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NOORDWES-UNIVERSITEIT
MAFIKENG CAMPUS

EVALUATING USE OF SATELLITE IMAGERY IN MAPPING DIFFERENCES IN GEOLOGICAL FERTILITY IN THE MAHIKENG –RAMOTSHERE MOILOA LOCAL MUNICIPALITIES BASED ON VEGETATION COVER

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

by

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SOLEMN DECLARATION

I, Flora Majunia Makgale, declare that this thesis which I hereby submit to the North West University as completion of the requirements set for the Master's degree in Geography is my own work and has not already been submitted to any university. Further, I declare that I have duly acknowledged all my sources of information.

SIGNED: ____________________

Flora Majunia Makgale

DATE: 19/09/2014

DEDICATION

I dedicate this research to my dear God for the divine enablement upon the completion. It's not by might nor by power, but by the Spirit of the living God.

ACKNOWLEDGEMENTS

I would like to acknowledge North West University, Mafikeng Campus, Department of Geography and Environmental Sciences by giving me the opportunity to pursue this research under its directive. Most importantly, I would like to express my sincere gratitude to my Supervisor Prof C. Munyati who was willingly assisting and stewarding for long difficult hours both in the office and in the field to make this study a success. His remarkable mentoring and encouraging spirit will remain a permanent mark to this achievement.

This research would not have been possible without the support of family and friends. I express sincere thanks to my wonderful children, Olorato and Ontlotlile Makgale who, through thick and thin, were able to endure long hours of my absence at home at the time of this study. Mr and Mrs Ngambi are cherished for always being there and assisting my children with homework. Great appreciation to the Mohale and Makgale families for their support during stormy and glorious days, especially my brother Tlalinyane Mohale for the manhood role that he played during the difficult times, to my Pastor, Moses Tlalang for a word of encouragement and all the individuals and organizations which impacted positively towards the success of this work, I want to thank you from the bottom of my heart.

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Last but not least, I want to acknowledge the great influence that my late husband, David Sediba Makgale made in my life. His footprints shall not fade.

ABSTRACT

In rural, predominantly communal areas of South Africa, historical factors have left a need for poverty alleviation that includes planning development through municipal spatial development frameworks. Mahikeng and Ramotshere-Moiloa Local Municipalities in the North West Province of South Africa are predominantly rural, and in need of development planning. Remote sensing can help provide data in support of the planning of development. This research aimed at establishing the extent to which differences in geological fertility can be delineated on satellite imagery, using the high spatial resolution (10m) SPOT 5 HRG and lower spatial resolution (250m) MODIS imagery as test case.

March-April 2012 SPOT HRG images covering the Mahikeng and Ramotshere-Moiloa Local Municipalities were obtained from the South African National Space Agency (SANSA). Sections of twelve SPOT HRG image scenes were required to cover the two local municipalities, which presented problems in obtaining same date images due to cloud cover problems. A same period MODIS 16-day (21 March – 06 April 2012) NDVI composite image (MOD13Q1) was obtained from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) in the USA. Rain season images were, therefore, utilised. The rain season was selected based on the fact that the rain season is the time when the vegetation (grass and trees inclusive) is at highest productivity and, therefore, differences in spectral response of the vegetation was judged to be most likely to manifest then. The images were projected to the Universal Transverse Mercator (UTM) projection and subset to extract the area covered by the two municipalities. A geological fertility map of the area was extracted from the 1:1 million geology map of South Africa. Vegetation cover on the images was enhanced using the Normalized Difference Vegetation Index (NDVI). Field work at 41 sites in protected areas in the study area yielded ground truth training data on vegetation attributes of canopy cover, tree density, tree height ranges, grass cover, and dominant vegetation types.

Field data indicated a weak but statistically significant correlation between geological fertility and canopy closure (r = 0.378, $P < 0.02$), which permitted the use of mapping vegetation density, using on the NDVI, as indicator of geological fertility. Supervised maximum likelihood classification was employed in the process. Using the geological map as reference data, the results showed that the higher resolution SPOT HRG images produced a more accurate classification (overall accuracy 68.3%, $\check{K}$ = 0.63) than the MODIS image (overall

accuracy 48.3%, $\check{K} = 0.39$). It was concluded that geological fertility can be inferred in the area on the basis of tree density, and using this characteristic, that remotely sensed imagery can contribute to agricultural development planning for poverty alleviation.

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LIST OF ACRONYMS

DRDLR	Department of Rural Development and Land Reform
CRDP	Comprehensive Rural Development Programme
GIS	Geographic Information System
GPS	Global Positioning System
HRG	High Resolution Geometric
SDF	Spatial Development Framework
MODIS	MODerate Resolution Imaging Spectrometer
NDVI	Normalized Difference Vegetation Index
SPOT	*Systemé **P**our l'**O**bservation de la **T**erre*

Chapter 1

INTRODUCTION

1.1 General Introduction

This research investigated the influence of geology on vegetation assemblages, particularly whether this influence can be delineated on satellite imagery in the Mahikeng and Ramotshere Moiloa Local Municipalities of Ngaka Modiri Molema District Municipality. Mahikeng and Ramotshere Moiloa Local Municipalities are located in the North West Province of South Africa (Figure 1.1).

Remote sensing has become a powerful tool for investigations in geology, geophysics, mineral resources and water supply all over Africa and world-wide (Frei et al., 2006). Pena & Abdelsalam (2005) highlighted that the advances made in the past 30 years in improving the system characteristics of orbital optical multi-spectral remote sensing data made an effective approach for lithological mapping. Lithological information can be deduced from a number of parameters such as general geological setting, soil, vegetation, landforms, drainage, structural features and spectral characters observed in remote sensing images (Gupta, 1991). Gupta (1991) further indicated that differences in lithological units maybe obvious on black and white photographs and images, false colour composites and colour infrared photographs. As such, one approach for the identification of geological formations over vast regions is the use of remote sensing data (Pena & Abdelsalam, 2005).

According to Jensen (2007), knowledge about vegetation community and species distribution patterns, alterations in vegetation phenology cycles and modifications in the plant physiology and morphology provide valuable insight into the geologic and physiographic characteristics of an area. Comparing remote sensing images of regions with reliable geological maps to those that have not been previously mapped can help in extending geological mapping beyond the local regions (Pena & Abdelsalam, 2005). Therefore, this research looked at how vegetation assemblages (i.e. woodland and grass, excluding crops) manifest in various substrates (which are related to underlying geology) in the Mahikeng-Ramotshere Moiloa Local Municipalities' area, North West Province. Remote sensing and Geographic Information Systems (GIS) were used as tools for investigation during the study.

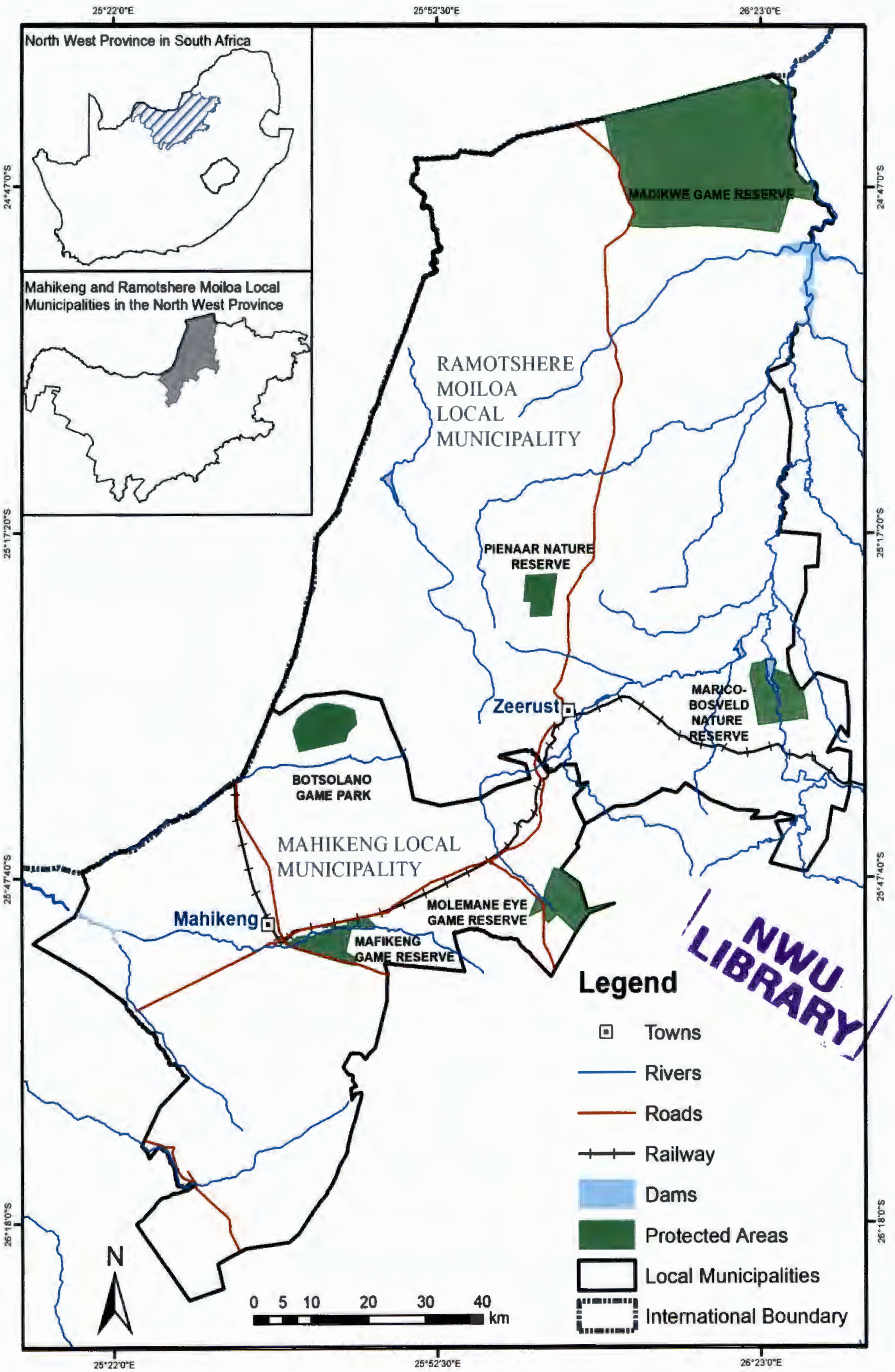


Figure 1.1 Location of Mahikeng and Ramotshere Moiloa Local Municipalities in the North West Province in South Africa.

1.2 Scope of the Study

1.2.1 Problem Statement

Mahikeng and Ramotshere Moiloa form part of the rural and poverty stricken areas in the Ngaka Modiri Molema District Municipality, where most people still depend on the small to medium agricultural activities for basic needs, which may be linked to the Apartheid legacy. Narain et al. (2007) point out that it is widely recognized that poor rural households in developing countries depend to a significant degree on income from local common-pool resources such as forests and grazing lands for their daily livelihoods. Therefore, the President of Republic of South Africa has mandated the Department of Rural Development and Land Reform (DRDLR) (i.e. the former Department of Land Affairs) to embark on the development of Comprehensive Rural Development Programme (CRDP) countrywide (DRDLR, 2012).

There is need for data on the nature and size of land for developmental use by rural people. Surveying large tracts of rural land may be time consuming if done by fieldwork. Therefore, if information on fertility of the land can be derived from satellite images, the process of planning resettlement (e.g. on restituted land) and land use for the rural poor can be expedited. At the time of this study, spatial planning in municipalities in the North West Province lacked the availability of up-to-date spatial data upon which to base spatial planning, particularly the planning of rural agriculture to help to alleviate poverty. This study was initiated to seek a solution to such spatial data needs in municipal spatial planning.

1.2.2 Aim and Objectives

1.2.2.1 Aim

The aim of the research is to establish the extent to which differences in geological fertility can be delineated on satellite imagery, using SPOT 5 HRG and MODIS imagery as test case.

1.2.2.2 Specific Objectives

The specific objectives were:

1. To determine if there is a relationship between vegetation cover and geological fertility on the basis of spectral response of vegetation.

2. To establish whether differences in fertility of the geological substrate in the study area can be differentiated on the basis of vegetation assemblages.
3. To establish the potential role of remote sensing in supporting rural agricultural development planning in the study area based on vegetation cover assessment.

1.2.3 Research Hypothesis

The research hypothesis was that geological fertility influences vegetation community structure sufficiently strongly to manifest through spectral response of the plant communities. According to Munyati & Ratshibvumo (2010), the underlying geology has a strong influence on a vegetation community structure and density and thereby intensity of reflectance in the visible-mid infrared spectral regions, which can be detected by moderately to high spatial resolution sensors detecting electromagnetic radiation with broad spectral resolution in the visible, near and mid infrared spectral regions.

1.3 Importance of the Study

This study can be used to inform the basis of proper agricultural planning, rural resettlement as well as sustainable local economic development and reduction in poverty in the local communities. Aronoff (2005) has indicated that the management of food supplies is critical to the health and well-being of every nation. Cultural factors such as local farming traditions and differences in national political and social systems also affect agricultural productivity (Aronoff, 2005). According to Aronoff (2005) and Munyati & Ratshibvumo (2010), remote sensing has demonstrated potential role in ecosystem assessment.

According to Statistics South Africa (2011), about 54% of the land in Mahikeng Local Municipality (MLM) is farmland while 43% of the land is under Tribal Authorities and in Ramotshere Moiloa Local Municipality (RMLM) about 66% of land is farmland while 31% is under Tribal Authorities. Based on Statistics South Africa data, these two municipalities may be classified as predominantly rural without necessarily looking into population density.

1.4 Definition of Terms

The following terms will have the following meanings throughout out this study:

Geology - The scientific study of the origin of the Earth along with its rocks, minerals, land forms, and life forms, and of the processes that have affected them over the course of the Earth's history (Press et al., 2004).

Lithology - Refers to the fundamental physical and chemical properties of rocks, including for example, the gross distinction between sedimentary, igneous and metamorphic rocks (Campbell and Wynne, 2011).

Geological fertility - The inherent ability of parent material rocks to supply essential plant nutrients through the process of weathering (Palviainen et al., 2012; Dickinson, 2008; Munyati and Ratshibvumo, 2010).

Vegetation - Is an aggregation of plants with mutual interrelationships among each other and with the environment (Campbell and Wynne, 2011).

Rural areas - Rural areas are defined as the sparsely populated areas in which people farm or depend on natural resources, including the villages and small towns that are dispersed through these areas. In addition, they include the large settlements in the former homelands, created by the apartheid removals, which depend for their survival on migratory labour and remittances (RDF, 2007).

Remote Sensing - is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand et al., 2008).

Geographic Information Systems (GIS) - is a software application that runs on a hardware and it is used to capture, store, manipulate, analyze, manage, and present all types of geographical data (Lillesand et al., 2008).

Global Positioning Systems (GPS) - refers to a portable device used for capturing information in the field through receiving sensitive signals transmitted by a network of Earth orbiting satellites. The satellites are positioned in an orbit such that each point on the Earth's surface will be in view of at least four satellites or as many as twelve at given time (Campbell and Wynne, 2011).

Comprehensive Rural Development Programme (CRDP) - is a strategy from the Office of the President to eradicate poverty and meet millennium goals by 2014 (DRDLR, 2011).

1.5 Structure of the Thesis

The thesis has six chapters. Chapter one introduces the study and highlights the main focus as well as key relevant issues. Chapter two gives a description of the study area and its history in brief. It also touches on the climate, geology, topography, hydrology as well as vegetation, settlements and demographics of the area. Chapter three contains a literature review, highlighting relevant previous findings by other researchers that have a relevance to the focus of the study. Chapter four details the research methodology and establishes the relationship between research variables. Chapter five presents the study findings, interpretation of results and discussion. Chapter six outlines the conclusions and recommendations emerging from the study.

Chapter 2

DESCRIPTION OF THE STUDY AREA

2.1 Introduction

This chapter describes the study area. The main characteristics of the area are summarized. Particular emphasis is placed on the physical characteristics of the area as they relate to the vegetation. The chapter also presents a brief historical account of the study area as it relates to land use and spatial planning.

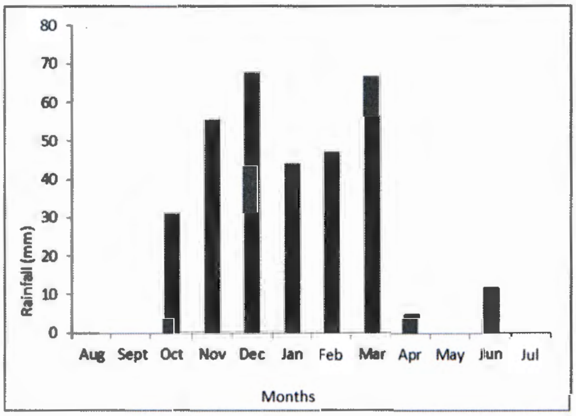
2.2 Location and Brief History of the Study Area

Mahikeng and Ramotshere Moiloa are two adjacent local municipalities located in the northern part of North West Province in South Africa (Figure 1.1) with extents of $3698m^2$ and $7193m^2$, respectively. They are both bordering Botswana, which contributes positively to the socio-economic factors of the area. The socio-economic activities of both Mahikeng and Ramotshere Moiloa Local Municipalities are the legacy of the establishment of the former Bantustans (the black African homelands). Black people were forcefully removed from their homes and resettled in remote infertile land with the intention to segregate black South Africans from whites (Shackleton, 1993). The purpose of the removals was concentrating the members of designated ethnic groups, thus making each of those territories ethnically homogeneous as the basis for creating "autonomous" nation states for South Africa's different black ethnic groups (Shackleton, 1993).

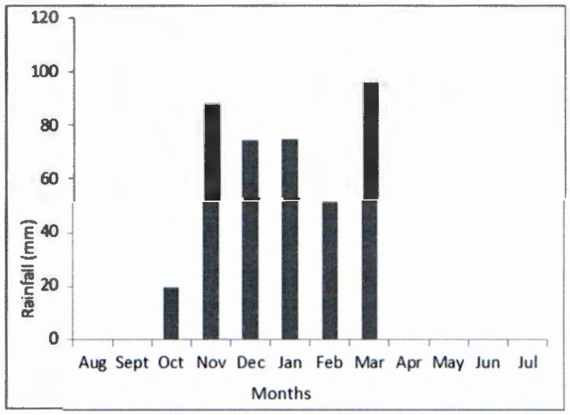
The Bantustans were first introduced in 1940 and Bophuthatswana (within which areas in Mahikeng and Ramotshere Moiloa fall), Transkei, Venda and Ciskei were declared independent while others (like Zululand, Lebowa and Qwa-Qwa) received partial autonomy, but were never given independence (Shackleton, 1993). Bantustans amounted to 13% of the country's land and the remainder was allocated to the white population (Shackleton, 1993). With the demise of the Apartheid regime in South Africa in 1994, the Bantustans were dismantled and their territory reincorporated into the Republic of South Africa (Lahiff, 2008).

2.3 Climate

The area is dominated by semi-arid to arid weather conditions with average rainfall of 500mm to 600mm, whereas some of the areas receive 600mm to 700mm (Mucina and Rutherford, 2006). Figure 2.1 shows monthly rainfall in the study area during the 2011/12 rain season, showing that the peak rain period (rain season) is from October to April. Draught is an ever-present problem in the area, and the rainfall is unpredictable and unreliable, often fluctuating widely around the annual mean (Thomas et al., 2007). Devastating floods occasionally follow severe droughts, which undermines ecological balance (Mucina and Rutherford, 2006).



(a) Mahikeng



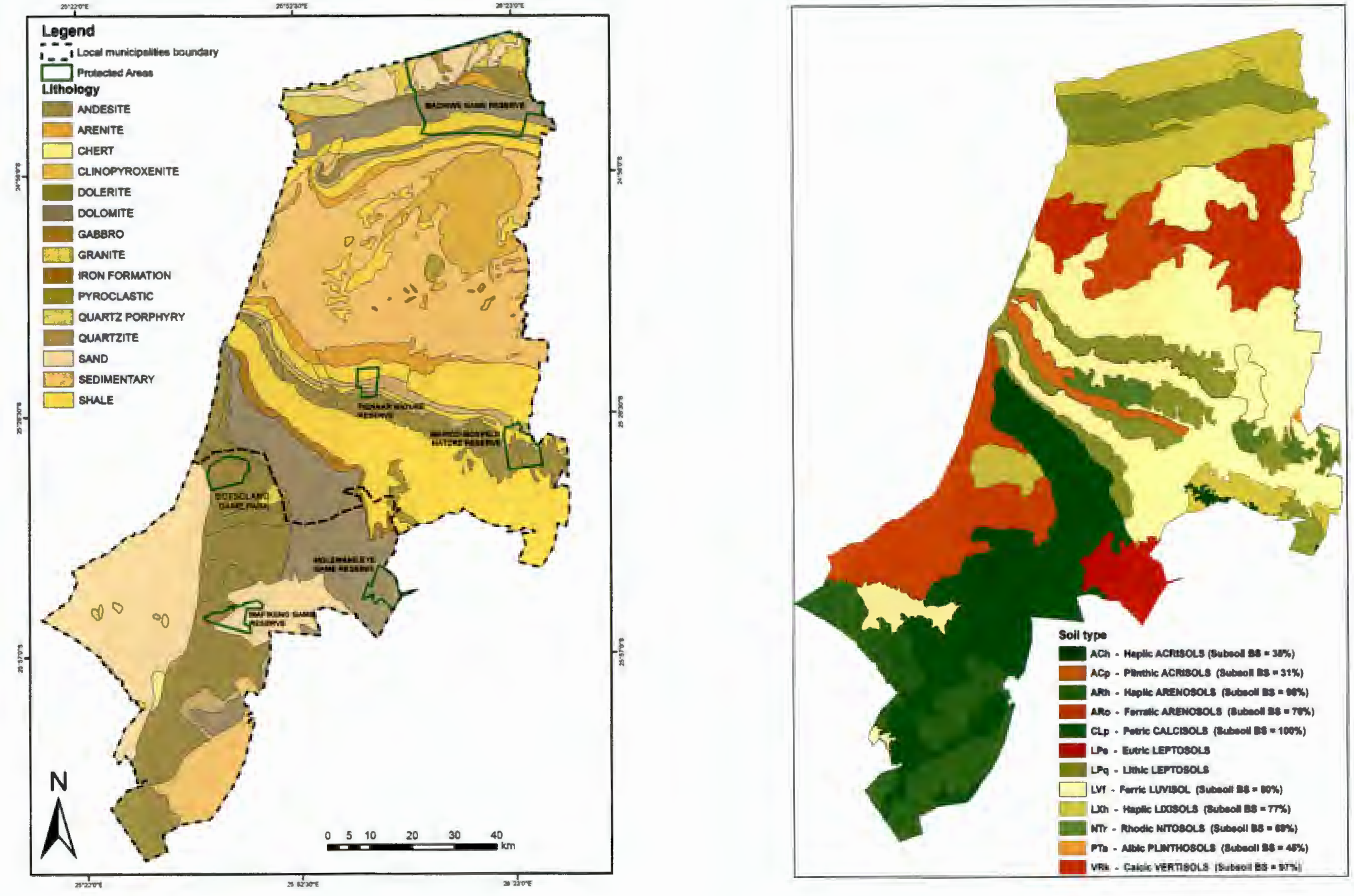
(b) Zeerust

Figure 2.1 Monthly rainfall in the 2011/12 rain season at Mahikeng (a) and Zeerust (b). Data Source: South Africa Weather Services.

2.4 Geology and Soils

There is a variety of rock types in the study area (Figure 2.2a), whose properties are summarised in Table 2.1. As shown in Table 2.1, some of the rocks contain some major elements that are essential as plant nutrients, such as Potassium (K) and Phosphorous (P) that are macro nutrients, and others that are essential to plants, including bases like Magnesium (Mg), Calcium (Ca), Sodium (Na). The Council for Geosciences has classified such rocks as high fertility geology. Rock types of high fertility include shale, gabbro and sedimentary rocks (Table 2.1). There is a close relationship between the geology and soil (Figure 2.2b).

As parent material with differing inherent fertility, these rocks have given rise to the soils in the area (Figures 2.2a, 2.2b). Soil is the weathered material between the atmosphere at the Earth's surface and the bedrock below the surface to a maximum depth of approximately 200 cm (Jensen, 2007; Serbin et al., 2009). Jensen (2007) further indicated that a mature fertile soil is the product of centuries of physical and chemical weathering of rock, combined with the addition of decaying plants and other organic matter. Organic matter adds another macronutrient to soil, this being Nitrogen (N) whose amount is highly variable even within the same soil depending on the presence of organic material (Brady and Weil, 2009).



(a) (b)

Figure 2.2 Rock types (a) and soils (b) in the study area. Sources: (a) Council for Geosciences (Pretoria) 1:1 million geology map of South Africa. See Table 2.1 for a description of the characteristics of the rock types; (b) ARC Institute of Soil, Climate and Water (Pretoria) 1:1 million soils map of South Africa (where BS = Base Saturation).

Table 2.1 Rocks types found in the study area and their properties *.

Rock	Type	Mineral composition	Fertility
Andesite	Igneous	Generally composed of groundmass of pyroxene (augite) and plagioclase, possibly with minor amounts of amphibole (homblende) and glass: phenocrysts of plagioclase and often pyroxene, occasionally olivine or amphibole. Silica (SiO_2) content 52-63%.	Medium
Sedimentary	Sedimentary	Various minerals compacted into rock following sedimentary accumulation processes.	High
Quartzite	Metamorphic	It is principally composed of 95-97% silica (SiO_2), 0.5-1.5% of Iron (Fe_2O_3), 1- 1.5% of Alumina (Al_2O_3), less than 1% of Soda (Na_2O) & Potash (KrO) & less than 0.5% of Lime (CaO), Magnesia (MgO), Loss On Ignition (LOI).	Low
Sand	Sedimentary	It is principally composed of 95-97% silica (SiO_2), 0.5-1.5% of Iron (Fe_2O_3), & Alumina (Al_2O_3), less than 1% of Soda (Na_2O) & Potash (KrO), less than 0.5% of Lime (CaO), Magnesia (MgO), Loss On Ignition (LOI).	Low
Dolomite	Sedimentary	It is a double carbonate of 54.35% Calcium ($CaCO_3$) and 45.65% of Magnesium ($MgCO_3$) ~ $CaMg(CO_3)_2$.	Medium
Iron Formation	Sedimentary	Dominated by the minerals greenalite, minnesotaite and stilpnomelane. Greenalite $[(Fe^{2+}, Mg)_6 Si_4 O_{10} (OH)_8]$ and minnesotaite $[(Fe^{2+}, Mg)_3 Si_4 O_{10} (OH)_2]$ are ferrous analogues of antigorite and talc respectively, while stilpnomelane $[KO_{.6} (Mg, Fe^{2+}, Fe^{3+})_6 Si_8 Al(O, OH)_{27}.2\text{-}4H_2O]$ is a complex phylosilicate.	Low
Shale	Sedimentary	It is composed of flakes of clay minerals and fragments of other minerals – quartz (SiO_2), calcite ($CaCO_3$). Clay minerals: kaolinites ($Al_2Si_2O_5(OH)_4$), montmorillonites (Ca, Na, H)(Al, Mg, Fe, Zn)$_2$(Si, Al)4$O_{10}(OH)_2 - xH_2O$), illites ((K, H)$Al_2(SiAl)_4$O10$(OH)_2 - xH_2O$), chlorites (X4–6Y4O10(OH, O)$_8$; where X = Al, Fe, Li, Mg, M, Ni, Zn or Cr, Y = Al, Si, B, or Fe.	High
Arenite	Sedimentary	Sand clastic rock, various minerals.	Low
Clynopyroxenite	Metamorphic	It falls in a group of pyroxenes and it is typically occupied by Ca^{2+}, but may also be occupied in part by Na^+, Mg^{2+} or Fe^{2+}. The Ca clinopyroxenes are ($CaMgSi_2O_6$) and ($CaFeSi_2O_6$).	High
Gabbro	Igneous	Consists of pyroxene (containing Fe, Mg, Si, O), plagioclase ((Na, Ca)Al1–2Si_3–2O_8), amphibole (containing Fe, Mg, Si, O and hydroxyl (OH)) and olivine ((Mg, Fe)2SiO_4.	High
Quartz Porphyry	Igneous	Consist primarily of quartz (SiO_2).	Low
Granite	Igneous	About 72% quartz (SiO_2), with feldspars – orthoclase ($KAlSi_3O_8$), plagioclase ((Na, Ca)Al1–2Si_3–2O_8)	Low

*Properties information sourced from Press et al., 2004. Rock types present in the area sourced from 1:1 million geology map of South Africa prepared by the Council for Geosciences, Pretoria.

The geology and soils data in Figure 2.2 were mapped at the small scale of 1:1 million. This was the only scale available and primary data could not be obtained in the time of this study. Press et al. (2004) described minerals as building blocks of rocks and are scientifically known as naturally occurring solid crystalline substances, generally inorganic with a specific chemical composition. According to Serbin et al. (2009), the majority of minerals in the Earth's crust are silicate minerals, of which SiO_4^- tetrahedra comprises the major anion. Serbin et al. (2009) further explained that the Carbonate group minerals, such as calcite and dolomite, are the main components of limestone and dolomite rocks, respectively, and comprise the main bedrock components for a large proportion of the Earth's surface. According to Gupta (1991), the geology of an area directly influences soils, landforms, vegetation and habitats.

2.5 Topography and Hydrology

The topography and hydrology of the study area are illustrated in Figure 2.3, in which tightly packed contours indicate steep slopes and widely spaced contours indicate flat land. The land elevation in the area ranges between 900m and 1600m above sea level. Ramotshere Moiloa Local Municipality is characterized by hilly terrain in the south and north east, but relatively flat land in between. The hilly terrain manifests as parallel ridges that run in an east-west direction in the Madikwe Game Reserve region to the north and around Zeerust-Dinokana in the south. In the north, the ridges are of medium fertility dolomite and chert lithology, while in the south they are made up of arenite, andesite, and shale. The highest elevation in the Ramotshere Moiloa is approximately 1600m above sea level. Mahikeng Local Municipality has generally flat topographic features with minimal river network (Figure 2.3) as compared to Ramotshere Moiloa Local Municipality. It is characterized by limestone in the west (including the Mahikeng area) and east, andesite in the middle and sedimentary rock in the south east. A central ridge in the area divides the drainage system into two stream networks(Figure 2.3): one to the south towards the Molopo River and one to the north towards the Limpopo River. The supply of water in the area is through dolomitic eyes.

2.6 Vegetation

The vegetation of the study area (Figures 2.4 and Figure 2.5) is characterized by diversity in height, type and density influenced by underlying geology and topography (Appendix 1). The largest vegetation unit by area of cover is the Dwaalboom Thornveld that dominates the northern half of the study area mainly in Ramotshere-Moiloa Local Municipality. This vegetation unit is located on high fertility sedimentary rocks (compare Figures 2.2 and 2.4). The hill ridges (Figure 2.3) are covered mainly by Madikwe Dolomitic Bushveld and Dwarsberg-Swartruggens Mountain Bushveld that have dense woodland with tall trees (Appendix 1). The other wooded sites in the area are covered by various types of thornveld that typically has scattered thorny tree cover (Appendix 1; Figure 2.5). The grassland areas are largely devoid of trees and covered by a herbaceous layer that consist of grass of various species as summarized in Appendix 1.

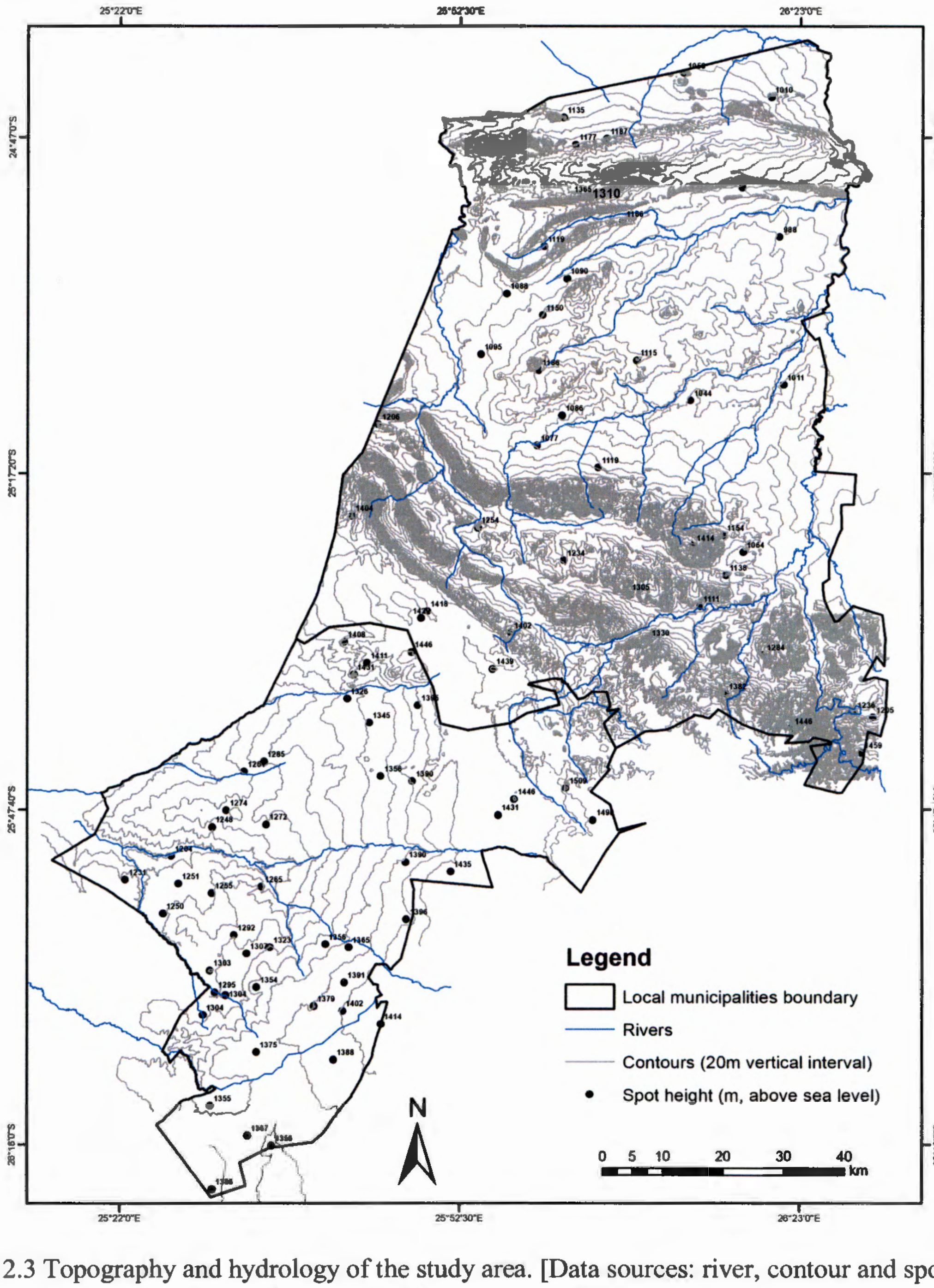


Figure 2.3 Topography and hydrology of the study area. [Data sources: river, contour and spot height data from the National Geo-spatial Information, NGI, Cape Town].

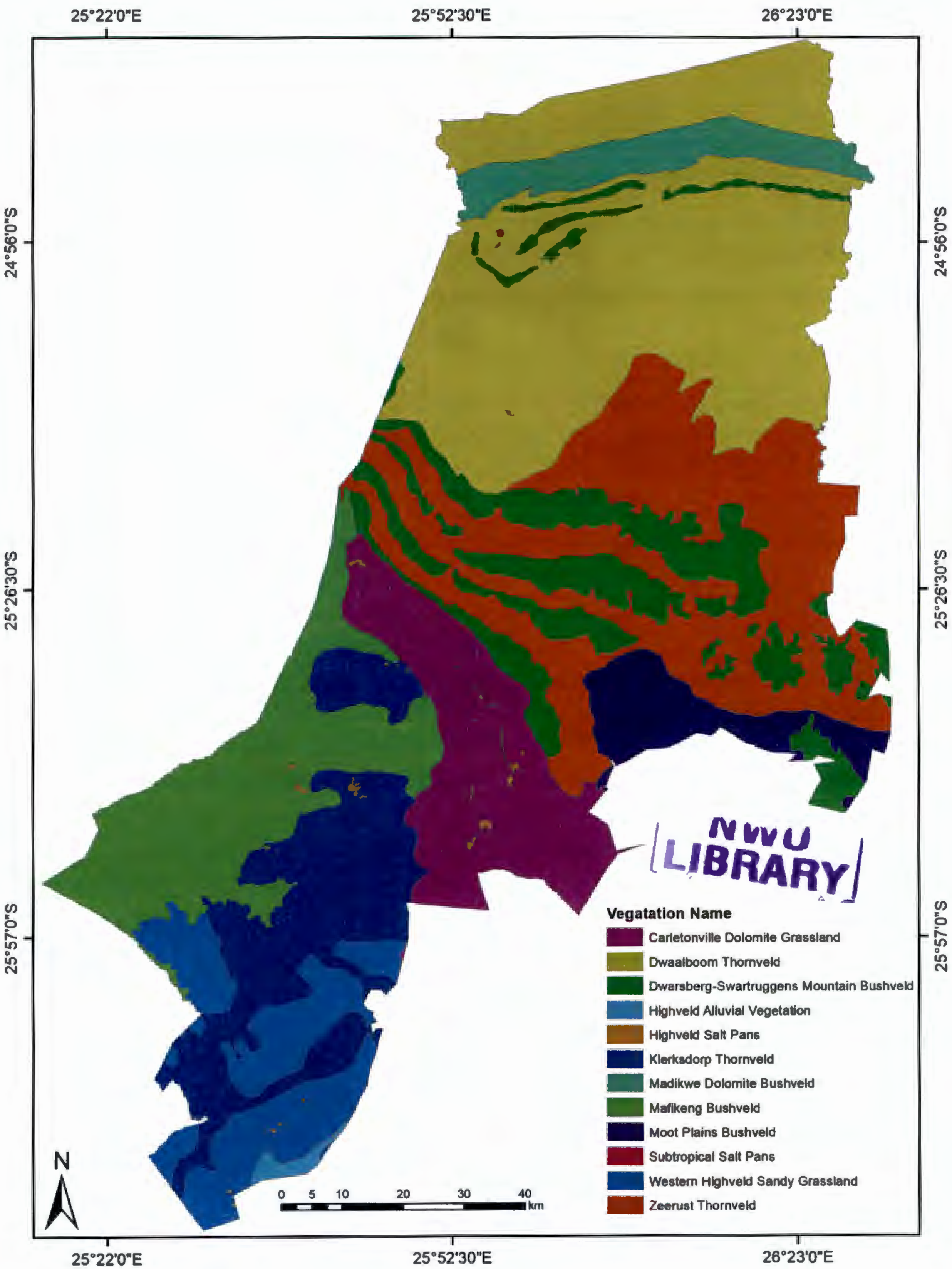


Figure 2.4 Vegetation distribution in the study area. Source: Mucina and Rutherford (2006). See Appendix 1 for a description of the characteristics of the vegetation types.


(a) Dwaalboom Thornveld in Madikwe Game Reserve.


(b) Klerksdorp Thornveld in Mafikeng Game Reserve.


(c) Dwarsberg-Swartruggens Mountain Bushveld in Marico Bushveld Nature Reserve.


(d) Zeerust Thornveld in Pienaar Nature Reserve.


(e) Klerksdorp Thornveld in Botsalano Game Reserve.


(f) Carletonville Dolomitic Grassland at Molemane Eye.

Figure 2.5 Pictorial illustrations of selected vegetation types found in the study area. Photos by author, taken October 2012 to March 2013.

2.7 Settlements and Demography

Mahikeng and Zeerust are the two largest settlements in the study area, and are the administrative seats for Mahikeng Local Municipality and Ramotshere-Moiloa Local Municipality, respectively. Surrounding these towns are small village settlements (Figure 2.6) that are largely a result of resettlements during the Apartheid era. In Ramotshere-Moiloa these villages are concentrated to the west and north of Zeerust (Figure 2.6), in what was Lehurutshe District under the Bophutatswana homeland, while areas east of Zeerest are sparsely settled by village communities because they were part of South Africa during the Apartheid era. The sparsely settled region between Zeerust and Mahikeng is also a legacy of Apartheid. There is a dense concentration of villages that used to be part of Bophuthatswana around Mahikeng, particularly to the west of the town (Figure 2.6).

According to StatsSA (2011), the populations of Mahikeng and Ramotshere Moiloa were 291527 and 150714, respectively, in the 2011 census. Out of these population figures, 7.19% and 8.71 % for Mahikeng and Ramotshere Moiloa, respectively, were the second largest percentages of dwellers in farm squatter camps after the formal structure dwellers found in the yard or farm, which constituted 80.57% and 79.63% respectively (StatsSA, 2011). Table 2.2 summarises some selected demographic and related characteristics of the two local municipalities.

Table 2.2 Summary demographic and related statistics in the study area based on Census 2011.

Attribute	**Mahikeng Local Municipality**	**Ramotshere-Moiloa Local Municipality**
Population	291 527	150 714
Population density (number per km^2)	78.82	71.92
Population breakdown by race:		
Black African	278 282	142 221
Coloured	6 691	1 345
Indian or Asian	2 328	1 096
White	3 770	5 659
Other	457	392
Number of individuals with no income	131 628	62 376
Unemployment rate (%)	36	36
Literacy rate (%)	86.61	76.39

Source: Statistics South Africa (StatsSA).

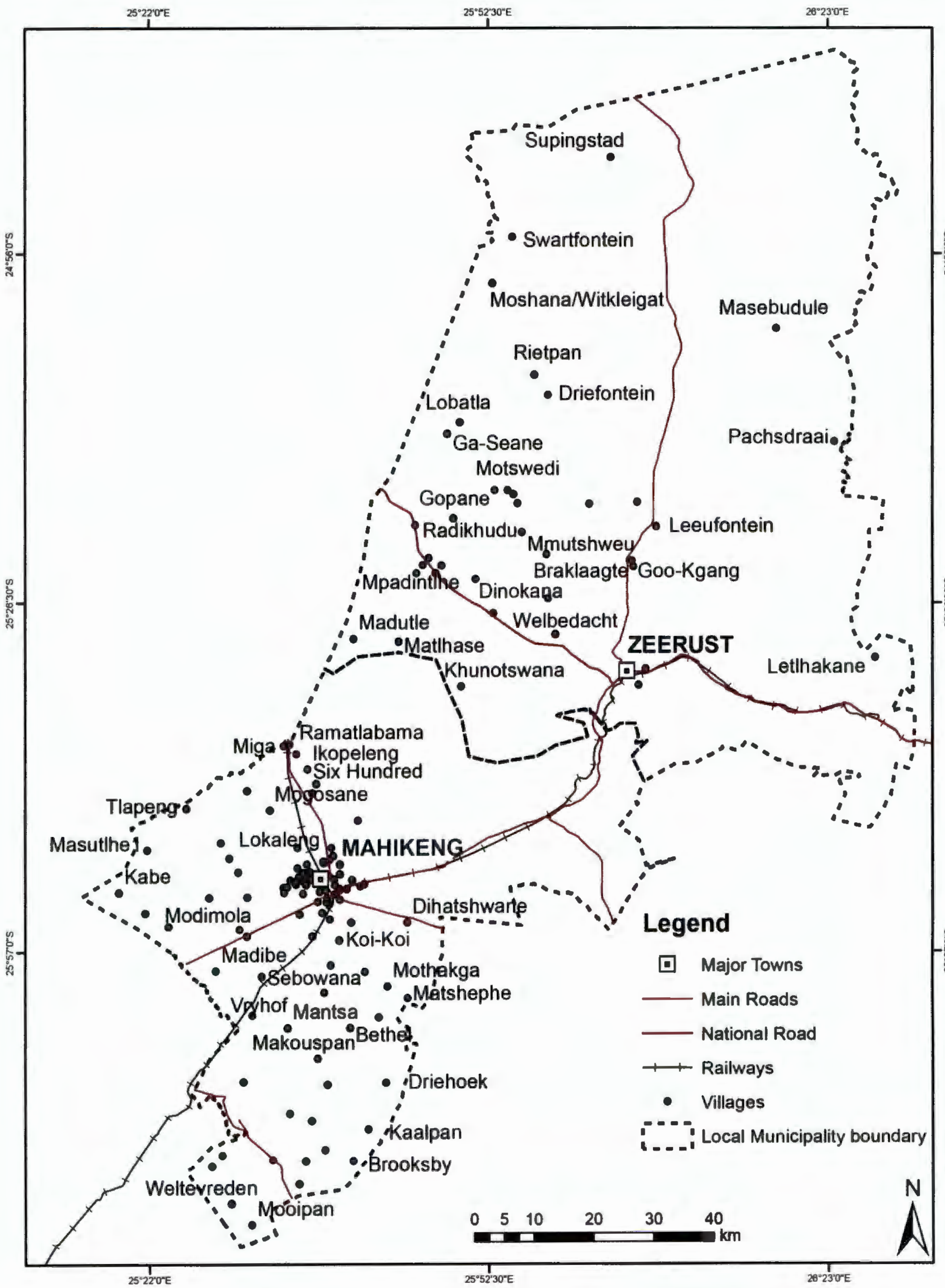


Figure 2.6 Settlements in the study area.

Chapter 3

LITERATURE REVIEW

3.1 Introduction

This chapter reviews material from literature about aspects related to the study and remote sensing methodology. The chapter begins with a summary of the land re-distribution programme in South Africa. It then explores remote sensing methodology related to geology, and highlights some illustrative case studies.

According to Wessels et al. (2007) and Sedano et al. (2005), many 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 (Wessels et al., 2007). Due to environmental, social and economic reasons, ecosystems experience several highly dynamic natural and human driven processes as selective logging, itinerant agriculture, frequent forest fires and fuel wood collection (Sedano et al., 2005). As such, Watkeys et al. (1993) emphasized that future improvements to agriculture and reserves depend upon important geological input both on the environmental side, in order not to interfere with natural long-term changes, as well as on the applied side, particularly concerning the development of an infrastructure. Satellite remote sensing has proven to be a suitable tool to collect spatial data in areas where, due to accessibility and cost constraints, it would be otherwise very difficult (Sedano et al., 2005), in order to inform sustainable development.

3.2 Land Redistribution to the Previously Disadvantaged

Lahiff (2008) pointed out that debate around land reform since 1994 has been dominated by the extent of land redistributed from white to black owners, usually expressed as a proportion of the total area of agricultural land owned by white people at the end of Apartheid. Lahiff (2008) further explained that by March 2007, the land reform programme in all its forms had transferred somewhere in the order of four million hectares, roughly 5% of white-owned land, to historically disadvantaged South Africans. Of this, approximately 45% came from restitution and 55% under various aspects of redistribution, including the Settlement/Land Acquisition Grant (SLAG), Land Reform for Agricultural Development (LRAD), commonage, farm worker equity schemes, state land disposal and tenure reform (Lahiff, 2008). In the AgriTv programme broadcast on the 29 February 2012, the Minister of Rural

Development and Land Reform indicated that up to 95% of the land restitutions has been achieved since 1994.

3.3 Government Strategy in Assisting Previously Disadvantaged Groups in Utilizing the Redistributed Land

DRDLR (2012) elucidated that one of the government initiatives in addressing rural poverty as well as the Apartheid legacy is through Comprehensive Rural Development Programme (CRDP). DRDLR (2012) indicated that the CRDP is focused on enabling rural people to take control of their destiny, with support from government, thereby dealing effectively with rural poverty through the optimal use and management of natural resources. This is through three strategies. Firstly, Agrarian Transformation that includes, but not limited to the establishment and strengthening of rural livelihoods for vibrant local economic development, livestock farming, cropping, etc. Secondly, Rural Development that includes, but not limited to the establishment of milk parlours, dipping tanks, road networks, communication networks, community gardens, irrigation schemes for small scale farmers, etc. and last but not least, Land Reform that includes but not limited to increasing the pace of land redistribution, increasing the rate of land tenure reform, speeding the settlement of land restitution claims (DRDLR, 2012).

Lahiff (2008) pointed out that the aim of combined Land Redistribution and Tenure Reform Programme includes, but not limited to, redistribution of 30% of white-owned agricultural land by 2014 for sustainable agricultural development, provision of long-term tenure security for farm dwellers and other vulnerable groups, contribution to poverty reduction, contribution to economic growth, etc. For example, AgriTv (2012) demonstrated that the North West Provincial Shared Service Centre of the Department of Rural Development and Land Reform has injected capital to the amount of more than R42-million to four broiler farms as part of a recapitalisation strategy. This initiative by the Minister for Rural Development and Land Reform is meant to increase agricultural production, guarantee food security, job creation and graduate small scale farmers to commercial farmers in the agricultural sector.

3.4 The Need for Up-to-date Spatial Data to Inform Proper Planning

According to Campbell and Wynne (2011), modern society depends on land use data for both scientific and administrative purposes due to the fact that they form essential components of local and regional economic planning to ensure that various activities are positioned on the landscape in a rational manner. For example, accurate knowledge of land use pattern permits planning to avoid placing residential housing adjacent to heavy industry or in a floodplain (Campbell and Wynne, 2011) or in an area suitable for agricultural use. According to Mohammed (1981), agriculture development in a true sense denotes the quality of the agricultural system of a region in terms of productivity, diversification and commercialization consistent with the desired state of agrarian relation and ecological balance.

Campbell and Wynne (2011) indicated that soil maps portray distribution of pedologic units, which together with other maps and data convey a comprehensive picture of the physical landscape. As a result, soil maps can be considered to be among the most practical forms of landscape maps and are used by farmers, planners and others who must judge the best locations for specific agricultural activities, for community facilities or construction of buildings and highways (Campbell and Wynne, 2011). Beaumont (1982) pointed out that the use of terrain classification in conjunction with sequential satellite coverage is considered as a basis for establishing, monitoring and subsequently analysing the relationship between development and induced benefits within the rural agricultural development sector and for the establishment of a system of data storage. Beaumont (1982) further explained that the value of a data storage system is evaluated as a means of preventing wasteful repetition of survey effort and facilitating the transfer of relevant data on rural development to similar areas within Benin and throughout West Africa.

Adequate knowledge on crop producing areas allows decision makers to locate populations that are most vulnerable to food insecurity and poverty. Amissah-Arthur and Miller (2002) expressed the importance of integrating data from multiple sources that include socio-economic, climate, weather, agriculture, ecosystem and market data to obtain better information for African decision and policy makers, which maybe a good research example. Despite the technology's capabilities, some of which have been demonstrated in the southern Africa region and elsewhere, routine use of remote sensing in mapping and monitoring changes in habitats and vegetation types has not been adopted fully by conservation agencies, including in developed countries (Munyati & Ratshibvumo, 2010) and the more expensive and time consuming field surveys are still the more common approach (Munyati & Ratshibvumo, 2010).

Land cover information is needed to monitor the impact and effectiveness of management actions associated with sustainable development policies. Natural resource management and environmental monitoring are tightly linked to food security and poverty alleviation strategies in the African countries (Sedano et al., 2005). The lack of reliable and up to date information about natural resources of these countries prevents the formulation, development and monitoring of environmental strategies and policies (Sedano et al., 2005).

3.5 The Influence of Geology on Vegetation Assemblages

Skidmore et al. (2010) explained that the parent material directly influences the chemical and physical properties of the soil which may in turn affect vegetation. The influence of the geology on the vegetation in the Kruger National Park's high and low fertility zones is due to the mineral composition of the parent lithology (Munyati et al., 2013). Skidmore et al. (2010) pointed out that at a local level other environmental factors are important in determining vegetation patterns, e.g. soil profile depth, water availability and nutrient availability.

Vegetation (i.e. trees, shrubs and grass) attains its maximum above ground biomass during wet season in South African savannas (Skidmore et al., 2010). In the absence of other perturbations, vegetation differences as influenced by geological fertility factors can be best manifested in the rain season and mapping them by remote sensing was deemed best performed in this season (Munyati et al., 2013). Fire, insects and diseases are among the major natural disturbances that alter forested landscapes (Aronoff, 2005). Insects' damage causes changes in morphological and physiological characteristics of trees, which affects their appearance on remotely sensed imagery (Aronoff, 2005). Skidmore et al. (2010) stressed that fire is a key factor influencing vegetation in the savannas, causing reduced plant biomass, accelerated nitrogen mineralization and increase in post-fire growth. In addition, if the grazing pressure is heavy, then the vegetation will become sparser and much more open ground will result (Simmons, 1989). By mapping the distribution of foliar biochemicals from remotely sensed images, patterns emerge which may be linked to and allow us to understand dominant drivers of vegetation patterns (Skidmore et al., 2010). For example, climate variables (including temperature and precipitation) are known to affect vegetation at continental and regional scales, but climatic factors show much lower variation over a few kilometers (with the exception of mountainous areas) (Skidmore et al., 2010).

3.6 Remote Sensing in Mapping Land Use and Land Cover

According to Thompson (1996) there has been a lack of a standard approach to classification of remotely sensed images in South Africa, with researchers using their own various land cover/land use classes. Therefore, Thompson (1996) devised a land cover/land use classification scheme for remotely sensed data in South Africa, which appeared to have been derived based on the USGS system in Lillesand et al. (2008). According to Thompson (1996), any land cover standard classification system for South Africa should satisfy the following criteria:

- The classification should be broad enough so that it can meet the needs of a wide variety of users.
- The prior classification should be independent of the area to be mapped, the data and the mapping techniques that are used.

Thompson's classification scheme is divided into three hierarchical levels (Table 3.1):

- *Level I* - with 12 broad land cover types that can be identified off high resolution satellite imagery such as Landsat TM and SPOT without the use of ancillary data.
- *Level II* - with 23 subclasses that can be identified from remote sensing data without the use of ancillary data if the data format is suitable.
- *Level III* - which is flexible, defines subcategories developed by individual planners.

Thompson's classification scheme is scale independent although the expected operating range is envisaged to be at scale between 1: 50 000 and 1: 250 000, based on typical Landsat and SPOT application (Thompson, 1996).

3.7 Image Classification

Lillesand et al. (2008) described image classification as a procedure for automatically categorizing all pixels in an image into land cover classes or themes. Normally, multispectral data are used to perform the classification and the spectral pattern present within the data for each pixel is used as the numerical basis for categorization (Lillesand et al., 2008). Information classes are for example, the different kinds of geology, different kinds of forest or different kinds of land use that convey information to planners, managers, administrators or scientists who use information derived from remotely sensed data (Campbell & Wynne, 2011). According to Campbell and Wynne (2011), a classifier refers to a computer programme that implements a specific procedure for image classification. Over the years, scientists have devised many classification strategies. However, the analyst must select a classification procedure that will best accomplish a specific task.

Table 3.1 Thompson's proposed standard Land cover classification classes for use with remotely sensed data in South Africa.

Level I	**Level II**
Forest and Woodland	Forest Woodland Wooded grassland
Thicket, bush land, scrub, forest and high fynbos	Thicket Scrub forest Bush land Bush clumps
Shrubland and low fynbons	High health land (high fynbos) Shrub land Low fynbons (health land)
Herbland	
Grassland	Unimproved grassland Improved grassland
Forest plantation	Pine species Eucalyptus species Wattle/other species Indigenous species
Water bodies	
Barren lands	Bare rock / soil Degraded land
Cultivated land	Permanent crops Temporary crops
Urban/built up land	Residential Commercial Industrial/ transport
Mines and quarries	

Source: Thompson (1996).

3.7.1 Supervised Classification

Supervised classification can be defined as the process of using samples of known identity to classify pixels of unknown identity (Lillesand et al., 2008). Samples of known identity are the pixels located within training areas or training field (Lillesand et al., 2008).

3.7.1.1 Advantages of Supervised Classification

Campbell & Wynne (2011) listed the advantages of supervised classification as follows:

- The analyst has a control of a selected menu of informational categories tailored to a specific purpose and geographic location.
- Supervised classification is tied to specific areas of known identity, determined through the process of selecting training sites.
- The analyst using supervised classification is not faced with the problem of matching spectral categories on the final map with informational categories of interest.
- The operator may be able to detect serious errors in classification by examining training data to determine whether they have been correctly classified by the procedure.

3.7.1.2 Disadvantages of Supervised Classification

Campbell & Wynne (2011) has highlighted the limitations of supervised classification as follows:

- The analyst imposes a classification structure on the data, and thus may not match the natural classes that exist within the data, and therefore, may not be distinct or well defined in the multidimensional data space.
- Training data are often defined primarily with reference to informational categories and only secondarily with reference to spectral properties.
- Training data selected by the analyst may not be representative of conditions encountered throughout the image.
- Conscientious selection of training data can be a time consuming, expensive and tedious undertaking even if ample resources are at hand.

3.7.2 Unsupervised Classification

Unsupervised classifiers do not use training data as basis for classification, but involve algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the basis of natural groupings or clusters present in the image values (Lillesand et al., 2008).

3.7.2.1 Advantages of Unsupervised Classification

According to Campbell & Wynne (2011), the following are the advantages of unsupervised classification:

- There is no extensive prior knowledge of the region required.
- Opportunity for human error is minimized.
- Unique classes are recognized as distinct units.

2.7.2.2 Disadvantages of Unsupervised Classification

Campbell & Wynne (2011) listed the disadvantages of unsupervised classification as follows:

- Unsupervised classification identifies spectrally homogeneous classes within the data that do not necessarily correspond to the informational categories that are of interest to the analyst.
- The analyst has limited control over the menu of classes and their specific identities.
- Spectral properties of specific informational classes will change over time.

In theory, the combination of Supervised and Unsupervised classification, known as *Hybrid Classification*, is more accurate than either of the two alone (Lillesand et al., 2008). In hybrid classification, Unsupervised classification is employed first to cluster the pixel data into spectral signatures, which are then edited by the analyst through naming of the classes and deleting or merging signatures to improve the classification as appropriate, then a Supervised classification is run to generate the final output (Lillesand et al., 2008). Therefore, the Hybrid classification approach is employed in this study.

3.8 The Role of Remote Sensing in Vegetation Mapping

Campbell and Wynne (2011) indicated that the Earth's vegetation cover was often the first surface encountered by the energy used for remote sensing ,and thus, so far, remote sensing imagery records mainly the character of vegetation at the surface. Therefore, the ability of remote sensors to interpret the Earth's vegetation canopy formed the key to knowledge of other distributions such as geologic and pedologic patterns that were not directly visible but do manifest themselves indirectly through variation in the character and distribution of the vegetation (Campbell and Wynne, 2011).

According to Aronoff (2005), remote sensing analysts use indices calculated from digital multispectral image data. In many drought –prone countries in the sub-Saharan Africa, there is a lack of continuous up to date and reliable information on crop conditions (Aronoff, 2005) and thus, the Global Information and Early Warning System (GIEWS) makes use of remotely sensed data, in particular Normalized Difference Vegetation Index (NDVI) images derived from NOAA/AVHRR and SPOT/VEGETATION sensors to provide seasonal coverage over the large areas (Aronoff, 2005). The globally available satellite images such as the Landsat Thematic Mapper (TM) imagery are widely used in the classification processes with the purpose of generating lithological maps and detecting mineral anomalies, mostly in arid and semi-arid regions (Li et al., 2011). Assessing within field conditions requires high resolution multispectral satellite data Ikonos (4m), OrbView (4m), QuickBird (2.44) or airborne multispectral imagery with fine spatial (Aronoff, 2005).

Chandna et al. (2012) pointed out that based on satellite data, the cultivatable area of a district may be estimated by excluding the estimated areas under settlements, permanent water bodies and crops. Munyati et al. (2013) have indicated that one of the most widely used methods in vegetation type mapping on remotely sensed images is pixel-based image classification. Pixel-based image classification using hard classifiers assigns a pixel to only one class even when the pixel belong to two or more classes on the ground, the result of which is that hard classifiers tend to impose distinct habitat boundaries when in reality zones of intersection between different vegetation types separate the habitats.

A further disadvantage of the traditional hard classifier approaches is that they result in non-homogeneous, 'pixelised' (salt and pepper) vegetation mapping as opposed to solid (homogenous) habitat zones (Munyati et al., 2013). Factors like only moderate spatial resolution of 30m and the low spectral resolution in seven bands only, limit the usefulness and classification accuracy of Landsat TM image data when based solely on spectral bands (Li et al., 2011). Moreover, lithological boundaries are not necessarily distinct and sharp and can be obscured by screen and other deposits (Li et al., 2011). In addition to that, different kinds of rock may show analogous spectral characteristics, resulting in spectral overlap and misclassification.

3.8.1 Vegetation Mapping Examples in Savanna Areas Using Remote Sensing

Below are few examples of savanna vegetation mapping using remote sensing techniques:

1. In their study on land cover assessment with MODIS imagery in Southern African Miombo ecosystems, Sedano et al. (2005) compared the MODIS Global Land Cover Classification Product with recent land use and land cover maps at the national level over a characteristic location of Miombo woodlands in the province of Zambezia, Mozambique. Three different land cover-mapping approaches were applied to the MODIS images: single date maximum likelihood classification, principal component analysis of band-pair difference images, and multitemporal NDVI analysis. Overall accuracy of 85% was obtained. The overall kappa coefficient was used to test the results obtained.

   The results showed that land cover classifications from MODIS images can provide good quality results, with some cases presenting overall kappa coefficient accuracies around 0.89, and individual accuracies over 80% for every single land cover type. The estimation of agriculture land was excellent, with accuracies higher than 95% for almost all the cases analysed. Over 90% grassland accuracies were obtained for the cases of PCA pair differences analyses and over 75% for the cases of multitemporal NDVI analyses when the May image was considered. Wetlands were estimated with accuracies over 80% for single date and multitemporal NDVI analysis when an adequate combination of dates was selected.

2. Tottrup and Rasmussen (2004) mapped long-term changes in savanna crop productivity in Senegal through trend analysis of 20 years' time series of remote sensing data. The objective of this research was to evaluate the capability of a remote sensing method for assessing long-term trends in crop productivity. The study covered two different areas, one with a negative trend and one with a positive trend in crop productivity. In order to achieve the study's objectives, Advanced Very High-Resolution Radiometer (AVHRR) data from the NOAA satellite were used to compute the NDVI of the areas, and Landsat TM and ETM+ imagery of 1999 for individual targeted areas was rectified and automatically classified using supervised classification with the maximum likelihood classification algorithm. Field data and observations were also integrated in the analysis. A post-classification comparison

was then conducted to reveal the most recent changes in land cover in the two study areas.

Although high overall accuracy assessment of 89% and 90% and kappa coefficient of 80% and 85% were respectively obtained, the findings showed that Landsat TM and ETM+ cannot be used on a long-term trend investigation back to 1981 due to its availability. NOAA NDVI imagery (of lower spatial resolution than Landsat TM/ETM+) was deemed to be the best data in obtaining the convenient results for the study. The area with a negative trend in NDVI represented an area that has been exposed to prolonged intensive cultivation. The high cultivation density throughout the area left little room for expansion into new land, and fallow land was encroached upon to increase the area cultivated. The term used to characterize a situation where farming was intensified at the expense of the traditional fallowing system is saturation (Tottrup and Rasmussen, 2004). In a system that relies on fallowing to restore soil fertility, saturation constitutes a step towards soil degradation.

Thus, the negative trend in crop productivity may be interpreted as a sign of soil fertility deterioration (Tottrup and Rasmussen, 2004). The situation is slightly different in the positive trend area. Large areas of natural vegetation still exist in this region, and the positive trend may be seen as a response to the conversion of areas of savanna into new farmland. Although rainfall is important for agricultural production in the positive trend area, the relationship between NDVI and annual rainfall has been shown to be ambiguous. However, it was noteworthy that the regression between NDVI and annual rainfall in the northernmost station was significant ($P < 0.05$). Therefore, the NDVI trend analysis method can be used to investigate broad-scale environmental changes, and serve as a starting point for more detailed studies by pinpointing areas of radical change. Again, this method can also be used to identify areas with positive trends in vegetation development, where detailed studies may provide information and knowledge about factors enabling crop growth (Tottrup and Rasmussen, 2004).

3. In their investigations on Landsat TM image segmentation for delineating geological zone correlated vegetation stratification in the Kruger National Park of South Africa, Munyati et al. (2013), found that image segmentation techniques offer great

possibilities for homogenous habitat classification. The study aimed at establishing the extent to which established, field surveyed and geology-related vegetation types in South Africa's Kruger National Park (KNP) can be reproduced using image segmentation.

Rain season Landsat TM images of 30m resolution covering the study area were acquired and projected to the UTM projection through the widely spread GCPs on the image to keep the Root Mean Square Error (RMSE) to sub-pixel level. The nearest neighbour resampling algorithm within ERDAS was used. The images were selected to coincide with the peak in vegetation productivity, which was deemed best time of year when discrimination between key habitats in KNP was most likely to be successful. Field visits to homogeneous vegetation locations were done during the same rainy season in order to obtain data for image interpretation and vegetation mapping. Image segmentation using eCognition 5.0 was employed for purposes of mapping the vegetation zones encompassed by the image mosaic. Image segmentation was able to approximate the vegetation zones of the park quite accurately. For purposes of comparing the vegetation mapping from image segmentation procedures, a supervised maximum likelihood classification (MLC) of the image was undertaken, using ERDAS Imagine 9.1. From the image segmentation method, high overall classification accuracy of 85% was obtained. However, the MLC was considerably less accurate in mapping the vegetation zones, with an overall accuracy of 37% and an overall Kappa coefficient of 24.2%.

The study by Munyati et al. (2013) indicated that the geology of KNP influences the spectral response of the vegetation to the extent that, through image texture and differing spectral reflectance intensities, the zones can be mapped as different objects using image segmentation techniques. Therefore, from the results of this study, image segmentation seems an appropriate habitat mapping approach for savanna areas. The homogenous habitat maps resulting from an image segmentation approach appeared more useful for purposes of mapping status and extent of the savanna habitats to the conservation manager, despite the inability of image segmentation to map zones of transition between habitats. Image segmentation, therefore, appeared to be a useful method of mapping savanna habitats (Munyati et al., 2013).

4. Skidmore et al. (2010), in their study of forage quality of savannas (simultaneously mapping foliar protein and polyphenols for trees and grass using hyperspectral imagery) proved that other environmental factors such as soil profile depth, water availability and nutrient availability are important in determining vegetation. According to Skidmore et al. (2010), the parent material directly influences the chemical and physical soil properties which may in turn affect vegetation. In general, plants occurring on higher-nutrient soils, such as the basalt, have higher concentrations of leaf nutrients Skidmore et al. (2010). HyMap hyperspectral imagery of 500–2400 nm spectral range, 96 bands, 15 nm bandwidth, 4.2 m spatial resolution was acquired and field data was also obtained. A vegetation classification scheme based on dominant tree species but also related to the park's geology was tested, the geology generally consisting of high and low fertility lithology. When considering the concentration of polyphenols in mopane, there was a significant interaction effect between fire and parent material (F (2, 280) = 13.35, P<0.001). For grass, there was no significant interaction effect between parent material and fire on foliar nitrogen.

3.9 Summary

A review of the literature reveals that:

1. A large percentage of Mahikeng-Ramotshere Moiloa Local Municipalities and the country at large has previously disadvantaged people who are still residing in the far rural or farm areas and depend intensively on natural resources to small and medium scale agricultural activities for their basic needs.

2. The government has come up with an initiative in addressing rural poverty as well as the Apartheid legacy through the Comprehensive Rural Development Programme. The programme is focusing on enabling rural people to take control of their own destiny with the support from the government, thereby dealing effectively with rural poverty through the optimal use and management of natural resources, using the Agrarian Transformation, Rural Development and Land Reform.

3. Remote sensing has become powerful in enabling the modern society of scientists and administrators to make informed decisions since spatial data forms an essential

component of local and regional economic planning to ensure that various activities are positioned on the landscape in a rational manner. The spatial technologies of remote sensing and GIS form the basis of establishment, monitoring and subsequently analyzing the relationship between developments and induced benefits within the rural agricultural development sector.

4. Despite the spatial technology's capabilities, routine use of remote sensing in mapping vegetation to inform agricultural and settlement planning has not been adopted fully by key role players. As a result, the more expensive and time consuming field surveys are still the more common approach.

5. The Normalized Difference Vegetation Index (NDVI) is widely used in mapping savanna vegetation. NDVI trend analysis method can be used to investigate broad-scale environmental changes, and serve as a starting point for more detailed studies by pinpointing areas of radical change. Again, this method can also be used to identify areas with positive trends in vegetation development, where detailed studies may provide information and knowledge about factors enabling crop growth.

6. Land cover information is needed to monitor the impact and effectiveness of management actions associated with sustainable development policies and thus, natural resource management and environmental monitoring are tightly linked to food security and poverty alleviation strategies in the African countries. So, the lack of reliable and up to date information about the natural resources of these countries prevents the formulation, development and monitoring of environmental strategies and policies. Agricultural scientists, resource managers and policy makers require updated information on agricultural land use to address a broad range of issues.

7. Parent material directly influences the chemical and physical properties of the soil which in turn affects vegetation and thus, the influence of the geology on the vegetation in the high and low fertility zones is due to the mineral composition of the parent lithology.

8. Environmental factors are important in determining vegetation patterns, e.g. soil profile depth, water availability and nutrient availability. Land resources are finite and overexploitation is leading to land degradation, declining crop yields and the risk of

food shortages. Fire, insects and diseases are among the major natural disturbances that alter forested landscapes. Insects' damage causes changes in morphological and physiological characteristics of trees, which affects their appearance on remotely sensed imagery.

9. Scientists have devised many image classification strategies, however, the analyst must select a classification procedure that will best accomplish a specific task. Both the supervised and unsupervised classification has advantages and limitations. So, the choice of the classifier is determined by the analyst's objectives.

10. Savanna vegetation mapping using remote sensing has been proved to be successful with relatively high accuracies despite the diverse vegetation formations that range from grassland, shrubs, to woody vegetation, through the use of various classification techniques based on various researchers' specific objectives.

Chapter 4

METHODOLOGY

4.1 Introduction

This chapter presents the methods used in addressing the aim and objectives of the research stated in Section 1.2.2. The methods involved field work as well as laboratory analysis of image data. Products from some of the image processing procedures are presented in so far as they do not constitute results related to the objectives, while the bulk of the results of image processing are left to Chapter 5.

4.2 Design of the Study

The methodological framework of the research is summarized in Figure 4.1. The research used three categories of data. Firstly, ***Systemé Pour l'Observation de la Terre*** (SPOT) and **MODerate** Resolution **I**maging **S**pectrometer (MODIS) satellite images, secondly a digital geological map of the area and thirdly, field data. SPOT images are of higher spatial resolution than MODIS images, but individual SPOT image frames cover smaller swath widths than MODIS images. Given these differing spatial characteristics, images from the two sensors were utilized in order to determine whether high spatial resolution, low swath width images are more suitable in mapping the spectral response of vegetation as influenced by geological fertility, or vice versa, also taking into consideration synoptic coverage of the study area (the two local municipalities) by a given image on a given data. Once-off (i.e. one date only as opposed to a time series) rain season images were utilized in the study. The rain season was selected based on the fact that the rain season is the time when the vegetation (grass and trees inclusive) is at highest productivity and, therefore, differences in spectral response of the vegetation was judged to be most likely to manifest then.

4.3 Image Data

Images at two spatial resolution scales, a 10m resolution SPOT 5 HRG and 250m resolution MODIS were used for the study, as justified in Section 4.2. The spatial and spectral characteristics of these images are summarized in Table 4.1. Rain season image dates were utilized. Other similar studies (e.g. Skidmore et al., 2010; Munyati and Ratshibvumo, 2010; Munyati et al., 2013) have judged rain season images to be the ideal season for mapping the vegetation in the savanna areas since vegetation is at its maximum productivity during then.

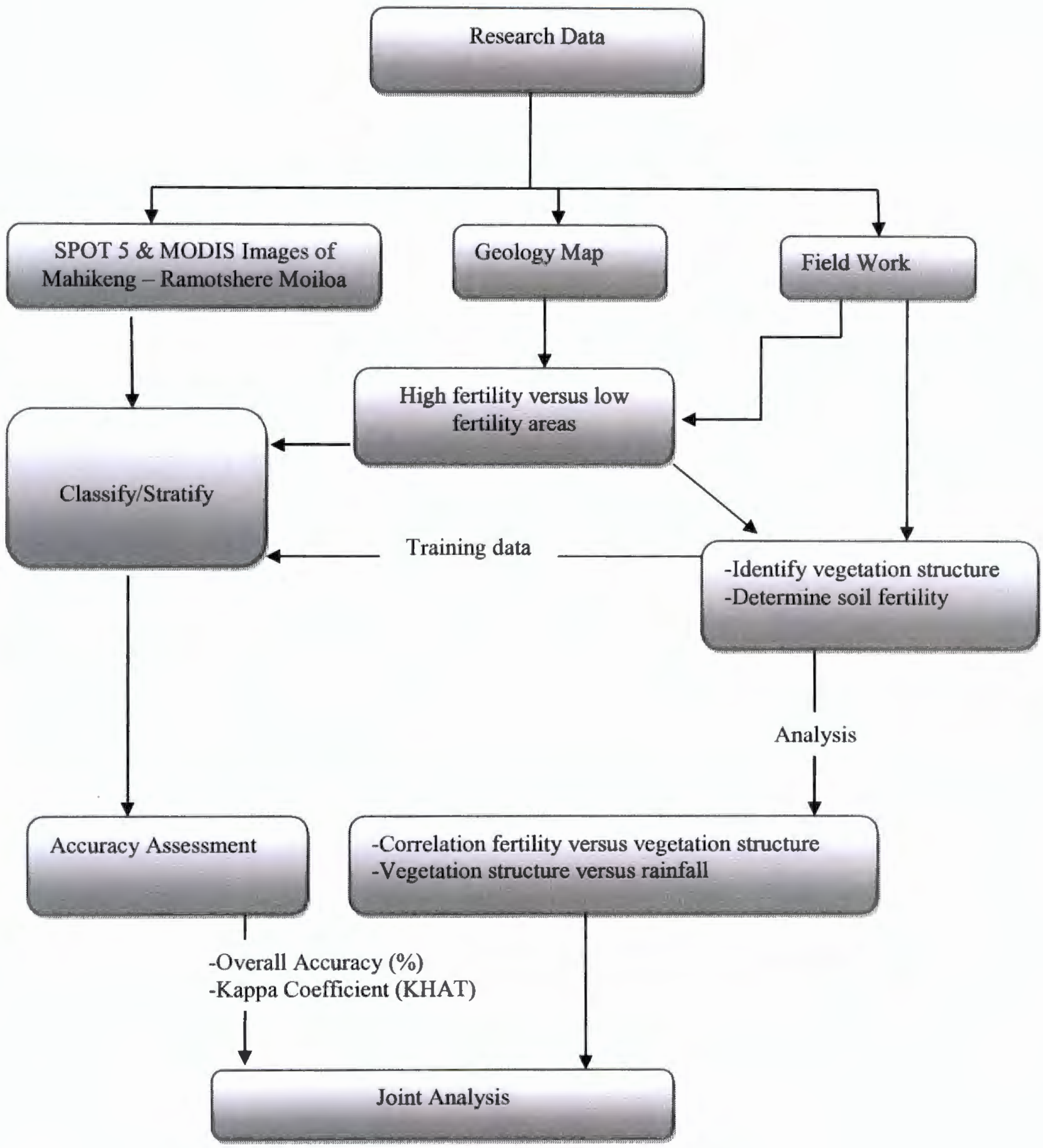


Figure 4.1 Summary of research methodology

Table 4.1 Comparison of spatial and spectral coverage of sensors utilized.

Sensor	Swath width	Spatial resolution	Wavelengths in NDVI computation bands: Red	Wavelengths in NDVI computation bands: Near infrared
SPOT 5 HRG	60 km	10 m	0.61 – 0.68 μm	0.78 – 0.89 μm
MODIS	2 330 km	250 m	0.62 – 0.67 μm	0.841 – 0.876 μm

4.3.1 SPOT Images

Due to the scene swath width of 60 km (Table 4.1), one SPOT image could not cover the study area (the two local municipalities, Mahikeng – Ramotshere Moiloa). Up to thirteen SPOT image scenes were needed to cover the study area, which presented problems in that no date had all 13 adjacent and cloud free SPOT images that were required to cover the entire study area. Therefore, the thirteen adjacent rainy season SPOT 5 High Resolution Geometric (HRG) image scenes that were obtained were not all acquired on the same date (Table 4.2), primarily due to cloud cover constraints. However, all the images were from the same rain season, in March-April 2012. One image was from the date 02 May 2012, because there was no other suitable cloud free image for this section of the study area for the period January-April 2012. The image scenes were selected from the South African National Space Agency (SANSA) catalogue and then ordered from SANSA.

Table 4.2 List of SPOT5 HRG images acquired for the study (see Figure 4.2 for scene coverage).

Date	K/J Reference	Scene ID	Cloud Cover
21 March 2012	127/399	51273991203210829462J	1%
21 March 2012	127/400	51274001203210829552J	1%
21 March 2012	127/401	51274011203210830032J	1%
21 March 2012	127/402	51274021203210829552J	0%
21 March 2012	127/403	51274031204210830202J	3%
01 April 2012	128/399	51283991204010817542J	1%
01 April 2012	128/400	51284001204010818022J	2%
01 April 2012	128/401	51284011204010818112J	6%
01 April 2012	128/402	51284021204010818192J	3%
01 April 2012	128/403	51284031204010818282J	3%
02 May 2012	129/400	51294001205020821002J	0%
11 April 2012	129/401	51294011204110825362J	2%
11 April 2012	128/403	51294021204110825452J	0%

4.3.2 MODIS Images

A 250m-resolution MODIS 16-day (21 March – 06 April 2012) NDVI composite image (MOD13Q1) was obtained. The MOD13 product has previously been shown to match NDVI values computed from ground data more closely than the single-day MODIS NDVI product (Cheng 2006) and was, therefore, preferred to the single-day product. The MOD13Q1 image was downloaded from the Oak Ridge National Laboratory Distributed Active Archive Center, ORNL DAAC (ORNL DAAC, 2012). For the download, the scene centre was set near Zeerust (26°6'44.018"E, 25°32'14.606"S) and a rectangular scene approximately 100 km x 100 km was then specified until the entire study site was covered. The MOD13Q1 image was in GeoTIFF format in geographic coordinates, with NDVI values stretched on a signed 32 bit scale. The GeoTIFF format was converted to the ERDAS *.img* format by image import.

4.4 Geology Map

A digital 1:1 million geology map of South Africa prepared by the Council for Geosciences was obtained as base map for analyzing geological fertility. From the map, a shapefile of the study area was used in ArcMap 10.1 to extract (clip) the geology of the study area shown in Figure 2.2.

4.5 Image Pre-Processing

4.5.1 Geometric Processing

It was important to utilize a common map projection for the SPOT 5 HRG and MODIS images that were acquired for the study. Both the SPOT and MODIS images were obtained in an un-projected geographic coordinate system. The SPOT images were in a latitude and longitude coordinate system, while the MODIS images were in decimal degrees. Using ERDAS Imagine 2013 software, the thirteen SPOT 5 image scenes were individually re-projected to the Universal Transverse Mercator (UTM) Zone 35 South WGS84 projection. Ground Control Points (GCP's) that were widely distributed in the image scenes were used in the process. Then the Nearest Neighbor (NN) resampling algorithm was employed, primarily because it does not alter the Digital Number (DN) values during the process of assigning DN values to the rotated image matrix (Lillesand et al., 2008; Jensen, 2005).

The image scenes were then subset using the merged municipalities' boundary shapefile in ERDAS Imagine 2013. Figure 4.2 shows the layout of the SPOT image subsets covering the two municipalities, following the subsetting operation to extract the area from the full scenes listed in Table 4.2. The subsets that were from the same dates were merged into mosaic as shown in Figure 4.3. Images subsets from different dates were not merged into mosaics in order to avoid the modification of the image statistics (Jensen, 2005).

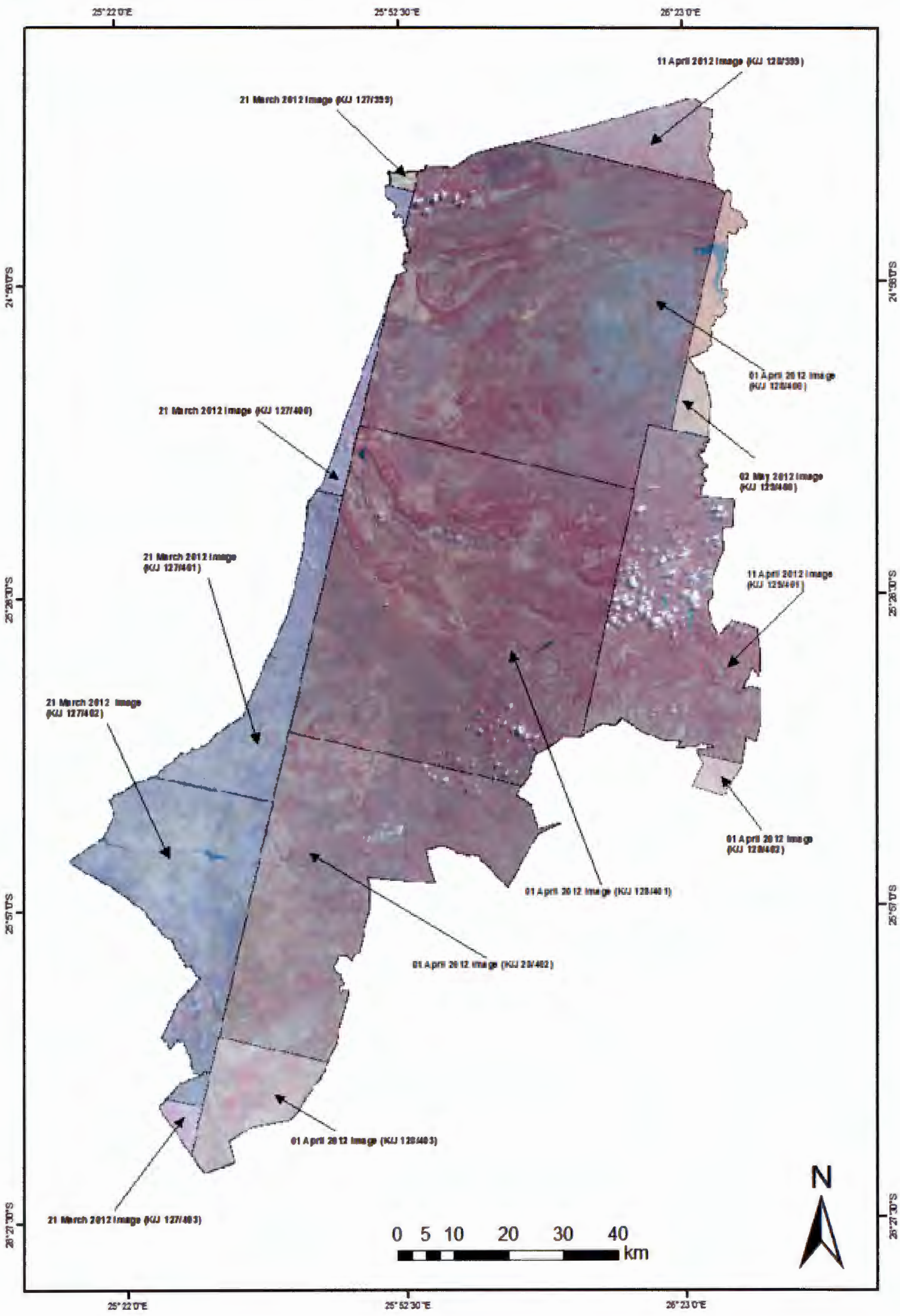


Figure 4.2 Layout of the SPOT image frames covering the study area that were acquired for the study.

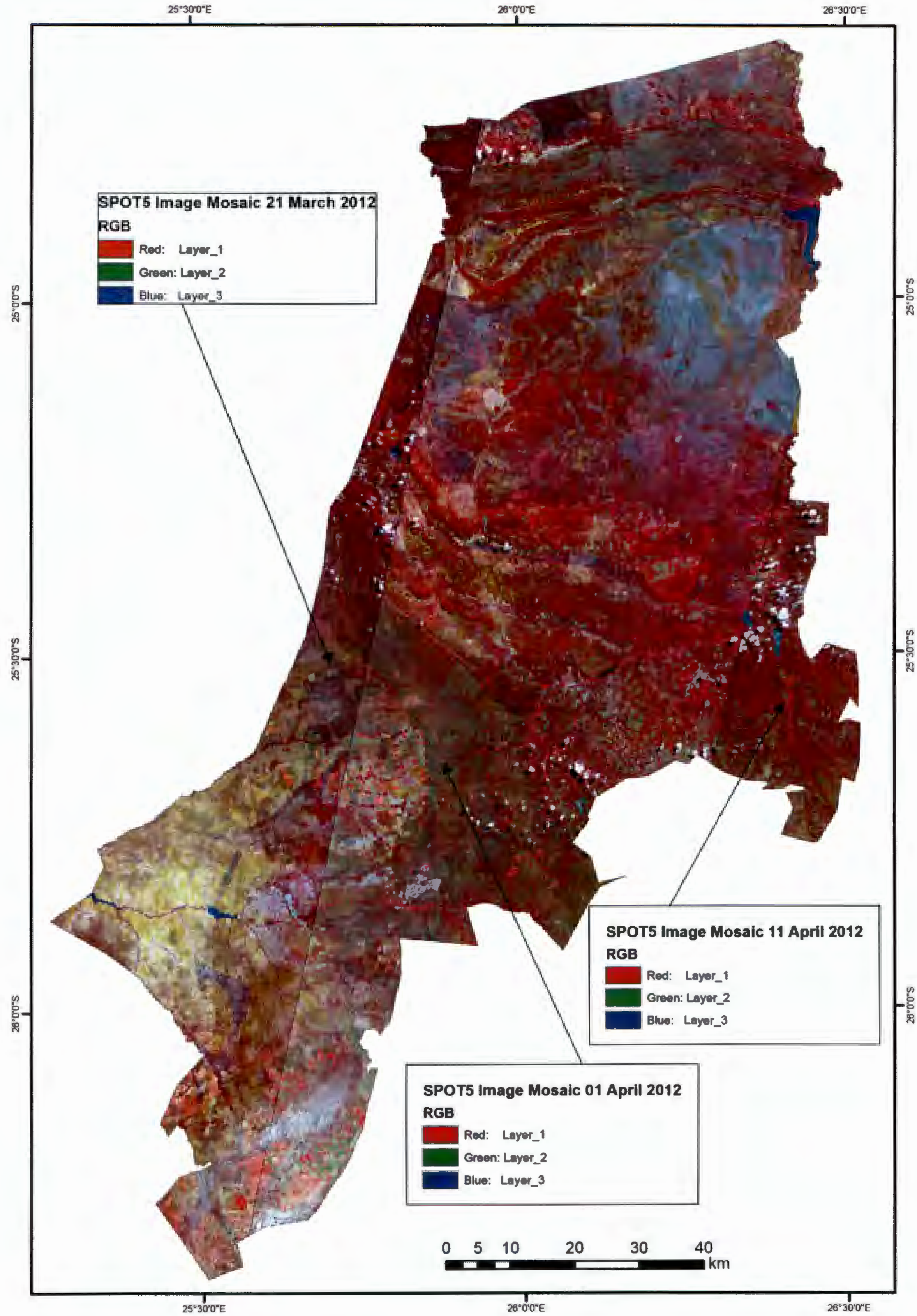


Figure 4.3 A mosaic of the March-April 2012 SPOT images of the study area that were used.

From the mosaic operation for the SPOT image subsets (Figure 4.3), three main image date groups emerged, these being 21 March 2012, 01 April 2012, and 11 April 2012 (the 02 May image covering only a small portion of the area - Figure 4.2 - was excluded). The intermediate image enhancement procedures that employed the Normalized Difference Vegetation Index (NDVI) analyzed the image mosaics from these main dates separately, in order not to modify the image statistics and thereby introduce error to the NDVI.

The process of extracting the MODIS MOD13Q1 product outlined in Section 4.3.2 resulted in two same 16-day composite period (21 March-06 April 2012) extract scenes. This is because the extraction process allowed a maximum of a 100km x 100km scene at a time. The first (northern, centred at Zeerust) 100km x 100km scene that was extracted was inadequate to cover the whole study area. Therefore, an additional 40km x 40km subset covering the southern section of the study area was extracted. The two extracts were then merged into a mosaic using ERDAS Imagine 2013 software, since they were from the same date. Then a shapefile of the study area was used to subset the study area from the image mosaic, using ERDAS Imagine 2013. Figure 4.4 shows the subset MODIS images mosaic of the study area.

4.5.2 Image Enhancement

The vegetation in the study area (described in Section 3.6) has inherent structural differences, particularly in density (see Appendix 1). Therefore, this research sought to map the vegetation based on density differences. The Normalized Difference Vegetation Index (NDVI) enhances vegetation density based on the high reflectance of Near Infra Red (NIR) energy and absorption of Red (R), as in equation 1.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

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). The MODIS image was obtained from the ORNL DAAC already in NDVI value format (ORNL DAAC, 2012). Therefore, in order to achieve comparability, NDVI images were derived for the SPOT 5 HRG, using the in-built NDVI model in ERDAS Imagine 2013 that utilizes the function in equation 1. Therefore, computation of the NDVI utilized the SPOT HRG band 3 (NIR) and 2 (R) whose spectral ranges of coverage are shown in Table 4.1.

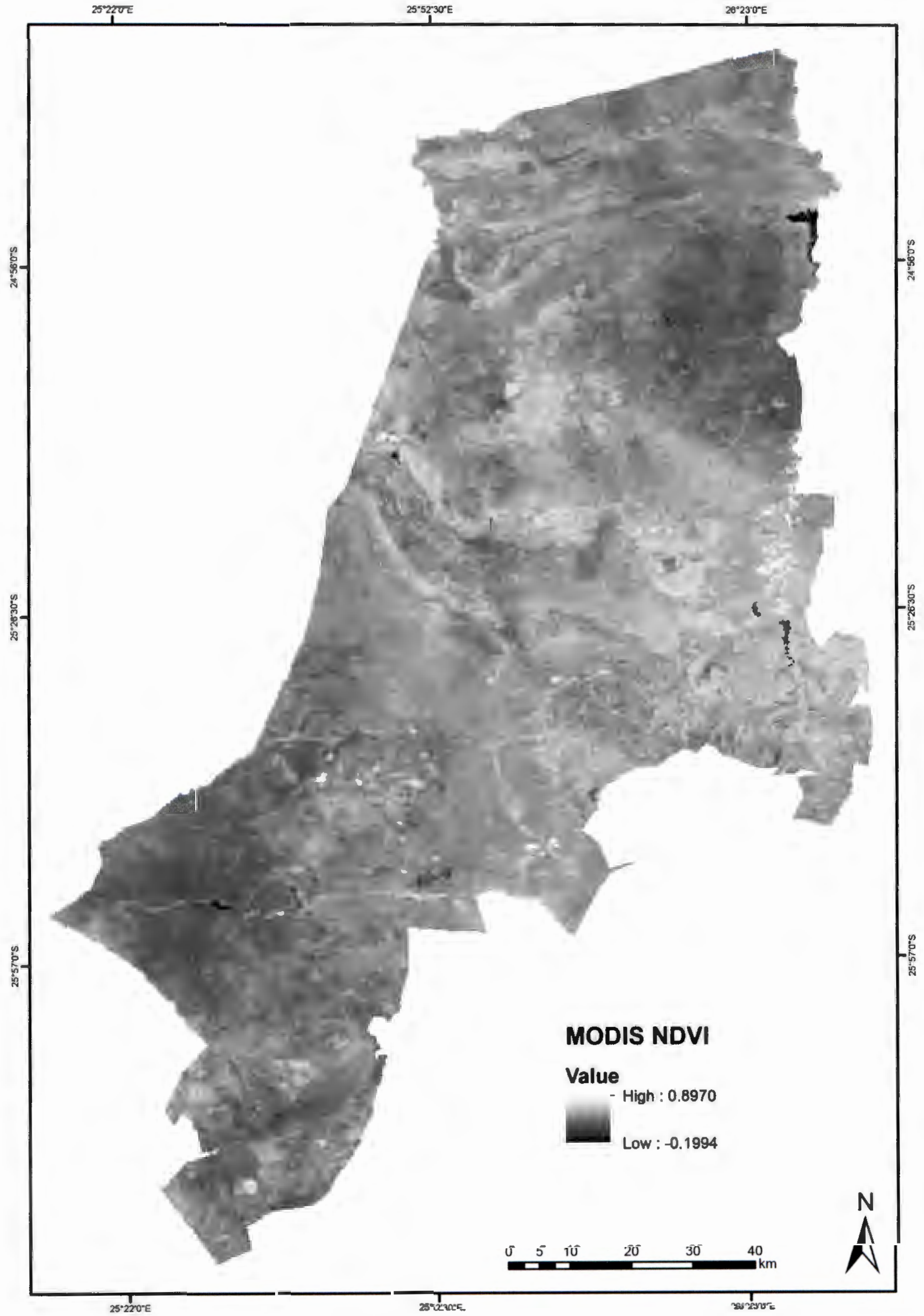


Figure 4.4 A March-April 2012 mosaic MODIS NDVI image of the study area that was acquired for the study.

The NDVI is very susceptible to error introduced by atmospheric effects (scattering and absorption of red and near infrared) which necessitates atmospheric corrections if comparisons of NDVI values or vegetation vigour over a period of time for a given pixel are needed (Lillesand et al., 2008; Jensen, 2005). In this research, comparison of NDVI values or vegetation vigour over a period of time was not the focus, but rather a mere enhancement of the location of vegetation on one date imagery prior to image classification was what was sought. In such circumstances when 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). Additionally, performing atmospheric correction requires information on the composition of the atmosphere at the time of acquisition of the image (Lillesand et al., 2008; Jensen, 2005). This information was not available for the historical 2012 SPOT HRG images and, therefore, no atmospheric corrections were performed prior to the derivation of NDVI images from the SPOT images. The NDVI values were derived from the mosaic same-date image subscenes shown in Figure 4.3. The resulting SPOT NDVI images are shown in Figure 4.5. The MODIS MOD13Q1 composite NDVI product comes with prior atmospheric processing to correct atmospheric effects (ORNL DAAC, 2012).

The lack of atmospheric corrections on the SPOT images did not seem to introduce much error in enhancing vegetated areas, as can be visually discerned on Figure 4.5 in comparison with Figure 4.3. This is because the vegetated areas were clearly enhanced (as the light tones). Additionally, a comparison of the frequency distribution histograms of the NDVI values on the atmospherically corrected MODIS images with those on the SPOT images reveals a largely similar trend of near-normal (near Gaussian) distributions (Figure 4.6). The difference is that the MODIS normal distribution histogram is centred at a higher NDVI value (0.475) while the SPOT histogram is centred at the lower value of 0.15, which indicates that the vegetation was more vigorous on the MODIS image. The statistics of the NDVI images are summarized in Table 4.3.

4.6 Field Data

Field work was conducted in the protected areas in the study area for purposes of obtaining vegetation density data for use as training data during the image classification process, as well as interpreting the results. The work was conducted during the 2012/2013 rain season. The location and names of the protected areas in the area are as shown in Figures 1.1 and 2.2.

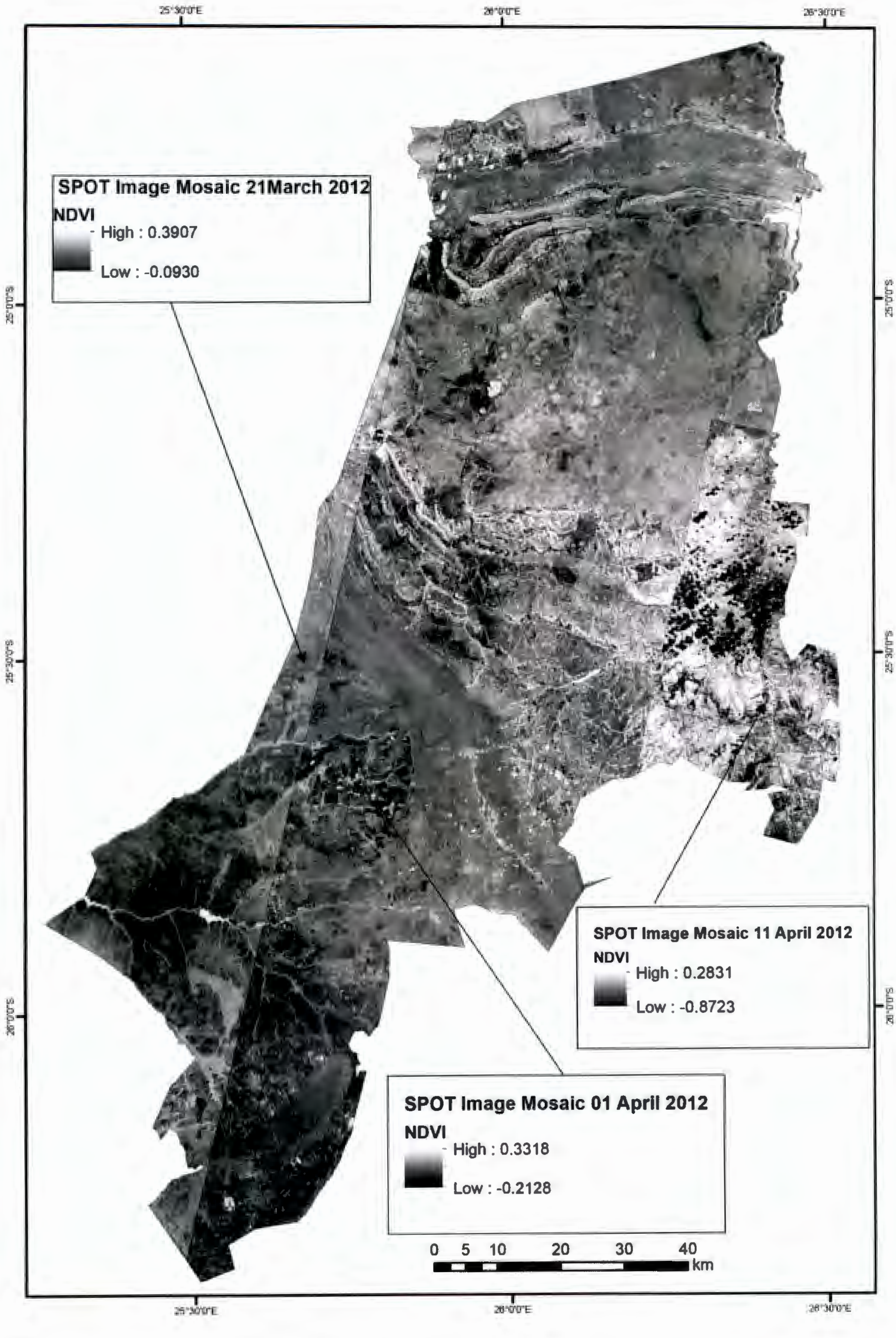
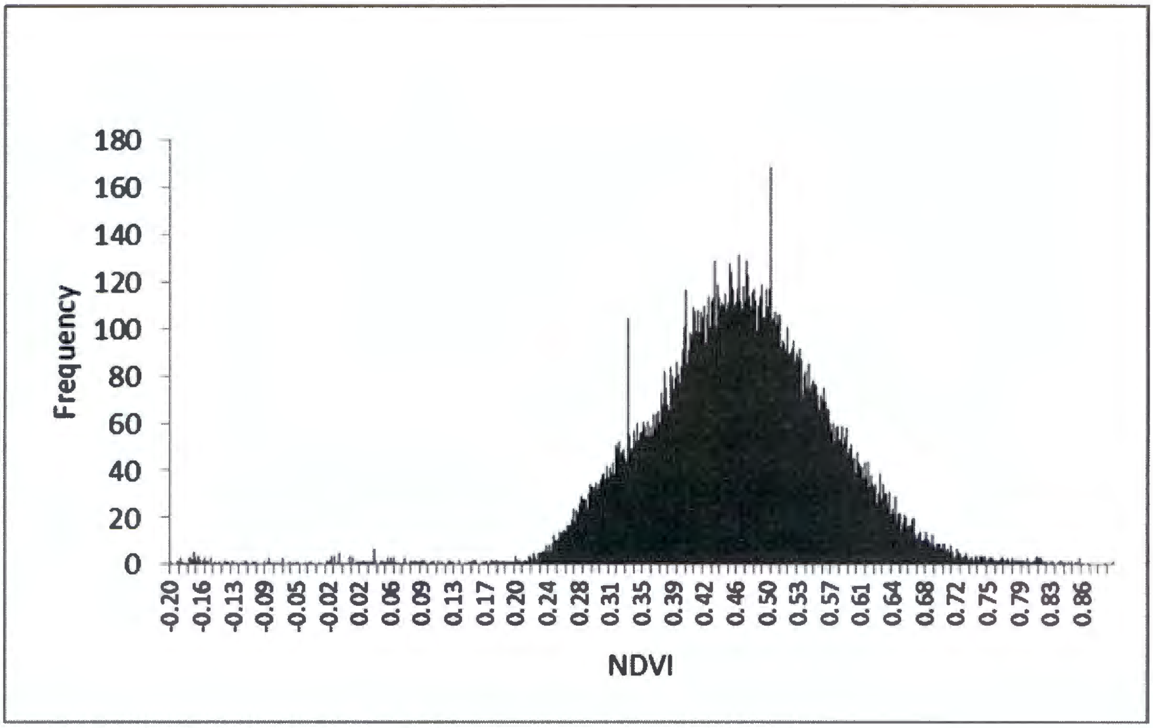
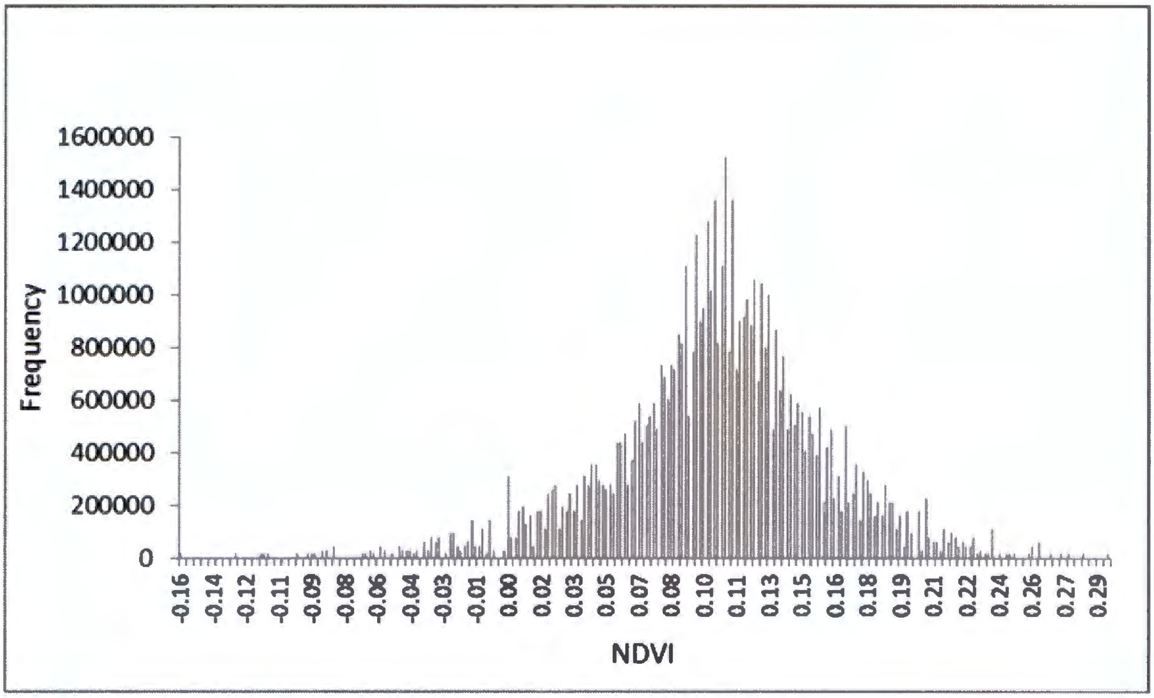


Figure 4.5 NDVI images derived from the March-April 2012 images of the study area that were used (see Figure 4.3).



(a) MODIS MOD13Q1composite image in Figure 4.4.



(b) SPOT HRG images in Figure 4.5 (all three dates combined).

Figure 4.6 Comparison of the histograms of the NDVI values from the MODIS and SPOT HRG images of the study area that were used.

Table 4.3 NDVI Statistics from the SPOT HRG and MODIS images that were used.

Statistic	SPOT 5 HRG NDVI image (Figure 4.4)	MODIS MOD13Q1 NDVI image (Figure 4.5)
Minimum	-0.8723	-0.1994
Maximum	0.3907	0.8970
Mean	0.0370	0.2079
Median	-0.0005	0
Mode	-0.0005	0
Standard deviation	0.0590	0.2384

Protected areas were targeted for the field work because the vegetation is relatively less disturbed by human activity than in the surrounding communal and private ownership commercial farms. Some of the commercial farms that are cattle and game ranches also have relatively undisturbed vegetation, but private property restrictions presented difficulties in their use as sample locations.

During field work, the following were obtained:

i. Tree density, as number of trees per hectare.
ii. Canopy closure, as a percentage.
iii. Tree height, in meters
iv. Dominant type of vegetation, whether grass, trees or shrubs.
v. Grass cover, as a percentage in a 1m x 1m quadrat.
vi. Soil samples, for purposes of laboratory analysis of the two commonly used fertility indicators of Base Saturation (BS, %) and Cation Exchange Capacity, CEC (meq / 100 g). The analysis of soil fertility was deemed necessary in order to establish whether high fertility geology resulted in high soil fertility. The ARC soils map (Figure 2.2b) uses CEC and BS as indicators of fertility.

The field sampling sites were predetermined in the laboratory. The process of predetermining the sites employed a variant of quota sampling. In each protected area the area under high, medium and low fertility geology was computed using ArcMap 10.1 by creating an area field in the attribute table and then computing using the "Calculate Geometry" function. Then the number of sample sites for each category of geological fertility, at a transect layout sampling frequency of approximately 10km, was determined on the basis of the area it covered. Using this procedure a total of 41 sample sites were used: 20 in Madikwe Game Reserve, 8 in

Mafikeng Game Reserve, 4 in Botsalano Game Reserve, 3 in Marico Bosveld Nature Reserve, 4 in Molemane Eye Game Reserve, and 2 in Pienaar's Nature Reserve. The coordinates of the sample sites were uploaded into a hand-held Garmin eTrex ® Global Positioning System (GPS) that had a field accuracy of 4m prior to the field work. The GPS handset was then used for navigating to the field sites, using the "Go To" function.

At each sample site a 100m x 100m (1 hectare, i.e. 10 000m^2) sample plot was established, and the corner points marked by placing vividly coloured ranging poles. The coordinates of the centre of the plot were then determined and recorded using the GPS handset, in the UTM system. Data on the variables of interest were then collected as follows and recorded on a field data sheet:

(a) ***Tree density*** *(number of trees per hectare)*- all the mature trees in the plot were counted. Three observers per plot performed the counting, for purposes of consistency.

(b) ***Canopy closure*** *(%)*- a visual estimation was made. The ideal would have been to use a precision instrument such as a densiometer but this was not available.

(c) ***Tree height*** *(m)*- an estimate was made using the known height of the ranging poles that were used. Given that the ranging pole was 2m tall, the number of ranging poles that could fit the particular trees was estimated at a distance. A general indication of heights was made by determining the heights of the shortest and tallest trees at the site, and a tree height range was then recorded on the field data sheet. The ideal would have been to use a clinometer to determine the tree heights more precisely, but this instrument was not available.

(d) ***Dominant type of vegetation*** *(grass, trees, shrubs)* - this was determined by a visual estimation. The ideal would have been to measure the widths of land covered by each category of vegetation and then to compute the area covered by each and determine its % cover out of the 1 hectare plot. This was a time consuming exercise that was not possible given the time and financial constraints of the study.

(e) ***Grass cover*** *(%)*- this was visually estimated in a 1m x 1m quadrat.

(f) ***Soil samples*** *(for fertility analysis: BS(%), CEC(meq/g))*- a soil auger was used for obtaining soil samples at a depth of 20cm. Two soil samples were obtained at each plot, and the samples placed in paper bags, labeled and then sent to the North West University (Mafikeng Campus) soils laboratory at Molelwane for analysis. Standard laboratory procedures for determining Base Saturation (BS, %) and Cation Exchange Capacity (CEC, meq/100g) were then used in the laboratory.

All the field sampling was conducted in the period November-December 2012 to February-March 2013, which was during the rainy season. Therefore, the grass and trees were in leaf during the field work.

4.7 Statistical Analysis of Vegetation Cover Field Data

Spearman's correlation coefficient (*r*) was used to determine whether there was a statistically significant relationship (5% threshold) between geological fertility and the vegetation cover variables (tree density, canopy closure, tree height, grass cover) in the field. For tree density, the absolute value of number of trees counted per hectare as determined in the field was used without modification in the correlation analysis. For the other variables that utilized visual estimation in the field (see Section 4.6), numerical codes were assigned to the estimated field values as in Table 4.4.

Table 4.4 Numerical codes assigned to field data vegetation cover variables and geological fertility in the analysis of statistical significance of correlation with geological fertility.

Variable	Numerical code		
Geological fertility	1 = low fertility	2 = medium fertility	3 = high fertility
Canopy closure	1 = <50%	2 = 50% to79%	3 = ≥80%
Tree height	1 = <2m	2 = 2m to 3m	3 = >3m
Grass cover	1 = <50%	2 = 50% to79%	3 = ≥80%

4.8 Vegetation Mapping using Image Classification

4.8.1 Image Classification

Using ERDAS Imagine 2013, a hybrid image classification approach that employed elements of supervised and unsupervised classification was employed. The first step in the approach was to cluster the image mosaics (in Figures 4.2 and 4.3) into three classes approximating high, medium and low fertility. These three classes were informed by the data from field work, in which it was established that there was a weak but statistically significant correlation between geological fertility and canopy closure ($r = 0.378$, $P < 0.02$). For this reason the NDVI images that, according to established theory, enhance vegetation density (see Section 4.5.2), the images were separately classified into the three vegetation density classes of high, medium and low density. Therefore, the classification scheme that was adopted did not use the scheme recommended by Thompson (1996) as in Table 3.1, but was tailor made for this study.

Following the initial clustering into the three clusters using the ISODATA (Iterative Self Organizing **Data** analysis) algorithm within ERDAS (set to 0.999 convergence threshold), the clusters were named as high, medium or low density vegetation by locating representative field sites at which vegetation cover in the respective categories was recorded, using the GPS coordinates that were recorded for the sample sites. Thereafter, the supervised Maximum Likelihood Classifier (MLC) was then employed in classifying the images into high, medium and low density vegetation cover.

4.8.2 Comparison of High versus Low Spatial Resolution Vegetation Mapping: Accuracy Assessment

The classified images that resulted from the vegetation mapping procedures in Section 4.8.1 were each subjected to a classification accuracy assessment. Using the accuracy assessment function in ERDAS Imagine 2013, a stratified random sample of 120 points was generated for each of the SPOT and MODIS image classifications, and the assignment of the random points into low vegetation density, medium vegetation density or high vegetation density classes by the image classification scheme was judged against the geological fertility map (Figure 4.7) as the reference ("correct") classes. The use of the geological fertility map as reference data was because field sampling showed that there was a statistically significant positive correlation between vegetation density and geological fertility (see Section 4.8.1). An accuracy assessment report (user's accuracy, producer's accuracy, overall classification accuracy, and kappa coefficient) was then generated. From the report error (confusion) matrices were created, which enabled the assessment of the comparative suitability of mapping the relationship between geological fertility and the vegetation cover at high or low fertility geology.

4.9 Ancillary Data

To isolate the influence of rainfall from that of geology on vegetation structure, 30-year seasonal rainfall data for Zeerust and Mafikeng Stations was analysed for statistical difference (*t*-test, significance level 5%). This made it possible to isolate the influence of rainfall on the vegetation density. Based on the statistical analysis and the delineation of vegetation on the images it was then possible to assess the extent to which geological differences in the study area can be mapped on the basis of vegetation cover.

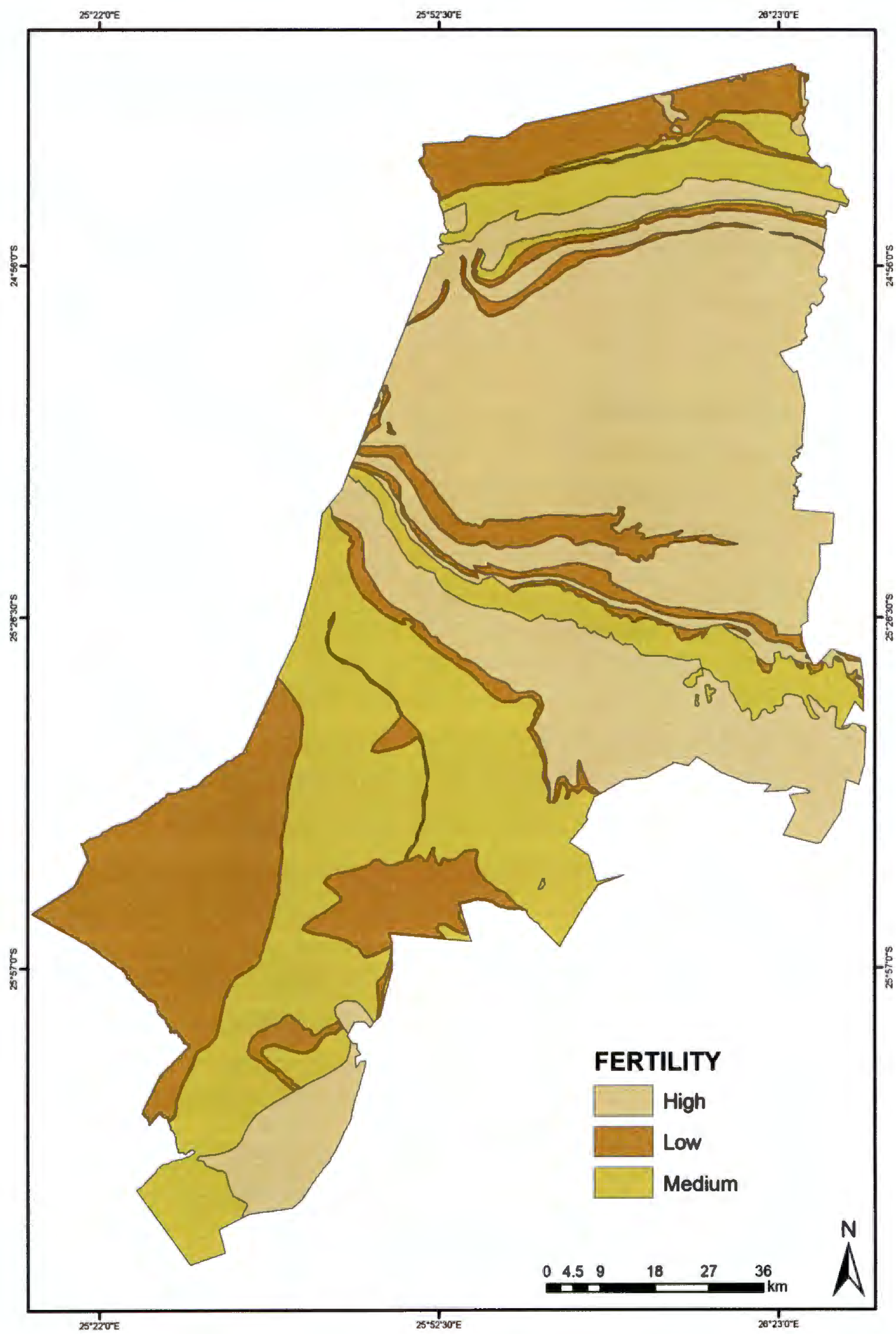


Figure 4.7 A map of the geological fertility of the study area that was used in assessing accuracy of image classification into a vegetation density thematic layer during vegetation mapping. Compare with Figures 2.2, 2.4, 4.3 and 4.4. Source: Council for Geosciences 1:1 million geology map of South Africa.

Chapter 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the results from the study, as well as an interpretation and discussion. The results are presented so as to answer the aim and objectives of the research that are listed in Section 1.2.2.

5.2 Field Data

The data that was obtained from the field on tree density, canopy closure, tree height, type of vegetation and grass cover is shown in Appendix 2. Details of the field estimation methods that were used in deriving the data are presented in Section 4.6. There were generally positive but weak relationships between geological fertility and the vegetation cover variables, based on the sample data (Figure 5.1). This correlation was statistically significant with respect to geological fertility versus number of trees per hectare - i.e. tree density ($r = 0.318$, $P < 0.05$), geological fertility versus canopy closure ($r = 0.378$, $P < 0.02$), and geological fertility versus tree height ($r = 0.358$, $P < 0.05$). However, the correlation between geological fertility and grass cover was not statistically significant ($r = 0.258$, $P > 0.05$).

The statistically significant positive correlation between geological fertility and tree density and canopy closure means that geological fertility can reliably be inferred on the basis of tree cover in the two local municipalities. Locations with high tree density indicate high fertility geology which, in young soils such as inceptisols and entisols, indicate fertile soil. Due to laboratory equipment breakdown the results on fertility of the soil samples (Base Saturation, Cation Exchange Capacity) were not available to verify the relationship between soil and geological fertility in the area. Therefore, this indicator can be used in planning agriculture in the area. It is also verifiable in the existing reality in the Mahikeng-Ramotshere Moiloa area in that most arable commercial farms are located not on the grassland vegetation Carltonville Dolomite grassland just north of Botsalano Game Reserve but in the more wooded vegetation types (topography permitting if the land is flat), such as the Mafikeng Bushveld between Mahikeng and Ramatlhabama (see Figures 2.2 and 2.4). Fertile geology also results in more nutritious grass, which makes high geological fertility areas more suitable for cattle and game farming, as has been observed in the Kruger National Park (van Wilgen et al., 2000).

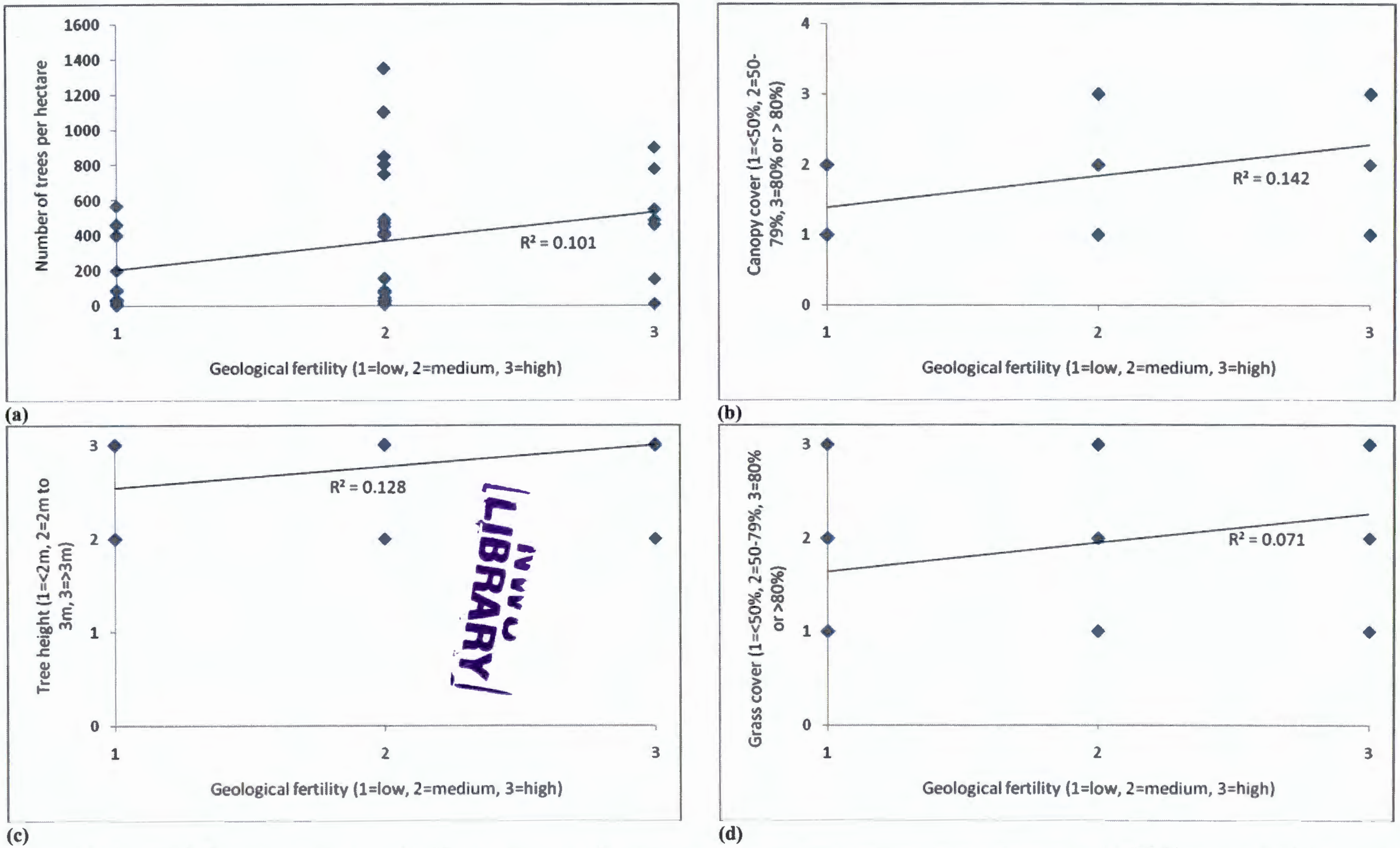


Figure 5.1 Graphical illustration of the positive linear relationship between geological fertility and vegetation structure in the field based on field sample data: (a) geological fertility versus tree density, (b) geological fertility versus canopy cover, (c) geological fertility versus tree height, and (d) geological fertility versus grass cover.

According to van Wilgen et al. (2000), the low nutrient status of the soils in the southwest section results in relatively low grazing pressure, in contrast with the high fertility (basalt substrate) southeast section where grasses are more palatable and tend to be heavily grazed. Extrapolating this relationship between grazing preference and geological fertility to the Mahikeng and Ramotshere-Moiloa local municipalities helps explain why there is an abundance of cattle and game ranches in the wooded land between Mahikeng and Zeerust for example (as well as north of Zeerust to just south of Madikwe Game Reserve), compared to none in the low fertility area to the west of Mahikeng where there is a high density of villages (Figure 2.6). Figures 2.2b and 4.7 prove the relationship between geological fertility and soil fertility, with fertile geology having fertile subsoil. On Figures 5.1(b), (c) and (d), the graphical plot appears to show that only 8, 6 and 9 points were plotted, respectively. However, all 41 points from the field sampling were plotted. The appearance of only 8, 6 and 9 points is due to the fact that many points coincided.

5.2.1 Vegetation Density in Relation to Geological Fertility

These results from the field indicate that geological fertility has a significant influence on tree density, tree canopy closure and tree height. The positive correlation means that more fertile geology results in higher tree density, a more closed tree canopy and taller trees. However, the non-significant correlation between geological fertility and grass cover means that more fertile geology does not necessarily result in more dense grass cover. The lack of a statistically significant relationship between geological fertility and grass cover is perhaps comprehensible because grass taps nutrients only in the upper horizons of the soil (the *O*- and *A*-horizons within the upper 20cm of the soil. On the other hand, tree roots tap into the underlying loose, weathered parent material bed rock and tap the high fertility nutrients that are contained therein. Additionally, grass cover is highly vulnerable to disturbance agents on the surface of the land, such as grazing pressure, fire, and uprooting by water and wind erosion.

However, the results from this study that indicate that high fertility geology results in tall and closed canopy dense woodland are contrary to what has been observed in the Kruger National Park. Soil texture has been shown to limit tree size and tree density in the Kruger National Park. The soils of the high fertility zone, derived from basic rocks (that include basalts), are fine textured and support mainly multiple-stemmed shrubs, whereas the low fertility zone's soils (parent lithology being granitic gneiss, etc) are coarse-textured, supporting mixed savanna woodlands (Fraser et al. 1987). In the Ramotshere-Moiloa and Mahikeng Local Municipalities, high fertility lithology such as gabbro and shale has relatively dense, tall tree cover.

5.3 Vegetation Mapping on the Images: SPOT HRG versus MODIS

The vegetation density maps that resulted from mapping using the high spatial resolution (10m) SPOT HRG images (Figure 4.3) and the low spatial resolution (250m) MODIS image (Figure 4.4) differed slightly. The resulting vegetation density maps at the two spatial resolutions are shown in Figures 5.2 and 5.3, respectively. In general, however, the dense vegetation was generally reproducible at both spatial resolutions, particularly the vegetation along the hill ridges (compare Figure 2.4 with Figures 5.2 and 5.3).

Based on an assessment of classification accuracy (Tables 5.1 and 5.2), the vegetation density as influenced by geological fertility could more accurately be mapped on the higher spatial resolution SPOT image than on the MODIS image. The vegetation density map from the SPOT image had a higher overall accuracy of 68.3% compared to 48.3% on the MODIS image. The Kappa coefficient of agreement also indicates the results from the SPOT image classification to be better. The Kappa coefficient of agreement (K_{hat}, or $\check{K}$) expresses the extent to which a classification differs from a completely random classification (Congalton, 1998).

Table 5.1 Error (confusion) matrix of the SPOT HRG image in mapping the vegetation.

	Reference data				
Classification data	High density	Medium density	Low density	Totals	User's accuracy
High density	**50**	10	5	65	76.9%
Medium density	7	**17**	10	34	50.0%
Low density	3	3	**15**	21	71.4%
Total	60	30	30	**120**	
Producer's accuracy	83.3%	56.7%	50.0%		
Overall accuracy = **68.3%**					
Overall Kappa, $\check{K}$ = **0.63**					

Table 5.2 Error (confusion) matrix of the MODIS image in mapping the vegetation.

	Reference data				
Classification data	High density	Medium density	Low density	Totals	User's accuracy
High density	**40**	7	6	53	75.5%
Medium density	13	**10**	16	34	25.6%
Low density	7	13	**8**	28	28.6%
Total	60	30	30	**120**	
Producer's accuracy	66.7%	33.3%	26.7%		
Overall accuracy = **48.3%**					
Overall Kappa, $\check{K}$ = **0.39**					

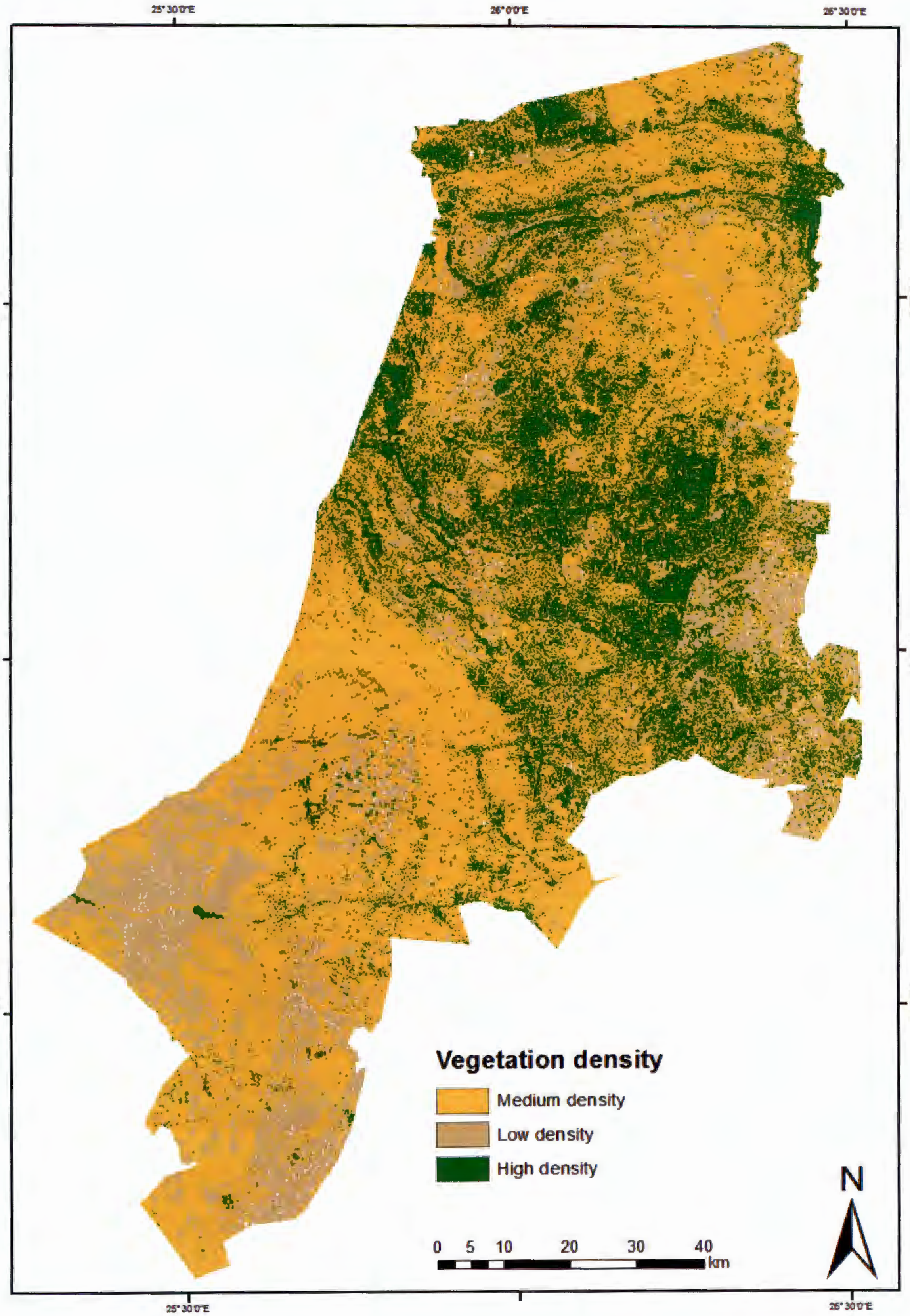


Figure 5.2 Result of mapping vegetation density on the SPOT HRG images of the Mahikeng and Ramotshere Moiloa Local Municipality study area.

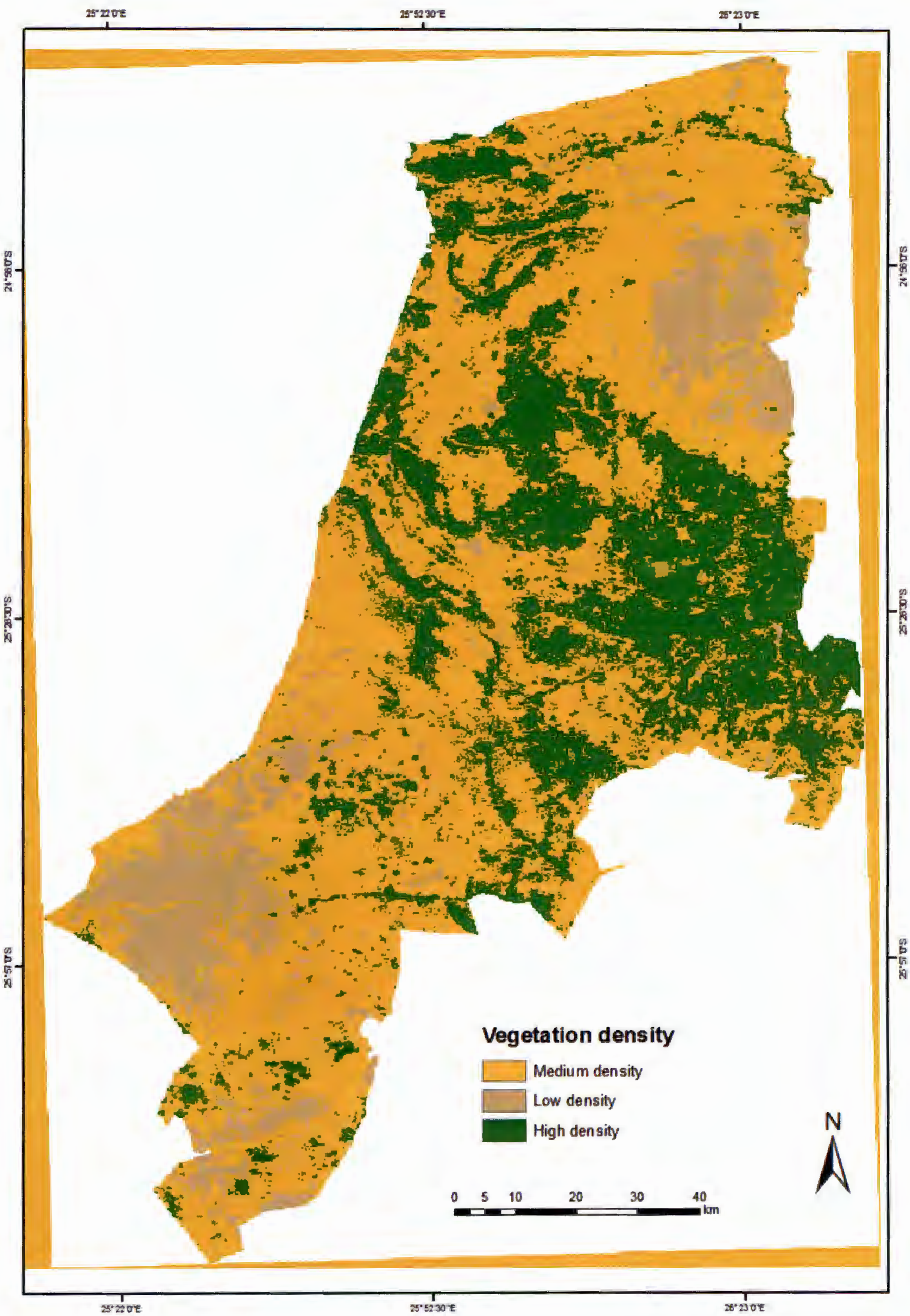


Figure 5.3 Result of mapping vegetation density on the MODIS image of the Mahikeng and Ramotshere Moiloa Local Municipality study area. Compare with Figures 2.4 and 4.7.

With an overall Kappa coefficient of 0.63 (i.e. $\check{K}$ = 0.63), the SPOT image classification avoided 63% of the errors that a completely random classification would generate. The MODIS image classification was worse in this regard, avoiding only 39% of the errors ($\check{K}$ = 0.39). With overall classification accuracies of 68.3% and 48.3%, both classifications fall short of the 85% minimum accuracy threshold for Level I mapping by the 2000 South African National Land Cover (NLC2000) project (Fairbanks et al., 2000).

The high density vegetation class was the most accurately delineated class on both classifications, based on the high user's accuracies of 76.9% and 75.5% for the SPOT and MODIS images (Tables 5.1 and 5.2, respectively). This class is also the most distinct in the field in terms of geological fertility, based on the high producer accuracies of 83.3% and 66.7% on the two classifications. The medium density vegetation class was the least accurately delineated on both classifications, based on its user's accuracy values of 50.0% and 25.6% for the SPOT and MODIS image classifications, respectively, which were lower than the low vegetation density user's accuracies. There was a lot of spectral confusion between the medium density class and the low density class. The distinctness of the high density vegetation that resulted in high user's and producer's accuracy is largely because in the high fertility and wooded areas the canopy cover is also high (Figure 5.1b), which results in high NDVI (e.g. the woodland on the ridges; see Figures 4.4 and 4.5). In the less wooded, low geological fertility areas, the main spectral response in form of the NDVI is from the herbaceous layer (grass, herbs). The vigour of the herbaceous layer is highly vulnerable to rainfall events, which introduces problems in mapping herbaceous vegetation using the NDVI (Munyati and Mboweni, 2013). This helps to explain the low delineation accuracy of medium density and low density vegetation on the two classifications.

Although the classification scheme and method that was used is generally reliable based on the relatively high overall accuracy on the SPOT image that was higher than 50% and the avoidance of 63% of the errors that a completely random classification would generate, a number of factors could have reduced the accuracy. Firstly, the vegetation in the study area is not completely free from human disturbance and, therefore, the relationship between geological fertility and tree density has been modified. On the large arable commercial farms, tree cover has been removed and replaced by crops. These farms should have been excluded from the analysis, but updated data on their location was not available during the analysis which resulted in cropland also being classified as part of vegetation during the analysis.

Secondly, in the communal areas vegetation cover has been degraded (e.g. Makgale, 2006; Munyati and Makgale, 2009), which introduced error to the analysis. Thirdly, the vegetation in some of the protected areas where sampling was undertaken is itself not completely free from disturbance. In Madikwe Game Reserve, a lot of destruction of tree cover by elephants was observed during field work, especially *Acacia* trees. Madikwe Game Reserve was also under human settlement before its proclamation as a conserved area (North West Parks and Tourism Board, Personal Communication).

The SPOT image performed better than the MODIS image in mapping the vegetation based on vegetation density largely because of the lower spatial resolution in the MODIS image. The lower spatial resolution results in land cover class aggregation as features on the ground that are different in nature are aggregated into one pixel, in the 250m pixel in this case (Munyati and Mboweni, 2013). The SPOT image had less of this error due to the high spatial resolution of 10m. However, the high spatial resolution SPOT images have the disadvantage that a lot of scenes are required to cover a large piece of land, as can be seen for the Mahikeng-Ramotshere Moiloa study area in this study (Figure 4.2). There are very few cloudless rainy season dates when all the study area can have cloud-free images to enable the use of the high spatial resolution imagery.

5.4 Relationship between Vegetation Mapping and Geological Fertility

The results from the study indicate that mapping differences in vegetation density can result in a loose correlation with geological fertility in the study area. High density vegetation was found to be more useful in this regard, and it could in turn be mapped more accurately than low density vegetation.

Based on the results, a general indication of geological fertility can reasonably be inferred in the Mahikeng and Ramotshere-Moiloa Local Municipalities on the basis of woody vegetation cover. Areas with high tree density are generally indicative of high geological fertility in the area, which in turn can indicate rich pasture land for game and livestock grazing, as explained in Section 5.2.

5.5 Usefulness of Remotely Sensed Vegetation Mapping in Spatial Planning

From this study, remote sensing can play a role as part of the spatial planning process in the two local municipalities under study. Given the general objective of redressing historical inequities in the area (Section 3.3) and the need for up-to-date spatial data (Section 3.4), there appears to be a role for remote sensing in spatial planning in the area.

Mapping vegetation in the area using remote sensing can play a role in Phase 3 (Spatial Analysis and Synthesis) of the process of developing a Spatial Development Framework by a municipality. According to the Department of Rural Development and Land Reform (DRDLR) guidelines (DRDLR, 2011: p13):

> *"The Spatial Analysis should not be a random collection of information for the sake of producing a report. Information gathering should be focused on the implications for the development of the municipality (for instance an understanding of the soils in the municipal area, will help direct growth away from arable land); emphasizing the spatial implications of the trends and drivers of urban growth and development".*

As shown in this study, inferences on the fertility of the area can be drawn based on tree density. On newly acquired farmland, for example, the local municipality concerned can obtain information that can enable the understanding of the soils of the area so that decisions can be made on whether to make it arable or settlement land. This can expedite the planning process, perhaps as a preliminary substitute for land surveys which are more time consuming. Once the decision is made to use the land as arable land, then detailed soil surveys involving the collection of soil samples can give information on soil fertility and soil depth so that a suitable crop can be selected for the area in joint consideration with the rainfall characteristics. This way remote sensing can contribute to alleviating the widespread poverty (Table 2.2) in the Mahikeng and Ramotshere Moiloa Local Municipalities.

5.6 Vegetation Cover Spectral Response versus Geological Fertility

Vegetation enhancement in this study was accomplished using near infrared and red spectral bands (Table 4.1). The vegetation could then be mapped on the basis of vegetation density, which generally correlates with geological fertility in the area.

This implies that the underlying geology of the Mahikeng and Ramotshere-Moiloa Local Municipalities has a strong influence on vegetation community structure and density and, thereby, intensity of reflectance in the visible-mid infrared spectral regions, which can be detected by moderately to high spatial resolution sensors detecting reflected electromagnetic radiation with broad spectral resolution in the visible, near and mid infrared spectral regions. Using appropriate image processing techniques such as the Normalized Difference Vegetation Index (NDVI), the vegetation can then be mapped. Similar to what Munyati and Ratshibvumo (2010) deduced by for the Kruger National Park, the low fertility and high fertility substrates of the Ramotshere-Moiloa and Mahikeng Local Municipalities area, through edaphic and landscape characteristics, influence the vegetation structure and density to a sufficiently strong extent that the spectral reflectance characteristics between the two zones are distinguishable on multispectral remotely sensed imagery.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the conclusions that were drawn from the results of the study, in relation to the objectives. Based on the study, recommendations for similar future studies are then listed.

6.2 Conclusions

- The aim of the study was to establish the extent to which differences in geological fertility can be delineated on satellite imagery, using SPOT 5 HRG and MODIS imagery as test case. It can be concluded that differences in geological fertility in this semi-arid savanna area can most reliably be delineated on the basis of tree density on high spatial resolution imagery such as SPOT 5 HRG multispectral imagery.
- The first objective of the study was to determine if there is a relationship between vegetation cover and geological fertility on the basis of spectral response of vegetation. It can be concluded that the low fertility and high fertility geology substrates of the Ramotshere-Moiloa and Mahikeng Local Municipalities area, through edaphic and landscape characteristics, influence the vegetation structure and density to a sufficiently strong extent that the spectral reflectance characteristics between the two zones are distinguishable on multispectral remotely sensed imagery.
- The second objective of the study was to establish whether differences in fertility of the geological substrate in the study area can be differentiated on the basis of vegetation assemblages. It can be concluded that the differences in the fertility of the geological substrate in the Ramotshere-Moiloa and Mahikeng Local Municipalities area can best be differentiated on the basis of tree density.
- The third objective of the study was to establish the potential role of remote sensing in supporting rural agricultural development planning in the study area based on vegetation cover assessment. It can be concluded that remote sensing potentially can support municipalities in the process of developing Spatial Development Frameworks as they

strive to plan rural development to reduce poverty and plan optimal use of land for agricultural development.

6.3 Recommendations

The following recommendations can be made as new lines of inquiry and to make future similar work more accurate:

1. There is potential to explore the relationship between topography, and the related soil depth, on tree cover using 3-dimensional analysis techniques (e.g. Digital Elevation Models, DEMs).
2. Excluding non-natural vegetation such as crops and plantations can improve the accuracy of the work.
3. Sampling vegetation in un-disturbed private property land uses can improve the ground truthing data.
4. A larger number of field sampling sites than was used in this study can improve the ground truthing data.
5. The use of the requisite vegetation description instruments such as clinometers (for tree height determination) and densiometers (for canopy cover determination) can improve the ground truthing data as opposed to the use of visual estimation as was the case in this study.

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APPENDICES

APPENDIX 1

Description and Characteristics of the Vegetation Types in the Study Area (source: Mucina and Rutherford, 2006).

Vegetation	Characteristics	Climate
Western Highveld Sandy Grassland	It occurs from Mahikeng to Schweizer-Reneke in the south and from Broedersput and Kameel in the west of Lichtenburg and Ottosdal (small portion is conserved in Barberspan) in the east. It is characterized by flat to gently undulating plains with short, dry grassland, with some woody species occurring in bush clumps. Vegetation include among others: *Anthephora pubescenens, Aristida congesta, Cymbopogon pospischilii, Cynodon dactylon, Eragrostis lehmanniana, Sporobolus africanus, Aristida adscensionis, Themeda triandra, Aristida canescens, Digitaria argyrograpta,* 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.	Generally worm temperature, but high summer temperature, summer rainfall of 520mm with severe frequent frost occurs in winter.
Highveld alluvial Vegetation	It is found along upper Riet, Harts, upper Modder, upper Caledon, Vet, Sand, Vals, Wilge, Mooi, middle and upper Vaal Rivers, etc. It is defined by flat topography supporting riparian thickets mostly dominated by *Acacia karroo*, accompanied by seasonally flooded grasslands and disturbed herblands often dominated by alien plants. Small trees include *Acacia karroo, Salix mucronata, Ziziphus mucronata, Celtis africana, Rhus lancea*, etc. Tall shrubs include *Gymnosporia buxifolia, Rhus pyroides, Diospyros lyciodes, Ehretia rigida*, etc. The geology and soils are made up of deep sand to clayey alluvial soils developed over Quaternary alluvial sediments. The rivers are perennial, often flood in summer.	Seasonal rainfall: precipitation in the western part is erratic: 300 – 400mm and is increasing sharply towards east and north to 600mm. Summer temperatures surpass 35^0C with frequent winter frost.
Mafikeng Bushveld	It occurs west of Mahikeng and south of Botswana boarder 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, 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.	Summer rainfall of about 520mm in the east with very try winter and frequent frost.

Appendix 1 *(continued)* Description and characteristics of the vegetation types in the study area (source: Mucina and Rutherford, 2006).

Vegetation	Characteristics	Climate
Klerksdorp Thornveld	Occurs in Ottosdal and Botsalano Game Park in the North of Mahikeng as well as in vicinity of Madibogo in the South of Mahikeng (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 Climber 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.	Generally worm temperature, but high summer temperature, summer rainfall region of 533mm with severe frequent frost occurs in winter.
Moot Plains Bushveld	It is found along south of Swartruggens –Zeerust line. It is open to close, low, often thorny savanna dominated by various species of *Acacia* in the bottomland and plains as well as woodlands of varying heights and density on the lower hillsides. Herbaceous layer is dominated by grasses. Small trees include *Acacia nilotica, Acacia tortilis, Acacia heteracantha, Rhus lancea* and tall shrubs include *Buddleja saligna, Euclea undulate, Olea europaea, Olea Africana,* etc. Its geology and soil is made up of clastic sediments and minor carbonates and volcanics of the Pretoria Group and some Malmani dolomites in the west, all of the Transvaal Supergroup (Vaalian) and mafic Bushveld intrusives.	Very try winter with summer rainfall of about **55**mm in the west to **700**mm in the east and frequent winter frost. The maximum temperature of 33.6 ^{0}C in January and -3.1^{0}C in June.
Subtropical Salt Pans	It is characterized by shallow depressions, often found on old alluvial terraces of rivers, surrounded by zones of bank reeds or low herblands and in more perennial pans also filled with a dense carpet of macrophytic floating vegetation. The Graminoids include *Cynodon dactylon, Diplachne eleusine, Eragrostis rotifer, Chloris virgate, Phragmites mauritianus*, etc. Herbs include *Isoetes schweeinfurthii, Persicaria*, etc. Megagraminoid include *Phragmites mauritianus*, etc. Graminoids include *Digitaria didactyla, Echinochloa pyramidalis*, etc. The pans occur on Cenozoic alluvium, sand and calcrete, but also significantly on sediments of the Cretaceous Zululand Group.	The pans receive seasonal summer rainfall 311-964mm and subtropical temperature from 18^{0}C to 22^{0}C with Grassland Biome.

Appendix 1 *(continued)* Description and characteristics of the vegetation types in the study area (source: Mucina and Rutherford, 2006).

Vegetation	Characteristics	Climate
Highveld Salt Pans	These are found roughly between Mahikeng and Koster in the north, but the high concentration is in Delareyville (Barberspan, a Ramsar site). They occur in arid to semi-arid elevated regions of the Highveld. There are 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 pansae unusually formed by shales of the Ecca Group giving rise to vertic clays.	There is summer rainfall in northeastern region. They receive overall rainfall of less than 500mm per year, characterized by thunderstorms leading to high water run-off and low soil absorption. Temperature next to Mahikeng is 16.7^{0}C.
Carletonville Dolomitic Grassland	It occurs in Ottoshoop (small portion of Molemane Eye Game Reserve) and it is associated slightly undulating plains dissected by prominent rocky chert ridges. Species-rich grass-lands forming a complex mosaic pattern dominated by many species. It is dominated by graminoids such as *Aristida congesta, Digitaria tricholaenoides, Diheteropogon amplectens, 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 *Eucleaundulata, 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.	Generally warm temperature, but high summer temperature, summer rainfall region of **593mm** with severe frequent frost occurs in winter.

Appendix 1 *(continued)* Description and characteristics of the vegetation types in the study area (source: Mucina and Rutherford, 2006).

Vegetation	Characteristics	Climate
Zeerust Thornveld	It occurs along Zeerust, Groot Marico and Mabaalstad (4% conserved in Pienaar and Marico Bushveld Nature Reserves and 16% has been transformed to cultivation). Characterized by deciduous, open short thorny woodland, dominated by tall *Acacia* species such *Acacia burkei*, *Acacia erioloba,* and small trees such a as *Acacia melifera, Tortilis, A.nilotica, Rhus lanca, Acacia fleckii* with herbaceous layer of mainly grasses on deep, high base-status and some clay soils on plains and lowland also between rocky ridges of Dwarsberg-Swartruggens Mountain Bushveld. Its geology and soils are sediments of Pretoria Group (Transvaal Supergroup) mostly consist of shale with less quartzite and conglomerate.	It experiences summer rainfall of 550-600mm with very dry winter and fairly frequent frost in winter. It has maximum and minimum temperature of 36.7^{0}C in January and -0.4^{0}C in June.
Dwaalboom Thornveld	It occurs along Nietverdiend area (6% of Madikwe Game Reserve). It is characterized by plains with layers of scattered, low to medium high deciduous microphyllous trees and shrubs with a few broad-leaved tree species and almost continuous herbaceous layer dominated by grass species. *Acacia tortilis and A. nilotica* dominate on the medium clays. There are tall trees such as *Acacia erioloba* and small trees such as *Acacia erubescens, A.nilotica, A. tortilis* subsp, A. *fleckii* subps, *Rhu lancea, Ziziphus macronata*. It also has tall shrubs such as *Acacia hebeclada* and short shrubs such as *Acacia tenuispina*. Its geology and soils are comprised of vertic black ultramafic clays which developed from norite and gabbro. Some with high base status and eutrophic red soils. Underlaying geology is an Archaea granite-gneiss.	It has summer rainfall of 500-600mm and a very dry winter with fairly frequent frost in winter. It has the highest mean annual potential evaporation of savanna vegetation units outside the two Kalahari bioregions.
Madikwe Dolomitic Bushveld	It occurs along the international boarder at Ramotswa in the west via the Rand Van Tweede Poort, Tlhapise and Maakane to Madimong in the east (cover 17% in the Madikwe Game Reserve). It is defined by gently ridges and low hills up to about 100 to 150m above the surrounding plains. Trees and shrubs layers often not clearly distinct, especially on steeper slopes. They are dominated by deciduous trees, particularly *Combretum apiculatum* and *Kirkia wilmsii* especially on the east. Tall trees include among others *Sclerocarya birrea* subsp, *Acacia caffra* and the small trees are *Combretum apiculatum, Kirkia wilmsii, Ozoroa paniculosa, Rhus lancea, Ziziphus mucronata*. Tall shrubs include *Grewia flava, Tarchonanthus*, etc. It has stony, shallow soils of the Glenrosa and Mispah forms underlain mainly by dolomite, subordinate chert, minor carbonaceous shale, limestone and quartzite of the Malmane Subgroup (Chuniespoort Group, Transvaal Supergroup and Vaalian Erathem).	It receives summer rainfall from about 520mm in the west to 650mm in the east with very dry winter and fairly frequent winter frost.

Appendix 1 *(continued)* Description and characteristics of the vegetation types in the study area (source: Mucina and Rutherford, 2006).

Vegetation	Characteristics	Climate
Dwarsberg-Swartruggens Mountain Bushveld	It occurs on hills and ridges east of the Lobatsi River through the Zeerust and the Swartruggens area (2% is conserved in the Marico Bushveld Nature Reserve). It is characterized by tall trees such as *Acacia robusta* and small trees like *Acacia caffra, Acacia erubescens, 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 Climber 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 experiences summer rainfall of 550-650mm with very dry winter and fairly frequent frost in winter. It has maximum and minimum temperature of 35.2^0C in January and -0.4^0C in June.

APPENDIX 2

Field Data on Vegetation Cover Variables at Sample Sites

X UTM	Y UTM	Soil sample	Lithology	Geological fertility	Fertility code	BS (%)	Canopy	Canopy Code	Tree height (m)	Tree height code	Grass Cover (%)	Grass code	Tree count	Tree Description
414129.0	7266343.28	MD1	Granite	Low	1		< 50%	1	2 – 3	2	70	2	203	Predominantly *Acacia*
420589.8	7268596.5	MD2	Gabbro	High	3		< 50%	1	2 – 3	2	80	3	150	Dominanatly *Acacia Karroo*
424904.8	7265760.28	MD3	Sand	Medium	2		50 – 79 %	2	3 – 4	3	60	2	470	Dominantly *Acacia Melifera, Acacia Karroo*
439578.8	7251211.18	MD4	Dolomite	Medium	2		> 80%	3	3 – 4	3	90	3	850	Dominantly *Acacia Arioloba, Dichrostachys Cinerea*
431414.5	7244879.15	MD5	Granite	Low	1		50 – 79 %	2	1 – 2	2	60	2	460	Dominantly *Acacia Karoo, Acacia Robusta*
436451.4	7265246.13	MD6	Andesite	Medium	2		> 80%	3	3 – 5	3	70	2	750	Dominantlly *Acacia Melifera, Acacia Tortilis, Acacia Erioloba*
436846.1	7272727.94	MD7	Granite	Low	1		50 – 79 %	2	2 – 3	2	50	2	400	*Acacia Erioloba, Acacia Karoo, Acacia Robusta*
435610.3	7258265.57	MD10	Dolomite	Medium	2		< 50	1	2 – 3	2	< 50	1	75	*Acacia Karroo, Dichrostachys Cinerea*
433749.6	7259892.29	MD11	Dolomite	Medium	2		50 – 79 %	2	3 – 4	3	60	2	450	*Acacial Karroo, Acacia Erioloba, Acacia Tortilis*
437693.9	7253069.61	MD12	Shale	High	3		> 80%	3	2 – 5	3	< 50	1	780	Dominantly *Acacia Malefera, Rhu Slancia*
440621.4	7256579.44	MD13	Dolomite	Medium	2		50 – 79 %	2	3 – 5	3	80	3	490	Dominantly *Morula Tree, Acacia Erioloba, Dichrostachys Cinerea*
439423.0	7273617.89	MD8	Granite	Medium	2		> 80%	3	2 – 3	2	50	2	804	Dominantly *Acacia Karroo, Acacia Tortilis*
429482.2	7260468.04	MD15	Dolomite	Medium	2		< 50%	2	2 – 4	3	50	2	85	Dominatly *Acacia Karroo, Rhu Slancia, Acacia Tortilis*
427721.6	7258604.15	MD16	Dolomite	Medium	2		< 50%	2	2 – 4	3	50	2	75	Dominantly *Acacia Tortilis, Acacia Karroo*
421089.7	7258817.02	MD17	Dolomite	Medium	2		50 – 79 %	2	3 – 5	3	< 50	1	403	Dominantly *Acacia Totilis, Acacia Erioloba*
417657.1	7258718.36	MD18	Dolomite	Medium	2		50 – 79 %	2	2 – 8	3	< 50	1	418	Dominanatly *Acacia Erioloba, Marula Tree*
417523.0	7253251.58	MD19	Shale	High	3		> 80%	3	2 – 4	3	50	2	487	Dominantly *Acacia Robusta, Acacia Karoo, Acacia Tortilis*
424354.8	7253160.10	MD20	Shale	High	3		50 – 79%	1	3 – 5	3	80	3	550	Dominantly *Acacia Melifera, Acacia Tortilis*
431081.1	7255115.50	MD21	Shale	High	3		> 80%	3	4 – 5	3	80	3	900	Dominantly *Acacia Tortilis, Acacia Robusta,*
431044.6	7256761.92	MD22	Dolomite	High	3		50 – 79 %	3	5 – 7	3	70	2	460	Marula Tree *Acacia Melifera, Acacia Tortilis*
371662.5	7140220.12	MF1	Andesite	Medium	2		< 50%	1	2 – 4	3	< 50	1	47	*Rhu Slancia, Grewia Fluvensis*
373105.1	7141937.72	MF2	Sand	Low	1		< 50%	1	1 – 5	3	< 50	1	92	*Rhu Slancia, Shiera, Zizivas Macronata*
373146.6	7141897.13	MF3	Sand	Low	1		< 50%	1	1.5 – 3	2	< 50	1	35	*Acacia Karroo, Rhu Slancia*
374853.6	7141906.81	MF4	Sand	Low	1		< 50%	1	2 – 5	3	70	2	29	*Rhu Slancia, Acacia Tortilis*
373164.2	7138409.20	MF5	Sand	Low	1		< 50%	1	3 – 4	3	< 50	1	11	*Rhu Slancia, Puzel* bush
373328.0	7136595.28	MF6	Sand	Low	1		< 50%	1	1 – 3	2	< 50	1	27	*Ruslancia, Acacia Karroo*
369766.2	7136557.15	MF7	Sand	Low	1		< 50%	1	2 – 3	2	< 50	1	5	*Acacia Tortilis, Ziziphus Macronata*
366503.9	7139981.62	MF8	Andesite	Medium	2		< 50%	1	1 – 8	3	50	2	24	*Acacia Tortilis, Rhu Slancia, Grewia Vlava*
404802.5	7146021.85	BO1	Sand	Low	1		< 50%	1	2 – 5	3	> 80	3	87	Dominantly *Acacia Karroo, Rhu Slancia, Ziziphus Macronata, AcaciaTortilis*
367848.6	7171605.23	BO2	Andesite	Medium	2		< 50%	1	1 – 4	3	> 80	3	29	Dominantly *Acacia Karroo, Acacia Melifera, Ziziphus Macronata*
371097.6	7175156.04	BO3	Andesite	Medium	2		< 50%	1	1 – 3.5	2	> 80	3	25	Dominantly *Acacia Karroo, Ziziphus Macronata, Acacia Robusta*
372782.8	7173375.61	BO4	Andesite	Medium	2		50 – 79 %	2	2 – 5	3	50	2	408	Dominantly *Acacia Erioloba, Acacia Robusta, Ziziphus Macronata, Rhu Slancia*
446528.5	7175887.1	CGR1	Andesite	Medium	2		> 80%	3	4 – 8	3	< 50	1	850	Dominantly *Acacia Tortilis, Rhu Slancia, Acacia Erioloba*
448173.9	7173903.57	CGR2	Andesite	Medium	2		> 80%	3	2 – 4	3	< 50	1	1350	Dominantly *Acacia Karoo, Acacia Mellifera, Acacial Tortilis*
448283.6	7173870.77	CGR3	Andesite	Medium	2		> 80%	3	2 – 4	3	bare ground	1	1100	Dominantly *Acacia Karroo, Acacia Tortilis, Acacia Erioloba, Acacia Melifera*
404802.5	7146021.85	ML1	Dolomite	Medium	2		< 50%	1	5 – 6.3	3	> 80	3	30	*Rhu Slancia, Acacia Karroo, Ziziphus Mucronata*
408324.8	7147721.95	ML2	Dolomite	Medium	2		50 – 79%	2	1.5 – 8	3	> 60	2	155	*Ziziphus Macronata, Acacia Mellifera, Acacia Karroo, Rhus Pyroides, Rhu Slancia, Deermekar*
406727.4	7142336.05	ML3	Dolomite	Medium	2		< 50%	1	5 – 4.8	3	> 80	3	10	*Acacia Karroo, Rhu Slancia, Ziziphus Macronata, Deermekar*
401671	7143978.49	ML4	Sedimentary	High	3		< 50%	1	1.5 – 3.8	3	> 80	3	11	*Ziziphus Macronata, Olive Tree, Acacia Karroo*
403878	7191784	P1	Shale	High	3		50 – 79%	2	0.5 – 4	3	< 50	1	550	Dominantly *Acacia Karroo*
404546	7192807	P2	Quartzite	Low	1		50 – 79%	2	1.8 – 7.5	3	70	2	570	Dominantly *Acacia Erioloba, Rhu Slancia*

* MD = Madikwe Game Reserve, MF = Mafikeng Game Reserve, BO = Botsalano Game Reserve, CGR = Marico Bosveld Nature Reserve, ML = Molemane Eye Game Reserve, and P = Pienaar's Nature Reserve.

APPENDIX 3

T-Test Analysis of Rainfall Mafikeng and Zeerust Rainfall

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	557.2533333	537.7821429
Variance	29217.56878	24866.12893
Observations	30	28
Hypothesized Mean Difference	0	
df	56	
t Stat	0.451235491	
P(T<=t) one-tail	0.326781218	
t Critical one-tail	1.672522303	
P(T<=t) two-tail	0.653562436	
t Critical two-tail	2.003240719	

Null hypothesis (Ho) = there is no significant difference in mean reainfall between Zeerust and Mafikeng.

Alternative hypothesis = there is a significant difference in mean rainfall between Zeerust and Mafikeng

Calculated t = 0.4512 , P= 0.65; therefore accept Ho and conclude that there is no significant difference in the mean rainfall between Zeerust and Mafikeng.

Appendix 1 *(continued)* Description and characteristics of the vegetation types in the study area (source: Mucina and Rutherford, 2006).

Vegetation	Characteristics	Climate
Dwarsberg-Swartruggens Mountain Bushveld	It occurs on hills and ridges east of the Lobatsi River through the Zeerust and the Swartruggens area (2% is conserved in the Marico Bushveld Nature Reserve). It is characterized by tall trees such as *Acacia robusta* and small trees like *Acacia caffra, Acacia erubescens, 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 Climber 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 experiences summer rainfall of 550-650mm with very dry winter and fairly frequent frost in winter. It has maximum and minimum temperature of 35.2^{0}C in January and -0.4^{0}C in June.

APPENDIX 2

Field Data on Vegetation Cover Variables at Sample Sites

X_UTM	Y_UTM	Soil sample	Lithology	Geological fertility	Fertility code	BS (%)	Canopy	Canopy Code	Tree height (m)	Tree height code	Grass Cover (%)	Grass code	Tree count	Tree_Description
414129.0	7266343.28	MD1	Granite	Low	1		< 50%	1	2 – 3	2	70	2	203	Predominantly *Acacia*
420589.8	7268596.5	MD2	Gabbro	High	3		< 50%	1	2 – 3	2	80	3	150	Dominanatly *Acacia Karroo*
424904.8	7265760.28	MD3	Sand	Medium	2		50 – 79 %	2	3 – 4	3	60	2	470	Dominantly *Acacia Melifera, Acacia Karroo*
439578.8	7251211.18	MD4	Dolomite	Medium	2		> 80%	3	3 – 4	3	90	3	850	Dominantly *Acacia Arioloba, Dichrostachys Cinerea*
431414.5	7244879.15	MD5	Granite	Low	1		50 – 79 %	2	1 – 2	2	60	2	460	Dominantly *Acacia Karoo, Acacia Robusta*
436451.4	7265246.13	MD6	Andesite	Medium	2		> 80%	3	3 – 5	3	70	2	750	Dominantlly *Acacia Melifera, Acacia Tortilis, Acacia Erioloba*
436846.1	7272727.94	MD7	Granite	Low	1		50 – 79 %	2	2 – 3	2	50	2	400	*Acacia Erioloba, Acacia Karoo, Acacia Robusta*
435610.3	7258265.57	MD10	Dolomite	Medium	2		< 50	1	2 – 3	2	< 50	1	75	*Acacia Karroo, Dichrostachys Cinerea*
433749.6	7259892.29	MD11	Dolomite	Medium	2		50 – 79 %	2	3 – 4	3	60	2	450	*Acacial Karroo, Acacia Erioloba, Acacia Tortilis*
437693.9	7253069.61	MD12	Shale	High	3		> 80%	3	2 – 5	3	< 50	1	780	Dominantly *Acacia Malefera, Rhu Slancia*
440621.4	7256579.44	MD13	Dolomite	Medium	2		50 – 79 %	2	3 – 5	3	80	3	490	Dominantly *Morula Tree, Acacia Erioloba, Dichrostachys Cinerea*
439423.0	7273617.89	MD8	Granite	Medium	2		> 80%	3	2 – 3	2	50	2	804	Dominantly *Acacia Karroo, Acacia Tortilis*
429482.2	7260468.04	MD15	Dolomite	Medium	2		< 50%	2	2 – 4	3	50	2	85	Dominatly *Acacia Karroo, Rhu Slancia, Acacia Tortilis*
427721.6	7258604.15	MD16	Dolomite	Medium	2		< 50%	2	2 – 4	3	50	2	75	Dominantly *Acacia Tortilis, Acacia Karroo*
421089.7	7258817.02	MD17	Dolomite	Medium	2		50 – 79 %	2	3 – 5	3	< 50	1	403	Dominantly *Acacia Totilis, Acacia Erioloba*
417657.1	7258718.36	MD18	Dolomite	Medium	2		50 – 79 %	2	2 – 8	3	< 50	1	418	Dominanatly *Acacia Erioloba, Marula Tree*
417523.0	7253251.58	MD19	Shale	High	3		> 80%	3	2 – 4	3	50	2	487	Dominantly *Acacia Robusta, Acacia Karoo, Acacia Tortilis*
424354.8	7253160.10	MD20	Shale	High	3		50 – 79%	1	3 – 5	3	80	3	550	Dominantly *Acacia Melifera, Acacia Tortilis*
431081.1	7255115.50	MD21	Shale	High	3		> 80%	3	4 – 5	3	80	3	900	Dominantly *Acacia Tortilis, Acacia Robusta,*
431044.6	7256761.92	MD22	Dolomite	High	3		50 – 79 %	3	5 – 7	3	70	2	460	Marula Tree *Acacia Melifera, Acacia Tortilis*
371662.5	7140220.12	MF1	Andesite	Medium	2		< 50%	1	2 – 4	3	< 50	1	47	*Rhu Slancia, Grewia Fluvensis*
373105.1	7141937.72	MF2	Sand	Low	1		< 50%	1	1 – 5	3	< 50	1	92	*Rhu Slancia, Shiera, Zizivas Macronata*
373146.6	7141897.13	MF3	Sand	Low	1		< 50%	1	1.5 – 3	2	< 50	1	35	*Acacia Karroo, Rhu Slancia*
374853.6	7141906.81	MF4	Sand	Low	1		< 50%	1	2 – 5	3	70	2	29	*Rhu Slancia, Acacia Tortilis*
373164.2	7138409.20	MF5	Sand	Low	1		< 50%	1	3 – 4	3	< 50	1	11	*Rhu Slancia, Puzel* bush
373328.0	7136595.28	MF6	Sand	Low	1		< 50%	1	1 – 3	2	< 50	1	27	*Ruslancia, Acacia Karroo*
369766.2	7136557.15	MF7	Sand	Low	1		< 50%	1	2 – 3	2	< 50	1	5	*Acacia Tortilis, Ziziphus Macronata*
366503.9	7139981.62	MF8	Andesite	Medium	2		< 50%	1	1 – 8	3	50	2	24	*Acacia Tortilis, Rhu Slancia, Grewia Vlava*
404802.5	7146021.85	BO1	Sand	Low	1		< 50%	1	2 – 5	3	> 80	3	87	Dominantly *Acacia Karroo, Rhu Slancia, Ziziphus Macronata, AcaciaTortilis*
367848.6	7171605.23	BO2	Andesite	Medium	2		< 50%	1	1 – 4	3	> 80	3	29	Dominantly *Acacia Karroo, Acacia Melifera, Ziziphus Macronata*
371097.6	7175156.04	BO3	Andesite	Medium	2		< 50%	1	1 – 3.5	2	> 80	3	25	Dominantly *Acacia Karroo, Ziziphus Macronata, Acacia Robusta*
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448173.9	7173903.57	CGR2	Andesite	Medium	2		> 80%	3	2 – 4	3	< 50	1	1350	Dominantly *Acacia Karoo, Acacia Mellifera, Acacial Tortilis*
448283.6	7173870.77	CGR3	Andesite	Medium	2		> 80%	3	2 – 4	3	bare ground	1	1100	Dominantly *Acacia Karroo, Acacia Tortilis, Acacia Erioloba, Acacia Melifera*
404802.5	7146021.85	ML1	Dolomite	Medium	2		< 50%	1	5 – 6.3	3	> 80	3	30	*Rhu Slancia, Acacia Karroo, Ziziphus Mucronata*
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406727.4	7142336.05	ML3	Dolomite	Medium	2		< 50%	1	5 – 4.8	3	> 80	3	10	*Acacia Karroo, Rhu Slancia, Ziziphus Macronata, Deermekar*
401671	7143978.49	ML4	Sedimentary	High	3		< 50%	1	1.5 – 3.8	3	> 80	3	11	*Ziziphus Macronata, Olive Tree, Acacia Karroo*
403878	7191784	P1	Shale	High	3		50 – 79%	2	0.5 – 4	3	< 50	1	550	Dominantly *Acacia Karroo*
404546	7192807	P2	Quartzite	Low	1		50 – 79%	2	1.8 – 7.5	3	70	2	570	Dominantly *Acacia Erioloba, Rhu Slancia*

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Null hypothesis (Ho) = there is no significant difference in mean reainfall between Zeerust and Mafikeng.

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Calculated t = 0.4512 , P= 0.65; therefore accept Ho and conclude that there is no significant difference in the mean rainfall between Zeerust and Mafikeng.