

**A REMOTE SENSING AND GIS SCHEME FOR RANGELAND QUALITY
ASSESSMENT AND MANAGEMENT IN THE NORTH WEST
PROVINCE, SOUTH AFRICA**

NAHOM GUDETA FAJJI

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University

SUPERVISER: Prof. L.G. Palamuleni

CO-SUPERVISOR: Prof. V. Mlambo

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AUTHOR'S DECLARATION

I hereby declare that the research work presented in this thesis has never been submitted in its fullness or in part to any other university for a degree. Therefore, it represents my own original work except where proper acknowledgements are made.

Nahom Gudeta Fajji

November 3rd 2015

Dedication

In memory of my parents

To my wife Grace, daughter Ruhammah and son Ammi

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Abstract

South African rangelands contribute 80 % of the total area of the country although most of them are believed to be degraded due to anthropogenic activities. In the North-West province of South Africa, degradation of rangeland is of concern mainly because of the long history of environmental and political neglect and over utilization of the land. The North-West province is characterized by three rainfall zones: low, medium and high with three major rangeland management regimes in the form of communal rangelands, protected areas and private ranches. Depending on the amount of rainfall and the type of rangeland management strategies, productivity level differs across the rangelands.

However, the differences in the productivity level among these rangelands have not been defined quantitatively in previous studies. The focus of this study was to determine the productivity level of different rangelands and quantitatively identify the underlying differences. Therefore, this study is an attempt to assess the ability of remote sensing SPOT-5 data in extracting and mapping rangeland biophysical information in three rainfall zones in the North West Province, South Africa. Vegetation indices (Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and the Spectral Mixture Analysis (SMA)) were computed and integrated with field based aboveground biomass data using regression technique. A remote sensing and GIS scheme for assessment of rangeland quality and management was established.

Results showed that high and medium rainfall areas are more productive than the low rainfall areas. The coefficient of determinations for the impact of rainfall distribution and temperature on above ground biomass (AGB) production was $R^2 = 0.47$ and 0.53 respectively. Significant differences ($P \leq 0.05$) between different rangeland management regimes across all the rainfall zones were observed. Thus, rainfall distribution, temperature during growing season and rangeland management strategies play major role in determining AGB productivity of rangelands. Evaluation of the performance of the vegetation indices for AGB estimation revealed that the SAVI performed well in the low rainfall areas but the coefficient of determination between the AGB and SAVI was not significant at $p \leq 0.05$. The SMA also performed better than the NDVI in low rainfall areas but because of its weaknesses in the high and medium rainfall areas this tool is not ideal for quantifying AGB in the North-West province. In spite of its weakness in the low rainfall areas, the NDVI had displayed stronger coefficient of determination with AGB. Hence, the NDVI was found to be the most efficient vegetation index for quantifying AGB in the North-West province.

Using GIS, several datasets topographic data, rainfall distribution data, remote sensing data, ground-based data, water resource data and distribution of animal unit data across rangelands were integrated in order to develop a *Rangeland Grazing Suitability Scheme*. The scheme provides a structure for monitoring grazing capacity of rangelands. This scheme shows the level of grazing that a particular rangeland should be exposed to and it could be very helpful for cattle ranchers and extension personnel in selecting areas for grazing for a given period of time. The scheme has a capacity for balancing forage availability in relation to forage demands by animal units. Results of the scheme showed that private ranches and protected areas in medium and high rainfall zones are highly productive with higher carrying capacity and available foliage to animals than the communal areas and the low rainfall zones. Private ranches and protected areas are under-grazed while the communal areas are exposed to high exploitation and overgrazing in all rainfall zones. In addition, distance to watering points was a limiting factor in accessing forage in the communal lands and *Molopo Nature Reserve* while slope played a major role in limiting forage accessibility in the *Pilanesberg National Park*. It is envisaged that adoption of this scheme by stakeholders and rangeland managers would increase the efficiency of rangeland monitoring process thereby increasing their productivity. The scheme has a capacity of balancing forage availability in relation to forage demands by animal units.

Key Words:

Above-ground biomass, communal rangelands, forage, GIS, NDVI, private ranches, protected areas, rangelands, remote sensing

ACRONYMS

AGB	Above Ground Biomass
ANOVA	Analysis of Variance
AUM	Animal Unit Month
AVHRR	Advanced Very High Resolution Radiometer
DEAT	Department of Environment Affairs and Tourism
DEM	Digital Elevation Model
ESRI	Environmental Science and Research Institute
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
GCP	Ground Control Points
GIS	Geographic Information System
GPS	Global Positioning System
GV	Green Gegetation
MESMA	Multiple Endmembers Spectral Mixture analysis
MODIS	Moderate-Resolution Imaging Spectroradiometer
MSAVI	Modified Soil Adjusted Vegetation Index
NDII	Normalized Difference Infrared Index
NDVI	Normalized Difference Vegetation Index
NLC	National Land Cover
NOAA	National Oceanic and Atmospheric Administration
NPV	Non-Photosynthetic Vegetation
NRLD	National Review of Land Degradation
RSME	Root Square Mean Error
SAVI	Soil Adjusted Vegetation Vndex

SMA	Spectral Mixture Analysis
SPOT	Satellite Pour l’Observation de la Terre
SR	Simple Ratio
SWIR	Shortwave Infrared
UN	United Nations
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator

CHAPTER ONE

1. BACKGROUND TO RANGELAND MANAGEMENT

1.1 Introduction

A rangeland is any extensive area of land that is occupied by native herbaceous or shrubby vegetation, which is grazed by domestic or wild herbivores (Rudolph, 2009). The vegetation of rangelands may include tall grass prairies, steppes or short grass, desert shrub lands, shrub woodlands, savannahs, chaparrals, and tundra. Rangelands thus occupy about 40–50% of the land area of the Earth and provide valuable grazing lands for livestock and wildlife (Mitchell, 2010). They are habitat for a wide array of game and non-game animal species, home for a diverse and wide range of native plant species, source of high quality water, clean air and open spaces, hunting and nature experiences, as well as the foundation for low-input, fully renewable food and fibre production systems of grazing industries (Mannetje, 2001). Due to the diversity of goods and services derived from rangelands, their management and health are linked closely to the economic well-being of many communities (Pelser, 2001).

In South Africa, rangelands cover more than 80% of the land surface and are critical for sustained supply of essential ecosystem goods and services (Hoffman & Todd, 2000; Shackleton *et al.*, 2001). These resources contribute highly to the economic development of the country through agriculture and provision of food products (Havstad *et al.*, 2007). Large and small scale commercial and subsistence livestock production depends largely on rangelands. In the North West province of South Africa, degradation of rangelands is of concern mainly because of the long history of environmental and political neglect; and over-utilization of the land. This situation has been attributed to the high human population as people were involuntarily forced to settle and confined into smaller areas in communal lands, as well as inappropriate range management systems in privately owned commercial lands (Hoffman & Todd, 2000; Shackleton *et al.*, 2001); loss of vegetation cover, changes in plant species composition, bush encroachment, and other forms of range degradation in general (Hoffman & Ashwell, 2001).

Management of rangelands is very crucial and requires taking diverse issues into account. One of the issues that rangeland management should consider is livestock that is a major means of

livelihood in arid and semi-arid regions (Harrington *et al.*, 1984). Degradation of rangelands is mainly attributed to the stocking rate of livestock in a given area. It should, however, be noted that degradation of land and vegetation is mainly a consequence of complex interactions between climate, inappropriate resource management practices, policies and regulations, lack of law enforcement and political dominance of groups or individuals in addition to unsustainable grazing pressures (Mitchell, 2010). Adopting sustainable alternative strategies for rangeland management is thus believed to improve and give more power to local people to protect the environment within the existing ecosystem and traditional social structure as well as networking. Therefore, relevant management strategy depends on careful inventory and monitoring of the resources found on these lands. According to Tueller (1995), remote sensing and GIS are considered to be powerful techniques in assessing the conditions of rangelands over a larger area across the world. Hence, this study will develop a GIS and remote sensing scheme for monitoring and managing rangeland conditions in the North-West province of South Africa.

1.2 Problem statement

The National Review of Land Degradation that was compiled in 1996 observed that communal lands (land contemplated in Section 2, which is, or is to be, occupied or used by members of a community subject to the rules or custom of that community (Communal Land Rights Act, 2004)) in the North-West province, South Africa, are widely degraded compared to protected areas (A geographical space, documented, committed and managed, through legitimate or other effective methods, to accomplish a lasting protection of nature with coupled ecosystem services and cultural values (Millennium Ecosystem Assessment, 2005)), commercial farms and/or privately owned ranches (extensive land which can be used for livestock rearing or private game reserve) (Hoffman *et al.*, 1999; Hoffman & Todd, 2000). Hoffman & Todd (2000) and Wessels *et al.* (2007) reported that highly degraded communal lands are characterized by high human and livestock density, overgrazing, soil erosion and the loss of more palatable grass species and bush encroachment. Given the high population growth rate of the indigenous population resulting from natural increase and forced resettlement, communal lands of the North-West province have been highly degraded due to overgrazing and intensive farming (Wessels *et al.*, 2004). Fragmentation of rangelands caused through politically induced racial discrimination resulted in an uneven distribution and privatization of land. This coupled with drought, which is a common phenomenon of the region, laid a foundation for high disparities in

the level of rangeland productivity among communal lands and commercial lands in the province (Vogel & O'Brien, 2003). However, quantitative measures of rangelands on these conditions and their change in space and time due to degradation have not been reported in this area. Few studies have been commissioned to understand the differences in the level of degradation of these rangelands, which are managed under different rangeland regimes (Shackleton, 1993; Snyman, 1998; Hoffman *et al.*, 1999; Dube & Pickup, 2001; Wessels *et al.*, 2004; Wessels *et al.*, 2007; Munyati & Mboweni, 2013). This is mainly due to lack of well-established methodology for the assessments and quantification of the qualities of these rangelands. Therefore, up-to-date information to plan a proper rangeland management strategy is vital.

1.3 Study area

The North-West province of South Africa is located between 22°39'21" E and 25°17'28" E and 24°43'36"S and 28°00'00"S. It includes four districts namely: Ngaka Modiri Molema, Bojanala, Dr. Kenneth Kaunda, and Dr. Ruth Segomotsi Mompati.

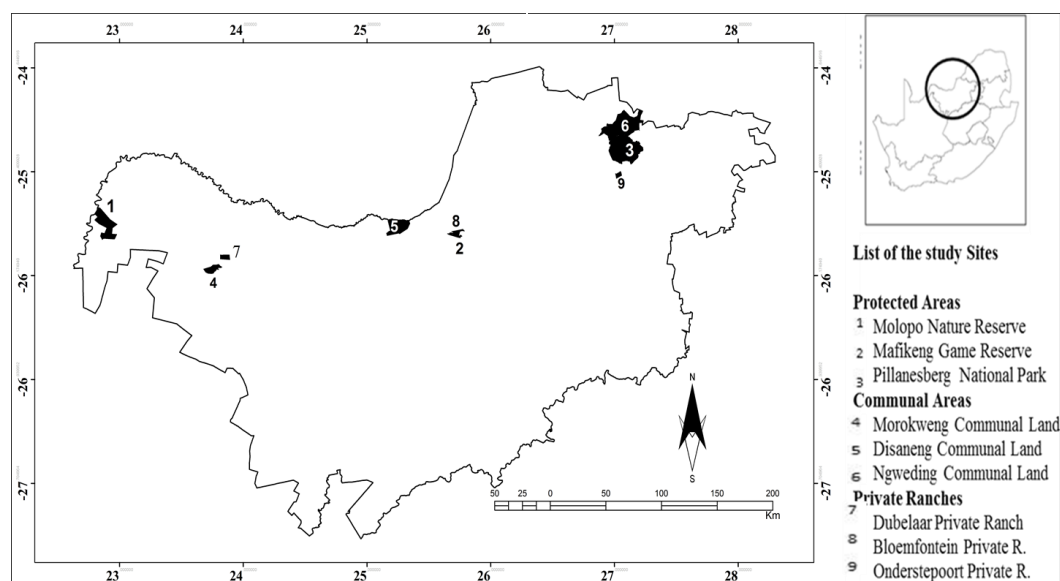


Figure 1: North-West province and the locations of the study sites

Most of the North-West province (71%) falls within the Savanna biome, while the remaining part falls within the Grassland biome (Mangold *et al.*, 2002). According to Schultze, (1997) and Hudson (2002), there are four types of ecological zones in the North-West province, namely:

the Highveld in the south-east, the Bushveld in the north-east, and the Middleveld as a narrow zone between the Highveld and the Bushveld, and the Kalahari Desert in the west. The climate of the Province is characterised by well-defined seasons with hot summers and cool sunny winters. The province has the most uniform terrain of all the provinces, with an altitude ranging from 920-1782 metres above sea level (Mangold *et al.*, 2002).

1.3.1 Climatic conditions

According to FAO's annual rainfall distribution and climatic classification in South Africa, the North-West province can be classified into three major rainfall zones based on the average rainfall received, namely: arid (low rainfall zones (200 - 400 mm)), semi-arid (medium rainfall zones (401- 600 mm)), and sub-humid (high rainfall zone (601 – 800 mm)). Rainfall varies from the more mountainous and wetter eastern region to the drier, semi-desert plains of the Kalahari in the west. Climatic conditions vary significantly from west to east. The far western region is arid (receiving less than 300 mm of rainfall per annum), encompassing the eastern reaches of the Kalahari Desert. The rainy season usually occurs from October to March which is summer season with more sunshine days and warm temperatures. The province has a higher average rainfall per annum compared to the South African average (Table 1). Therefore, the area has a higher advantage for agricultural activity than the country's average (Masigo & Matshego, 2002). However, most parts of the province have not enough rainfall and surface water. Consequently, shortage of water affects the extent of soil fertility to sustain large scale crop production in the region (Vogel, 1994; Cowling *et al.*, 1997; Mousa *et al.*, 2007).

1.3.2 Soils and vegetation

The western part of the province is dominated by the Kalahari Thornveld and shrub bushveld while the central part is predominantly sour and sourish mixed bush veld. The eastern part is a mixture of other turf thornveld and mixed bush veld (Masigo & Matshego, 2002). The predominant soil characteristics are red-yellow apedal soils which have low clay content particularly in the western parts of the province, followed by plinthic catena and glenrosa and mispah forms. On the other hand, Leptosols and Regosols are found on mountainous terrain in the study area. Leptosols are defined as very shallow, azonal soils overlying continuous rock or extremely gravelly and stony basements, which develop in the presence of hard and weathering rock that allows only minimal pedological development (FAO, 2005).

Table 1: Comparison of climatic elements of the North-West province and South Africa

Climate	South Africa	North West Province
Temperature °C (January)	24.10	20.90
Temperature °C (July)	12.00	12.20
Average rainfall (January) mm	117.00	15.00
Average rainfall (July) mm	3.00	82.00
Number of rain days (January)	13.00	6.00
Number of rain days (July)	1.00	12.00
Sun days (January)	23.00	28.00
Sun days (July)	24.00	16.00
Annual Rainfall (mm)	539.00	515.00

Source: The South African Weather Service

1.1.3 Land use in the North-West province

Land use in the North-West province includes commercial farming, subsistence cultivation, and game reserves (e.g., Madikwe, Mafikeng, and Botsalano game reserves, Pilanesberg National Park, Molopo nature reserve and private game reserves, commercial cattle ranching and communal grazing). The natural vegetation varies from indigenous woodlands to open grasslands but primarily comprises savannah woodlands and thickets. According to Worth (1987) and Department of Environmental Affairs and Tourism (DEAT) (2001) the North-West province is also one of the areas that provide a large proportion of South Africa's livestock production. This area was politically and economically neglected for a long time by the apartheid regime (Hoffman & Ashwell, 2001). This scenario imposed unsustainable land use practices that were associated with rangeland degradation. Although rangeland degradation in this area has been investigated by many, there is conspicuous absence in the literature of concerted attempts to reconstruct long-term trends of this dynamic. This investigation attempts to bridge this gap by making an objectively premised time series assessment of long term changes in land use and land cover in this environment.

According to Masigo & Matshego (2002), 28.3% of the total area of the North-West province is arable land, 56.8% is grazing land, game reserves is 6.4% and 8.5% land is occupied by housing. The bulk of the agricultural land is situated in the Ngaka Modiri Molema District Municipality (about 8 400 square kilometres) which is double the figure of Dr Ruth Segomotso Mompati District Municipality at approximately 4700 square kilometres. Most of the commercial agricultural lands are concentrated in the Ngaka Modiri Molema District

Municipality, Dr Kenneth Kaunda District Municipality and Dr Ruth Segomotso Mompati District Municipality which have approximately 4 200 square kilometres each. The location of semi-commercial and subsistence farming is mainly concentrated in the Ngaka Modiri Molema District Municipality and Bojanala Platinum District Municipality areas. The latter scenario is closely correlated with the distribution of land under control of tribal authorities in the North West (DEAT, 2001; Palmer, 2008). The high rainfall zone generally is located in the great escarpment of South Africa which forms the major barrier to the moisture that reaches the interior part of the country (Palmer, 1998; Pretorius, 2009), whereas the medium and low rainfall zones are located in the flatter and lower lands in the north western and western parts of the country.

1.4. Specific study areas

1.4.1 Low rainfall zone

The low rainfall zone in the North-West province is characterized by seasonal precipitation with annual rainfall falling mostly in October to March (80%) and in winter (20%) from April to September (Figure 2) (Mangold *et al.*, 2002). Specific climatic characteristics is semi-arid summer rainfall with very dry winters at Morokweng site, and the Molopo Nature Reserve site is characterized by summer and autumn rainfall with very dry winters. Mean annual precipitation in these regions varies between 250 and 400 mm with frequent frost in winter (Figure 2).

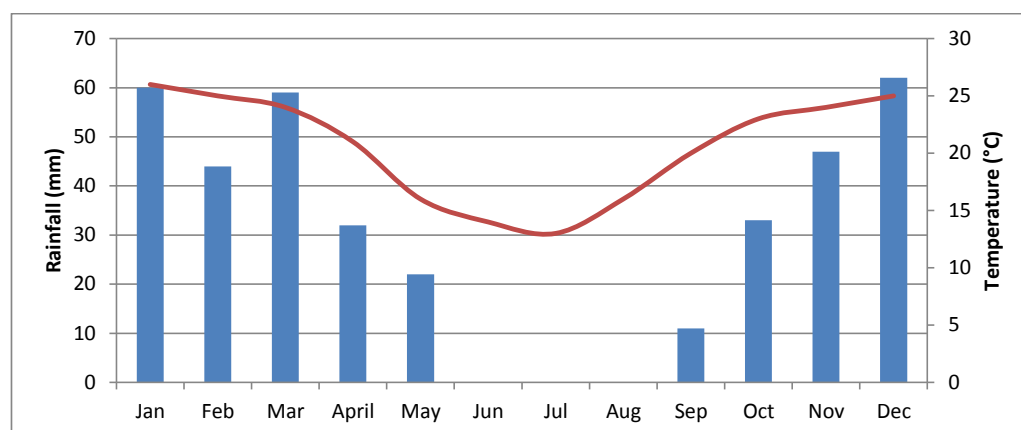


Figure 2: Average annual rainfall and temperature in the low rainfall zones of the North West province

(Source: South African Weather Service)

The vegetation in this area is classified as the savanna biome, dominated by the Kalahari thornveld and shrub bushveld vegetation type (Low & Rebelo, 1996; Tainton, 1999). It was described as the Eastern Kalahari Bushveld recently (Mucina & Rutherford, 2006). The vegetation is characterized by a moderately well-developed tree layer with *Acacia erioloba* and *Boscia albitrunca* as dominant trees, along with isolated individuals of *Acacia luederihii* and *Terminalia sericea* (Moussa *et al.*, 2009a). The shrub layer is moderately developed and individuals of *Acacia mellifera*, *Acacia hebeclada*, *Lycium hirsutum*, *Grewia flava* and *Acacia haematoxylon* are the most abundant ones. Grass species such as *Stripagrotis uniplumis*, *Eragrostis lehmanniana* and *Schmidtia kalahariensis* are common (Low & Rebelo, 1996). The dynamics of vegetation in these ecosystems are affected by natural hazards such as drought and highly variable precipitation (Vetter, 2005; Nkambwe & Sekhwela, 2006) though the ecosystem can develop adaptation to cope with this phenomenon (Moussa *et al.*, 2009b). During the growing season, the grass cover changes depending on the amount of rainfall. The high grazing intensity, especially in the communal areas, by livestock and the erratic rainfall are changing the composition of this vegetation (Low & Rebelo, 1996). High grazing pressure associated with selective grazing promotes the expansion of less preferred grass and woody species while erratic rainfall favours deep rooting woody species at the expense of shallow rooting grass species leading to facilitated expansion of woody species hence bush encroachments. In this region of the North West Province, the ecological transition of grass-dominated rangelands into more uniform shrub-encroached communities is dominated by *Acacia mellifera*, poses a threat to agricultural activities (Mangold *et al.*, 2002; Thomas & Dougill, 2007).

The soils are predominantly sandy depositions where oxidic and lithic soil groups are dominant (Soil Classification Working Groups, 1991) with calcretes along the riverbed of the fossilized Phepane and the Molopo River (Moussa, 2009a). Red and yellow sandy, well-drained soils with a high base status dominate the low rainfall zone (Agricultural Geo-referenced Information System (AGIS), 2010). Sand dunes occur near the drainage valleys such as the Molopo River (Van Niekerk, 2011). The Gordonia Formation, informally termed Kalahari sand, is a deep, red aeolian sand of recent age with surface *calcrete*, *silcrete* and *ferricrete* (Low & Rebelo, 1996; Rutherford *et al.*, 2006) that covers most of the underlying Kalahari Group sediments in this region (Partridge, 2006). Plant transpiration is higher than the actual precipitation, significantly resulting from the high evaporation rate of soils and the surrounding atmospheric conditions due to the high temperatures (Mucina & Rutherford, 2006).

1.4.2 Medium rainfall zone

The medium rainfall area has a predominantly semi-arid climate based on the Thornthwaith's classification method (Fajji *et al.*, 2011). Average annual rainfall in the region varies between 450mm and 600mm (Figure 3) which most of it occurs during the summer season (November – April). Because of the higher evapotranspiration rate in the area, the amount of rainfall received is always insufficient to support agricultural activity. The potential evapo-transpiration rate reaches about 1300mm during the rainy season (summer) compared to the actual amount of rainfall received. The potential evapotranspiration is almost about 4 to 5 times the actual rainfall. Daily average air temperature varies from 10°C to lower 20s in winter and from 16°C to 30°C during the summer season. Maximum air temperature during the summer goes up to 35°C and the minimum drops to 0°C during the winter season. Maximum, minimum and average humidity is 61, 49.5 and 30.6 respectively (South African Weather Service (SAWS), 2012). Vast area of this region used to be a typical agricultural area in semi-arid climate.

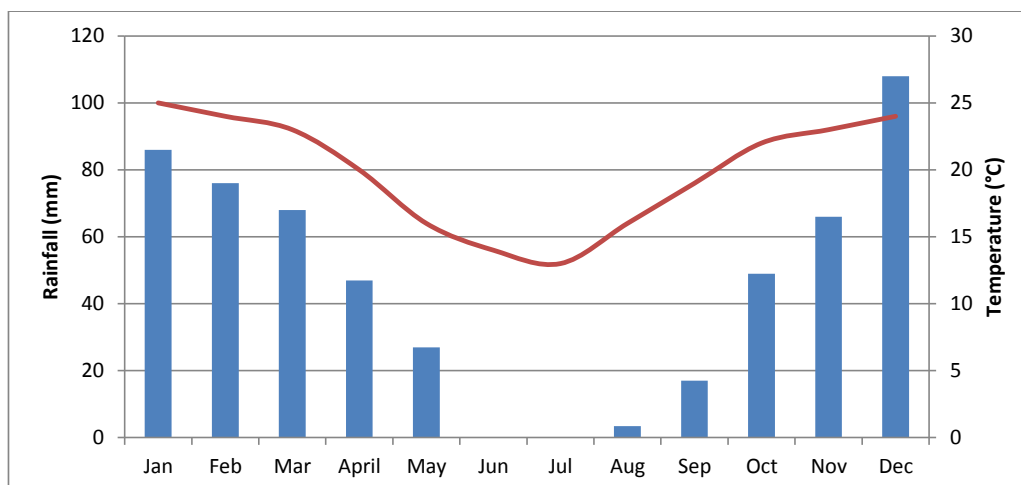


Figure 3: Rainfall and temperature distribution in the North-West province (Source: South African Weather Service)

The landscape of the region is relatively flat with plains (Seitlhamo, 2002). The elevation ranges from 2000-1400 metres above mean sea level. Andesitic lavas of the Allanridge Formation, Ventersdorp Supergroup are dominant (Mucina & Rutherford 2006) with weak drainage system; hence evapotranspiration rate from the soil surface is high. The area has been affected during different drought events in the region (Hoffman & Ashwell, 2001). The region is dominated by a combination of dry land cropping and livestock production. Agricultural activity in the area is characterized by increased fallow lands and lower yield per unit area

(Bachtair *et al.*, 2003). The reasons for the decline in crop production is the change in the government policies, more particularly the decrease of government support to the farmers in the areas such as agricultural finance, fencing, mechanization and extension services and changes in rainfall over time (Bachtair *et al.*, 2003). Acocks (1988) classified the savannah vegetation as mixed bushveld. Mucina & Rutherford (2006) reclassified the vegetation as dry *Cymbopogon-themeda* veld. Well-developed tree and shrub layer, dense stands of *Terminalia sericea*, *Acacia luedenritzii* and *Acacia erioloba* in certain areas are common types of trees in the region. Shrubs include *Acacia karoo*, *Acacia hebeclada* and *Acacia mellijera*, *Dichrostachys cinera*, *Grewia java*, *Grewia retinervis*, *Rhus tetrinervis* and *Ziziphus mucronata*. The most common grasses in this region according to Adcock (1991) are *Enneapogon scoparius*, *Cymbopogon plurinodis*, *Heteropogon contortus*, *Themeda triandra*, *Elionurus muticus*, and *Eragrostis lehmanniana*.

1.4.3 The high rainfall zone

The high rainfall zone is located within the vast savannah biome and it is considered as one of the many landscapes found on the extensive undulating interior plateaus of South Africa with its altitude ranging between 1200-1500 meters above mean sea level. This region is characterized by isolated rings of the Pilanesberg Alkaline Ring Complex, which arises from the surrounding flat bushvelds plains. The formation of this crater gave birth to a rugged landscape offering a wide topographical variety, consisting of rocky outcrops and ravines with intervening valleys. The soils in this region are commonly shallow, stony and low in humus content due to superficial weathering and decomposition of organic matter (De Villiers & Mangold, 2002). The widespread soil types are Cambisols, vertic black clay soils and Regosols. The vertic black clay soils are mainly found in the basic and ultrabasic igneous rock, around Pilanesberg National Park (De Beer *et al.*, 1987).

The climate of this region is influenced by two air masses of different origin (World Water Assessment Programme, 2009), the Inter Tropical Convergence Zone and the sub-tropical eastern continental moist maritime air masses with contrasting seasons: wet hot summer months and mild to sunny warm winters (Burgess *et al.*, 2004). The temperature of the region is generally governed by the topography of the area ranging from 22°C to 34°C in summer and 16°C to 20°C in winter. The temperature fluctuation corresponds with seasonal rainfall patterns in the region (Van der Meulen, 1978). Rainfall is highly seasonal (Figure 4) with around 90% of the annual precipitation occurring in the summer months between October and April (World Water Assessment Programme, 2009). The mean annual rainfall ranges between 600-800mm.

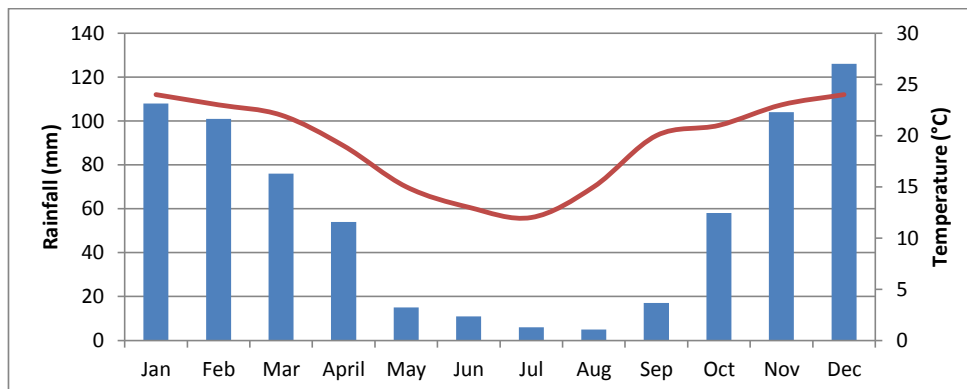


Figure 4: Average annual rainfall and temperature in the high rainfall zones of the North-West province

(Source: South African Weather Service)

This region comprises of various vegetation types with a continuous and dominant grass stratum intermixed with woody elements of differing height and density (Van der Meulen & Westfall, 1979; Driver *et al.*, 2005). The vegetation classification by Acocks (1988) and Low & Rebelo (1996) correspond with the physiographic divisions of the region. Mixed Bushveld savanna parkland occurs predominantly in the gently undulating terrain in this region (Cole, 1996). The red to greyish gravelly sands of this area supports a combination of closed parkland and open woodland savanna characterized by different vegetation elements, such as: *Spirostachys africana*, *Acacia tortilis* and *Acacia nilotica* trees, *Carissa bispinosa* and *Euclea undulata* shrubs, as well as the grasses *Sporobolus iocladius* and *Heteropogon contortus* (Cole, 1996; Mucina & Rutherford, 2006).

1.5 Justification of the study

South Africa as a whole is characterized by extremely high rangeland degradation with severe ecological and economic consequences (Dean & MacDonald, 1994; Snyman, 1998; Hoffman & Todd, 2000; Dube & Pickup, 2001) resulting from highly contrasting rangeland management regimes (Wessels *et al.*, 2007). According to Wessels *et al.* (2004), the land tenure system, climatic conditions and livelihood strategies are the major causes of rangeland degradation. The study area is the North-West province of South Africa. The study area was chosen because it includes many of the extensively degraded rangelands according to National Land Cover (NLC) and National Review of Land Degradation (NRLD) (Liniger & Van Lyden, 1998; Botha and

Fouche, 2000; Hoffman & Ashwell, 2001) and it also includes fertile and productive soils, mainly in privately owned farmlands.

Remote sensing and GIS are powerful tools that have the potential to assist in obtaining accurate information for mapping and monitoring of natural environments; particularly rangelands in different ecosystems (Tueller, 1995; Wessels *et al.*, 2007). Multispectral and hyperspectral remote sensing and GIS have been used for several decades in monitoring and mapping of vegetation distribution in degraded areas (Okin *et al.*, 2001; Pinet *et al.*, 2006). Hence, the priority of this study was to establish a remote sensing and GIS scheme that combines ancillary data and satellite imagery data in assessing the quality of rangelands and extent of rangeland degradation under different management systems in the North-West province of South Africa.

Up-to-date information is essential for enhancing our understanding of why the extent of these problems appear to be mainly caused by high population and environmental stresses caused by political, social and natural factors. This study is therefore, designed to establish a remote sensing and GIS scheme for rangeland quality assessment and management scheme that can be used in the North-West province of South Africa.

1.6 Research aim and objectives

1.6.1 Aim

The aim of this study was to establish a remote sensing and GIS scheme for assessment of rangeland quality and management of rangelands in the North-West province of South Africa.

1.6.1.1 Objectives

The aim of this project was to:

1. Assess rangeland quality status in North-West province using ground based data, remote sensing and GIS.
2. Identify biophysical indicators of rangeland quality that can be assessed using remote sensing and GIS.
3. Design a GIS protocol that integrates rangeland quality data for the management of the rangelands.

1.7 Research hypotheses

1. Due to high livestock and human population, communal grazing lands are much less productive than privately owned grazing lands or protected areas.
2. The spatial distribution of climatic factors such as precipitation and temperature dictate the biomass production in different rangelands of the North-West province.
3. Biophysical rangeland attributes of a spatial nature can be discriminated on high spatial resolution imagery.
4. Remotely sensed rangeland variables can be integrated with ancillary data in a GIS environment for ecologically sustainable management of rangelands.

1.8 Organization of the thesis

This subsection provides an overview of how the remaining chapters of this thesis (chapter 2-7) are organized.

Chapter 1 provides an overview of the research, objectives and aim, research hypotheses, and a general introduction of the different sections of the thesis. It also presents detailed information about the study area including the description of the general location, topography, climate, geology, vegetation, and soil.

Chapter 2 is a review of relevant literature on issues of rangeland management and application of remote sensing and GIS methodology.

Chapter 3 is an assessment of the current rangeland qualities and pasture lands based on ground based data and climatic data.

Chapter 4 presents results of image classification in the form of map outputs that show different land cover types that were mapped and tables that show area coverages of these land cover types.

Chapter 5 explores the ability of appropriately selected remote sensing techniques that were used to estimate different biophysical variables. This chapter also examines the suitability of conveniently selected vegetation indices for quantifying aboveground biomass.

Chapter 6 focusses on development of GIS model (not on a GIS model development) for rangeland management in arid and semi-arid areas (not for arid and semi-arid rangeland management).

Chapter 7 provides a synoptic overview of the major findings of this investigation and an assessment of the strengths and weaknesses of the different GIS and remote sensing techniques that were used and concludes by providing suggestions for future studies.

1.9 Limitations of the study

Limitations that were encountered during this study were lack of historical or background data about the vegetation distribution and rangeland health conditions. As this study indicated in the methodologies and materials, the study sites were randomly selected as representative of the major three rainfall zones in the North-West province. However, there was no well documented information on important indicators of rangeland health conditions for the communal rangelands and private ranches. Moreover, results from the few plots that were studied, provide a generalized view of rangeland productivity at a local scale.

Generalization of results based on what was observed in the field from the few sample plots at local and landscape level is very speculative due to high levels of spatial variations in nature of different biophysical variables. This makes generalization of results from the different rainfall zones and different rangeland management regimes on the impacts of grazing and nature of rangeland management strategy very difficult (variation in the nature of rainfall distribution, temperature, soil type) in spite of the common assumption of the impacts of rainfall distribution and management strategies and grazing effects on the selected sample sites.

In this study, satellite data between February and March was supposed to be used but for some of the study sites accessing SPOT-5 imagery for these two months was not possible. However, this problem was complemented by accessing early April, 2014 imagery. Research on assessing rangeland conditions based on limited ancillary data and short period ground based data could not be enough to fully understand conditions of rangelands changes and draw conclusive

evidence on rangeland management strategies and impacts of climatic factors on the levels of rangeland productivity as well as develop meaningful grazing practices. However, the output of this research gives a very important insight on the general condition of rangelands in the North-West province, South Africa.

CHAPTER TWO

2. THE LITERATURE REVIEW

2.1. Introduction

This chapter analyses previous literature on conditions and usefulness of rangelands in South Africa and the application of remote sensing and the geographic information system (GIS) for rangeland quality assessment and management. The conceptual framework used for this study is discussed.

2.2 Rangeland models

In search for appropriate range management strategies, ecologists have proposed different theories ranging from the dated Range Succession model, the State-and-transition Model and the more recent framework known a Sustainable Rangeland Management. These models are summarized in subsection 2.2.1-2.2.3 below.

2.2.1 The Range succession model

The successional approach was derived from Clementsian ideas of plant ecology (Tobey, 1981; Westoby *et al.*, 1989). This model assumes that a rangeland at a given place has a single persistent state in the absence of grazing. High grazing pressure produces changes in a direction opposite to the successional tendency (Westoby *et al.*, 1989). Grazing pressure is the stress on plant populations due to the grazing of animals (Holechek *et al.*, 1999). By adjusting the stocking rate and the grazing pressure, it is possible to produce an equilibrium in the conditions of vegetation. The object of management under the range successional model is to identify a stocking rate that establishes a long term balance between grazing pressure and the succession tendency (Westoby *et al.*, 1989; Yates & Hobbs, 1997; Briske *et al.*, 2003; Wessels *et al.*, 2007). The model assumes that drought and high grazing intensity have similar impacts on plant communities and that overgrazed or drought damaged range can recover by resting or reducing stocking rates. However, this model has been criticized for its failure to take into account the vegetation changes in response to heavy grazing which can result in an irreversible, not consistent and remitting condition (discontinuous) condition (Westoby *et al.*, 1989; Briske *et al.*, 2003; Wessels *et al.*, 2007).

2.2.2 The State-and-Transition model

This model organizes rangelands by means of catalogues of possible transition between different vegetation states. According to this model a combined effect of climatic and management actions are major requirements for the transition to take place (Westoby *et al.*, 1989; Yates & Hobbs, 1997). This model is helpful in documenting our understanding of how different processes result in patterns in an ecosystem. The model defines the different discrete types of vegetation called “states” that occur as a result of an area’s characteristics like climate, soils, history, or disturbances. However, this model does not give much emphasis to the natural capabilities of the ecosystem’s self regulation and stability but focussed largely on the importance of climatic and other environmental variables and their impacts on the states of the plants which are all external driving forces of ecosystem behaviours (Van de Koppel *et al.*, 2002; Briske *et al.*, 2003).

2.2.3 The Sustainable Range Management strategy

Rangeland ecosystem health is defined as “the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained” (National Research Council (NRC), 1994). The amount and type of soil erosion are one set of indicators on the degree of rangeland health; the amount of plant production and plant residue are other indicators of a healthy ecosystem (Pellant *et al.*, 2000). This framework integrates social, economic and ecological elements of rangelands. The sustainable rangeland management strategy requires resource conservation to meet the needs of future generations and recommends optimum exploitation and utilization of goods and services to satisfy the desires of current and future generations (Mitchell, 2010; Clarke & MacDonald, 2012). After the relevancy of the sustainable resource management strategy has been evaluated for the purpose of analysing the conditions of the study area, it has been chosen as guidance in this research.

2.3 Conceptual framework

The sustainable rangeland management framework (Mitchel, 2010) is taken as the conceptual framework for this study. The framework has 64 indicators. In this study, attempts have, however, been made to reduce the indicators to seven by selecting only those which could best fit into remote sensing and GIS model. The selection criteria are based on measurability using existing remote sensing and GIS techniques, analytical soundness, clear time frame and easiness of interpretation and comprehensibility. The seven indicators are outlined below.

2.3.1 Area and percentage of rangeland with a significant change in bare ground

The importance of measuring bare ground is a function of its direct relationship to erosion risk (Mitchel, 2010). Known values of the proportion of a bareground as an indicator of changes in land management and watershed function are very important (Kiyani, 2013). This indicators can be monitored over extensive areas with relatively lower costs using remote sensing techniques (Booth & Tueller, 2003).

2.3.2 Rangeland area by plant community

This indicator describes rangeland plant communities and their arial extents, with the difference between times being a reflection of temporal changes based on South African plant community description. The integration of remote sensing and GIS technology and ground sampling in a probability based sampling design would simplify the process (Franklin & Wulder, 2002).

2.3.3 Above-ground biomass

Biomass is the mass of plants per unit area at a given time. It is a direct measure of plant production, carbon storage and energy availability for potential grazers (Mitchell, 2010). Biomass production is highly variable due to precipitation, temperature, soil quality and other factors and monitoring can be done using remote sensing (Nemani *et al.*, 2003; Booth & Tueller, 2003).

2.3.4 Area and percentage distributions of rangeland by accelerated water and wind erosion

Soil erosion by wind or water causes the loss of all or part of the surface horizon. Soil surface horizons of soils are important to maintain because they contain most of the organic material and are the exchange medium for transferring nutrients from the soil to plants. Losses of soil through erosion may lead to reductions in vegetation productivity of a site (Dormaar & Williams, 1998; Davenport *et al.*, 1998). Because upper soil horizons, typically contain the highest organic matter and nutrient content, this component of the soil generally controls the rate of water infiltration and plant establishment and growth (Telis, 2001). Excessive erosion can contribute soil sediments to waterways thereby reducing water quality (Mitchel, 2010). Although Remote-sensing techniques can provide information on soil erosion, their utility has not been adequately explored. Hence, additional research to perfect and test various methods for obtaining accurate data over larger areas is highly needed. Recent publications using large scale imagery may be useful for measuring erosion features (Booth *et al.* 2005; Booth & Cox, 2008).

2.3.5 Fragmentation of rangelands

Rangeland fragmentation is a loss of connectivity of rangelands or rangeland cover types (Mitchell, 2010). Fragmentation can affect plant and animal species and ecosystem functions. Okin *et al.* (2009) described fragmentation as an interruption process affecting the sustainability of rangeland ecosystems. In arid and semi-arid lands, this can impact the social and economic system by causing habitat loss, limiting options of people and animals, options that are particularly important in temporally heterogeneous environments (Hobbs *et al.*, 2008).

2.3.6 Proportion of available rangeland grazed by livestock

The proportion of available grazing rangeland measures the availability of suitable rangelands for domestic animals on an annual basis (Mitchell, 2010). Information on land use pattern can be acquired from the area of rangeland grazed by livestock and it can also be influenced by non-livestock commodities and wildlife. Using a habitat suitability approach, the data on rangeland grazed by livestock can be collected (Wade *et al.*, 1998).

2.3.7 Intensity of human uses

Intensity of human rangeland usage as an indicator provides an alternative measure of intensive human use of rangelands through the assessment of road density and housing densities (Radeloff *et al.*, 2010). Intensive human uses of rangelands are ubiquitous thus this indicator is meaningful in all geographic areas (Theobald, 2003). Human intensive use of rangelands causes loss of different species and fragmentation of the ecosystem. This increases open spaces enhancing susceptibility of soil to wind and water erosion, creating opportunities for successful establishment of invasive plants and animals; and reduced primary and secondary productivity and biodiversity of rangelands (Forman & Alexander, 1998).

2.4 Knowledge gaps identified

In 1994, the National Research Council of the United States of America suggested that the focus of rangeland management should be related to ecosystem health and holistic management of landscapes (Mitchel, 2010). However, due to differences between the information needed by range managers and information provided by scientists (Tueller, 1995; Hunt *et al.*, 2003), efficient ecosystem management has not yet been attained. The progress in holistic management of landscapes is hindered by inadequate and unreliable ecosystem information on past and present processes and structural conditions of target ecosystems (Sample, 1994). In addition, the inconsistencies of techniques and methods used for monitoring and managing these

target ecosystems and insufficient knowledge of GIS and remote sensing techniques are contributing to the inefficiency of the current rangeland management systems (Booth & Tueller, 2003; Hunt, 2003). Hence, the focus of this research is to identify GIS and remote sensing approaches that provide viable techniques for rangeland management in the North West Province, South Africa.

2.5 Characteristics of dryland ecosystems

Drylands are comprised of areas that receive low rainfall compared to their potential evapotranspiration rate at a growing periods of 1-179 days (FAO, 2000). About 45 percent of the total land surface is occupied by dry lands and close to 30 percent of the world's total carbon in above-and-below ground biomass occurs in drylands (Mainguet, 1999). Drylands are classified into grasslands, shrublands, savannas, xerophytic woodlands, and hot and cold deserts based on the value of an aridity index. This index is calculated as the ratio of annual precipitation to annual potential evapotranspiration. According to this method drylands are classified into hyper-arid (<0.05), arid ($0.05-0.20$), semi-arid ($0.20-0.50$), and dry sub-humid ($0.50-0.65$). Yearly rainfall patterns of drylands are characterized by a dry period which is different from 2 to 10 months in different regions (Wang *et al.*, 2012).

Seasonal precipitation is one of the major climatic variables in drylands. Vegetation in these regions suffer from shortage of water but it can develop adaptations to cope with this phenomenon. Lack of water in the soil is caused by the high evaporation of water from the soil and the surrounding atmosphere coupled with high plant transpiration due to the high temperatures (Propastin, 2006). In addition, the soil and climate characteristics highly affect the composition and distribution of plants in drylands. Due to moisture deficiency throughout the growing period of vegetation, drylands' plant species show a high degree of adaptation to aridity, exhibiting a large variety of grasses, shrubs, and forbs present in drylands. Generally, in dry regions ecosystem dynamics are affected by natural hazards such as drought and desiccation.

Ecologists highlight high dependency of arid and semi-arid rangeland ecosystems on climatic conditions (Vetter, 2005; Robinson *et al.*, 2008). The high climatic variability in drylands is a result of the high precipitation variations. The coefficient of variation of rainfall in these regions is between 25-40 %. Many studies in dry regions have revealed that long-term ecosystem behavior can be explained better by rainfall variations than by the mean annual

rainfall (Shepherd & Caughley, 1987; Ellis *et al.*, 1994). Since the 1970s, environmental monitoring using remote sensing and GIS has provided reliable means for monitoring ecosystem variations and ecosystem changes, land degradation as well as their causal relationships (Booth & Tueller, 2003). Satellite data detect patterns of inter-annual and seasonal variations in land surface features as a result of climatic changes and human activities (Propastin *et al.*, 2006). Basically, ecosystem variations are affected by drought and desiccation (Lambin & Ehrlich, 1996), fluctuations in rainfall (Anyamba *et al.*, 2001; Olsson *et al.*, 2006; Balas *et al.*, 2007), and temperature increase (Xiao & Moody, 2004). Most of the previous research about ecosystem dynamics in dry regions indicated that monitoring of land degradation and desertification need to analyze climatic data and satellite images over a long period of time (Nicholson *et al.*, 1990; Wang *et al.*, 2003; Robinson *et al.*, 2006).

2.6 Importance of rangelands in South Africa

Numerous attempts have been made to estimate the total rangeland area in South Africa (Wessels *et al.*, 2007). Approximately 80% of the total land area in South Africa is rangelands (Palmer & Ainslie, 2007). Rangelands are major terrestrial ecosystems in the country and play an essential role in the economy of the country (Hudak, 1999). Rangelands provide medicinal plants, as well as herbs for animal feeding and meat production. For many pastoralists, rangelands are the major source of income (Naidoo *et al.*, 2013). Informal grazers also directly depend on rangelands for their livelihoods.

Although rangelands have been degraded in the recent decades, important goods and services are still obtained from them. Rangelands in South Africa are also the primary terrestrial store of carbon on account of their scale. Rangelands also provide habitat for different species of flora and fauna. In arid and semi-arid areas, the rangelands plant cover conserves the soil against erosion caused by flooding, and wind (Moghaddam, 2006). Furthermore, South African rangelands are important in terms of bio-diversity and rare species. Game reserves and tourism are increasingly important activities in rangeland areas in South Africa (Moussa *et al.*, 2009b).

2.6.1 Conditions of rangelands in South Africa

South African rangelands are facing severe degradation mainly due to heavy grazing by domestic livestock exacerbated by inadequate stock watering points (Hudak 1999; Roux and Vorster, 1983), bush encroachment, high population density and poverty (Hudak, 1999) causing reduced productivity of rangelands. In particular, rangeland degradation is a consequence of

anthropogenic activities, drought, climate change/climate variability, desertification and soil degradation (Majara, 2005; Salvati & Zitti, 2009). Drought has a negative impact on the general productivity of rangelands through reduced rain-fed crops, reduced availability of water for irrigation and reduction in the carrying capacity of rangelands to support grazing and lack of drinking water for livestock (Wessels *et al.*, 2007). Seasonal fluctuations of rainfall influence the concentration and mix of herbivores, and can cause a decline in water supply to a level that is insufficient to fulfill requirements for maintaining healthy rangeland productivity (Majara, 2005).

Overstocking leads to over exploitation and permanent transformation of grasses (Palmer & Ainslie, 2007). Insufficient watering points is another cause of rangeland degradation as most rangelands of South Africa are too dry as a result of natural climatic conditions which causes high concentrations of animals within the available few watering points. These sorts of concentrations by animals cause degradation of vegetation and soil resulting from trampling effects (Palmer & Ainslie, 2007). As the number and duration of grazing cycle increases, biomass is removed while, trampling of perennial grasses and destruction of plant root systems by livestock undermines recovery (Alkemade *et al.*, 2010). The roots of these grasses suffer from loss of above-ground vegetation parts and soil compaction, particularly when these vegetations are grazed heavily during flowering and seed time. Consequently, they produce fewer seed thereby decreasing the population species composition though this is influenced by the time of the year that a pasture is grazed. Hyder *et al.* (1975) pointed out that repeated heavy grazing during any particular month in the growing season of a year had nearly three times higher effect on major plant species as did grazing during the months when plants were senescent. Hence, the way at which a plant community responds to the effects of a specific grazing pressure depends on the season.

The communal areas of South Africa are the most degraded rangelands related to high rural population density and poverty. Rangelands in communal areas are used largely as a source of livestock feed in addition to providing secondary resources such as wild food, firewood, water and medicinal plants (Lesoli, 2011). Besides, the rural populace practice subsistence agriculture which is characterised by improper land management activities such as cultivation of fragile soils, reduced fallow, uncontrolled use of fire, diversion of rivers for irrigation purposes, or irrigation of inadequate soils; practices that result in aggravated soil erosion (Hoffman & Todd, 2000). Moreover, over-exploitation of natural vegetation for fuel wood, fencing and construction, are some of the impacts of human activities on the rangelands leaving the

rangeland without enough cover where the remaining vegetation no longer provides sufficient protection from soil erosion (Hudak, 1999; Hoffman & Todd, 2000).

The increase of bush encroachment phenomenon in South Africa is causing a decrease in palatable grass species which are substituted by less palatable trees and woody shrubs (Seymour & Desmet, 2009; Archer *et al.*, 2011). Bush encroachment is characterized by rapid spread of woody species across rangelands which displace native vegetation and disrupt important ecosystem processes, and that leads to reduction in rangeland carrying capacity (Bright, 1998; Kaiser, 1999; Van Wilgen *et al.*, 2008). The reduction in carrying capacity is of great significance because rangelands of South Africa contain a large and rapidly growing proportion of the country's population, including many commercial livestock farmers whose livelihood are threatened by these phenomena (Lamprey, 1983; Scholes & Archer, 1997; Hudak, 1999; Ward, 2005). Factors causing bush encroachment are poorly understood in South Africa or anywhere else in the world. However, it is believed that climate change and the increasing atmospheric CO₂ concentration are considered as causes for bush encroachment (Wolfe & Erickson, 1993; Welz, 2013). Some findings also suggest that overgrazing by domestic animals and disturbances to the natural rangeland environment are major causes of bush encroachment (Ringrose *et al.*, 1990; Archer *et al.*, 1995; Ward, 2005; O'Connor *et al.*, 2014) whilst heavy grazing reduces the productivity of rangelands (Rutherford & Powrie, 2013).

Consideration of sustainable rangeland management and careful usage of these resources is very crucial for conservation and improving the current conditions of these natural resources. Relevant inventory and assessment of these rangelands is paramount to ensure their long term productivity. Application of remote sensing for rangeland management and assessment is believed to be the most efficient and inexpensive technique that could be used to provide relevant products, such as forage availability and rangeland quality, that can be used and would be adopted by rangeland managers (Hunt *et al.*, 2003; Washington-Allen *et al.*, 2006).

2.7 Characteristics of remote sensing

Remote sensing is an acquisition of information about an object or phenomenon, by using either recording or real-time sensing device(s) that are not in physical contact with the object, using aircraft, spacecraft or satellite (Lillesand *et al.*, 2008). Electromagnetic energy from the sun that is reflected, transmitted or absorbed reaches the earth's surface. A basic assumption made in

remote sensing is that specific targets (vegetation of various species, built up areas, different soil types or water bodies) have specific combinations of reflected and absorbed electromagnetic radiation at different wavelengths which can help to identify an object. The spectral signatures can vary during the year depending on different factors, such as the sun angle, seasonal rainfall distribution and the phenology of plants. In principle, a material can be identified from its spectral signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials (Pearlman *et al.*, 2000). There is a wide variety of satellite-based sensors currently providing operational raster remotely-sensed data for GIS and remote sensing users. The spatial, spectral, and temporal characteristics of these systems vary according to specific design and goals (Wu *et al.*, 2000). For the purpose of assessing the rangelands of the study area, the Satellite Pour l'Observation de la Terre (SPOT) images were used.

2.7.1 Satellite Pour l'Observation de la Terre (SPOT)

SPOT is an operational, commercial remote sensing programme that operates on a global scale. An established global network of control centers, receiving stations, product generation centres, and data distribution outlets ensure access to SPOT data. Five SPOT satellites have been placed into orbit since 1986. This allows data continuity for environmental applications for a continuous data supply (Graham & Gallion, 1996). SPOT was designed to provide remotely-sensed data suited for land cover, agriculture, forestry, geology, regional planning, and cartography applications (Htun, 1997).

Data from the High Resolution Visible sensor (HRV) provide both multispectral coverage with 20 m spatial resolution and panchromatic imagery with 10 m resolution. The high resolution of SPOT's panchromatic data are particularly well suited to urban and cartographic applications as well as for pan-sharpening the low resolution multispectral data for detail assessment of natural vegetation and other natural resources at a landscape level using vegetation indices (VI) such as NDVI and SAVI and spectral mixture analysis (SMA).

2.7.2 Rangeland management and remotely sensed data

A sustainable natural resource management has become a fundamental objective in rangeland resource management (Booth & Tueller, 2003). Repeatable and up-to-date spatial information is very important for efficient supervision strategy (Van der Merwe, 2001). The use of spatial information presents a better understanding of the status of natural resources and forms the foundation for the identification of appropriate strategies for sustainable rangeland management (Tueller, 1989). Constant changes due to the dynamic nature of rangelands at spatial and

temporal scales due to climatic, soil and management impacts; regular follow ups can result into better understanding of the composition, succession and distribution patterns of vegetation and it can reduce the subtle nature of the natural environment over long time frames. Rangeland disturbances such as loss of palatable grasses, loss of top soil, bush encroachment and invasion of alien plant species can occur over a range of spatial scales, from stand/plot level to landscape and regional level (Coops *et al.*, 2009). Many scientists have demonstrated the usefulness of space borne remote sensing data for rangeland monitoring and mapping (Kenk *et al.*, 1988; Booth & Tueller, 2003; Numata *et al.*, 2007; Coops *et al.*, 2009; Munyati & Sinthumule, 2013). Space borne remote sensing systematically and frequently acquires information for areas which are difficult to access, provides a synoptic view of large areas at a country, a continent or a global level coverage in a manageable number of images or photographs, and maintains a permanent record of conditions at the time of acquisition (Tueller & Booth, 2003; Washington-Allen *et al.*, 2006). These data types are helpful for monitoring the extent, type, and location of rangeland changes. Based on remote sensing data, a variety of data concerning rangelands can be gathered such as identification of plant community (Ferrier, 2002; Kukkala & Moilanen, 2013; Engler *et al.*, 2013), biomass estimation (Todd *et al.*, 1998; Van Der Meer *et al.*, 2002; Samimi & Kraus, 2004), plant species composition change (Van Niel, 1995; Hunt *et al.*, 2003; Madsen *et al.*, 2010; Santos *et al.*, 2010), delineation of rangeland fragmentation and different rangeland regime boundaries (Saure, 2004; Ojoyi *et al.*, 2014), chlorophyll mapping (Todd *et al.*, 1998; Numata *et al.*, 2003; Fensholt *et al.*, 2004; Kruskopf & Flynn, 2006), water bodies in the rangelands and their quality, etc. These data can be used effectively for rangeland ecosystem management. Many scientists have made use of remote sensing techniques for mapping the spatial distribution of different grass species over large geographic areas of rangelands, causing the provision of different spatial resolution imageries that provide timely and accurate information (Shoshany, 2000; Ustin *et al.*, 2009; Mansour *et al.*, 2012).

The flexible nature of remote sensing and the rate with which results can be produced from it are vital, and can present important information for a wide range of physical and socio-economic inquiries conducted by researchers and different government agencies for planning purposes (Stefanov, *et al.*, 2001). Digital remotely sensed data are cost effective and ease the amount of field work, enabling more frequent monitoring and quality assessment for rangeland management and habitat preservation (Booth & Tueller, 2003; Hamada *et al.*, 2007, Munyati, 2009).

Using satellite imagery and field data, Munyati *et al.* (2010) studied the expansion of woody vegetation (bush encroachment) by resampling the 20m medium spatial resolution SPOT data with 10 m higher resolution panchromatic imagery to perform an image fusion operation to enhance the visibility of the distribution of woody vegetation in Mokopane Biodiversity Conservation Centre, Limpopo province, South Africa. From the field data, the authors identified three bush encroachment categories based on the number of woody plants in the study sites. The authors used the field data for training purposes to classify the images into different categories. The result showed that heavily encroached areas are avoided by grazers resulting in overgrazing of limited open grasslands and causing low visibilities in game reserves in sighting game species by game viewers. The authors emphasized the usefulness of the multispectral imagery for assessing and managing the conditions of encroaching species of plants. However, in spite of the techniques employed for assessing the problem and great effort to extract all possible spectral information from the satellite data, the low resolution nature of the multispectral data which was used in the study process can manipulate the outcomes of the research even when the image is pan-sharpened with high resolution panchromatic data. Pan-sharpening with panchromatic data in return affects the integrity of multispectral data during image classification and multispectral mixture analysis.

Numata *et al.* (2007) used field data on vegetation biomass and soil condition and remotely sensed imagery in Amazonia, Brazil to measure the biophysical connection between grazing intensity, pasture age and remote sensing indices derived from Landsat Thematic Mapper imagery. Two types of spectral measures were performed, namely: spectral vegetation indices (Normalized Difference Vegetation Index (NDVI)), (Soil Adjusted Vegetation Index (SAVI)) and (Normalized Difference Infrared Index (NDII)); and (Spectral Mixture Analysis (SMA) (Non Photosynthetic Vegetation (NPV), Green Vegetation (GV), soil, shade and NPV + soil. The results from the image analyses were compared with field data. The result from the NPV was highly correlated with the field measurements and the authors suggested that the NPV fraction is a good indicator for pasture land assessment. However, despite the effectiveness of the model used in Numata *et al.*'s study, the applicability of the model in arid and semi-arid areas is questionable as this study was carried out (in more) humid region. The relative coarse nature of the resolution of the image which was used during this study might also reduce the integrity of the model.

Using a linear regression on remotely sensed data, Amiri & Tabatabaie (2009) performed a selection of vegetation indices of summer rangelands in southern Isfahan Province of Iran. The

authors used ASTER image data and compared the results with vegetation cover estimates at monitoring points made during field assessments. The results showed that there is a strong relationship between satellite data and vegetation characteristics and prediction of vegetation cover with the NDVI was more accurate within the rangelands. Booth & Tueller (2003) and Wallace *et al.* (2006) have also shown that vegetation characteristics are correlated with remotely sensed vegetation indices, mainly NDVI. In addition, NDVI is beneficial when it is used to determine land cover types across landscapes by classifying the landscape into categories based on the vegetation type within an area. For example, an area within a pasture may have a number of trees, shrubs, and grasses. However, if the grasses make up the majority of the total area, the pasture would be given a grassland land cover type. A study conducted for an estuary system in North Carolina and Virginia, USA successfully used the NDVI to produce a land cover analysis specifying vegetated and non-vegetated areas (Knight *et al.*, 2006).

Archer (2003) used satellite data to explore the uses of NDVI in assessing the impacts of different stocking practices on biomass in the eastern Karoo, South Africa. Based on 14 years of NDVI time series on the effects of precipitation, the results showed that there were distinctive differences among the farm plots which were included in the study, mainly due to differences in stocking intensities. The author indicated that the NDVI result was highly correlated with field data. The NDVI technique depicts over-dependency on spatial resolution (Munyati & Mboweni, 2013), and fails to reflect vegetation succession, below-ground biomass and the value of forage in terms of palatability (Box *et al.*, 1989; Vashum & Jayakumar, 2012). However, many scientists across the world are increasingly using vegetation indices and spectral mixture analyses from remotely sensed satellite data to assess rangeland conditions using different biophysical indicators (Costa & Rehman, 2005; Numata *et al.*, 2007; Munyati and Sinthumule, 2013). As rangeland productivity is an important indicator of condition of rangelands, these techniques have become most important source of information for mapping and estimating the above-ground biomass productivity of different rangelands (Sun *et al.*, 2007; Cho *et al.*, 2007; Brinkmann *et al.*, 2011).

2.8 Remote sensing and above ground biomass estimation

With growing number of human population and changes in land cover/land use, coupled with climate change and variability, a systematic quantification of available biomass is necessary at local, regional or national level in order to develop strategies for sustainable rangeland management strategy (Angerer, 2008).

Several techniques have been developed for estimating AGB with different level of accuracy, time spent and logistical conveniences. This includes direct measurement, where biomass is sampled and weighed by involving a quadrat method; and estimation techniques where the weights are estimated by the observer (Angerer *et al.*, 2009). The quadrat method is the most common method of the direct measurement approach. It has a circular, rectangular or square frame of known area representing a place on the ground and the vegetation biomass within the quadrat will be clipped (USDA, 2003). The clipped samples are usually oven dried to remove water in order to articulate the dry biomass, and then the biomass can be extrapolated to wider areas to make estimation of production of the vegetation biomass for the area of interest.

The estimation technique involves two methods: weight unit method and double sampling method. The weight unit method involves estimation of weight of plants of different categories (species, plant part or groups of plant) (USDA, 2003). Estimation will then be calibrated by visually choosing a plant or part of a plant that has equivalent weight to the weight unit, once a weight unit is established (Herrick *et al.*, 2005). Then the plant biomass is harvested, weighed and compared with the weight of the weight unit. Once the unit is estimated, the calibration is completed then the quadrat sampling can be conducted and recorded. The plants in the quadrat then are cut to compare the harvested grass weights against the weight unit. The harvested biomass is then oven dried and weighed to calculate a dry matter conversion (Catchpole & Wheeler, 1992). This method is time efficient and cost effective compared to the direct measurement technique but it involves complicated calibration procedures (Chen *et al.*, 2011). With a slight deviation from the required procedures, a misleading result can be reached. In contrast, the double sampling technique engages development of a different statistical correlation between AGB and visual estimates (Catchpole & Wheeler, 1992). Visual estimation of the measured variable is collected from a number of sample points where biomass is collected and weighed. A regression equation is then developed between the estimate and the actual measurement (Herrick *et al.*, 2005).

The above field techniques are the most popular and precise methods for evaluating forage quantity on rangelands. However, due to the vast nature of grasslands and rangelands, their inaccessible locations and the diverse combination of animal species that graze on these lands, quantification of vegetation biomass for rangeland management using these techniques is challenging (Angerer *et al.*, 2009). The alignment of ground-based and satellite-based spectral measurement developed recently, have improved the quantification techniques of above-ground biomass. By relating field based above-ground dry plant biomass to spectral responses and

using bandwise regression which is a multiple linear regression with individual spectral bands as potential explanatory variables, total forage production of a pastureland can be determined (Lawrence & Ripple, 1998).

Remote sensing imagery has greater ability to examine remote areas that may be inaccessible and obtain information at greater temporal frequencies than from field sampling about rangeland productivity (Tueller, 1996). Remote sensing can estimate the forage biomass based on statistical relationship between the spectral bands in the image and vegetation biomass (Dungan, 1998). For example, Fang *et al.* (2011) used correlation coefficient to assess the relationship between herbaceous AGB and different vegetation indices using SPOT-5 for estimating the total herbaceous AGB within the semi-arid of Idaho, USA. Similarly, Tucker *et al.* (1985) applied both linear and logarithmic regression techniques between the NDVI and AGB data to predict biomass production on a regional scale in the Sahel region of Senegal. By conducting a ground survey program in north central Mexico, Graci -Daguer (1993) validated the usefulness of NOAA-AVHRR for AGB monitoring by performing a regression analysis between NDVI and AGB which was collected from the field sample points to assess their relationship. The result showed that there was a significant relationship between the two variables ($r^2 = 0.73$). Kawamura *et al.* (2005) indicated that the Enhanced Vegetation Index (EVI) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite was found useful in predicting live biomass and total biomass in the Xilingol Steppe of Inner Mongolia. Al-Bakri & Taylor (2003) used a linear regression model to estimate shrub biomass production in Jordan. The approach proved to have the potential for estimating carrying capacity of rangelands in Jordan. Shino *et al.* (2003) used a correlation analysis between different VI and grass biomass to test the usefulness of Landsat data for estimating biomass production in central Italy. Results indicated that the NDVI data provided the most accurate estimate of grass biomass.

Vegetation indices such as the NDVI, SAVI and SMSA have been correlated with AGB and good correlations were found, and applied to forecast the productivity of rangelands in different biomes (Kawamura *et al.*, 2004; Kogan *et al.*, 2004; Mirik *et al.*, 2005; Wessels *et al.*, 2006; Numata *et al.*, 2008; Chen *et al.*, 2011). In addition, estimation of the quantity of available AGB in rangelands can be used to determine the livestock carrying capacity of these natural resources and subsequent planning of a sustainable grazing strategy.

Different methods have been developed to assess rangeland productivity depending on the rate of biomass yield of the ecosystem (Sala & Austin, 2000). In rangelands, harvesting biomass at the peak of the growing season and relating it with satellite data of the same season is one of the common methods that are used to estimate rangeland production (Roy & Ravan, 1996; Sala & Austin, 2000; Hill, 2004; Maskova *et al.*, 2008). Biomass harvesting is the most efficient method of estimating grassland productivity at both temporal scale and spatial extent (Jobbagy *et al.*, 2002; Yang *et al.*, 2009). Thus, in rangeland ecosystems, the forage availability and its impact on the carrying capacity of the land is determined by the amount of above-ground biomass (Jobbagy & Sala, 2000; Yahdjian & Sala, 2006; Yang *et al.*, 2009). However, this method of AGB estimation based on clipping vegetation to ground level are time consuming, expensive and feasible at a smaller scale (Chen *et al.*, 2010). Remote sensing techniques offer an effective solution for accurately estimating AGB in rangelands (Aranha *et al.*, 2008; Ren & Zhou, 2012; Elsfelder *et al.*, 2012) and on a larger scale. SPOT satellite constitutes one of the most useful sources of remotely-sensed data. They carry multispectral sensors that take images of the earth surface in four different spectral bands (in the range of 0.45-2.33 μm) with 10m of ground resolution. SPOT images are widely used for monitoring plant cover using different vegetation indices (Qi & Wallase, 2002; Beerli *et al.*, 2007). Vegetation indices take benefit from the distinctive reflective properties of photosynthetically active vegetation (Schino *et al.*, 2003). Visible red reflectance measured by the SPOT spectral band 2 (0.58 to 0.68 μm) corresponds to the part of the spectrum where the chlorophyll pigment in leaves causes considerable photosynthetic absorption of incoming radiation. Near infrared reflectance measured by the SPOT spectral band 4 (0.73 to 1.10 μm) corresponds to the part of the spectrum where spongy mesophyll, plant cell structural material, leads to considerable reflectance (Ripple, 1985). Most vegetation indices are therefore based on various arithmetic combinations of reflectance values in the SPOT spectral bands 2 and 4. Using the ratio of these two bands, quantification of above-ground biomass is can be achieved (Schino *et al.*, 2003; Liu *et al.*, 2004; Jin *et al.*, 2014). Biomass estimation represents the quantification of organic matter in a given area and is expressed as the weight of organic matter per unit area (Chen *et al.*, 2011).

2.9 Determining rangeland livestock carrying capacity

Livestock carrying capacity of rangelands can be defined as the maximum number of livestock units vegetation on a rangeland can support without causing degradation (McCabe, 2004). In

order to avoid serious damage to the soil and vegetation through grazing and ensuring availability of sufficient forage for herbivores to remain healthy, there must be a controlled animal number and grazing time (Sprinkle & Bailey, 2004). Washington-Allen *et al.* (2004) indicated that the effective way of determining rangelands livestock carrying capacity is to assess rangeland productivity and estimation of total biomass production. Determination of the number of herbivores in the rangelands and grazing times according to the available forage requires application of relevant techniques. Remote sensing and GIS in conjunction with ground based data and ancillary data are used widely to determine carrying capacity of rangelands (Freidel *et al.*, 1994; Schino *et al.*, 2003; Baugh & Groenaveld, 2006.)

Estimation of biomass signifies the quantity of matter in a given area and are stated either as the weight of organisms per unit area or as the volume of organisms per unit volume (Chen *et al.*, 2011). Once the amount of usable forage is determined, the available forage would be multiplied by the percent allowable for utilization by foragers (grazers) depending on pasture characteristics such as distance from water and topography (BLM, 1999; de Leeuw *et al.*, 2001). According to Rasmussen *et al.* (2001) the number of livestock that can be grazed on the management unit surveyed for the desired grazing period would be computed by dividing the weight of usable forage by the forage demand of the grazers.

2.10 Integration of GIS and remote sensing for rangeland management

Rangelands are highly complex ecological systems which are subjected to significant spatio-temporal natural variables. This spatial and temporal heterogeneity, when integrated with complex environmental factors, signifies that it is very difficult to use pragmatic studies to acquire a reasonable awareness of how available biomasses are used by grazers in response to factors such as topography, watering points, and management (Wood, 2004) which impact the availability of biomass to grazers.

Using GIS software and digital elevation model (DEM), computation of slope and watering points distance for grazing capacity reduction is possible by determining the percentage of the slope and distance. Once the slope percentage is determined from the DEM, and buffers of the distance classes are built around each water point, appropriate reduction in grazing capacity depending on steepness of the gradient and distance from watering points and the kind of grazing animal can be assigned using GIS (Angerer, 2009). Integration of multiple data layers and spatial simulation using GIS techniques is possible for investigating the cause-and-effect

relationships among different spatial incidents. A number of scientists from different fields have researched these issues, focussing on rangeland productivity quantification processes, quality assessment and management. Research with significant input of remote sensing and GIS has focused on a variety of aspects, including mapping, quantifying and monitoring approaches (Rosenbaum & Popescu, 1996; Li & Yeh, 1998; McCormick, 1999; Metternicht & Fermont, 1998; Duan & Grant, 2000; Lu *et al.*, 2004; Wessels *et al.*, 2006; Numata *et al.*, 2008; Bozkurt *et al.*, 2012).

Currently, the growing concerns about the worsening condition of rangelands and the need for improved rangeland productivity and environmental information which sustainable rangeland management strategies has given rise to emphasis on the utility of remote sensing and GIS techniques (Jianlog *et al.*, 1995). Remote sensing and GIS are used progressively as tools to assist in rangeland resources inventory and assimilation of data and as an instrument for analysis, modelling and forecasting purposes to support decision making (Tueller, 1996).

Bozkurt *et al.* (2012) evaluated grasslands suitability for beef cattle grazing. A grassland suitability and availability map was produced based on a GIS model and remote sensing data in Kars province, eastern Turkey. In order to monitor the chemical composition of grasses, three sub-plots were fenced and herbage biomass at a ground level was measured to produce a grassland availability map. The study used Landsat TM satellite data to measure spectral reflectance of green cover. After creating a reflection histogram of all the bands and interpretation of the reflectance curves from the satellite data, image data was integrated with the field data using a GIS environment to produce a classification and suitability map based on the parameters from the field data. The result showed that two thirds of the total area of the Kars province is grassland. It was concluded that GIS modelling and RS data can provide better information and easier integration of various information layers to support a model of grassland assessment for livestock management.

Bizuwerk *et al.* (2005) made an investigation to identify how efficiently land managers were utilizing the land in the Awash River Basin, Ethiopia. The study used Digital Elevation Model image to find slope values for the study area as well as water data layers to show areas in close proximity to water. Areas were given weighted values based on erosion levels, average rainfall, distance from water, and slope gradient, and then analysed to determine overall suitability. Results showed that 33% of the Basin was suitable for grazing and a large portion of suitable area was being used for agriculture crop production. Hence, based on the results, land managers

were advised either to reduce crop production by moving crops to other locations for the optimization of suitable areas for grazing or reduce grazing pressures in over-utilised areas.

By integrating remote sensing and GIS, many scientists across the world have studied spatial characteristics of different biophysical indicators of rangelands. For example, Lu *et al.* (2004) used the revised universal soil loss equation (RUSLE), remote sensing and GIS to map soil erosion risk in Rondonia, Brazil. Using soil map and soil survey data, the authors developed the soil erodibility factor and generated topographic factor using a digital elevation model as well as the cover management factor which was developed based on vegetation, shade and soil fraction images derived from SMA of Landsat ETM+ imagery. Using these data, a soil erosion risk map with five classes based on a simplified RUSLE within a GIS environment was produced. The soil erosion risk map was linked to land use/land cover map to assess the relationship between soil erosion risk and land use/land cover distribution. The result showed that forest dominated areas face low soil erosion compared to agroforestry and pasture which are affected by medium to high erosion risks.

Several studies have integrated GIS and remote sensing to map the distribution of plant species, their ecosystems, landscapes, bio-climatic conditions and factors facilitating invasions. Thus, there is an increasing number of research work dealing with the application of remote sensing and GIS in the data collection and analysis of rangeland health conditions, plant species abundance and their distribution, mapping soil types, soil depth, soil surface texture, human interaction with the natural environment, modelling physical and environmental phenomena (Li & Yeh, 1998; McCormick, 1999; Joshi *et al.*, 2003; Lu *et al.*, 2004). Therefore, GIS and remote sensing can be useful techniques to provide greater flexibility and accuracy for grassland assessment.

In South Africa, many scientists have used remote sensing and GIS as a source of data and data analysis tools for rangeland management (for example Jarman & Bosch, 1973; Viljoen *et al.*, 1993; Palmer & van Rooyen, 1998; Tanser & Palmer, 1999; Wessels *et al.*, 2004; Archer, 2003; Wessels *et al.*, 2004, 2008; Munyati *et al.*, 2010). Wessels *et al.* (2004) studied human induced land degradation in the former homelands in north eastern South Africa using a 1km AVHRR $\sum$ NDVI time series (1985-2003) to compare degraded rangelands to non-degraded rangelands within the same land capability units. The process of comparison involved testing for differences in spatial mean NDVI, calculating the relative degradation impact, analysing the relationship between relative degradation impact and rainfall; and comparing the resilience and

stability of paired areas in response to natural variation in rainfall. The result showed that the sum of NDVI of degraded areas was lower for most of the land capability units but in some cases the relative impact of the degradation decreased following high rainfall. The productivity of degraded areas was constantly lower than non-degraded areas, although the ecosystem function of these areas was not dramatically reduced. Such information is vital for rangeland managers and stakeholders to make an informed decision in the process of mapping, monitoring and assessing these natural resources by developing a sustainable ecosystem management strategy.

2.11 Conclusion

Rangelands play major roles in supporting the livelihood of many communities in different regions of the world by supplying goods and services. Therefore, proper management process of these natural resources crucial to ensure their productivity in a sustainable manner by considering application of relevant rangeland monitoring techniques. Different management strategies have been developed and used to monitor and maximize the productivity of rangelands; among these remote sensing and GIS are proved to be the most efficient ones. These techniques are very helpful in assessing and measuring different biophysical parameters of rangelands that can be used to determine their conditions. Remotely sensed imagery can be used to perform indepth analysis of rangeland conditions by calculating vegetation indices and spectral mixture analysis. These data are particularly very useful for estimation of above-ground biomass and other related biophysical parameters.

CHAPTER THREE

3. RANGELAND PRODUCTIVITY ASSESSMENT IN RELATION TO GROUND BASED DATA, RAINFALL, TEMPERATURE AND MANAGEMENT STRATEGIES

3.1 Introduction

Rangeland productivity is characterised by several factors such as water and nutrient availability (Hooper & Johnson, 1999), rangeland management strategies (Dale *et al.*, 2000) and complex adaptation processes (Walker & Jansen, 2002). For example, low and variable annual rainfall and the high evapotranspiration rate together coupled with nutrient poor soil and poor rangeland management strategies can cause strong limitations in the overall production of rangelands. The balance between rainfall and potential evapotranspiration rate determines plants' biological situation (Brown & Havstad, 2004). Precipitation-evapotranspiration levels interact and influence the rates of the carbon and nitrogen cycles. Evaporation rates are dependent on temperature: as average temperature decreases, evaporation rate decreases; as temperature increases, evaporation rate increases. Water is the primary limiting resource on rangelands, and vegetation production depends heavily on water availability and suitable growing temperatures (Hooper & Johnson, 1999; Hunt *et al.*, 2003). The combined effects of temperature and precipitation influence the quantity and quality of plant growth and can limit livestock production if not considered during the preparation of long term rangeland management plans (Lessoli, 2011). Thus, the productivity of rangelands is a factor of climatic elements which determine the quantity of the above-ground biomasses in grasslands and rangeland management strategies (Sala *et al.*, 1988; Archer, 2003; Wessles *et al.*, 2004; Fang *et al.*, 2011; Wessles *et al.*, 2007; Yang *et al.*, 2009). The semi-arid and arid regions of South Africa have greater evapotranspiration with higher demand of precipitation; and they are characterised by high proportions of bare ground. This situation intensifies the occurrence of some forbs and weedy species because of their ability to exploit the open spaces.

Rangelands have been severely affected by anthropogenic disturbances, imbalanced utilisation, and neglect of proper management and restoration (Kelly *et al.* 2005; Wessels *et al.*, 2007). These ecosystems are exposed to degraded soil fertility, acute shortage of water and unstable micro environmental conditions, which would strongly constrain their productivity. Moreover,

in South Africa, land use is generally based on ecological situation and historical backgrounds (Samimi & Kraus, 2004). Communal areas which are engaged in subsistence agricultural activity are characterised by high human population, soil erosion, excessive wood harvesting and increase in unpalatable plant species (Hoffman & Todd, 2000; Wessels *et al.*, 2004). Commercial and protected areas are also believed to have similar problems but with lower magnitude (Samimi & Kraus, 2004) as quoted from (Eckhardt *et al.*, 2000). Finding a way of restoration and sustainable use of these ecosystems is a fundamental subject in order to increase productivity, improve environmental conditions and achieve sustainable livelihoods.

To ensure long term productivity and sustainability of rangelands, it is vital to devise relevant management strategies that can be used to monitor rangeland production. Several studies have been conducted to assess the spatial patterns of above-ground biomass and its relationship with climatic variables and rangeland management strategies (Epstein *et al.*, 1997; Samimi & Kraus, 2004; Kawamura *et al.*, 2005). Plant biomass quantification, a crucial biophysical parameter of vegetation, is an essential procedure for rangeland management. Vegetation biomass estimation not only is necessary for studying productivity, carbon sequestration, and nutrition allocation in terrestrial ecosystems but also crucial to the natural resource management since the quantity of vegetation biomass directly impacts human usage of surface vegetation and affects other biophysical parameters (Limbu, 2011). However, there is limited information on the level of rangeland productivity in different rainfall zones of the North-West province of South Africa. This region is characterised by spatial variation in precipitation, temperature and the impact of different land tenure systems. The purpose of this study was to investigate conditions of rangelands and assess the magnitude of variations in terms of forage productivity in the study sites due to environmental factors such as precipitation and temperature; and internal spatial disparities due to rangeland management strategies.

3.2 Materials and methods

3.2.1 Data types and sources

Materials which were used in this study are climatic data and field data. These data were collected from different sources.

3.2.1.1 Field data

A field survey was conducted by a team from the North West University, Mafikeng Campus and a number of local residents using a random block design sampling technique during late

February - early April, 2014 when the vegetation reached its optimum growth level in the study region. The sample sites were selected in terms of cost and accessibility and these study sites were sampled along a pre-defined rangeland moisture gradient. To overcome the problems of subjective sampling, a randomized block sampling technique was employed (Figure 5).

The data were collected from different spatial locations by dividing the North West Province into three distinctive zones. The major criteria for categorizing the study sites into different zone were amount of precipitation. According to FAO (2009), the North West Province of South Africa is divided into three rainfall zones, namely: high rainfall zone (HRFZ), medium rainfall zone (MRFZ) and low rainfall zone (LRFZ). In addition, there are three major types of rangeland regimes in the province, namely: protected areas, communal lands and private ranches.

From each rainfall zone three rangeland regimes in close proximity to each other were selected. Thereafter, the sites were subdivided into low and high grazing intensity units using ocular cover estimate technique (Daubenmire, 1959) based on the quantity of forage available on the fields. Thus rainfall, rangeland regimes and grazing intensity were used to define sampling classes based on the assumption that these are major factors affecting the quality and conditions of the rangelands.

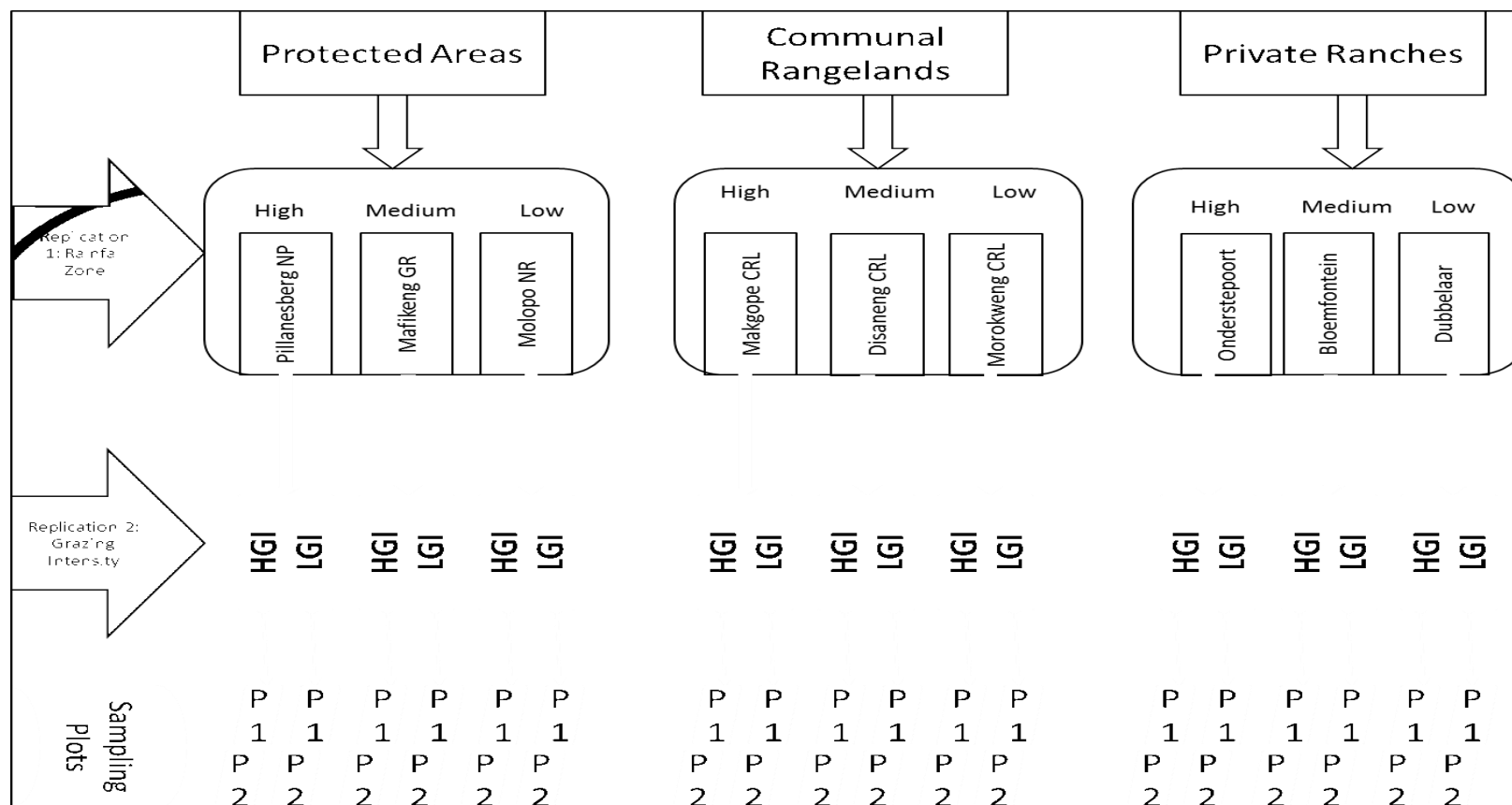


Figure 5: A flow chart of the field data collection process.

Note: HGI (High Grazing Intensity), LGI (Low Grazing Intensity), P1 (Plot 1) and P2 (Plot 2).

A total of thirty-six field plots (each plot measuring 100m by 100m) were sampled from the entire study area (Figure 6). Five 2m×2m sub-plots were sampled within each plot, one at the centre of the plot and four at the four corners of each sub-plot using a quadrat (Ray & Murray, 1996) for harvesting AGB and estimating other biophysical parameters. Within each plot and sub-plot, latitudinal and longitudinal coordinates (m) using a Garmin GPS at $\pm 3\text{m}$ accuracy level, proportion of bare ground (%), and indicators of erosion (m) were recorded.



Figure 6: Sample points from the study sites - high grazing intensity and low grazing intensity

Thereafter, all the grasses in the sub-plots in which the boundary was set using a quadrat covering 4m^2 (Figure 6) were cut at the ground level and immediately weighed to obtain a wet weight (kg) of the grass. The collected material was transferred to the laboratory where the samples were dried in the oven at 75°C for 72 hours and weighed again to measure the water content and total dry biomass.

3.2.1.2 Climatic data

Mean growing season rainfall data and average temperature records from 1993-2014 of the study sites were sourced from the South African Weather Services. As rainfall is one of the climatic elements playing major roles in tropical and subtropical regions, analysing the amount and distribution of rainfall over time is extremely important to assess the extent to which rangelands could recover through the natural process.

3.3.2 Data analysis

3.2.2.1 Relationship between AGB and rainfall, temperature and management strategies

Spatial patterns, environmental controls such as temperature and precipitation, and rangeland management regimes were investigated in relation to the above ground biomass. Regression analysis was performed to assess the impact of spatial distribution of precipitation, rangeland management strategies and average growing season temperature on above ground biomass in three rainfall zones (300 - 400 mm, 400 - 600 mm and 600 -750 mm) using Equation 3.1.

$$y = \alpha_0 + \beta x + \epsilon, \quad \text{Equation 3.1}$$

where

y = Above-ground biomass

x = precipitation and growing season's temperature

α = Intercept of the regression line

β_0 = gradient of the regression line

ϵ = a random disturbance or error.

The relationship between precipitation (x) and growing season average temperature (y) was also assessed using Pearson's correlation coefficient (Equation 3.2):

$$r = \frac{\frac{1}{n} \sum xy - \bar{x}\bar{y}}{S_x S_y}, \quad \text{Equation 3.2}$$

where

$$S_x = \sqrt{\frac{1}{n} \sum x^2 - \bar{x}^2}; \quad S_y = \sqrt{\frac{1}{n} \sum y^2 - \bar{y}^2}. \quad \text{Equation 3.3}$$

The result was used to determine the relationship between these variables and their impact on rangeland productivity across the study sites.

Differences in rangeland productivity were also assessed among the three rangeland management regimes namely communal, private and protected rangelands using analysis of variance (ANOVA).

3.4 Results and discussion

This section discusses results obtained from analysis of the impacts of rainfall distribution and temperature conditions on rangelands of the North-West province. The regression analysis between different variables yielded acceptable results. There was a positive relationship between rainfall distribution and aboveground biomass production in all study sites. A negative relationship was detected between rainfall distribution and temperature. High rainfall areas are associated with low temperature while low rainfall areas generally experience higher temperature.

3.4.1 Effects of rainfall and temperature on AGB productivity

The average AGB from the low rainfall zone was the lowest (907 kg ha⁻¹) followed by the medium rainfall zone (2148 kg ha⁻¹) while the high rainfall zone produced the highest average AGB (2646 kg ha⁻¹) with the exception of the Ngweding communal area (Figure 7). As the rainfall decreased from east to west (from high rainfall zone to low rainfall zone) the AGB production also decreased. The impact of the spatial distribution of rainfall and temperature on the AGB production was significant ($R^2 = 0.44$) (Figure 8). The rainfall distribution and growing season temperature were negatively correlated ($R = -0.94625$) (Figure 9). The impact of temperature on the AGB production was significant ($R^2 = 0.44$) with higher temperature being associated with low AGB production.

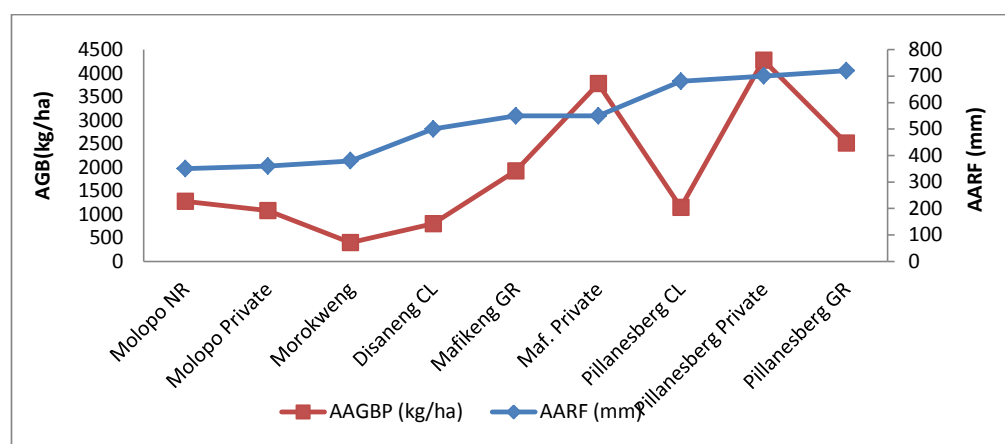


Figure 7: Aboveground biomass production in relation to distribution of rainfall

Note: AAGBP Aggregate aboveground biomass, AARF Annual average rainfall, NR Nature Reserve, CL Communal Land, GR Game Reserve

Rainfall had a significant effect on the above-ground biomass production with an R^2 value of 0.44 (Figure 8). Low precipitation inhibited above-ground biomass, whereas higher precipitation stimulated aboveground biomass production (Table 3). On average, higher rainfall and medium rainfall zones produced 188% and 135% more AGB than the low rainfall zone, respectively. There is close similarity in terms of AGB production between the high rainfall zone and medium rainfall zone with the high rainfall zone producing 22% more average AGB. AGB decreased significantly from the high rainfall zone to low rainfall zone. The mean AGB was 2800 kg/ha in the high rainfall zone, 2158 kg/ha in the medium rainfall zone, and 920 kg/ha in the low rainfall area (Table 3).

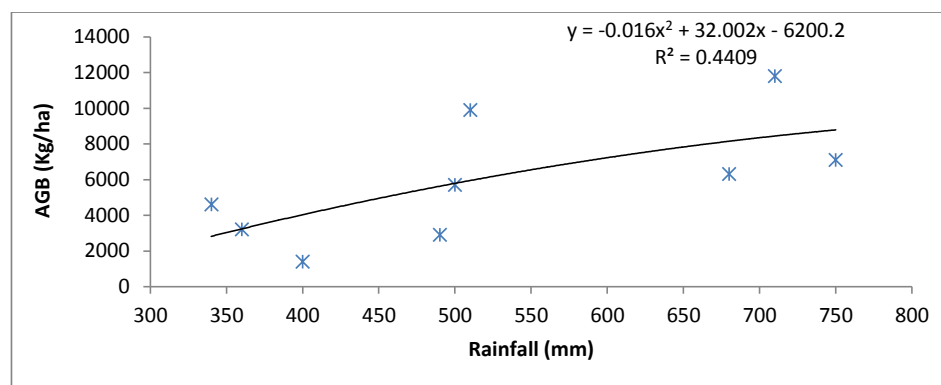


Figure 8: Relationship between rainfall distribution and above ground biomass production

During this study, water availability and rainfall conditions were identified as crucial factors in controlling the spatial distribution of rangeland vegetation and aboveground biomass productivity in the regions as observed from the strong relationship between aboveground biomass and precipitation. This finding is in agreement with other authors (Scholes, 1993; Fay *et al.*, 2000; IPCC, 2007; Chen *et al.* 2010) who indicated that gross ecosystem productivity has a higher sensitivity to higher precipitation that favors carbon sequestration. Conversely, lower precipitation can reduce nutrient availability because lack of water limits soil microbial processes (Stephenson, 1990; Sala *et al.*, 1988, Diaz, 1996; Sardans *et al.*, 2008). Lower precipitation not only suppresses plant biomass and physiological processes, it can also cause mortality of plants (Ogaya & Penuelas, 2007). Semi-arid and arid regions are characterised by low levels of soil water availability and extended periods of water shortages. While small events of rainfall can briefly improve these problems and recover plant-water relations (Sala & Lauenroth 1982), the high evaporation and evapotranspiration rate rapidly removes this water

from the soil (Knap *et al.*, 2008). Moreover, the precipitation patterns change frequently with a shift to larger, less frequent events, particularly in the low rainfall zone (Houghton, 1996, Fay *et al.*, 2000). This scenario can bring larger quantities of water to the ecosystem in a short period of time and can increase the amount of water availability in the soil for plants. However, these ecosystems have low vegetation coverage unlike the high rainfall zones and surface runoff in these regions occurs more frequently and strongly (Bai *et al.*, 2008; Knap *et al.*, 2008). These phenomena accelerate nutrient loss and eventually reduce plant response to the sporadic water additions (Kong *et al.*, 2013).

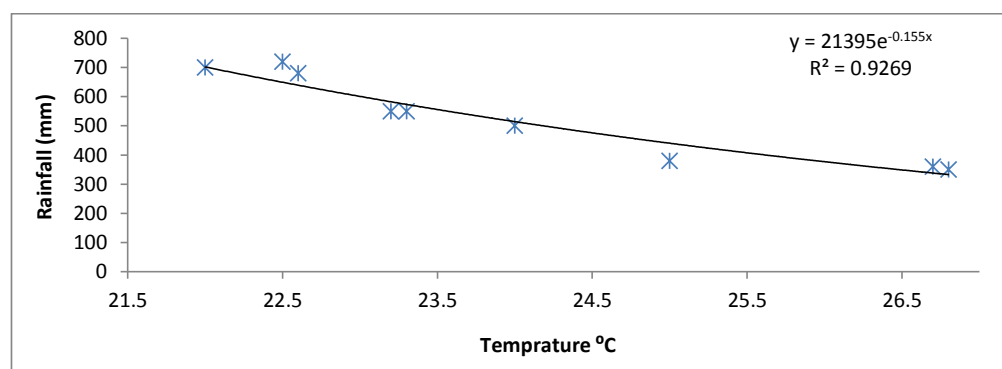


Figure 9: Relationship between rainfall and temperature in the study area

There was a negative relationship between temperature and rainfall distribution ($R^2 = 0.92$). As the temperature decreased the amount of rainfall increased (Figure 9). Though there is no clear indication of one variable influencing the other, the combined effects of these factors clearly influenced vegetation distribution and AGB production. As the temperature increased, rainfall decreased and AGB decreased; on the contrary, as the temperature decreased, rainfall increased and AGB productivity of rangelands also increased.

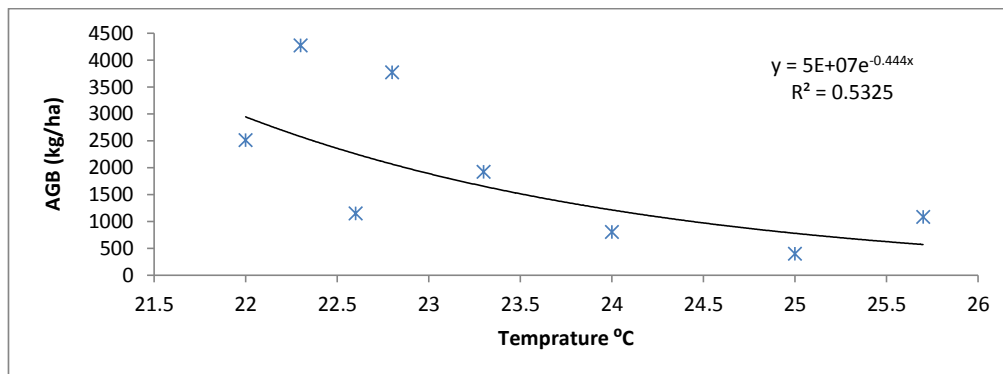


Figure 10: Relationship between temperature and aboveground biomass

Temperature regulates the rate of physical processes and influence the growth and development of plants (Mamushina & Zubkova, 1996; Heggie & Halliday, 2005; Khodorova & Boitel-Conti, 2013). However, plants' response to temperature is conditioned by other environmental factors such as soil moisture and human activities (Larcher, 1980; Heggie & Halliday, 2005). Brown (1988) stated that soil moisture is the most crucial factor that limits the growth and survival of rangeland plants. When rate of transpiration exceeds rate of absorption of water, water deficit develops in plant tissues causing a slowing down of root and leaf growth. This is in line with the findings of this study that in the low rainfall zone, temperatures were higher, soil moisture was lower, and the quantity of AGB was low. Conversely, in the medium and high rainfall zones, temperatures were relatively lower, precipitation was higher, and there was relatively higher quantity of AGB.

A moderate relationship was detected between temperature and AGB ($R^2 = 0.5325$) (Figure 10). Above-ground biomass increased with a slight decrease of temperature from the high rainfall zone to low rainfall zone. In this study, the above-ground biomass was negatively correlated to the average temperature proving that higher temperature has a negative impact on the AGB in the study area mainly due to higher evaporation and evapotranspiration rate causing moisture stress and limiting vegetation growth. The results confirm the findings reported in previous studies, which highlighted the relationships between high temperature and lower rainfall in arid and semi-arid regions (Emett *et al.*, 2004; De Boek *et al.*, 2008; Wu *et al.*, 2011).

Table 2: Above-ground biomass across the study sites over high and low grazing intensities and their corresponding average annual rainfall and temperature

Study Sites	HGI1(kg/ha)	HGI2(kg/ha)	LGI1(kg/ha)	LGI2(kg/ha)	Average biomass (kg/ha)	AARF(m)	AAGBP (kg/ha)	T (C ⁰)
Molopo NR	680	700	1810	1850	1260	350	1275	26.8
Dubbelaar PR	652	750	1390	1415	1052	360	1082.5	26.7
Morokweng CL	310	315	515	490	408	380	402.5	25
Disaneng CL	689	658	880	950	794	500	804	24
Mafikeng GR	1335	1250	2450	2600	1909	550	1925	23.3
Lenric PR	3158	3050	4260	4500	3742	550	3775	23.2
Ngwedding CL	870	800	1370	1500	1135	680	1150	22.6
Onderstepoort PR	3280	3350	4260	5200	4023	700	4275	22
Pillanesberg NP	1390	1430	3752	3600	2543	720	2515	22.5

NB: (NR) Nature Reserve; (PR) Private Ranch; (CL) Communal Land; (GR) Game Reserve; (NP) National Park.

HGI1: high grazing intensity, Plot 1; HGI2: high grazing intensity, Plot 2; LGI: low grazing intensity, Plot 1; LGI2: low grazing intensity, Plot 2; AARF: annual average rainfall; AAGBP: average above-ground biomass; T: temperature.

According to Knap *et al.* (2008), warm temperatures and low precipitation in South Africa result in a large deficit of water balance in the ecosystem during the dormant season resulting into extremely low levels of soil moisture. In the lowland South African savannahs and grasslands, the limitation in soil moisture defines the growing seasons and the conditions of above-ground biomass (Hoffman & Ashwell, 2001). Because in these regions, soil moisture is low early in the growing season, these grasslands are very sensitive to inter-annual variability of water inputs at this time of the year. In addition, several studies have shown that decomposition rates increase with the increase of temperature, provided that there is enough moisture (Parton *et al.*., 1993; Burke *et al.*., 1995; Craine *et al.*, 2009; Conant *et al.*, 2011) ensuring the availability of important nutrients in the soil. However, lack of sufficient rainfall in the low land savannas of South Africa hinders faster decomposition of dead biomasses, limiting the amount of available nitrogen and carbon in the soil (Moussa, 2007). It is due to this reason that the AGB in cooler rangeland ecosystems have stronger positive response to warm temperature compared to warmer dry and semi-dry ecosystems (Running *et al.*, 2009).

3.4.2 Impacts of rangeland management systems on AGB productivity

Above-ground biomass was harvested from three rainfall zones associated with three different types of rangeland management regimes, namely: communal lands, private ranches and protected areas. Results revealed that there were significant differences in AGB production

between these rangeland regimes [$F(2, 177) = 85.20, P < 0.001$] (Table 3). Biomass production from the communal lands was the lowest compared to the protected areas and the private ranches across the rainfall zones with the private ranches yielding highest AGB. The average AGB production from the three rangeland management strategies in ascending order is: communal rangelands (990 kg/ha), protected areas (3530 kg/ha) and private ranches (5972 kg/ha).

Table 3: Analysis of variance table showing the effect of rangeland management strategy on AGB productivity in the North West Province

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	129835.76	2.00	64917.88	85.20	0.00	3.05
Within Groups	137158.38	176.00	761.99			
Total	266994.14	178.00				

The following sub-sections provide detailed results and discussion of the relationship between rainfall zones, rangeland management strategies and AGB productivity.

3.4.2.1 Low rainfall zone

Above-ground biomass (AGB) production level in the low rainfall zone is presented in Table 2. In this region, AGB average production was 408 kg/ha in the communal lands, 1260 kg/ha in private ranch and 1052kg/ha in protected area. The overall average AGB was 907kg/ha from this zone (Figure 11). The standard deviation (SD) of AGB in the region was 1882kg which is very high in terms of the general AGB production capacity of the region. There was a significant difference in the level of AGB production among the three study sites [$F(2, 57) = 71.39; P < 0.001$] (Table 4). However, no significant difference was detected between the private and protected areas in terms of AGB production.

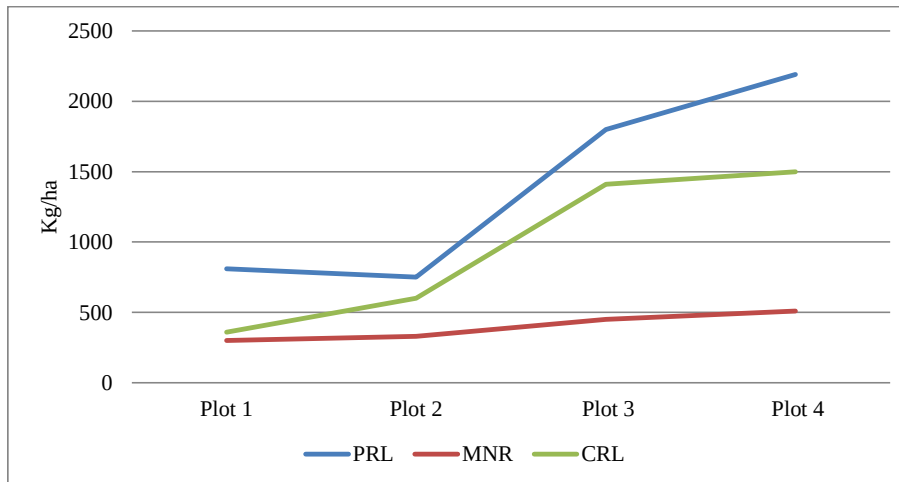


Figure 11: AGB production in the low rainfall zones

Note: MNR Molopo Nature Reserve, CRL Communal Rangeland, PRL Private Rangeland

Table 4: Analysis of variance table showing the effect of rangeland management strategy on AGB productivity in low rainfall region

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	19530.59	2.00	9765.30	71.39	0.00	3.16
Within Groups	7797.40	57.00	136.80			
Total	27327.99	59.00				

3.4.2.2 Medium rainfall zone

Above-ground biomass production level in the medium rainfall zone is presented in Table 2. In the medium rainfall zone, AGB average production was 794 kg ha⁻¹ from the communal lands, 1909 kg ha⁻¹ from protected areas and 3742 kg/ha from private ranches. The overall average AGB was 2115 kg ha⁻¹. The SD of the AGB production of the region was 1381 kg ha⁻¹. There was a significant difference in the level of AGB production between the three rangeland management regimes [F (2, 57) = 40.7; P<0.001] (Table 5).

Table 5: Analysis of variance table showing the effect of rangeland management strategy on AGB productivity in medium rainfall regions

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	65238.00	2.00	32619.00	40.70	0.00	3.16
Within Groups	45680.61	53.00	801.41			
Total	110918.61	55.00				

3.4.2.3 High rainfall zone

Above-ground biomass production level in the high rainfall zone is presented in Table 3. In the high rainfall zones, the average AGB production was 1135 kg/ha in the communal rangelands, protected areas 2543 kg/ha and private ranch 4023 kg/ha. The overall average AGB was 2647kg/ha. The SD of the AGB in the region was 1946kg. There was a significant difference in terms of AGB production among the rangeland regimes [(F (0.05, 2, 57) = 34.15; P<0.001] (Table 6).

Table 6: Analysis of variance table showing the effect of rangeland management strategy on AGB productivity in high rainfall regions

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	51114.29	2.00	25557.14	34.15	0.00	3.16
Within Groups	42657.12	57.00	748.37			
Total	93771.41	59.00				

Results from this study showed that the AGB production measured from the three land tenure systems differed statistically [F (0.05, 2, 177) = 85.20, P < 0.001] (Table 4). AGB production from communal lands ranged from 402 kg/ha in the low rainfall zone to 1150kg/ha in the high rainfall zone. In the private ranch, AGB production was the highest and ranged from 1080kg/ha in the low rainfall zone to 9990kg/ha in the high rainfall zone. This study hypothesized that the variation in AGB production in different rainfall zones of the study area were due to differences in managerial activities and spatial effects. Low AGB was recorded from all study sites of the communal areas where most of these rangelands were described by Moussa *et al.* (2009) as areas of high proportion of bare ground, low quantity of palatable grasses and high levels of soil erosion. These factors are considered as indicators of rangeland degradation that can result in low AGB production (Hoffman & Todd, 2000). Generally, communal areas are characterised by high human population and livestock density, over utilization of rangeland resources (Wessels *et al.*, 2004) and bush encroachment, particularly in the low rainfall regions (Moussa *et al.*, 2009a). These phenomena subject the communal rangelands to overgrazing and over cultivation (Fox & Rowntree, 2001; Wessels *et al.*, 2004). Heavy grazing pressure can cause compositional changes and local extinction of some grasses species following droughts (O’Conner, 1994). Considering the erratic nature of the rainfall in South Africa, particularly in the North West Province, over utilization of these rangelands can lead to an ecological decline having a profound effect on the overall productivity of these resources.

Above-ground biomass production from the private ranches and protected areas were higher as compared to the communal areas in all rainfall zones. This is attributed to higher maintenance

and management processes such as keeping recommended stocking rates (Moussa *et al.*, 2009). Hence, AGB productivity in the private and protected areas is healthy and high. However, there was higher proportion of bare ground in both private and protected areas in the low rainfall zone ranging between 30% and 50%, which could be a consequence of lack of soil moisture availability. Generally, rangelands under private and protected areas were characterised by lower indicators of erosion, higher AGB productivity and composed of high quality palatable grasses (Moussa *et al.*, 2007). The findings of this study were consistent with other studies (Chenje & Johnson, 1996; Hoffman & Ashwell, 2001; Sammi & Kraus, 2004) indicating that communal rangelands were less productive as compared to the surrounding private ranches and protected areas due to higher livestock population. In these communal rangelands users strive to maximize output at the expense of the natural environment without due considerations for the sustainability of rangeland resources.

3.5 Conclusion

During this study, climatic data such as average temperature and rainfall data, AGB and data on rangeland management regimes were collected. The results suggested that AGB productivity was profoundly affected by spatial distribution of rainfall and temperature. The low rainfall zone produced the lowest AGB, while the high rainfall zones had the highest AGB. As such, low rainfall coupled with high temperature, negatively affected the productivity of the rangelands. Rangeland management strategy was also identified as one of the factors that determine the productivity of these rangelands.

Communal rangelands were the lowest productive units due to the high numbers of human and animals resulting in over-exploitation of rangeland resources, whereas the private ranches were highly productive due to proper maintenance and management activities. Despite the short time period of this study, the results are in agreement with the available literature that low rainfall conditions limit AGB production of rangelands.

In the case of rangeland management regimes in South Africa, communal areas are less productive than the surrounding private ranches and protected areas, although in some cases, comparison with the previous studies were very difficult because of different locations of the study sites, criteria and methodologies applied. However, it was clear that the lower AGB production in communal areas, as compared to the private ranches and protected areas; was caused by differences in managerial activities and combined effects of human activities and

climatic variations. However, the magnitude of the impacts of these phenomena is not clear, hence the need for further studies.

CHAPTER FOUR

4. APPLICATIONS OF SPOT IMAGERY FOR LANDCOVER MAPPING AND ASSESSING INDICATORS OF EROSION AND PROPORTIONS OF BARE GROUND IN ARID AND SEMI ARID AREAS

4.1 Introduction

Inappropriate land use and high population density in concurrence with fragile ecological conditions have greater influence on the natural state of rangelands in semi-arid and arid areas where land degradation and expansion of woody vegetation often further deteriorate the livelihoods of the impoverished people who directly depend on natural resources (Frederikson, 1993). In the North-West province, unpalatable trees and shrub encroachment, a wide spread form of rangeland degradation at the expense of palatable vegetation over longer period of time as well as expansion of bare ground are major problems. This scenario is believed to be triggered and aggravated by climatic phenomena and livestock grazing (Hudak, 1999; Archer *et al.*, 1995). Heavy livestock grazing considered being the main cause of vegetation degradation (Hudak, 1999; Ringrose *et al.*, 1990) particularly in the communal areas (Wesseles *et al.*, 2004; ICRA, 2003). Monitoring of rangelands is therefore, a very important factor.

The proportion of bare ground is a relevant indicator of rangeland condition at a given region at a landscape level (NRC, 1994; Pyke *et al.*, 2002; O'Brien *et al.*, 2003; Booth & Tuller, 2003). A normal hydrologic cycle leads to a healthy rangeland with greater potential of green biomass production with less bare ground cover. Disruption of hydrological cycle in rangelands can cause a desert like weather pattern (Weber, 2006) resulting into an increasing proportion of bare ground exposure. This scenario is a bigger challenge in most communal lands of South Africa. In areas where stocking rates are low, the way livestock use the rangelands may play an important role in triggering land degradation. For example, restriction of livestock movements at a confined locality can cause serious rangeland degradation even when the number of the livestock is smaller (Sneath, 2000). Curtin *et al.* (2002) indicated that despite an average reduction of livestock, stocking rates in some regions of the world, the recent increase in livestock quantities per individual farms is causing higher land degradation around residential areas.

Assessment of the distribution and development of different biophysical phenomena in rangelands is hampered by lack of relevant data on soil, vegetation, topography and socio-economic conditions. Acquiring meaningful data on rangelands requires collection and evaluation of different patterns of biophysical factors over large areas (Washington-Allen *et al.*, 2006; Sant *et al.*, 2014). Traditional field based data is not enough to accurately assess rangeland conditions over large spatial extents outside of a sampling unit (Donahue, 2000).

The application of remote sensing is an important technique for rangeland assessment and reducing the problems that are associated with the traditional field based data collection. The spectral variation from the satellite image together with a field data can provide a guide to the surface characteristics and spatial distribution of different features (Sant *et al.*, 2014). Multispectral satellite imagery can be used effectively for land cover classification and mapping of rangelands (Pickup *et al.*, 1994; Clark *et al.*, 2001). However, lack of proper training in remote sensing among range managers and stakeholders poses a problem in application of this technique, in spite of availability of computer hardware and software and high satellite imagery costs are no longer constricting factors (Sant *et al.*, 2014). Beerli *et al.* (2007) indicated that remote sensing allows a quick, cost effective and systematic way of acquiring reliable and up-to-date information. Many studies have shown that application of remote sensing have improved rangeland management and assessment processes by providing multiple means through its expanded temporal and spectral scales (Booth & Tueller, 2003). Vegetation mapping has been made using multispectral satellite imagery particularly SPOT 5 (Grant *et al.*, 2013).

Vegetation mapping that shows environmental variations over extensive landscape is essential for rangeland management (Booth & Tueller, 2003). There is no comprehensive rangeland vegetation distribution and characteristics mapping in the North-West province by taking into considerations the different rangelands management regimes regarding the application of spectral discrimination of land cover classes. Therefore, this study attempts to characterise the different land cover classes and mapping vegetation distribution and rangeland conditions using SPOT 5 imagery and explores the potential of SPOT 5 imagery for mapping vegetation cover, proportion of bare ground and indicators of erosion using a maximum likelihood classifier.

4.2 Materials and methods

4.2.1 Data types and sources

Climatic data, satellite data and field data were used in this study. These data were collected from different sources.

4.2.1.1 Satellite imagery

SPOT 5 imageries of the study areas were acquired between February 28, 2014 and April 6, 2014 for use in this study.

4.2.1.2 Rainfall data

Average rainfall data of each study site was collected from the South African Weather Services.

4.2.1.3 Field data

Field data was collected during the peak growing seasons of the study sites between February and April 2014 on two biophysical indicators such as proportion of bare ground and indicators of erosion (gullies, rills and dongas).

Assessing proportion of bare ground:

Bare ground location was recorded from 177 sample points by taking differential GPS readings from the study sites. These GPS locations were identified on the satellite imagery and were used as training areas for image classification (for detail, refer Section 3.2.1.1).

Indicators of erosion:

Data on these indicators were collected during the assessment of the proportion of the bare ground from 177 points by measuring the width of gullies, rills and dongas. GPS positions of the locations of the erosion indicators were taken in order to identify them on the high resolution (pan-sharpened) SPOT satellite images. The sizes of these indicators on the images were determined and compared with field derived sizes.

4.2.2 Analysis of SPOT 5 data

4.2.2.1 Image pre-processing

SPOT 5 data were processed to top-of-the-atmosphere reflectance using the Cos(t) image based correction method (Chavez, 1988) in ERDAS Imagine 2013 environment. The images were then georectified (RMSE =7.6 m) using high resolution aerial photograph and projected into UTM (WGS 84) using a first order affine transformation and nearest neighbor resampling.

4.2.2.2 Image classification

One important part of digital image analysis is the identification of certain groups of pixels that have specific spectral characteristics and to establish the various features or land cover classes characterized by these groups (Lillesand *et al.*, 2008). Satellite image classification is the process of categorizing all the pixels in an image into a finite number of individual classes based on the spectral information and characteristics of these pixels. The classification results in a classified image that is basically a thematic output of the original image. Remote sensing image data in this study was classified using maximum likelihood classification (MLC) which is a hard classification approach. The maximum likelihood classification method is derived from Bayes' theorem. This method is a popular method by which the population of the statistics such as variance and mean are estimated to maximize the likelihood or probability from a defined probability density function in the given feature space. Correct representation of a population can be achieved by selecting statistically unbiased sampling of training data from the population. The probability density in the maximum likelihood classification technique is selected to be a multiple normal distribution and this multiple normal distribution gives the mean and the variance-covariance matrix which is the maximum likelihood estimator.

4.2.2.3 Classification scheme

The maximum likelihood classification technique is exclusively based on spectral properties computed mathematically on a pixel basis. This classification algorithm entails training areas to be identified for every land cover class. These training areas were selected to represent the spectral behavior within each class. Major attention was drawn to the basic ground cover types such as (i) water body, (ii) built up area, (iii) shrub-land and tree, (iv) herbaceous vegetation and grass, (v) bare ground and (vi) indicators of erosion. Primarily, these classes can be compared to ecological site descriptions that are used as benchmarks in monitoring rangeland ecosystems (Peterson *et al.*, 2009; Weber *et al.*, 2009). The classes shown in Table 7 were extracted as thematic classes from the image and for which area statistics were generated.

Table 7: Image interpretation classes used in the classification

<i>Class Name</i>	<i>Description</i>
Water Body	Area dominated by water bodies such as dams, wider rivers and ponds
Bare Ground	Area dominated by newly ploughed farm land, fallow fields and Bare soils
Indicators of erosion	Area dominated by indicators of erosion such as rills, gully's and dongas
Built-up areas	Areas dominated by villages and inhabited areas
Grasses/Herbaceous veg.	Areas dominated by grasses, herbs and pasture
Trees/Shrubs	Areas dominated by <i>Acacia</i> trees and other woody plants including scattered trees and shrubs

Spectral signatures for bare ground and the rest of land cover classes training sites were extracted from all satellite imagery layers and assessed for signature separability in order to determine appropriate decision rules. Maximum likelihood classification was performed from the extracted spectral signatures using Equation 4.1 and 4.2.

$$\text{Mean; } \mu_{ai} = \frac{1}{n} \sum_{j=1}^n x_{ij} \quad (i = 1, 2, \dots, m) \quad \text{Equation 4.1}$$

$$\text{Variance-Covariance matrix } \Sigma_e = \frac{1}{m} \sum_{i=1}^m (x_i - \mu_a)(x_i - \mu_a) \quad \text{Equation 4.2}$$

where:

m = number of bands

n = number of pixels

4.2.2.4 Classification accuracy assessment

Ground-truth sites were documented during field visits getting GPS coordinates and photographs (e.g Figure 5) within the study region between February and April, 2014. Each ground-truth site was digitized as area of interest (AOI) through visual selection of homogeneous areas close to collected GPS coordinates using a false colour and true color image of SPOT 5 of March and April 2014 of the study sites. To minimize mapping errors during visual digitalisation of the ground-truth data, one hundred and fifty sampled grid values were computed from ground-truth AOI-mask for each land cover class from the ground truths from each protected area and communal lands in all rainfall zones but only ninety sampled points were computed from each private ranch in all rainfall zones in ArcGIS 10.2 environment. The resulting new mask was used to compute spectral index thresholds for each land cover class dataset. Additional information besides the ground truth-data was obtained from Google

Earth, aerial photographs and topographic maps of the study sites to generate independent test sites as a basis for formal accuracy assessment of the final mapping result.

Accuracy of the classified images were analysed using the standard error matrix (Congalton & Green, 2009) that reported users' accuracy, producers' accuracy, overall accuracy and the Kappa coefficient of agreement statistics (Titus *et al.*, 1984; Foody, 2002). The Kappa coefficient ($\check{K}$) is a measure of classification accuracy which incorporates the off-diagonal elements as well as the diagonal terms to give a more reliable assessment of accuracy than overall accuracy using Equation 4.3 (Bishop *et al.*, 1975):

$$\check{K} = \frac{N \sum_{i=1}^k x_{ii} - \sum_{i=1}^k (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^k (x_{i+} * x_{+i})} \quad \text{Equation 4.3}$$

where:

k = the number of rows in the error matrix

x_{ii} = the number of observations in i row and column

x_{i+} = the marginal totals of row

x_{+i} = the marginal totals of column

N = the total number of observations.

SPOT 5 imageries of the study sites were used to determine major land-use land-cover classes. Visual interpretation of the images during land cover classification was improved by means of ground-based data. Land cover classification results are presented with a display of land cover maps. This is followed by a description of the characteristics of each classified land cover class. Related information portraying spatial extents and distribution of each classified land cover class has been highlighted.

4.2.3 Relationship between proportion of bare ground and rainfall

Spatial patterns of proportion of bare ground and spatial distribution of rainfall are highly correlated. Regression analysis was performed to assess the impact of spatial distribution of precipitation on the proportion of bare ground in the study sites.

4.3 Results

4.3.1 Land use/Land cover statistics

In this study, land cover classification was performed primarily to map major land cover classes and determine the capability of SPOT data to map land cover types, extent of bare ground and indicators of erosion. Table 8 presents the percentage coverage of each major land cover type and their corresponding areas. In the low rainfall area, of Morokweng communal lands, bare ground comprised the larger area coverage followed by grasses/herbaceous vegetation with the least extent of indicators of erosion (Figure 12). The Molopo Nature Reserve and Dubbelaar private ranch in this region were largely dominated by grasses/herbaceous vegetation with relatively higher bare ground proportion (Figure 12). In the medium rainfall zone, bare ground coverage was lower comprising of 17% in the Disaneng communal area (Figure 12), 8% Mafikeng Game Reserve and 10% in the Lenric private ranch. In the medium and high rainfall regions, grass/herbaceous vegetation cover comprised of the largest proportion. The bare ground in the Onderstepoort private ranch in the high rainfall region was 6% (Figure 12). Bare ground comprised the largest proportion in the communal areas and these areas are believed to be degraded (Hoffman *et al.*, 1999; Hoffman & Todd, 2000) as compared to the protected areas and the private ranches. Communal areas are characterized by a high number of livestock, soil erosion, and the loss of palatable grazing species (Hoffman *et al.*, 1999; Hoffman & Todd, 2000) causing over utilization of pasture lands beyond their carrying capacity. Shackleton (1993) indicated that animal stocking rates in the communal areas are more than twice that of the neighboring commercial farms. Consequently, there is a general agreement that this land degradation is due to overgrazing (Hoffman & Ashwell, 2001; Scholes & Biggs, 2004).

Rainfall Zones	LRF ZONE						MRF ZONE						HRF ZONE					
Study Sites	Morokweng CRL		MOLOPO NR		Dubbelaar PR		Disaneng CRL		MHK_GR		Lenric PR		Ngwedding CRL		Pillanesberg NP		Onderstepoort PR	
Land Cover Classes	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)	LC (%)	Area (Km²)
Cloud Cover	0	0	8	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Body	1	3	1	3	0	0	1	4	2	3	0	0	0	0	2	8	0	0
Indicators of Erosion	1	2	2.5	3	1	2	0.6	1	1	1.4	0	0	0.3	1	0.4	3	0	0
Builtup Area	11	23	0	0	0	0	1	3	0.5	1	0	0	9	143	0	0	1	0.7
Bare Ground	43	102	26	128	37	42	17	81	8	15	10	1	21	325	19	327	9	6
Grass/Herb	28	69	43	221	50	56	43	295	64	98	70	4	60	768	44	801	59	40
Tree/Shrub	16	38	22	108	13	15	22	265	31.5	56	20	2	10	345	35	580	31	21

Deleted:

Table 8: Percentage of land use land cover across the three rainfall zones of the study sites

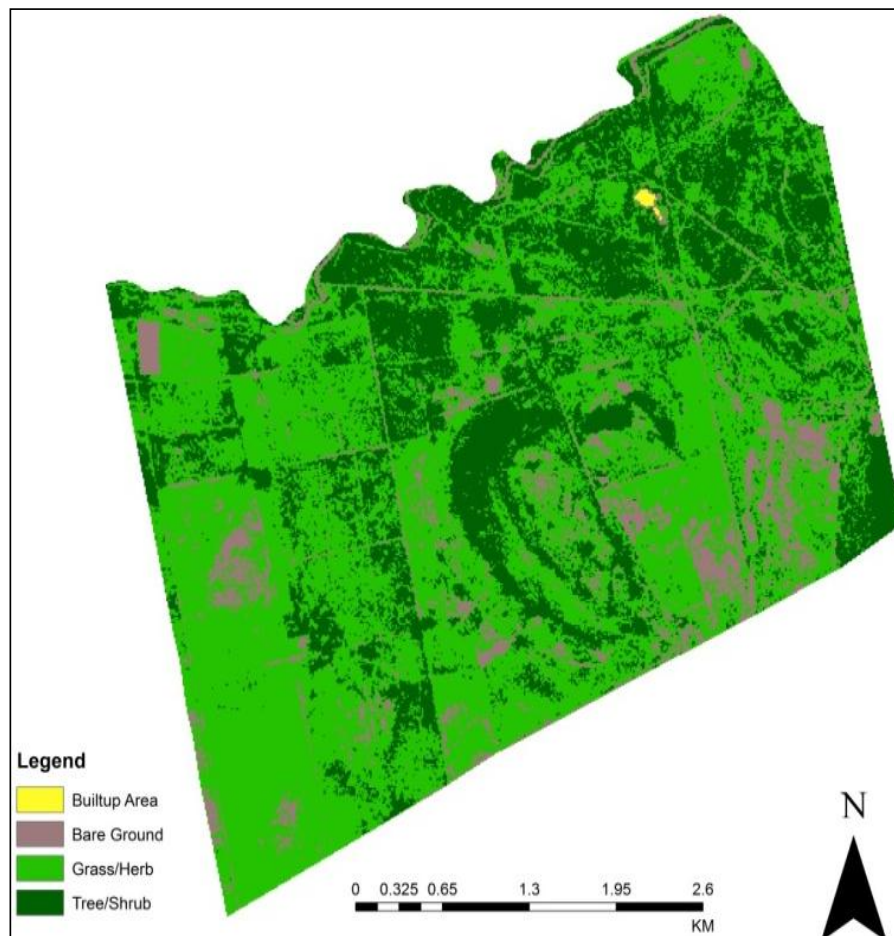


Figure 12: Distribution of land cover classes and proportion of bare ground in Onderstepoort private ranch

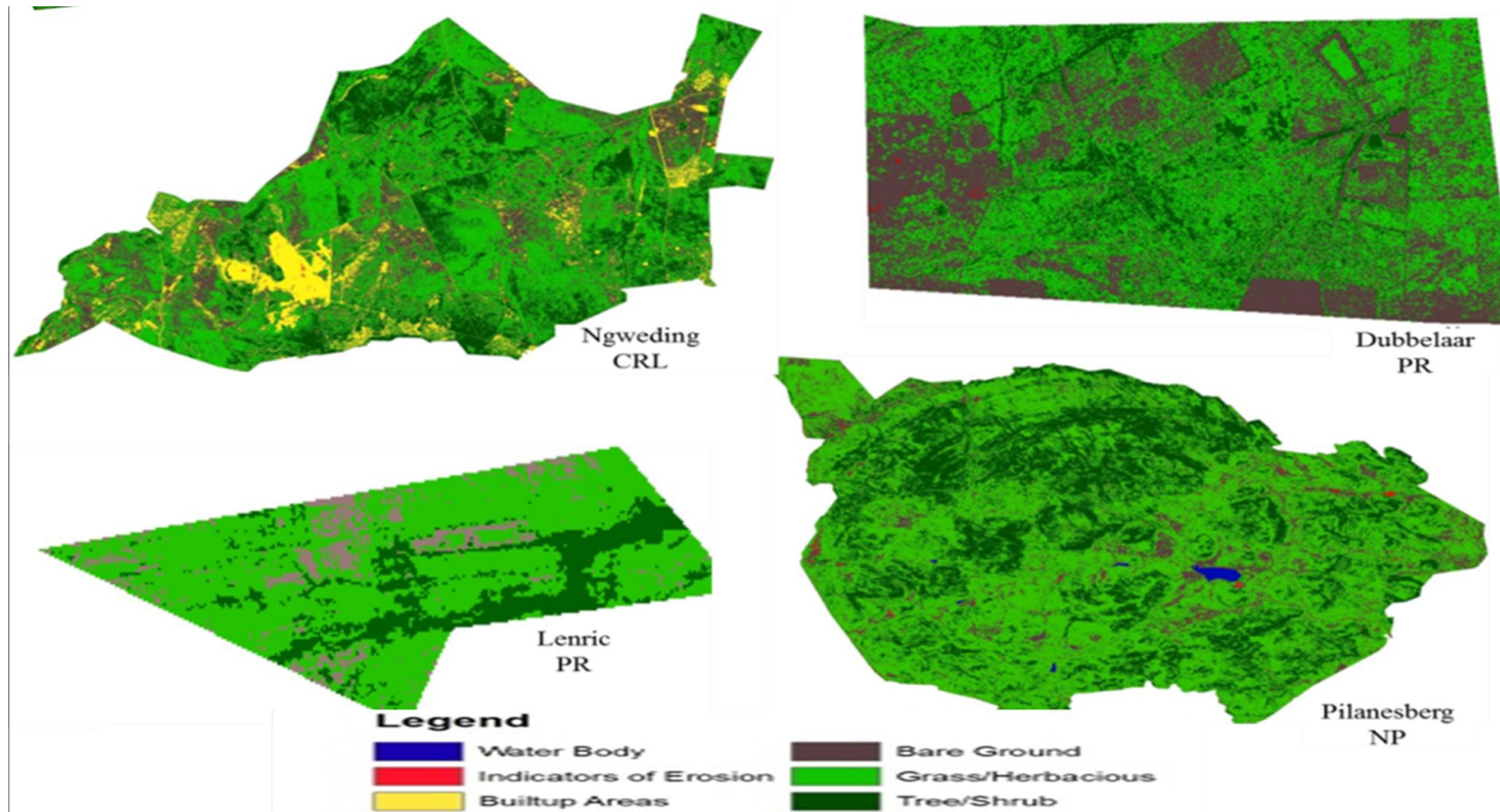


Figure 13a: Distribution of land use/land cover classes and proportion of bare ground

NOTE: (CRL) Communal Rangeland; (NR), Nature Reserve; (GR), Game Reserve; (PR), Private Ranch; (NP), National Park.

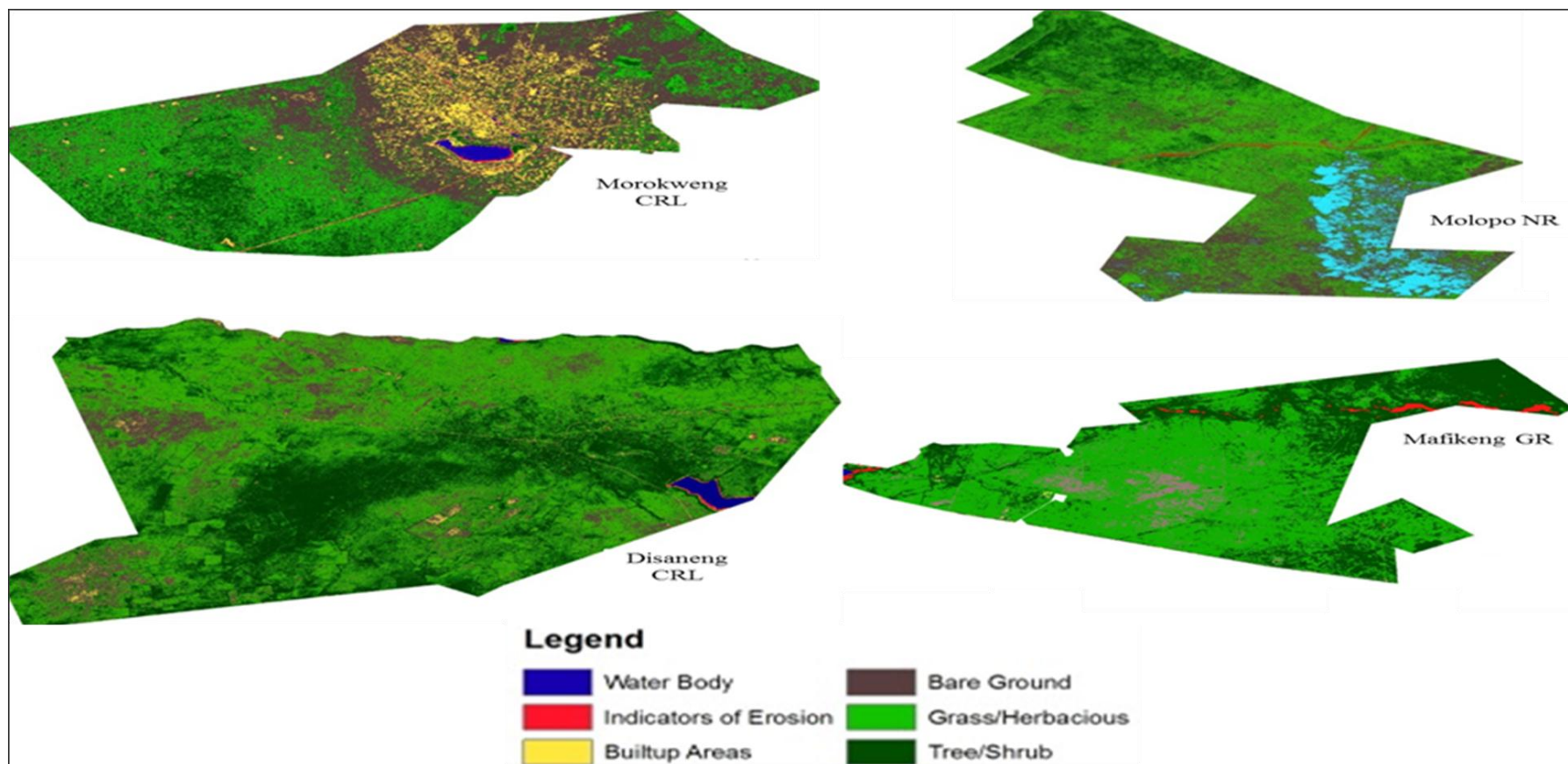


Figure 14b: Distribution of land use/land cover classes and proportion of bare ground

NOTE: (CRL) Communal Rangeland; (NR), Nature Reserve; (GR), Game Reserve; (PR), Private Ranch; (NP), National Park.

4.3.2 Accuracy assessment

Accuracy was established empirically by selecting sample pixels from the image and verifying their labels against classes determined from reference data. The proportion of pixels from each class labeled in the image correctly by the classifier was estimated as well as the proportion of pixels from each class incorrectly labeled into every other class. These results were articulated in tabular form treated as the 'error matrix' (Lillesand *et al.*, 2008). The land cover classification accuracy is mainly affected by: categorical resolution (number of land cover classes) and, spectral resolution (using a few spectral bands rather than all bands) (Guerschman *et al.*, 2003).

In this study, maximum likelihood classification yielded an overall accuracy of 0.74 and 0.74 with overall Kappa index of agreement 0.66 and 0.80 in the Morokweng communal rangeland, and Molopo Nature Resesrve respectively in the low rainfall area (Table 9 and 10).

Table 9: Error matrix for land cover classes in Morokweng communal rangeland

Land Use/Land Cover Classes	Water Body	Bare Ground	Indicators of Erosion	Built up Areas	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Water Body	5	0	0	0	0	0	5	1.00
Bare Ground	0	21	0	2	3	3	29	0.72
Indicator of Erosion	0	2	3	0	1	2	8	0.38
Cloud/Built up Areas	0	3	0	10	2	3	18	0.55
Grass	0	2	2	1	39	5	49	0.80
Shrubs	0	1	5	0	3	33	42	0.79
No. of Ground Truth Pixels	5	29	10	13	48	45	150	
Producers Accuracy	1.00	0.72	0.30	0.77	0.81	0.74	Overall Accuracy	0.74

K = 0.66

Table 10: Error matrix for land cover classes in Molopo Nature Reserve

Land Use/Land Cover Classes	Water Body	Bare Ground	Indicators of Erosion	Cloud/Built up Areas	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Water Body	1	0	0	0	0	1	2	0.50
Bare Ground	0	26	2	2	3	0	33	0.79
Indicator of Erosion	0	0	3	1	0	1	5	0.60
Cloud/Built up Areas	0	2	0	19	2	1	24	0.79
Grass	0	2	1	1	40	3	47	0.85
Shrubs	1	0	1	2	4	31	39	0.80
No. of Ground Truth Pixels	2	30	7	25	49	37	150	
Producers Accuracy	0.50	0.87	0.43	0.76	0.84	0.84	Overall Accuracy	0.80

$K = 0.74$

The Dubelaar private ranch classification yielded an overall Kappa index of 0.81 while the overall user's accuracy was 0.71 (Table 11).

Table 11: Error matrix for land cover classes in Dubelaar Private Ranch

Land Use/Land Cover Classes	Bare Ground	Indicators of Erosion	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Bare Ground	22	1	3	0	26	0.88
Indicator of Erosion	0	1	0	1	2	0.50
Grass	3	0	34	5	42	0.80
Shrubs	1	1	2	16	20	0.85
No. of Ground Truth Pixels	26	3	39	22	90	
Producers Accuracy	0.85	0.33	0.88	0.72	Overall Accuracy	0.81

$K = 0.71$

The overall accuracy 0.81, 0.77 and 0.76 with overall Kappa index of agreement 0.72, 0.66 and 0.62 was yielded in the Disaneng communal rangeland, Mafikeng Game Reserve and the Lenric private ranch around Mafikeng Game Reserve region respectively in the medium rainfall area (Table 12, 13 and 14).

Table 12: Error matrix for land cover classes in Disaneng communal rangeland

Land Use/Land Cover Classes	Water Body	Bare Ground	Indicators of Erosion	Built up Areas	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Water Body	8	0	0	0	0	0	8	1.00
Bare Ground	0	37	0	1	6	2	46	0.80
Indicator of Erosion	0	0	2	0	0	0	2	1.00
Built up Areas	0	1	0	2	0	2	5	0.40
Grass	0	3	0	0	44	6	53	0.83
Shrubs	0	1	2	2	5	26	36	0.72
No. of Ground Truth Pixels	8	42	4	5	55	36	150	
Producers Accuracy	1.00	0.88	0.50	0.40	0.80	0.72	Overall Accuracy	0.81

$K = 0.72$

Table 13: Error matrix for land cover classes in Mafikeng Game Reserve

Land Use/Land Cover Classes	Water Body	Bare Ground	Indicators of Erosion	Built up Areas	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Water Body	3	0	1	0	0	1	5	0.60
Bare Ground	0	13	0	1	6	2	22	0.59
Indicator of Erosion	0	1	3	0	2	1	7	0.43
Built up Areas	0	1	0	2	0	1	4	0.50
Grass	0	2	0	0	54	12	68	0.79
Shrubs	0	1	2	0	5	41	47	0.87
No. of Ground Truth Pixels	3	17	6	3	65	58	150	
Producers Accuracy	1.00	0.76	0.50	0.75	0.83	0.71	Overall Accuracy	0.81

$K = 0.66$

Table 14: Error matrix for land cover classes in Lenric Private Ranch

Land Use/Land Cover Classes	Bare Ground	Grass	Tree/Shrubs	No. of Classified Pixels	User Accuracy
Bare Ground	14	0	0	14	1.00
Grass	7	32	5	44	0.73
Shrubs	3	7	22	32	0.69
No. of Ground Truth Pixels	24	39	27	90	
Producers Accuracy	0.58	0.82	0.81	Overall Accuracy	0.76

$K = 0.62$

The overall accuracy in the High Rainfall Zone was 0.77, 0.81 and 0.89 in the Ngweding Communal rangeland, Pillanesberg National Park and the Onderstepoort private ranch around the Pillanesberg National Park with overall Kappa index of agreement 0.69, 0.73 and 0.83 respectively (Table 15, 16 and 17).

Table 15: Error matrix for land cover classes in Ngweding Communal Area

Land Use/Land Cover Classes	Bare Ground	Indicators of Erosion	Built up Areas	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Bare Ground	26	0	3	3	2	34	0.76
Indicator of Erosion	0	2	0	0	1	3	0.67
Built up Areas	2	0	14	4	3	23	0.61
Grass	3	0	1	40	5	49	0.82
Shrubs	0	2	2	3	34	41	0.83
No. of Ground Truth Pixels	31	4	20	50	45	150	
Producers Accuracy	0.84	0.50	0.70	0.80	0.76	Overall Accuracy	0.77

K = 0.69

Table 16: Error matrix for land cover classes in the Pillanesberg National Park

Land Use/Land Cover Classes	Water Body	Bare Ground	Indicators of Erosion	Grass	Shrubs	No. of Classified Pixels	User Accuracy
Water Body	12	0	0	0	0	12	1.0
Bare Ground	0	17	1	2	1	21	0.81
Indicator of Erosion	0	1	2	0	2	5	0.40
Grass	0	3	0	51	8	62	0.82
Shrubs	0	2	2	6	40	50	0.80
No. of Ground Truth Pixels	12	28	5	59	51	150	
Producers Accuracy	1.00	0.76	0.40	0.83	0.71	Overall Accuracy	0.77

K = 0.73

Table 17: Error matrix for land cover classes in Onderspoort Private Ranch

Land Use/Land Cover Classes	Bare Ground	Built up Areas	Grass	Tree/Shrubs	No. of Classified Pixels	User Accuracy
Bare Ground	17	0	3	0	20	0.85
Built up Areas	0	1	0	1	2	0.5
Grass	2	0	32	4	38	0.73
Shrubs	0	0	2	29	31	0.83
No. of Ground Truth Pixels	19	1	37	33	90	
Producers Accuracy	0.89	1.00	0.83	0.73	Overall Accuracy	0.89

$K = 0.83$.

All classes from all study sites resulted into producer accuracies higher than 70% except the built up areas and indicators of erosion in almost all study sites which yielded producers accuracy of $\geq 50\%$. The low accuracy of the built up areas and indicators of erosion in all the study sites might be attributed to the similarities of the spectral signatures of the land cover classes in the regions. In most of the study sites, built-up areas pixels were classified as bare ground and shrub. The misclassification of the built up area to the bare ground could be attributed to the bare ground and built up areas have similar spectral reflectance and physical structure. Indicators of erosion was the most misclassified land cover class during this study probably because of lack of distinctive spectral reflectance of this land cover class. The producer's accuracy of indicators of erosion was 30% while the user's accuracy was slightly higher (38%). This means that although 30% of the indicators of erosion were correctly identified, only 38% of the areas labelled indicators of erosion were actually indicators of eroded areas, implying a significant misclassification of the pixels in that category in Morokweng communal area Table 8. Similarly, a user's accuracy of 40% and a producer's accuracy of 33% for the indicators of erosion in Disaneng communal area in the medium rainfall region was also one of the lowest accuracy levels acquired (Table 12) and this scenario was also seen in other study sites.

Some difficulties were detected also when spectrally separating the farmlands and bare ground; grass and herbaceous vegetation particularly in the low rainfall area. Therefore, the farm land and bare ground were combined into one single class (bare ground) and grasses and herbaceous vegetation were also classified into one class called grass/herbaceous. There was a massive presence of taller and greener trees around Disaneng village, north of Disaneng Dam (Figure

13). The spectral reflectance of the trees overshadowed the spectral reflectance of built-up areas and it was extremely difficult to extract and characterize the built-up areas independently. The low producer's (0.4) and user's (0.4) accuracies in this specific area might be related to these factors.

It was noted that there was a weakness in the methodology which was employed to classify the land cover classes from the SPOT 5 satellite imagery. Previous studies have shown that supervised classification techniques such as Maximum Likelihood Classification (MLC) algorithm could not express water erosion features at an acceptable level of accuracy due to the spectral similarities with other land cover features (Solaimani & Hadian-Amri, 2008; Pirie, 2009; Torkashvand & Alipour, 2009). However, all classes from all study sites possess overall Kappa Index of agreement of above 60% indicating a moderate agreement with the ground truth.

4.4.4 Impact of rainfall distribution and management regimes on the proportion of bare ground

Rainfall distribution and the proportion of bare ground were negatively correlated ($r = -91$) with a high coefficient of determination ($R^2 = 0.80$, $P < 0.001$) (Figure 14) indicating that the distribution of rainfall had a significant effect on the proportion of bare ground in the study sites. The average proportion of bare ground for the entire study sites was 22% with a standard deviation of 11%. The highest average proportion of bare ground was 35% in the low rainfall area followed by 16% in the high rainfall area and the least average proportion of bare ground was found in the medium rainfall area (15%). As rainfall increased from the low rainfall areas to the high rainfall areas, the proportion of bare ground decreased significantly.

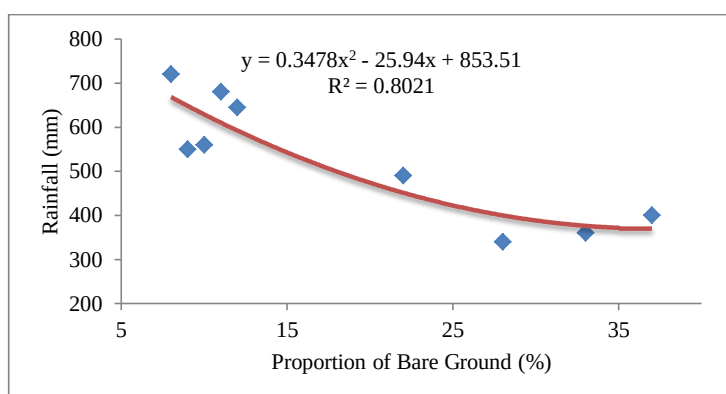


Figure 15: Relationship between rainfall distribution and proportion of bare ground

The proportion of bare ground in the low rainfall area was the highest (43%) followed by private (37%) and protected rangelands (26%). The protected rangelands in high rainfall areas and low rainfall areas were covered with 19% and 26% of bare ground, respectively (Figure 15). Communal rangelands had the highest proportion of bare ground while protected areas had the least across all the rainfall zones. The proportions of bare ground in the high rainfall areas and the medium rainfall areas were low, comprising only 16% and 15% of the total areas of these respective rangelands (Table 8). At low rainfall region, where the rainfall normally is below 400mm, the proportion of bare ground was the highest. These arid and semi-arid regions are dynamic in nature where spatio-temporal variability of abiotic factors dictate the biotic factors (Westoby *et al.*, 1989; Govender *et al.*, 2006; Zhang *et al.*, 2012) particularly rainfall.

The distribution of rainfall has a major impact in overall abundance of vegetation across the study sites. The low and extremely erratic rainfall has a clear effect on the growth of vegetation in the low rainfall areas. In these areas, there is a closer similarity in terms of the proportion of bare ground among the three rangeland regimes indicating the stronger relationship between the rainfall distribution and conditions of vegetation rather than other factors such as management strategy. The nature of rainfall distribution can cause alteration of a stable state of rangelands resulting into a reduced biomass production (Holmgren *et al.*, 2006).

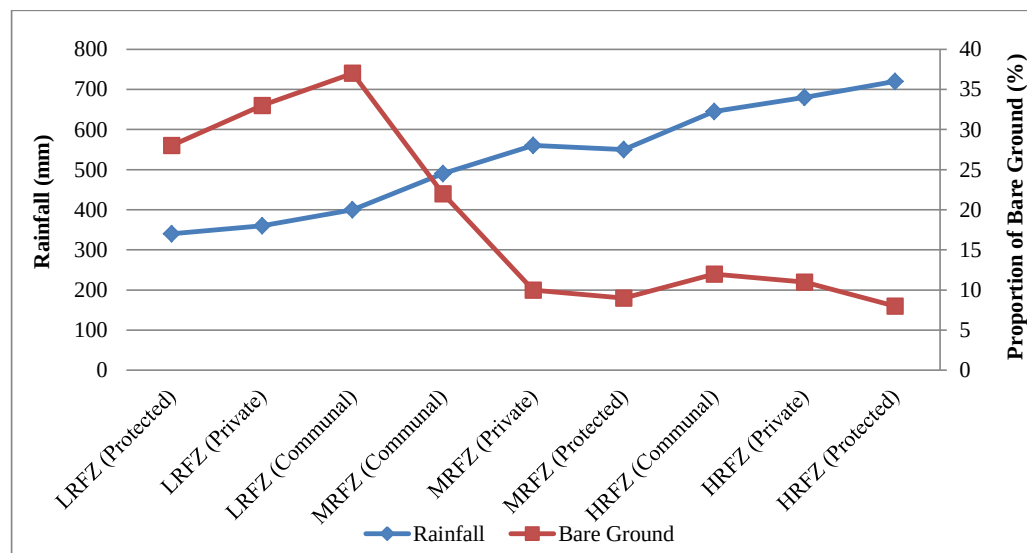


Figure 16: Relationship between rainfall distribution and proportion of bare ground across the study sites in the North West Province

Continuous and unchecked grazing conditions resulted in communal rangelands losing vegetation cover, hence the higher proportion of bare ground with long term negative implications for the overall health of the rangelands (Hoffman & Ashwell, 2001; Wessels *et al.*, 2004; Mousa *et al.*, 2009a). Shrub encroachment and the replacement of perennial grasses by less palatable annual grasses are common phenomena around communal rangelands and are often considered as indicators of land degradation (Perkins & Thomas, 1993; Thomas & Tulyman, 2004). As a result of overgrazing and inappropriate management practices, *Acacia malifera* tree, which is unpalatable to livestock, is found encroaching into the communal grazing areas, especially in the low rainfall region at the expenses of the palatable herbaceous vegetation (Moleele *et al.*, 2002; Dougill *et al.*, 2010). This condition increases rural poverty levels by creating situations where the long-term goal of sustainable rangeland use and management is undermined by short-term needs of food security (Perkins, 1996; Chanda *et al.*, 2003; Bedunah & Angerer, 2012).

In addition, it was observed that the proportion of the bare ground was higher around and near watering points in protected areas and around settlement areas in the communal rangelands. This was also evident from the classified images of the study sites (Figure 13). However, satellite imageries failed to show the extent and locations of smaller watering points (ponds less than 100m²) in low and medium rainfall areas. Unpalatable and weaker sparse grass species characterize the zone in the immediate vicinity of watering points (0-100m), whereas places farther away from the watering points were characterized by high abundance of highly desirable and palatable grasses. These findings are in agreement with previous studies. For instance, areas that are closer to watering points in which grazing pressure is higher; palatable perennial plants decline in quantity and density and are replaced by less desirable forages or bare ground (Hunt *et al.*, 2006).

Vegetation cover is a crucial factor in reducing the effect of water soil erosion. If the area is covered by bare ground or very little vegetation cover, soil erosion by water increases. Plant and residue cover protects the soil from rain drop and splashing impacts by slowing down the movement of surface runoff and allowing excess surface water to infiltrate. The effectiveness of a plant in terms of reducing the impact of soil erosion depends on the spatial extent and quantity of vegetation cover. The presence of vegetation residue that completely covers the soil and intercepts all falling rain drops at and closer to the surface are some of the most efficient factors in protecting the top soil from various types of erosion. Therefore, the results of this study suggest that low rainfall areas, which are characterized by higher proportion of bare ground, are the most vulnerable regions for higher level of erosion by water and wind. Moreover, these areas experience isolated heavy rainfall during summer seasons making them susceptible to land degradation due to loss of the fertile top soil. In particular, the communal areas in all rainfall zones are the most vulnerable rangelands because they are characterised by higher number of human and livestock population (Shackleton *et al.*, 2001; Wessells *et al.*, 2004; Moussa *et al.*, 2009).

4.4.5 Conclusion

In this study, SPOT 5 imagery was used for mapping land cover features in the study sites and this data source was also assessed for its capacity for mapping different biophysical indicators of rangelands such as indicators of erosion and proportion of bare ground besides land cover classes using the maximum likelihood classification technique. SPOT 5 data was found to be highly useful for mapping and assessing rangeland land cover classes with acceptable accuracy particularly the proportion of bare ground which is a good indicator of rangeland health and

other land cover classes such as water body, built up areas, grass/shrub and tree/shrubs in spite of some characteristic problems. However, SPOT 5 imagery was found to be irrelevant for assessing indicators of erosion such as gulleys, rills and dongas due to coarse 10m x10m spatial resolution. The study sites are located in arid and semi-arid areas, the presence of indicators of erosion in most of the study sites is also limited because of low rainfall. More research focusing on reconciling field data and satellite imagery has to be carried out to improve results. Strong coefficient of determination ($r^2 = 0.80$) was detected between average rainfall and proportion of bare ground indicating that rainfall is the most important factor in controlling the spatial distribution of vegetation in the study sites.

CHAPTER FIVE

5. EVALUATING THE ABILITY OF DERIVED VEGETATION INDICES AND COVER FRACTION IN ESTIMATING RANGELAND ABOVEGROUND BIOMASS IN SEMI-ARID ENVIRONMENTS

5.1 Introduction

Spectral vegetation indices utilize unique spectral signatures of green vegetation. Different types of vegetation often show typical variability from one another due to different parameters such as shape and size of plants, water content, and associated background. Vegetation indices are applicable to both low and high spatial resolution multispectral satellite sensors, such as NOAA AVHRR, Terra MODIS, Landsat TM and MSS, SPOT HRV/XS, and many others that acquire data in the visible and near-infrared regions. Vegetation indices have been used in a variety of frameworks to assess green biomass and also as an alternative to overall environmental change, especially in the context of drought, land degradation risk assessment and rangeland management (Kogan, 1990; Tripathy *et al.*, 1996; Liu & Kogan, 1996; Wessels *et al.*, 2007; Numata *et al.*, 2007). Different vegetation indices have been developed based on the combinations of two or more spectral bands, assuming that multi-band analysis would provide more information than a single one. Most common types of spectral vegetation indices are the Normalized Difference Vegetation Index (NDVI) and the Spectral Mixture Analysis (SMA). Vegetation indices use radiance, surface reflectance or apparent reflectance values in the red (R) and near infrared (NIR) spectral bands (Gitelson, 2004; Tucker *et al.*, 2005; Zoran & Stefan, 2006; Brown *et al.*, 2006; Angerer *et al.*, 2009). These indices are correlated with various vegetation parameters such as green biomass (Mutanga *et al.*, 2012; Ullah *et al.*, 2012), chlorophyll concentration (Peng *et al.*, 2011; Garbulsky *et al.*, 2011; Clevers & Kooistra, 2012), leaf area index (Mountrakis *et al.*, 2011) and photosynthetic activity (Tueller, 1989; Huete *et al.*, 2002).

The NDVI is a measurement of the balance between energy received and energy emitted by vegetation on Earth (Chuvieco, 1998). When it is applied to plant communities, an estimation of the density and coverage of green vegetation can be determined by measuring the quantity of vegetation present in a given area and its state of health or vigour of growth with computed values ranging between -1 to +1 (Lillesand *et al.*, 2008). NDVI is used by rangeland scientists as an alternative method for vegetation productivity assessment (Pettorelli *et al.*, 2005) and as an appropriate tool for vegetation cover monitoring from global to local scales. It can show

seasonal, annual and inter-annual changes in vegetation. This index has effectively been applied in several studies related to vegetation assessment and desertification (Wessels *et al.*, 2004; Symeonakis & Drake, 2004; Tucker *et al.*, 2005); vegetation cover mapping (Booth & Tueller, 2003; Wang *et al.*, 2005); live plant biomass estimation (Hobbs, 1995; Numata *et al.*, 2007; Clark *et al.*, 2011; Edson & Wing, 2011; Huang & Anderegg, 2012; Gao *et al.*, 2013); drought monitoring and determining percentage of absorbed photosynthetically active radiations (APAR) (Sellers *et al.* 1992; Jin *et al.*, 2013); crop estimations and net primary production (NPP) (Paruelo *et al.* 1997) and environmental monitoring and change detection at different scales (Kowabata *et al.*, 2001; Coppin *et al.*, 2004).

In order to minimize the effects of soil background on the vegetation signal, Huete (1988) proposed the Soil-Adjusted Vegetation Index (SAVI). This index incorporates a constant soil adjustment factor L (where $L=0.5$) into the denominator of the NDVI equation. L varies with the reflectance characteristics of the soil (e.g., colour and brightness). Moreover, in an attempt to reduce variations in reflectance in soil background, Qi *et al.* (1994) proposed the modified SAVI (MSAVI). MSAVI substitutes the constant L with a dynamic soil-adjusting factor and was applied to a cover measure of cotton and range grass canopies with dark and light soil backgrounds. SAVI uses a manual adjustment L while MSAVI utilises a self-adjustment of L . SAVI minimises soil brightness prompted variation that occurs in NDVI, as such it is considered to be the most efficient index where there is low vegetation cover. To some extent, SAVI is the ratio between the near infrared and the red fraction with the addition of a parameter to the red reflectance (Qi *et al.*, 1994). The parameter L is empirically derived and ranges from 1 for very high plant cover to -1 for very low plant cover. Initially, Landsat and SPOT SAVI models included a constant value of 0.5; however, increasing the constant to 0.75 for the low vegetation cover of rangelands might improve classifications (Huete, 1988; Neale & Sivaragan, 2011; Katagis *et al.*, 2012; Wu *et al.*, 2013).

Spectral Mixture Analysis (SMA) has been commonly used to obtain sub-pixel vegetation information from remotely sensed imagery in rangeland management (Numata *et al.*, 2007). The core assumptions for SMA are: (a) the landscape is composed of few structural components, denoted as endmembers, each of which is spectrally unique from the others; (b) the spectral signature for each component is constant throughout the entire spatial extent of analysis, and (c) the remotely sensed signal of a pixel is linearly related to the fractions of endmember present. A careful selection of suitable endmember helps to produce a successful SMA (Tompkins *et al.*, 1997; Elmore *et al.*, 2000). Choosing endmembers engages identifying

the number of endmembers and their matching spectral signatures. Though multispectral sensors collect remote sensing data at several wavelengths, we can only use a very limited number of endmembers in SMA. It is the dimensionality of the data, not the number of bands that determines how many endmembers can be used in SMA (Radeloff *et al.*, 1999).

The SMA result can be conveyed by the percentage cover of each defined ground cover material or endmember in each pixel. This method is advantageous for deriving not only vegetation data, but also land cover fraction for all the endmembers used in the study. SMA offers the spectral data in terms of multiple endmember fraction coverage and not as a single pixel classification, consequently allowing a more detailed analysis of pixel contents (Adams *et al.*, 1995). Time series or multiple geographic location SMA fraction coverage is more easily comparable than the products from classification based on digital numbers. Moreover, the SMA data is generated into a physically based measure and can easily be integrated into studies as measures of percent lively vegetation cover rather than indexed relative measures. Elmore *et al.* (2000) obtained percent live cover estimates using SMA to be precise within 4.0% and change in percent live cover to have an accuracy of 3.8%. SMA has also been used to assess urban environments (Phinn *et al.*, 2002; Small, 2002), determining water turbidity (Östlund *et al.*, 2001), and mapping rangeland degradation (Adams, 1995). SMA can be used to provide a wide range of spectral measurement of vegetation responses and fractions model of biophysical vegetation components in grassland and Savannah ecosystems (Peddle *et al.*, 1999; Elmore *et al.*, 2000; Peddle *et al.*, 2001; Heinz & Chang, 2002). Vegetation fractions yielded by SMA have been employed to describe fractional vegetation cover (Ju *et al.*, 2003), seasonal changes in vegetation cover (Hoster *et al.*, 2003), detection of land cover change (Elmore *et al.*, 2000; Roberts *et al.*, 2002), and regeneration of rangelands after disturbance (Raino *et al.*, 2002).

Roberts *et al.* (1998) introduced the multiple endmembers spectral mixture analysis (MESMA) technique to identify materials in a multispectral and hyperspectral image using endmembers from a spectral library. MESMA has been applied in various environments for rangelands and vegetation biophysical analysis. Roberts *et al.* (2003) and Dennison *et al.* (2000) used MESMA to map vegetation species and land cover types in the Southern California chaparral. Numata *et al.* (2007) used MESMA in an attempt to assess pasture degradation in Rondonia, Brazil by building a conceptual model for pasture physical change using three fractions such as non photosynthetic vegetation (NPV), green vegetation (GV) and shade to characterize possible pasture degradation processes. Painter *et al.*, (1998; 2003) mapped snow grain size in the Sierra

Nevada, USA using an MESMA approach while Okin *et al.* (2001) assessed vegetation cover in semi- arid environments in California using this technique.

In spite of the research efforts, there are limitations to the utility and accuracy in usage of SMA and MESMA approaches. SMA is restricted in the total number of potential endmembers and constrained by the types of endmembers which can be used, specifically when using multispectral data (Okin *et al.*, 2001; Numata *et al.*, 2007). Endmembers must be spectrally distinct from one another and generally account for the dominant land cover and spectral characteristics of the scene by undermining the minor contribution of other land cover types. Usually research is limited to land cover classes such as vegetation, soil, and shade when using multispectral satellite imagery. Additionally, SMA requires a good deal of processing capabilities, field spectral measurements and expertise in order to find pure spectra of appropriate endmembers in the scene.

Despite different opinions from different sources, vegetation indices and spectral mixture analyses are used to monitor and understand the nature of rangelands and their productivity by several range scientists in different regions of the world to sustain the functionality of rangeland ecosystems (Numata *et al.*, 2007). In this study the ability of NDVI, SAVI and SMA was assessed quantitatively to extract meaningful rangeland biophysical parameter information from SPOT-5 data from the North-West province, South Africa. Methodologies required to incorporate ground based measurements with satellite based data are discussed below. For this study, field data that were carefully measured at a specific time period and satellite data that coincide with this time period were utilized. Hence, the main purpose of this research was to compare the effectiveness of the NDVI, SAVI and the SMA for quantifying and mapping the AGB in three rainfall zones across private ranches, communal and protected areas in the North West Province, South Africa.

5.2 Materials and methods

5.2.1 Data types and sources

Field data and SPOT 5 imagery from the South Africa National Space Agency (SANSA) were used in this study.

5.2.1.1 Field data

Field data collection was conducted in the middle of the rainy season from the study sites between 28 February, 2014 and 6 April, 2014 to capture vegetation conditions around the peak growing season.

Above ground biomass: A growth area of 100 m × 100 m was selected (Figure 16) in which five 2 m × 2 m areas were identified, one situated at the center and the remaining four at the four corners of each plot. The grass in the quadrats was cut and weighed to determine the wet weight of the grass and then sealed in a plastic bag before being placed in a drying oven at 72°C for 48 hours and weighed to obtain the dry biomass measurements (for detail, refer to section 3.2.1.1).



Source: author

Figure 17: Field measurement during the field data collection from Disaneng communal rangeland: February 28, 2014

5.2.1.2 Satellite imagery

SPOT 5 multispectral imagery (10 m x 10 m) was acquired from the South African National Space Agency (SANSA) for the period between late February and early April, 2014. Imagery from the SPOT 5 sensor was acquired to match these dates as closely as possible. The SPOT-5 image includes five bands, including one panchromatic band with 5m spatial resolution; two visible (green and red) bands with wavelengths of 0.5–0.59 µm and 0.61–0.68 µm respectively; one near infrared (NIR) band with wavelengths of 0.78–0.89 µm; and one short-wave infrared (SWIR) band with 20 m spatial resolution (Lu *et al.*, 2008) with wavelengths of 1.58–1.75 µm.

5.2.2 Data analysis

Satellite imagery data and field data were analyzed using the methods in the following sections. The images were atmospherically corrected and converted to reflectance using the Cos(t) model

(Chavez, 1996) to reduce variability of vegetation indices due to the heterogeneity in the radiometric processing of data (Guyot & Gu, 1994). All images were georectified using nearest-neighbor resampling technique. The NDVI, SAVI and SMA were then computed. Then these variables were integrated with field based above-ground biomass data using a regression technique. The following section discusses in detail the data analysis techniques.

5.2.2.1 Remote sensing data

5.2.2.1a Image pre-processing

Atmospheric correction

Solar radiation that is reflected by the Earth's surface and the objects in it to satellite sensors is modified by the interaction of the irradiance energy with the atmosphere. The reason for applying the atmospheric correction is to establish accurate surface reflectance values of objects and to recover physical parameters of the Earth's surface by removing atmospheric effects from satellite images (Hadjimitsis *et al.*, 2004). Uncorrected satellite data assumes that the radiance of different objects of interest from the ground has reliable different reflectance characteristics for differentiation and that atmospheric effects are not strong enough to affect the basic spectral separations (Lu *et al.*, 2002). The atmospheric correction is essential in this study mainly because, quantitative analysis by combining field data with spectral data for biomass estimation and band ratio operations for vegetation indices computations are performed. Removing atmospheric effects involves calibration and atmospheric correction using Equation 5.1 (Kaufman, 1989):

$$L_m = L_0 + \frac{\rho^{ST} \text{down } T_{up}}{\pi(1 - s\rho)} \quad \text{Equation 5.1}$$

where L_m = measured at-sensor radiance

L_0 = path radiance for zero surface reflectance

ρ = surface reflectance

S = mean solar spectral irradiance

T_{down} = total downward transmittance from top of the atmosphere (TOA) to the ground

T_{up} = total upward transmittance from ground to sensor

s = spherical albedo of the atmosphere, i.e., the fraction of the upward radiance which is backscattered by the atmosphere

Calibration adjusts the image by converting raw radiance values of each pixel to top-of-atmosphere absolute (radiance) or relative (reflectance) values. Atmospheric correction then adjusts these values to ground radiance or reflectance at each pixel based on sun-ground-sensor geometry and atmospheric composition (Lu *et al.*, 2002).

Geometric correction

Geometric correction is a process of warping the image to fit a planimetric grid or map projection. This process is crucial in remote sensing and global resource management. It uses a resampling model that offsets for systematic distortion effects and performs transformations needed to project the image in a specified map projection. Accurate geometric correction is very crucial for rangeland assessment and for studies that integrate field information. In this study, all the satellite images were geometrically registered in a common projection (WGS 84 datum) using image to image registration procedures and GCPs with RMS error of less than 0.5 pixels.

5.2.2.1b Calculating NDVI

NDVI images are obtained by calculating the ratio between the visible red and near-infrared bands of satellite images. NDVI values range between -1 and 1, where higher values represent more vigorous and healthy vegetation growth which provides an effective measure of photosynthetically active biomass. Lower values which are less than 0.2 correspond to bare ground or rock and sand, moderate values (0.2 – 0.3) indicate shrub and grasslands, while temperate forests are represented by higher NDVI values ranging 0.6 to 0.8 (Inoue *et al.*, 2008). The NDVI is calculated as follows (Equation 5.2):

$$NDVI = \frac{NIR - R}{NIR + R} \quad \text{Equation} \quad 5.2$$

where: NIR and R are the spectral reflectance values in the near infra-red and visible red bands respectively.

5.2.2.1c Calculating SAVI

In places where vegetative cover is low and the area is dominated by bare soil, the reflectance of light in the red and near-infrared spectra can impact vegetation index values. This can create a problem especially, when different soil types are compared that may reflect different amounts of light in the red and near infrared wavelengths. The SAVI was developed as a modification to the NDVI for correcting the influence of soil brightness when vegetative cover is low. The

SAVI is structured similar to the NDVI but with the addition of a soil brightness correction factor (Equation 5.3),

$$SAVI = \frac{NIR - R}{NIR + R + L} * (1 + L) \quad \text{Equation 5.3}$$

where: NIR is the reflectance value of the near infrared band

RED is reflectance of the red band, and

L is the soil brightness correction factor.

The value of L varies depending on the amount of green vegetation cover: in densely vegetated areas, $L \approx 0$; and in areas with no green vegetation, $L \approx 1$. Generally, an $L \approx 0.5$ is the default value used in most situations and it is highly efficient.

5.2.2.1d Calculating SMA

Spectral mixture analysis (SMA) was performed to the four reflectance bands of SPOT 5 imagery to estimate green vegetation (green), and bare ground, using the linear SMA tool in Erdas Imagine 2013 software package. The solution of a linear model in SMA enables the calculation of the relative proportions that a given cover type contributes to a pixel's reflectance. The linear mixture model is defined using Equation 5.4 (Adams *et al.* 1995):

$$R_{\lambda} = \sum_{i=1}^N (f_i p_{\lambda i}) + \epsilon_{\lambda} \quad \text{Equation 5.4}$$

where $p_{\lambda i}$ is the reflectance of endmember i^{th} pixel for a given band(λ)

f_i is the spectral fraction of the endmember

N is the number of endmembers and

ϵ_{λ} is the residual noise error.

A root mean square error (RMSE) was calculated for each pixel of each scene to assess the proficiency of the model (Drake *et al.* 2002, Numata *et al.*, 2007) using the following (Equation 5.5).

$$RMSE = \sqrt{\frac{\sum_{\lambda=1}^M (\epsilon_{\lambda})^2}{M}} \quad \text{Equation 5.5}$$

where: M is the number of bands.

5.2.2.1e Integration of above ground biomass (AGB) and remotely sensed data

A quantitative study was undertaken in this study based upon a remote sensing, GIS and exploratory spatial data analysis and statistical regression techniques. AGB was collected from quadrat having areas of 4m², collected from three different rainfall zones in the 2014 rainy season to capture the maximum growth of the vegetation of the study sites during the months of February, March and April, 2014. Using regression model, a relationship was established between AGB data as a dependent variable and the remote sensing data such as NDVI, SAVI and SMA as independent variables (Figure 17). The purpose of this process was to drive the appropriate independent variable (vegetation indices and fractions) which could provide the best estimated results. The coefficient of determination (R^2) is an indicator that can be utilized to decide whether or not the regression model is acceptable as R^2 is a measure of the percent of variation described by the regression model. Estimation of forage quantity from the vegetation indices (NDVI and SAVI) data and SMA data were performed by relating these vegetation indices and AGB which were modeled using the following mathematical functions:

Linear Regression,

$$y = a + bx \quad \text{Equation 5.6}$$

Exponential model,

$$y = e^{(\alpha + \beta X + \varepsilon)} \quad \text{Equation 5.7}$$

Quadratic model,

$$\text{sqrt}(y) = b_0 + b_1x \quad \text{Equation 5.8}$$

Logarithm model,

$$y = b_0 + b_1 \log x \quad \text{Equation 5.9}$$

Power model,

$$y = ax^b \quad \text{Equation 5.10}$$

where: y is the estimated quantity, x denotes VI values and a and b are the coefficients adopted in the regression models.

These models were tested with a regression analysis of vegetation indices in different rangelands in different parts of the world with concurrent biomasses (Pinter *et al.*, 1983; Rasmussen, 1992; Gamon *et al.*, 1995; Thenkabail *et al.*, 2004). In this study, coefficient of determination (R^2) was used to differentiate model qualities using SPSS 22.0 (SPSS inc.) software. The best fitted models were used to create biomass distribution maps of the study sites.

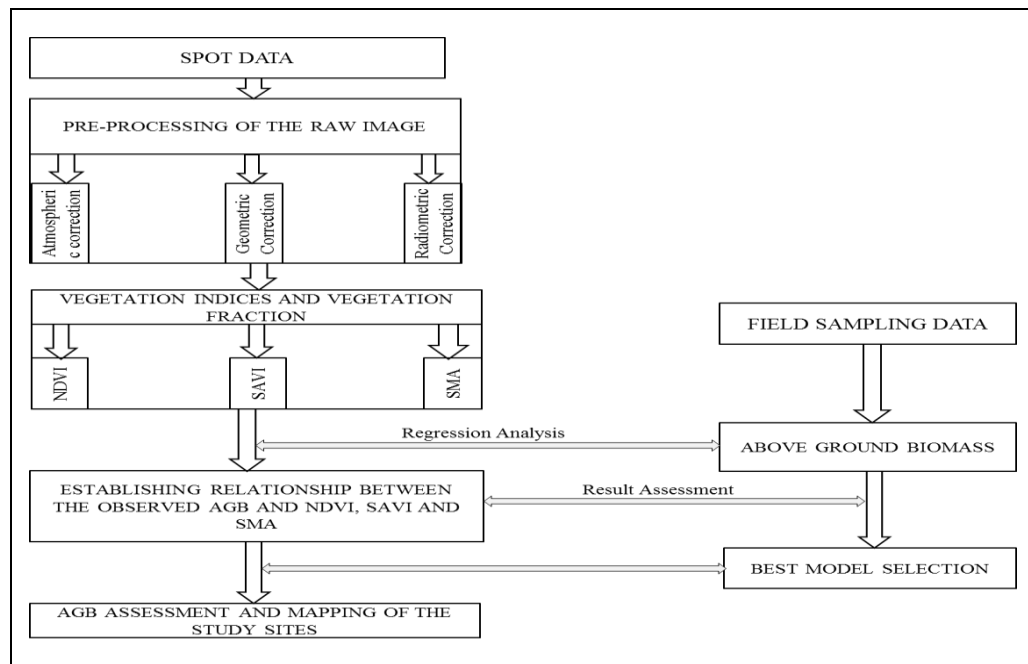


Figure 18: Flow chart showing major steps of the study

5.3 RESULTS

5.3.1 Relationship between vegetation indices (NDVI and SAVI) and vegetation fraction (SMA) and AGB

5.3.1.1 Regression analysis

Summary statistics of agronomic data collected across all sampling sites for each plot are reported in Table 18. The highest values for AGB yield (159 kg/100m²) and the lowest value for AGB yield (10 kg/100m²) were obtained from private ranches in a high rainfall area and the communal rangeland (Morokweng area) of the low rainfall area, respectively.

There were significant differences among the sampling sites across the study areas in terms of AGB production. Significant differences were also found between the NDVI values in different rainfall areas during the study period. The high rainfall areas were characterized by higher vegetation indices and low rainfall areas by lower vegetation indices. A close relationship was detected between the NDVI and AGB for medium and high rainfall areas, while the low rainfall areas displayed weaker.

The highest variability in biomass measurements were observed in medium rainfall zones of the private ranches and the lowest in low rainfall areas of communal lands. This is due to the fact that these grasslands are located along different rainfall gradients with different water and nutrients availability that result in different rates of growth and biomass accumulation. The variation of biomass range observed in these rangelands might be attributed to management practices (overgrazing due to over stocking in the communal areas and underutilization of grasses in the private ranches).

Table 8: Statistical summary of inventoried sub-plot data of the study sites

Parameters	Study Sites	Sample Size (4m ²)	Mean (kg/100m ²)	Minimum (kg/100m ²)	Maximum (kg/100m ²)	Std Dev
Low Rainfall Areas	Communal RL	4*5	13.3	10	18	3.1
	Private Ranch	4*5	45.5	20	63	13
	Protected Areas	4*5	31	17	49	17
Medium Rainfall Areas	Communal RL	4*5	28	12	30	23
	Private ranch	4*5	99	48	145	35
	Protected Areas	(3*5) + 100m ²	57	38	78	22
High Rainfall Areas	Communal RL	4*5	63	73	88	18
	Private ranch	4*5	117	79	159	39
	Protected Areas	4*5	71	39	103	44

On the basis of the relationship between the field data and vegetation indices (NDVI and SAVI) and vegetation fractions (SMA), regression coefficients were developed. Table 19 shows results of regression coefficients and characteristics of rangeland parameters where NDVI was calculated using Equation 5.2; SAVI was calculated individually for each rainfall zone using an increment value of $L = 0.75$ for low rainfall areas; $L = 0.5$ for medium rainfall areas and $L = 0.35$ for high rainfall areas (Huete *et al.*, 1988) depending on the percentage fraction of vegetation cover using Equation 5.3; and SMA was calculated using Equation 5.4.

Five statistical regression models were developed in order to compare the performance of the vegetation indices and the vegetation fraction for estimating the AGB. A result with the best coefficient of determination was used for mapping the distribution of the AGB in the study sites.

Table 9: Coefficient of determination between NDVI, SAVI, and SMA and above ground biomass (AGB)

METHODS		NDVI-AGB (R ²)			SAVI-AGB (R ²)			SMA-AGB (R ²)		
		HGI	LGI	Combined	HGI	LGI	Combined	HGI	LGI	Combined
Low Rainfall zones Low Rainfall Zones	Linear	0.25	0.44	0.46**	0.52	0.56	0.64	0.34*	0.105	0.44*
	Exponential	0.28	0.49*	0.47**	0.53	0.58	0.55	0.35*	0.110	0.53*
	Quadratic	0.18	0.27	0.46**	0.63	0.57	0.64	0.35*	0.095	0.45*
	Logarithmic	0.18	0.16	0.34*	0.40	0.48	0.51	-	-	-
	Power	0.23	0.15	0.37*	0.42	0.52	0.50	-	-	-
Medium Rainfall Zones	Linear	0.37*	0.44*	0.63*	0.37*	0.36*	0.60**	0.14	0.27	0.51**
	Exponential	0.38*	0.40*	0.54*	0.38*	0.37*	0.57*	0.22	0.28	0.48**
	Quadratic	0.38*	0.45*	0.53*	0.38*	0.45*	0.53**	0.20	0.27	0.50**
	Logarithmic	0.38*	0.41*	0.51*	0.39*	0.16	0.44*	0.21	0.26	47**
	Power	0.51**	0.36*	0.46*	0.50*	0.16	0.43*	0.25	0.23	51**
High Rainfall zones High Rainfall Zones	Linear	0.39**	0.72**	0.70**	0.48*	0.49	0.69**	0.16	0.13	0.51*
	Exponential	0.39**	0.65**	0.55**	0.45*	0.43	0.64**	0.19	0.12	0.57*
	Quadratic	0.41**	0.61**	0.63**	0.48*	0.50	0.59**	0.16	0.14	0.61*
	Logarithmic	0.38**	0.59**	0.60**	0.39*	0.44	0.44**	0.18	0.12	0.48*
	Power	0.34**	0.54**	0.50**	0.38*	0.49	0.42**	0.16	0.12	0.47*

Note: The significance level of 0.00 indicates that we can reject the null hypothesis that X (NDVI) does not predict Y (AGB). * Correlation is significant at the 0.05 level (one-tailed), ** Correlation is significant at the 0.01 level (one-tailed).

Regression models of AGB as a function of spectral indices (NDVI and SAVI) and vegetation fraction (SMA) were compared. From the high grazing intensity sites in the LRFZ, AGB was not significantly correlated to the NDVI and SAVI at $p \leq 0.05$ (Table 19). However, in the low grazing intensity site and the combined treatments (high grazing intensity and low grazing intensity) the regression coefficient for AGB and the NDVI was significant (Figure 18). Similarly, in this region significant linear and non-linear coefficient of determination was detected between the AGB and the SMA in the high grazing intensity and combined. Although the SAVI was a better fit model, both linearly and non-linearly, for estimating biomass for all treatments (high grazing intensity, low grazing intensity and combined) in the low rainfall zone than NDVI and SMA, no regression coefficient was significant at $p \leq 0.05$.

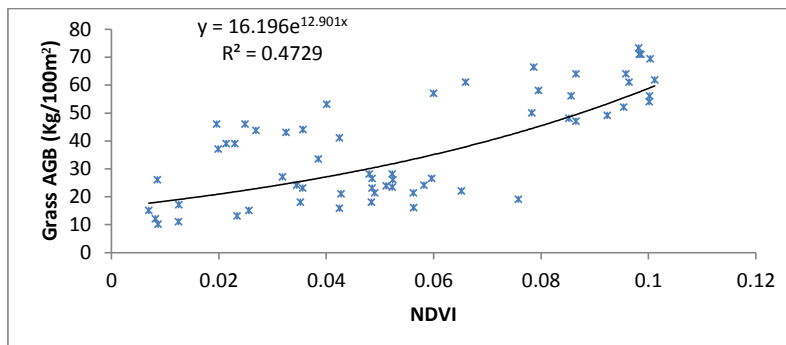


Figure 19: Regression coefficient of the grass AGB and the NDVI in the low rainfall area; showing the combined (HGI and LGI) samples

Coefficients of determination between the AGB and NDVI were significant for all treatments (high grazing intensity, low grazing intensity and combined) in the medium rainfall zones at $p \leq 0.05$ (Figure 19).

Significant coefficient of determination was detected between the AGB and the SAVI in these regions but the logarithmic and the power models did not produce a good fit. The SMA was poorly correlated to the AGB in the high grazing intensity sites and low grazing intensity sites in the medium rainfall zones. However, the combined treatment's coefficient of determination between the AGB and SMA was significant with coefficient of determination of 0.50, 0.45 and

0.52 for linear, exponential and quadratic models respectively. Significant coefficient of determination was detected between the AGB and NDVI in the high rainfall zones (Figure 20).

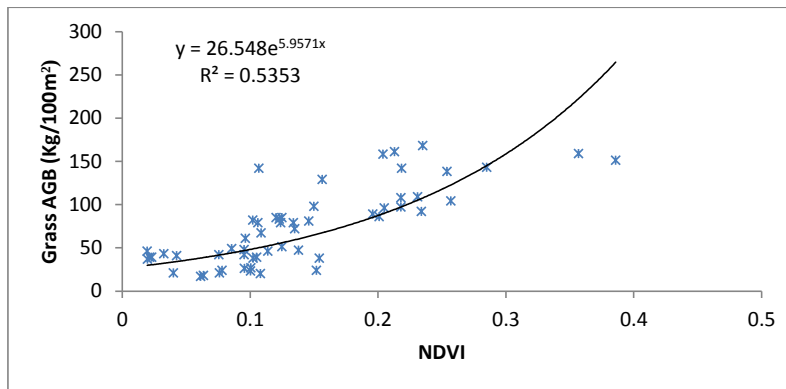


Figure 20: Regression coefficient of the grass AGB and the NDVI in the Medium rainfall area; showing the combined (HGI and LGI) samples

Similarly, significant coefficient of determination was detected between the SAVI and the AGB in the high rainfall zone, although the regression coefficient between the AGB and the SAVI was not significant at $p \leq 0.05$ in the low grazing intensity sites. The coefficient of determination between the SMA and AGB was not significant in the high grazing intensity and low grazing intensity sites in the high rainfall zone but there was a significant coefficient of determination for the combined treatment in linear and non-linear relations. As it is shown on Table 19, many linear and non-linear relations between AGB-NDVI, AGB-SAVI and AGB-SMA were assessed. Similar to results of previous studies (for example Gamon *et al.*, 1995; Barati *et al.*, 2011) most of the highly significant correlation coefficients were obtained by non-linear relations.

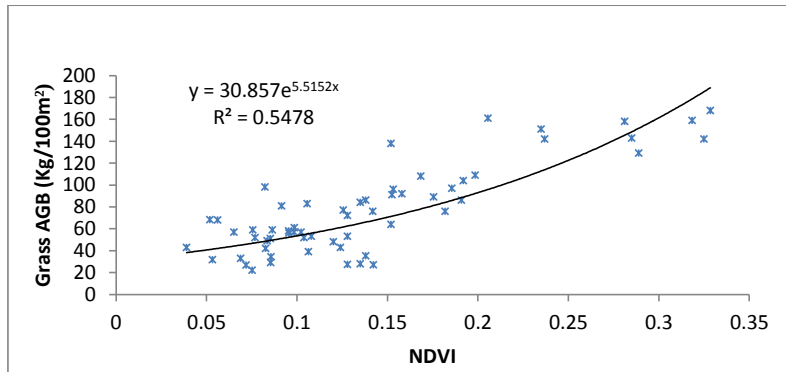


Figure 21: Regression coefficient of the grass AGB and the NDVI in the High rainfall area; showing the combined (HGI and LGI) samples

5.4 Discussion

Rangeland management strategies, geographical locations and grazing intensities affect the usefulness of remote sensing data for assessing vegetation parameters on rangelands. The remote sensing data that were used in this study were found to be appropriate for estimating AGB in different geographical locations and grazing intensities with different accuracy levels. The study sites most likely contained higher proportion of green vegetation which is photosynthetically active because the satellite images of the sites were taken during the rainy season of the region, so spectral indices sensitive to the contrast between the red and the infrared reflectance, such as NDVI and SAVI, were highly sensitive to variations in biomasses.

In the low rainfall zone, on the HGI and LGI sites the coefficient of determination between AGB and NDVI was lower than the SAVI and AGBas well as between SMA and AGB. However, the coefficient of determination between AGB and NDVI in the combined treatments was significant. The low coefficients of determination between AGB and NDVI in low rainfall areas might be attributed to the effect of soil background as the region is characterized by sparse vegetation with a higher proportion of bare ground and abundance of non-photosynthetic materials such as dry stems and dry leaves. Different soil background contributes reflected spectral additives differently where values of vegetation cover are low and this leads to interferences with spectral signatures in areas where ground cover values are high due to back-

scatter (Huete *et al.*, 1988; Fredrickson *et al.*, 2007). It is for these reason spectral indices have a limitation of not being able to minimize soil background effects particularly in the low rainfall areas. This effect can be a major limiting factor in a quantitative assessment of AGB.

Dead material and bare soils were major components of vegetation canopies in the low rainfall zones. This is a result of erratic rainfall and, overgrazing in communal rangelands and long term conservation activities in nature conservation areas and private ranches. In these sites, during early rainy season (January and February), there are large quantities of standing dead grass biomasses (Moussa *et al.*, 2009). In addition to the bare soil, dead material causes greater challenges in the development of remotely sensed NDVI for AGB quantification. Palmer & Rooyen, (1998) and Van Rooyen, (2000) indicated that there are challenges of excessive background noise due to high iron oxide content. Iron rich soils, particularly those with sandy soil texture have high red and NIR reflectance (Richter *et al.*, 2009). Similarly, Apan (1997) indicated that the main reason for lower NDVI correlation with vegetation cover percentage in low rainfall areas was the effects of background soil on plant cover. The studies done by Hobbs (1995), Jianlong (1998) and also by Todd *et al.* (1998) provided similar results. In addition, plants from arid and semi-arid areas also lack a strong red edge due to evolutionary adaptations to the harsh environment, causing reduced leaf absorption in the visible and exhibiting strong wax absorption around 1720nm (near infrared) (Ehlevinger & Bjorkman, 1978; Ray, 1995; Okin, 2001). The spectral variability within the same and various species of vegetation in arid areas creates greater difficulties during the process of spectral analysis (Duncan *et al.*, 1993).

Because of low percentages of vegetation cover in low rainfall areas and the prevalent effects of background reflection as well as the nonlinear nature of relationships between spectral reflectance and plant specifications, the coefficient of determination between NDVI and the AGB has practically low coefficient of determination. This was also supported by Palmer & Rooyen (1998) as well as Van Rooyen (2000). During this study, the examination of the spectral profiles of bare ground showed a significant similarity with areas that were covered with substantial amount of vegetation indicating high reflectance of the red spectrum and very high reflectance of the NIR. This similarity contributed to significant noise in the process of attempting to map vegetation biomass in the region using vegetation indices.

There was also a relatively lower coefficient of determination between AGB and SMA in low rainfall areas because arid and semi-arid areas are dominated by a large soil background where soils are brighter and mineralogically heterogeneous minimizing the spectral contribution of plants. Besides, the images of the study areas were taken during the rainy season when some of the soils were saturated with rain water and others (especially soils from areas with steeper gradients) remained dry due to the higher evaporation rates. These conditions cause an alternative spectral reflectance resulting in a heterogeneous spectrum from the same object.

The coefficient of determination between AGB and SMA was relatively higher in the medium and high rainfall areas using the quadratic and exponential regression models respectively. Nonetheless, due to the overall weakness of the SMA to determine vegetation parameters of the study sites, it is not an ideal model for determining AGB or monitoring rangeland conditions in the North West province, South Africa.

The coefficient of determination between AGB and SAVI was higher in the low rainfall region but none of the models produced a significant coefficient of determination at $P \leq 0.05$ level. In this study, average vegetation cover fractions were used to estimate the L parameter, which was found to be 0.75, 0.5 and 0.35 in low, medium and high rainfall zones, respectively. The L parameter was used to compute the SAVI. As is shown in Table 19, the coefficient of determination of NDVI and SAVI are different. Huete (1988) proposed 0.5 as the optimum value of L, but the coefficient of determination in this study did not improve the results significantly. This is because using a unique L value for different sites with different spectral characteristics does not significantly improve the outcome (Huete, 1988). The coefficient of determination of the SAVI was significantly higher in low rainfall areas and it produced a relatively lower coefficient of determination in medium and high rainfall areas than the NDVI. During this study, soil line determination was very difficult. The general assumption was implemented without field determination of this variable, therefore the outcome of this tool for determining the quantity of AGB or using it to manage rangelands in the study sites might not produce a credible result.

Due to the gradual increase of the vegetation cover in the medium and high rainfall zones, the correlation coefficients between AGB and NDVI was significant in all treatments though the

high grazing intensity sites' coefficient of determination between AGB and NDVI was weaker particularly in the medium rainfall zone. Coefficient of determination between AGB and NDVI in the combined treatments was the best fit, particularly in the high rainfall zones. The high coefficient of determination between AGB and NDVI in medium and high rainfall areas is due to the fact that these areas have higher LAI during rainy seasons. There is vigorous growth of vegetation and NDVI is sensitive to changes in red spectrum, which varies with the amount and conditions of green biomass. As the quantity of green biomass increases, the reflected red spectrum decreases and the ratio between the red and infrared spectrum increases. The contrast between the red and infrared spectrum that is reflected by green biomass and other objects enables the NDVI to be a useful estimator of biomass (Booth & Tueller, 2003).

Both vegetation indices (NDVI and SAVI) were poor predictors of biomass on high grazing intensity sites than on low grazing intensity sites, probably due to the presence of senescent or dry vegetation and higher proportion of bare soil. Higher grazing intensity sites have greater proportions of standing dead and litter components and higher proportion of bare grounds relative to grazed sites. Since non-photosynthetic vegetation displays higher visible reflectance, indices which rely on the contrast between visible and near-infrared reflectance lose their ability to determine the quantity of vegetation biomass. The higher visible and infrared reflectance pattern of dry vegetation also restricts the response of spectral index to biomass quantity. The contrast between green biomass and dry soil is reduced as vegetation dries. Therefore, the spectral indices respond less to biomass variation.

The coefficient of determination between AGB and the NDVI was higher than SAVI and SMA on low grazing intensity sites particularly in the medium and high rainfall zones. Thus, the NDVI proved to be the most efficient estimator of the AGB in the combined high grazing intensity and low grazing intensity sites in medium and high rainfall zones. Comparable to the vegetation indices tested during this study, NDVI confirmed to be the most accurate indicator of grass biomass. This study is in agreement with previous studies by Todd *et al.*, (1998); Lawrence and Ripple, (1998); Baugh & Groeneveld, (2006).

Lawrence & Ripple (1998) indicated that none of the indices that they used such as SR, SAVI, OSAVI, TSAVI, MSAVI and GVI are more accurate than NDVI for estimation of vegetation

cover fraction in arid and semi-arid areas. In their study, the coefficient of determination obtained from OSAVI was 0.59, MSAVI was 0.55, SAVI was 0.55, SR was 0.60, TSAVI was 0.62, GVI 0.40 while for NDVI was 0.65. Similarly, the SAVI computed by Baugh and Groeneveld (2006) had lower coefficient of determinations of 0.43 with average rainfall.

Numerous studies have indicated that NDVI can be used for the estimation of AGB and other vegetation characteristics when there is a gradual increase of green vegetation up to a certain quantity. For example, Elvidge (1995) indicated that the NDVI index was the most suitable index for analysis and management of semi-arid rangelands and studying rangeland productivity in semi-arid regions. Paruelo *et al.*, (1997) found that NDVI had a higher correlation with the ANPP ($R^2 = 0.74\%$) even though the plant cover rates were low. Sepehri, (2003) demonstrated that in regions with high plant cover percentage; the NDVI index was highly correlated with plant cover. Similarly, Farzadmehr *et al.* (2004) in their study performed in the Semirom semiarid region estimated that the correlation between NDVI index and plant cover data was significant at $P \leq 0.05$.

5.5 Conclusion

In this study, SPOT 5 multispectral imagery was found to be very useful for assessing live biomass in the North West province. The relationships between NDVI and the biomasses of the study sites varied widely due to the spatial distribution of vegetation over various types of rainfall zones, soils of different characteristics, and slopes of variable steepness. Field-based and satellite-based estimates of AGB over large areas are therefore characterized by similar degrees of uncertainty, although the sources of such uncertainties are clearly different from one another (Friedl *et al.*, 1994; Schino *et al.*, 2003). In spite of such sources of errors, satellite data accurately measured indicators of rangeland biomass and allowed the production of biomass maps that are open to repeatable and inexpensive updating. Such maps can be used to assess risks of soil erosion, as well as vegetation cover change.

SPOT imagery has been widely used for rangeland management purposes (Tibbitts *et al.*, 2010; Chen *et al.*, 2011). However, its usage as a predictor of AGB is less common. The results of this study showed that these images present a good alternative for managing and monitoring

rangeland productivity at medium spatial resolutions. AGB production is the major determinant factor for forage availability and stocking density. Ranchers, communal animal herders and agricultural extension officers are able to track the spatial and temporal distribution in forage availability. This will provide the stakeholders with better understanding of their environment to plan for the usage and management of forage resources. The use of SPOT images to estimate AGB will also provide range scientists with a critical set of data to develop predictive models of forage availability based on climatic and management variables. Furthermore, the combinations of climatic and managerial data sources offer more accurate depictions of forage resources.

In this study, vegetation indices such as NDVI and SAVI and vegetation fraction (SMA) were assessed for their ability to quantify AGB in the North West province. The indices performed differently in different study sites depending on the quantity of vegetation and spectral composition of those individual sites. The SAVI performed well in the low rainfall areas but the coefficient of determination between the AGB and SAVI was not significant at $p \leq 0.05$. The SMA also performed better than the NDVI in low rainfall areas but because of its weaknesses in the high and medium rainfall areas, this tool is not ideal for quantifying AGB in the North West province. In spite of its weakness in the low rainfall areas, the NDVI had displayed stronger coefficient of determination with AGB. Hence, the NDVI was found to be the most efficient vegetation index for quantifying AGB in the North-West province.

CHAPTER SIX

6. FORAGE ASSESSMENT AND DETERMINATION OF RANGELAND CARRYING CAPACITY

6.1 Background

Rangelands have supplied goods and services to human kind for thousands of years and are used largely as a source of livestock feed but provide secondary resources such as wild food, firewood, water and medicinal plants (Bagchi & Ritchie, 2010; Lesoli, 2011). However, human interference with these natural resources often alters their natural characteristics (Wessels *et al.*, 2008; Cheng *et al.*, 2011; Glover *et al.*, 2012). In the North-West province of South Africa, raising livestock is a crucial economic activity and grazing is practiced all-year round. Grazing on rangeland biodiversity translates to the removal of biomass, trampling and destruction of plant root systems and replacement of wild grazers by livestock (Alkemade *et al.*, 2012).

Due to high demand of beef domestically and abroad and a conducive marketing system, livestock production is generally one of the agricultural sectors that occupy extensive rangelands (Beyene *et al.*, 2014). With increasing livestock production, pressure on rangelands is high particularly in communal areas (Wessels *et al.*, 2004). In this region, potential of rangeland productivity varies depending on the amount of rainfall and rangeland management regime (see Chapter 3 of this thesis). Most of the communal lands in the province are considered to be degraded as compared to the protected areas and private ranches. In recent decades, the increasing demand for natural resources and animal production to cope with the increasing number of human population has exerted great pressure on these rangelands (Hoffman & Todd, 2000). Overgrazing, soil erosion, and loss of palatable grass species, bush encroachment and drought (Hoffman & Todd, 2000; Wessels *et al.*, 2007) are common characteristics of communal and some private and protected rangelands. In addition, fragmentation of rangelands caused by racial discriminations resulted into uneven distribution and privatisation of rangelands (Wessels *et al.*, 2008).

Reversing environmental degradation in the study area and maintaining higher productivity level of rangelands requires balanced grazing. Livestock in some of the study sites such as the communal and protected rangelands move every day from place to place seeking feed. Stocking rate in these areas is not based on range productivity or seasonal conditions of pastures. Snyman & Fouché (1993) indicated that these scenarios can lead to rangeland degradation and poor animal conditions. Given the above situation and the importance of livestock production in the province, rangeland evaluation and assessment is very crucial. It is vital for the local government and stakeholders to know and understand their rangeland health conditions and how much livestock/animals their rangelands can support. Regulation of the number of animals which could be adequately sustained by the available forage is the most accepted measurement that can lead to improved rangeland productivity (Nestel, 1984; Savadogo *et al.*, 2007; Kassahun *et al.*, 2008). Such regulation can be attained based on the rangelands' resource information that can be used to establish the potential stocking rates. For example, vegetation productivity of rangelands is one of the most relevant rangeland resource information which provides crucial biophysical parameters for calculating livestock carrying capacity of rangelands (Harrison & Shackleton, 1999; Hunt *et al.*, 2003; Hunt & Miyake, 2006). Consequently, a relevant assessment technique for monitoring and improving the current conditions of rangelands is one of the most important issues facing the future of animal production in the study area vis-à-vis livelihoods of the communities.

Remote sensing and GIS are very powerful tools for monitoring natural resources. There are many advanced remote sensing methods that have been utilized worldwide for estimating biophysical parameters of rangeland vegetation such as pasture quantity (Tueller, 1987; Schino *et al.*, 2003; Samimi & Kraus, 2004; Edrininghe *et al.*, 2004; Boschetti *et al.*, 2007); pasture growth rate (Hill *et al.*, 2004); and primary production (Todd *et al.*, 1998; Paruelo *et al.*, 2000) among others. Normalized difference vegetation index (NDVI) is strongly correlated with above ground biomass production in several rangelands (Diouf & Lambin, 2001) and is often used as a tool to estimate available forage for grazers (Tucker & Sellers, 1986; Nemani *et al.*, 2003; Wessels *et al.*, 2007). Several regression models have been developed between vegetation indices and ground truth site herbaceous biomass and this has greatly improved the accuracy of forage estimations and determinations of rangeland productivity patterns in several geographic

locations (Wylie *et al.*, 1995, Mutang & Skidmore, 2004; Brinkmann *et al.*, 2011; Gao *et al.*, 2012).

In the North-West province, studies about rangeland health and general distribution of vegetation have been carried out using small sampling areas (Mousa *et al.*, 2009) or on larger scale using remote sensing to monitor the dynamics of rangeland productivity focusing on vegetation mapping, forage adaptation and impact of biophysical parameters on the spatial distribution of vegetation (Wessels *et al.*, 2007; Munyati & Mboweni, 2013). These studies emphasised on sustainable usage of rangeland resources that gives more attention to conventional land cover estimates. Nonetheless, such estimates require the determination of rangeland productivity and long term carrying capacity by using land conservation parameters and animal output without taking into consideration the importance of reasonable rangeland stocking rates. Therefore, accurate rangeland condition and quantification of their productivity in relation to their potential to support livestock production is required. To this end, to determine the quantity of available forage in rangelands in the North-West province, South Africa, remotely sensed data and GIS ancillary data, ground sample data were utilised to develop a Rangeland *Grazing Suitability Scheme* using ESRI's ArcGIS 10.3.1 Model Builder Tools. Furthermore, a systematic process to calculate usable biomass/forage for cattle grazing using slope and distance-to-water around slope barriers for selected rangelands in various rainfall zones was created. The developed scheme is designed to promote sustainable rangeland management practices by decision makers and stakeholders since it incorporates rangeland conditions and stocking rates.

6.2 Materials and methods

6.2.1 Satellite data

SPOT 5 multispectral imagery (10 m x 10 m) was acquired from the South African National Space Agency (SANSA) for the study areas (22 April, 2014). The images were georectified against 2009 SPOT 5 imagery (5m x 5m). The images were atmospherically corrected with ERDAS Imagine 2014 using ACTOR model. All atmospheric effects were corrected using the Cost(t) model (Chavez, 1996) and SPOT Image Corporation supplied input parameters that are reported in the metadata. The imagery then was projected into UTM (WGS 1984).

6.2.1.1 Field data

From the end of February to mid-April in 2014, more than 170 field sample data were collected. From each sampling sites, above ground biomass, canopy cover, latitudinal and longitudinal coordinates (m) using a Garmin GPS at ± 3 m accuracy level, proportion of bare ground and indicators of erosion, were collected. After other measurements were taken, all the grasses in the sub-plots in which the boundary was set using a quadrat covering 4m² were cut and transferred to the laboratory where the samples were dried in the oven at 75°C for 72h and weighed to determine the total dry biomass. Field data sampling sites were selected based on types of rainfall zones, rangeland management regime and accessibility ensuring an even distribution of sample points across the study sites. For each study sites a transect was established and started at least 50m away from the fence lines in the protected areas and private ranches and 100m away in the communal areas to avoid the impact of roads and animal trails that typically run along major roads and fence lines. Details of the field data sampling and analysis can be found in Section 3.2 of Chapter 3.

6.2.1.2 Water sources data

Data on watering points and other sources of water were acquired from the Department of Agriculture and Tourism and Parks Boards of the North-West Province, South Africa. Missing data from the departments' database were digitized from satellite imageries. The locations of the watering points were collected using a Garmin GPS during field work.

6.2.1.3 Remotely sensed data

NDVI data was obtained by calculating the ratio between the visible red and near-infrared bands of SPOT 5 satellite images (section 5.2.2.1b, Chapter 5 of this thesis).

6.2.1.3a Integration of ground-based biomass data and remotely sensed data

Measurements of AGB were made at quadrat level using areas of 4m² from three different rainfall zones in the 2014 rainy season to capture the maximum vegetation growth. The location of ground sample points (n=174) were identified from the NDVI derived data. The corresponding NDVI values were collected from the NDVI derived data to perform a regression analysis between the two variables to determine their relationship. The optimal regression

models were then developed for each rainfall zone using Equation 6.1, 6.2, and 6.3 for low rainfall area, medium rainfall area and high rainfall area respectively.

$$Y = 11.076e^{(8.69278NDVI)} \quad (R^2= 0.47, P<0.001) \quad \text{Equation 6.1}$$

$$Y = 15.864e^{(8.1693*NDVI)} \quad (R^2=0.53, P<0.01) \quad \text{Equation 6.2}$$

$$Y = 29.873e^{(4.1121*NDVI)} \quad (R^2=0.75, P<0.001) \quad \text{Equation 6.3}$$

where:

Y = the estimated AGB

e = the exponential factor

NDVI = Normalized Difference Vegetation Index.

Using the ArcGIS spatial analyst tools, the above-ground biomass map was prepared using the regression models. These relationships were applied to the pixels identified as grasslands based on a land cover map which was derived from SPOT 5 satellite data. A land use and land cover map which was produced using a maximum likelihood classification method was used to mask water bodies and built up areas to separate biomass producing rangelands from non-productive parts of the rangelands using ArcGIS 10.3.1.

6.2.1.4 Livestock data

Livestock data was obtained from the Department of Agriculture and the North-West province Parks and Tourism Board for the year 2014 for communal areas and protected areas, respectively. The livestock data for private ranches was obtained from the respective farmers during field data collection in 2014. The data included the number of all species of grazers and browsers and their number was converted to animal unit month concept using the commonly used animal unit equivalent (Table 20 shows examples of some of the animals' weight being converted to animal units).

Table 10: Animal unit equivalent (AUE) standard

Class	Animal type	Animal Weight (kg)	Animal unit equivalent
1	Cow	1,100	1.0
2	Bull	1,700	1.3
3	Horse	1,300	1.2
4	Donkey	1,100	1.0
5	Sheep	120	0.2
6	Goat	90	0.15
7	Pig	-	0.4
8	Antelope	120	0.2
9	Wild Beast	1000	1.0

Source: Holechek *et al.* (2009)

6.2.1.5 Digital elevation data

Features of the landscape terrain have great impact on how livestock utilize vegetation. The Slope of the terrain influences the accessibility of forage to grazers. For example for cattle, steep slopes are hard to move easily; therefore, utilization of forage by cattle on slopes greater than or equal to 60% is very low (Holechek *et al.*, 2001).

The digital elevation data was determined using the Shuttle Radar Topography Mission (SRTM) where the median slope for each 10m x 10m grid cell was determined from 30m grid cells. This data was used to derive a slope map. The study sites are characterized by gentle gradient except for the Pillanesberg National Park where the gradient in some locations exceeds 60°. The study sites suitable for livestock grazing were prepared by dividing the slope map into slope classes according to Holchek *et al.* (1988) classification techniques (Table 21). A percent slope layer was created for each study site from the 1/3-degree (30 meter) Digital Elevation Model data (DEM). The percent slope layer covered each study site and once it was created, several models were iterated and computed using the slope layer. This process speeded up the analysis process

and saved disk storage space without the need to store the derived percent slope layers each time the model was run.

The classification of the percent slope layer created the slope reduction categories using 10 to 30 percent slope groupings developed by Holechek *et al.* (1998) and Guenther *et al.* (2000). The selection of areas with slopes greater than 60% created the terrain boundary layer which was treated as inaccessible forage. Figure 21 shows the general data analysis process in this chapter.

Table 11: Approximate reduction of livestock grazing capacity for different slope percentages

Class	Slope (%)	Reduction in Grazing Capacity (%)
1	0-10	0
2	11-30	30
3	31-60	60
4	> 60	100

Source: Holechek *et al.* (2001)

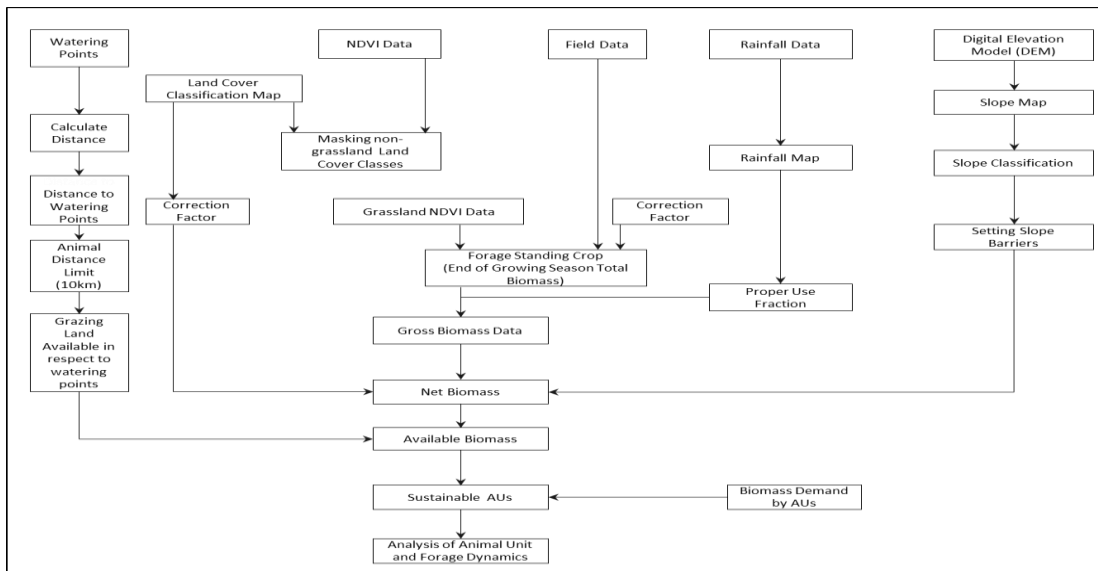


Figure 22: Flow chart of the rangeland livestock carrying capacity assessment methodology

6.2.3 Data analysis

6.2.3.1 Correction factor for watering points

Another major aspect dictating availability of livestock forage is distance to watering points whereby the animal grazing potential decreases as distance from watering points increases (Adle & Hall, 2005). Distribution of watering points across a given rangeland plays a key role on animal grazing patterns (Pringle & Landsberg, 2004; Adler & Hall, 2005; Howes & McAlpine, 2008). Therefore, there is need to evaluate the impact of the spatial distribution of watering points on livestock forage accessibility.

Rivers and natural watering sources were digitized from existing topographic maps of the study sites but locations of artificial watering points were acquired from the North West Parks and Tourism Board. The values that range between 0-10km (Barels *et al.*, 1995; Taxopeus, 1996) were used in this study to apply restrictions to AU month⁻¹ year⁻¹ (Table 22). Distance to watering points map was obtained by combining the digitized natural and artificial sources of water. This map was acquired by buffering the watering points to determine the water distance correction factor which was then rasterized. Distance map was then calculated from the rasterized water sources map using ArcGIS 10.3.1 spatial analysis tools.

Table 12: Distance to water source classes for rangeland forage accessibility

Classes	Distance from water sources (km)	Accessible forage for animals (%)
1	< 3	100
2	3-6	75
3	7-10	25
4	> 10	0

Source: Holecheck *et al.* (2001)

6.2.3.2 Correction factor for rainfall distribution

In this study, annual average rainfall data from 2010 to 2014 was acquired from the South African Weather Services for the entire study sites. The weather stations' longitudinal and latitudinal coordinates and the corresponding average rainfall data were entered into a spreadsheet from which a rainfall station map was prepared for the North West Province. The

stations' rainfall data were used to create a rainfall distribution raster map using ordinary krigging method (Equation 6.4). Ordinary kriging prepares a continuous field raster representation map by interpolating the average rainfall data (Figure 22). This map was used to determine the rainfall distribution correction factor (Table 23) as vegetation distribution is affected by the dynamics of rainfall (Li et al., 2006; Chu et al., 2007).

$$Z(m) - P(m) = \sum_{\alpha=1}^{n(m)} \lambda_{\alpha}(m) - [Z(m\alpha) - P(m\alpha)] \quad \text{Equation 6.4}$$

where:

$\lambda_{\alpha}(m)$ = kriging weight assigned to the coordinate

$Z(m\alpha)$ = the parameter

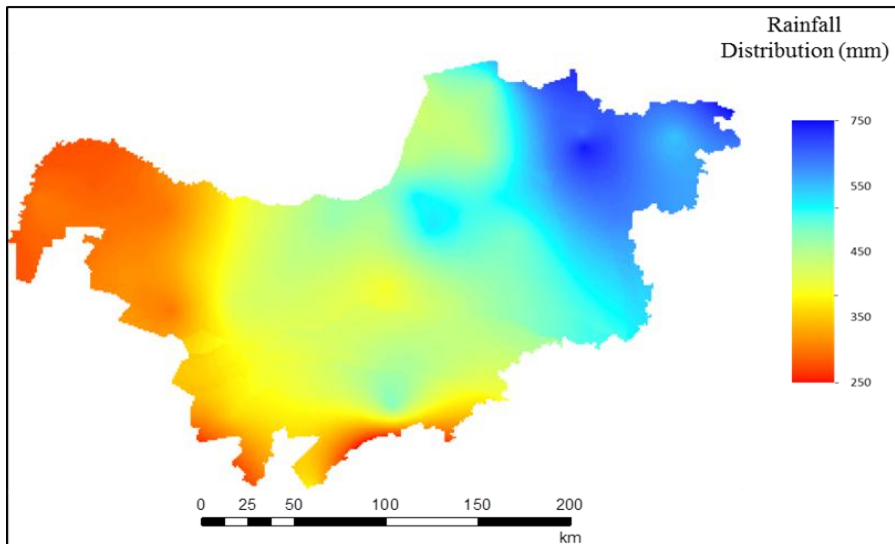
$P(m\alpha)$ and $P(m)$ = the expected values of $Z(m)$ and $Z(m\alpha)$ respectively

Table 13: Correction factor for rainfall distribution to determine consumable fodder in rangelands

Class	Rainfall (mm)	Consumable fodder (%)
1	200-400	40
2	401-550	45
3	551-700	50

Source: Holecheck *et al.* (2009)

Foliage of trees and shrubs was estimated using the Kirms & Norton (1985) and Bonhan (1989) reference unit technique from the entire quadrat measuring 100 m × 100 m. Plant parts such as shoots, which are small units of given dimensions, were selected as reference units (Bonhan, 1989). According to Kirms & Norton (1985) and Kamau (2004), the estimated weight of the reference unit was 10-20% of the foliage weight of the average plant in size. However, in this study reference units equated to 10-30% as the low rainfall areas were mainly comprised of woody materials with less foliage. Average green weight of plants was clipped from reference units and green weight was determined.



Source: Author

Figure 23: Rainfall distribution in the North West Province, South Africa

The average weight of clipped reference unit was multiplied by the total number of estimated reference units to determine biomass production (Bonham, 1989). Then the entire reference unit was dried in the oven at 75°C for 72 hours and weighed to determine the dry weight. Platis & Papanastasis (2003) assessed the spatial distribution of available forage in kermes oak shrublands using high resolution aerial photographs to estimate available biomass. The regression of available forage with shrub cover measured on the ground and on aerial photographs produced higher coefficient of determination ($R^2 > 0.70$) when the shrub height was up to 0.5 m. This implies that shrub cover measured on aerial photographs can be used to predict available forage in shrublands.

Finally, the three range-forage determination models, namely: the slope-reduction model, the impact of rainfall distribution model and the distance from watering points' model were used to develop the final reduction model. It is important to stress that the final reduction in grazing suitability is both cumulative and additive. For example, a 10 percent reduction for slope added to a 30 percent reduction for distance from watering points and to 10 percent reduction for impact of rainfall distribution would result in a total reduction of 50 percent. Holechek (2001) indicated that a 50 percent reduction is considered 50 percent suitable.

6.2.3.3 Rangeland carrying capacity and stocking rate determination

Rangeland productivity can be explained through forage availability. Forage availability can also be determined through careful analysis of some biophysical parameters. Some of these parameters have been described in this thesis (e.g. rainfall distribution, slope, water bodies and land cover).

Forage availability in the growing season has been suggested as one of the most significant estimators of rangeland productivity (Tueller, 1996; Diaz-Solis *et al.*, 2003; Mutanga *et al.*, 2012). In this study, the available forage was determined through remote sensing techniques and field measurements using Equation 6.5 using the model that is presented on Figure 23.

$$T_{uf} = A_f * S_f * W_{df} * R_f * A_{(ha)} \quad \text{Equation 6.5}$$

where:

T_{uf} = total usable forage

A_f = total available forage by the end of the growing season

S_f = slope factor

W_{df} = watering point distance factor

R_f = rainfall distribution factor

$A_{(ha)}$ = area in hectare

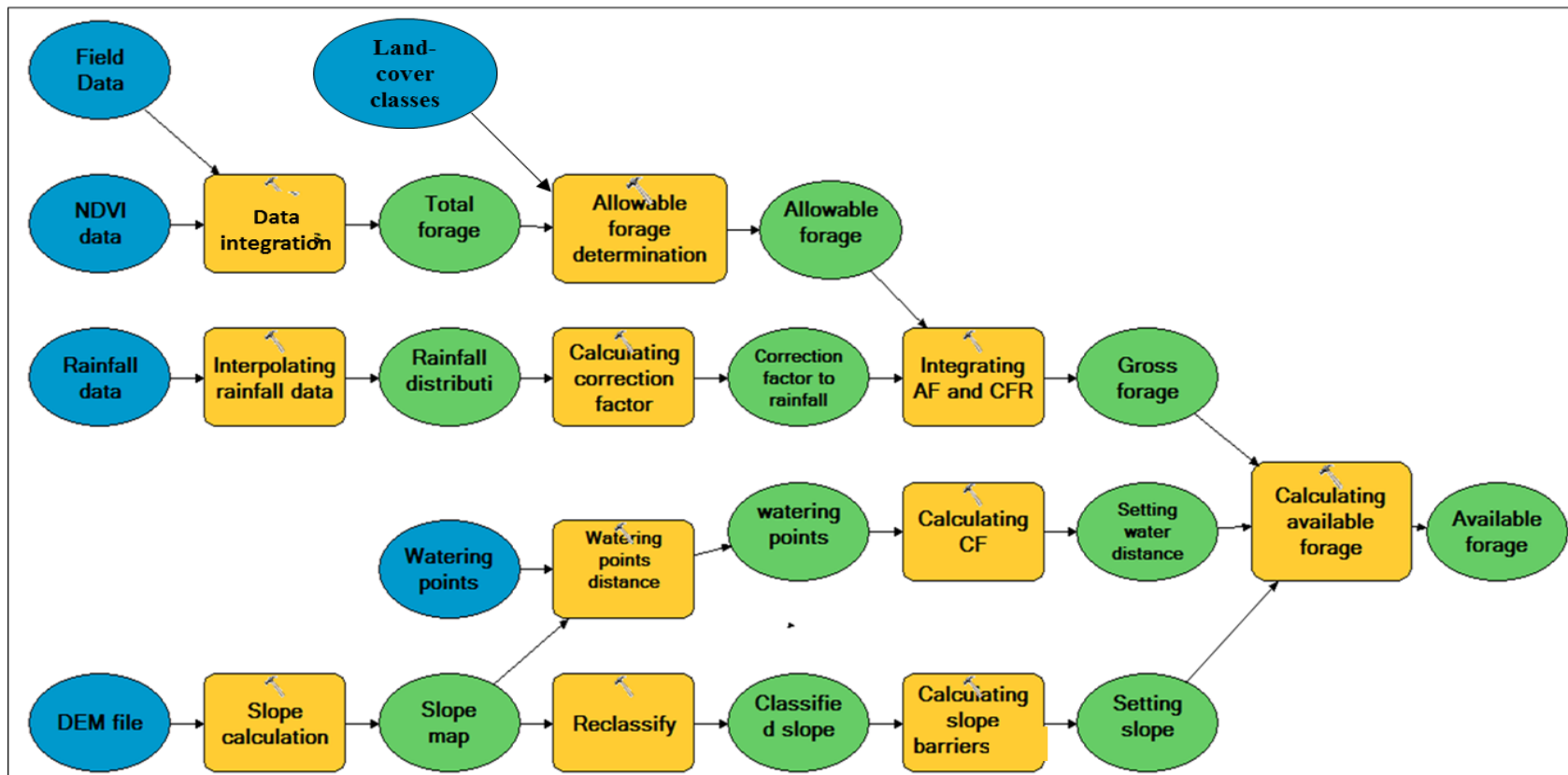


Figure 24: Grazing Suitability Scheme used to determine available forage for grazing using ArcGis 10.3.1 model builder with inputs of the above ground biomass map, elevation data, water sources and rainfall distribution map

The resultant total usable forage was then classified into forage that should be used sustainably by the grazing animals (i.e. allowable forage) and forage that should be left behind to protect the environment and allow the process of regeneration (Angerer, 2008). To determine the total amount of forage that is available for grazing, the total usable forage was multiplied by the percent of allowable forage for grazing (Equation 6.6).

$$T_g = T_{uf} * A_{af} \quad \text{Equation 6.6}$$

where:

T_g = total amount of forage that is available for grazing

A_{af} = percent allowable forage

To determine the total number of animals that the rangelands can support for a given period of time, the total available forage for grazers was divided by the forage demand of the animal unit time using Equation 6.7.

$$N_{ga} = (T_{uf} * A_{af}) / F_d \quad \text{Equation 6.7}$$

where:

N_{ga} = number of grazing animal units

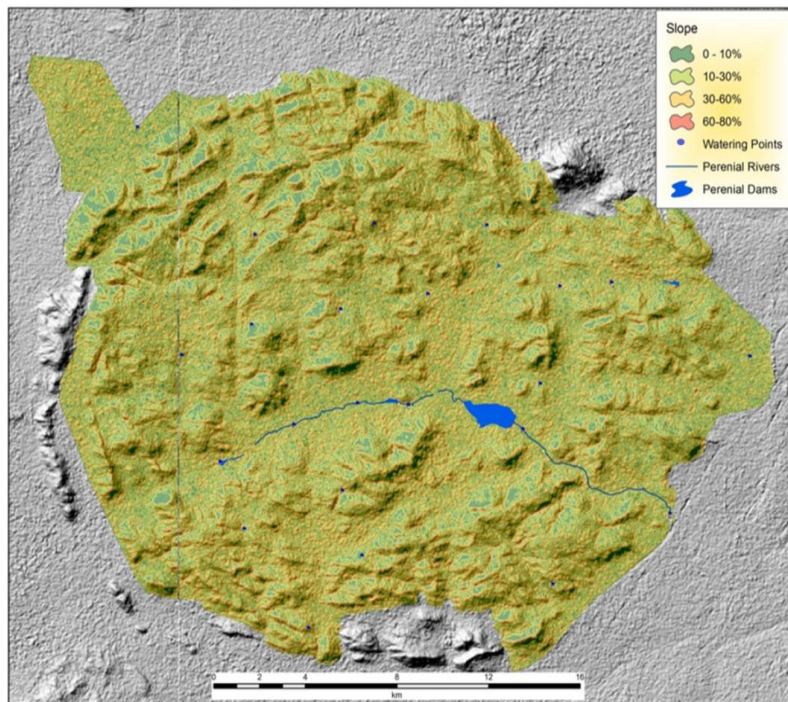
F_d = forage demand per animal unit (kg)

6.3 Results and discussion

6.3.1 Effects of slope and watering points on the available forage

The determination of the amount of allowable forage methodology involved the integration of slope, watering points and rainfall distribution. The percent slope of each study site was calculated at 10, 30 and 60 percent to determine the quantity of allowable forage for animal intake with reduction rate of 0%, 30%, and 100% (Table 21). Distances around watering points were calculated at 3, 6 and 10 km from the water sources with reduction rates of 0%, 30% and 100% (Table 22).

The result showed that slopes of most of the study sites were less than 15% with the exception of the Pilanesberg National Park where the percent slope within the north eastern and southern section of the park reached more than 60%, which limited accessibility of forage to 0% (Figure 24). However, the effect of slope in all other study sites was insignificant as the slope generally was much less than 30%. Therefore, in these study sites, slope barriers did not have any limiting effect on accessing the total allowable forage (Table 24). The high percent slope effects moderately affected the grazing capacity of foragers here. The outcome of the impact of steep slope in this site was a 0-100% change in forage accessibility. Slope is a very important parameter in determining risks of rangeland degradation. A slope plays a vital role in soil erosion, particularly in hilly areas.



Source: Author

Figure 25: Percent slope map of the Pilanesberg National Park

A steep slope aggravates soil erosion in the absence of vegetation cover. The result showed that slopes of most of the study sites were less than 15% with the exception of the Pilanesberg National Park where the percent slope within the north eastern and southern section of the park reached more than 60%, which limited accessibility of forage to 0% (Figure 24). However, the effect of slope in all other study sites was insignificant as the slope generally in these study sites was much less than 30%.

Table 14: Impact of slope barriers on the availability of forage

Study Sites	Total Area	No Slope Barrier	Percent Suitable	60% Slope Barrier	Percent not Suitable
Low Rainfall zone					
Molopo Nature Reserve	240km ² /24000ha	0km ² /0 ha	100	0km ² /0 ha	0
Morokweng Communal Area	65km ² /6500ha	0km ² /0 ha	100	0km ² /0 ha	0
Dubbelaar Private Ranch	2.80km ² /280ha	0km ² /0 ha	100	0km ² /0 ha	0
Medium Rainfall Zone					
Mafikeng Game Reserve	48km ² /4800ha	0km ² /0 ha	100	0km ² /0 ha	0
Disaneng Communal Area	179km ² /17900ha	0km ² /0 ha	100	0km ² /0 ha	0
Lenric Private Ranch	1.87km ² /187ha	0km ² /0 ha	100	0km ² /0 ha	0
High Rainfall Zone					
Pilanesberg National Park	490km ² /49000ha	416.5km ² / 41650 ha	85	73.50km ² / 7350 ha	15
Ngwedding Communal Area	406km ² /40635ha	0km ² /0 ha	100	0km ² /0 ha	0
Onderspoort Private Ranch	17.17km ² /1717ha	0km ² /0 ha	100	0km ² /0 ha	0

6.3.1.1 Effects of watering points distances and slope on gross forage production

As distance from watering points increased, the gross forage production increased in all the study sites while the proportion of bare ground decreased. The forage production gradually increased to an asymptote at around 1000m while the proportion of bare ground rapidly decreased to an asymptote after 600 m with maximum proportion of close to 80% closer to water sources (Figure 25). A strong positive coefficient of determination was also detected between forage production and distance from water source ($R^2 = 0.98$; $P < 0.05$) (Figure 26). The decrease of the forage production with the distance to water sources were more likely attributed to livestock grazing as

livestock prefer to forage near water sources. This study agrees with previous studies on the effects of grazing on rangelands. Bastin *et al.* (1993) measured herbage litter and total cover in central Australia. The result clearly showed that there was an increase of green vegetation cover as distance from water sources increased. Results from other studies also showed a decrease in vegetation cover as grazing pressure increased near water sources (Beymer & Klopatek, 1992; Harris & Asner, 2002). High grazing pressure is considered as one of the major factors that increases proportion of bare soil in most of arid and semi-arid rangelands (Beymer & Klopatek, 1992).

In comparison of slope classes, the forage production value was consistently higher on steeper slopes (Figure 27). The scenario that was observed around watering points, as water source distances increased the forage production increased, was also noticed in all slope classes (Figure 27). As slope percent increased, the forage production also increased significantly. (For example Figure 27b shows that areas with a slope of $>45^\circ$ produced available forage $> 150\text{kg}$). Bare soil cover was consistently higher in lower slope classes. There was a consistently higher risk of degradation in slope 15-30%.

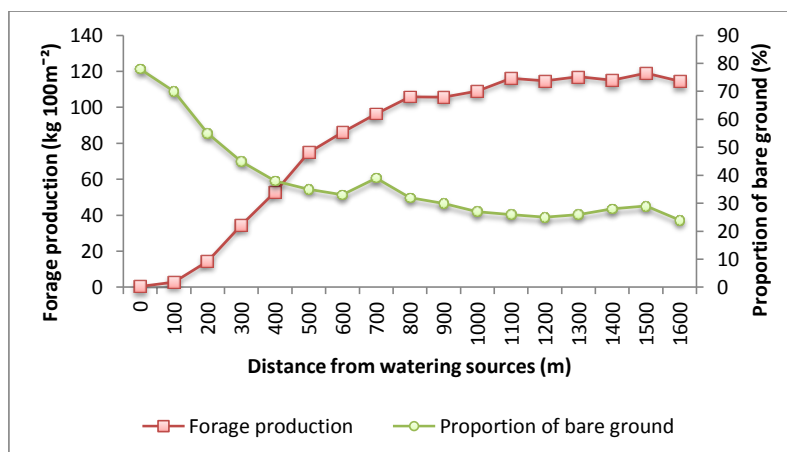


Figure 26: Impacts of distances of watering points on forage productivity and proportion of bare ground in the study sites in Pilanesberg national park

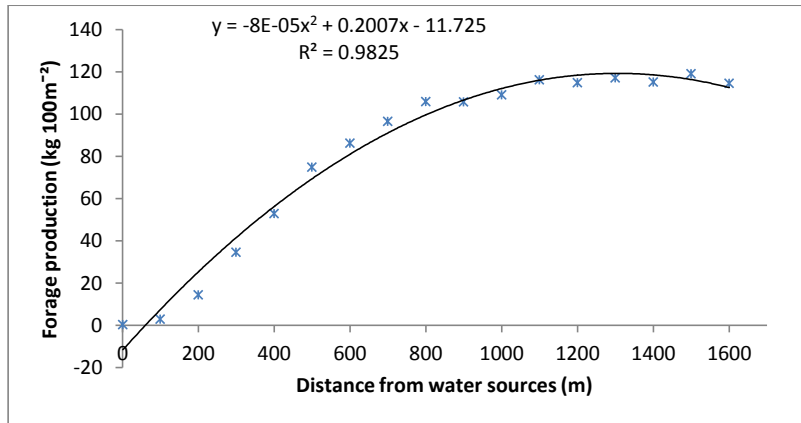


Figure 27: Relationship between water sources and forage production

The increase of risk of degradation in slope class 15-30% is related to a decrease with vegetation cover. This is attributed to higher rate of surface runoff hindering vigorous vegetation growth (Mwendera & Mohamed, 1997). Less forage producing localities in the communal areas and game reserves were found around and near built up areas and watering points. Lessening condition in rangeland forage productivity as watering distance decreased suggests that there might be long term rangeland degradation in the area. These patterns are characteristics of rangeland degradation due to grazing (Bastin *et al.*, 1993; Pickup & Chewing, 1994; Harris & Asner, 2003).

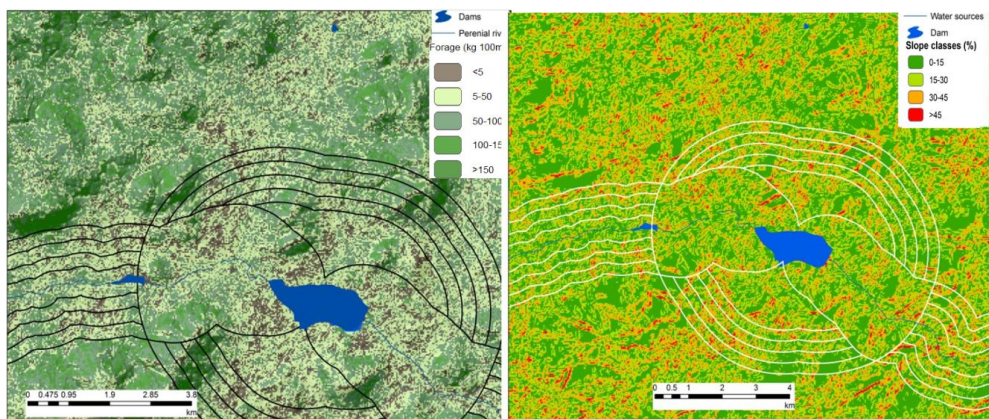


Figure 28a: Comparison of rangeland forage productivity due to the influences of distances from watering points and slope

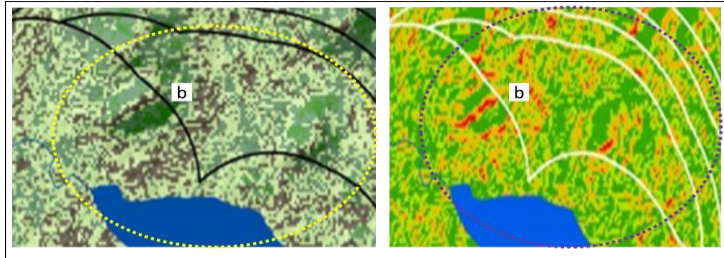


Figure 27b: Close comparison of rangeland forage productivity due to the influences of distances from watering points and slope

6.3.2 Impact of rainfall distribution on forage production

Weak coefficient of determination was detected between average forage production and rainfall distribution ($R^2 = 0.45$, $P < 0.05$) (Figure 28) indicating that rainfall distribution is not the only determinant factor in rangeland forage production but rather there are also other factors that need to be taken into consideration. There was also significant coefficient of determination between rainfall distribution and proportion of bare ground. High rainfall areas tend to have lower proportion of bare ground while low rainfall areas tend to have higher proportion of bare ground. Watering points distance affected the protected areas and the communal lands but the three private ranches where the size of these ranches was within 3 kilometer radius from the watering points were not affected.

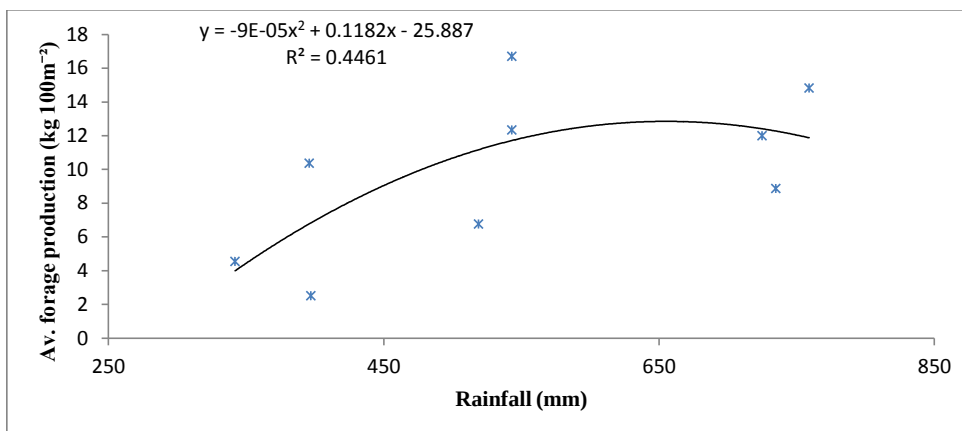


Figure 29: Impact of spatial distribution of rainfall on rangeland forage productivity

6.3.3 Impact of watering point distances on accessing allowable forage

The communal lands are the most affected sites where reduction of allowable forage ranged between 0 to 75%. Reduction of allowable forage due to watering points was significant and this factor affected the accessibility of forages of most of the study sites except the three private ranches where there was a fair distribution of watering points across the sites, particularly in the communal lands of the low and medium rainfall zones. In this study only perennial sources of water were taken into consideration to avoid over-estimation and under-estimation of available biomasses, since seasonal water sources are not reliable (Figure 29). A summary of the analysis of water source sub-models on available forage for grazing are shown in Table 25. This is used to evaluate the applicability of the water source sub-model. In some of the study sites, there was problem of inconsistency of watering points particularly in Pilanesberg National Park where the average number of watering points was adjusted to avoid confusion.

Table 15: Relationship between total allowable forage and distances to watering points

Rainfall Zones	Localities	Gross biomass (tons)	Net biomass (tons)	Accessible (tons)	Loss of Biomass due to WPD (tons)	Loss of biomass due to WPD (%)
LRFZ	Molopo NR	5872.50	5050.35	4141.00	1929	17.77
	Morokweng CRL	1630.00	1559.91	1000.00	495	32.42
	Dubbelaar PR	290.00	276.80	264.21	12.5	0.00
MRFZ	Mafikeng GR	5532.15	5024.00	4562.00	192	3.68
	Disaneng CRL	12070.00	9656.00	7007.00	2764	23.99
	Lenric PR	293.00	288.92	265.81	23.1	0.00
HRFZ	Pilanesberg NP	43126.00	41284.72	30674.55	9260	22.43
	Ngwedding CRL	28352.00	27476.8	22539.22	4307	15.63
	Onderspoort PR	2722.00	2577.14	2434.11	143	5.30
Total		104906.65	99887.65	93194.64	72914.08	

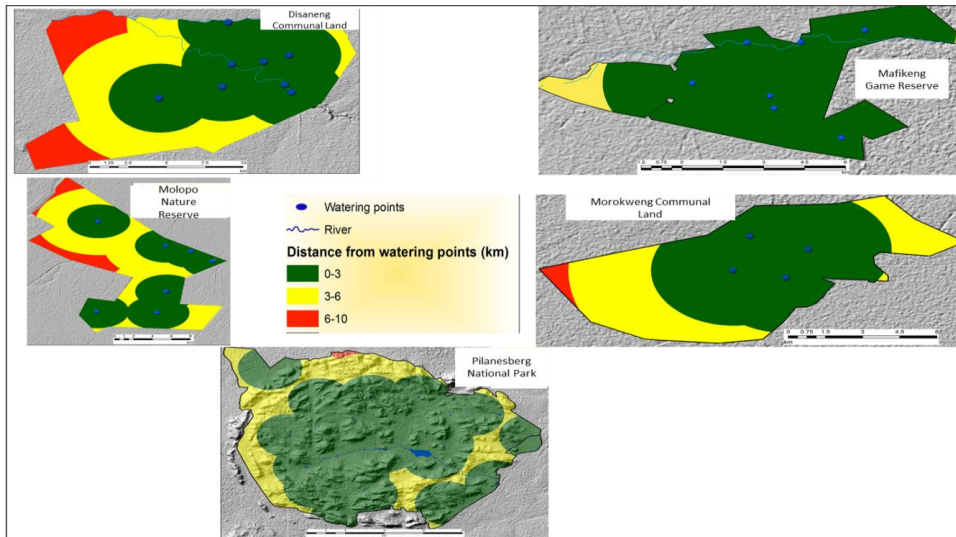


Figure 30: Buffer distances from watering points in the study sites

Additional watering points were added in the model development in Pilanesberg and Disaneng sites beside the artificial watering sources based on the presence of permanent water sources. This model was found to be very useful for showing the joint impact of distance to watering points and slope on accessible forage as these variables are major determinants of livestock distribution across rangelands. This study is in alignment with previous studies (Gillen *et al.*, 2000; George *et al.*, 2001). As slope and watering point distance decrease foraging by animals increases on a given landscape.

6.3.4 Gross and available forage production

Table (25) shows the gross biomass production and distribution at the end of the rainy season in 2014. Out of the 99887.65 tons total forage produced by the study sites, 72903 tons (73% of the total forage) was available for animals. The average gross forage yield was 0.94 ton ha⁻¹ with available forage per hectare ranging between 0.25 and 1.7 ton ha⁻¹. The amount of forage per mapping unit is related to the amount of average annual rainfall distribution and the efficiency of rangeland management regimes. The influence of rainfall distribution rating had a significant impact as the total forage in the low rainfall zone was assumed that only 40% of end of rainy season grass was available for grazing due to factors such as shortage of water, availability of few watering points and adverse climatic conditions, highly limiting accessibility of forages

(Bailey et al., 1996); medium rainfall zone 45% and the high rainfall zone 50%. The private ranch in the medium (Lenric Private Ranch) and high (Onderstepoort Private Ranch) rainfall zones had the highest average biomass production level followed by Mafikeng Game Reserve, Dubbelaar Private Ranch in the low rainfall zone, Pilanesberg National Park, Ngweding communal area, Disaneng communal area, Molopo Nature Reserve and Morokweng communal land. Comparison of the gross biomass showed that the high rainfall zone generally had higher biomass production. The effect of slope on forage accessibility was insignificant in most of the study sites as these sites' topography is generally flat with less than 30% slope. The highest difference between net biomass production and accessible forage was recorded in Morokweng communal area (36%), Disaneng communal land (27%) (Figure 31) and Pilanesberg National Park (25.74%) (Table 25). The loss of most of biomass in the communal areas is due to higher distances from watering points, inappropriate land uses and poor land suitability evaluations while inside the Pilanesberg National Park inaccessibility is due to the steep gradient of the area (Figure 30).

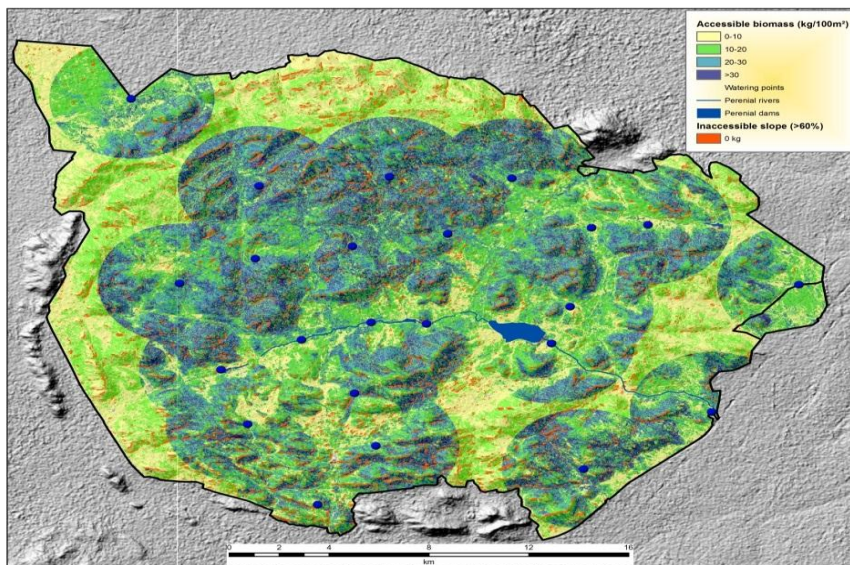


Figure 31: Amount of forage production in kilogram (kg) per 100m² of Pilanesberg National Park

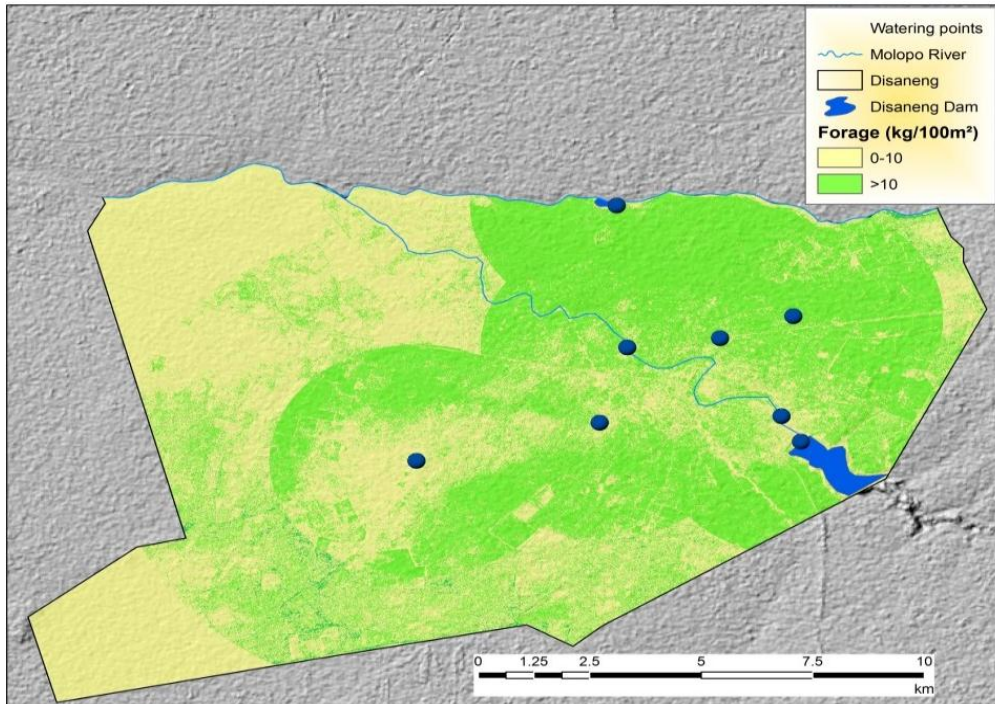


Figure 32: Amount of forage production in kilogram (kg) per 100m² of Disaneng Communal land

The lowest difference between gross forage and accessible forage was observed in all private ranches (ranging between 4.5-8%) and Mafikeng Game Reserve (9%) (Figure 32). This might be attributed to the topography of these sites and well-coordinated rangeland management strategies. The assessment of the accessible forage for animal grazing in relation to watering points showed that on average 15% of the net biomass was inaccessible due to shortage of watering points. This indicates that consideration of the distribution of watering points is crucial for planning a proper utilization of rangelands since the distribution of watering points influences the grazing potentials of grazing lands.

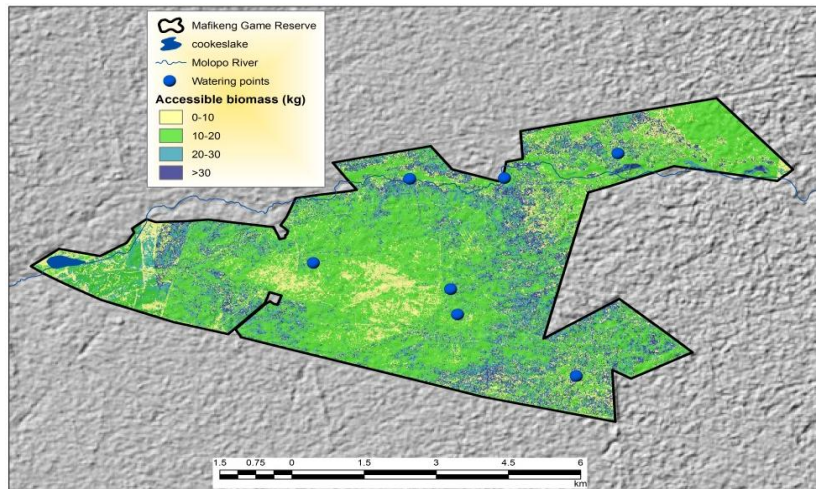


Figure 33: Amount of forage production in kilo gram (kg) per 100m² of Mafikeng Game Reserve

Among the study sites, Morokweng had the highest inaccessibility proportion of forage (Figure 33) probably due to lack of permanent watering points and the erratic nature of rainfall and sandy soils in the region leading to high infiltration rate, higher evaporation of surface water leading to lower water table and this ultimately limits the occurrence of surface water.

Comparison of averages for gross biomass production (ton ha⁻¹) of the study sites is given in Table 28. The result showed that the overall average forage production was 0.94 ton ha⁻¹ for all study sites. The maximum biomass production was recorded in the Lenric Private Ranch (1.67 ton ha⁻¹) in the medium rainfall area followed by Onderstepoort Private Ranch (1.59 ton ha⁻¹) in the high rainfall zone, Mafikeng Game Reserve (1.25 tone ha⁻¹) and Dubbelaar Private Ranch (1.04 ton ha⁻¹). The minimum gross biomass production was recorded (0.25 ton ha⁻¹) in Morokweng communal land followed by Molopo Nature Reserve (0.45 ton ha⁻¹) in the low rainfall zone (Figure 34). The major reasons for higher forage production in high quantity forage producing rangelands per unit area are due to introduced grasses and higher maintenance and management standards.

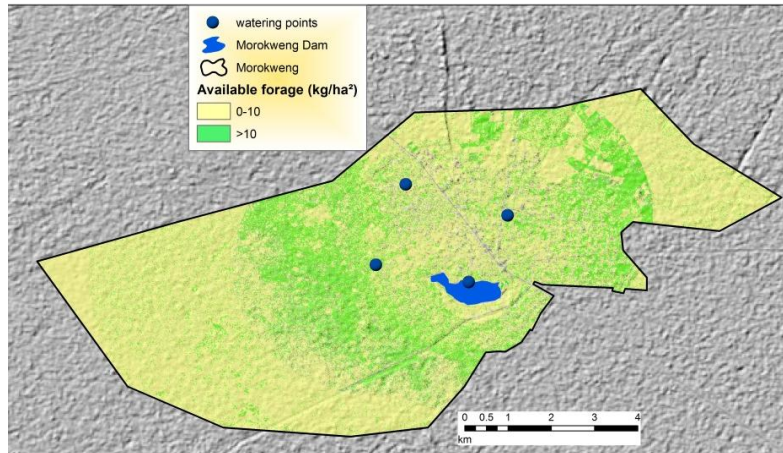


Figure 34: Amount of forage production in kilogram (kg) per 100m² of Morokweng Communal Area

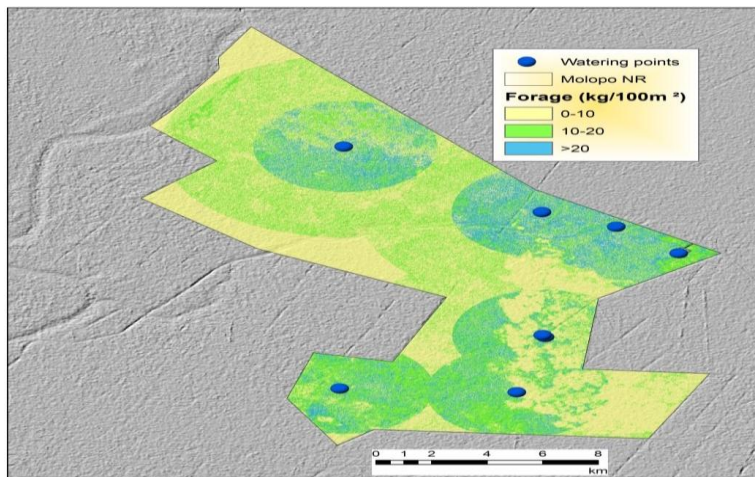


Figure 35: Amount of forage production in kilogram (kg) per 100m² of Molopo Nature Reserve

In contrast, low forage production in some rangelands is due to climatic factors and acute exploitation of rangelands by humans (Hofmann & Todd, 2000; Wessels *et al.*, 2004). Hofmann & Todd (2000), Wessels *et al.* (2004) and Fisher *et al.* (2010) reported that the combinations of factors, such as overutilization of agricultural lands, unsustainable rangeland management and increased soil erosion; misuse of water resources with intensive irrigation activities resulting into salinization, deforestation, increased aridity, changes in population distribution, inappropriate

grazing practices, overgrazing, bush encroachment and reduction in herbaceous forage production and land abandonments might be derivors of rangeland degradations in most of these rangelands. Loss of large quantity of vegetation from these rangelands can lead to the loss of functionality of ecosystem through reduction in biodiversity and reduced livestock carrying capacities (Schksinger *et al.*, 1990) with associated social and economic consequences (Savory *et al.*, 1999; Griffin, 2002).

Table 16: Rangeland gross biomass, net biomass and accessible biomassproductions

Rainfall Zones	Locality	Gross biomass (tons)	Net biomass (tons)	Accessible (tons)	Difference between Accessible and net Biomass (%)	ABP (tons) ha ⁻¹	Average Forage (tons) ha ⁻¹ (per rainfall zones)
Low Rainfall Zone	Molopo NR	5872.50	5050.35	4141.00	17.89	0.45	0.58
	Morokwe CRL	1630.00	1559.91	1000.00	36.00	0.25	
	Dubelaar PR	290.00	276.80	264.21	4.50	1.04	
Medium Rainfall Zone	Mafikeng GR	5532.15	5024.00	4562.00	9.19	1.23	1.19
	Disaneng CRL	12070.00	9656.00	7007.00	27.43	0.67	
	Lenric PRL	293.00	288.92	265.81	8.00	1.67	
High Rainfall Zone	Pilanesberg NP	43126.00	41284.72	30674.55	25.74	0.88	1.06
	Ngwedding CRL	28352.00	27476.8	22539.22	17.97	0.70	
	Onderstepoort PRL	2722.00	2577.14	2434.11	5.55	1.59	
	Total	99887.65	93194.64	72914.08	15.90	0.94	0.94

Comparison of means for biomass production (ton ha⁻¹) of the three rainfall zones, namely low, medium and high rainfall zones is given in Table 26. The result shows that the average forage production in the low rainfall zone was significantly low (0.58 ton ha⁻¹) as compared to the medium rainfall zone (1.2-ton ha⁻¹) and the high rainfall zone (1.06 ton ha⁻¹). The variation in biomass production among the rainfall zone might be attributed to the nature of the corresponding rainfall, behaviors of the grazers' landscape and other biophysical factors. Forage productivity, composition and the spatial distribution of rangeland ecosystems are mainly determined by climate and soil properties and behaviours of herbivores (Scholes *et al.*, 1997; Sankaran *et al.*, 2005; Wiegand *et al.*, 2006; Higgins *et al.*, 2007). According to Wiegand *et al.* (2006) and Scholes (2009) mean annual precipitation of rangelands and animal behaviours are major regulators of grass biomass production.

6.3.5 Carrying capacity ($\text{ha AU}^{-1} 6 \text{ months}^{-1}$) of the study sites

Table 29 shows the overall carrying capacity of the study sites with average carrying capacity of $4.21 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$. The result indicates that in 2014 end of growth season biomass production was fair in some of the study sites. The carrying capacity was excellent at Lenric Private Ranch ($1.42 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$) and Onderstepoort Private Ranch ($1.53 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$). Dubbelaar Private Ranch ($2.27 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$), Mafikeng Game Reserve ($1.95 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$), Pilanesberg National Park ($3.3 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$) and Molopo Nature Reserve ($5.9 \text{ ha AU}^{-1} 6 \text{ months}^{-1}$).

From the study sites, more than 26,000 animal units were recorded. Among these sites, ratios of forage demand to forage accessibility for Morokweng (2.7) and Disaneng (1.8) was the highest and this shows that these localities were the most densely stocked rangelands while Onderspoort Private Ranch (0.2), Mafikeng Game Reserve (0.3) and Molopo Nature Reserve (0.3) were the lowest (Figure 35). The map of the rangeland status was derived from differences between the accessible forage and animal forage demand by converting it to $\text{kg}/100\text{m}^2$ (100m^2 = the spatial resolution of the SPOT 5 satellite imagery). Figure 36 shows an example of the status of rangelands after animals grazed the sites for six dry months completed.

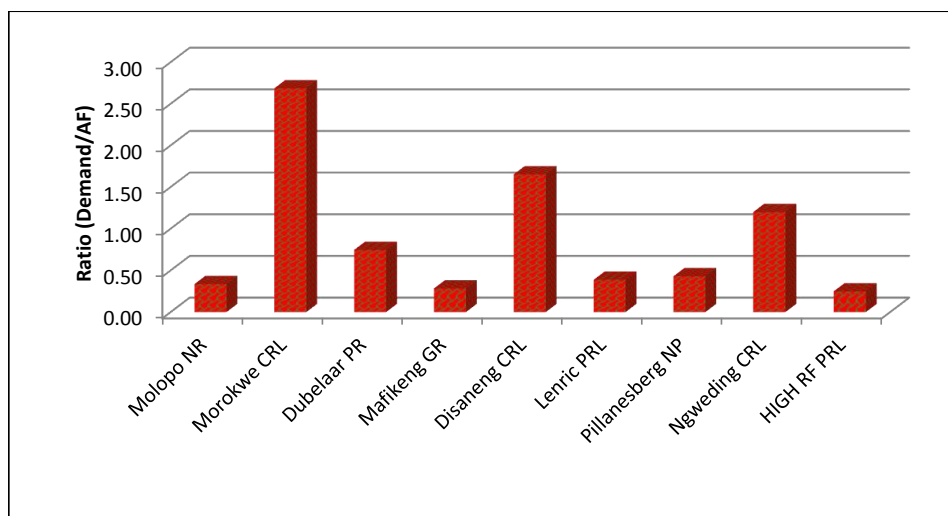


Figure 36: Ratio of forage demand of animals across the study sites per available forage in the study sites
 Note: AF-actual forage, NR-nature reserve, CRL-communal rangeland, PR-private ranch, NP-national park, GR-game reserve. (The smaller the ratio, the better the condition)

From table (27), negative values in the differences between the actual and potential animal units (AU) in six months indicate overgrazing while the positive values indicate under-stocking or optimum stocking rates. The poorest carrying capacity was recorded in Morokweng and Disaneng communal lands. Figure 37 shows the comparison between the potential and the actual rangeland carrying capacity. The actual stocking rate in two of the study sites Morokweng (63% excess animal units) and Disaneng (40% excess animal units) were far above the grazing capacity of these rangelands. Long term overgrazing in these localities is a common phenomenon (Wessele *et al.*, 2004). This scenario results in the eventual over utilization and mismanagement of rangeland vegetation (Ainalis *et al.*, 2010) owing to higher number of livestock and human population, excessive fire wood collection and higher amount of unpalatable plant species (Hofmann & Todd, 2000; Wessels *et al.*, 2004).

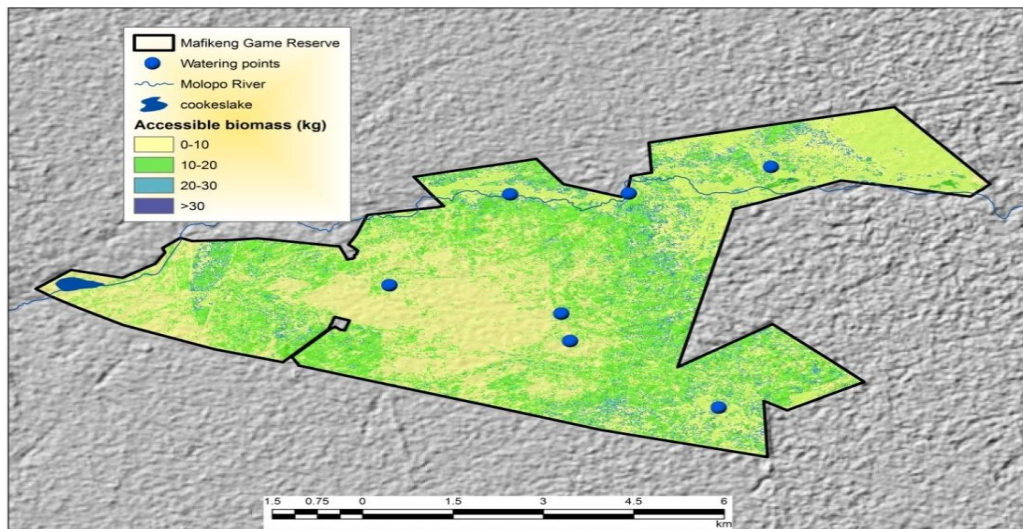


Figure 37: Amount of forage production in kilo gram (kg) per 100m² of Mafikeng Game Reserve by the end of the dry season

Most of the commercial farmers own mechanized infrastructures such as tractors, combines, advanced irrigation systems, modern storage facilities, etc., for rangeland management and they are more likely to invest capital and labor in the rehabilitation process of their ranches because they understand the benefits of improving the productivity of their rangelands and animals that would result in a positive feedback over a long period of time (Stocking & Murnaghan, 2001; Harmse, 2013). In contrast, communal rangelands are managed by poorer communities with less or without infrastructure to improve the productivity of their rangelands. Here, the land is freely accessed by every member of the community and have free bridle to make use of any resources. In most cases the users do not have any intention of investing on improvement scheme on the land as they have limited and unsecured control over these resources (Stocking & Murnaghan, 2001). This scenario can decrease the ability of the community to maintain the land productivity (Meadows & Hoffman, 2002).

Table 17: The ratio of distribution of rangelands (hectare) per unit animal and carrying capacity of the study sites

Study Sites	ha/AU	Actual Stocking	Actual AU (carrying capacity) 6 month ⁻¹	Potential AU (carrying capacity) 6 months ⁻¹	Differences between Actual and Potential in 6 months	Area (ha)
Molopo NR	17.39	1380	24592.3	4098.7	2718.7	24000
Morokwe CRL	5.11	1273	2843.0	473.8	-799.2	6500
Dubelaar PR	3.04	210	940.0	123.3	31.3	280
Mafikeng GR	6.86	655	13840.2	2306.7	1651.7	4492
Disaneng CRL	2.69	6647	24129.5	4021.6	-2625.4	17900
Lenric PRL	3.67	51	790.6	131.8	80.8	187
Pillanesberg NP	7.75	6320	88220.4	14703.4	8383.4	49000
Ngweding CRL	4.18	9728	63066.1	9677.7	-50.7	40635
Onderstepoort PR	6.15	279	6722.9	1120.5	841.5	1717

Smet & Ward (2005) indicated that due to these reasons, communal rangelands are more degraded than protected areas and commercial ranches. The rates of degradations in these communal areas are believed to be increasing (Wessels *et al.*, 2008). Since the livelihoods of the communities in the communal rangelands depended on subsistence farming and livestock production, the rapidly growing human population had no alternative but to over-exploit the land. Animal stocking rates in communal areas is more than double that of the neighboring commercial farms and protected areas. Similar findings were reported by Shackleton (1993) mentioning that high stocking rate was the cause of major degradation in the communal rangelands.

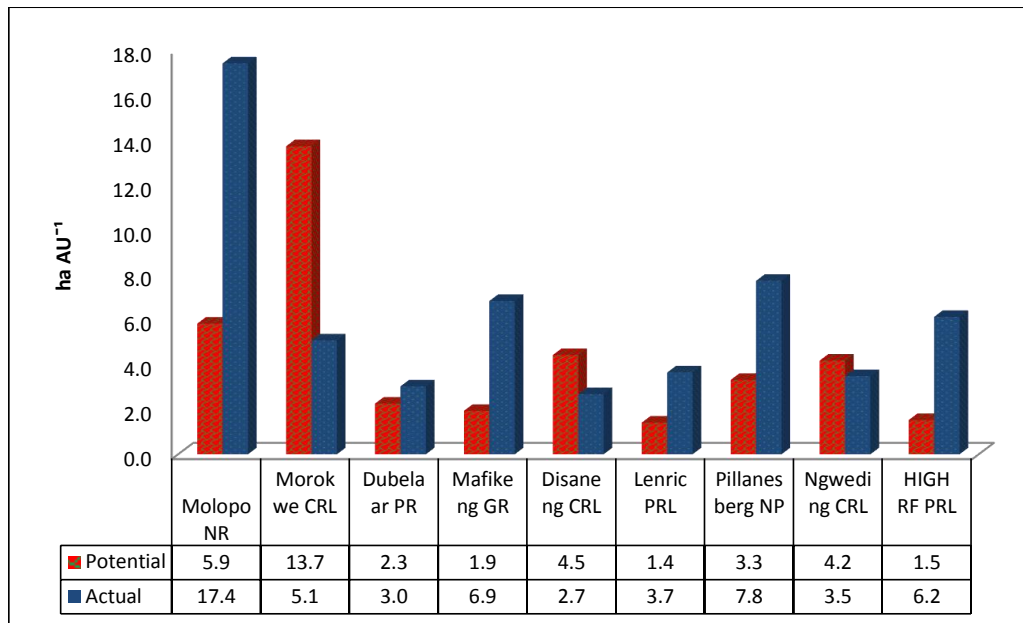


Figure 38: Actual and potential rangeland (hectare) distribution per animal units across the study sites

Another significant problem in communal grazing areas, particularly in the low rainfall region is bush encroachment. Timberlake and Reddy (1986) stated that reduction in rangeland productivity and grazing potential due to expansion of shrub and tree cover are significant and often the impact is larger than the impact of rainfall distribution and soil characteristics. According to Toxopeus (2000) increases in woody vegetation cover reduces the palatable forage cover by reducing available space for the forage to grow and increasing competition for minerals whereas reduction in woody vegetation enhances the forage productivity of rangelands as spatial limitations and competition for minerals will not be an issue.

6.4 Conclusion

Satellite remote sensing in conjunction with GIS are useful tools for quantifying and determining forage distribution in rangelands. In this study rangeland carrying capacity of the nine study sites using the GIS model was determined. This methodology managed to accurately account for increased distance around terrain barriers. The results were reasonable when water sources were

predominantly perennial streams. The results for Pilanesberg National Park and Disaneng Communal area were not correct due to the absence of a stock pond in the water source layer in the communal area; and over-estimating water availability due to using a named intermittent stream in the Pilanesberg National Park. The water source layer was modified by adding watering points and a stock pond, removing part of the intermittent watercourse, and ran the model again. The modified water source layer was confirmed reasonable with field truthing data. This demonstration supported the advantage of models that would systematically recalculate rangeland carrying capacity.

This rangeland carrying capacity model is very useful to determine optimal placement of additional water sources to increase cattle distribution across rangelands. The rangeland carrying capacity maps identify areas over six kilometers from water and classified these areas as 100 percent inaccessible for grazing. Consideration of placement of new watering points in these inaccessible areas could increase grazing areas available for animals. The model also balances forage supply from the rangelands in relation to forage demands of animal units in the rangelands enabling the range managers to analyze the potential and actual carrying capacity of their rangelands. Holechek *et al.* (2001) and Mapiye *et al.* (2009) recommended that livestock grazing should be monitored in areas of moderate state to avoid over utilization of rangelands. This model shows the level of grazing that a particular rangeland should be exposed to and it could be very helpful for cattle ranchers and extension personnel in selecting areas for grazing for a given period of time. This activity might increase the efficiency of rangeland managers by easing rangeland monitoring process and increasing the productivity of rangelands.

Rangelands are essential sources of forage for livestock production. Raising cattle is a very crucial economic activity in the North West Province, South Africa. Therefore, quantification of available forage is necessary in order to determine the carrying capacity of rangelands for a sustainable rangeland management strategy. In this study forage availability was determined in three rainfall zones (high, medium and low rainfall zones) and three rangeland management regimes, namely: protected, private and communal rangelands in each rainfall zone. The result showed that the rangelands had varied forage productivity with the private ranches from all rainfall zones producing the highest quantity while communal lands produce the lowest forage biomass. Rainfall distribution also had a notable impact on the level of rangeland productivity

with the high and medium rainfall zones producing higher quantity of forage and the low rainfall areas producing less amount of forage. Using various variables such as topographic data, rainfall distribution data, remote sensing data, field-based data, water resource data and distribution of animal unit data across rangelands proved to be very useful for rangeland productivity modeling using GIS. In this study, GIS based analysis has shown that consideration of spatial variability in the distribution of rangeland resources and factors that influence them is a significant aspect in rangeland management and assessment process for making an informed decision.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Rangeland covers 40-50 %of the total surface area of the earth and provides highly valuable grazing lands for wild life and livestock. However, these valuable natural resources are under a threat from humans and natural causes. This study was conducted to assess the applicability of satellite data to quantify and map the spatial distribution of rangeland biophysical parameters (aboveground biomass) from different geographic locations in the North West Province, South Africa. The major factors affecting the quality and conditions of the rangelands which are rainfall zones (high, medium and low), rangeland regimes (protected areas, communal lands and private ranches) and grazing intensity (high and low) were used to define sampling classes. Remote sensing vegetation indices (NDVI and SAVI) and vegetation cover fraction (SMA) were computed from SPOT-5 imagery and used to quantify the above ground biomass. A total of thirty-six field plots (each plot measuring 100m by 100m) were sampled from the entire study area. Five 2 m×2 m sub-plots were sampled within each plot for harvesting above ground biomass. Regression models of the aboveground biomass as a function of spectral indices and vegetation fraction were compared. For each rainfall zone, three tests were compared: 1, 2) relationship between AGB and vegetation indices per grazing intensity; 3) combined grazing intensity. In addition, several datasets namely topographic data, rainfall distribution data, remote sensing data, ground-based data, water resource data and distribution of animal unit data across rangelands were integrated in a GIS environment order to develop rangeland carrying capacity scheme.

Results of the study revealed that in the North-West province South Africa, rangelands are highly degraded due to overstocking and mismanagement particularly in the communal areas. The communal rangelands are the least in biomass productivity as compared to the protected areas and private ranches. The differences in rangeland productivity between the rangeland management strategies are due to managerial activities, climatic variables such as precipitation

distribution and temperature. High and medium rainfall areas relatively produce higher amount of biomass compared to the low rainfall areas. This implies that rainfall distribution is one of the important factors controlling rangeland productivity in the province. Low rainfall areas particularly, communal lands are the most negatively impacted rangelands due to the combined effects of poor management, overgrazing and overpopulation in conjunction with the meagre rainfall and the higher temperature the region experiences. Studies have shown that low rainfall and high temperature result in large deficit of water balance in the ecosystem.

Though disparities in rangeland productivity due to rangeland management and variations due to climatic factors can be seen from many sources, the magnitude of these disparities and variation due to the above variables cannot be fully explained by using ground based inventory only. Remote sensing is one of the most efficient tools for assessing rangeland conditions. In this study, SPOT-5 satellite imagery was used to analyse major land cover classes and quantify above ground biomass productivity of rangelands. Satellite imagery measured grasslands, shrubs, and trees and water bodies and bare grounds at a higher accuracy but failed to measure built up areas and indicators of erosion with acceptable accuracy. The unacceptable accuracies obtained for built up area and indicators of erosion were attributed to similarities of spectral reflectance of the built up areas and bare grounds and lack of distinctive reflectance and physical structures of indicators of erosion.

Vegetation indices such as NDVI and SAVI and spectral mixture analysis (SMA) which were derived from SPOT-5 imagery were assessed for their efficiency to quantify AGB by integrating them with ground based data. The SMA performed well in the low rainfall zone despite its failure in densely vegetated localities. However, SMA did not correlate with the AGB in the medium and high rainfall areas. The SAVI had the highest coefficient of determination in the low rainfall zone but the result was not significant at $P \leq 0.05$ especially in the medium and high rainfall regions. The NDVI had low coefficient of determination in the low rainfall areas but it performed well in the medium and high rainfall regions. The low coefficient of determination in of the NDVI the low rainfall regions was due to the effect of soil background as this region is characterized by sparse vegetation due to the presence of high proportion of bare-ground. Nonetheless, the overall performance of the NDVI was far superior to SAVI and SMA. Hence, NDVI was used in this study to quantify AGB in the North-West province.

Above ground biomass of the study sites was quantified using the model that was developed from the relationship between NDVI and ground based data. The total biomass of the study sites with average precipitation data was used to determine gross biomass data. This data was integrated with DEM data, watering points distance data and rainfall data to quantify available biomass for grazers. Precipitation and watering points distance had great impact on available biomass in low rainfall areas and communal rangelands. The erratic nature of rainfall in low rainfall regions limits availability of potable water for animals causing limitations on the number of watering points. A strong positive coefficient of determination was also detected between forage production and distance from water source ($R^2 = 0.98$; $P < 0.05$). The decrease of the forage production with the distance to water sources were more likely attributed to livestock grazing as livestock prefer to forage near water sources. In the communal areas, lack of maintenance and misuse of watering points, uncorresponding number of animals with the watering points cause limitations in the usage of forage in the rangelands. Distance from watering points had limited impact on rangeland forage accessibility in private ranches and protected areas particularly in medium and high rainfall areas because of optimally placed watering sites in the ranches. Slope had little restriction on the availability of biomass in all the study sites with the exception of the Pilanesberg National Park where steep gradient is the typical landscape and in some localities the slope exceeds 60%. The result showed that the private ranches are the places with the highest carrying capacity in the medium and high rainfall areas and the communal areas are the least particularly in the low rainfall areas.

The rangeland carrying capacity model which was developed in this study by integrating various parameters using a GIS environment was found to be useful in determining an optimal placement of some resources such as additional watering points; and identifying overstocked and under stocked rangelands. The model has a capacity of balancing forage supply in rangelands in relation to forage demands by animal units.

7.2 Recommendations

In order to make an impact, scientific research findings need to be accessible and meaningful for policymakers, practitioners and communities. This section provides key recommendations derived from this study.

- ✓ In order to achieve reliable information on rangeland productivity dynamics and assessing the factors that dictate biomass production, future studies should use convenient and efficient methods such as increasing the number of sample points, use of replicates, biophysical parameters, plant species compositions and long term climatic patterns.
- ✓ Focussing on the human and rangeland interaction at landscape level to have a deeper understanding so as to bring a lasting solution for the current acute rangeland degradation scenario. An assessment of the level of human dependence on rangeland would be ideal.
- ✓ Involving local communities in rangeland rehabilitation process, this will help to identify certain local indicators of rangeland productivity that can be integrated to boost scientific knowledge and training stakeholders with primary scientific knowledge to enhance rangeland productivity and combat rangeland degradation.
- ✓ Integration of remote sensing satellite imagery with ground based data (vegetation dynamics, soil characteristics, land use and land cover, topographic elements) to acquire better understanding of the rangeland conditions and their level of productivity should be encouraged. The focus should be on pixel based evaluation procedures to enhance land cover classification and improve forage quantification.
- ✓ High resolution satellite imagery for assessing the different rangeland parameters (climatic, topographic, land cover, soil, water, vegetation, etc.) should be accessible at demand to produce a more meaningful output that can be used by rangeland managers to enhance rangeland productivity and facilitate and ease ground based rangeland monitoring processes.

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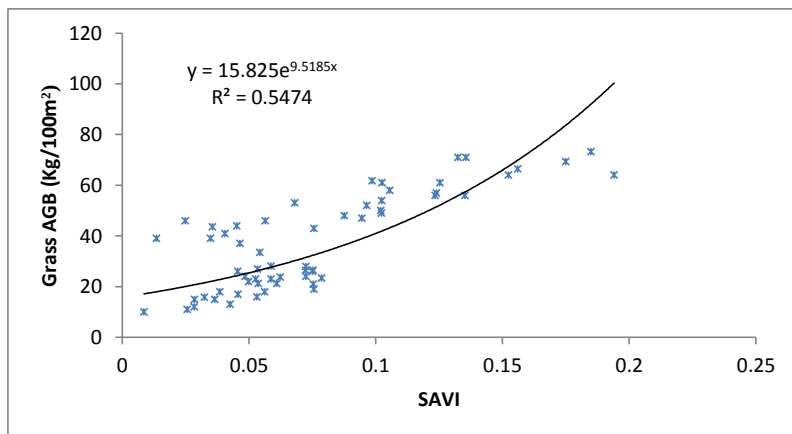
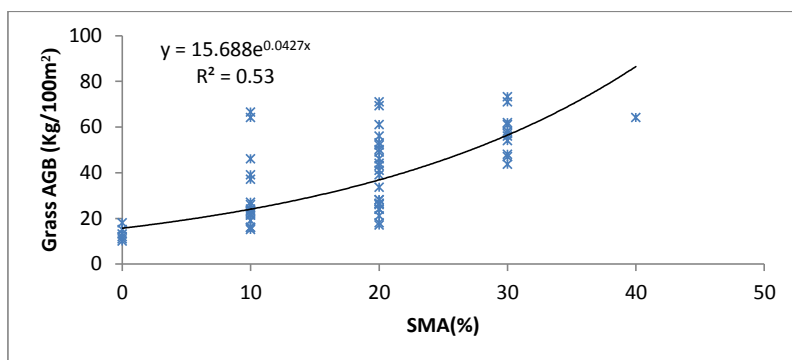
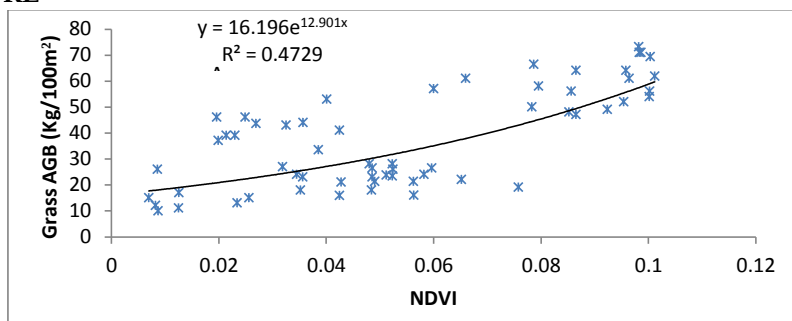
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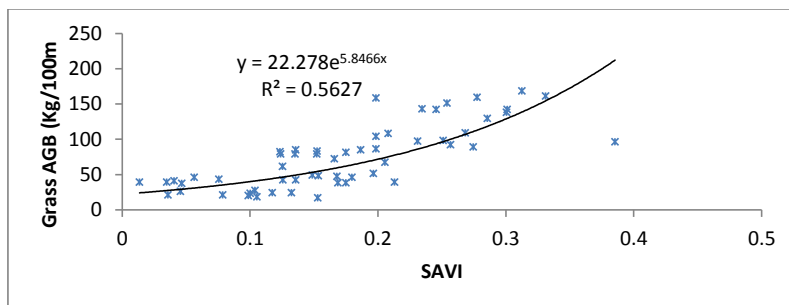
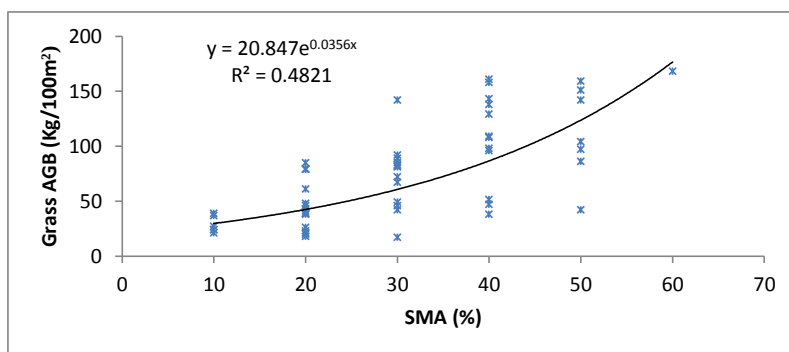
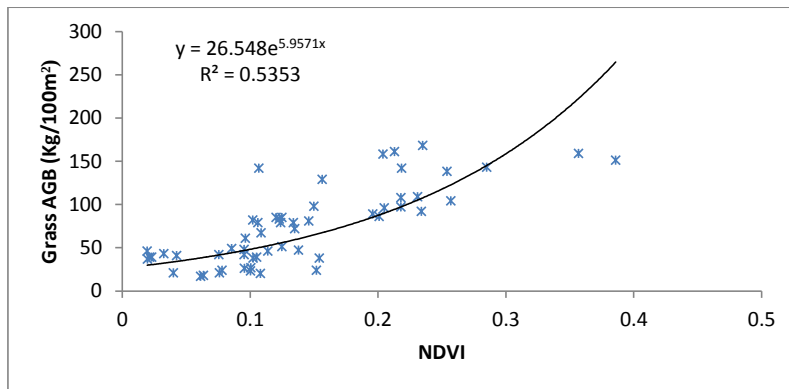
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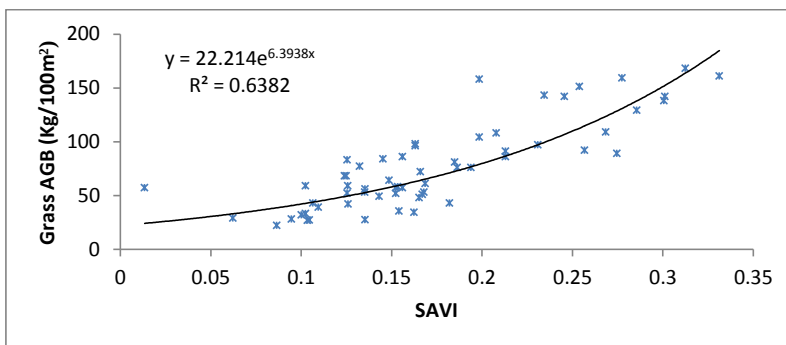
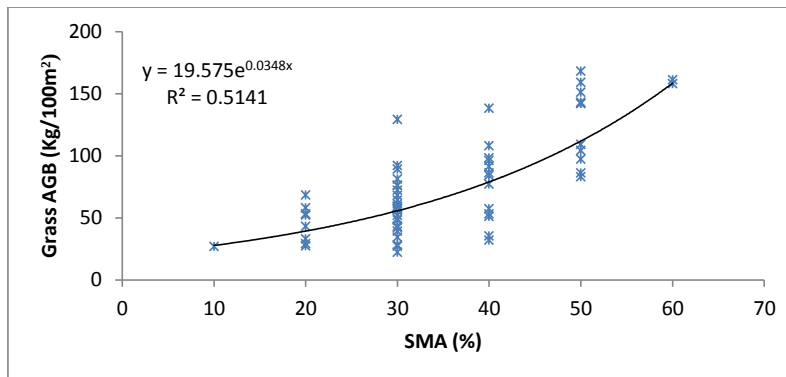
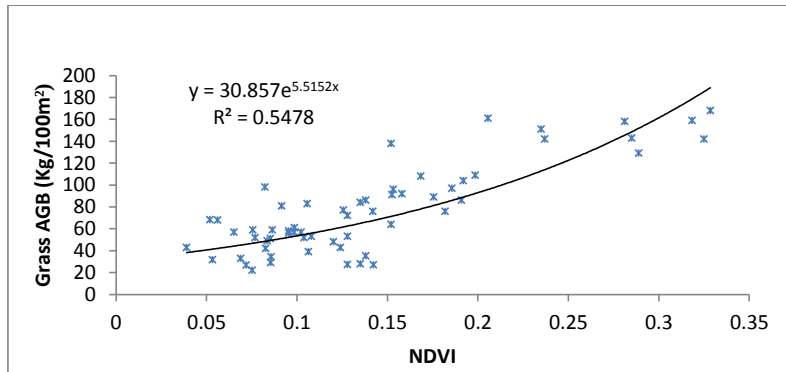
ANNEXURE



Annexure 1-3: Relations between grass biomass and vegetation indices in in the North West Province, South Africa:
NDVI, SMA and SAVI of the low rainfall areas.



Annexure 3-6: Relations between grass biomass and vegetation indices in in the North West Province, South Africa:
NDVI, SMA and SAVI of the medium rainfall areas.



Annexure 7-9: Relations between grass biomass and vegetation indices in in the North West Province, South Africa:
NDVI, SMA and SAVI of the high rainfall areas.

Note: All regression coefficients on the above figures are expressed in exponential mode

Anexure 10: Field biophysical data and the corresponding SAVI, SMA and NDVI data. Note: HGI high grazing intensity, LGI low grazing intensity, P1 plot one and P2 plot two.

Study Areas	Sample sites	Sample	Date	Zone	Easting	Northing	Indicators of Erosion(m)		AGB (Kg/100m ²)		Proportion of (%) Bareground	SAVI	SMA (%)	NDVI
							Width	Depth	Wet	Dry				
Protected Area (LRFZ)	HGI (P1)	S1	14/03/14	34J	690192.1	7138335	0.6	0.5	21.3	11.5	75	0.061	10	0.049
		S2	14/03/14	34J	690190.5	7138224.2	0.7	0.2	26	10.8	75	0.0751	10	0.0524
		S3	14/03/14	34J	690290.7	7138222.7	0.8	0.5	18	12.6	70	0.1023	20	0.0485
		S4	14/03/14	34J	690292.3	7138333.5	0.5	0.3	21.3	11.4	60	0.0653	10	0.0562
		S5	14/03/14	34J	690197	7138329.4	0.5	0.2	33.5	12.6	65	0.0542	20	0.0386
	HGI (P2)	S1	14/03/14	34J	689369.4	7150867.4	0.6	0.5	22	9.6	65	0.0499	10	0.0652
		S2	14/03/14	34J	689366.3	7150645.8	0.2	0.1	27	11.1	60	0.0534	10	0.0319
		S3	14/03/14	34J	689466.3	7150976.7	0.2	0.1	28.1	11.4	55	0.0587	20	0.0523
		S4	14/03/14	34J	689471.6	7150976.7	0.5	0.2	26.4	12.0	65	0.0723	20	0.0486
		S5	14/03/14	34J	689372.9	7150756.5	0.1	0	28	12.3	70	0.0725	20	0.048
	LGI (P1)	S1	15/03/14	34J	689482.4	7151752.2	0.2	0.5	43.6	13.1	50	0.0356	30	0.0269
		S2	15/03/14	34J	689480.9	7151641.4	0.3	0.3	44	13.2	45	0.0452	20	0.0357
		S3	15/03/14	34J	689581.2	7151639.9	0.5	0.1	41	12.3	50	0.0406	20	0.0425
		S4	15/03/14	34J	689582.8	7151750.7	0.2	0.1	39	11.7	55	0.0136	20	0.0214
		S5	15/03/14	34J	689531.8	7151696	0.3	0.2	46	13.8	55	0.0564	20	0.0196
	LGI (P2)	S1	15/03/14	34J	685384.4	7152918.2	0.3	0.1	39	11.7	45	0.0348	10	0.023
		S2	15/03/14	34J	685382.9	7152918.2	0.2	0.1	43	12.9	45	0.0756	20	0.0325
		S3	15/03/14	34J	685483.2	7152806	0	0	37	11.1	50	0.0465	10	0.0199
		S4	15/03/14	34J	685484.8	7152916.8	0.1	0.1	46	13.8	40	0.0249	10	0.0249
		S5	15/03/14	34J	685433.8	7152862.1	0.1	0.2	53	15.9	45	0.0359	20	0.0401

Communal Area (LRFZ)	HGI (P1)	S1	13/03/14	34J	774898.4	7108122	0.6	0.2	12	3.6	80	0.0542	0	0.0082
		S2	13/03/14	34J	774896.1	7108011.2	0.5	0.2	11	3.3	75	0.0256	0	0.0125
		S3	13/03/14	34J	774996.1	7108009.1	0.6	0.3	15	4.5	70	0.3456	10	0.007
		S4	13/03/14	34J	774998.5	7108119.9	0.4	0.1	13	3.9	68	0.1056	0	0.0234
		S5	13/03/14	34J	774902.3	7108066.5	0.5	0.2	10	3.0	75	0.0852	0	0.0087
	HGI (P2)	S1	13/03/14	34J	780634.7	7109549.6	0.4	0.1	15.8	5.9	75	0.0863	10	0.0425
		S2	13/03/14	34J	780734.7	7105238.5	0.6	0.3	16	6.3	70	0.0965	10	0.0563
		S3	13/03/14	34J	780632.3	7109441	0.2	0.1	15	6.0	75	0.135	0	0.0256
		S4	13/03/14	34J	780737.1	7109660.5	0.2	0.1	17	5.1	75	0.0457	20	0.0126
		S5	13/03/14	34J	780685.9	7109606.5	0.5	0.2	18	5.4	75	0.1235	0	0.0352
	LGI (P1)	S1	13/03/14	34J	774939.9	7105349.3	0.6	0.2	23	14.4	60	0.153	10	0.0485
		S2	13/03/14	34J	774937.5	7105238.5	0.2	0	23.8	13.5	55	0.1054	20	0.0512
		S3	13/03/14	34J	775037.5	7105237.5	0.1	0.1	24	12.9	50	0.1324	20	0.0582
		S4	13/03/14	34J	775039.9	7165347.2	0.1	0.1	23.4	12.0	69	0.0786	10	0.0523
		S5	13/03/14	34J	774989.8	7105342.7	0.2	0.1	21	11.4	55	0.1002	20	0.0428
	LGI (P2)	S1	13/03/14	34J	775425.9	7104673.7	0.7	0.2	24	12.9	58	0.1175	10	0.0345
		S2	13/03/14	34J	775423.5	7104562.9	0.5	0.2	26	14.1	50	0.0456	20	0.0086
		S3	13/03/14	34J	775523.6	7104560.8	0.5	0.1	23	12.6	45	0.104	10	0.0356
		S4	13/03/14	34J	775525.9	7104671.6	0.4	0.1	26.5	9.3	55	0.0987	20	0.0596
		S5	13/03/14	34J	775430.8	7104668.1	0.6	0.2	19	8.1	50	0.0756	10	0.0758
Private Ranch (LRFZ)	HGI (P1)	S1	16/03/14	34J	782310.8	7117609.8	0.2	0.1	48	14.4	68	0.0876	30	0.0852
		S2	16/03/14	34J	782308.4	7117498.9	0.3	0.1	52	15.6	65	0.0965	20	0.0954
		S3	16/03/14	34J	782408.5	7117496.8	0.2	0	49	14.7	65	0.1023	20	0.0924
		S4	16/03/14	34J	782410.9	7117607.6	0.3	0.1	50	15.0	68	0.152	20	0.0783

		S5	16/03/14	34J	782359.6	711755.3	0.1	0	47	14.1	74	0.0945	30	0.0865
	HGI (P2)	S1	16/03/14	34J	784420.7	7117896.6	0.2	0.1	73.2	24.0	70	0.185	30	0.0982
		S2	16/03/14	34J	784418.2	7117785.8	0.2	0.1	66.4	23.4	75	0.156	10	0.0787
		S3	16/03/14	34J	784518.1	7117783.6	0.1	0	64	22.8	70	0.194	10	0.0958
		S4	16/03/14	34J	784520.8	7117894.4	0.2	0.1	71	23.1	75	0.1324	20	0.0986
		S5	16/03/14	34J	784469.5	7117840.1	0.1	0.1	61.8	24.9	65	0.0986	30	0.1012
	LGI (P1)	S1	16/03/14	34J	784234.9	7118452.9	0	0	69.3	24.3	50	0.175	20	0.1004
		S2	16/03/14	34J	784232.5	7118455.1	0.1	0	61	23.7	50	0.1523	20	0.066
		S3	16/03/14	34J	784332.6	7118452.9	0.1	0	58	25.5	55	0.1865	30	0.0795
		S4	16/03/14	34J	784335	7118563.7	0.2	0.1	54	20.1	60	0.2054	30	0.1001
		S5	16/03/14	34J	784283.7	7118509.4	0	0	71	25.5	65	0.1356	30	0.0983
	LGI (P2)	S1	17/03/14	34J	785485.7	7116210.1	0	0	57	23.7	60	0.124	30	0.06
		S2	17/03/14	34J	785483.3	7116099.3	0.1	0	64	24.9	55	0.1524	40	0.0865
		S3	17/03/14	34J	785583.4	7116099.3	0.2	0.1	61	18.3	50	0.1254	30	0.0964
		S4	17/03/14	34J	785585.8	7116207.9	0.2	0	56	23.7	55	0.1352	20	0.0856
		S5	17/03/14	34J	785534.6	7116153.6	0.1	0	56	24.6	50	0.1235	30	0.1002
Protected Area (MRFZ)	HGI (P1)	S1	27/02/14	35J	372320	7137543	0.7	0.2	41	12.3	60	0.0406	20	0.0425
	HGI (P2)	S1	29/02/14	35J	370062.9	7136741.8	0.6	0.2	39	11.7	57	0.0136	20	0.0214
		S2	29/02/14	35J	369860.4	7136961.3	0.5	0.2	46	13.8	55	0.0564	20	0.0196
		S3	29/02/14	35J	369663.3	7136627	0.4	0.1	39	11.7	49	0.0348	10	0.023
		S4	29/02/14	35J	369966	7136708.5	0.5	0.2	43	12.9	56	0.0756	20	0.0325
		S5	29/02/14	35J	370263.3	7136743.7	0.3	0.1	37	11.1	60	0.0465	10	0.01986
	LGI (P1)	S1	6/3/2014	35J	368843	7138502	0.2	0.1	96	28.8	20	0.3854	40	0.205
		S2	6/3/2014	35J	368944.3	7138392.2	0.2	0	109	32.7	25	0.2684	40	0.231

		S3	6/3/2014	35J	369043.4	7138504	0.3	0.1	97	29.1	15	0.231	50	0.218
		S4	6/3/2014	35J	368941	7138724.5	0.1	0.1	104	31.2	10	0.1986	50	0.257
		S5	6/3/2014	35J	368941	7138724.5	0.2	0	98	29.4	15	0.251	40	0.15
	LGI (P2)	S1	6/3/2014	35J	373640.1	7139878.1	0.3	0	108	32.4	25	0.208	40	0.218
		S2	6/3/2014	35J	373538.8	71399879	0.3	0.1	86	25.8	20	0.1986	50	0.201
		S3	6/3/2014	35J	373741.4	7139768.3	0.2	0.1	92	27.6	24	0.2568	30	0.234
		S4	6/3/2014	35J	373941.8	7139770.3	0.2	0.1	89	26.7	15	0.2746	30	0.196
		S5	6/3/2014	35J	373838.4	7140101.6	0.2	0.3	72	21.6	10	0.166	30	0.135
	HGI (P1)	S1	8/3/2014	35J	328983.7	7173805	0.7	0.2	21	6.3	70	0.0359	20	0.0401
		S2	8/3/2014	35J	328783.2	7143802.7	0.8	0.3	17	5.1	65	0.153	30	0.0613
		S3	8/3/2014	35J	328882	7143914.8	0.1	0	18	5.4	60	0.1054	20	0.0635
		S4	8/3/2014	35J	328980.9	7144029.9	1.2	0.5	24	7.2	65	0.1324	10	0.152
		S5	8/3/2014	35J	328884.9	7143693.3	0.7	0.3	21	6.3	60	0.0786	10	0.0762
Communal Area (MRFZ)	HGI (P2)	S1	8/3/2014	35J	330812.6	7141945.5	0.9	0.3	23	6.9	55	0.1002	20	0.1004
		S2	8/3/2014	35J	330961.9	7142058.2	0.8	0.2	24	7.2	58	0.1175	10	0.078
		S3	8/3/2014	35J	330812.6	7141945.5	0.8	0.4	26	7.8	65	0.0456	20	0.0956
		S4	8/3/2014	35J	330809.8	7142167	0.7	0.2	27	8.1	60	0.104	10	0.1006
		S5	8/3/2014	35J	330910	7142168.3	0.7	0.3	20	6.0	58	0.0987	20	0.108
	LGI (P1)	S1	9/3/2014	35J	330060.9	7145813.5	0.5	0.1	39	11.7	45	0.213	20	0.105
		S2	9/3/2014	35J	330162.6	7145704	0.4	0.1	48	14.4	30	0.1534	20	0.0954
		S3	9/3/2014	35J	330112.5	7145703.3	0.5	0.1	42	12.6	40	0.1258	50	0.0756
		S4	9/3/2014	35J	330060.9	7145813.5	0.4	0.2	49	14.7	45	0.1486	30	0.0856
		S5	9/3/2014	35J	330111.8	7145758.7	0.3	0.2	47	14.1	35	0.168	40	0.138

	LGI (P2)	S1	9/3/2014	35J	322448.7	7145048.5	0.6	0.1	38	11.4	46	0.175	40	0.1542
		S2	9/3/2014	35J	322549	7145049.8	0.5	0.1	51.3	15.4	50	0.1965	40	0.125
		S3	9/3/2014	35J	322550.2	7144939.1	0.4	0.2	38	11.4	45	0.1687	20	0.1024
		S4	9/3/2014	35J	322450.2	7144937.7	0.5	0.2	46	13.8	50	0.1797	30	0.114
		S5	9/3/2014	35J	322499.6	7144993.8	0.3	0.1	42	12.6	20	0.1357	30	0.09547
Private Ranch (MRFZ)	HGI (P1)	S1	10/3/2014	35J	370126	7140508.6	0	0	81	24.3	45	0.175	30	0.146
		S2	10/3/2014	35J	370026.8	7140396.8	0	0	79	23.7	50	0.1523	20	0.134
		S3	10/3/2014	35J	370127.1	7140397.8	0	0	85	25.5	45	0.1865	30	0.125
		S4	10/3/2014	35J	370025.8	7140507.6	0	0	67	20.1	40	0.2054	30	0.1085
		S5	10/3/2014	35J	370076.4	7140452.7	0	0	85	25.5	35	0.1356	20	0.1205
	HGI (P2)	S1	10/3/2014	35J	369826.4	7140394.8	0	0	79	23.7	40	0.124	20	0.106
		S2	10/3/2014	35J	369827.5	7140284.1	0	0	83	24.9	46	0.1524	30	0.123
		S3	10/3/2014	35J	369927.7	7140285.1	0	0	61	18.3	50	0.1254	20	0.0964
		S4	10/3/2014	35J	369926.6	7140395.8	0	0	79	23.7	45	0.1352	20	0.124
		S5	10/3/2014	35J	369877.1	7140339.9	0	0	82	24.6	45	0.1235	30	0.1021
	LGI (P1)	S1	10/3/2014	35J	368825.5	7140274.1	0	0	151	45.3	10	0.254	50	0.386
		S2	10/3/2014	35J	368826.4	7140163.4	0	0	143	42.9	20	0.2345	40	0.285
		S3	10/3/2014	35J	368926.6	7140164.4	0	0	158	47.4	10	0.1986	40	0.2041
		S4	10/3/2014	35J	368925.5	7140275.1	0	0	142	42.6	10	0.3012	30	0.1068
		S5	10/3/2014	35J	368876	7140219.2	0	0	138	41.4	15	0.3007	40	0.254
	LGI (P2)	S1	11/3/2014	35J	369029	7139943.8	0	0	159	47.7	20	0.2775	50	0.357
		S2	11/3/2014	35J	369030.1	7139833.1	0	0	161	48.3	15	0.3312	40	0.213
		S3	11/3/2014	35J	369130.4	7139834.1	0	0	168	50.4	15	0.3125	60	0.235
		S4	11/3/2014	35J	369129.3	7139944.8	0	0	129	38.7	20	0.2856	40	0.1564

		S5	11/3/2014	35J	369079.7	7139889	0	0	142	42.6	21	0.2456	50	0.2185
Protected Area (HRFZ)	HGI (P1)	S1	25/3/2014	35J	511680.2	7205592.9	0.7	0.2	57	17.1	45	0.156	40	0.0985
		S2	25/3/2014	35J	511680.1	7205482.1	0.8	0.3	48	14.4	50	0.1652	30	0.1201
		S3	25/3/2014	35J	511780.8	7205482.1	0.7	0.2	57	17.1	65	0.01345	30	0.0652
		S4	25/3/2014	35J	511780.9	7205592.8	0.6	0.2	42	12.6	60	0.126	30	0.0827
		S5	25/3/2014	35J	511730.5	7205537.5	0.5	0.1	39	11.7	65	0.10952	30	0.1063
	HGI (P2)	S1	25/3/2014	35J	502620.4	7217999.6	0.7	0.2	51	15.3	50	0.167	40	0.0853
		S2	25/3/2014	35J	502620.4	7217888.9	0.7	0.2	43	12.9	45	0.1821	20	0.03895
		S3	25/3/2014	35J	502721.1	7217888.9	0.8	0.3	51.8	15.5	45	0.1523	30	0.0768
		S4	25/3/2014	35J	502721.2	7217999.6	0.5	0.1	43	12.9	50	0.1065	30	0.124
		S5	25/3/2014	35J	502670.8	7217944.2	0.6	0.1	56	16.8	55	0.1354	30	0.09564
	LGI (P1)	S1	26/03/2014	35J	504331.5	7211133.8	0.3	0.1	96	28.8	20	0.1632	40	0.1532
		S2	26/03/2014	35J	504331.5	7211023.1	0.2	0.2	109	32.7	15	0.2684	50	0.19856
		S3	26/03/2014	35J	504432.2	7211023.1	0.2	0.2	97	29.1	5	0.231	50	0.18567
		S4	26/03/2014	35J	504432.2	7211133.8	0.1	0.2	104	31.2	20	0.1986	50	0.192
		S5	26/03/2014	35J	504381.8	7211078.5	0.2	0.2	98	29.4	10	0.1632	40	0.0823
	LGI (P2)	S1	26/03/2014	35J	510065.3	7200611.2	0.2	0.1	108	32.4	15	0.208	40	0.1685
		S2	26/03/2014	35J	510065.3	7200500.5	0.3	0.2	86	25.8	20	0.213	50	0.191
		S3	26/03/2014	35J	510166	7200500.4	0.3	0.2	92	27.6	25	0.2568	30	0.158
		S4	26/03/2014	35J	510166.1	7200611.1	0.3	0.1	89	26.7	20	0.2746	30	0.17562
		S5	26/03/2014	35J	510115.7	7200555.8	0.2	0.1	72	21.6	20	0.166	30	0.128
Communal Area (HRFZ)	HGI (P1)	S1	2/4/2014	35J	495966.9	7223978.7	0.6	0.1	28	8.4	50	0.09468	30	0.135
		S2	2/4/2014	35J	495966.9	7223868	0.7	0.1	33	9.9	65	0.1025	20	0.0689

		S3	2/4/2014	35J	495968.9	722387.2	0.8	0.2	27.3	8.2	60	0.1354	20	0.128
		S4	2/4/2014	35J	496067.7	7223978.8	0.5	0.1	34.3	10.3	55	0.1624	30	0.08563
		S5	2/4/2014	35J	496017.3	7223923.4	0.5	0.1	22	6.6	49	0.0865	30	0.07523
	HGI (P2)	S1	2/4/2014	35J	504740.5	7228629.1	0.8	0.2	29	8.7	55	0.0623	20	0.0856
		S2	2/4/2014	35J	504740.5	7228518.4	0.7	0.2	35.3	10.6	40	0.1542	40	0.138
		S3	2/4/2014	35J	504841.4	7228518.4	0.5	0.1	26.7	8.0	45	0.10356	10	0.0719
		S4	2/4/2014	35J	504841.4	7228629.1	0.6	0.2	31.8	9.5	50	0.1002	40	0.05326
		S5	2/4/2014	35J	504990.9	7228573.8	0.5	0.1	27	8.1	56	0.10463	30	0.1423
	LGI (P1)	S1	2/4/2014	35J	508371.4	7228295.2	0.4	0.1	52	15.6	25	0.1254	20	0.104
		S2	2/4/2014	35J	508371.3	72282185	0.8	0.2	59	17.7	30	0.1025	30	0.08635
		S3	2/4/2014	35J	508472.2	7228184.4	0.6	0.1	58	17.4	25	0.1534	20	0.0954
		S4	2/4/2014	35J	508472.2	7228295.2	0.7	0.1	59	17.7	45	0.1258	30	0.0756
		S5	2/4/2014	35J	508421.8	7228289.6	0.4	0.1	64	19.2	40	0.1486	30	0.152
	LGI (P2)	S1	2/4/2014	35J	508173.4	7234606.9	0.3	0.1	53	15.9	35	0.168	40	0.108
		S2	2/4/2014	35J	508173.4	7234496.2	0.4	0.2	49	14.7	25	0.1432	30	0.08356
		S3	2/4/2014	35J	508375.2	723449.6	0.4	0.2	57	17.1	20	0.1523	30	0.10235
		S4	2/4/2014	35J	508274.3	7234606.8	0.3	0.2	61	18.3	25	0.1687	30	0.09856
		S5	2/4/2014	35J	508324.7	7234551.4	0.4	0.1	53	15.9	30	0.1352	20	0.128
Private Ranch (HREFZ)	HGI (P1)	S1	3/4/2014	35J	505228.7	7186993.6	0.2	0.1	81	24.3	40	0.185	30	0.0916
		S2	3/4/2014	35J	505228.7	7186882.9	0.2	0.1	68.2	20.5	35	0.124	20	0.0519
		S3	3/4/2014	35J	505329.2	7186882.8	0.3	0.1	76	22.8	45	0.194	30	0.182
		S4	3/4/2014	35J	505329.3	7186993.6	0.2	0.1	77	23.1	30	0.1324	40	0.1256
		S5	3/4/2014	35J	505279	7186938.2	0.1	0.1	83	24.9	30	0.1254	50	0.1056
	HGI (P2)	S1	3/4/2014	35J	501709.3	7186219.4	0.1	0.1	76	22.8	35	0.1864	30	0.142

		S2	3/4/2014	35J	501709.3	7186108.7	0.2	0.1	86	25.8	2	0.156	40	0.138
		S3	3/4/2014	35J	501809.8	7186108.6	0.2	0.1	91	27.3	30	0.213	40	0.1526
		S4	3/4/2014	35J	501809.8	7186219.4	0.3	0.1	68	20.4	35	0.125	30	0.0562
		S5	3/4/2014	35J	501759.6	7186164	0.2	0.1	84	25.2	40	0.1452	40	0.135
	LGI (P1)	S1	3/4/2014	35J	502715	7187437.3	0	0	151	45.3	5	0.254	50	0.235
		S2	3/4/2014	35J	502715	7187326.6	0	0	143	42.9	10	0.2345	50	0.285
		S3	3/4/2014	35J	502815.5	7187326.6	0	0	158	47.4	10	0.1986	60	0.2812
		S4	3/4/2014	35J	502815.6	7187437.3	0	0	142	42.6	5	0.3012	50	0.237
		S5	3/4/2014	35J	502765.3	7187381.9	0	0	138	41.4	15	0.3007	40	0.152
	LGI (P2)	S1	4/4/2014	35J	504726.2	7187547.5	0	0	159	47.7	10	0.2775	50	0.3185
		S2	4/4/2014	35J	504726.1	7187436.8	0.1	0	161	48.3	5	0.3312	60	0.2056
		S3	4/4/2014	35J	504826.6	7187326	0	0	168	50.4	20	0.3125	50	0.3285
		S4	4/4/2014	35J	504826.7	7187547.4	0.1	0.1	129	38.7	15	0.2856	30	0.289
		S5	4/4/2014	35J	504776.4	7187492.1	0	0	142	42.6	15	0.2456	50	0.325

Anexure 11a: Forage distribution characteristics statistical reports

Study Sites	Area (ha)	ABP	% accessible	loss/Water	Loss%	ASN	AUM	6 Months
Molpo NR	24000.00	0.45	82.23	1929.0	17.77	1380	24592.29	4098.71
Morokweng CRL	6500.00	0.25	67.58	495.0	32.42	1273	2842.98	473.83
Dubbelaar PR	280.00	1.04	99.18	0.0	0.00	92	762.53	127.09
Mafikeng GR	4492.00	1.23	96.32	192.0	3.68	655	13840.22	2306.70
Disaneng CRL	17900.00	0.67	76.01	2764.0	23.99	6647	24129.48	4021.58
Lenric PR	187.00	1.67	96.96	0.0	0.00	51	790.63	131.77
Pilanesberg NP	49000.00	0.88	77.57	9260.0	22.43	6320	88220.39	14703.40
Ngwedding CL	40635.00	0.70	84.37	4307.0	15.63	9728	64066.12	10677.69
Onderstepoort PR	1717.00	1.59	99.77	0.0	0.00	279	7082.64	1180.44
Total	144711.00	0.72	81.25	18964.3	18.75	26425	226327.27	37721.21

Anexure 11b: Forage distribution characteristics statistical reports

Study Sites	ASD	D/A	CC	RC	TGC	DSN	AD	ha/an	D/A
Molopo NR	3005640.0	0.3	5.86	Fair	4098.7	-2718.7	0.06	17.39	-197.1
Morokweng CL	2772594.0	2.7	13.72	Poor	473.8	799.2	0.20	5.11	62.8
Dubbelaar PR	200376.0	0.7	2.20	Good	127.1	-35.1	0.33	3.04	-38.1
Mafikeng GR	1426590.0	0.3	1.95	Good	2306.7	-1651.7	0.15	6.86	-252.2
Disaneng CL	14477166.0	1.7	4.45	Poor	4021.6	2625.4	0.37	2.69	39.5
Lenric PR	111078.0	0.4	1.42	V. Good	131.8	-80.8	0.27	3.67	-158.4
Pilanesberg NP	13764960.0	0.4	3.33	Good	14703.4	-8383.4	0.13	7.75	-132.6
Ngwedding CL	21187584.0	0.9	3.81	Fair	10677.7	-949.7	0.24	4.18	-9.8
Onderstepoort PR	607662.0	0.2	1.45	V. Good	1180.4	-901.4	0.16	6.15	-323.1

YEAR 2012

7. Inspection/census figures

7.1 Commercial Farmers

SV Area & Regions	District code	Cattle	Sheep	Goats	Horses	Donkeys	Mules	Pigs
Mahikeng	483	79400	34190	23054	1727	260	0	220
Ratlou	381	89726	7643	5217	1076	260	0	220
Ditsobotla	484	88454	14163	1744	601	260	0	220
Tswaing	482	80921	13893	2544	930	260	0	220
Ramotshere	485	88454	14163	15721	1727	260	0	220
Dr Modiri Molema		426955	84052	48280	6061	1300	0	1100
Madibeng	472	27800	9852	3440	298	31	10	8170
Moses Kotane	475	7220	130	650	13	12	4	0
Moretele	471	2780	75	42	0	9	0	0
Kgetleng River	474	115058	4980	9740	150	57	8	9670
Rustenburg	473	31647	1680	755	438	27	3	15787
Bojanala		184505	16717	14627	899	136	25	33627
Klerksdorp	403	82807	10085	1294	429	15	0	2721
Maquassi Hills	404	85414	17397	1165	426	29	11	20570
Potchefstroom	402	49803	9431	2210	286	51	0	15836
Ventersdorp	401	70250	22340	3458	119	86	0	55420
Dr K. Kaunda		288274	59253	8127	1260	181	11	94547
Molopo	495	59758	7075	9937	1698	286	0	46
Kagisano	491	32688	8161	8573	0	0	0	0
Naledi	492	80259	14363	8986	751	16	4	1702
Taung	494	21664	6100	8796	31	0	0	117
Lekwa-Teemane	496	68898	15340	2169	206	0	0	15438

Mamusa	493	66800	2751	174	133	0	0	2223
Dr RS Mompoti		330067	53790	38635	2423	302	4	19526
TOTAL		910818	141066	70540	5072	1695	40	150007

7.2 Communal Farmers

7.3 Livestock Census: North West Province

SV Office		Cattle	Sheep	Goats	Horses	Donkeys	Mules	Pigs	Dogs	Ostriches	Fowl
Madibeng	472	47795	10511	9941	303	834	15	8968	12521	780	1915000
Moses Kotane	475	63251	1495	13340	175	2335	4	764	12553	13	41894
Moretele	471	31750	1084	2524	5	729	5	642	1785	0	21642
Kgetleng River	474	116158	5015	10275	150	86	13	9756	4276	146	477570
Rustenburg	473	49425	2625	4041	518	578	27	16540	31745	570	8406804
Bojanala		308379	20730	40121	1150	4562	64	36670	62880	1509	10862910
Klerksdorp	403	84546	12944	3875	518	101	2	7950	7173	0	22022
Maquassi Hills	404	96734	27275	2991	456	58	17	21715	2475	104	98812
Potchefstroom	402	56300	9829	2681	325	62	0	16822	2857	146	530386
Ventersdorp	401	72538	22810	3940	142	119	0	55752	11824	132	276151

Dr K. Kaunda		310118	72858	13487	1441	340	19	102239	24329	382	927371
Molopo	495	62411	7505	11959	1795	447	0	46	1368	120	2308
Kagisano	491	79386	19139	30192	0	0	0	10	1227	1314	1374
Naledi	492	81432	14451	9046	911	98	8	1859	652	22	995
Taung	494	47890	13242	18665	42	0	0	242	2120	392	6413
Lekwa-Teemane	496	71350	16261	2742	209	2	0	15481	1755	131	1873
Mamusa	493	67047	2753	174	133	0	0	2223	640	0	598
Dr RS Mompoti		409516	173351	72778	3090	547	8	19861	7762	1979	13561
TOTAL											

YEAR 2013

7. LIVESTOCK CENSUS

7.1 Commercial Farmers

SV Area & Regions	District code	Cattle	Sheep	Goats	Horse s	Donkey s	Mule s	Pigs	Dogs	Ostrich es	Fowls	Cats
NGAKA MODIRI MOLEMA												
Mahikeng	483	9099	2197	1255	51	58	0	880	1479	0	0	0
Ratlou	481	33137	378	76	13	23	0	1123	143	0	0	0
Ditsobotla	484	81221	46815	2189	166	601	0	1849	0	0	0	0

Tswaing	482	0	0	0	0	0	0	0	0	0	0	0
Ramotshere	485	40261	10789	1440	64	80	23	4004	2283	0	0	278
		163718	60177	4960	294	762	23	7856	3905	0	0	278
TOTAL												
DR KENNETH KAUNDA												
Klerksdorp	403	83824	11164	1472	355	16	0	3093	5453	3	650	0
Maquassi Hills	404	41316	11127	581	302	21	7	12341	1412	31	43321	0
Potchefstroom	402	43281	8750	2531	547	68	0	16595	2341	187	56146 7	0
Ventersdorp	401	73890	24260	4680	125	90	0	14500	1250	140	28216 0	0
		242311	55301	9264	1329	195	7	46529	10456	361	88759 8	0
TOTAL												
DR RUTH SEGOMOTSI MOMPATI												
Molopo	495	88410	8621	11901	1673	905	0	4	1095	0	3305	0
Kagisano	491	0	0	0	0	0	0	0	0	0	0	0
Naledi	492	39321	5633	2808	191	54	0	2726	1399	14	1140	0
Taung	494	11813	1514	2211	16	9	0	44	198	1	375	0
Lekwa- Teemane	496	39297	7935	855	111	22	0	43187	244	124	1504	0
Mamusa	493	0	0	0	0	0	0	0	0	0	0	0
		178841	23703	17775	1991	990	0	45961	2936	139	6324	0
TOTAL												
GRAND TOTAL		584870	139181	31999	3614	1947	30	10034 6	17297	500	89392 2	278

There are 1,970 Commercial farmers in Ngaka Modiri Molema District.

7.2 Communal Farmers

SV Area & Regions	District code	Cattle	Sheep	Goats	Horse s	Donkey s	Mules	Pigs	Dogs	Ostriches	Fowls	Cats
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NGAKA MODIRI MOLEMA												
Mahikeng	483	29637	13657	14068	456	1936	0	2477	0	0	0	0
Ratlou	481	48625	9096	1128	292	1560	26	266	1788	0	0	0
Ditsobotla	484	4863	1497	1744	326	601	0	394	746	0	0	0
Tswaing	482	10327	7007	3633	560	1569	0	536	4779	0	0	285
Ramotshere	485	57162	4527	15135	64	3478	39	416	3352	0	0	832
		150614	35784	35708	1698	9142	65	4089	10665	0	0	1117
TOTAL												
DR KENNETH KAUNDA												
Klerksdorp	403	632	1009	852	0	23	0	3614	178	0	1423	0
Maquassi Hills	404	11204	6001	2147	43	12	1	923	2222	0	13012	0
Potchefstroom	402	6680	296	526	59	26	0	841	927	0	1836	0
Ventersdorp	401	4980	1800	950	59	41	0	1200	1340	0	12450	0
		2346	9106	4478	161	102	1	6578	4667	0	28721	0
TOTAL												
DR RUTH SEGOMOTSI MOMPATI												
Molopo	495	5913	1444	4420	134	217	0	0	349	0	472	0
Kagisano	491	91108	15267	25573	12	0	0	235	1719	0	0	325
Naledi	492	2308	1263	1976	98	28	0	688	2684	0	43	0
Taung	494	66895	30614	40755	1349	5778	41	2491	5538	0	51325	1040
Lekwa-Teemane	496	4682	2035	1259	9	1	0	1173	180	0	643	60
Mamusa	493	0	0	0	0	0	0	0	0	0	0	0
		164993	49179	69563	1468	5147	41	4587	10121	0	52011	1425
TOTAL												
GRAND TOTAL		317953	94069	109749	3327	14391	107	15254	25453	0	80732	2542

There are 9,642 Communal Farmers in Ngaka Modiri Molema region.

7.3 Livestock Census: North West Province (commercial & communal farmers)

SV Area & Regions	Cattle	Sheep	Goats	Horses	Donkeys	Mules	Pigs	Dogs	Ostriches	Fowls	Cats

NGAKA MODIRI MOLEMA												
Mahikeng	483	38736	3657	15323	507	1994	0	3357	1479	0	0	0
Ratlou	481	81762	9474	1204	305	1613	26	1389	1931	0	0	0
Ditsobotla	484	86084	48312	3933	492	1202	0	2243	746	0	0	0
Tswaing	482	10327	7007	3633	560	1569	0	536	4779	0	0	285
Ramotshere	485	97423	15316	16575	128	3558	62	4420	5635	0	0	1108
TOTAL		314332	83766	40668	1992	9936	88	11945	15470	0	0	1393
DR KENNETH KAUNDA												
Klerksdorp	403	84456	12173	2324	355	39	0	6707	5631	3	2073	0
Maquassi Hills	404	52520	17128	2728	345	33	8	13264	3634	31	56333	0
Potchefstroom	402	49961	9046	3060	606	94	0	17436	3268	187	563303	0
Ventersdorp	401	78870	26060	5630	184	131	0	15700	2590	140	294610	0
TOTAL		265807	64407	13742	1490	297	8	53107	15123	361	916319	0
DR RUTH SEGOMOTSI MOMPATI												
Molopo	495	43891	5729	4367	734	453	38	0	600	0	1404	0
Kagisano	491	80360	23570	48099	4187	8113	628	31	4068	15	18050	0
Naledi	492	19507	2911	2373	160	66	0	97	545	8	534	0
Taung	494	30239	16695	21730	1267	5010	0	2160	4907	0	39502	0
Lekwa-Teemane	496	33297	8263	478	489	0	0	9888	199	0	0	0
Mamusa	493	46129	26507	872	57	0	0	866	3566	0	0	0
TOTAL		253423	83672	77919	6894	13642	666	13042	13885	23	59490	0
BOJANALA REGION												
Madibeng	472	43275	9988	9780	230	468	12	8966	5400	347	500789	0
M. Kotane	475	120000	10000	14000	1000	800	0	1700	1800	10	12000	0

Moretele	471	43089	1029	4406	0	9	0	713	2172	0	15539	0
Kgetleng	474	119902	4040	5232	1012	524	54	9936	5254	150	477952	0
Rustenburg	473	45456	2540	4009	540	540	28	16890	31768	570	8406890	0
Total		371722	27597	37427	2782	2341	94	38205	46394	1077	9413170	0
GRAND TOTAL		1205284	259442	169756	3012	26216	856	116299	90872	1461	10388979	1393

7.4 The following number of animals was inspected during the reporting period In Bojanala District:

SV Area & Regions	Cattle	Sheep	Goats	Pigs	Donkeys	Horses	Poultry	Dogs	Buffalo	Game	Cats
Madibeng	26234	3312	6895	19200	15	0	1306	511	186	0	54
Moses Kotane	58730	2802	11578	641	36	1	49771	1253	0	76	21
Moretele	43089	1029	4406	713	9	0	15539	2172	0	0	38
Kgetleng River	168192	57435	5354	304	0	0	0	43	294	33	0
Rustenburg	29068	3576	3307	2832	377	126	9045	469	101	502	1
TOTAL	325313	68154	31540	23690	437	127	75661	4448	581	611	114

YEAR 2014

7. Inspection/census figures

7.1 Commercial Farmers

SV Area & Regions	District code	Cattle	Sheep	Goats	Horses	Donkeys	Mules	Pigs	Dogs	Ostriches	Fowls	Cats
NGAKA MODIRI MOLEMA												
Mahikeng	483	34981	7350	6945	66	846	0	287	37	0	0	0
Ratlou	481	9600	1925	58	0	0	0	1053	438	0	0	8
Ditsobotla	484	0	0	0	0	0	0	0	0	0	0	0
Tswaing	482	0	0	0	0	0	0	0	0	0	0	0
Ramotshere	485	0	0	0	0	0	0	0	0	0	0	0
TOTAL		44581	9275	7003	66	846	0	1340	475	0	0	8
BOJANALA												
Madibeng	472	0	400	220	0	0	0	803	0	0	70000	0
Moses Kotane	475	0	0	0	0	0	0	0	0	0	0	0
Moretele	471	0	0	0	0	0	0	0	0	0	0	0
Kgetleng River	474	110454	37525	1316	37	0	0	121	1833	0	90000	58
Rustenburg	473	23460	2894	3972	235	342	0	3264	1590	0	11741	4
TOTAL		133914	40819	5508	272	342	0	4188	3423	0	171741	62
DR KENNETH KAUNDA												
Klerksdorp	403	93969	10617	1319	146	9	0	3477	3085	0	549000	0
Maquassi Hills	404	36258	5287	3889	63	2	4	25877	1635	4	54274	0
Potchefstroom	402	40251	74375	2176	612	77	0	17258	2294	173	572696	0
Ventersdorp	401	81230	17458	3247	113	95	0	53480	3430	146	340600	0
TOTAL		251708	107737	10631	934	183	4	100092	10444	323	1516570	0
DR RUTH SEGOMOTSI MOMPATI												
Molopo	495	75109	8371	11740	1564	755	0	4	1146	0	1305	0
Kagisano	491	47715	7864	11207	1	0	13	22	1048	13	933	0

Naledi	492	50821	8235	1376	187	18	0	2467	618	5	1471	0
Taung	494	7583	295	493	0	0	0	0	510	7	0	0
Lekwa-Teemane	496	31269	6004	572	106	9	0	39881	203	32	460	0
Mamusa	493	52731	26451	951	0	57	0	965	4073	0	165	0
TOTAL		265228	57220	26339	1858	839	13	43339	7598	57	4334	0
GRAND TOTAL		695431	215051	49481	3130	2210	17	148959	21940	380	1692645	70

7.2 Communal Farmers

SV Area & Regions	District code	Cattle	Sheep	Goats	Horses	Donkeys	Mules	Pigs	Dogs	Ostriches	Fowls	Cats
NGAKA MODIRI MOLEMA												
Mahikeng	483	0	0	0	0	0	0	0	0	0	0	0
Ratlou	481	33989	5054	711	0	0	0	216	2544	0	0	41
Ditsobotla	484	0	0	0	0	0	0	0	0	0	0	0
Tswaing	482	12704	8194	4558	539	1675	0	667	4993	0	0	236
Ramotshere	485	0	0	0	0	0	0	0	0	0	0	0
TOTAL		46693	13248	5269	539	1675	0	883	7537	0	0	277
BOJANALA												
Madibeng	472	16090	808	827	0	0	0	100	4196	0	136	7
Moses Kotane	475	32644	2578	5472	0	0	0	821	6655	0	32831	0
Moretele	471	59966	902	4746	0	0	0	285	768	0	14953	1
Kgetleng River	474	0	0	0	0	0	0	0	0	0	0	0
Rustenburg	473	2022	0	0	0	0	0	600	101	0	210	0
TOTAL		110722	4288	11045	0	0	0	1806	11720	0	48130	8
DR KENNETH KAUNDA												
Klerksdorp	403	3114	3986	2528	0	21	0	5421	214	0	23385	0
Maquassi Hills	404	3247	4645	1621	14	24	2	943	2157	0	18315	0

Potchefstroom	402	7088	319	863	81	46	0	1021	1362	0	2431	0
Ventersdorp	401	3470	520	435	21	35	0	360	640	0	8570	0
		16919	9470	5447	116	126	2	7745	4373	0	52701	0
TOTAL												
DR RUTH SEGOMOTSI MOMPATI												
Molopo	495	29291	726	4756	106	119	0	0	534	0	137	0
Kagisano	491	34368	5984	1753 6	0	0	1	0	516	0	548	42
Naledi	492	5719	1043	159	45	26	0	55	556	0	478	2
Taung	494	40570	1815 3	1904 8	0	0	0	0	635	0	1767	30
Lekwa-Teemane	496	3233	1293	713	10	3	0	77	61	0	111	0
Mamusa	493	0	0	0	0	0	0	0	0	0	0	600
		11318 1	2719 9	4221 2	161	148	1	132	2302	0	3041	374
TOTAL												
GRAND TOTAL		28751 5	5420 5	6397 3	816	1949	3	1056 6	2593 2	0	10387 2	659

7.3 Livestock Census: North West Province

SV Area & Regions		Cattle	Sheep	Goats	Horses	Donkeys	Mules	Pigs	Dogs	Ostriches	Fowls	Cats
NGAKA MODIRI MOLEMA												
Mahikeng	483	3498 1	7350	6945	66	846	0	287	37	0	0	0
Ratlou	481	9600	1925	58	0	0	0	1053	438	0	0	0
Ditsobotla	484	0	0	0	0	0	0	0	0	0	0	0
Tswaing	482	1270 4	8194	4558	539	1675	0	667	4993	0	0	0
Ramotshere	485	0	0	0	0	0	0	0	0	0	0	0
		5728 5	17469	1156 1	605	2521	0	2007	5468	0	0	0
TOTAL												
BOJANALA												
Madibeng	472	16090	1208	1047	0	0	0	903	4196	0	701 36	7
Moses Kotane	475	32644	2578	5472	0	0	0	821	6655	0	328 31	0

Moretele	471	59966	902	4746	0	0	0	285	768	0	14953	1
Kgetleng River	474	110454	37525	1316	37	0	0	121	1833	0	90000	58
Rustenburg	473	25482	2894	3972	235	342	0	3864	1691	0	11951	4
TOTAL		244636	45107	16553	272	342	0	5994	15143	0	219871	70
DR KENNETH KAUNDA												
Klerksdorp	403	97083	14603	3847	146	30	0	8898	3299	0	572385	0
Maquassi Hills	404	39505	9932	5510	77	26	0	26820	3792	4	72589	0
Potchefstroom	402	47339	74694	3039	693	123	0	18279	3656	173	575127	0
Ventersdorp	401	84700	17978	3682	134	130	0	53840	4070	146	349170	0
TOTAL		268625	117207	16078	1050	309	0	107837	14817	323	1569271	0
DR RUTH SEGOMOTSI MOMPATI												
Molopo	495	5913	916	724	127	53	15	0	69	0	143	0
Kagisano	491	18537	6313	10645	1	0	0	22	550	0	292	0
Naledi	492	5598	1414	219	73	5	0	28	414	0	614	0
Taung	494	3100	1239	1500	84	501	0	112	437	415	52	0
Lekwa-Teemane	496	29089	5957	953	92	12	0	39921	233	143	460	0
Mamusa	493	46129	26057	872	34	64	0	950	3378	0	140	0
TOTAL		108366	41896	14913	411	635	15	41033	5081	558	1701	0
GRAND TOTAL		678912	221679	59105	2338	3807	15	156871	40509	881	1790843	70

7.4 The following number of animals was inspected during the reporting period In Bojanala District:

SV Area & Regions	Cattle	Sheep	Goats	Pigs	Donkeys	Horses	Poultry	Dogs	Buffalo	Game	Cats
Madibeng	16090	1208	1047	903	0	0	136	4196	94	0	7
Moses Kotane	32644	2578	5472	821	0	0	32831	6655	0	64	0
Moretele	59966	902	4746	285	8	0	14953	768	0	0	1

Kgetleng River	11045 4	3752 5	1316	121	0	37	0	1833	206	40	58
Rustenburg	25482	2894	3972	3864	342	235	11951	1691	5	606	4
TOTAL	24463 6	3758 5	16553	5994	350	272	59871	1514 3	305	710	70

Game Animals

Table 18: Final population estimates for Pilanesberg National Park for 2014

Species	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Buffalo	157	166	176	137	132	130	105	126	151	166	173	215	219	202
White rhino	208	229	230	263	283	256	266	280	261	291	260	263	293	279
Hippopotamus	39	37	47	47	51	40	39	40	41	38	44	55	56	55
Zebra	1083	1264	1022	1002	1143	1223	1049	1602	1376	1706	1570	1697	1704	1708
Sable	34	29	30	9	12		9	4			5	4	5	4
Ostrich	8	7	3	1	2	5		1					4	2
Waterbuck	192	139	164	105	89	106	95	122	102	144	125	182	172	174
Gemsbuck	58	73	34	39	15	14	5	4	4	2	4	3	1	1
Hartebeest	86	76	52	51	58	46	46	77	57	50	66	59	58	50
C/ reedbuck								4				3	9	1
Wildebeest	594	512	583	433	469	615	565	1476	1649	1720	1914	1891	1773	1496
Tsessebe	49	62	38	54	25	44	41	58	42	68	61	70	68	61
Warthog	264		142	148	125	199	184	185	172	189	237	305	324	339
Impala	1380	1356	949	1361	810	1420	1067	2488	2184	2237	2665	2622	3126	3099
Springbuck	72	41	46	37	53	57	40	71	79	58	100	97	129	128
Elephant	111	162	170	124	133	141	120	142	146	208	183	199	211	208
Eland	374	229	153	143	121	140	80	97	94	83	66	47	41	34
M/reedbuck	150		45	41		72	28	84	48	89	86	89	84	102
Black Rhino	52	52	63		67	59	49	53	63	64	66	58	56	58
Giraffe	127	122	114	102	51	119	100	144	110	125	140	149	170	156
Kudu	318	239	247	205	197	185	227	409	311	516	454	512	564	606
Klipspringer	46		29	19	43	35	20	66	19	22	29	19	43	41

Table 19: The final population estimates for game in Molopo Nature Reserve for 2014

Species	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Duiker										54	26	31	32	31	67	87
Eland	299	362	308	505	623	558	579	439	480	601	668	590	789	838	587	381
Bat-eared fox														5	5	10
Gemsbok	550	650	800	1050	1251	1228	1148	593	799	1689	1516	1543	1650	1563	1377	915
Giraffe		14	10	9	22	21	18	19	21	27	29	33	25	25	21	21
Brown hyena														1	1	0
Impala		184	81	130	76	75	55	73	58	29	29	44	54	56	31	73
Jackal										20	9	18	17	26	24	39
Kudu	72	94	95	141	140	130	115	129	127	147	174	178	247	226	229	285
Ostrich					83	48	46			34	64	55	69	61	77	60
Red hartebeest	412	516	478	578	607	631	638	266	256	345	401	459	551	621	343	161
Springbok	44	34	74	75	61	58	87	315	223	129	125	122	128	147	93	265
Steenbok										230	83	130	91	99	140	225
Warthog										114	156	159	151	114	73	102
Waterbuck	16	13	17	26	43	42	40	36	34	24	21	38	53	38	51	50
Blue wildebeest	280	365	407	345	536	572	579	495	650	647	483	535	835	1137	1129	587
Zebra	125	209	134	334	376	396	273	182	188	114	114	213	263	278	275	163

Table 20: Results of the aerial surveys for Mafikeng Game Reserve

Species	Total 1	Total 2	Average	Standard Deviation	Coefficient of variation
Blesbok	275	200	238	53	22%
Buffalo	61	60	61	1	1%
Duiker	2	1	2	1	47%
Eland	40	43	42	2	5%
Gemsbok	38	36	37	1	4%
Giraffe	19	17	18	1	8%
Impala	219	211	215	6	3%
Jackal	3	1	2	1	71%
Kudu	55	60	58	4	6%
Ostrich	43	45	44	1	3%
Red hartebeest	113	120	117	5	4%
Common reedbuck	2	1	2	1	47%

Mountain reedbuck	0	4	2	3	141%
White rhino	50	46	48	3	6%
Springbok	171	104	138	47	34%
Steenbok	3	3	3	0	0%
Warthog	184	64	124	85	68%
Waterbuck	68	62	65	4	7%
Black wildebeest	164	172	168	6	3%
Zebra	131	130	131	1	1%