's climate, as climate changes, each kind of vegetation changes as well, dying out in places where climate becomes too stressful, and prospering where climate becomes salubrious.

As the Earth warms from increasing atmospheric greenhouse gases, the redistribution of vegetation can induce the terrestrial biosphere to become either a source of additional CO₂ (quicken the warming) or a sink for CO₂ (reducing the warming) (Bugmann et al., 2000). For example, a warmer Earth could support more forests that contain high carbon densities, but the warmest places on Earth today support only sparsely-vegetated deserts. In general, the redistribution of global vegetation in response to climate and land use change during the next

century is likely to generate a several-decade long pulse of carbon dioxide from the biosphere into the atmosphere. The result will enhance the build-up of greenhouse gases resulting from anthropogenic emissions. This necessitates action to restore the world's lost and degraded forest cover, as the restoration of the natural forests could help tackle climate change (Munyati and Kabanda, 2009).

While vegetation growth and distribution is largely determined by climate (Wang, 2004), vegetation and land-use characteristics can have an effect on the climate (Zeng and Neelin, 2000; Wang, 2004). Feedbacks from the land surface affect boundary layer fluxes of moisture, energy and atmospheric dynamics. Vegetation-climate interactions occur through various thermal, hydrological and biogeochemical processes (Wang and Tenhunen, 2004) involving such variables as soil moisture, surface albedo, evapotranspiration (hence precipitation), surface roughness and atmospheric dynamics. Changes in temperature and rainfall coupled with different anthropogenic activities (wood gathering, agriculture, overgrazing deforestation and urbanisation) could affect vegetation cover at varying levels (Tubiello and Fischer, 2007; Brown and Funk, 2008).

According to a study by (Gibson, 2005), in some cases changes enabled sustainable use of resources, and increased the landscape and biological diversity and in other cases, patterns of change over time showed that both land-use and rainfall variability contributed to the decrease in vegetation cover (Hulme et al., 2001). Reviews by Lucier et al., (2009) and Fishlin et al., (2007) on detected impacts, vulnerability and projected impacts of climate change on vegetation density found that impacts varied across the continents with some vegetation types being more vulnerable than others. Impacts included increased growth, increased frequency and intensity of fires, pests and diseases and a potential increase in the severity of extreme weather events such as droughts, rainstorms and wind. Human activities, including forest conservation, protection and management practices, interact with climate change and often make it difficult to distinguish between the causes of changes observed and projected. Deforestation and fires in the Amazon region, for example, form a vicious circle with climate change (Aragão et al., 2008, Nepstad et al., 2008), with the potential to degrade up to 55% of the Amazon rain forests (Nepstad, 2008, Nepstad et al., 2008).

2.4 Consequences of change in vegetation density on biodiversity conservation

In the last decades, humans have more than ever been changing the world's ecosystems to meet the growing demands for food, freshwater, timber, fuel and minerals (Millennium Ecosystem Assessment, 2005a). Human alteration of the global environment has triggered the sixth major extinction event in the history of life and caused widespread changes in the global distribution of organisms. These changes in biodiversity alter ecosystem processes and change the resilience of ecosystems to environmental change. This has profound consequences for services that humans derive from ecosystems (Bulte et al., 2005).

The convention on biological diversity (CBD) defined biodiversity as the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'' (Balmford et al., 2005; Mace et al., 2011, Mace et al., 2007). The diversity of species on Earth constitutes a natural heritage and life-support system for every country and all people. Nevertheless, species are disappearing at 50-100 times the natural rate largely due to human activities including the over-exploitation of biodiversity, habitat degradation and fragmentation, global climate change, pollution, and invasion by introduced species. As species and their habitats disappear, humanity risks losing the ecological systems that make human life itself possible. About 45% of the Earth's original forests are gone, cleared mostly during the past century and approximately 8000 tree species, or 9% of the total number of tree species worldwide, are currently under threat of extinction (Millennium Ecosystem Assessment (MEA), 2005a).

Dilley et al., (2013), states that the number of gorillas in Congo has declined by more than 70 percent in the last 10 years. Estimates by the Diane Fossey Gorilla Fund International (DFGFI) suggest there are now fewer than 5000 lowland gorillas, down from about 17000 in 1994. According to the DFGFI, the number of gorillas decreased dramatically after people fled their homes during a series of civil wars in Congo and neighbouring Rwanda, taking refuge in the forests that are home to the apes (Dilley et al., 2013). Cloud forests in equatorial and sub-equatorial regions of Latin America, Africa and Asia, could disappear because of a warmer climate predicted by scientists as the result of increased atmospheric concentrations of sunlight-trapping gases released from fossil fuel burning, forest clearing, fire road construction and the introduction of species from other parts of the world. Their combined

effects could mean loss of huge concentrations of unique mammal, bird and frog species as well as stopping the supply of water to surrounding regions (Balmford et al., 2005).

The Intergovernmental Panel on Climate Change (IPCC) project that the average surface temperature will increase by 2 to 6.4°C by 2100 compared to pre-industrial levels. This is expected to cause global negative impacts on biodiversity (IPCC, 2011). According to the projections, the following changes or losses will take place:

- Climate change is likely to exacerbate the loss of biodiversity and increase the risk of extinctions.
- Water availability and quality will decrease in many arid and semiarid regions.
- The risk of floods and droughts will increase.
- The reliability of hydropower and biomass production in some regions will decrease.
- Diseases, such as malaria, dengue and cholera, are likely to become more frequent in many regions and so are other health problems linked to heat stress, malnutrition, and natural disasters.
- Agricultural productivity may decrease in the tropics and sub-tropics, and fisheries may be adversely affected as well.
- Changes in climate, in land use, and in the spread of invasive species will limit both the capability of species to migrate and the ability of species to survive in fragmented habitats.

Recent changes in climate, such as warmer temperatures in certain regions, have already had significant impacts on biodiversity and ecosystems. They have affected species distributions, population sizes, and the timing of reproduction or migration events, as well as the frequency of pest and disease outbreaks (IPCC, 2011). Projected changes in climate by 2050 could lead to the extinction of many species living in certain limited geographical regions. By the end of the century, climate change and its impacts may become the main direct driver of overall biodiversity loss (IPCC, 2007).

According to statistics from the World Data Centre for Greenhouse Gases (Muduli et al., 2012), the average global CO₂ concentration in 2010 was 389.0 parts per million (ppm), which is 11.9 ppm more than in 2004, and this figure had increased by 39% from the pre-industrial global level of 280.0 ppm. The average CH₄ concentration was 1808.0 parts per billion (ppb) in 2010, which represents an increase of 158% from approximately 700.0 ppb in

the pre-industrial era (WMO 2004–2010). It is known that CO₂ is removed from the atmosphere primarily through absorption by green plants. The above statistics confirm that loss of biodiversity does indeed result in increased Green House Gases (GHG) (Sun, 2002).

In South Africa, the unsustainable use of natural resources for rural livelihood and overgrazing has led to serious vegetation degradation. Rangeland degradation, especially bush encroachment and soil erosion, are particularly acute in the North West Province, where all districts show signs of desertification and loss of biodiversity resulting in deterioration of human and healthcare. Approximately 91% of South Africa is potentially susceptible to desertification (Hoffman and Ashwell, 2001). The National Action Programme mandates that monitoring and evaluation of the status of land degradation should be done and implementation of the NAP took place (Gibson, 2005). The modifications of natural vegetation cover and soil conditions usually lead to changes in rainfall runoff characteristics of the catchment area, which consequently change river flow regimes (Palamuleni et al., 2011).

For the past decades, local communities have been involved in conservation as a strategy for enhancing biodiversity conservation and poverty alleviation calling for the harmonization of conservation and development policies and plans across countries (Tanner, 2004). The strategy has entailed a change from state-controlled to community-controlled wild life management with the expectation that traditional ecological knowledge could play a significant role in supporting local institutions and traditional practices (Phutege and Chanda, 2004).

According to Rozemeijer et al., (2000), a number of community based tourism studies in the Southern African Development Community (SADC) such as Botswana, Namibia, Tanzania and Zimbabwe have been involved in ecotourism as an important tool for constructing an integral rural development strategy. In these communities, biodiversity conservation has been identified as a possible avenue for diversification and community development. However, such countries tend to approach the concept as a pro- poor strategy for poverty alleviation rather than as an ecotourism development tool (Gerosa, 2003).

The loss and degradation of natural areas and the negative impacts on environmental services have encouraged social and environmental scientists to investigate which land tenure system or regime is more constructive for land degradation or resource conservation studies (Bonilla-Moheno et al., 2012). There is increased debate that secure access to productive land

influences the capacity of the rural poor to invest in their productive activities and in the sustainable management of their resources (Teka et al., 2013). Farmers are more likely to make medium- to long-term land improvements if their tenure is secured because they are more likely to benefit from the investment (Teka et al., 2013).

Providing security of tenure is a precondition for intensifying sustainable land management strategies thereby mitigating degradation of the land. In Ethiopia, the land reform act of 1975 proclaimed a radical land reform which nationalized all rural lands and eliminated private ownership of land and this action caused uncertainty amongst farmers and rural communities (Meshesha et al., 2012). Consequently, most farmers felt uncertain and hesitant about land ownership thus reduced motivation to take care of their land and practice conservation methods. Lack of people's involvement in managing their own natural resource attached with complete non-existence of clear management practices means that the remaining resources are endlessly prone to heavy pressure from people living in and around them (Glover et al., 2012).

In the Amazon region, community lands also receive increased pressure, possibly due to the regional infrastructural plans and speculation of future forest values. Since many of the areas with land and forest rights concerns are in remote areas and refer to areas where people may have conflicting interests, regularizing these rights has been a major challenge in the past. Some progress has nevertheless been made in Latin America (Sunderlin et al., 2008; White and Martin, 2002).

Similarly, in South Africa, current land degradation is closely linked with the Native Land Act of 1913 and 1936. The Act stipulated formation of communal homelands where black Africans were resettled and confined (Fox and Rown tree, (2001). Before the Native Land Act of 1913 and 1936, the Chiefs and their village headmen used to control communal rangelands and were in charge of allocating land to the people, and impose rules as to how to utilize the resource (Mokhahlane, 2009). However, during the apartheid era, the accountability of controlling rangelands went to the government and various laws and permits regarding natural resource management were established and passed. The communal grazing system gives open access for those communities within the area, which leads to irresponsibility because of lack of ownership (Kgosikoma et al., 2012). Overgrazing is associated with communal grazing because there is no clear land tenure or property rights agreement that make it conducive for the farmers to invest in conservation of shared rangelands (Thomas, 2008).

South Africa is one of the most biologically diverse countries in the world (King et al., 2005) with the Cape fynbos region being one of the world's biodiversity "hot spots". The fynbos is under continuous threat from development, wild fires, invasive alien species, agriculture, pollution and other factors. About 1400 of plants are considered rare, endangered or close to extinction (Dilley et al., 2013). Hence, concern over this loss and its impact on human wellbeing has prompted national and international agreements to halt these alarming trends (Reyers and McGeoch, 2007).

A holistic knowledge of ecosystem function and form is an indispensable prerequisite for an effective conservation and management of highly valued renewable environmental resources (Wessels et al., 2004). A need for a holistic long term approach to conservation has sparked a renewed international interest in vegetation science phytosociology (Wright et al., 2001). The establishment of conservation areas will greatly help to reduce anthropogenic threats to ecosystem form and functions (Margules and Pressey, 2000; Fairbanks et al., 2001). Through the National Spatial Biodiversity, a national comprehensive assessment of the status of biodiversity was done (Driver, 2005) to identify a number of priority areas for conservation and resource management across the landscape.

According to the 2012-2020 United Nations Decade on Biodiversity (2012-2020 UNDB) (2012), world leaders at the United Nations Conference on Sustainable Development (RIO+20 –Earth summit 2012, derived from the 1992 convention on biodiversity, climate change and desertification) agreed to strive for a land degradation neutral world. Key to achieving this will be translating this goal into actionable targets at national, regional and international level. Key elements of action will include the conservation and sustainable use of biodiversity and the restoration of ecosystems as highlighted in the Hyderabad Call for a Concerted Effort on Ecosystem Restoration. The aim of the convention is to conserve ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities and the poor and vulnerable.

Despite the importance that natural forests play, poor planning, political interventions through policy making and human activities such as agriculture and settlement expansion have replaced natural forest cover and wetlands (Ramonkutty et al., 2006; Monela and Solberg, 1998) over large areas of global land surface. One of the most important land use changes is that the world's forest, grasslands and woodlands have declined and cropped land

areas have expanded (Slayback, 2003; Tubiello and Fischer, 2006; Brown and Funk, 2008). The land use choices made will vary in space and time and so will the resulting land cover (Cihlar and Jansen, 2001).

In general, human-induced changes to natural hydrological regimes in desert streams reduce temporal and spatial heterogeneity of plant habitats, resulting in the loss of biodiversity and homogenization of plant community composition and structure. Given the ecological importance of plant communities in desert rivers (e.g., for channel bank stabilization and wildlife habitat), there may be significant secondary impacts as well. There is some evidence to suggest that restoration of natural hydrological regimes in ephemeral streams may be partly sufficient to reverse such deleterious changes in plant communities (Stromberg, 2001).

In the absence of major changes in policy and human behaviour, our effects on the environment will continue to alter biodiversity. Land-use change is projected to have the largest global impact on biodiversity by the year 2100, followed by climate change, nitrogen deposition, species introductions and changing concentrations of atmospheric CO₂. Land-use change is expected to be of particular importance in the tropics, climatic change is likely to be important at high latitudes, and a multitude of interacting causes will affect other biomes (MEA, 2005; Junk, 2002). The success of conservation therefore depends on understanding the form and function of the plant communities and their environmental drivers (Pienkowski et al., 1998). The Mafikeng and Botsalano conservancy Nature reserves are examples of such conservation areas in the study area.

2.5 Role of vegetation density in ephemeral rivers

The vegetation of ephemeral streams plays an important role in regulating and conserving scarce natural resources within the arid landscape. In ephemeral stream channels, vegetation may establish on sand bars, and subsequently initiate the formation of various depositional features such as small current shadows, bars, benches, ridges, or islands (Tooth and Nanson, 2000). Spatially extensive assemblages of any plant species have the potential to alter geomorphology and geomorphic processes through bioturbation, alteration of nutrient or fire cycles, and patterns of succession (Lovich, 1996).

Vegetation is known, in some situations, to play a vital role in mediating the relationship between large, rare flood events and channel form in some dry land river systems (Griffin and Smith, 2004; Vincent et al., 2008). However, lack of significant channel adjustment

following vegetation removal under some conditions in some systems points to high spatial and temporal variability of response among dry land Rivers (Jaeger and Wohl, 2011). Understanding the mechanisms by which vegetation moderates the geomorphic effectiveness of large flood events as well as its relative importance in different, highly variable dry land environments is, therefore, vital to predicting how these systems may respond to the loss or re-establishment of riparian vegetation.

The structure and distribution of vegetation are critical components in the function of watersheds that provide many important ecosystem services in the arid regions of the world. The morphology of ephemeral rivers is related to the type and distribution of stream bank vegetation. For example, banks that would normally erode easily are often held in place by the roots of the riparian trees, shrubs and grasses (Glenn et al., 2007). Likewise, as streams adjust to changes in water and sediment loads, vegetation may also change.

Vegetative communities along ephemeral and intermittent streams provide structural elements of food, cover, nesting and breeding habitat, and movement/migration corridors for wildlife that are not as available in the adjacent uplands. Functional services of these communities include moderating soil and air temperatures, stabilizing channel banks and interfluvies, seed banking and trapping of silt and fine sediment favourable to the establishment of diverse floral and faunal species, and dissipating stream energy which aids in flood control.

The density of vegetation in arid areas is dynamic in space and time and across a broad range of scales, hence the need to quantify the interdependence between vegetation density and river discharge dynamics is now a central problem in meteorology, hydrology and ecology (Scanlon et al., 2002). In ephemeral and episodic rivers, the vegetation becomes increasingly important as a tool in the determination of the ecological reserve. For example; Riparian vegetation intercepts surface and subsurface water flowing from drainage basins and forms a functionally important interface between terrestrial and aquatic ecosystems.

The influence of riparian vegetation on hydrological processes (Tabacchi et al., 2003) and, conversely, the impact of hydrological processes on riparian vegetation have been the focus of considerable scientific investigation. Through such investigations, ecologists and hydrologists have formed productive, collaborative relationships and together have generated broad conceptual understanding of hydrological factors controlling riparian ecosystem structure and function and associated feedbacks with stream hydrology and geomorphology.

Vegetation regulates many watershed functions, including the hydrologic cycle, by influencing the timing, quality, quantity, and release of water within the watershed. The benefits of properly functioning watersheds are numerous. Agriculturally, a properly functioning watershed will maintain the highest forage production, will ensure better resistance to drought, and will maintain better livestock health and gains.

Ecologically, watersheds provide habitat for biotic organisms and regulate processes such as soil erosion and sedimentation. Other functions and values include maintenance of high quality and quantity of fresh drinking water, flood control, diverse wildlife and recreational opportunities (Howe et al., 2008). Generally, changes in vegetation density result in significant hydrologic changes whereby removal of forest covers results in decreased interception, evapotranspiration and increased runoff volumes (Dagnachew et al., 2003).

Riparian vegetation helps in improving water quality and infiltration of the soil (Almeida et al., 2010). The recovery of stream ecosystem after disturbance is governed largely by the recovery rate of riparian vegetation and the magnitude of disturbance. Another role of riparian vegetation zone as noted by Maluleke , (2003) is that it helps prevent the river from down-cutting a straight path, thus promoting the meandering nature of channels, increasing groundwater discharge and maintaining an elevated water level.

In addition, riparian forests provide resources such as wood for construction and fuel, medicines and fruit, and essential fodder and shade for people, wildlife and livestock. However, reduced natural forest ecosystem simultaneously reduces leaf area index and evaporation from open water surface. Makrieva and Gorshkov, (2007) suggest that water evapo-transpired by forests is typically returned with interest, so one would expect a decline in rainfall, leading to lower runoff over a wider region, if forests are depleted. The importance of in-channel and riparian vegetation to channel stability, channel evolution and recovery following floods in various arid and semi-arid environments is well recognized (e.g. Rowntree et al., 2000; Tooth, 2000; Tooth and Nanson, 2000a, 2000b; Friedman and Lee, 2002; Sandercock et al., 2007; Dunkerley, 2008; Stromberg et al., 2010).

Stromberg et al., (2006) found that in the San Pedro River there is a sharp decline in the riverine marsh type as perennial flows become intermittent. As flows become more ephemeral, and the stream channel loses vegetation cover and widens, hydromesic pioneer forests (cottonwood-willow (*Populusfremontii-Salix ooddingii*)) give way to mesic pioneer

shrublands (dominated by saltcedar (*Tamarix ramosissima*), an introduced species) as tolerance levels for survivorship relative to ground-water depth and fluctuation are exceeded.

Similarly, along the San Pedro River, all annuals showed strong increases in richness and cover in the year following a large fall flood, while hydraulic perennials had a small net increase in richness. Thus, both disturbance and increased moisture conditions caused by floods, as well as moisture from seasonal rains, contribute to increased richness and cover of herbaceous plants in the bottomlands of the San Pedro River, a spatially intermittent desert river (Bagstad et al., 2005). For example, trampling by heavy grazing tend to increase sediment production and deposition, decrease water infiltration rate, increase soil bulk density, and increase the susceptibility of soil to erosion by floods and wind (Allsopp et al., 2007; Kauffman and Sarr, 2002). Either interaction or individuality of these factors hinders seed germination and establishment on the stream banks and flood plains (Jacobson et al., 2000a; Sarr, 2002). This may explain the reduction of vegetation importance values and species richness with increasing grazing intensity closer to settlements.

Miller (2005) noted that “the most important functions in dry land ecosystems are those that control the retention of water and nutrient resources because productivity and diversity cannot be sustained in systems that fail to retain these resources.” Vegetation in ephemeral stream channels play a key role in resource retention by protecting soils from wind and water erosion, slowing floodwater velocity, and moderating temperatures. A study by Cable et al., 2003, and Hultine et al., 2004 concluded that living and dead plant roots and coarse debris at the ground surface create and alter infiltration flow paths, facilitating rapid transmission of direct precipitation, through fall, and stem flow to deeper soil layers. Roots create macropores for infiltration and percolation and also modify water transport processes in riparian floodplains through “hydraulic redistribution” When living root systems span soil layers with different moisture levels, water is passively redistributed along gradients from wet to dry soil layers through uptake and leakage by fine roots.

Ephemeral stream vegetation also influences biogeochemical cycles by providing leaf litter, and food and cover for wildlife. In some cases, vegetation can intercept rainfall, preventing it from infiltrating into the soil, and influencing the local water balance and ecosystem processes (Owens et al., 2006; Miller, 2005). Changes in the abundance or composition of the plant community thus affect an array of ecosystem functions and processes. Plants that have the greatest effects on the structure and functioning of dry land ecosystems are small trees,

shrubs, sub-shrubs and perennial grasses (Whitford, 2002). Riparian tree cover increases flow resistance inducing sediment deposition, and root systems stabilize deposited sediments. As a result, riparian trees can control sediment dynamics and drive 'bio geomorphic succession' within the active corridor of fluvial systems (Corenblit et al., 2009). Thus, riparian trees not only respond to hydrological processes but also trap, reinforce, and aggrade landforms which, in turn, affect the exposure of the trees to hydrological processes.

Change of vegetation cover can affect catchment water balance by influencing soil moisture through canopy interception and transpiration (Eagleson, 2002). Change of water balance can also have an effect on the vegetation cover. This interaction and feedback between water balance and vegetation cover are difficult to diagnose and quantify, which therefore calls for the development and use of catchment Eco hydrological models that couple hydrologic processes and vegetation dynamics. Thus, effective management of water resources in arid and semi-arid environments requires awareness of the interdependencies of hydrologic, biogeochemical and ecological processes, and collaboration between ecologists and hydrologists.

In summary, riparian areas associated with ephemeral and intermittent streams play a significant role in the physical, biological, and chemical integrity of an ecosystem and must be afforded the same importance as other wetter systems in the land management decisions. As a result, land managers should avoid the temptation to develop management strategies that are directed solely at either riparian or upland communities. Instead, management of the entire watershed will improve riparian and upland plant communities and maintain watershed functions (Sonoran Institute, 2007).

2.6 Remote sensing and vegetation characteristics

Traditionally, information about vegetation characteristics has been collected using on-ground assessment methods (e.g. field surveys, literature reviews, map interpretation and collateral and ancillary data analysis), conducted at the scale of individual sites (Gibbon and Freudenberg, 2006). However, these traditional methods have proved to be not effective to acquire vegetation cover characteristics because they are time consuming, date lagged and often too expensive. In contrast, remote sensing has attracted scientific awareness ensuing in the provision of varied spatial resolution imageries that are not feasible and cost effective but also give appropriate and precise information (Ustin et al., 2009).

Remote sensing is the advanced tool for surveying and provides the synoptic view of the area. This technique offers quick and repetitive data and is accurate and potentially inexpensive and could thus successfully evaluate and monitor natural resource management over large areas (Wessels et al., 2008). However, it should also be noted that there are limitations to this technology. As a synergistic tool, remote sensing does not unfailingly distinguish between different vegetation types and, therefore, might hide changes in vegetation cover not associated with changes in overall greenness, such as shifts in vegetation composition. Other limitations arise from the technological and cost-induced trade-offs between different types of resolution, such that simultaneous increases of spatial, spectral and temporal resolutions, all of which can provide more precise information in different aspects of vegetation dynamics, in one system are inhibited (Cihlar, 2000).

More recently, there is growing demand to use information on vegetation condition in a broader regional context and to monitor achievement, and to report on progress towards regional, state and national targets of vegetation condition using remote sensing (Parkes and Lyon, 2006; Neldner, 2006). For example, the advanced Space borne Thermal Emission Radiometer (ASTER) is increasingly being recognised as a source of remotely sensed data because of its high spatial resolution (Mendoza et al., 2004). Similarly, high temporal resolution sensors, National Oceanic and Atmospheric Administration- Advanced Very High Resolution Radiometer (NOAA-AVHRR and Moderate Resolution Imaging Spectroradiometer (MODIS), have been applied with preference for MODIS due to its high spatial resolution (Huet et al., 2002) and data quality mapping and monitoring wetland vegetation used by Wattled cranes for the case of Kafue Flats, Zambia. Furthermore, hyperspectral remote sensing has been used (Schmidt and Skidmore, 2003) for vegetation monitoring and mapping. While most of the above data sources are suitable for single mapping, monitoring of seasonal phenology requires regular availability of data.

Various sources of imagery are known for their differences in spectral, spatial, radiometric and temporal characteristics and thus are suitable for different purposes of vegetation mapping (Chandra, 2011). Kumar et al., (2013) demonstrated the use of high resolution World View-11 satellite data to extract built up land and vegetation using normalized index techniques. The normalized difference vegetation index (NDVI) based on Red Edge and NIR2 bands of World View-11 produced high accuracy in the estimation of vegetation compared to the use of Red and Near Infra-Red (NIR) bands. The aim of the study was to develop automated feature extraction using normalized indices. The study further utilised a

grid technique in estimating built up and vegetation density from precisely classified images. The advantage with this approach is the possibility to calculate the maximum occupied class for each grid cell and hence reduces the volume of data.

In addition, results demonstrated accurate assessment of built-up and vegetation density in heterogeneous landscape of urban areas. However, images with coarse and spatial resolution larger than 5m require threshold segmentation so as to extract vegetation at large scale. Moreover, this approach degrades the quality of the image due to the fact that vegetated areas appear over-estimated in unsupervised classification due to spectral mixing with non-vegetated area (Kumar et al., 2012).

Studies by Zhang et al., (2003); Boles et al., (2002) and Elmore and Asner, (2009) have demonstrated the fundamental importance of multi-temporal remotely sensed data in revealing vegetation dynamics. For example, the International Geosphere–Biosphere Program pioneered a global land cover mapping in the development of the Global Land Cover Characterization (GLCC) Database that was based on 1-km Advanced Very High Resolution Radiometer (AVHRR) in 1992 and observed that vegetation indices derived from remotely sensed data in general are useful in indicating presence of vegetation, including monitoring its dynamics. The studies included the simple vegetation index (SVI), transformed vegetation index (TVI) and the normalized difference vegetation index (NDVI) (Munyati and Mboweni, 2012).), as well as related derivative indices. These vegetation indices enhance vegetation on multispectral images primarily on the basis of the high reflectance in the near infrared and strong absorption in the red regions of the electromagnetic spectrum. Results revealed that grassland patches in marginal areas are being engulfed by desert extending at an average rate of 11-21m/year, grassland degradation and reactivation of sand dunes caused by overgrazing and cultivation around water points/ settlements(Munyati and Mboweni, 2012).Therefore, different indices, image enhancement techniques and analysis can be used for estimating land cover, if climate conditions, land use, soil and salinity and its spatial variability and other factors in each area are considered carefully.

Munyati and Mboweni (2012) examined the effect of pixel size on NDVI values of land cover features in north western South Africa using the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS). Results showed that there is a need to integrate high and low spatial resolution imagery in monitoring vegetation condition using NDVI. The study also noted that NDVI values derived from multiple spatial resolution sensors reveal consistency for uniform vegetation cover.

However, the problem of using multispectral imagery in a semi- arid area is that NDVI values at low spatial resolution suffer from the effect of aggregation of near-infrared and red energy from adjacent vegetated and non-vegetated cover types. Munyati and Mboweni (2012) concluded that the effect is seldom taken into consideration or quantified in NDVI analyses of the vegetation of semi-arid lands.

Huang and Siegert (2006) studied the desertification processes by using time series of SPOT Vegetation (VGT) images and produced a land cover map focussing on the detection of sparse vegetation in north China. A classification system for different land cover types targeting sparse vegetation cover was developed to resolve problems related to the seasonal changes and the highly variable natural conditions. As Huang and Siegert (2006) noted, SPOT VGT imagery is very useful to detect large-scale dynamics of environmental changes due to the wide swath and sensitivity of the images to vegetation growth. Similarly, from multi-temporal SPOT4 VGT sensor data, Wang et al., (2006) built a two-level land cover classification system for identifying Poyang Lake Basin's land cover clusters. At continental scale, Cabral et al., (2006) built a dataset of monthly composite images composed of daily SPOT VGT images and developed a method suitable for producing a land cover map of Africa at a spatial resolution of 1 km. In addition, SPOT imagery has proven to be effective in monitoring the distribution and growth of particular plants. For example, SPOT 4VGT was used to produce a vegetation map and predict the distribution of nest-site habitats of eastern New Zealand falcons in Otago (Mathieu et al., 2006). Millward et al., (2006) used medium resolution satellite imagery to determine the changes in the landscape of the coastal zone near Sanya in Hainan Province, China. After a search for suitable satellite imagery, Millward et al., (2006) found that an effective way to identify changes was to integrate data from different sensor such as Thematic Mapper and Enhanced Thematic Mapper plus (TM and ETM+) images in addition to SPOT high resolution visible (SPOT HRV) images.

Mapping vegetation through remotely sensed images involves various considerations, processes and techniques due to the interaction of the Electromagnetic radiation (EMR) on the earth's objects and phenomenon (Chandra, 2011). Various regions of the EMR provide information of the spectral profile of data which could help in classifying vegetation properties. A study by Breunig et al., 2008 in central Brazil used reflectance and emissivity information from ASTER imagery to categorize exposed soils from non-photosynthetic vegetation (NPV) shortwave infrared (SWIR) and thermal infrared (TIR) data. The results showed that sandy soils primed at lower elevations and clayey soils at higher elevation. The

study concluded that ASTER 10/14 emissivity ratio data can be used to recognize areas of potential land degradation in central Brazil in the course of the determination of the largest sand fraction values in the scene. From the study, peak sandy surface at lower elevation and clay surface at higher elevation were observed and higher sandy surfaces were linked with land degradation. Nonetheless, the study observed that the soil community has not extensively used the prospective of ASTER to acquire information for soil studies.

The spatial technologies of remote sensing and GIS provide possibilities for production, storage and rapid updating of habitat maps given the threats to stability of habitats from human and natural factors (Munyati and Ratshibvumo (2010). One of the most widely used methods in vegetation type mapping using remotely sensed images is pixel-based image classification (Munyati et al., 2009). Computation of sub-pixel NDVI values (Busetto et al., 2008), including those at low spatial resolution scale, seems to be a necessary approach to overcoming the land-cover aggregation effect on the NDVI value of semi-arid savannas. Sub-pixel classification approaches that quantify the amount of photosynthetic vegetation in relation to dry-cover classes (Guerschman et al., 2009) can also yield better estimations of photosynthetic activity on semi-arid savannas. However, results from these studies indicated that pixel-based image classification using hard classifiers tend to impose distinct habitat boundaries when, in reality, zones of intersection between different vegetation types separate the habitats. Traditional hard classifiers approaches is that they result in non-homogeneous, “pixelised” vegetation mapping as opposed to (homogeneous) habitat zones (Munyati et al., 2009). In contrast, soft classifiers produce more realistic habitat maps with the percentage of each class found in each pixel (Mehner et al., 2004).

As sensor technology and methods for deriving information from remote sensing images have continued to improve. Various methods based on vegetation indices (VIs) have been designed to extract vegetation from the satellite data. Numerous studies have shown that satellite derived VIs are optical measures of canopy greenness, a composite property of leaf chlorophyll content, leaf area, canopy cover and structure (Glen, 2008). Although many different VIs have been formulated, most of them are related to Normalized Difference Vegetation Index (NDVI) and hence the most used Vegetation Indices are the NDVI and Leaf Area Index (LAI).

Results from a study by Huete et al., (2007) indicated that LAI is an important measure to quantitatively calculate the magnitude of the processes that take place in vegetated areas. Measurements of LAI have also been used to predict the development of ecosystems affected

by man, such as predicting future growth and yield or to model carbon dioxide dynamics. However, LAI cannot be applied to non-leaf canopy especially in swampy areas. In addition, it is also a method that is impossible to use for large heterogeneous environments since it takes too much time (Traverse et al., 2011).

In a study by Schroeder et al., (2006), Landsat TM images, striding a long period of time from 1986 to 2002, were used to conduct quantitative analyses of wetland landscape patterns and their dynamic changes in the estuary of the Minjiang River. Because of the different characteristics of spectral sensors (i.e. TM and ETM+) in the Landsat image series, it is necessary to correct the spectral reflectance between images acquired by those sensors. This is especially necessary in long-term vegetation cover monitoring research where both Landsat TM and ETM+ images are used. Moran et al., (2001) proposed an empirical line approach for reflectance factor retrieval from Landsat-5 TM and Landsat-7 ETM+. The correspondence analysis method based on the spectral transformation of individual date images into a component space was applied to two multi-temporal Landsat images of Raleigh, North Carolina for land use and land cover change detection (Cakir et al., 2006). Due to the limitation of spatial resolution, Landsat products are usually used to map vegetation at community level. Therefore, it is a challenging task to use Landsat images for mapping at species level, especially in a heterogeneous environment. However, when integrating with other ancillary data, it becomes possible to map species. An example of a species level of vegetation classification was implemented in the Amanos Mountains region of southern central Turkey using Landsat images, combined with the environmental variables and forest management maps, to produce regional scale vegetation maps with an overall high accuracy (Domacx and Su"zen, 2006).

In addition to the limitation caused by the medium spatial resolution of Landsat imagery, the relatively low temporal resolution might also restrict its application in vegetation mapping. Landsat satellites are popular and sun synchronous. It takes 16 days for the satellites to revisit the last location. This imposes a problem for vegetation mapping using Landsat imagery especially when the interest of period (IOP) falls in a rainy season, during which heavy cloud greatly decreases the image quality as in the case with this study. Since IOP usually has limited time window, it is very important to take the mapping purpose as well as the local climate and topography conditions into account for the selection of imagery source.

The assessment of spatial patterns of land cover changes over a long period using images of multi-temporal coverage is now possible considering the accumulation of remotely sensed images over the past decades; as such making it possible to generate an understanding of the drivers for the changes. According to Hayes and Sader (2001), change detection is a technique used in remote sensing to determine the changes in a particular research between two or more time periods, change detection involves the use of multi-temporal data sets to discriminate areas of land cover change between dates of imaging. Buchanan et al., (2008) used spectral signatures in supervised classification to detect change in deforestation rates in New Britain (an island situated off the east coast of New Guinea). New Britain is of global importance for biodiversity. It forms part of a high priority Endemic Bird Area (EBA) but conservation is often only directed towards areas containing globally threatened species while very few attempts are made to improve assessments of species extinction risk. The study used deforestation estimates, measured through satellite imagery to assess the conservation status of entire endemic birds, based on the International Union for the Conservation of Nature (IUCN) Red list.

The application of remote sensing in ecosystem-oriented natural resources management studies involves the acquisition and analysis of multi-temporal satellite imagery as it has often been demonstrated that satellite imagery correlates very strongly with land cover material (Phua, 2008). Multi-temporal remote sensing is an approach which involves the collection of remotely sensed data (satellite imagery) about a site on more than one occasion, and uses changes (through change detection procedures) within time as discriminates of ground conditions. The use of remote sensing for the estimation of vegetation biomass has proved to be of great importance in filling up data gaps and to estimate large scale variations, especially in low accessible places (Kashaigili and Majaliwa, 2010).

According to Munyati and Ratshibvumo (2010), the spatial technologies of remote sensing and GIS provide possibilities for production, storage and rapid updating of habitat maps given the threats to stability of habitats from human and natural factors. Munyati et al., (2009), concluded that one of the most widely used methods in vegetation type mapping using remotely sensed images is pixel-based image classification. However, results from this study indicated that pixel-based image classification using hard classifiers tend to impose distinct habitat boundaries when, in reality, zones of intersection between different vegetation types separate the habitats, whereas soft classifiers produce more realistic habitat maps with the percentage of each class found in each pixel (Mehner et al., 2004).

Integrated GIS and remote sensing have been successfully applied to map the distribution of several plant species, their ecosystems, landscape, bio-climatic conditions and factors facilitating invasions (Stow et al., 2000). Examples of such works include that of Hessburg et al., (2000) where aerial photo from 1932-1993 were used in the interior of northwest forest (located just 30 minutes from Houston in Texas, USA), and found emergent non-native herb lands. Vrindts et al., (2002) distinguished seven weed species with more than 97% accuracy with a limited number of wave band ratios. Stow et al., (2000) have examined the possibility of using colour infrared (CIR) digital camera imagery to discriminate *Acacia* species from indigenous vegetation (fynbos) in the Cape lowlands. Tanser and Palmer (1999) conducted a localized degradation assessment in South Africa using Landsat Thematic Mapper imagery by comparing the NDVI with the moving standard deviation index (MSDI). A rangeland condition appraisal was conducted by Mackay and Zietsman (1996) in the Ceres Karoo region of the Western Cape Province of South Africa by comparing field survey data with the Soil Adjusted Vegetation Index (SAVI). Two latest studies conducted by Wessels et al., (2004), Archer, (2004) have used productivity indicators to assess vegetation conditions. Wessels et al., (2004) have shown that moderate resolution NDVI data calculated from a time series (1985 to 2004) of NOAA- AVHRR satellite images could be used to detect land degradation in their study conducted in Limpopo Province of South Africa.

2.7 Summary

It is very clear from literature that there is potential for using a satellite derived index of productivity to analyse the vegetation density of the UMRCA. Different studies indicated the impacts of rainfall variability and anthropogenic activities on vegetation density at different levels. The extents of these impacts have been investigated in different parts of the world using different remote sensing techniques to establish and quantify changes in vegetation density, but could not conclude on which one technique was the best especially where change detection is in question. Much still needs to be learned about the ecological and hydrological interactions on ephemeral and intermittent streams due to variability and the often highly episodic occurrence of extreme events in these systems. Sometimes the environments are inhospitable, but arguably the greatest challenge is trying to use short-term projects to understand arid and semi-arid region streams whose variable behaviour sometimes demand years of data more than are needed on a mesic river.

As noted, ephemeral and intermittent streams constitute the vast majority of drainage ways in the arid and semi-arid areas of the world and play an integral role in overall watershed

function and thus specific ecological information is needed for critical target species, such as habitat requirements and role of vegetation density. Future research is needed for both the long-term monitoring of these systems over a range of conditions, and on developing modelling tools that can be applied to large temporal and spatial scales.

However, it is clear that at least two or more change detection methods need to be tested and then compared to get the best possible result based on accuracy assessment. As Image differencing is quite accurate and post classification comparison most common, these two methods have been tested for vegetation density change in the UMRC.

The next chapter presents the research methods and designs where ERDAS IMAGINE 2010 was used in analyzing and producing vegetal cover maps to complement the objective of the research.

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter the research methodology is presented. The data sources and the different analytical techniques employed are detailed in the chapter. In order to distinguish different methods and their importance, the various methods for each objective set in Chapter One are discussed. In-depth detail of the processes of relevant methods is presented in the subsequent sub-sections.

3.2 Data and data sources

To achieve the objectives of the proposed study, integration and application of different data sources was used including remotely sensed data covering the study area, topographical maps and ground truthing using Global Positioning System (GPS), and monthly climatic data (rainfall and temperature) obtained from the South African weather Service. Ortho Maps were obtained from the Department of Lands and Survey. The maps aided in defining the boundary of the UMRC and identify rainfall stations from where climatic data was obtained. In addition, the maps were used for selection of reference points to be used for accuracy assessment for the classified images.

3.2.1 Satellite data

Images were acquired from the South African National Space Agency (SANSA). Landsat TM/ETM+ at 30m resolution were available and provided better classification of vegetation cover using the red and infrared bands 3, 4 and 5. Band 5 is the short wave Infra-Red (SWIR) and is sensitive to the amount of water in plants, useful in crop drought studies and in plant health analyses. Band 4 is the near infrared (NIR) and is responsive in determining vegetation types. Band 3 is a visible red band and is very useful in discriminating between plant species (Lillesand et al., 2008). In addition to TM and ETM+, Landsat Data Continuity Operational Land Imager – Landsat 8 (LDCOLI) launched in February 2013 by NASA and USGS was used in the analysis of vegetation density in this study. Band 4 of Landsat 8 which denotes the red band and 7 which is the Short Wave Infra-Red 2 were used in calculating the NDVI. Table 1 give specifications of the Landsat scenes used for the study.

Table 1 Geometric Registration Error Factor for the images used

Image	Number of GCP's Used	Total RMSE
07 May 1989	36	27m
29 January 1996	36	28m
05 January 2005	36	28m
03 May 2013	61	23.2m

It would have been advantageous to obtain multi-temporal Landsat composites over time rather than snapshots for good vegetation density analysis. However, within the constraints of a limited number of suitable images in archive, a strategy for selecting Landsat imagery for this study was governed by cost-free available multi-temporal images, vegetation phenology and image quality (cloudiness, haze). In addition, seasonal concepts provide a framework for presenting the temporal and spatial patterns of vegetation in the database. Thus, only Landsat TM, ETM+ and OLI images satisfied the requirements of the aim and objectives of the study with summer images obtained in January for 1996 and 2005 and winter images for 1989 and 2013 (Table 1). The near-anniversary dates are composed of relatively homogeneous land cover associations (for example, similar floristic and physiognomic characteristics) which exhibit distinctive phenology (that is, onset, peak and seasonal duration of greenness) and have common levels of primary production. This pair of images ensures that radiometric differences are due only to land cover change.

The 2013 image was acquired by the Landsat 8 (launched in February 2013) Landsat Data Continuity Operational Land Imager (LDC OLI). For this study it was downloaded from the United States Geological Survey (USGS) website. The spectral characteristics of this image were slightly different from the TM/ETM+ images (Table 1). Analysis error due to these differences was minimised by selecting for use only the bands that were present or equivalent among the three sensors in Table 1

3.2.2 Ortho maps

Ortho-photo maps of 1:10 000 were obtained from the Department of Lands and Survey. These maps aided in extracting reference points for classification purposes and in defining the confines within which the UMRC falls.

3.2.3 Climatic data

Monthly rainfall data for the period 1984 to 2012 was obtained from the South African Weather Services (SAWS), for five stations in the Upper Molopo River Catchment Area. The stations were Mafikeng Weather Office, Mafikeng Museum, Mafikeng TNK, Rooigrond, and Slurry (Figure 3). Although there are more than five weather stations within the study area, many started reporting later than 1984 and, therefore, have shorter rainfall records. Therefore, such stations could not be used in this analysis.

The period 1984-2012 was the only period that the data covered. Therefore, the study period of 28 years was slightly less than the 30 years required by the World Meteorological Organisation for such long-term weather data studies (WMO, 1970). An additional limitation was that the data had gaps in records for some stations. The weather stations started reporting at different times and hence different reporting times (years). Some rainfall stations had gaps for some months and some missing values simply because they started reporting late or rainfall was missed for some days. Gaps were filled using the following formula.

$$\frac{\sum x}{N} \times \frac{100}{1} \quad \text{Equation 1}$$

Where:

N = total months of data span

x = months of missing data

$\sum$ = total months with missing data.

Thus the span of data collected, N=28 years x12= 336 months.

*12 because the rainfall data used in this study is were for each month of the year for 28 years.

Table 2 Weather stations in the study

Station Name	Station No.	Latitude	Longitude	Height (m)	AR
Mafikeng WO	0508047 0	-25.76	25.55	1281	126.5
Mafikeng TNK	0508261 0	-25.86	25.63	1278	159.8
Mafikeng Museum	0508232A5	-25.85	25.63	1278	129
Rooigrond	0508505 9	-25.94	25.80	1398	155
Slurry	0508649 3	-25.79	25.83	1387	111.7

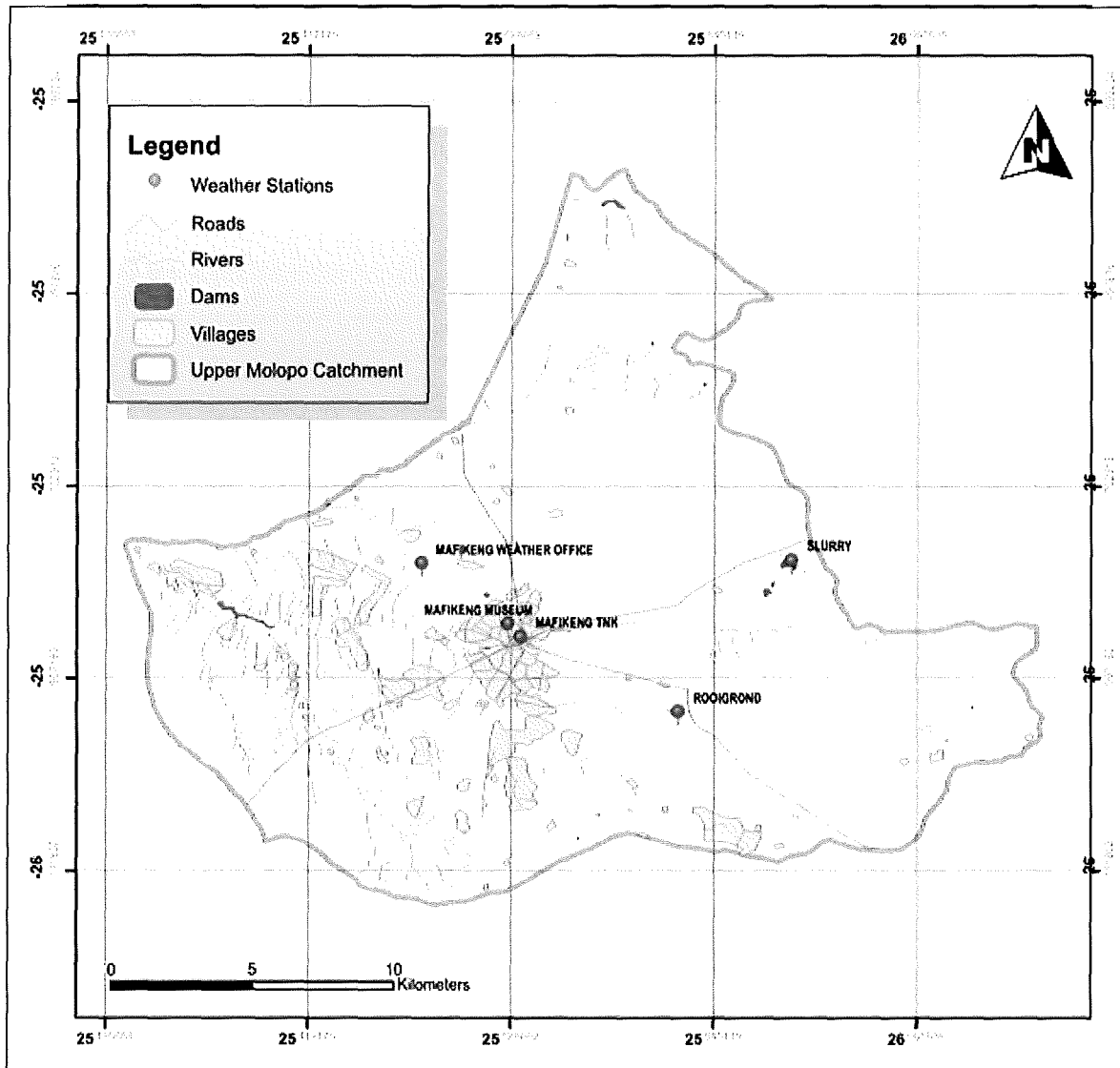


Figure 2 Location of weather stations

3.2.4 Training data field work

Field work trips were made in January-May 2013 for the purpose of obtaining training data that would guide image classification. Two sets of information were obtained during the field work: first was information on sample locations for Land Use and Land Cover (LULC) types

for the LULC classification scheme that was used, and second was training data on vegetation density categories.

The location of image classification training areas for each of the LULC classes that were used (Table 3) was recorded in the field using a handheld GPS (Garmin eTrex, 4m accuracy), in the UTM coordinate system. A sample location for each of the LULC classes was visited, resulting in a total of 6 LULC field sites. The original plan was to sample about 40 points for each land cover, totalling up 250 samples but due to accessibility problems presented by private property restrictions, only sites within 1 km of a road were visited in the field. Therefore, a stratified random sample of 100 field sites was used.

Training data for vegetation density mapping was determined using a detailed field survey procedure. Only woody vegetation density could be determined in the process, due to difficulties in quantifying grass cover. For quantifying woody cover, sites with noticeable differences in tree and shrub density were selected. A 30m x 30m plot was established at each chosen site in order to make the field data observation sites equal to the 30m spatial resolution of the Landsat images (Table 1). The canopy diameter (d) of each woody individual within the 30m x 30m (i.e. 900m²) plot was then measured by spreading measuring tape either beneath the canopy for tall trees or above the canopy for short shrubs. The canopy diameter then gave a canopy radius (r) measurement ($r = \frac{1}{2} d$). Treating the shape covered by the canopy as circular, the area covered by each canopy was then calculated as: $\text{Area} = \pi r^2$. The total area covered by all woody canopies (trees, shrubs) within the 900m² plot then gave a % woody cover value. The location of the centre of the plot was determined and recorded using a handheld GPS (Garmin eTrex, 4m accuracy), in the UTM coordinate system.

Only four sites were used for this detailed process, due to its time consuming and tedious nature. These were then used as training areas for classifying the images into vegetation density classes. Other restrictions included; lack of a densiometer to capture vegetation density and a very high resolution image which covered the whole study area. Therefore, a SPOT image which was too small to cover the entire study area was used as a base image to compare ground control points with the real field points.

For purposes of aiding change detection in the vegetation density trends noticed from the images, ancillary data on livestock numbers of Mafikeng district municipality and population numbers (Population Statistics) were used. The livestock data was obtained from Mmabatho Veterinary Office and the human population from statistics South Africa. The only available

livestock data was for 2002, and then 2007-2010. Only data for grazing / browsing and vegetation consuming livestock is used in this study. The data span for human population was from 1996 - 2011 censuses (Table 4).

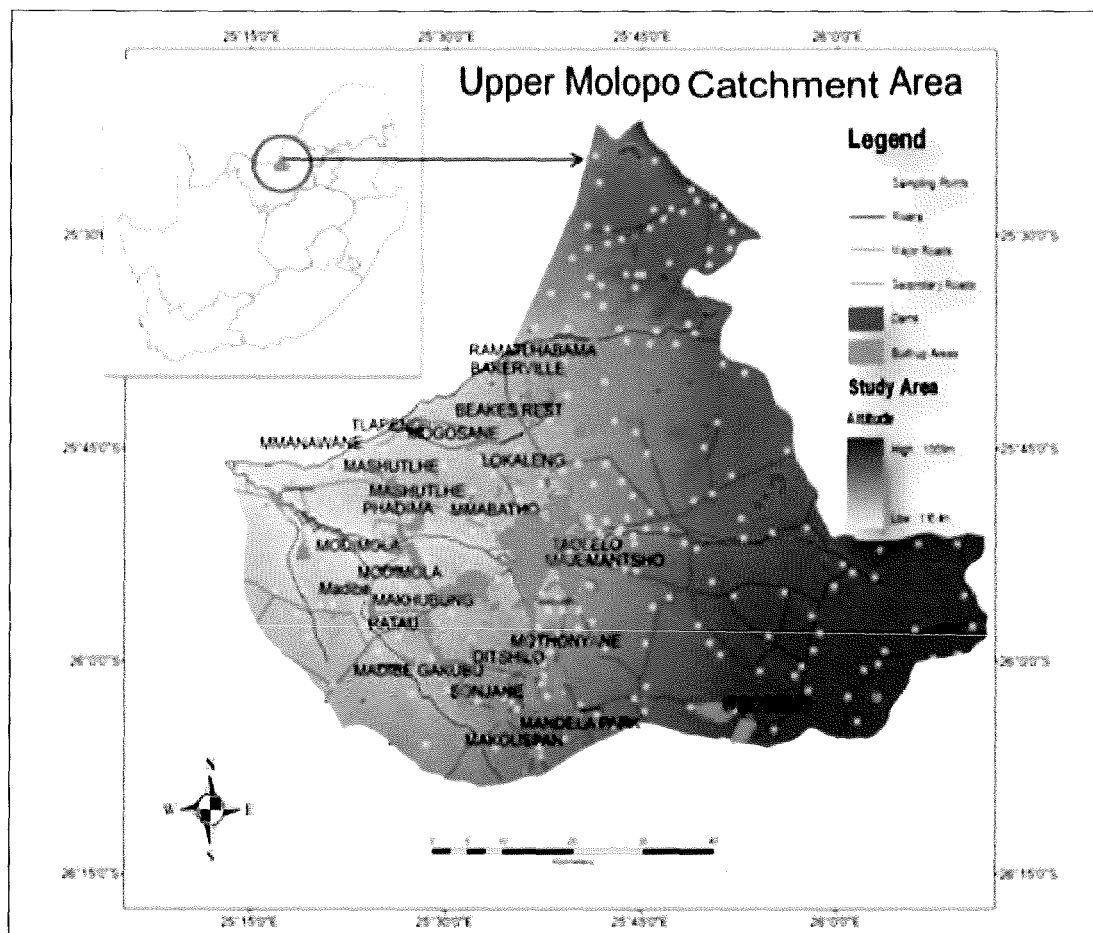


Figure 3 Location of field work sample sites

Table 3 Mafikeng Local Municipality Population data from 1996 – 2011

Year	Total Population
1996	242193
2001	259478
2007	261483
2011	291527

3.3 Image Processing

3.3.1 Image pre-processing

All image processing and subsequent image analysis was carried out using ERDAS Imagine software (ERDAS, 2013). Some supportive image processing operations were done using the ArcGIS software version 10.3. The following pre-processing procedures were carried out on all the satellite images. The Landsat TM, ETM+ and OLI Images were obtained at a pre-processing level (Level 1 A) at which geometric corrections were required.

3.3.2 Geometric corrections

This process was done to correct distorted or degraded image data to create a more faithful representation of the original site (Lillesand et al., 2008). To ensure accurate identification of temporal changes and geometric compatibility with other sources of information, the images were coded to the Universal Transverse Mercator (UTM) and the World Geodetic System (WGS84) coordinate system used in South Africa. At least 36 well distributed ground control points (GCPs) were used in the rectification process for each Image. This was done to match image coordinates with map coordinates.

The root mean square error (RMSE), which is a measure of the accuracy of transformation from one coordinate system to another, was applied and kept low (Table 4) at the recommended sub-pixel level. The Nearest Neighbour method was used in the resampling process because it does not convert the Digital Numbers, compared to other resampling algorithms like Bilinear Interpolation and Cubic Convolution that use averages (Lillesand et al., 2008; Jensen, 2005). In addition it has the advantage of computational simplicity (Kashaigili & Majaliwa, 2010).

Table 4 Geometric Registration Error Factor for the images used

Image	Number of GCP's Used	Total RMSE
07 May 1989	36	27m
29 January 1996	36	28m
05 January 2005	36	28m
03 May 2013	61	23.2m

3.3.3 Radiometric corrections

Ideally, images require correction of atmospheric effects. Accurate models for such atmospheric corrections require information on the composition of the atmosphere at the time the image was acquired (Lillesand et al., 2008; Jensen, 2005). This information was not available for the historic images (Table 1) that were obtained.

In such circumstances, if image classification is undertaken separately for different dates and then comparisons performed, atmospheric corrections may not be necessary and performing image classification without the corrections may not introduce serious error (Song et al., 2001). Separate classification and enhancement of the images was the approach that was adopted in this study and, therefore, no atmospheric corrections were performed.

3.3.4 Image enhancement

This process aimed at enhancing certain characteristics of the land surface for easy visualization and interpretation of images (Lillesand et al., 2008). Different bands of a multi-spectral image were combined to heighten different land cover areas in the given topology. Contrast enhancement techniques were employed for each individual image in the study. This expanded the range of brightness values in the images enabling discrimination between areas initially having a small difference in vegetation density.

3.3.5 Image classification

The images were classified using computer software ERDAS IMAGINE 2013, which is widely used to process satellite images at different levels. Image classification is a technique used in remote sensing to extract information from a satellite image with the aim of transforming it into a more easily interpretable form such as a map (Lillesand et al., 2008). Supervised classification, using Maximum Likelihood Classifier (MLC), was utilized. This involved the selection of training sites on the image, which represented certain land cover classes to be mapped. Training sites were generated by on-screen digitizing of selected areas for each land cover class identified on colour composite. The objective was to produce thematic classes that resemble or can be related to the actual land cover types in the study area. The advantage of digital image classification is that it can provide efficient, consistent and repeatable routines for mapping large areas (Kashaigili, 2006).

3.3.6 Development of a classification scheme

The names for major land cover types followed the standard land cover classification scheme for remote sensing in South Africa with some modifications based on a priori hierarchical structure that allow easy subdivision of broad generic classes into more specific, user or project a posteriori-defined subclasses (Thompson, 1996). The classes that were developed for use in this research are described in table 6. Based on field visits, representative locations of the classes were delineated on the images and then the Maximum Likelihood Classifier (MLC) was used for classification into LULC thematic layers in the process of supervised classification based on the training areas. The MLC was selected based on the fact that it is highly accurate (Lillesand et al., 2008; Jensen, 2005). The Agricultural land/Cultivation class was subdivided into two sub-classes: Rain fed agriculture and irrigated agriculture. Spectral signature statistics were then generated for each class and thematic images generated using only the Near Infra-red, Red and Green bands that were present and nearly equivalent in spectral range for all the four images that were used (Table 1).

Table 5 Land cover classes used in the classification scheme

Cover class	Characterization features
Forest and woodland	Forest >80% crown cover, Woodland 40-70% crown cover
Thicket and Bush land	Thicket >70% crown cover, Bush land <70% crown cover
Shrub land and Grass land /Pasture	Shrub land 2-5 m h > 70% crown cover, Grass land
Water bodies and wetlands	Water bodies: permanent open water such as dams, lakes and rivers. Wetlands: Natural or artificial areas where water levels
Agricultural land/ Cultivation	Permanent and temporary crops
Built- up land	Residential, commercial, industrial / Transport

3.3.7 Classification accuracy assessment

The accuracy of the classification and the output of the land cover (LC) mapping were assessed using representative samples taken during field observations. The accuracy statistics provided objective information about the quality of the LC classification. Accuracy assessment helped to identify misidentifications as well as understand and measure how

errors tend to be spatially correlated (Lillesand et al., 2008; Jensen, 2005). Accuracy assessment in this study was conducted using error matrix techniques. The error matrix is one of the tools used for classification accuracy assessment in order to compare known data (field data) with the corresponding results of automated classification (Wonde et al., 2011).

The error matrix compares two thematic maps (a “ground truth” map / the reference map) and a map derived from automated image classification) in a tabular form that describes the accuracy of a classified map with respect to a reference map. The most common accuracy assessment elements include: Overall Accuracy, Producers accuracy, Users Accuracy and Kappa Coefficient. Overall accuracy of the classification, producers and user’s accuracy and Kappa Coefficient were computed by dividing the total number of correctly classified pixels in the corresponding row or column from this matrix (Congalton and Plourde, 2002). Overall classification accuracy provides a general picture of how a specific classifier is performing while the user and producer accuracies help to ascertain whether the classified pixel actually represents the relevant information class on the ground (Tso and Mather, 2001) as determined in equation 2.

$$\text{Overall accuracy} = \frac{\sum (\text{correctly classified classes along diagonal})}{\sum (\text{Row total or column total})} \quad \text{Equation 2}$$

Producer's accuracy details the errors of omission. An error of omission results when a pixel is incorrectly classified into another category. It is an important measure because the producers of spatial data are interested in knowing how well a particular area on the Earth surface can be mapped. Producer's accuracies result from dividing the number of correctly classified pixels in each category (on the major diagonal) by the number of reference pixels used for that category (the column total) (Equation 3).

$$\text{Producer accuracy} = \frac{\text{number of correctly classified item in a column}}{\text{total number of items verified in a row}} \quad \text{Equation 3}$$

User’s accuracy represents the probability that a sample from the classified image actually represents that category on the ground. User’s accuracy details errors of commission. An error of commission indicates the probability that a pixel classified into a given category actually represents that category on the ground. User’s accuracy is important for users of spatial data because users are principally interested in knowing how well the spatial data actually represents what can be found on the ground (Congalton, 1991; Lillesand et al.,

2004). The user's accuracy is computed by dividing the number of correctly classified samples of the relevant class by the total number of samples that were verified as belonging to that class. User's accuracy was determined as in Equation 4.

$$\text{User accuracy} = \frac{\text{number of correctly classified item in a row}}{\text{total number of items verified in a row}} \quad \text{Equation 4}$$

Accuracy assessment of the classified maps was based on the independent field data set consisting of observations at the 100 homogeneous sampling points as described in section 3.1.4. The results were then tabulated to create an error matrix where the columns define the reference ground data and the rows define the classified image classes. The values in the cells of the table indicate how well the classified data agrees with the reference data. The diagonal elements of the matrix indicate correct classifications. The higher the proportion of the pixels within the user and producer accuracies for the individual class in question, the more accurate the classified maps are.

3.4 Vegetation density assessment

The vegetation density (canopy cover) values that were determined in the field at sample sites yielded data that could be organised into three density classes: high vegetation density ($\geq 80\%$), medium vegetation density (50-79%), and low vegetation density ($< 50\%$). The NDVI images that were generated were classified into three vegetation density classes. In the process, the field sampling sites were located on the images using their GPS coordinates, then their NDVI values determined, which led to the general vegetation density classes being grouped into corresponding NDVI classes as: low vegetation density = $\text{NDVI} < 0.3$, medium vegetation density = $\text{NDVI} 0.3-0.5$, and high vegetation density = $\text{NDVI} > 0.5$. Training area polygons were drawn around the sites and a Maximum Likelihood Classifier (MLC) then used for supervised classification into the vegetation density classes. NDVI values were calculated separately using the TM/ETM+ and OLI-8 near infrared (TM4) and red (TM3) bands as in equation 5, on the images resulting from the conversion to reflectance values.

3.4.1 Enhancement of vegetation density using the NDVI

This process aimed at enhancing the differences in vegetation density in the UMRCA study area. The Normalized Difference Vegetation Index (NDVI) enhances vegetation density (Kumar et al., 2013), based on the high reflectance of Near Infra-Red (NIR) energy and absorption of Red (R) as is in equation 5.

$$NDVI = \frac{NIR - R}{NIR + R} \quad \text{Equation 5}$$

The resulting NDVI values range between -1 and +1. Healthy vegetation generally has high NIR reflectance and absorbs strongly in the red spectral region (Lillesand et al., 2008). Therefore, healthy vegetation in prime condition (i.e. vigorous vegetation) generally has high NDVI values. The NDVI values for vegetated land are generally greater than 0.1, and values exceeding 0.5 indicate dense vegetation (Budde et al., 2004). A zero means no vegetation and close to +1 (0.8-0.9) will indicate the highest possible density of green leaves.

3.5 Change detection

Change detection is defined as the comparison and contrast of multi temporal images of the same geographical area in satellite based remote sensing. It is realized by image-handling techniques to analyze the transformed areas of the geographical area in different periods. Change detection analysis was done to examine the change in land use-land cover classes as well as vegetation density over the years. Various algorithms are available for change detection analysis and can be grouped into two major categories namely; pixel-to-pixel comparison of multi-temporal images before image classification and post-classification comparison (Jensen, 2005). In this study post classification comparison analysis was used. The area of cover of each LULC class per image was computed in ERDAS Imagine, and the results exported to a spreadsheet (Microsoft Excel). Graphs and tables could then be used to summarise the changes, and the amount of change computed in absolute terms as well as percentage (%) change. The same procedure was employed in analysing change in vegetation density. Same month pairs of images were compared: the May 1989 image versus the May 2013 image, and the January 1996 versus the January 2006 image (Figure 4).

3.6 Post classification comparison

Post-classification comparison method was used to assess vegetation density change because it is the most common approach (Jensen, 2005) for comparing data from different sources and dates. The approach identifies changes by comparing independently multi-date images on pixel-by pixel basis using a supervised mode classification. The 1989, 1996, 2005 and 2013 dates of imagery are independently classified and registered. The Gaussian Maximum Likelihood Classifier was employed as it incorporates sensitivity to variance thus avoiding the problem of overlapping by using an ellipse (Munyati and Ratshibvumo, 2010). A “conversion matrix” between Landsat 1989, 1996, 2005 versus 2013 was compiled in form of

a contingency table. This contingency matrix was used to quantify Land cover change (LCC) in terms of pixel values, hectares (ha) or percentage of area coverage.

3.7 Climatic data analysis

3.7.1 Standardized precipitation index

The Standardized Precipitation Index (SPI) is a probability index that defines and monitors drought. It allows an analyst to determine the occurrence of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data. The Standardized Precipitation Index was calculated using the difference between the actual and mean precipitation for a particular time scale, then dividing by the standard deviation. Probabilities are standardized so that an index of zero (0) indicates the median precipitation amount. Half of the historical precipitation amounts are below the median and half above the median. The index is negative for drought and positive for wet conditions. A drought event is defined as any time the SPI is continuously negative and reaches an intense high of -1.0 or lower. The drought event ends when the SPI becomes positive. Each drought event therefore has a duration defined by its beginning and end as indicated in Table 6.

Table 6 SPI values and corresponding climatic characteristics

Standardized Precipitation Index	Climatic Characteristics
>2.0	Extremely wet
1.5 – 1.99	Very wet
1.0-1.49	Moderately wet
-0.99-0.99	Near normal
-1.5- 1.99	Severely dry
-2 and less	Extremely dry

3.7.2 Rainfall anomaly index (RAI)

To determine the normality of the rainfall distribution in the study area, the rainfall anomaly index was computed. The daily rainfall data were summed-up using user-defined functions in Microsoft Excel to calculate total annual rainfall over the calendar year. The rainfall anomaly index (RAI) has been commonly used to monitor precipitation in drought-prone regions such as the West African Sahel and Southern African semi –arid climatic regions (Katz 1978; Hulme 1994). The construction of RAI involves standardizing the annual or seasonal total

rainfall for an individual station by subtracting the stations' mean and dividing by its standard deviation, with the mean and standard deviation being computed from the station's historical record. An index for each station was then constructed following Equation 5. Assume x_{ji} represents total rainfall for station i in year j . To construct RAI, annual (seasonal) rainfall total is normalized as follows:

$$R_{ji} = \frac{X_{ji} - \mu_i}{\delta_i} \quad \text{Equation 6}$$

where R is the normalized annual (seasonal) rainfall total for station i in year j ; μ_i and δ_i is the mean and standard deviation of the rainfall total during a specified reference period.

The rainfall variability at each rainfall station was determined using the departure from the mean (Equation 6).

3.7.3 Correlation analysis

The final part of analysis involved testing the original hypothesis using Pearson correlation coefficient to compute correlation of determination by linking changes in vegetation density against variations with the mean rainfall amount for the period 1989-2013. According to Welman et al., 2005, correlation helps in assessing the extent to which one variable influences another. Correlation between rainfall and vegetation density was calculated to determine if rainfall values correspond with the NDVIs.

Pearson correlation was carried out for the entire study area to establish relationship between change in vegetation density (y-dependant variable) and rainfall variations (x-independent variable), (Best and Roberts, 1975). By changing both the rainfall data and land cover classes into standardized units by using Equation 6, Pearson's product moment correlation coefficient was made to test the hypothesis by using Equation 7.

$$R = \frac{E [(X - \mu_X) (Y - \mu_Y)]}{\delta_X \delta_Y} \quad \text{Equation 7}$$

Where R is Product correlation coefficient, E is the expected value operator, X and Y are random variables, μ_X and μ_Y are expected values and δ_X and δ_Y are standard deviations of X and Y variables.

The Pearson's correlation is one in the case of perfect positive linear relationship, -1 in the case of a perfect negative linear relationship and values between -1 and 1 in all other cases indicating the degree of linear independence between the variables. As it approaches zero there is less relationship between the variables. The closer the coefficient is to either -1 or 1, the stronger the correlation between the variables. The NDVIs were also overlaid with the rainfall variations to determine the correlation between rainfall and vegetation density (Appendix 3). Ordinary kriging which is an interpolation method found in geostatistical software ArcMap 10.1 was used to show the spatial rainfall distribution of the study area. The normalised mean of all the five rainfall stations within the study area were used. Point rainfalls at unrecorded stations were assigned the record of the closest gauge in a main orientation N-S, E-W, SW-NE and SE and then the corresponding theoretical variograms were calculated.

3.8 Summary

The NDVI based on Red and NIR bands of Landsat ETM and ETM+ produced high accuracy in calculating the NDVIs per unit area. The researcher was able to identify areas of high and low vegetation density in a heterogeneous landscape of the Upper Molopo River Catchment area. This chapter presented research methodology in which extensive explanation of research design, data sources and data analysis was carried out. The next chapter (chapter four) presents the results with detailed discussion of the findings of the study.

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The objective of this study forms the basis of all the analysis carried out in this chapter. This section presents the results and discussion of the generated land cover analysis from classification of Landsat images. It includes assessment of the maps accuracy, analysis of the nature, extent and rate of land cover changes. Statistical trend analysis results of rainfall and river discharge are also discussed. The results are presented in the form of tables, bar charts and land use and land cover (LULC) change maps.

4.2 Land Cover dynamics in the Upper Molopo River catchment

The Upper Molopo River catchment land cover classification presented here is a result of the Maximum Likelihood classifier. Two pairs of biseasonal Landsat clear, cloud-free images were selected to classify the study area: Landsat TM 1989 and Landsat OLI-8 of 2013 (autumn) and Landsat TM 1996 and Landsat TM 2005 (summer).

4.3 Land Cover Analysis

Classification of land cover in the Upper Molopo River Catchment categorized seven major groups namely: Woodland, thicket, shrub land/ grassland/ pasture, water body/ wetland, rain fed agriculture, irrigated agriculture and built up (Table 5). The maps in Figures 4 and 5 indicate land cover in the Upper Molopo River Catchment in 1989, 1996, 2005 and 2013. Distribution of the spatial land cover categories in the study area follow.

4.3.1 Spatial distributions of land cover classes in 1989

Figure 4 and Table 7 display the extents of the coverage of land surface features and their respective distributions. The land cover classification in 1989 indicates large areas of woodland occupying 143121 ha (33.2 %). Woodland concentrated mainly in the central parts especially in areas close to settlements, lower eastern, northern tip and along the banks of Molopo River. Thicket (>70% crown cover, bush land <70% crown cover) is associated with closed woodland less than 15 m of height. This class covered 112961 ha representing 26.2% of the total area. Grassland/ shrub land / pasture land formed the second largest class after woodland covering 139037 ha of the total study area representing 32.3%.

Table 7 Spatial extents of land cover classes – autumn season (1989 and 2013).

Land cover categories	1989		2013	
	Area (ha)	%	Area (ha)	%
Woodland	143121	33	107159	25
Thicket	112961	26	159156	37
Grassland	139037	32	4213.5	0.9
Water body	2081.52	0.4	433.89	0.1
Rain fed agriculture	2144.79	0.5	87268	20
Irrigated agriculture	18533.6	4.3	2166.1	0.5
Built up land	12553.4	3	70036	16
TOTAL	430433	100	430433	100

Shrub lands may be the mature vegetation type in a particular region and remain stable over time; or a transitional community that occur temporarily as a result of disturbance such as fire or browsing. These shrubs in the study area are characterized by plants with adaptations to the dry climates which include small leaves to limit water losses and thorns to protect them from grazing animals, succulent leaves or stems, storage organs to store water and long tap roots to reach ground water. These plant types are common around Mafikeng town and the surrounding hilly escarpments. The water body covering 2081.52 ha takes up the least percentage of the total land cover (0.4%). Cultivated land and built up land in the study area occupied 4.8% and 2.9 % respectively.

4.3.2 Spatial distributions of land cover classes in 2013

The 2013 Landsat 8-OLI classification shows the areal extent occupied by thicket amounting to 159156 ha representing 37 % of the total area. Woodland occupied 107159 ha of the total area representing 25 %. Another class that dominated in this year was rainfed agriculture occupying a total area of 87268 ha (20 %). The built up land came fourth occupying 70036 ha (16 %) of the total area. Built up land consists of urban areas such as buildings, roads and cemeteries which includes Mafikeng and the surrounding villages. Grassland and irrigated agriculture occupied 0.5% and 0.9% of the total area representing the smallest portion of the land cover classification respectively. Water body takes up 433.89 ha representing the least percentage of the total land cover (0.1%) (Table7).

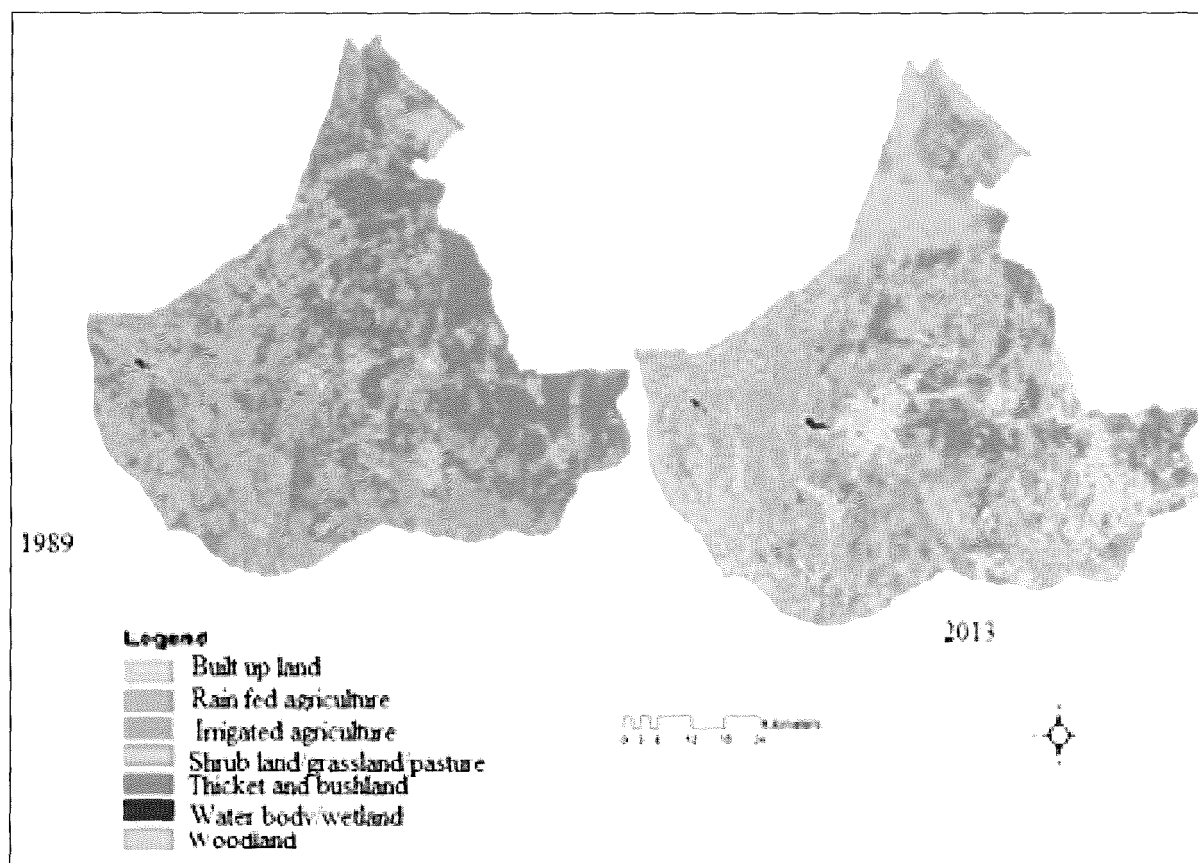


Figure 4 Land cover maps winter season (1989 and 2013).

4.3.3 Spatial distributions of land cover classes in 1996

In 1996, woodland and irrigated agriculture constituted the predominant type of land covers, approximate 20% in each of the land cover class. Woodland and irrigated agriculture which occupied the largest total area concentrated in the north eastern and south western parts of the catchment. Thicket and grassland constituted the second largest classes occupying 18% and 17% respectively. Thicket occupied mainly the central and north western parts of the study area. Grassland concentrated in the arid western parts of the catchment. Water body, rain fed agriculture and built up land constituted 0.1%, 13% and 11% of the total area of the region representing the small portion of the land cover classification (Table 8). Built up area occupied 49247.5 ha representing 11% of the total area while water body occupied 617.04 ha representing the least percentage in the total land cover (0.14%) with built up area and water bodies concentrated in the central and western parts of the catchment.

Table 8 Spatial extents of land cover classes summer season (1996 and 2005)

Land cover categories	1996		2005	
	Area (ha)	%	Area (ha)	%
Woodland	87945.8	20	122631	28
Thicket	76510.4	18	112895	26
Grassland	74885.8	17	18971.8	4
Water body	617.04	0.1	728.19	0.1
Rain fed agriculture	54323.3	13	20324.2	5
Irrigated agriculture	86905	20	150132	35
Built up land	49247.5	11	4750.38	1
Total	430432.6	100	430433	100

4.3.4 Spatial distributions of land cover classes in 2005

During this period, irrigated agriculture occupied the highest extent 150132 ha (35%) of the total land cover taking up more than one-third of the total area. Most cultivated land reflecting healthy crop concentrated in the south, eastern and central parts of the catchment under irrigated commercial farming. Woodland and thicket are second largest classes representing 28% and 26% respectively. These classes occupied mainly the eastern, north eastern and small portions of the north western parts of the study area. Rain fed agriculture occupied an area extent of only 5% and dominated the western semiarid portion of the catchment. Grassland followed with an area extent of 4% while built up area and water body occupied the least extents of 1% and 0.1% respectively (Table 8).

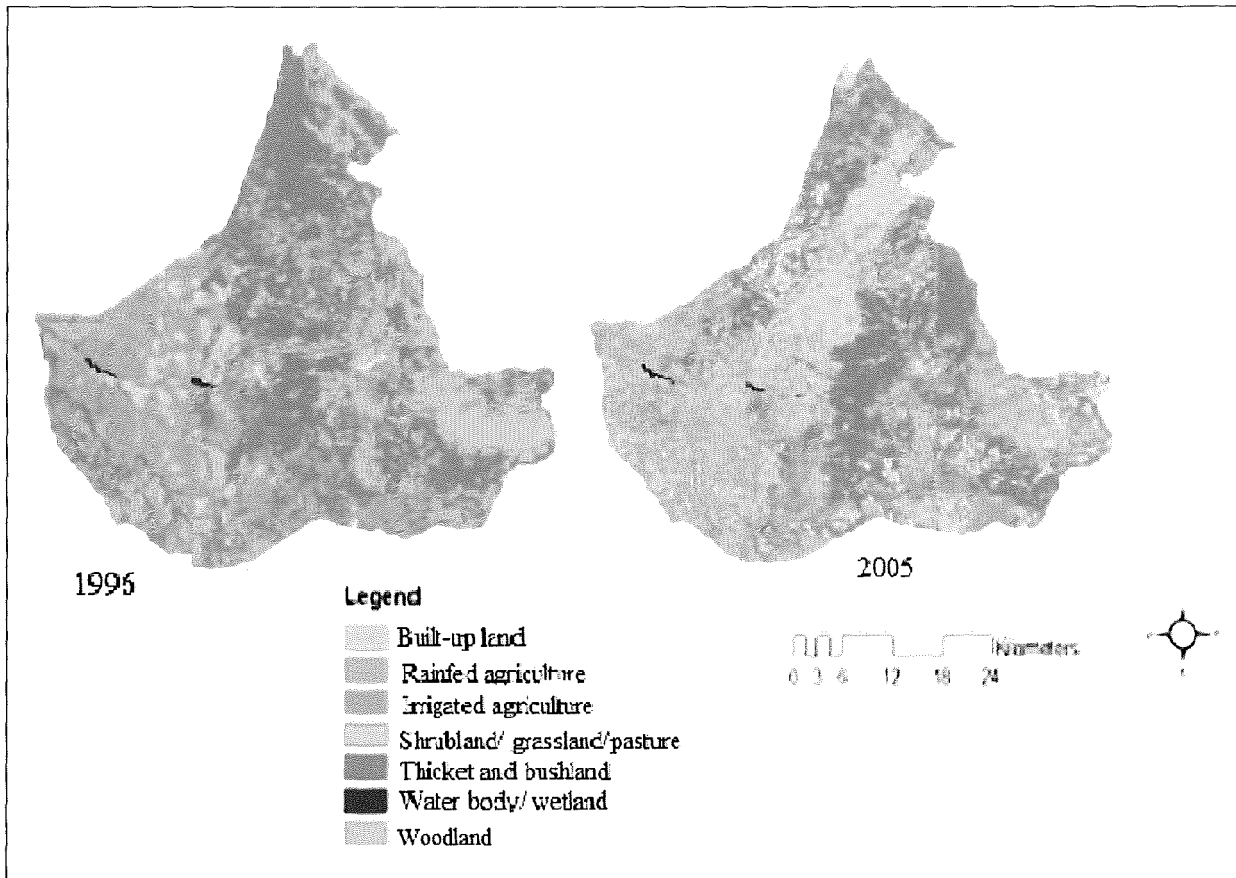


Figure 5 Land cover maps summer season (1996 and 2005)

4.4 Land Cover Change: Trend, Rate and Magnitude – summer season (1996 – 2005)

The general trend in the land cover classes for summer season shows an increase in the area covered by cultivated healthy crop and vegetation classes with the exception of grassland which declined from 17% in 1996 to 4% in 2005. Cultivated land under healthy crop increased by 15% followed by thicket and woodland with an increase of 9% and 8% respectively. The plausible reason for the increase in the above classes during this period could be attributed to heavy rains in the eastern parts of the river catchment's recharge aquifers and mountain dense stands of riparian vegetation in the dry reaches of the catchment (DWAF, 2004 a).

Overall, there was a total increase of 31% in cultivated areas corresponding to agriculture being the major economic activity of the study area and the subsequent forced settlement of the indigenous community in the home lands of South Africa during the apartheid period. Grasslands, rain fed agriculture and built up areas showed a total decline of about 31% of the land cover class area due to the fact that 1989 and 2013 images were acquired during the non-

growing season (autumn - winter). Water body remained at 0.1% for this period. The area extent under water remained unchanged because no major dams were constructed within the area after 1996 (Table 8).

Table 9 Land Cover Change: Trend, Rate and Magnitude – summer season (1996 –2005)

Land cover categories	1996		2005		Change	
	Area (ha)	%	Area (ha)	%	(ha)	(%)
Woodland	87929.3	20	122631	28	34701.7	8
Thicket	76510.4	18	112895	26	36384.6	8
Grassland	74885.8	17	18971.8	4	-55914	-13
Water body	617.04	0	728.19	0	111.15	0
Rain fed agriculture	54323.3	13	20324.2	5	-33999.1	-8
Irrigated agriculture	86905	20	150132	35	63227	15
Built up land	49261.8	11	4750.38	1	-44511.42	-10
Total	430432.6	100	430432.6	100		

During the summer season, the area under irrigated agriculture dominated all other classes by occupying a total area of 86905 ha (20%) in 1996 and 150132 (35%) in 2005. The overall increase in this class from 1996 to 2005 was 15%. The plausible explanation for the increase in irrigated agriculture could be due to the above normal precipitation experienced prior to and during image acquisition which filled up the dams making water for irrigation available (Appendix 3). The total area under rain fed agriculture decreased by 8% probably because of the increase in irrigated agriculture. Grassland decreased the most with a total of 13% which could be attributed to of the heavy rainfall received during this period. Increase in rainfall simultaneously resulted into the increase in woodland (from 20% to 28%) thereby supressing undergrowth (Pidwirny, 2011). In addition, there was a decrease of 10% in the area occupied by built up land. This could be attributed to the migration of the local people to major towns in search of better job opportunities. The study area experienced substantial net out migration between 1996 and 2001 due to the birth of a democratic South Africa in 1994 which could have opened up opportunities elsewhere in the country for the previously disadvantaged rural population (Palamuleni, 2010). The study further affirms that during this period (1996-2001), the Province as a whole experienced increased net out migration.

4.5 Land Cover Change: Trend, Rate and Magnitude – autumn season (1989 – 2013)

From 1989 to 2013, woodland decreased by 8 % which could be associated with rainfall variability and anthropogenic activities. Grassland constituted about 32% in 1989 but decreased to 0.9 % by 2013 which is almost an overall total areal loss of 31% (Table 9). Grassland decreased the most due to the grazing patterns taking place in the area associated with overgrazing and overstocking (Hammad and Tumeizi, 2010). Rain fed agriculture, built up land and thicket constituted the predominant types of land cover during autumn (non-growing season) with an approximate 43.9% of the total area. The areal extent under rain fed crop gained almost 20% during this period. This could be attributed to the conversion of land for food security since subsistence agriculture has low productivity; hence there has been an inevitable tendency to increase the amount of land being farmed (Palamuleni, 2010).

Table 10 Land Cover Change: Trend, Rate and Magnitude – autumn season (1989 – 2013).

Land cover	1989		2013		Trend cover change	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Woodland	143121.3	33	107159.3	2	-35962.0	-8
Thicket	112961.0	26	159155.8	37	46194.8	11
Grassland	139037.0	32	4213.5	0.9	-134823.5	-31
Water body	2081.5	0.5	433.9	0.1	-1647.6	-0.4
Rainfed agriculture	2144.8	0.5	87268.0	20	85123.2	20
Irrigated agriculture	18533.6	4	2166.2	0.5	-16367.5	-4
Built up land	12553.4	3	70036.0	16	57482.6	13
Total	430432.6	100.00	430432.6	100.00		

Built up land formed another class which showed a steady increase from 1989 to 2013. In 1989, the total area under built up land was 12553.4 ha (3%) but in 2013 it had increased to 57482.6 ha (16%) resulting in overall increase of 13%. This is because the catchment area is one of the most dynamic economic areas in the province because of its strategic location between the main cities of the North West province of South Africa and Gaborone of Botswana; a consequence of which has been the establishment of large industrial and service activities (Mahikeng Spatial Development Initiative Frame Work, 2010). In 1989, water body occupied a total area of 2081.52 ha (0.5%) and decreased to 433.89 ha (0.1%) in 2013 which

explains why the total area under irrigated agriculture has declined and total area under rain fed agriculture has increased. One of the reasons for the decrease in water bodies lie within the diverse climate of the study area which causes spatial and temporal variability in precipitation with subsequent impact on the dynamics of the natural vegetation (Vincent et al., 2010).

Cultivated land under irrigation and shrub land declined due to rainfall variability and anthropogenic activities such as overgrazing, general agricultural expansion and need for more land for settlements due to the increase in population. According to the 1996, 2001 and 2011 census data (Figure 18 a), the population in the region has been steadily increasing and hence the increase in the built up land may have exerted pressure on tree cover in the study area. Over the years, urban expansion driven by employment opportunities in urban centres and declining rainfall has led to the conversion of agricultural land to the built environment. Woodland and grassland declined by 8% and 31% respectively. The plausible explanation for the decline in woodland and grassland could be the spectral confusion between woodland and grassland due to land cover aggregation with neighbouring land cover types (Table 9). This explains the noticeable spatial extent of cropland under rain fed agriculture which increased from 0.5% in 1989 to 20% in 2013 representing a total net gain of 20% (Figure 5, Tables 9 and 10).

In general, the spatial extents of the land cover classes indicate marked change in all land cover categories between 1989 and 2013. Woodland decreased from 33% in 1989 to 25% in 2013 which is an overall net loss of 8%. Rain fed crop increased from 0.5% in 1989 to 20% in 2013 which could be due to increased aridity and more demand for food as the population size increases. On the contrary, irrigation agriculture decreased from 4% to 0.5% in 2013 which is an overall net loss of 4%. This decrease could be attributed to a shift in economic activities due to constant droughts in the region (Hulme et al., 2001). Besides, built up land increased from 3% in 1989 to 16 % in 2013 which could be attributed to the increase in population and possibly the result of the rural development program (RDP) after 1994 (Table 3 and Figure 18 a, c, d). There has also been a marked growth in the city of Mafikeng which is an integrated town (residential, industrial and commercial community). All these biophysical changes within the setting of the catchment's ecosystems reflect the dynamics of human impacts on the vegetation density of the Upper Molopo River Catchment.

Land cover change areal statistics for summer and autumn were summarised in Figures 4 and 5 to express the net land cover lost or gained in each class category over the 24 year period

(1989-2013). There are significant losses in the spatial extents of woodland, grassland, water body, and irrigation agriculture during winter period (1989-2013). Rain fed agriculture, built up land and thicket recorded significant gains. With the 2013 image, woodland class dominated all classes because of the dry non growing season when the image was acquired. Therefore, grassland and pasture land classes shifted into the thicket and woodland as woodland is not affected by dry conditions as grassland.

4.6 Thematic Land cover accuracy assessment

Accuracy assessment was based on the correlation between ground reference samples collected during field exercise and the satellite image classification to give an indication of the overall agreement between ground-truthing data and processed classifications. Based on the ground truth observations and the classification, the error matrix in Table 11 was constructed. Despite the spectral confusion and classification error, the classification scheme that was employed was satisfactory for LULC analysis yielding overall classification accuracy for all land- cover classes of 88% and the overall k statistic of 82%. All user's and producer's accuracy for most of the classes were higher than 76% except for grassland and water body which were very dry.

The minimum acceptable overall classification accuracy for Level I mapping in South Africa is 85% (Thompson, 1996). The producer's accuracy of built-up areas was 92.3% while the user's accuracy was slightly lower (75%). This means that although 92.3% of the built-up areas were correctly identified, only 75% of the areas labelled built-up were actually built-up areas, implying a significant misclassification of the pixels in that category. The most accurately classified land covers were the thicket and cultivated (healthy) crop with 100% accuracy for both producer and user accuracy. The user's accuracy of 100% for thicket / bush land and cultivated healthy crop ascertains their dominance occurrence within the Upper Molopo River Catchment. These results however, suggest that a good agreement exists between the classification and the actual land cover types considering the fact that at the time of field verification, water and grassland were dry due to drought experienced during the first half of 2013.

Table 11 Error matrix for 2013 image classification

Classified Data	Reference Data								User's accuracy
	Woodland	Thicket	Shrub/ grassland	Water	Rain fed	Irrigated	Built up	Totals	
Woodland	42	0	2	0	3	0	1	48	87.5%
Thicket	0	13	0	0	1	0	0	14	92.9%
Shrubs/grassland	0	0	1	0	0	0	0	1	100%
Water	0	0	0	0	0	0	0	0	0%
Rain fed	0	0	0	1	19	0	0	20	95%
Irrigated	0	0	0	0	0	1	0	1	100%
Built	1	0	0	1	2	0	12	16	75%
Column Total	43	13	3	2	25	1	13	100	
Producer's accuracy	97.7%	100%	33.3%	0%	76%	100%	92.3%		
Overall Accuracy	88%								
Kappa	83%								

Besides, the semi-arid environment of the UMRC with constant droughts, causes little chlorophyll in the vegetation while overgrazing causes exposure of soil between remaining vegetation resulting into similar spectral values making it difficult to distinguish between the classes. Grassland in the catchment form a complex matrix that is patchy in some places and heterogeneously mixed with other land cover classes. Differentiating between thicket and woodland was not straight forward due to the similarity in spectral signatures (Figure 6).

4.7 Vegetation density analysis

Two pairs of biseasonal Landsat clear, cloud-free images were selected to monitor and quantify the concentrations of green leaf vegetation within the UMRC. NDVIs were computed for 1989, 1996, 2005 and 2013 independently using the maximum likelihood classifier. Classification of vegetation density in this study categorised three major classes namely: low vegetation density (< 0.1), medium vegetation density ($>0.1- 0.5$) and high vegetation density (>0.5) (Kumar et al., 2013). For the TM/ETM+ images of 1989, 1996 and 2005, classification of vegetation density categorised three density classes whose NDVI values were: low vegetation density = $NDVI < 0.3$, medium vegetation density = $NDVI 0.3- 0.5$, and high vegetation density = $NDVI > 0.5$. For the 2013 Landsat 8 OLI image, the Near

Infra- Red band has a different spectral range of coverage (0.85-0.88 μ m) than that of the TM/ETM+ sensor (0.76-0.79 μ m).

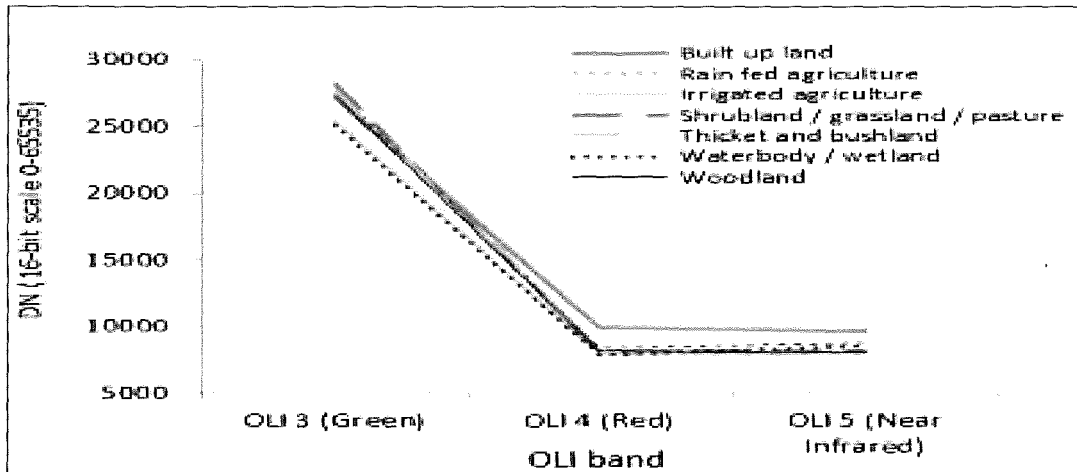
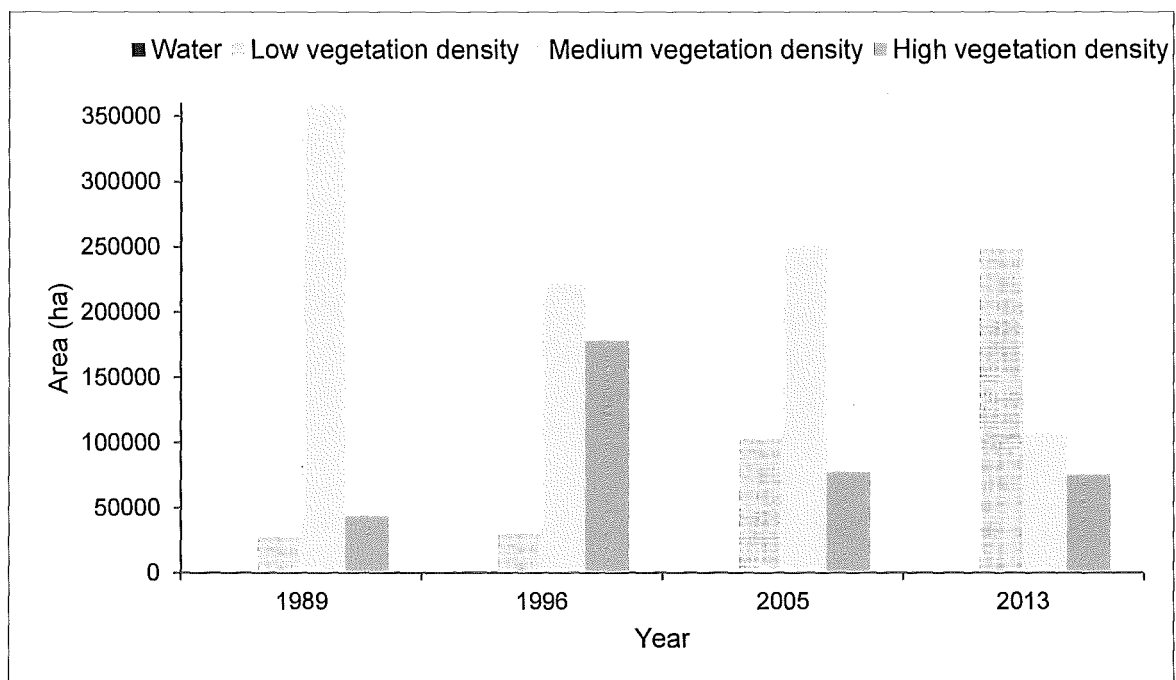
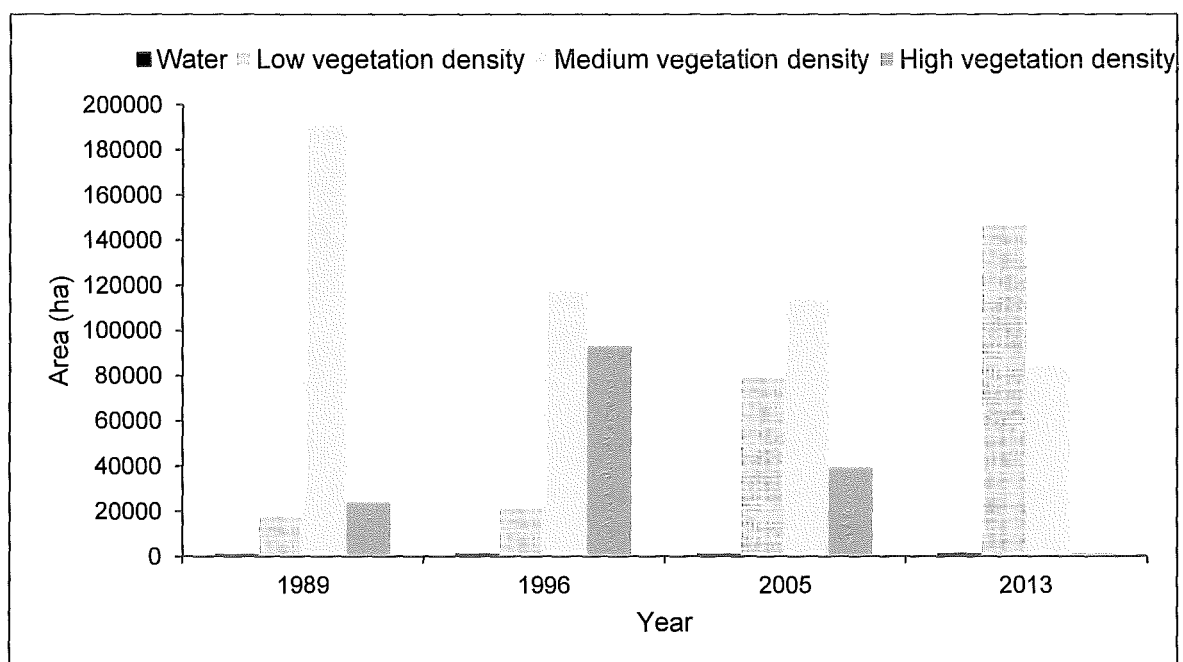


Figure 6 Spectral signatures of the land use and land cover classes

Its Red band also has a slightly different spectral range (0.64-0.67 μ m) compared to that of the TM/ETM+ sensor (0.63-0.69 μ m). These slightly different Red and Near Infrared band data were the ones employed in computing NDVI (Equation 5). As a result of these differences, the NDVI values that resulted from the 2013 OLI image were considerably lower than those from the TM and ETM+ images. This prompted a modification of the NDVI value class thresholds for the three vegetation density classes for the 2013 image only: low vegetation density = NDVI < 0.1, medium vegetation density = NDVI 0.1-0.3, and high vegetation density = NDVI > 0.3. The modified class thresholds were arrived at by locating the vegetation density field data training sites that were visited during field work, as described in Sections 3.3 and 3.3.1. In addition, 5km buffers were created to show proximity of settlements and category of vegetation density. Figure 7 shows the result of vegetation density classification for the whole study area and within 5km of settlements.



(a) Whole catchment



(b) Within 5km of settlements

Figure 7 Spatial distributions of vegetation density classes 1989-2013

In 1989, medium vegetation density occupied the largest total area of 190558.4 ha (82 %) followed by the high vegetation density class, 23932.8 ha (10.3%) and the low vegetation density occupying a total area of 17476.02 ha (7.5 %) and water body with the lowest total area of 472, 05 ha (0.2 %). NDVI values for the 1989 image shows high reflectance value indicating that there was high vegetation density for the area during this period. The reflectance values ranged from 0.771 (highest) to - 0.139 (lowest). In general, low vegetation density in the Upper Molopo River Catchment is associated with human settlement areas, in particular the high-density settlements situated on the western parts of the catchment as formal townships, informal townships and informal squatter camps.

4.8 Spatial distributions of vegetation density classes in 1989

NDVI values for the 1989 image shows high reflectance value indicating that there was high vegetation density for the area during this period .The reflectance values range from 0.771 (highest) to 0.139 (lowest). The area on the South East, Central and around Molopo river reflect the highest NDVI value of 0.774 while the western parts reflect the lowest NDVI value of -0.103 (Figure 9). The high NDVI reflectance values for the year 1989 can be attributed to the above normal rainfall in the years prior to the image acquisition (1988-May1989) as reflected in Appendix 4 and less settlements as indicated by the 5km buffers (Figures 9 and 10). NDVI and Mean Average Rainfall (MAR) are positively correlated (0.47) indicating that vegetation activity in the area is highly dependent on the amount of rainfall.

In general, low vegetation density is increasing while medium and high densities have decreased throughout the study period in exception of 1996 where vegetation was dense throughout the study area. The increase in vegetation density in 1996 corresponds to the increased rainfall in that year where all the five weather stations recorded above normal rainfall. NDVI and Mean Average Rainfall (MAR) are positively correlated (0.47) indicating that vegetation activity in the area is highly dependent on the amount of rainfall. In addition, the abundance and richness of vegetation activity from satellite data indicate that vegetation density in the study area is strongly seasonal with a late summer maximum vegetation density and near complete termination of vegetation density during winter months (07/05/1989 and 03/05/13 images). The area on the South East and around Molopo river have the highest vegetation density in summer months (January 1996 and 2005 images) 0.62 - 0.73 NDVI values while the western parts reflect the lowest NDVI value of -0.35. In addition, a

comparison of winter images (1989 and 2013) to the summer images (1996 and 2005) indicate the drier western areas assuming a medium density while the wetter eastern areas assume a low density. This explains that the drier western parts of the study area have adapted to dry conditions and therefore vegetation vigour does not depend on seasonal rainfall ($r = -0.36$; $P < 0.01$). Appendix 4, while the wetter eastern parts have adapted to the wetter conditions where the vegetation vigour depends on rainfall (Figures 10 and 12) summer images (1996 and 2005).

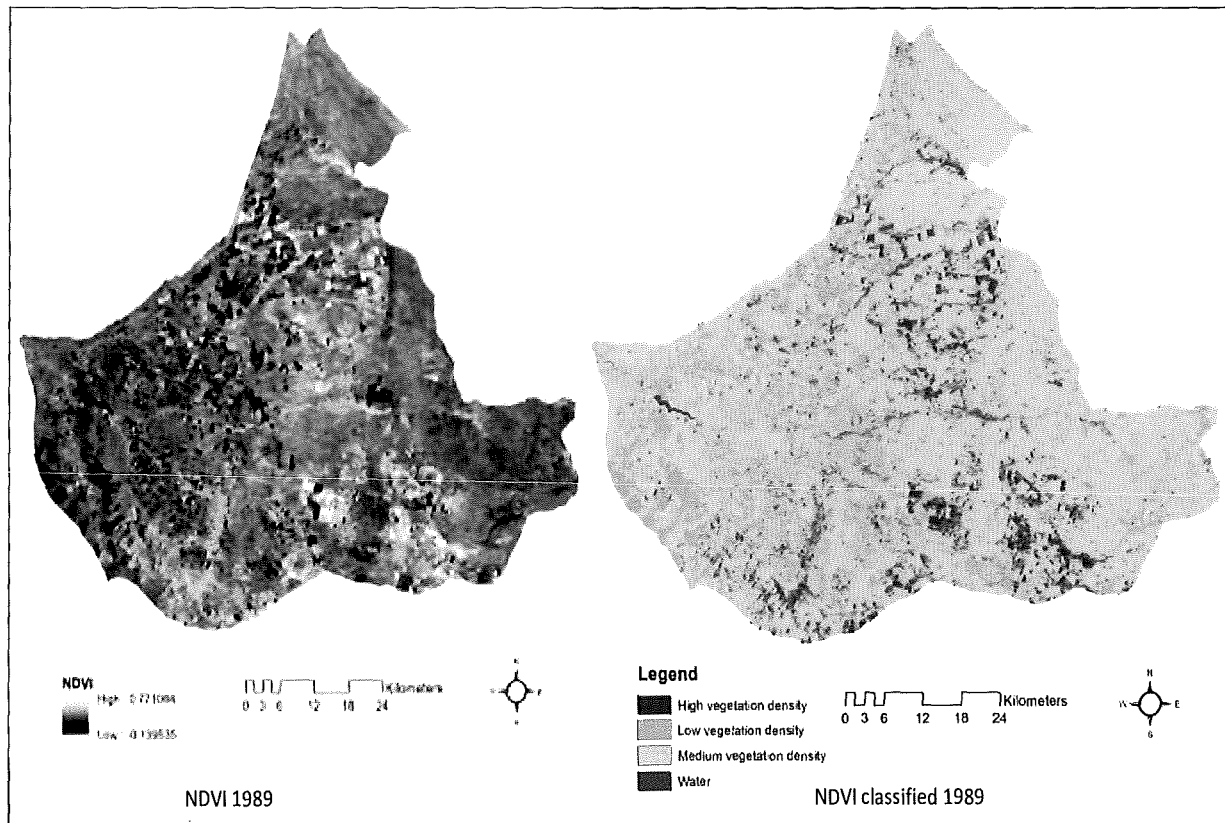


Figure 8 Vegetation density – 1989

Winter NDVI maps (Figure 8 and 14) are especially useful in indicating stresses and differences in productivity of vegetation because, in this water-limited environment, vegetation productivity is constrained the most. Typically, most of the NDVI values had a high frequency at low NDVI values representing non-vegetated pixels as well as a broad frequency distribution approximating the normal (Gaussian) distribution at a higher NDVI value representing green vegetation. The location of the normal distribution peak (i.e. mode) was taken as primary indicator of vigor status.

density (117633.4 ha) (51%) compared to the 1989 period where medium vegetation density occupied more than 80% of the total area.

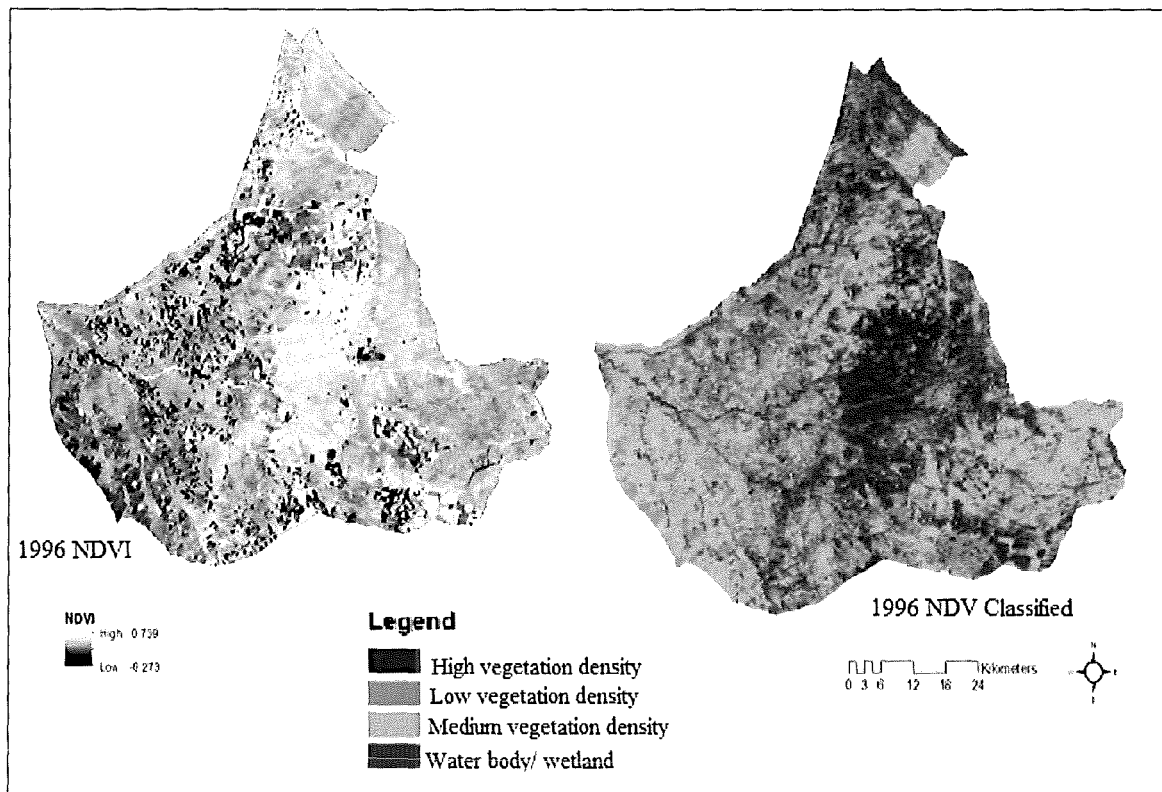


Figure 10 Vegetation density 1996

The dynamics underlying the increase in the total area occupied by high vegetation density and a decline in medium vegetation density during this period could be attributed to the plenty of pasture for the grazers and reduced competition for woody vegetation unlike during the non -growing season (autumn - winter) when grazers remove much of the grass sward while woody trees are benefited from reduced competition. Grazers identified in the study area in particular the western parts of the catchment are mainly goats and sheep which feed mainly on grass and not trees. This increases woody vegetation density during non -drought periods and results into a decline in medium and low vegetation densities (Figure 10).



Figure 11 Grazers identified in the study area

Observations from the 1996 5km settlement buffers reflect low vegetation density within 5kms from the settlements and high vegetation density beyond 5km. This implies that most of the animals graze within 5km from the settlements. High vegetation density is mainly in urban areas particularly Mafikeng town and its surrounding high class residential areas where the benefits of trees are highly appreciated. Medium density is more common in the surrounding rural areas and still occupies the largest extent although it declined from 82% in 1989 to 51% in 1996. Low vegetation density is concentrated in the western parts of the catchment which are mainly communal rangelands.

4.10 Spatial distributions of vegetation density classes in 2005

During this period, medium vegetation density still occupied the largest extent of about 49% of the total area. Low vegetation density reflects an increasing trend from 1989 to 2013. This class increased by 25% from 1996 to 2005. On the contrary, high vegetation density reflects a decreasing trend throughout the study period. From 1996 to 2005 alone, this class decreased from 40% to 17% which is a total decrease of 23%. It is quite possible that the decline in high vegetation density during this period is related to the reduction in rainfall between 1996 and 2005. To analyse this factor, rainfall data prior to the acquisition dates of the images in January 1996 and 2005 respectively was analysed (Appendix 4) which shows that prior to the image acquisition dates of 1996 and 2005, it was very dry. Although medium vegetation density recorded a decrease of about 2% from 1996 to 2005, it still occupied the largest extent of 113462.1 ha representing 49 % of the total area. The NDVI values for 2005 image range from 0.622 to -0.348 and reflect a decreasing trend from 1989 which is likely to

continue as the rainfall in the area is also at a decline.

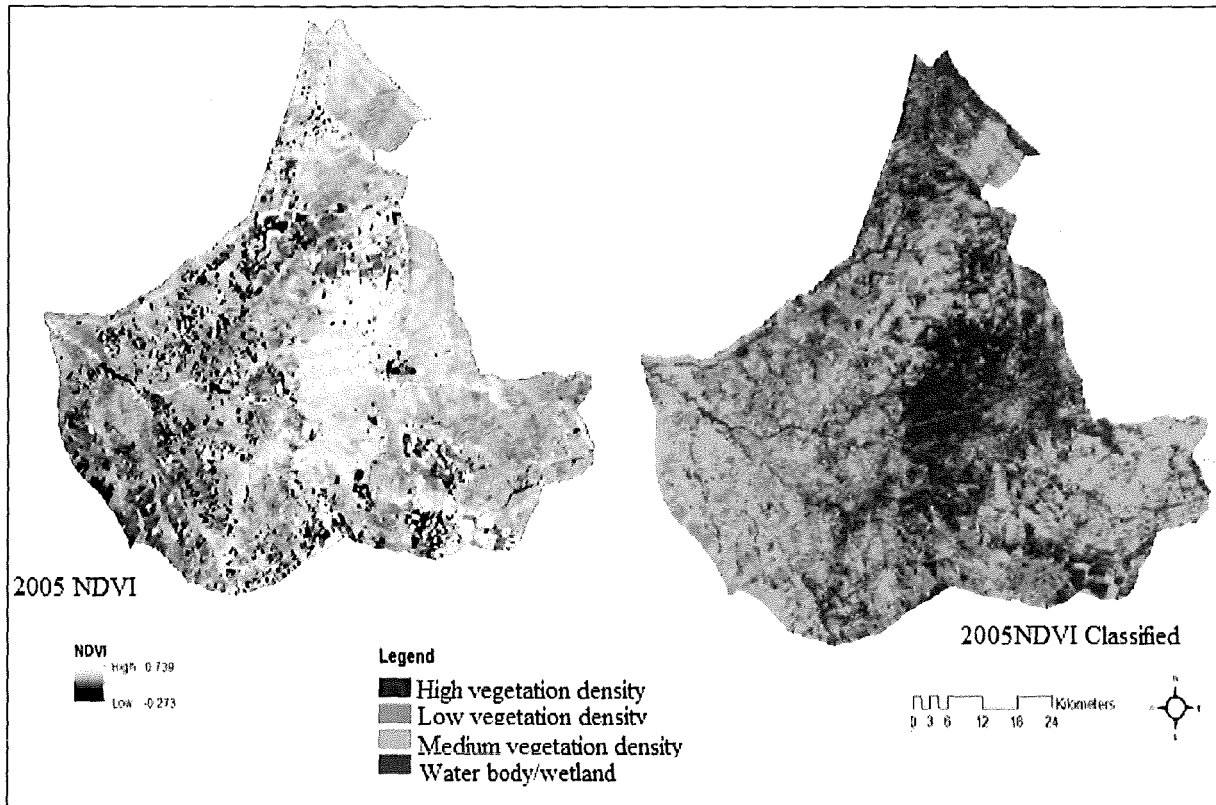


Figure 12 Vegetation density 2005

The results from the maximum likelihood classification indicate high to medium NDVI values on the eastern half of the study area and low NDVI values on the western half. Once again, the explanation for the differences in the reflectance values lie within rainfall variability within the study area (Figure 18) which is low and unreliable, rarely more than 500mm per year. Summers are very hot with daily maximum temperatures of over 32°C while winters are cold and dry. The western parts of the study area receive very little rainfall with very low humidity. The 2005 5km settlement buffers (Figure 13) reflect low vegetation density on the western parts of the study area which are more arid and are also used for communal grazing. Medium and high vegetation densities are concentrated in the central and north eastern parts which are privately owned.

particularly indigenous vegetation as the lush greens are found in the eastern parts of the NDVI classified images which correspond with the fact that South African rainfall decreases from east to west (Figure 17). Studies by Nicholse (2008) and Wessels et al., (2008) showed that the perceived decline in vegetative cover in arid and semi-arid lands could largely be attributed to variation in rainfall. Thus, the many different kinds of unmanaged vegetation are adapted to today's climate, as climate changes, each kind of vegetation changes as well, dying out in places where climate becomes too stressful, and prospering where climate becomes conducive.

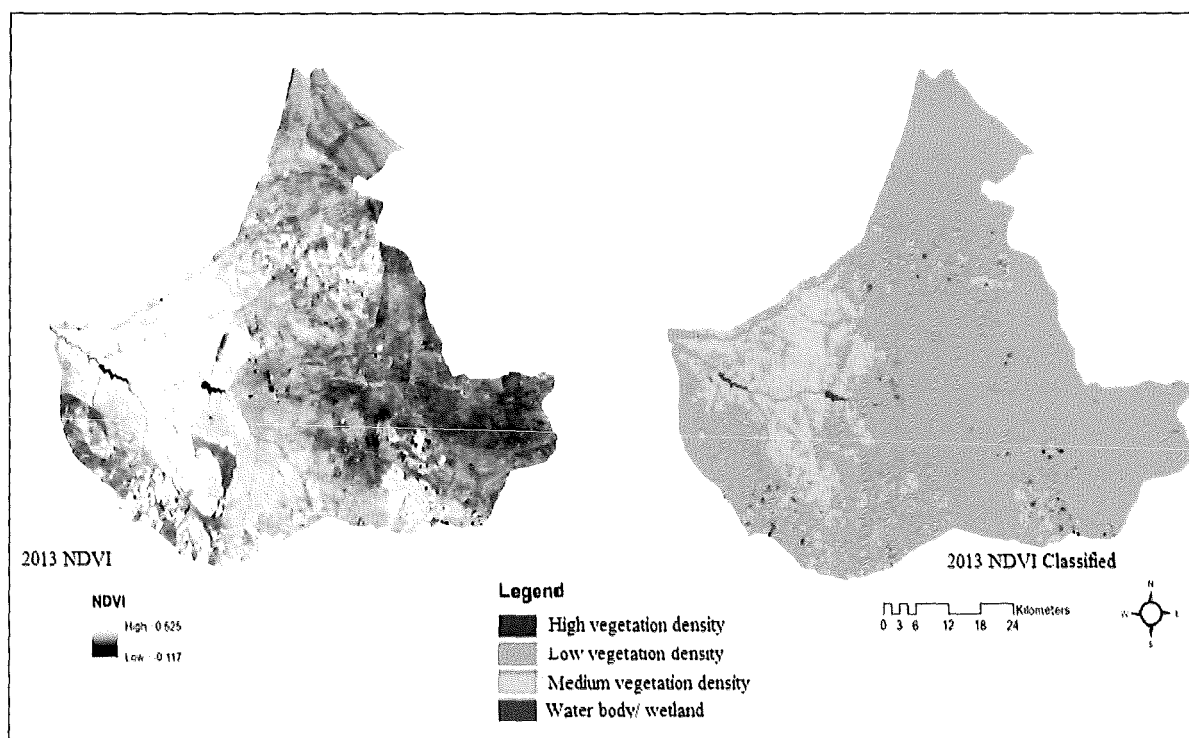


Figure 14 Vegetation density 2013

This shift showed dynamicity of vegetation categories over space and time. Low vegetation density category has been increasing from 1989 to 2013 which is indicative of the decreasing rainfall in the study area. The area occupied by low vegetation density increased from 78888.96 ha representing 34 % in 2005 to 146356 ha in 2013 (63%). This class dominated the 2013 categorisation and concentrated mainly the whole area in exception of the small area around the Disaneng and Modimola dams where there was medium vegetation density occupying only 1092.6 (0.5 %) of the total area.

The shift from low to medium vegetation density in the western semi- arid area may be due to the fact that the semi-arid west has more drought resistant vegetation types compared to the

eastern parts. *Acacia Tortillas* woodland and *Acacia Karoo* are dominant species within this area especially along the banks and on alluvial terraces, where they can depend on ground and flood water that infrequently occur in the area. Existence of such trees with their large multi-stemmed canopies and root biomass may contribute to promoting the infiltration and percolation of rain water into soil, causing an increase of soil moisture and water table level which allows these trees to remain physiologically active under drought conditions.

The prevalence of hydrologic variables typically morphometric characteristics over soil characteristics and grazing as a determinant of observed vegetation distribution may be related to the complex interactions among these factors and to the overriding role that ephemeral streams play in the patterns of plant recruitment and establishment in arid regions (Stromberg et al., 2009). This may also explain the reduction of vegetation species richness with increasing grazing intensity closer to settlements (Figure 15). The occurrence of degraded land around high-density settlements in the catchment can be explained by the established association between poverty and environmental degradation. Poverty has been shown to influence both affordability of soil conservation practices and accelerated rates of use of natural resources as a source of income, particularly in the African context (Barbier 2000). The high-density settlements, with high unemployment rates, are mainly inhabited by lower-income households who mainly depend on the catchments' resources for survival in form of mixed subsistence farming.

4.12 Vegetation density change: Trend, Rate and Magnitude-Summer season 1996-2005

Vegetation density change areal statistics are summarised to express the net vegetation lost and gained in each class over the 24-year period 1989-2013. The net gains and net losses for the various vegetation density categories in hectares and percentages are shown in Tables 9 and 11 and Figures 4 and 5. There are significant increases in the spatial extent of low vegetation density while medium and high vegetation decreased in extent. The analysis shows insignificant changes in the extent of water body.

The spatial extents of the classified vegetation density classes indicate marked change between 1996 and 2005. Water body did not change from 1996 to 2005. It remained at 0.3% mainly because after 1996, no major dams were constructed in the study area. Another reason for no change in the water body could be an aspect of misclassification due to similarity between dry river channels with soil or bare land. Additionally, the zero accuracy assessment

of the water body was due to the confusion between riparian vegetation and bareland as the reference image which was 2013, was acquired during a dry season when water colour tends to reflect chlorophyll.

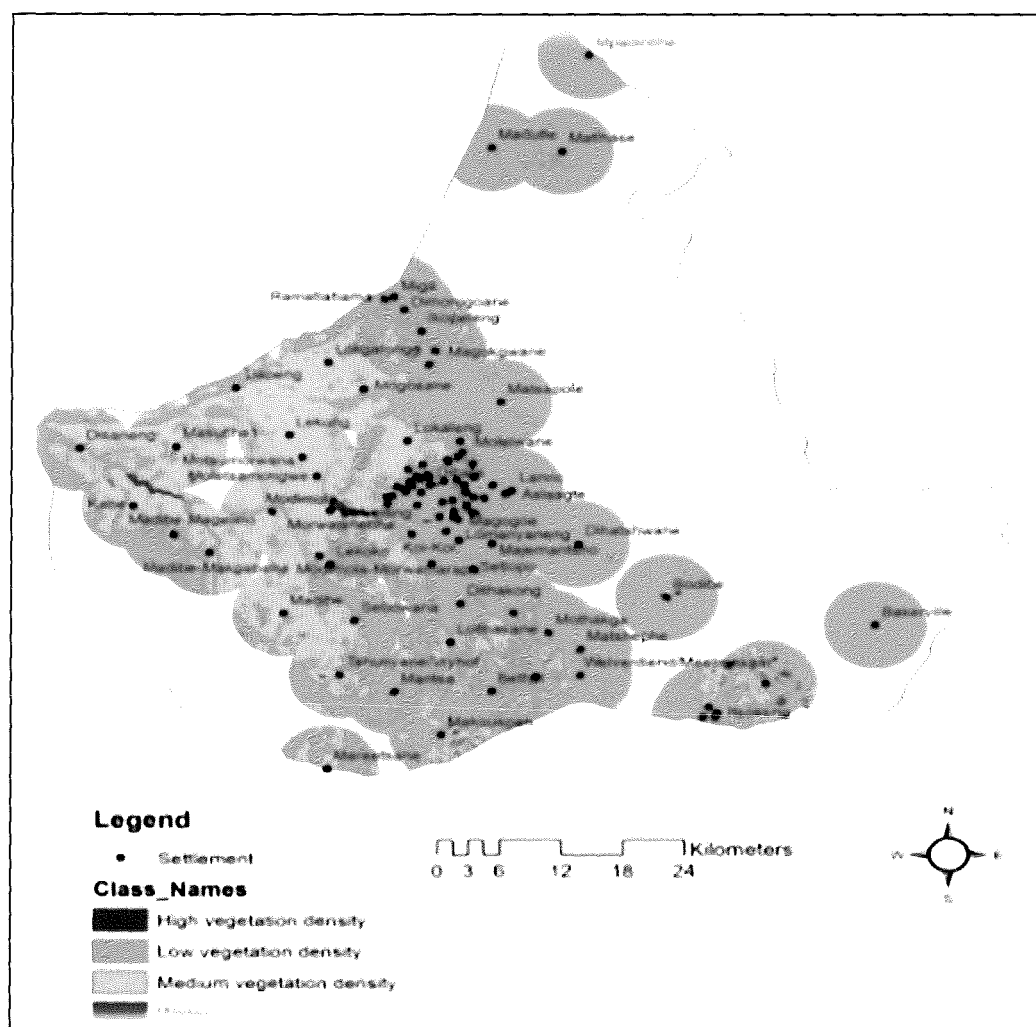


Figure 15 5km settlement buffers – 2013

Low vegetation density shows a marked increased extent of 25% from 1996 to 2005 which represents a total change of 34% for the summer period. The increase in the low density during this period (1996- 2005) could be ascribed to the anthropogenic activities taking place in the area such as overgrazing, and rapid increasing demands for more land for settlements, energy (fuel wood) and construction materials within the poor rural communities as it's in these areas that show more signs of land degradation (Figure 7). Medium vegetation density class shows a slight decline from 51% in 1996 to 49 % in 2005 which is almost an over- all 0.0% change. Conversely, there was a total decrease 0.6 % in the total area occupied by high

vegetation density. High vegetation density shows a sharp decline from 40% in 1996 to 17% in 2005 which is an overall change of 23% (Table 12).

4.13 Vegetation density change: Trend, Rate and Magnitude-Winter season 1989-2013

The initial cover (in 1989) of low vegetation density was very low compared to the medium and high vegetation classes but increased steadily to dominate the other classes by 2013 (Table 7). Low vegetation density represented only 17476.02 ha in 1989 representing 7.5% of the total area but by 2013, it had increased to 146356 ha representing 63% of the total area gaining 7.4% from the other classes. It is known that agriculture and grazing are the main livelihood strategies of the population living in this area. These activities could be responsible for the shift in the vegetation density in the UMRC.

In 1989, medium vegetation density and high vegetation density categories occupied 82% and 10.3% respectively, but by 2013, the same classes occupied 36% and 0.5% respectively which represents a total decline of 34% for medium vegetation density and 9.8% for high vegetation density. The overall total extent lost during this period (1989-2013) from the medium vegetation class is 0.6% while high vegetation density lost 1.0 % (Table 12).

Table 12 Vegetation density change in the Upper Molopo River Catchment 1989-2013

Classes	1989	2013	1989-2013 change	1996	2005	1996-2005 change
	Area(ha)	Area (ha)	%	Area (ha)	Area(ha)	%
Water	472.1	909.6	0.9	755.9	719.3	0.0
Low vegetation density	17476.0	146356.1	7.4	21074.0	78889	2.7
Medium veg. density	190558.4	84081	-0.6	117633.3	113462.1	0.0
High veg. density	23932.8	1092.6	-1.0	92976.1	39368.9	-0.6
Total Area	232439.3	232439.3		232439.3	232439.3	

The very low vegetation density was mainly around settlements and dense vegetation in low settlement areas. Noticeable was the composition of vegetation where the low density vegetation mainly comprised vegetation of grassland and thorn tree in association with rock

outcrops. The moderately dense vegetation was mainly open woodland as depicted in the 5km buffers (Figures 9, 13, and 15). In general, results from both climatic data and satellite imagery ascertain that the spatial distributions of vegetation density during different years and seasons in this region are a result of both human intervention and biophysical influences.

4.14 Thematic accuracy assessment of vegetation density analysis

The performance of the classification scheme was tested with respect to the newest May 2013 image only, an approach that is commonly utilised (Brandt and Townsend 2006; Buchanan et al., 2008). Stratified random sample pixel locations were generated from the classified 2013 image of the study area. Particular emphasis was on vegetation density classes in this category as the study aimed at analysing vegetation density in the UMRC. Accuracy assessment corresponds to the correlation between ground reference samples collected during field exercise and the satellite image classification to give an indication of the overall agreement between reference data and processed classifications. Based on the ground observations from 100 reference sites and classification, the error matrix in Table 13 was constructed.

Table 13 Error matrix for vegetation density

Classification Data	Reference Data					User's accuracy (%)
	High	Med	Low	Water	Total	
High density	12	0	5	0	17	70.6
Medium density	0	20	5	0	25	80
Low density	1	6	51	0	58	87.9
Water	0	0	0	0	0	
Total	13	26	61	0	100	
Producer's accuracy (%)	92.3	76.9	83.6			
Overall accuracy = 83.0%						
Overall Kappa = 69.6%						

An overall classification accuracy of 83.0 % was obtained and the overall k statistic for the vegetation analysis category was 69%. The producer's accuracy of low vegetation density class was 83.6% while the user's accuracy was slightly higher (87.9%). This means 87.9% of the low vegetation density areas were actually low density although 83.6% were correctly

identified as low density that although 83.3% of the built-up, implying a good classification of the pixels in that category. These results generally suggest that a good agreement exists between the classification and the actual vegetation classes with few misclassifications occurring across nearly all the three categories.

4.15 Rainfall characteristics of the Study Area

Rainfall data for all five weather stations used in this study were normalized using the Standardized Precipitation Index (SPI) in order to detect long term changes. Probabilities are standardized so that an index of zero (0) indicates the median precipitation amount. The index is negative for drought and positive for wet conditions. In this study, SPI of the months in which images were acquired are compared with the NDVIs of the same months to show whether rainfall has an impact on vegetation density (Appendix4). In general, 5 trends which alternated between dry and wet periods have been observed since 1970 -2010 (Figure 16).

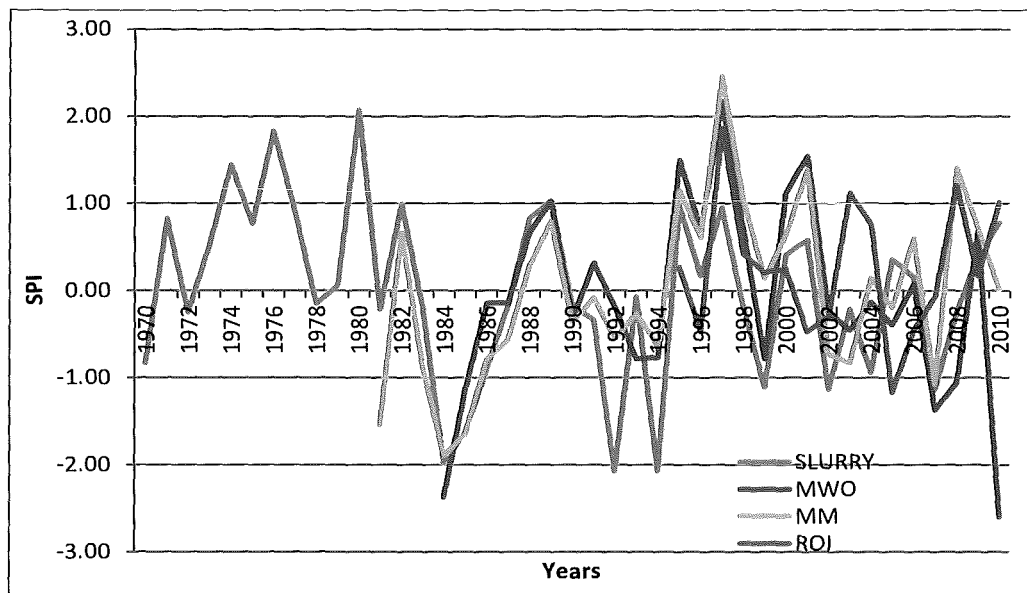


Figure 16 Time series of Standardized Precipitation Index all-weather stations1970-2010

An analysis of the long-term trends in the rainfall revealed that the rainfall in the area has been fluctuating, with wet and dry phases. In the long-term, rainfall has not reduced, and for the period of the image analysis (1989-2013), the area was actually in a wet phase (Figure 16). Reduced rainfall, therefore, was unlikely to be the cause of the decline in medium vegetation density and the increase in low vegetation density that was observed in this study (Section 4.3). The main cause of the decline in vegetation density in the study area is discussed in more details in Section 4.17.

4.16 Spatial Rainfall Distribution in the Study Area in relation to NDVI

The results show modest spatial trends, but strong and coherent temporal trends in the rainfall and NDVI values across the catchment. Spatially, these findings are consistent with those of Tennant and Hewitson (2002) in a study of intraseasonal rainfall over southern Africa. They found that there is an East-West rainfall gradient across the country and that rainfall variability exceeds 40 per cent in western semiarid region. The spatial trend in NDVI follows a similar trend to rainfall, with regions of high rainfall displaying an increasing trend in NDVI, while the more arid regions (western) show decreasing NDVI values. In addition, the results indicate that annual rainfall totals are explained more by the number of rainy days in the study area during summer time, but more by isolated, intense events in the western semiarid area (Figure 18).

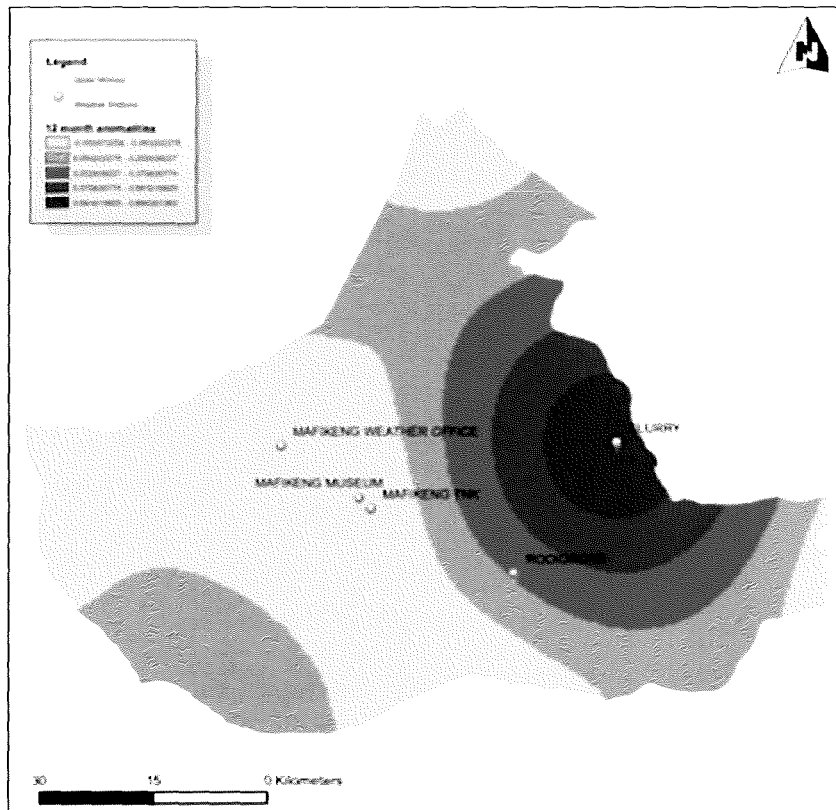


Figure 17 Spatial distribution of rainfall in Upper Molopo River Catchment in relation

Temporally, the trends for the 24 years of the study period are even clearer. Rainfall and the amount of land occupied by high vegetation density has been slightly decreasing across the catchment since 1989 with exception of 1996 where the area received above normal rainfall hence high NDVI compared to the 2005 and 2013 images where vegetation density was

relatively low. The analysis of rainfall distribution shows that some stations receive more rainfall from low frequency, high intensity events, whereas other stations get their rain through more frequent, less intense events. This observation is consistent with that of Tennant and Hewitson (2002) in a study of intraseasonal rainfall over southern Africa. This research, does not investigate changes in rainfall intensity over time. It does, however, analyse rainfall distributions and explained annual variations.

Literature has demonstrated that the NDVI maximum over southern Africa occurs during January-February lagging the rainfall maximum by 1-2 months (Anyamba et al., 2002). Time lags for vegetation response to rainfall vary depending on environmental factors such as soil type which largely determine the water holding capacity of soils. The temporal manner in which the precipitation is received also influences the NDVI lag. It is important to note that the results of this study agree with similar studies in South Africa showing an East- West gradient of decreasing rainfall, but of increasing rainfall variability across the catchment (Figure 17). The extent of the land occupied by high vegetation density is highly dependent on rainfall variability and has been decreasing over the years. Importantly the findings show a trend towards decreased rainfall throughout Upper Molopo River Catchment with reduction in NDVI values implying that drier conditions mean even greater rainfall variability than presently is the case and so less vegetal cover, which in turn, threatens the already precarious water security situation in the country as with what happened in Mafikeng in 2013.

4.17 Drivers of change in the vegetation density loss in UMRCA

For purposes of aiding in the explanation for land use pressure induced trends, ancillary data on livestock numbers, source of energy, type of dwelling (house) and the total population within the study area for the period and the livestock numbers (livestock census) in Ngaka Modiri Molema District municipality for the period 1996, 2001, 2007, 2011 were used to quantify the findings. This data analyzed possible causes for change in vegetation density (Figure 18).

The population of the area shows an increasing trend from 1996 to 2011 (Figure 18a). This corresponds with the decrease in vegetation density from the 1996 image where the vegetation was so dense compared to the 2013 image which shows a decrease in vegetation density. On contrary, the number of households using electricity is increasing while the number of households using firewood is decreasing. Livestock numbers particularly cattle is

still high though reflecting a declining trend from 2009. Sheep and goats which are known to strip the land bare because of their grazing and browsing habits show a relatively steady increase from 2007 (Figure 18d). Therefore, one could conclude that the most likely cause of loss of vegetation density within the area is overgrazing within the catchment.

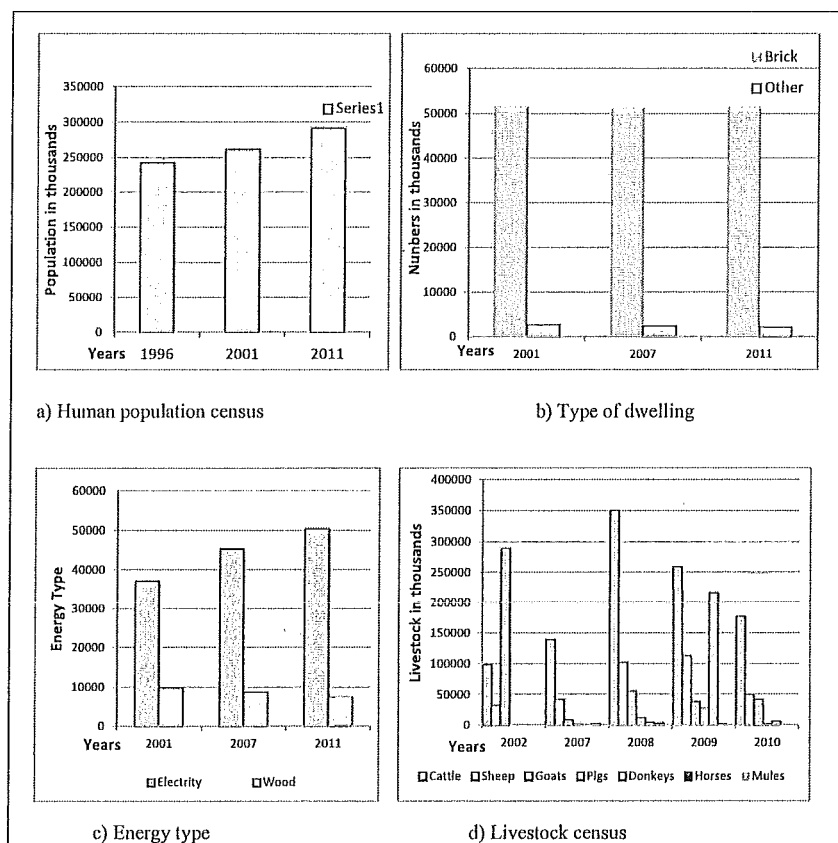


Figure 18 Change in human and livestock population, energy source and dwelling type in Mafikeng Local Municipality

The drivers of change in LULC are often classified into proximate and underlying causes. The proximate causes are the immediate actions of local people such as expansion of cropped areas, wood extraction, infrastructure expansion and others that change the physical state of land cover. The underlying factors push the proximate causes into immediate effect. Such factors include changes in demographic pressure, economic condition and technological and institutional factors.

In the study area, both proximate and underlying driving forces caused the observed changes in vegetation density. At the proximate level, expansion of settlements at the expense of natural vegetative covers such as woodland and grassland has been noted from about 3% in 1989 to over 10% in 2013 (Table 10). This expansion in built up land is likely to have

resulted in removal of tree cover for purposes of clearing land to make way for buildings. The built up area includes urban land in towns like Mafikeng, as well as villages whose housing infrastructure has been improved from traditional mud and thatch houses to brick structures since the 1994 political change in South Africa (Figure 18). After 1994, parts of the UMRCA that were formerly under the Bophutatswana homeland were re-incorporated into South Africa, and government policy thereafter has seen the construction of better dwelling houses in the area, which accounts for the increase in built up land. These houses are now located on separate stands per household, and each stand (plot) is a minimum of 20m x 20m and the stands, therefore, require clearing of vegetation. The increase in number of brick houses, therefore, has contributed to the decline in medium density vegetation near the settlements.

The fact that analysis of vegetation density within 5km of settlements showed a pronounced reduction in medium density vegetation and an increase in low density vegetation suggests that the human settlements are the main source of the disturbance to vegetation density in the area. Several human activities can cause disturbance to vegetation density, for example settlement expansions (which can be indicated by increase in number of residential houses), tree cutting for fuelwood and building construction, growth in human population (resulting in an increase in demand for fuelwood), increase in grazing and browsing intensity (which can be indicated by exponential increases in the number of vegetation-consuming livestock – Figure 18) and expansion of farm area. By pairing the human population data (Figure 18a), with the closest year medium density vegetation value (1996 population versus 1996 density, 2007 versus 2005 density, 2011 versus 2013 density), there was a strong and statistically significant negative correlation between human population and medium density vegetation ($r = -0.960$, $P < 0.01$; Appendix 2). In South Africa's rural North West Province, provision of energy from wood, urban expansion and agriculture (overgrazing) are seen as the largest threats in the catchment as all ecosystems have been transformed in some way through human activities (DEAT, 2003). Due to lack of resources, poor people mostly impact on the environment through their struggle for survival by over exploiting the already fragile natural resources for food, medical plants, firewood, building materials and overgrazing on marginal land (World Bank, 2002).

4.18 Summary

A substantial change in vegetation density from 1989 to 2013 has occurred in the area as medium density vegetation has shown a sustained trend of reduction and low density

vegetation a sustained trend of increasing. The results from both climatic data and satellite imagery ascertain that the spatial distributions of vegetation density during different years and seasons in this region are a result of both human intervention and biophysical influences. The decline in vegetation density in the area has occurred mainly within 5km of human settlements, indicating that anthropogenic activities are responsible for the decline in vegetation density. Decline in vegetation density has implications for the loss of biodiversity in both flora and fauna in the study area. The loss of plant biodiversity leads to a decline in ecosystem integrity and loss of plant genetic resources. This, in turn, implies loss of agricultural and pharmaceutical benefits. The next chapter (chapter 5) presents the conclusion and recommendations.

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This final chapter summarizes the main research findings of the study, by highlighting and giving an overview of the significant outcomes emanating from this research. Furthermore, it details the implications of these findings and thus provides suggestions and recommendations for future research to advance sustainable land management and agricultural development in the catchment. The aim of the study was to analyse multi-temporal vegetation density in the upper Molopo river catchment area between 1989 and 2013 using remote sensing techniques. Objectives were to map, identify the causes, and to establish the magnitude of change that has taken place over the years.

5.1.1 Conclusions from image interpretation and classification

Results from this study have shown that in the Upper Molopo River Catchment, there has been extensive clearance of natural vegetation cover giving way for settlements, open grassland and cropland areas. Thus, the area is more vulnerable to increased soil erosion over time. This study confirms that in South Africa, the unsustainable use of natural resources for rural livelihood and overgrazing has led to serious vegetation degradation. The research has shown a direct practical application of remote sensing for up-scaling traditional vegetation assessment methods. The findings revealed a substantial change in vegetation density; the major change taking place in the communal areas compared to privately owned areas. Woodland decreased by 8% while grassland which constituted about 32% in 1989 decreased to 0.9 % by 2013 which is almost an overall total areal loss of 31%. This evidence supports the first research hypothesis which stated that anthropogenic activities have caused a reduction in vegetation density in the upper Molopo river catchment area in the long-term. Results depicted significant negative correlation between human population and area of cover by medium vegetation density ($r = -0.960$, $P < 0.01$), implying that as human population increases, the medium vegetation density declines in area of cover. Increasing demographic pressure and associated demands on environmental resources, wide spread rural poverty and inadequate management of communal property resources owing to poorly defined ownership arrangements contribute to loss of vegetation density. This change is likely to continue and has negative environmental implications such as loss of biodiversity and complexity, alterations in surface runoff dynamics and lowering of groundwater tables, soil erosion and

disturbance in local climatic conditions as already indicated in the implications. These have the potential to affect significantly local food security and rural livelihood systems. There is therefore a need for short term and long term strategies to ensure sustainable land management and agricultural development in the catchment.

5.1.2 Conclusions on rainfall variability and anthropogenic activities

The findings of the study do not support the second research hypothesis which stated that long-term reduction in rainfall has caused a reduction in vegetation density in the upper Molopo river catchment area. The predominantly Acacia species woody vegetation of the area is adapted to aridity and is, therefore, unlikely to have died out as a result of drought experienced in the mid-1980s. In addition, a comparison of the winter images (1989 and 2013) and the summer images (1996 and 2005) indicate the drier western areas assuming a medium density while the wetter eastern areas assume a low density. This explains that the drier western parts of the study area have adapted to dry conditions and therefore vegetation vigour does not depend on seasonal rainfall ($r = -0.36$; $P < 0.01$). Vegetation activity in the south east of the UMRCA and along the Molopo River is high because of availability of water along the river and because of the generally higher rainfall received in the eastern sector.

In general, remote sensing techniques can identify areas with low, medium and high vegetation densities and some land cover classes in the area. Remote sensing techniques are also capable of mapping and quantifying vegetation density in dry and semi-arid areas like the North West Province of South Africa where droughts are common. The impacts of such drought episodes on vegetation can potentially be mapped and quantified using medium spatial resolution satellite images.

5.2 Recommendations

Change in vegetation density can affect the catchment's water balance by influencing soil moisture through canopy interception and transpiration. Change of water balance can also have an effect on the vegetation cover. This interaction and feedback between water balance and vegetation cover are difficult to diagnose and quantify, which therefore calls for the development and use of catchment Eco hydrological models that couple hydrologic processes and vegetation dynamics. Thus, effective management of water resources in arid and semi-

arid environments requires awareness of the interdependencies of hydrologic, biogeochemical and ecological processes, and collaboration between ecologists and hydrologists.

The season of imaging is an important factor that should be considered in future related studies as it is very important for both biodiversity studies (e.g. biomass prediction) as well as environmental monitoring studies (e.g. environmental change modelling). A quantitative evaluation and understanding of vegetation density has practical significance for land resource management, as it has multiple environmental implications ranging from local to global scales.

Future related research should consider the use of higher spatial resolution imagery of less than 30m resolution to enable better change detection in vegetation density analysis. Use of multi-temporal hyperspectral images will enable change detection of vegetation involving change from more palatable to less palatable species. This should be accomplished by undertaking field work using spectroradiometers to collect spectral signatures of the palatable species concurrently with the image acquisition time to make the ground truthing more useful.

A range of factors which were not investigated in this study due to time and financial constraints, such as fire frequency and intensity, herbivore numbers and soil fertility should be included as part of future related work, as these factors induce heterogeneity in vegetation composition over space and time. This will enable verification of whether soil types and rainfall variability are responsible for the differences in vegetation vigour as well as the differences in NDVI values.

Grazing intensity in UMRCA should also be studied at length as it has been shown to affect hydrologic condition and vegetation density of watersheds in some studies conducted in South Africa (Allsopp et al., 2007). For example, trampling by heavy grazing tends to increase sediment production and deposition, decrease water infiltration rate, increase soil bulk density, and increase the susceptibility of soil to erosion by floods and wind (Allsopp et al., 2007). Grazing intensity was however not conducted as part of this research but is a very important anthropogenic factor affecting vegetation density and, therefore, future studies should analyse it in detail.

Land cover maps can provide information as indicators of the overall management of the catchment area and direction of change in vegetation density over space and time.

Environmental parameters may be used as hints to plan the restoration of the catchment's vegetation and to support strategic decisions for conservation and development policy.

Conceivably, these results have important policy implications for the government to help its dry area farmers adapt to the pressures of climate. There is a need for short term and long term strategies to ensure sustainable land management in the catchment area, and in order to preserve vegetation density and biodiversity in their natural state as the structure and distribution of vegetation are critical components in the function of watersheds that provide many important ecosystem services in the arid regions of the world.

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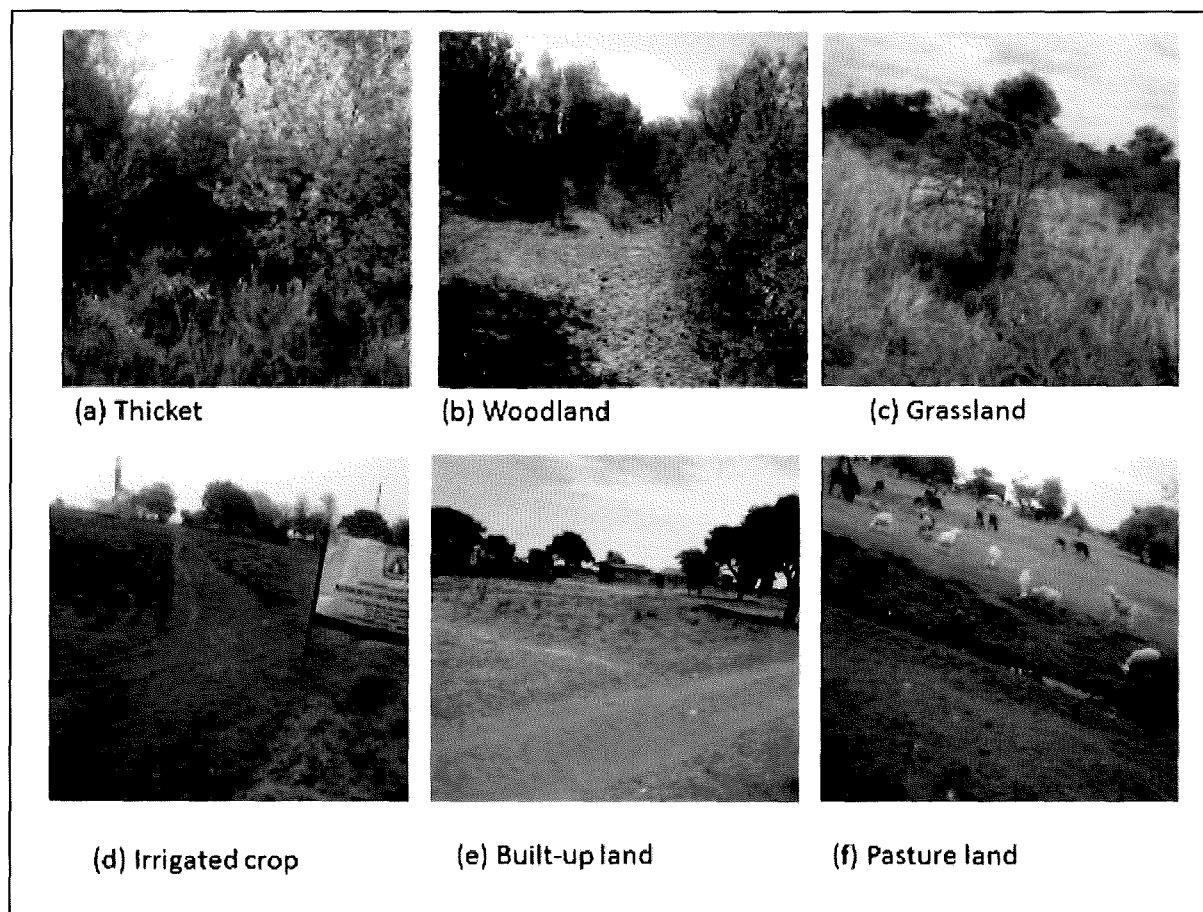
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Appendix 1 Field photos showing selected land cover categories



Appendix 2 Correlation Analysis Details

Variables

Human population in Mafikeng Local Municipality *versus* area of medium density vegetation in Upper Molopo River Catchment Area.

Statistical Hypotheses

Null hypothesis (H_0): there is no significant correlation between human population and area of cover by medium density vegetation.

Alternative hypothesis (H_1): there is a significant correlation between human population and area of cover by medium density vegetation.

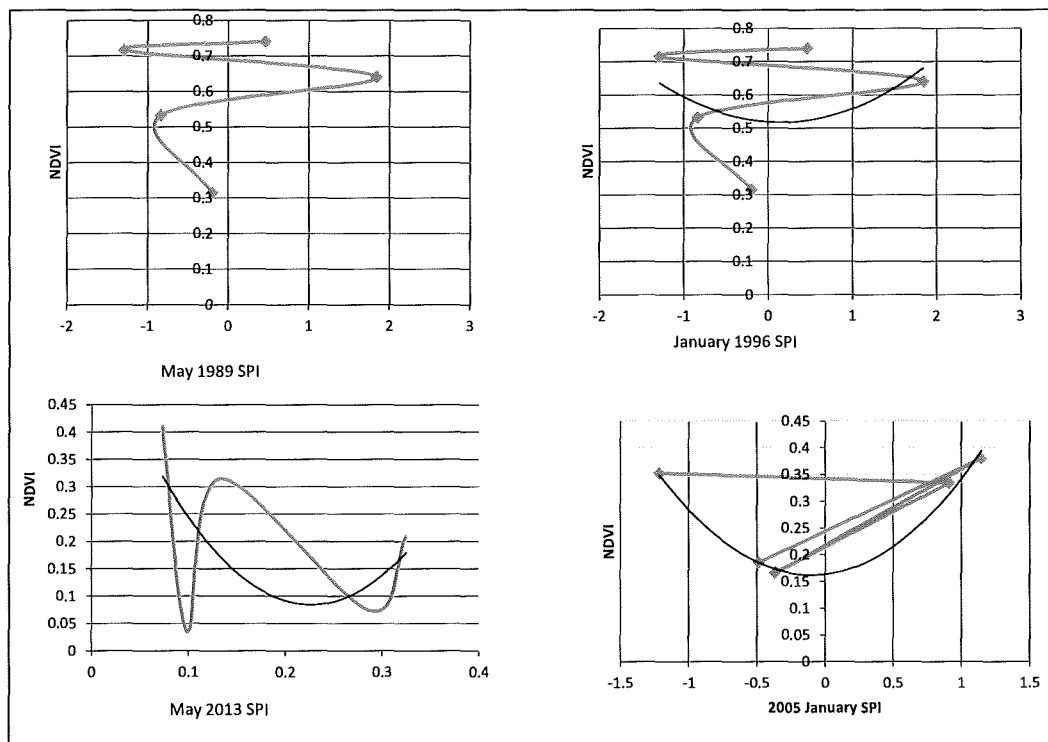
Correlation Coefficient, Probability and Significance

Product Moment correlation coefficient (r) = -0.960.

Probability < 0.01 (i.e. $P < 0.01$), highly significant.

Therefore, H_0 is rejected and H_1 accepted; conclude that there is a significant negative correlation between human population and area of cover by medium density vegetation (i.e. as human population increases in the Mafikeng Local Municipality, medium density vegetation declines in area of cover).

Appendix 3 SPI- NDVI Correlation analyses for summer (1996, 2005) and autumn –winter (1989-2013)



Appendix 4 A Comparative illustration of rainfall prior to image acquisition dates

