

Encroachment and expansion of woody species in the savanna areas of Masutlhe and Lekung in the North West Province: A case study

By:

T.K.J. Sebitloane

Student number: 18029981

Previous qualification: B.Sc Hons (Biology)

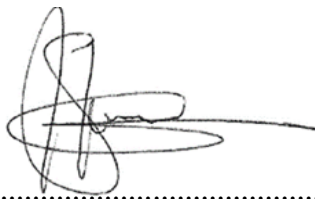
Thesis submitted in *partial* fulfillment of the requirements for the degree *Magister Scientiae* in the Faculty of Agriculture, Science and Technology at the Mafikeng Campus of the North-West University

Supervisor: Prof P.W. Malan

Co-supervisor: Prof C. Munyati

DECLARATION

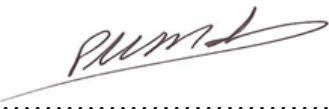
I, Tshegofatso Keritebetse Joyce Sebitloane (18029981), hereby declare that the dissertation titled: **The encroachment and expansion of woody species in savanna areas of Masuthe and Lekung in the North West Province: A case study** is my own work and that it has not previously been submitted for a degree qualification to another University.



Signature: Date: 2017-04-12

Tshegofatso K.J. Sebitloane

This thesis has been submitted with my approval as a university supervisor and I certify that the requirements for the applicable M.Sc. degree rules and regulations have been fulfilled.



Signed

Prof. P.W. Malan (Supervisor)

Date: 2017-04-12



Signed

Prof. C. Munyati (Co-Supervisor)

Date: 2017-04-12

DEDICATION

I dedicate this research to my Lord Jesus Christ, who protected, guided and strengthened me through this research and who made it possible for me to reach this level of my academia. May only His name be praised and glorified at all times.

ACKNOWLEDGEMENTS

- I owe lot of credit to my supervisor, Prof. P.W. Malan, for guiding, supporting and exposing me to the world of research.
- I would like to thank my co-supervisor, Prof. C. Munyati, for guidance, support and introducing me to Remote Sensing.
- I would also like to acknowledge the NRF (National Research Foundation) for funding this research.
- I would like to acknowledge the North West University (Mafikeng Campus) for funding part of this research.
- To my colleagues, Mr. Ndou and Sammy (Department of Geography and Environmental Sciences, Mafikeng Campus), for your assistance on GIS and remote sensing.
- To Professor T.A. Kabanda (Department of Geography and Environmental Sciences, Mafikeng Campus), for your assistance on climatic information and formulation of graphs.
- Dr. T.D. Kawadza for his assistance with the language editing of the manuscript.
- A great appreciation to my mentors Harmony and Precious Monageng.
- To my family for support and encouragement.

LIST OF FIGURES AND TABLES

FIGURES:

CHAPTER 3:	Page
Figure 3.1: Orientation of the North West Province (Department of Agriculture, Conservation, Environment and Tourism, 2002)	25
Figure 3.2: Geographical location of the study site	27
Figure 3.3: Average minimum temperature (°C) for the years 1990-2014	29
Figure 3.4: Maximum temperature for Mafikeng (1990-2014)	29
Figure 3.5: North West Province mean annual rainfall (Department of Agriculture, Conservation, Environment and Tourism, 2002)	31
Figure 3.6: Average rainfall of the North West Province (1990-2014) (South African Weather Service, Station)	32
Figure 3.7: North West Province Vegetation Types (Department of Agriculture, Conservation, Environment and Tourism, 2002)	33
Figure 3.8: Biomes in the North West Province (Department of Agriculture, Conservation, Environment and Tourism, 2002)	33
Figure 3.9: Soil Degradation extent per magisterial district (Department of Agriculture, Conservation, Environment and Tourism, 2002)	36
Figure 3.10: North West Province Geology (Department of Agriculture, Conservation, Environment and Tourism, 2002)	37
Figure 3.11: A clear representation of Bush encroachment and disturbance of human presence. Dense bushes visible in the background	37
Figure 3.12: A road and footpaths are clear evidence of land	38
Figure 3.13: Animal grazing in the area	38
Figure 3.14: Dense bushes are evidence of bush encroachment	39
Figure 3.15: Dense stands of <i>Vachellia tortilis</i>	40
Figure 3.16: Hard soil surface prevents grass growth.	41
CHAPTER 4:	
Figure 4.1: Procedure for determining quadrant size for a height class, e.g. 1 m tall plants (Coetzee and Gertenbach, 1977)	44
CHAPTER 5:	

Figure 5.1: Woody species densities in the Benchmark 1	52
Figure 5.2: Woody plant densities in Benchmark 1 according to height classes	53
Figure 5.3: Woody species densities in Benchmark 2	55
Figure 5.4: Woody plant densities in Benchmark 2 according to height classes	55
Figure 5.5: Woody species densities in study site 1 (Lekung village)	61
Figure 5.6: Woody plant densities in study site 1 (Lekung) according to height classes	62
Figure 5.7: Woody species densities in study site 2 (Masutlhe 1)	66
Figure 5.8: Woody plant densities of study site 2 (Masutlhe 2) according to height classes	67
Figure 5.9: Woody species densities in study site 3 (Masutlhe 2)	69
Figure 5.10: Woody plant densities in study site 3 (Masutlhe 2) according to height classes	69

CHAPTER 6:

Figure 6.1: Classified 21 August 2004 image	79
Figure 6.2: Classified 4 September 2006 image	80
Figure 6.3: Classified 14 July 2014 image	80
Figure 6.4: Overall trend in image classification class area in hectares	81
Figure 6.5: Overall trend in image classification class area in percentages	81

TABLES:

CHAPTER 4:

Table 4.1: List of materials	42
Table 4.2: List of images used	43
Table 4.3: Indication of the extent of bush encroachment TE ha ⁻¹ (Moore and Odendaal, 1987; National Department of Agriculture, 2002)	45

CHAPTER 6:

Table 6.1: Error matrix for the 21 August 2004 SPOT image classification	82
Table 6.2: Error matrix for the 4 September 2006	83
Table 6.3: Error matrix for the 14 July 2014 SPOT 5 image classification	83

LIST OF ACRONYMS

CNES: Centre National d'Etudes Spatiales

DACET: Department of Agriculture, Conservation, Environment and Tourism

GIS: Geographic Information System

GPS: Global Positioning System

IPCC: Intergovernmental Panel on Climate Change

NWP: North West Province

NWSEP: North West State of the Environment Report

SPOT: Systeme Pour L'Observation de la Terra

SAWS: South African Weather Service

TE ha⁻¹: Tree equivalents per hectare

UTM: Universal Transverse Mercator

ABSTRACT

Large areas of southern Africa are affected by woody plant encroachment. The increase in the tree-grass ratio in the savannas has been attributed to the replacement of indigenous herbivores by domestic grazing animals and the intense utilization of the natural vegetation by domestic livestock. The encroachment of woody species into savanna is a global phenomenon and often has an impact in the development of the herbaceous sward. It is especially in the communally managed, such as Masutlhe and Lekung and rural areas where woody plants often develop and expand at the expense herbaceous vegetation, mainly grasses. The encroachment of woody plant species was quantified at the selected sites and compared to nearby reference sites in Masutlhe and Lekung Villages. The prominent encroaching woody species included *Vachellia tortilis*, *Grewia flava* and *Ziziphus mucronata*. All selected sites, except the benchmark sites, had woody plant densities, exceeding 2 000 TE ha⁻¹ that will almost totally suppress grass growth. Remote Sensing techniques were used to analyse the overall trend of vegetation in the study area. High spatial resolution digital satellite images and appropriate image processing algorithms were used to facilitate monitoring of the woody encroachment. Mean Euclidean Distance Texture analysis in 3×3 moving windows enhanced woody cover. SPOT images of 2004, 2006 and 2014 were used to monitor change detection of vegetation. Land cover maps were established, comprising three classes woody vegetation, grass and bare area. Analysis of vegetation conditions trends revealed decline in grass cover with an increase in woody vegetation, especially in the villages of the study area.

TABLE OF CONTENTS

CHAPTER 1: Introduction	
1.1 Background	1
1.2 Problem statement	3
1.3 Aims and Objectives	5
1.3.1 Aim	5
1.3.2 Objectives	5
CHAPTER 2: Literature Review	6
2.1 Savannas in general	6
2.2 Tree-grass interactions	7
2.3 Grass quality in the savanna	9
2.4 Communal farming practices	9
2.5 Tenure (Ownership and Right of Access)	10
2.6 Causes of Bush Encroachment	14
2.7 The forces known to influence the rate and pattern of bush encroachment	19
2.8 Extent of woody plant encroachment in the Molopo Area	19
2.9 Remote sensing	20
2.9.1 Remote sensing application	20
2.9.2 Application of remote sensing in the assessment of bush encroachment	21
2.9.3 Remote sensing vegetation and image texture analysis	22
2.10 SPOT images	22
2.11 Remote sensing and image classification	23
2.11.1 Supervised classification	23
2.11.2 Unsupervised classification	24
CHAPTER 3: Study area and climate conditions	25
3.1 Location and description	25
3.2 Climate	27
3.2.1 Climate in the savanna	27
3.2.2 Climate of the North West Province and Mafikeng	28
3.3 Rainfall	30
3.3.1 Precipitation	31

3.4 Vegetation	32
3.5 Vegetation	34
3.5.1 Soils	34
3.5.2 Land types	35
3.5.3 Geology	35
CHAPTER 4: Methodology	42
4.1 Materials and methods	42
4.1.1 Remote sensing data	43
4.1.2 Field data and image pre-processing	43
4.1.3 Methods to quantify woody species	44
4.2 Data analysis	45
4.2.1 Ground truthing	45
4.3 Remote sensing methods	46
4.3.1 Selection of satellite images	46
4.3.2 Image processing	46
4.3.3 Pre-processing	46
4.3.4 Geometric rectification	46
4.4 Image processing	47
CHAPTER 5: Woody plant encroachment in the study area	49
5.1 Encroachment and expansion of woody plants in Masutlhe and Lekung	49
5.1.1 Bush encroachment in the benchmark sites of Masutlhe and Lekung	49
5.1.2 Bush encroachment in Benchmark 1	50
5.1.3 Bush encroachment in Benchmark 2	53
5.2 Bush encroachment in Lekung and Masutlhe villages	56
5.2.1 Bush encroachment in Lekung village (study site 1)	57
5.2.2 Bush encroachment in Masutlhe 1 (study site 2)	62
5.2.3 Bush encroachment in Masutlhe 2 (study site 3)	67
5.3 Conclusion	72
CHAPTER 6: Remote sensing	78
6.1 Results and discussion	78
6.1.1 Accuracy assessment	81
6.2 Discussion and conclusion	83

CHAPTER 7: General discussion and conclusion	85
7.1 General Discussion	86
7.2 Conclusion	87
7.3 Recommendations	88
REFERENCES	89

CHAPTER 1

INTRODUCTION

1.1 Background

The encroachment of woody species into grasslands (bush encroachment) is a global phenomenon (Schlesinger *et al.*, 1990; Van Auken, 2000; Roques *et al.*, 2001; Simonson and Johnson, 2005), having first been recorded in the 1930's and 1970's in the savanna area of the Northern Province and KwaZulu Natal and in the 1940's in the arid savanna of the Kalahari. Bush encroachment is caused by the increase in cover of usually indigenous trees and shrubs, usually, in response to poor management practices (Hoffman and Ashwell, 2001).

In southern Africa, the phenomenon of increasing woody plant density is commonly referred to as 'bush encroachment' and it involves the invasion of grasslands and the thickening of savanna (O'Connor and Crow, 1999). The grazing capacity of large areas of the South African savanna is reported to have declined as a result of being encroached by bush, often to such an extent that many previously economically viable livestock properties are now no longer viable. Removal of some or all of the woody plants will normally results in an increase of grass production and thus in grazing capacity. However, the results of woody plant removal may differ between veld types, with the outcome determined by both negative and positive responses to tree removal (Teague and Smit, 1992). Although by definition, all savannas consist of a grass and a woody component, functionally each situation is unique. Not only are there differences in physical determinants, but the biological interactions that are based on these determinants and individual species properties are unique to each spatial and temporal situation. In addition, past management practices added to the complexity, by bringing about the different kinds and degrees of modification (Teague and Smit, 1992).

The phenomenon of encroachment of woody species into grasslands, results in the shift from open grass dominated rangelands to thickets of woody plant dominated rangelands, particularly in savanna (Joubert *et al.*, 2008; Joubert *et al.*, 2013). According to Wiegand *et al.* (2006), encroachment by woody species into grassland-dominated areas is common in savannas and reduces grazing capacity. Moreover, some savanna landscapes have

already been completely encroached by woody species (Wiegand *et al.*, 2006). The process is on-going in other savanna areas affecting wildlife, and the sustainability of pastoral, subsistence and commercial livestock grazing (Archer *et al.*, 2000). Thus, encroachment has long been of concern to land managers in grasslands and savannas, but most research focused on the effects of woody plants on grass production (Archer *et al.*, 2001), instead of the underlying ecological mechanisms driving encroachment.

Bush encroachment is the suppression of palatable grasses and herbs by encroaching woody species, often unpalatable to domestic livestock (Ward, 2005). According to Archer *et al.* (2000), the reduction in carrying capacity is of great significance because savannas in southern and central Africa contain a large and rapidly growing proportion and this includes the world's human population, including many pastoralists whose livelihood is threatened by this process. Encroachment of woody plants has been among the major threats of the livelihoods of pastoralists and their ecosystem (Gemedo *et al.*, 2006).

Bush encroachment is a dynamic process that can be rapid and, after the species has encroached over the landscape with a high abundance, it can be impossible to manage the invasion (Rejmanek and Pitcairn, 2002; Pluess *et al.*, 2012). Removal of woody plants will normally result in an increase in grass production and thus in grazing capacity (Teague and Smit, 1992). However, the results of woody plant removal may differ between veld types (Teague and Smit, 1992). The outcome of woody plant removal is determined by both negative and positive responses to tree removal (Teague and Smit, 1992). This is because, in the savanna vegetation, the physical determinants, biological interactions and individual species properties are unique to each situation (Teague and Smit, 1992). In addition, past management practices have added to the complexity by bringing about the different kinds and degrees of modification (Teague and Smit, 1992).

Human activities have disturbed savanna ecosystems for a long time, as savannas are a resource for food and livestock breeding (Bellefontaine *et al.*, 2000). Particularly in recent times, man has destroyed vast tracks of natural vegetation to create more arable land, often maintained in a highly unstable condition. In most situations, the determinants of savanna systems have been modified by man, either directly or indirectly. According

to Teague and Smit (1992), the determinants may either be primary or secondary. Primary determinants are such as climate and soil, or secondary, such as fire and the impact of herbivores (Teague and Smit, 1992). According to Britton and Sneva (1981), examples of these determinants are exclusion of fires, replacement of most of the indigenous browsers, the restriction of movement of herbivores by erection of fences and provision of artificial watering points. Many communal areas in South Africa were subjected to 'Betterment', which was implemented in the 1950's (Von Maltitz, 1998). These communal areas were divided into three main resource areas:

- (a) homestead,
- (b) fields, and
- (c) rangeland (Von Maltitz, 1998).

In rural areas, communal tenure leads to overstocking and resource over-exploitation resulting in 'tragedy of the commons' (Hardin, 1968). The study was conducted in communal areas of Masutlhe and Lekung in the North West Province of South Africa.

1.2 Problem statement

Most researchers are of the opinion that bush encroachment is regarded as a serious threat to livestock production in southern Africa (Archer, 1990; Hudak, 1999; Shackleton and Gambiza, 2008). The selected sites of this study have been invaded by woody species, showing clear signs of being highly degraded through exploitation. Cattle grazing are the predominant land-use in the region. Dense bush, especially *Vachellia tortilis* and its consequent expansion, showed clear signs of interspecies competition, resulting in the rapid spread of woody species throughout the selected sites. The woody species are of little use to cattle, which are grazers, although browsing goats and sheep will utilize twigs and shoots. Grazing capacity is believed to decrease because the pioneer grasses are less notorious and less palatable than those requiring more optimum conditions (Jacobs, 2000).

Many land-use practices such as field cultivation, garden cultivation, grazing, livestock production and tree cutting in rural areas are still driven by inappropriate policy frameworks which emphasises the urgent need for local-level institutions assisting land users in sustainable land management (Von Maltitz, 2009). According to Squires *et al.*

(1992), most rangeland development projects have failed because they focused on addressing the technological aspects, without addressing socio-economic aspects.

The encroachment and expansion of woody species into grasslands results in a decrease in grass production and thus decreases the grazing capacity of the veld. This leads to a loss of soil structure, causing surface sealing, accelerated runoff, erosion and low germination of grasses (Hoffman and Ashwell, 2001). Moleele and Perkins (1998) suggested that bush encroachment takes place as a result of the exclusive use of moisture by encroachers, high soil nutrient concentrations, low fire intensity and high soil selectivity.

Over the past few decades, increasing dominance by woody encroachers and a corresponding decline in herbaceous production has been widely reported in the savannas (Ward, 2005; Scheiter and Higgins, 2009). Increases in woody plant abundance are normally accompanied by decreases in herbaceous production and undesirable shifts in composition (Archer, 1990). In southern Africa, the shift is associated with anthropogenic activities, especially high cattle densities in communal grazing areas (Van Vegten, 1981, Skarpe 1986, Ringrose *et al.*, 1996).

The absence of fires and browsers can also increase the level of competition between woody plants by impacting biomass accumulation, survival and growth (Goncalves and Batalha, 2011). As a management tool, fire can be used to control bush encroachment and in the arid savanna, fire has the role of maintaining trees and shrubs at an adequate height and in an acceptable state for browsing animals (Trollope, 1980). Previous research, on long-term fire effects, revealed that regular burning reduced tree size regardless of the frequency of burning, but failed to eliminate woody plants or drastically alter tree diversity at the experimental site (Furley *et al.*, 2008). Frequency of burning is an important management strategy to consider when managing woody plants (Rutherford, 1991). Fire acts predominantly by controlling the biomass of trees within the flame zone (those trees smaller than approximately 2 m), rather than as a cause of mortality. Fire browsing together acts as a powerful restriction on recruitment of trees to the mature, grass-dominating size classes (Rutherford, 1991).

Many studies have been performed on the above-ground competition for light, where woody species have a clear advantage, but the most intense competition takes place below- ground, where the balance between woody and herbaceous vegetation is most likely determined (Stevens and Fox, 1991). Trees have historically been viewed as superior competitors to grasses, especially in temperate zones and are widely regarded as having an impact on herbaceous production, particularly where livestock production is a primary land use (Scholes and Archer, 1997). Although grasses are better at extracting water in the upper soil layer, trees are able to persist because they have exclusive access to water in the deeper soil layers (O'Connor *et al.*, 2014).

1.3 Aim and Objectives

1.3.1 Aim

The aim of the study was to monitor and quantify the extent of invasive woody species and the rate of expansion in the selected study sites Masutlhe and Lekung villages.

1.3.2 Objectives

- * To use satellite images to detect change of woody plant succession over time
- * To quantify invasive tree densities in selected sites
- * To evaluate the rate of expansion of woody species in selected sites as compared to a selected reference site

CHAPTER 2

LITERATURE REVIEW

2.1 Savannas in general

The term “savanna” once restricted to describe central South America grasslands in Spanish is now widely accepted (Edwards, 1983; Rutherford and Westfall, 1994). The Savanna Biome of southern Africa spreads from north of 22°S latitude into northern Namibia, Botswana, Mozambique and South Africa. Savannas are one of the world’s major biomes and are the dominant vegetation of Africa (Scholes and Walker, 1993). Savannas occupy 54% of southern Africa and 60% of sub-Saharan Africa (Scholes and Walker, 1993). The vegetation of South Africa and Swaziland constitutes the southernmost extension of the most widespread biome in Africa (Mucina and Rutherford, 2006). It represents 32.8% of South Africa (399 600 km²) and 72.2% of Swaziland (12 900 km²) (Mucina and Rutherford, 2006).

Savannas are part of a continuum that includes arid shrub lands, light wooded grasslands, deciduous woodlands and dry forests (Justice *et al.*, 1994). The Savanna Biome occupies most of the far northern part of the Northern Cape, the western and north-eastern parts of the North-West Province, extreme western parts of the Free State Province, northern Gauteng with the more isolated occurrences in the south of this province, almost the entire Limpopo Province, north western and north-eastern Mpumalanga, most of central and eastern Swaziland, low-altitude parts of the eastern seaboard, inland of the Indian Ocean Coastal Belt in Kwazulu-Natal and the Eastern Cape Provinces and with the southernmost extension Albany Thicket of the Komga to Albany District (Mucina and Rutherford, 2006). Their importance lies in the large contribution that they make to informal and subsistence economics through the supply of grazing, firewood, timber and other resources; their contribution to the formal economy as the main location for livestock and ecotourism industries and their global impact through the emissions of trace gases from fires, soils, vegetation and animals (Justice *et al.*, 1994).

The North West Province (NWP) consists predominantly of open savanna with grazing lands evident, especially in the more arid areas where there is inadequate water for either rain fed or irrigated cultivation of crops (Hoffman and Ashwell, 2001). Woody plants invade natural grazing land on a continuous basis and pose a real threat towards productivity (Hoffman and

Ashwell, 2001). This implies that woody plant encroachment can be considered as an unwanted successional process. As a result, the encroachment of woody species into semi-natural grasslands has caused much concern (Partel and Helm, 2007).

Savannas are characterized by the presence of scattered trees, mostly *Vachellia erioloba* (Camel thorn) and *Vachellia tortilis* (Umbrella thorn). The shrub layer is dominated by *Senegalia mellifera* (Black thorn), *Grewia flava* (Velvet raisin) and *Tarchonanthus camphoratus* (Wild camphor bush) (Smit, 1999). The herbaceous sward mainly consists of tufted perennial grasses. The most common grass is *Eragrostis lehmanniana* (Lehmann's love grass). The following grass species have a more patchy distribution: *Stipagrostis uniplumis* (Silky bushman grass), *Heteropogon contortus* (spear grass), *Aristida diffusa* (iron grass), *Aristida congesta* (Tassel-three-awn grass), *Eragrostis obtusa* (dew grass), *Eragrostis superba* (Saw-toothed love grass) and *Enneapogon scoparius* (Bottle brush grass) (Gibbs–Russell *et al.*, 1991; Van Oudtshoorn, 1999).

Savannas represent water-limited ecosystems. The broad-scale distributions of the main structural savanna types in southern African are highly predictable from a knowledge of the water and nutrient availability in the environment (Carter, 1994). Bush encroachment is considered a major contributor towards the occurrence and even total absence of herbaceous plants in severe cases and this is due to the ability of some plants to survive in a water-limited environment (Smit *et al.*, 1999). It has been widely assumed that the main competition in savannas is for water. Furthermore, rains in these areas are frequently only enough to wet the soil surface. After the dominance of grasses has been broken the water is more available to shrubs and trees than before. In such a situation, woody species with shallow lateral roots have an added advantage compared to those with root systems more restricted to deep soil layers (Scholes and Archer, 1997).

2.2 Tree-grass interactions

Higgins *et al.* (2000), hypothesised that grass and tree coexistence is driven by the limited opportunities for tree seedlings to escape drought and the flame zone (those trees less than approximately 2 m) (Rutherford, 1981). Bush encroachment occurs due to increased tree recruitment caused by reductions in grass cover and fire intensity (Higgins *et al.*, 2000). The classical conceptual model on tree-grass interaction in savannas is based on rooting-depth

separation with respect to competition for water (Walker, 1971). This hypothesis proposes that trees have roots in both the surface and deeper soil layers, while grass roots are only in the surface layer. Van Wilgen (2009), argued that the co-existence of tree-grass interaction can traditionally be explained by either equilibrium or disequilibrium models. Equilibrium models propose that tree-grass coexistence is possible, because of separation of the root niche, with trees having sole access to water in deeper soil horizons and grasses having preferential access to, and being superior competitors for water in the surface soil horizons. However, disequilibrium models propose that there is no stable equilibrium, and that frequent disturbances through the existence of competition of either grasses or trees by periodically bringing about conditions in favour of either alternative competitors (Van Wilgen, 2009).

Stuart-Hill *et al.* (1987), argued that the results of the negative and positive interactions on grass production is dependent on tree density. Established trees create sub-habitats which differ from the open habitat and which extend different influences on the herbaceous layer (Kennard and Walker, 1973; Tiedemann and Klemmenson, 1973; Kellman, 1979; Grossman *et al.*, 1980; Stuart-Hill *et al.*, 1987; Belsky *et al.*, 1989; Smit and Swart, 1994; Smit 2004 and Smit and Rethman, 1998; 2000).

Many savanna woody plants have extensive shallow root systems but not necessarily to the exclusion of some deeper running roots. The shallow root system enables them to make use of relatively light showers when water does not penetrate far into the soil. The most often developed lateral root system, can sometimes extend 7 to 12.5 times that of the canopy radius and it includes species such as *Terminalia sericea*, *Burkea africana* and *Colophospermum mopane* (Rutherford, 1980; 1983). Savanna evergreen trees tend to have deep root systems, at least in dry savannas (Skarpe, 1996). Schulze *et al.* (1998), found downward transport of water in roots (inverse hydraulic lift) with water flow into deeper soil layers. The inverse hydraulic lift serves as an important mechanism to facilitate root growth through the dry soil layers underlying the upper profile where precipitation penetrates (Schulze *et al.*, 1998). The empirical observations of root distributions (Scholes, 1988; Scholes and Walker, 1993) show that the rooting depth separation between trees and grass is real but slight. The grass-root density exceeds tree-root density to a depth of nearly 1 m. Trees and grasses both have most

of their roots in the top 40 cm of the soil, which is not surprising, since in dry climates water seldom penetrates below this depth in significant quantities (Scholes and Walker, 1993).

Competition experiments for water, resources, soil and moisture have shown that mature trees are competitively superior to grasses while grasses tend to out-compete immature trees (Moore *et al.*, 1988). Furthermore, trees have both competitive and facilitative effects on grasses in their vicinity (Stuart-Hill, 1985; Barnard, 1987; Belsky *et al.*, 1989 and Tainton, 1999). The water-use niche of grasses, both in depth and time, is completely included by the tree niche (Knoop and Walker, 1985). The water-use efficiency of grasses is not substantially or consistently higher than that of trees; hence mature trees should always out-compete grass (Knoop and Walker, 1985). This asymmetry of competitive water use creates instability in the interactions between trees and grasses. Grazing effectively weakens the suppressive effect of the grass layer on young trees in a patch of a few hectares, leading to the conversion of an open savanna patch in a tree-dominated thicket (bush encroachment). With time, tree growth and inter-tree competition will convert the bush-encroached patch to an open savanna (Scholes and Archer, 1997).

2.3 Grass quality in the savanna

A number of factors can affect grass quality and consequently, animal production in semi-arid savannas. Water availability (Milchunas *et al.*, 1995) grazing, fire (Trollope, 1982) and soil quality (Snyman 1998, 2002) have been identified as the major factors affecting nutritional quality of grasses in semi-arid savannas. “Moderate” leaf removal by grazing animals have positive direct effects by improving photosynthetic rates, increasing availability of nutrients, reducing water stress for un-grazed plants and increasing nitrogen concentrations in some plants (Wolfson and Tainton, 1999).

2.4 Communal farming practices

Bush encroachment affects the agricultural productivity and biodiversity of 10-20 million ha of South Africa (Ward, 2005). Communal rangelands, constituting approximately 12% of the country, include the previous homelands such as Bophuthatswana (De Bruyn and Scogings, 1998), where the study sites of this research were located. Communal rangeland areas, where agriculture is largely subsistence-based, are communally-owned and managed (De Bruyn and Scogings, 1998). These areas are degraded, non-sustainable and non-

productive. Though degraded, these communal areas support a quarter of South Africa's human population and half of the livestock population (De Bruyn and Scogings, 1998). If all these plants were condensed into a single area, they would cover the equivalent of 1.7 million hectares which is more than the total area under commercial forestry and about the size of the Gauteng Province. Biological invasion is a major threat to biodiversity and economic livelihoods in South Africa. Invasive plants cost South Africa an estimated R 6.5 billion every year (Wilson *et al.*, 2013). According to Wilson *et al.*, (2013), if left unmanaged, the overall impacts on ecosystem services are likely to rise by an order of magnitude.

2.5 Tenure (Ownership and Right of Access)

In many areas of the world, one of the key causes of poor land management is uncertain tenure (Bainbridge, 2007). According to Bainbridge (2007), tenure includes land use rights, land use control and other forms of access to resources. Tenure agreements may be based on ownership, agreement and custom, lease, rent or squatting. It may be limited to only the right to browse branches from individual trees in some areas (Bainbridge, 2007).

Ranching and farming without secure tenure are common in much of the world (Bainbridge, 2007). Bainbridge (2007) concluded that a rancher, farmer or herder will not invest in careful stewardship or environmental repair without secure tenure and the belief of long-term benefits which occur from current actions. According to Hoffman and Ashwell (2001), communal land tenure, refers broadly to the system affecting the approximately 13% of land that was set aside for the homelands and self-governing territories by the colonial and apartheid government. Individuals under a communal land tenure system have few rights to own or sell land (Hoffman and Ashwell, 2001). Many communal areas have been classified as degraded on the basis of the structural differences in the vegetation when compared to commercial rangelands (De Bruyn and Scogings, 1999). Free access to communal resources is a recipe for environmental disaster as communal land tenure leads to overstocking and resource over-exploitation resulting in the "tragedy of the commons" (Hardin, 1968). Here 'tragedy of the commons' 'is an economic theory of a situation within a shared-resource system where individual users acting independently according to their own self-interest

behave contrary to the common good of all users by depleting that resource through their collective action.

According to Hoffman and Ashwell (2001), there are two distinct forms of land tenure that operate in South Africa, namely freehold and communal land tenure. Freehold tenure (commercial land tenure) essentially provides for individual or corporate ownership of a surveyed area that may be sold (Hoffman and Ashwell, 2001). Communal land tenure refers broadly to the system affecting approximately 13% of land that was set aside for the homelands and self-governing territories by colonial and apartheid governments (Hoffman and Ashwell, 2001). Political and economic conditions, demographic patterns and land use practices differ markedly in communal and commercial areas. According to Hoffman and Ashwell (2001) under communal land tenure, individuals have few rights to own or sell land which is ultimately owned by the state. On average about twice as much land is used for settlements in communal areas than in commercial farming areas (Hoffman and Ashwell, 2001).

Communal land in South Africa is characterized by continuous grazing usually with higher stocking densities than with commercial, commodity-based ranching (Scholes, 2009). According to Vetter (2013), communal rangelands are judged to be degraded based on several indices including species composition and standing biomass that compare neighbouring communal and commercial properties. According Scogings *et al.* (1999), communal rangelands are concentrated in the former homeland areas, which constitute about 13% of the land surface area but are home to 25% of the human population and hold about half of all livestock. Many communal areas in South Africa were subjected to the Betterment system, which was implemented in the 1950's. There are three categories of communal rangeland in South Africa (Scogings *et al.*, 1999)

- Designated rangeland in communal areas that were established as native reserves during or before the 1913 Land Act
- Rangelands that were recently commercial (freehold) farms that were transferred as part of homeland consolidation or more recent (post-1994) land redistribution
- Arable lands that are either abandoned or are still in use and become a common grazing resource after harvest, with crop residues providing grazing during dry season.

Scholes (2009) concluded that, in many communal lands, as compared to the commercial lands, there is a strong incentive for the individual to destock and stock animals kept as assets rather than production units. Moreover, degradation in southern Africa in communal areas can be attributed in part to the inability of land users to respond to environmental clues that warn of impending changes on the land (Beinart, 2000).

The population in communal areas comprises a significant part of the communal rangeland ecosystem, making it imperative to understand how their activities influence and effect ecosystem functioning (Oba and Kaitira, 2006). Moyo *et al.* (2008) observed that the grazing management strategies currently employed in communal areas are principally controlled and dictated by interactions between social, ecological and institutional factors. Thus, the poorer the resource base, the greater the dependence on rangelands and the greater the mobility that lead to increased population pressure and political changes that contribute to the breakdown of this type of pastoral production (Bainbridge, 2007).

When the overall vegetation was assessed, the rangeland was not in good condition because of the heavy bush encroachment, the communal rangeland was generally in a poor condition. Thus, communal areas have more woody species than commercial areas (Terefa *et al.*, 2007). Communal rangelands in South Africa are generally viewed as being degraded, non-sustainable and non-productive while commercial farms are perceived to be non-degraded, sustainable and productive (the very opposite to commercial farms) (Tainton, 1999; Hoffman and Ashwell, 2001). Higgins *et al.* (1999) concluded that communal grazing management significantly changed the composition and structure of woody plant communities.

The savanna is used largely for livestock grazing (Bagachi and Ritchie, 2010) and prolonged overgrazing is associated with land degradation (Cheng *et al.*, 2004). In open savanna, grass biomass always exceeds tree biomass but when heavy grazing occurs, grass biomass per unit rainfall is reduced, reducing competition with trees. According to Masike and Urich (2008), livestock in Botswana is an important economic activity, practiced in communal areas and rangelands. The uncertainty of land tenure (Hoffman and Ashwell, 2001), plays a critical role in woody plant encroachment in study sites. According to Bainbridge (2007),

colonialism and corporate piracy often have disrupted stable, long-term tenure relationships in drylands and rights may still be uncertain or limited decades after colonial powers leave.

Overgrazing is associated with communal grazing because there is no clear land tenure or property rights agreement that make it conducive for the farmers to invest in conservation of shared rangeland (Thomas, 2008). This then, releases water and nutrient resources for trees to germinate. Dembele *et al.* (2006), reported that the radial gradients of plant densities, and hence cover, are related to the regeneration gradient influenced by browsing pressure and or trampling on seedlings and saplings and its dire consequence on young and mature trees.

Exploiting natural resources without thought of the future depletes what is left for short term gain without any chance of rehabilitation (Reed, 2008). Thus, past failures of development initiatives to solve the problem of environmental degradation have been attributed to the lack of consultation and involvement of the rural populations (Tainton, 1999). The degradation of land seems to be most closely related to whether a district was managed commercially or communally (Hoffman and Ashwell, 2001). In communal areas, land tenure is a complex variable, comprising several more direct influences on degradation, such as history, demography, socioeconomic conditions and land-use factors. In South Africa, communal tenure is synonymous with high population density, poverty, poor infrastructure and a strong reliance on natural resources for survival (Hoffman and Ashwell, 2001).

Communal lands have much broader livelihood strategies, of which livestock production may only be a small part (Dikeni *et al.*, 1996). Livestock are kept for multiple reasons including draft animal power, security, milk and meat. Communal land managers aim to maximise animal numbers per area and focus on the maintenance and survival of those animals (Dikeni *et al.*, 1996). Management of the communal systems tends to be at low cost. Communal farmers see degradation as a long-term decline in livestock survival rates that are perceived to be independent of rainfall or drought (Dikeni *et al.*, 1996). The economic effects of such degradation in communal areas are often very slow in expressing themselves (Dikeni *et al.*, 1996). Communal rangeland management is a challenging process, the diversity of stakeholders and their socio-economic conditions make it difficult to apply to

communal rangelands (Tainton, 1999). Degradation in South African communal rangelands can be attributed in part to the inability of land users to respond decisively to environmental clues which warn of impending state changes (Vetter, 2007). As population sizes near carrying capacity, increased dependence in the population growth rates decrease with increasing population size because of the effects of competition on reproductive and mortality rates. Moreover, rangelands are judged to be degraded based on several indices (species composition and standing biomass) which compare neighbouring communal and commercial properties (Vetter, 2007).

2.6 Causes of bush encroachment

Changes in woody cover have been attributed to land-use practices. The links between causes and effects of bush encroachment are still widely debated (Archer, 2005; Britz and Ward, 2007). Homewood and Rogers (1991), argued that it is difficult to generalize about causes of change in range condition because of site specific interactions among ecological features and human use.

Most often, woody plant increases have been ascribed to poor land-use practices. The general increase in savanna trees in South Africa in more recent times has been assisted by increasing CO₂ concentrations (Bond *et al.*, 2003). The causes of bush encroachment are not simple in that bush encroachment, can occur on both heavily grazed areas as well as in areas where grazing is infrequent and light (Bond *et al.*, 2003). To efficiently manage on-going woody plant invasion, it is necessary to monitor the species spread regularly and there is an urgent need for new techniques enabling timely, fast and precise monitoring (Hulme *et al.*, 2009). Early and fast detection is needed to make the management cost-effective (Vila and Ibanez, 2011). It is essential to better understand the demography of thickening species by investigating aspects of their phenology and how climate, competition, fire and browsing affect large mammalian herbivores indirectly and determine changes in the structure as well as the dynamics of vegetation communities across terrestrial ecosystems (Belsky, 1994; Jachmann and Croes, 1991; Augustine and McNaughton, 1998; Harmer, 2001).

In many areas of the world, one of the key causes of poor land management is uncertain tenure (Bainbridge, 1996). Changes to the structure of an ecosystem affect both its ecological and social values and recently, tree and shrub encroachment has presented

numerous challenges for land managers (Noble, 1997; Bovey, 2001). Tenure includes land-use rights, land-use control, and other forms of access to resources (Bruce and Fortmann, 1989). A rancher, farmer or herder will not invest in careful stewardship or environmental repair without secure tenure and the belief that long-term benefits will result from current actions. These land managers usually have large areas under their control that they fail to enforce even weak environmental protections and have little funding to support management initiatives such as fencing, well building and water projects that would better protect resources (Chambers *et al.*, 1997).

Archer *et al.* (1995) and Van Auken (2009) argued that the primary causes of bush encroachment are not apparent, either globally, or in southern Africa (Hoffman *et al.*, 1999; Ward, 2005; 2010; Buitenwerf *et al.*, 2012). The establishment of herbaceous plants can be considered as secondary succession, which is defined as succession that occurs after the destruction of part or all of the original vegetation in a site (Gabriel and Talbot, 1984). Gabriel and Talbot (1984) defined plant succession as a progressive development, finally terminating in a climax community. Climax vegetation is thus, a final stable plant community in an ecological succession which is able to reproduce itself indirectly under existing environmental conditions (Gabriel and Talbot, 1984).

Subsistence in the rural dryland areas worldwide depends on the effective and sustainable utilization of natural resources, which are increasingly threatened by land degradation (Hoffman and Ashwell, 2001). The African continent is spatially the most impacted with more than 70% of its agricultural drylands being already deserted (Hoffman and Ashwell, 2001).

Reed (2008) postulated that Bush encroachment may be caused by the changes in land-use practices rather than climate. The most important factor influencing bush encroachment was thought to be the replacement of individual browsing animals with grazers such as cattle and sheep (Hoffman and Ashwell, 2001). Overgrazing, fire frequency, soil moisture, nutrients and global warming, have also been associated with bush encroachment (Van Auken, 2009). Climate change and change in historical atmospheric carbon dioxide concentrations, ([CO₂]), fire regimes, rodent populations and livestock grazing have been registered as

driving forces in this shift in vegetation (Archer *et al.*, 1995; Brown *et al.*, 1997; Weltzin *et al.*, 1997).

Growing populations and diminishing resources still add to the environmental stress. Factors such overgrazing, mismanagement and overexploitation of resources and ignorance are what lead reduced biodiversity and invasion and expansion of woody species (Oba *et al.*, 2000). A review of studies from semi-arid ecosystems (Schlesinger *et al.*, 1990; Wilson, 1998), showed that an increase in density of woody plants beyond a critical density suppresses herbaceous plant growth (Oba *et al.*, 2000) mainly due to severe competition for available soil water. Loss of vegetation cover and lack of tree regeneration caused by heavy browsing, grazing and wood cutting are said to initiate a sequence of processes that feedback on the local climate, causing a sustained decrease in rainfall (Schlesinger *et al.*, 1990).

Competition is a universal characteristic of all plant (and animal) communities and has a major impact on the composition and condition of these communities. The pattern of competition may also be changed by elimination of the competition of the grass layer by overgrazing. This, however, implies that more water in both deeper and surface soil becomes available for woody growth. Thus, the destruction of grasses also reduces fire damage and should lead to a regulation of woody individuals by competition between themselves (Skarpe, 1990). Competition always occurs when the demands of two or more individuals for any growth requirements are in excess of the supplying power of the environment. An inevitable consequence of the increasing density of plants in a community is that some or all of the individuals may receive an insufficient amount of a limiting resource to fulfil their needs (Tainton, 1999). The factors for which plants compete are numerous, but those for which competition is generally most intense are light, moisture and nutrients (Tainton, 1999).

For woody plants with potentially long life-spans and low post-establishment mortality rates, seedling recruitment is probably the most critical stage in the life history (Harper, 1977). Woody plants are able to store carbohydrates from the previous season and therefore expand their leaves before or immediately after the first rains (the few deep roots may assist here) (Rutherford, 1984). This allows trees several weeks of preferential resource access before grasses are able to grow enough leaf to be competitors with trees. Most tree growth

and shoot development takes place in the first part of the season and sometimes again at the end of the wet season (Rutherford, 1984).

The structure of the woody component of savanna is important to animals – for example tree height which determines the available browse, dense woody entanglements forming impenetrable barriers, availability of shade and protection against predators or scavengers are all critical for the animals in the area (Bothma *et al.*, 1994). Thus, the problem of bush encroachment is a global concern because it lowers carrying capacity and this reduces livestock production (Dean and Macdonald, 1994; Jacobs, 2000; Smit, 2004). In Africa, the main encroaching species are the thorn trees (e.g. *Vachellia karroo*; *V. reficiens*, *V. tortilis*, *Senegalia mellifera* and *Dichrostachys cinerea*) (Kraaij and Ward, 2006). Furthermore, these species also tend to have high levels of phenolic compounds (e.g. tannins) in their leaves, which reduce their digestibility to livestock and wildlife. The combination of thorniness and low digestibility of *Vachellia* trees reduces their accessibility and natural value to consumers (Jacobs, 2000).

The difference in species composition observed between protected (fenced-off and privately owned) and unprotected (full access and utilization of resources without proper monitoring and management) savannas may be explained mostly by a combined effect on selective logging and cutting and livestock grazing. Unprotected savannas are highly subjected to human disturbances such as overexploitation, overgrazing, mismanagement total disregard of conservation strategies (Noble and Dirzo, 1997; Sagar *et al.*, 2003).

Woody plants are thought to have a competitive edge over herbaceous plants, due to a very often extended taproot system, implying that the savanna has an inherent tendency to become increasingly woody. The negative effect of trees on grasses may result from rainfall interception, litter accumulation, shading, root competition, or a combination of these factors (Scholes and Archer, 1997). The herbaceous component of savanna communities is normally relatively shallow rooted, implying that its growth is often dependent on moisture held within that layer. The upper layers of the soil profile are available to grasses. Here, the grass has a competitive advantage over the woody species because of its fibrous root system (Scholes and Archer, 1997). Furthermore, trees are thought to have a competitive advantage in resource-rich and heterogeneous soils and less effective in resource depleted soils. Where

above-ground competition depends largely on grassland management (grazing, mowing, burning), below-ground competition depends largely on soil resource quantity and distribution (Partel and Helm, 2007). Tree and grasses interact through harsh root competition, but below-ground processes have been neglected in the dynamics of semi-natural grasslands. According to Partel and Helm (2007), trees and shrubs have deep root systems and they can forage over nutrient-rich and nutrient-poor patches below the ground. Herbaceous species, in contrast, have shallow root systems that cannot reach out from poor patches (Campbell *et al.*, 1991; Grime, 1994).

The relatively high nutrient status of soil beneath, compared to between tree canopies (Bosch and Van Wyk, 1970; Kennard and Walker 1973; Tiedemann and Klemmenson 1973; Kellman 1979; Bernhard-Reversat 1982; Belsky *et al.*, 1989; Young, 1989; Smit and Swart, 1994), would be expected to lead to a relatively higher nutrient content of the grass growing in open savanna. Topography, soil structural properties, soil moisture and nutrients all contribute to the tree-grass dynamics within savanna systems (Britz and Ward, 2007). The specific factors involved in determining the tree-to-grass ratio and bush encroachment are not well understood (Ward, 2005; Britz and Ward, 2007). Soil texture is a crucial determinant of the tree-to-grass ratio due to its effects on plant growth, soil moisture, nutrients presence and availability (Britz and Ward, 2007).

The encroachment of woody species into temperate grasslands has also been explained by increased atmospheric nitrogen pollution (Kochy and Wilson, 2001). The larger the tree, the larger the area of resource depletion and the greater its competitive effect on its neighbours. Also, a large proportion of the roots are concentrated at shallow depths (Castellanos *et al.*, 1991; Smit and Rethman, 1998) where they would actively compete with the shallow rooted herbaceous plants.

Evidence that bush encroachment is caused by the changes in land-use practices rather than climate exist (Hoffman and Ashwell, 2001). The most important factor influencing bush encroachment is thought to be the replacement of individual browsing animals with grazers such as cattle and sheep (Hoffman and Ashwell, 2001). Thus, growing populations and diminishing resources add to environmental stress. A review of studies from semi-arid ecosystems showed that an increase in density of woody plants beyond a critical density

suppresses herbaceous plant growth (Oba *et al.*, 2000), mainly due to severe competition of available soil water. Loss of vegetation cover and lack of tree regeneration caused by heavy browsing, grazing and wood cutting are said to initiate a sequence of events that feedback on local climate, causing a sustained decrease in rainfall (Schlesinger *et al.*, 1990).

Some species may tolerate disturbances while others may disappear (Houehanou *et al.*, 2013). The diversity of explanations for bush abundance of trees might be due to the fact that different species having varying phenologies in varying climate, soils and thus underlying mechanisms of bush abundance and thickening may differ (Joubert *et al.*, 2008).

2.7 The forces known to influence the rate and pattern of bush encroachment

Woody encroachment drivers are many and complex (Ward, 2005; Archer, 2010). On a global and regional scale, atmospheric warming, elevated concentration of carbon dioxide and nitrogen deposition could be possible drivers (Archer, 1995; Wigley *et al.*, 2010). According to O'Connor *et al.* (2014), the suppression of fire during the early twentieth century is one of the major contributing drivers of bush encroachment. O'Connor *et al.*, (2014), argued that severe grazing by livestock or wildlife could promote bush encroachment by reducing the fuel load or by reducing grass competition. Historical changes in grazing pressure are central to understanding bush encroachment, specifically the effect of disease pandemics and the pattern on grass competition and fire suppression and in some cases seed dispersal (O'Connor *et al.*, 2014). O'Connor *et al.* (2014), however, concluded that increased atmospheric [CO₂] is the major driver of bush encroachment.

2.8 Extent of woody plant encroachment in the Molopo area

Woody plant proliferation in grasslands and savannas over the past century has been widely documented and its causes debated (Archer, 1994; Archer, 1995; Van Auken, 2000). According to Molatlhegi (2008), Mogodi (2009) and Comole (2014), the extent of woody plant encroachment in the Molopo Area in the North West Province resulted in the drastic shift from a grass dominated area to a woody dominated area, changing the ecosystem completely to woodland savanna. Furthermore, the encroachment of woody species resulted in the reduction of woody biodiversity (Comole, 2014), limiting the encroaching woody species in rangelands to dense areas of *Vachellia tortilis*, *V. hebeclada*, *Senegalia*

mellifera and *Dichrostachys cinerea* (Molatlhegi, 2008, Mogodi, 2009, Comole, 2014) and *Prosopis velutina* in the riparian areas (Comole, 2014).

2.9 Remote Sensing

2.9.1 Remote sensing application

Remote Sensing is broadly defined as the science of obtaining information about an object without direct physical contact with the object (Lillesand *et al.*, 2004). The term Remote Sensing refers to methods and techniques that make use of electromagnetic energy, such as light, heat and radio waves as the means of detecting and measuring target characteristics (Sabins, 1987).

Remote sensing has been found to be a cost effective approach to detect changes over large areas and even geographic regions and it has been of importance in monitoring the changing patterns of vegetation (Vrieling, 2006). Mapping and monitoring vegetation species in disturbed areas requires that there be extensive coverage and that quantitative, timely, accurate and regularly collected information be gathered. All these factors have made the use of remote sensing a powerful tool (Austin *et al.*, 2009).

According to Wessels *et al.*, (2006), remote sensing is the advanced tool for surveying and provides the synoptic view of the area. This technique offers quick and repetitive data and is accurate and potentially inexpensive and natural resource management over large areas (Wessels *et al.*, 2006).

However, these traditional methods of mapping and monitoring vegetation have proved not to be effective to acquire vegetation cover characteristics because they are time consuming, date lagged and often too expensive (Austin *et al.*, 2009). In contrast, remote sensing has attracted scientific awareness ensuing in the provision of varied spatial resolution imageries that are not physically feasible and cost effective but also give appropriate and precise information (Austin *et al.*, 2009).

More recently, there is a growing demand to use information on vegetation condition in a broader regional context and to monitor achievement, and to report on progress towards

regional, state and national targets of vegetation condition using remote sensing (Parkes and Lyon, 2006; Neldner, 2006).

The spatial technologies of remote sensing and GIS provide possibilities for production, storage and rapid updating, of habitat maps given the threats to stability of habitats from human and natural factors (Munyati and Ratshibvumo (2010). One of the most widely used methods in vegetation type mapping using remotely sensed images is pixel-based image classification (Munyati *et al.*, 2011).

2.9.2 Application of remote sensing in the assessment of bush encroachment

In the past, assessment of woody vegetation density and canopy cover in the vast arid to semi-arid savanna environments has been limited to analysis of field data (Adjorololo, 2008). The acquisition of field data for relatively large areas can be impractical, considering that longer time of fieldwork is required. In this respect, remote sensing applications can provide information that is quick, timely and economical for the estimation of vegetation resources over large and complex savanna environments (Adjorololo, 2008).

Moreover, remote sensing has been utilized as a primary source of spatial data to characterize patterned woody vegetation density and canopy structure in the southern African savanna ecosystems (Hudak and Weissman, 1998; Yang and Prince, 2000; Hudak and Weissman, 2001; Wessels *et al.*, 2006). Remote sensing has also been used to develop updated vegetation maps and establish statistics about percentage woody canopy cover in semi-arid savanna environment (Stuart *et al.*, 2006; Wessels *et al.*, 2006).

The utility of remote sensing in the assessment of bush encroachment has been demonstrated by a number of authors. A variety of imagery has been utilized in the process, ranging from aerial photographs (e.g. Hudak and Weissman, 1998; O'Connor and Crow 1999), satellite imagery (e.g. Hudak and Weissman, 2001) combinations of aerial photographs and satellite imagery (e.g. Hudak and Weissman, 2001; Laliberte *et al.*, 2004) to airborne hyper spectral images (e.g. Asner and Martin, 2008). On multispectral panchromatic aerial photographs, which are particularly useful in assessments involving periods predating satellite images (e.g. Hudak and Weissman; 2001; Laliberte *et al.*, 2004), changing in image texture as woody cover increases have been shown to be key indicators of bush encroachment (Hudak and Weissman, 1998; 2001; O'Connor and Crow, 1999; Roques *et al.*, 2001).

High spatial resolution is important in detecting bush encroachment on remotely sensed images (Hudak and Weissman, 2001; Laliberte *et al.*, 2004), primarily because the encroaching bushes have small crown diameters.

2.9.3 Remote sensing of savanna vegetation and image texture analysis

Remote sensing on tree canopy cover often follows the spectral or spatial domains which are the two main approaches applied in vegetation studies (Jupp and Walker, 1997). For remote sensing investigations, the image texture response therefore, contains important information about the spatial and structural arrangement of the remotely sensed objects (Tso and Mather, 2001).

Texture information contained in remote sensing data has been very useful for a wide range of remote sensing applications, for example, to assess global land cover, image texture analysis has played an important role in the classification of vegetation communities, which have been remotely sensed (Miranda *et al.*, 1998; Carter and Knapp, 2001).

Texture information extracted from high-resolution multispectral images has been intensively studied and considered useful for the discrimination of different land cover classes such as water bodies, urban areas and agricultural fields (Atkinson and Curran, 1997; Chica-Olmo and Abarca-Hernandez, 2000).

2.10 SPOT images

Système Pour L'Observation de la Terre (SPOT) is a series of Earth observation imaging satellites designed and launched by Centre National d'Etudes Spatiales (CNES) of France, with support from Sweden and Belgium. SPOT was launched in 1986, with successors following every 3/4 years. All satellites are in sun-synchronous, near polar orbits and altitudes around 850 km above the Earth (Yichum *et al.*, 2008).

SPOT has a number of benefits over the space borne optical sensors. Its fine spatial resolution and pointable sensors are the primary sensors for its popularity. SPOT allows applications requiring fine spatial detail (such as urban mapping) to be addressed while

retaining the ease and timeliness advantage of satellite data. The potential implementations of SPOT data are numerous. Applications requiring frequent monitoring are well served by SPOT sensors (Yichum *et al.*, 2008).

2.11 Remote sensing and image classification

Image classification serves a purpose to analyse the distribution of vegetation types and determine their relationships (Ndou, 2013). Mueller-Dombois and Ellenberg (1974) defined the classification of vegetation as a fundamental tool for obtaining knowledge about the vegetation cover and its relationship with the Earth's environment. This process converts satellite data into information based on pixel values within the image. This process has made it possible for researchers to study the Earth's surface using satellite data (Goodchild, 1994; Gao, 2009).

According to (Campbell, 2006), image classification can be applied to various sensing applications, used for image analysis and pattern recognition. Monitoring vegetation conditions is accompanied by the classification of remote sensing images (Van Til *et al.*, 2004). For the purpose of classification and mapping of vegetation cover and scale, remotely-sensed data are used (Perumal and Bhaskaran, 2010). Yongxue *et al.* (2006) defined remote sensing image classification as land-use or cover class extraction from satellite imagery. Classification smooths out significant variations and simplifies images into thematic maps of land cover. According to Gibson and Power (2000), the process of classification assigns pixels which have similar spectral characteristics which are assumed to belong to the same class are then identified and assigned a unique colour. Once an image is classified, the dataset can be interrogated and the area of different classes can be set (Gibson and Power, 2000). The unsupervised and supervised class approaches can be used. Image classification is separated into a supervised and an unsupervised classification.

2.11.1 Supervised classification

Supervised classification involves three major steps, namely (1) selection or generation of training areas (2) evaluation of training signature statistics and spectral pattern and (3) classification of images (Lillesand and Keifer, 1994; Trotter, 1998). Supervised classification requires significant interaction with the analyst, to a certain category. This method involves the need for prior knowledge of the ground cover of the study site (Hasmadi

et al., 2009). The user (analyst) decides on the number and types of classes to be extracted. It requires training data to generate classes defined by where the same generated training data are used to train a classified algorithm (Kamaruzaman *et al.*, 2009).

2.11.2 Unsupervised classification

The unsupervised classification involves the examination of unknown pixels in an image and combining them into a number of classes on the basis of natural groupings or clusters present in an image (Babykalpana and Thanushkodi, 2010). This classification method requires minimal interaction with the analyst and searches for manual groups of pixels within an image (Campbell, 2006). According to Campbell (2002), unsupervised classification has the following advantages: human error is minimized, no extensive prior knowledge of the region is required and unique classes are recognized as distinct units. The disadvantages of unsupervised classification include spectrally homogeneous classes within the data that do not necessarily correspond to the information categories that are of interest to the analyst. As a result, the analyst also has limited control over the menu of classes and their specific identities (Campbell, 2002). It is on this basis that the unsupervised classification was preferred ahead of supervised approach in the current study.

CHAPTER 3

STUDY AREA AND CLIMATE CONDITIONS

3.1 Location and description

The study area was conducted in the semi-arid Savanna Biome in the North West Province, South Africa. The North West Province (NWP) (Figure 3.1.), of South Africa is surrounded by the provinces of Gauteng, Limpopo (formerly Northern Province), the North Cape, Free State and the Republic of Botswana (Figure 3.1.). It is the 6th largest of the 9 provinces in South Africa. The North West Province is predominately rural, with 65.1% of the population living in rural areas and 34.9% in urban areas. However, the rate of urbanization is increasing, largely due to the lack of employment in rural areas (State of the Environment Report Overview, 2002).

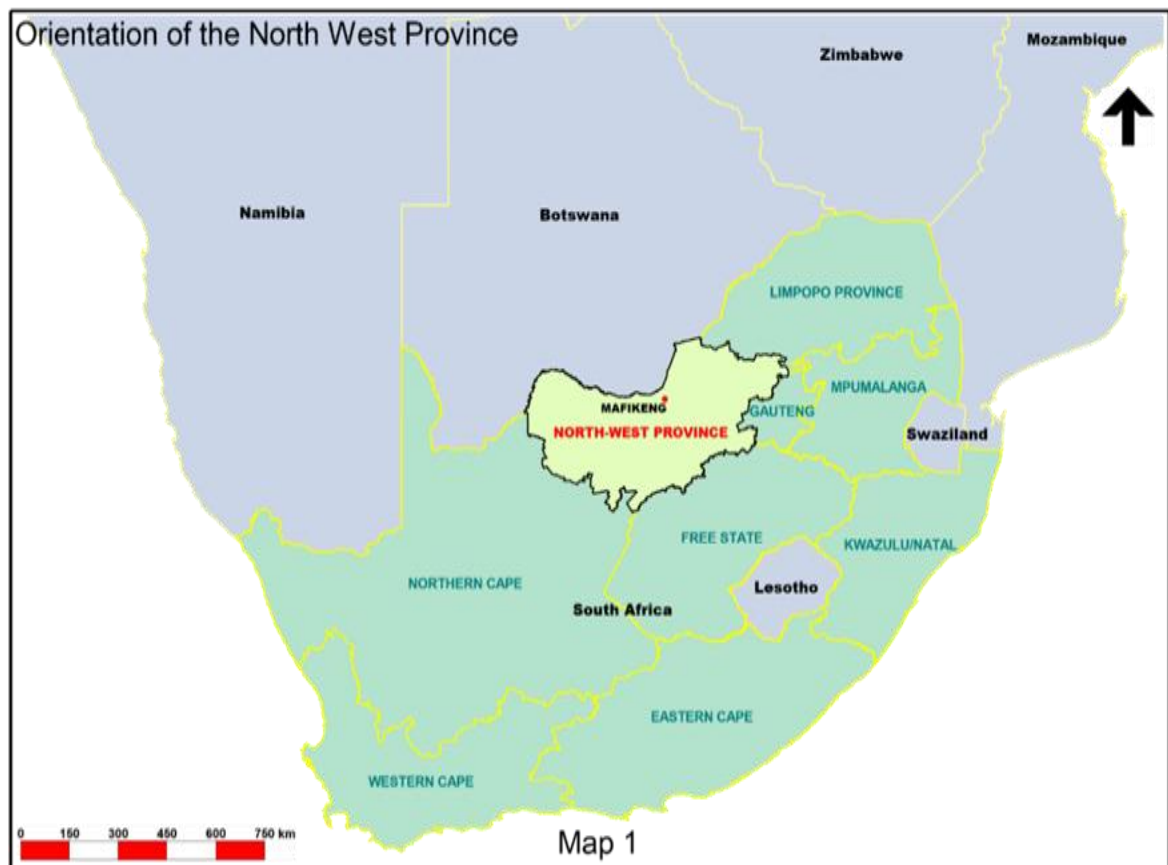


Figure 3.1: Orientation of the North West Province (Department of Agriculture, Conservation, Environment and Tourism, 2002).

The study was conducted along the selected sites along the Mafikeng-Disaneng road, approximately 27 km from Mafikeng town (now named Mahikeng) in the Lekung and Masutlhe Villages in the North West Province, South Africa (Figure 3.2). The three selected sites were located within the coordinates S 25° 47' and E 25° 21'. In general, the North West Province, is showing signs of increased soil degradation (Figure 3.9) the most severely affected areas are those that are communally managed (North West Province State of the Environment Report, 2002). The Benchmark sites (reference sites), were located within the same ecological zone as the research sites (Figure 3.2).

The study area (Lekung, Masutlhe 1 and Masutlhe 2) and the reference sites (benchmark sites), were located within the vast Savanna biome, which covers large parts of southern Africa. All the areas were located in the North West Province (Figure 3.1). Each of the sites can be described as being in a poor condition because of overgrazing, overstocking of cattle, soil erosion, wood cutting and mismanagement of resources.

According to the North West Province State of the Environment Report of 2002 (State of the Environment, 2002), rural settlements, informal settlements and traditional villages generally on state or tribal land are poorly developed or have only a few basic services. The three survey sites also had two benchmark sites (reference sites) that were located within close proximity to the sites approximately 20 – 30 km from Mafikeng (Figure 3.2) in a protected area which were under no human influence such as grazing of cattle, tree cutting, littering or exploitation of resources as compared to the study sites. According to Roux (1986), a veld benchmark is veld with the best possible botanical composition and cover (excellent condition) in relation to prevailing climate. It thus, implies that these benchmark sites have been well managed in the past (Roux, 1986). These areas were not affected by humans or animals and there were no visible disturbances. Tainton (1999), explained that a benchmark site (reference site) should be in a good condition and have production capacity. The selected benchmark sites proved to be in good condition as they were fenced off, well managed and protected with a standard production capacity. The surrounding community had no access to the protected area and thus had no interaction with the area.

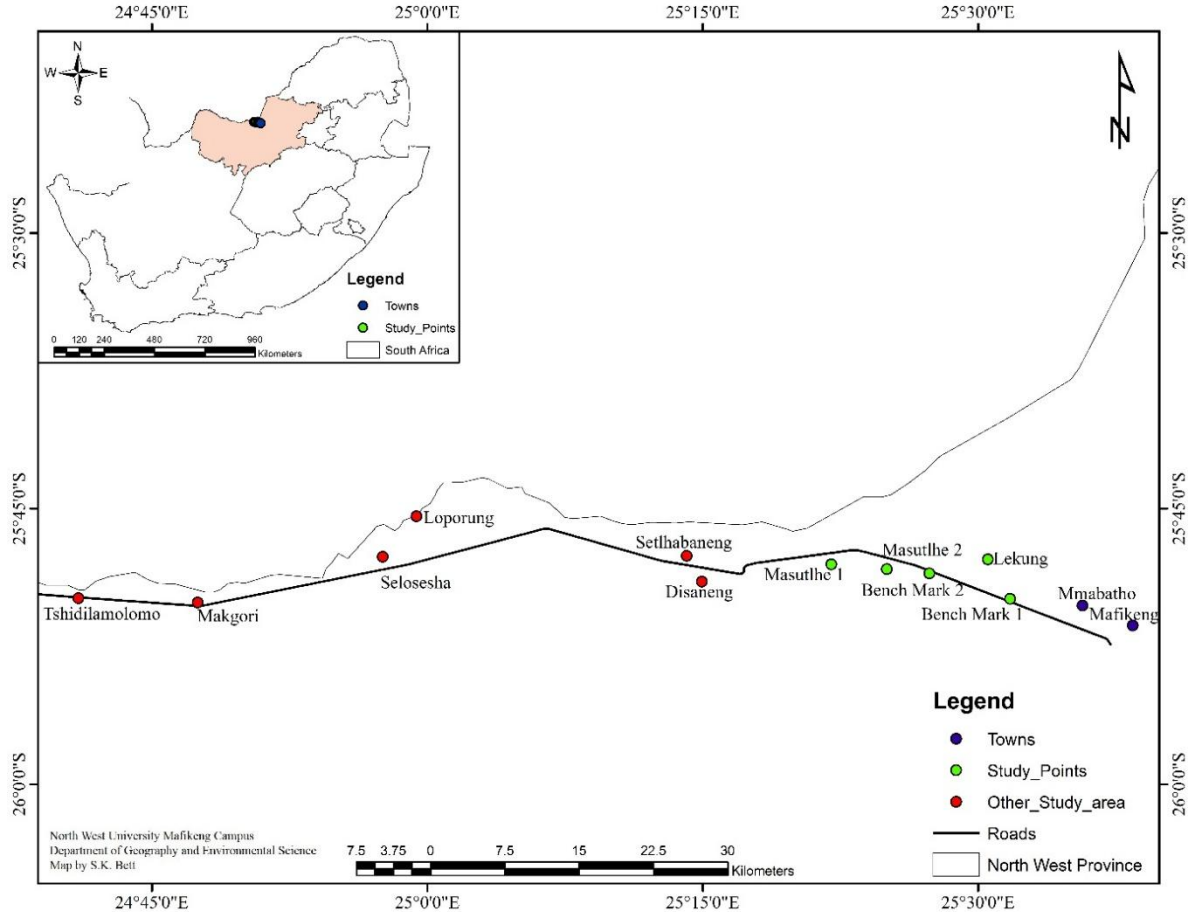


Figure 3.2: Geographical location of the study site.

3.2 Climate

Climate plays an important role in determining the availability of water resources, the nature of the natural landscape and vegetation type (State of the Environment Report, 2002). According to Tainton (1999), climate is a major determinant of the geographical distribution of species and vegetation types. The IPCC (2011), argued that recent changes in climate such as temperature in certain regions have already had significant impacts on biodiversity and ecosystems. Thus, within any area of general climatic uniformity, local conditions of temperature, light, humidity and moisture vary greatly and these factors play an important role in the production and survival of plants (Tainton, 1999). Temperature and rainfall are considered the major climate entities affecting plant diversity.

3.2.1 Climate in the savanna

The Savanna in South Africa and Swaziland does not occur at high altitudes and is found mostly below 1 500 m and extending to 1 800 m on parts of the Highveld mainly along the southern most edges of the Central Bushveld (Schulze, 1997). Temperatures in the savanna are therefore, higher than those of the adjacent grassland at higher altitudes. The mean daily maximum temperature for February rarely drops below 26°C and exceeds 32°C in the Kalahari region and some low-altitude parts of savanna in the east (Schulze, 1997).

Worldwide, savannas have a strongly seasonal rainfall with wet summers and dry winters (Nix, 1983). The Savanna biome typically has a distinct dry season, with most of the area in South Africa receiving 5 mm in each of the months of June, July and August. Most savanna areas in Southern Africa have what is classified as strong summer rainfall or summer rainfall (Rutherford and Westfall, 1994).

3.2.2 Climate of North West Province and Mafikeng

There are wide seasonal and daily variations in temperature in the North West Province. According to De Villiers and Mangold (2002), the climatic conditions in the North West Province vary considerably from west to east. In the western regions the climate is mainly hot and temperature while the central regions area dominated by typically semi-arid conditions (De Villiers and Mangold, 2002). The summers are warm to very hot with average daily maximum temperatures of 30°C in January (North West Province State of the Environment Report, 2002). According to Mucina and Rutherford (2006), the temperatures remains above 40°C for the most part of the area, with temperatures dropping to below 10°C in May-August. The highest altitudes are recorded at 1290 m, with the minimum rainfall reaching 541 mm. There are wide seasonal and daily variations in temperature, being very hot in summer (daily average high temperature of 32°C in January) and mild too cold in winter (average daily minimum in July is 0.9°C) (North West State of the Environment Report Overview, 2002).

Mafikeng has a typical semi-arid savanna climate, with a dry season extending from May to October. The mean monthly minimum temperatures vary from 2.7°C in July to 17.7°C in January, while mean maximum temperatures change from 20.7°C in June to 30.6°C in December. Climate diagrams of Mafikeng (Mahikeng) for the period of (1990-2014) are represented in Figures 3.3 and 3.4 respectively.

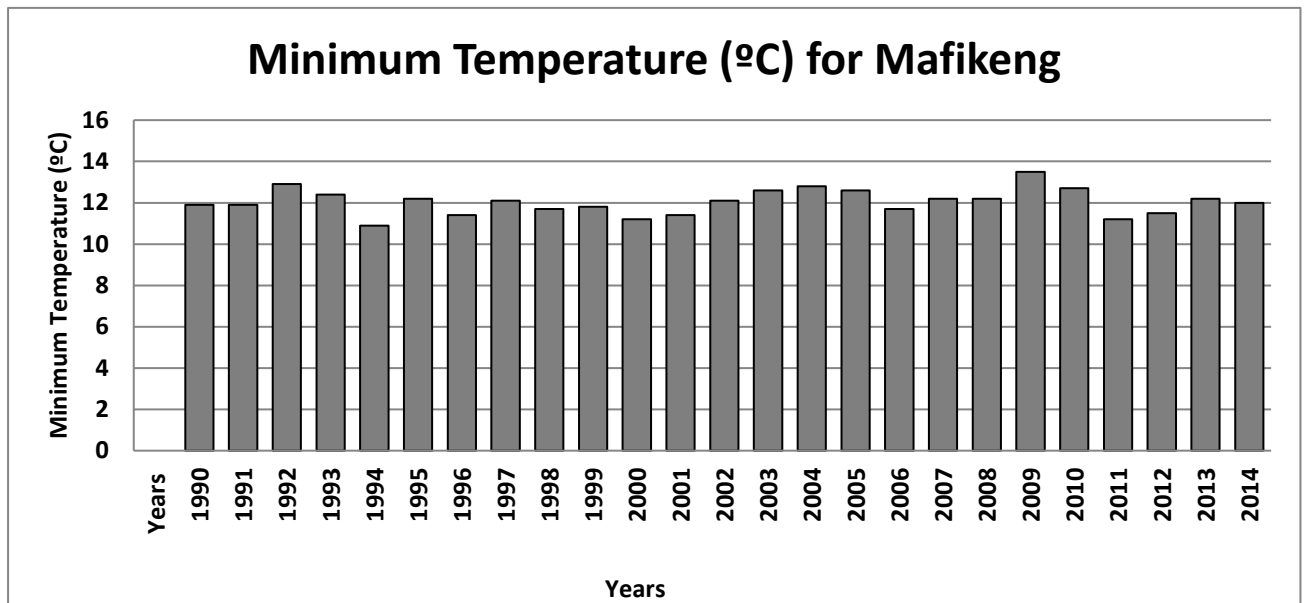


Figure 3.3: Average minimum temperatures (°C) for the years 1990-2014 (South African Weather Service.)

Temperature data was obtained from the South African Weather Service. Average monthly minimum and maximum temperatures are given for the 1990-2014. Figure 3.3 shows the trend for the 26 years. According to Figure 3.3, the years of 1992 and 2009 had the highest minimum temperatures with the year 1994 having the lowest minimum temperature.

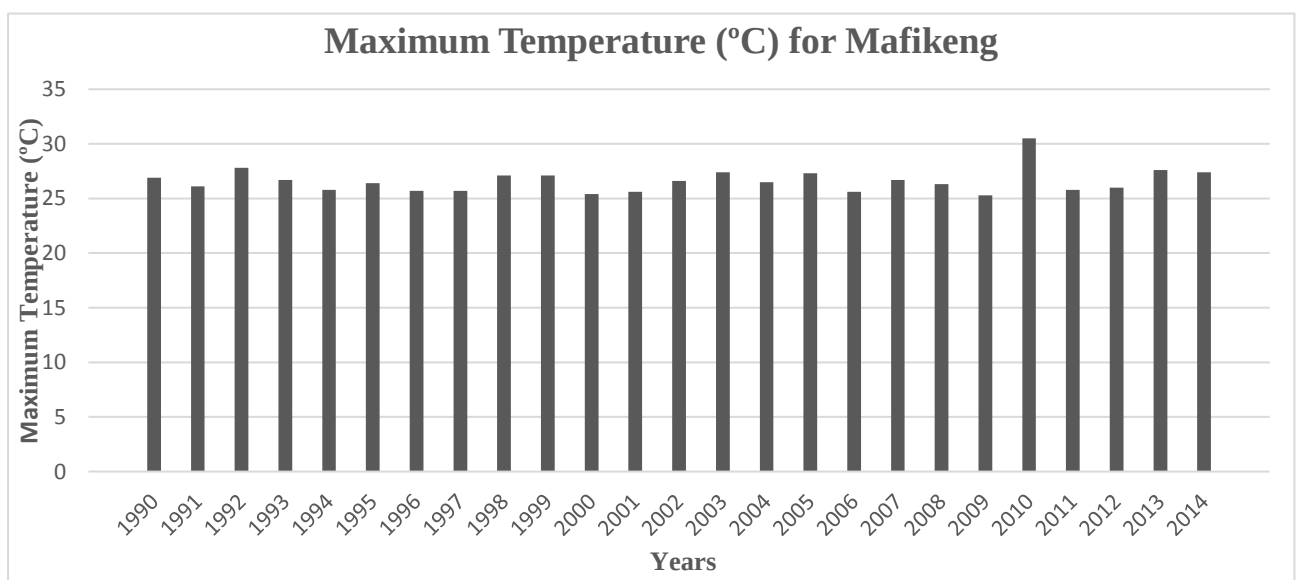


Figure 3.4: Maximum temperatures for Mafikeng (1990-2014) (South African Weather Service)

According to Figure 3.4, the long-term analyses revealed that the maximum temperatures in the area have been fluctuating. The year 2010 had the highest maximum temperature at 30.5°C with 1991 had the lowest at a temperature of 26.1°C. According to Huxman *et al.*, 2004, climate has a strong influence on dry land vegetation types, biomass and diversity. Climate factors such as precipitation, radiation and temperature are key determinants for the distribution and productivity of vegetation around the world.

3.3 Rainfall

Rainfall is the factor which most clearly determines the distribution of plant communities in South Africa, as well as the potential productivity of the communities (Tainton and Hardy, 1999). Rutherford (1978), reported a positive and generally linear correlation between rainfall and herbaceous dry matter at a number of sites in southern Africa. Rutherford (1978), approximated that two thirds of the country receives less than 500 mm of rain per annum while values of less than 100 mm are not uncommon in the western parts of South Africa. According to Schulze (1997), the regions which receives a rainfall between 600 mm and 1000 mm skirt the foothills of the Drakensburg and associated mountains and indicate most of Lesotho and Kwazulu-Natal, parts of the southern Cape coast, parts of Mpumalanga and eastern and central Free State. Schulze (1997), suggested that successional development of the vegetation to a forest or shrub climax is normally possible only in areas which receive a rainfall higher than 750 mm per annum. Where rainfall range is between 250 mm to 750 mm, a grassland or savanna (Bushveld) climax generally develops and below 250 mm a Karoo climax which adapted specifically to arid conditions grows.

Rainfall is highly variable in time and regionally. Droughts and floods occur regularly at both provincial and local scales. They play a significant role in almost every aspect of the social, economic and ecological environment within the Province (North West State of the Environment Report, 2002).

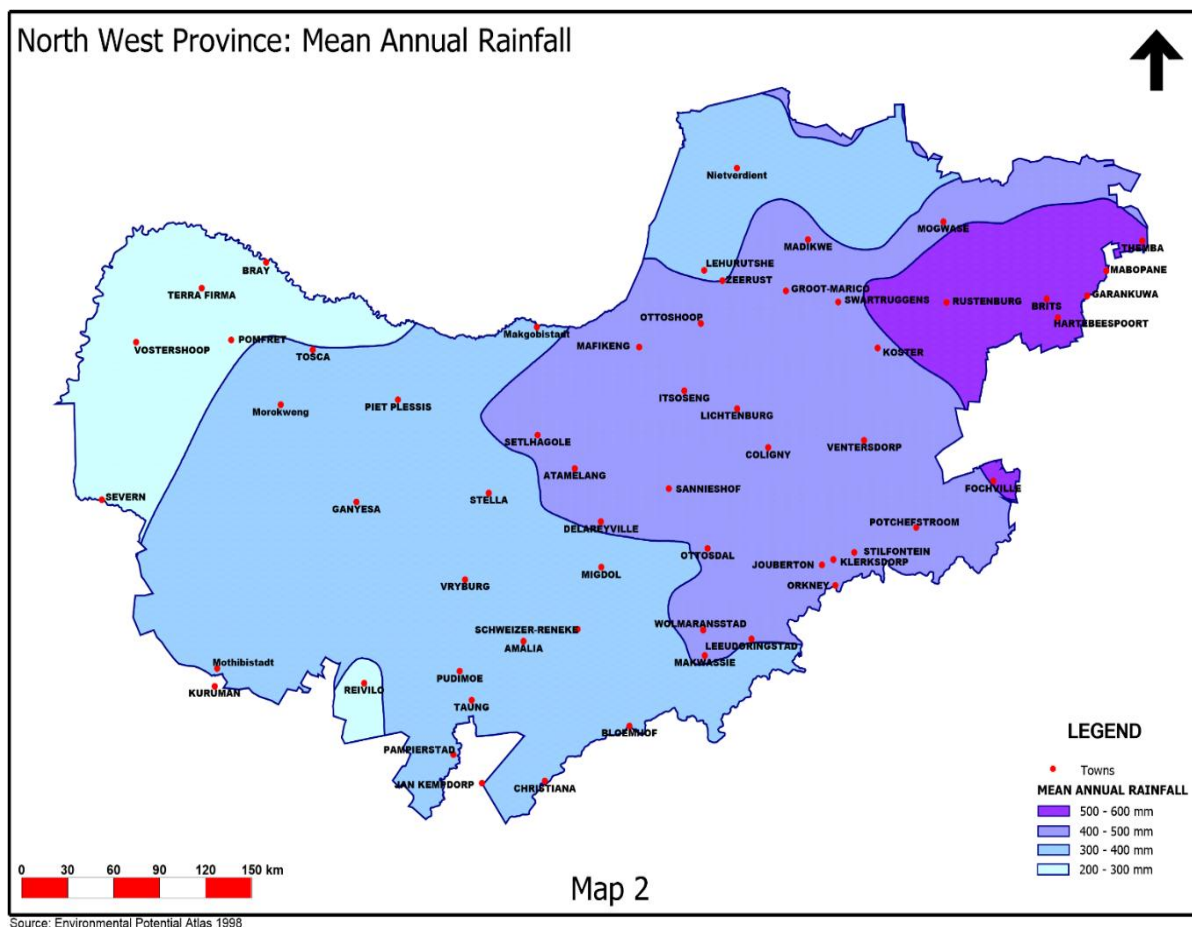


Figure 3.5: North West Province mean annual rainfall (Department of Agriculture, Conservation, Environment and Tourism, 2002)

3.3.1 Precipitation

The North West Province (Figure 3.1) falls within a summer rainfall region, and rainfall often occurs in the form of late afternoon thunderstorms (State of the Environment Report, 2002). Rainfall in the province is highly variable both regionally and in time. The western part of the province which is classified as being arid receives less than 300 mm of rain per annum, while the central semi-arid regions receive 500 mm of rain per annum. The eastern and south-eastern part of the region receives over 600 mm of rain per annum (Figure 3.5). Droughts and floods are regular occurrences at provincial and local scale. In most parts of the province, evaporation exceeds rainfall (Tainton, 2000).

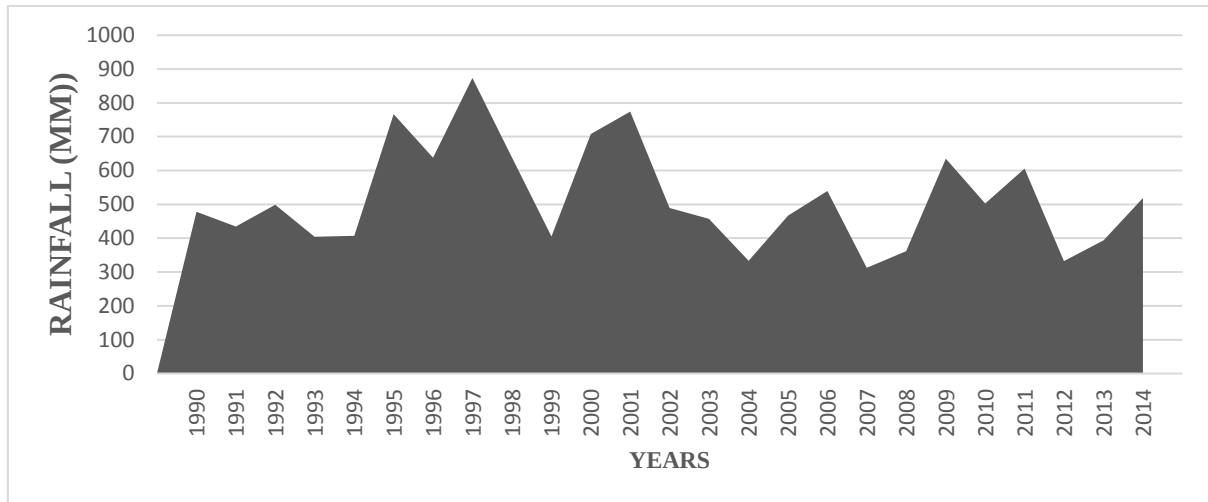


Figure 3.6: Average rainfall of North-West Province (1990-2014) (South African Weather Service, Station)

Monthly rainfall data for the period of 1990-2014 was obtained from the South African Weather Service (SAWS), Figure 3.6 shows a more accurate presentation of the long-term average rainfall for Mafikeng for the period of (1990-2014). A high of 873.6 mm was recorded for the year 1997 and a low of 312 mm recorded for 2007.

3.4 Vegetation

According to Low and Rebelo (1996), Mafikeng falls within the Savanna Biome. The vegetation has been classified as the Mafikeng Bushveld vegetation type. Scholes and Archer (1997), define the savanna as vegetation where trees and grasses interact to create a biome that is neither grassland nor forest. In the Southern Africa, the savanna Biome is the largest Biome, occupying approximately 46 % of its area (Low and Rebelo, 1996).

The study area is situated within the Mafikeng Bushveld. The Mafikeng Bushveld is characterised by well-developed trees and shrub layers, dense tracts of *Terminalia sericea*, *Vachellia luederitzii*, and *Acacia* species, *Grewia flava*, *Grewia retinervis*, *Searsia tenuinervis* and *Ziziphus mucronata*. The prominent encroaching woody species and significant grasses in the study sites included *Vachellia tortilis* (Umbrella thorn), *Grewia flava* (Raisin bush), *Ziziphus mucronata* (Buffalo thorn) as encroaching species and *Eragrostis lehmanniana*, *Stipragrostis uniplumis* as grasses.

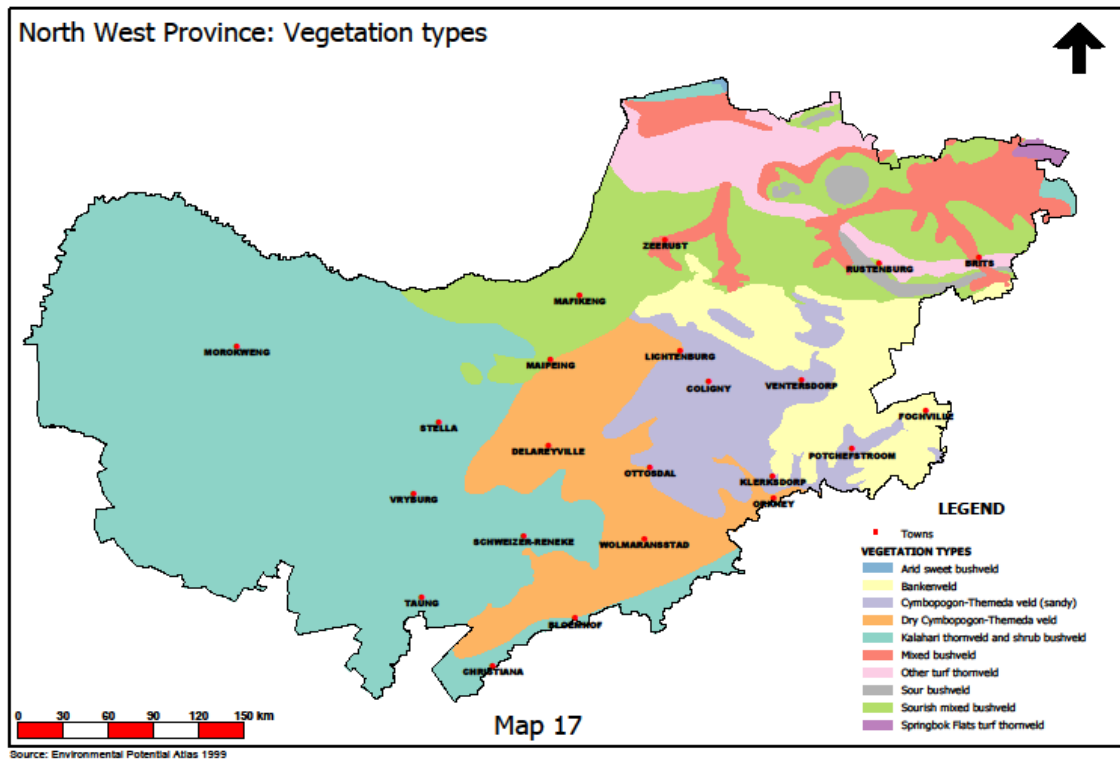


Figure 3.7: North West Province Vegetation types (Department of Agriculture, Conservation, Environment and Tourism, 2002).

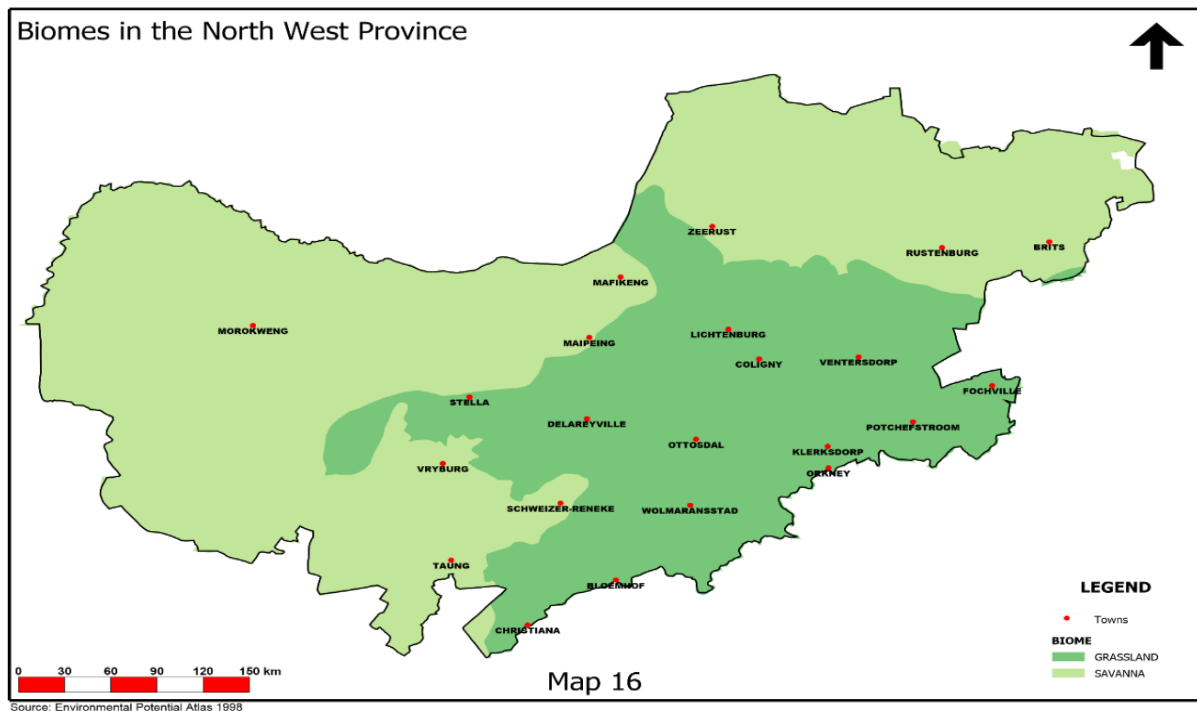


Figure 3.8: Biomes in the North West Province (Department of Agriculture, Conservation, Environment and Tourism, 2002).

3.5 Geology and soil types

According to De Villiers and Mangold (2002), soils are dynamic in nature and are constantly evolving and degrading by means of natural and man induced processes. Since, the early 1970's, our knowledge of the distribution and properties of soils has increased significantly especially in the traditionally cultivated parts of the country (De Villiers and Mangold, 2002).

In South Africa communal rangeland management is often associated with severe soil degradation, heavy stocking and poor management such as overgrazing (Shackelton 1993; Harrison and Shackelton, 1999; Hoffman and Ashwell, 2001). In general, the North West Province is showing signs of increased land and soil degradation (Figure 3.8) (North West Province State of the Environment Report Overview, 2002). All magisterial districts show signs of degradation and desertification. The most severely affected are those that are communally managed. This has numerous negative consequences for agriculture in the province such as increased productivity of the croplands (North West Province State of the Environment Report, 2002).

3.5.1 Soils

According to Mucina and Rutherford (2006), the Mafikeng Bushveld vegetation type is characterized by Aeolian Kalahari sands of tertiary to recent origin on flat sandy plains at soil depths of approximately 1.2 m. The soil consists of Clovelly and Hutton forms (Mucina and Rutherford, 2006). Different authors or researchers reported on the soil of Kalahari Thornveld in different ways. Acocks (1988) as well as Low and Rebelo (1996) described the Kalahari soil as loose sandy soils while De Villiers and Mangold (2002) classified it as freely drained to semi-arid, red and yellow soils with a clay content of approximately 15 %, which have developed calcareous crusts.

Hutton and Clovelly soils are the most prominent in the area.

Hutton soils are a medium to coarse loamy sand to loam texture and are mostly non-calcareous with a high bare status (Van der Meulen, 1978). These soils are shallow (300-600 mm). The shallowness and low clay content of these soils results in a relatively low soil or water potential (Van der Meulen, 1979). MacVicar *et al.*, (1977), described Clovelly soils

as acidic and noticeably dense in the subsoil layer in spite of being classified as having apedal (structure less but physically favourable and clear characteristics of B horizon) characteristics.

3.5.2 Land types

The study area is located in land types. Thus, the land types present in the study area are Ae, Ah and Be (Mucina and Rutherford, 2006). The A land type also refers to as land which does not qualify as a plinthic catena and in which one or more of the above soil forms occupy at least 40% of the area (Land Type Survey Staff, 1988). Mucina and Rutherford, 2006, described land types A-A3 as red-yellow, well-drained soils lacking a strong texture contrast. Moreover, land types Ae described as A4-red consists of massive or weakly structured soils with high base status (associates of well-drained Lixisols, Cambisols and Luvisols (Mucina and Rutherford, 2006). Ae land types are characterized by *Vachellia tortilis*, and *Vachellia erioloba* on sandy soil (Mucina and Rutherford, 2006). Ae land types refers to red, high base status soils that are more than 300 m deep with no dune (Land Type Survey Staff, 1988). All the A land types consist of yellow and red soil. Soil forms in land type include Inanda, Kranskop, Magwa, Hutton, Griffin and Clovelly (Land Type Survey Staff, 1988). The yellow soil in Ae land type yellow soil occupy less than 10% of the area. Ae land type is characterised by *Acacia* species, mainly *Vachellia tortilis* and *V. nilotica* on clayey soil and *V. erioloba* on sandy soil (Mucina and Rutherford, 2006).

The B land type occupies a very large area of the South African interior (Land Type Survey Staff, 1988). The South African interior is occupied by a catena which in its perfect form is represented by Hutton, Bainsvlei, Avalon and Longlands forms. The valley bottom is occupied by one or other gley soil (Land Type Survey Staff, 1988).

3.5.3 Geology

The geology of the North West Province (Fig.3.10) is significant because of its mineral resources which are rich in exploitable platinum, gold, uranium, iron, chrome, manganese and diamonds (North West State of the Environment Report, 2002). The geology of the Mafikeng Bushveld (SVK 1), occurs on Aeolian Kalahari sand on flat sandy plains with relatively deep soils of Clovelly and Hutton forms. Approximately 75% of the Mafikeng Bushveld vegetation type is intact but considered to be vulnerable (National List of

Threatened Ecosystems, 2011). The main agent of transformation to date is from crop farming to further loss of this vegetation type is considered undesirable (National list of threatened ecosystem, 2011).

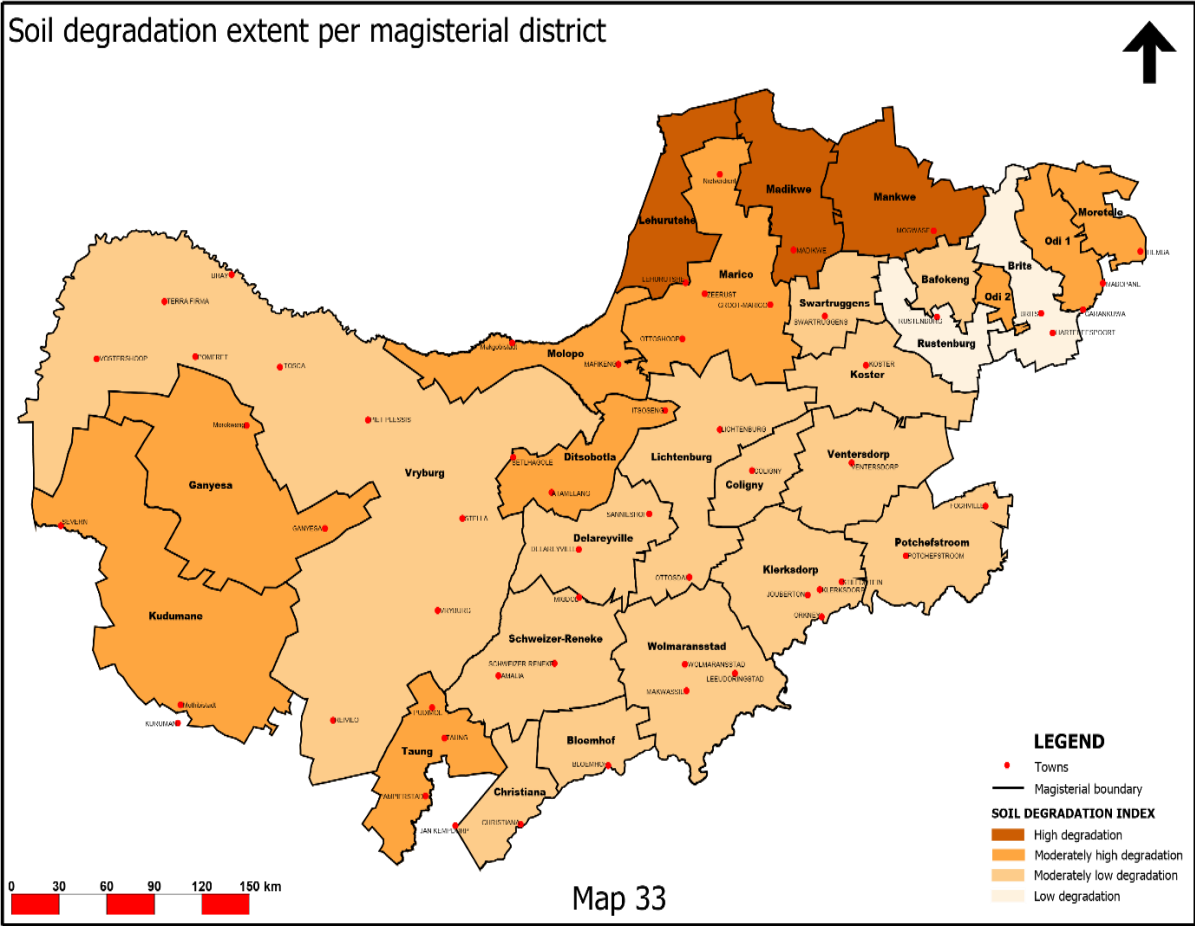


Figure 3.9: Soil degradation extent per magisterial district (Department of Agriculture, Conservation, Environment and Tourism, 2002).

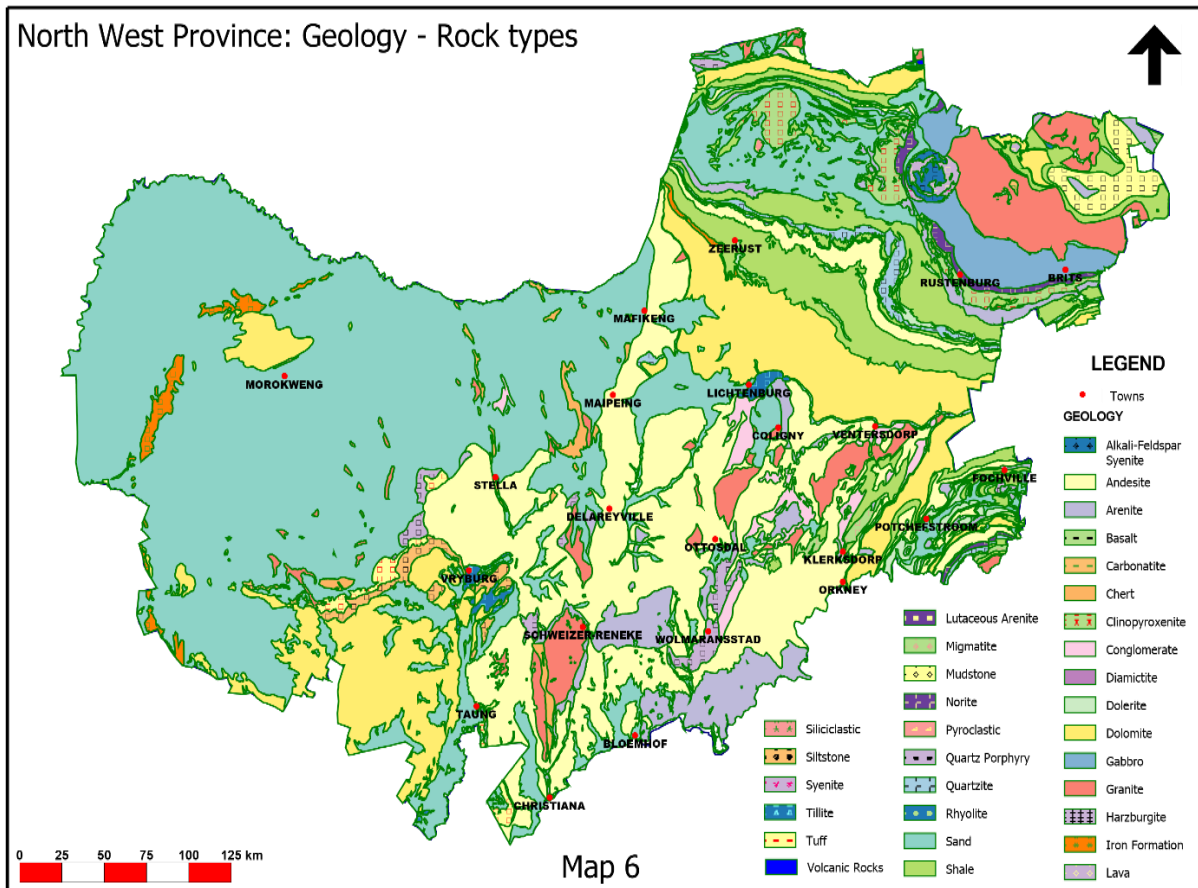


Figure 3.10: North West Province Geology (Department of Agriculture, Conservation, Environment and Tourism, 2002)

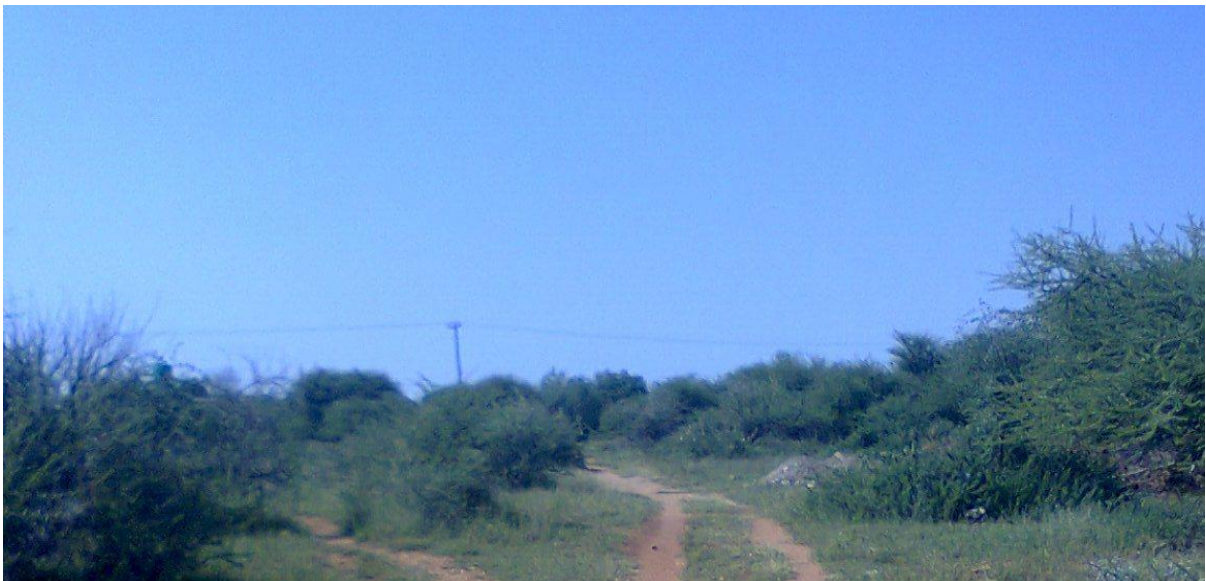


Figure 3.11: A clear representation of Bush encroachment and disturbance of land. A road and footpaths are clear evidence of human activity.



Figure 3.12: A road and footpaths are clear evidence of human presence. Dense bushes visible in the background.



Figure 3.13: Animal grazing in the area.



Figure 3.14: Dense bushes are clear evidence of bush encroachment



Figure 3.15: Dense stands of *Vachellia tortilis*



Figure 3.16: Hard soil surface prevents grass growth

CHAPTER 4

METHODOLOGY

4.1 Materials and methods

Vegetation is probably the single-most influential characteristics of the environment that can reveal many pieces of vital information on various aspects of an area under observation (Van Rooyen, 2002). In order to quantify the woody plant densities in the respective study sites (Lekung, Masutlhe 1 and Masutlhe 2; see Figure 3.2) the variable quadrant method for describing woody plant composition and structure was used (Coetzee and Gertenbach, 1977). This method was also applied by various researchers (Sidiyasa and Samsuodin, 2003; Molatlhegi 2008; Mogodi, 2009; Comole, 2014) to quantify the woody plant densities in their chosen study areas. GIS and remote sensing methods were employed to ensure the achievement of the objectives of this research study (Chapter 1). ERDAS Imagine 2015 was utilised for image processing, and support mapping was undertaken using ArcMap 10.3.1. A handheld GPS was used for position location in the field. The materials and equipment used for this research are listed in Table 4.1.

Table 4.1: List of materials

No.	Material
1.	Measuring poles
2.	Data collection sheets
3.	GPS apparatus
4.	Camera
5.	ERDAS Imagine 2015 [®]
6.	Arc Map 10.3.1
7.	Meter tapes

4.1.1 Remote sensing data

SPOT images were selected for the study, because of the requirement for high spatial resolution. The images acquired dated from 2004, 2006 and the newest 2014 (Table 4.2). Images were acquired with an appropriate time period in order to study bush encroachment where grasses are largely in senescence.

Table 4.2: List of images used

Date	K/J reference	Satellite	Spatial Resolution (m)
21 August 2004	127/402	SPOT 4	20
04 September 2006	127/402	SPOT 2	20
14 July 2014	128/402	SPOT 5	5
14 July 2014	126/401	SPOT 5	5

4.1.2 Field data and image pre-processing

Field quantification and validation of woody vegetation was undertaken at the study sites, in order to derive data on woody vegetation for use in image interpretation. Training data for vegetation density was determined using a detailed field survey procedure. The variable quadrant method was utilised for quantification of the woody vegetation.

The variable quadrant method was designed to overcome the shortcomings of fixed-plot-size sampling of structurally complex vegetation, where there are marked differences in the density of plants at different height classes (Coetzee and Gertenbach, 1977, Sidiyasa and Samsedin, 2003). Moreover, fixed-plot methods tend to oversample the lower height classes, where plant density is high and under sample the low-density upper height classes, while enumerating for each height class according to its density (Coetzee and Gertenbach, 1977, Sidiyasa and Samsedin, 2003). It was for this reason that the variable quadrant method was used in this study. According to this method (Coetzee and Gertenbach, 1977), each quadrant square starts at a minimum of 10 m × 10 m followed by 20 m × 20 m, 30 m × 30 m, 40 m × 40 m and ends at 50 m × 50 m. Species were recorded according to their given height classes. The quadrant is namely actually a square with centre at the centre of the cross and divided by the cross into four quarters, each size of the largest test square (Coetzee and Gertenbach, 1977). The height classes were 0-0.5

m, 0.5-1 m, 1-2 m, 2-3 m, 4-5 m, and 5-6 m. Moreover, to determine the appropriate quadrant size for each height class, at least one individual woody plant of the height class of interest must be found in each of the 5×5 m quadrants (marked by the 5-m mark on the rope) around the mid-point in one or more of the four quadrants, then the quadrant size is expanded another 5 m. The expansion, thus, continues at 5 m intervals until all four quadrants have at least one individual of that height class.

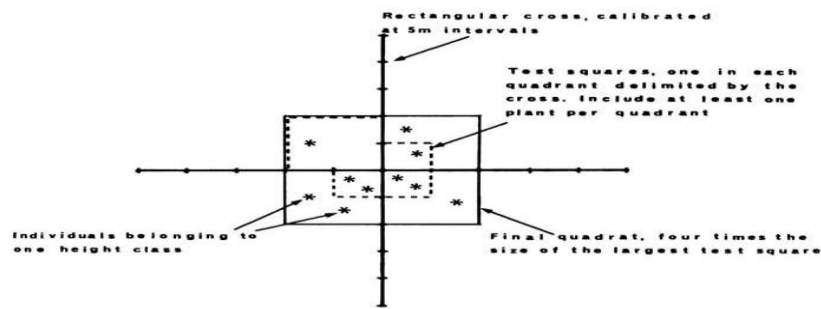


Figure 4.1: Procedure for determining quadrant size for a height class, e.g. 1 m tall plants (Coetzee and Gertenbach, 1977).

For each height class, the phytomass (Tree Equivalents (TE) ha^{-1}) was calculated, using the formula, $\text{phytomass} = n \times h \times 1.5^{-1}$ (n , number of plants ha^{-1} ; h , mean height of the shrub or tree (m) (Dreber *et al.*, 2014).

Moreover, according to this method (Coetzee and Gertenbach, 1977), canopy regime for all woody plants is calculated from the average maximum canopy diameters at that height level ($A = \pi \cdot r^2$). Canopy cover is calculated as a horizontal spread of the canopy diameters and is expressed as percentage of sampling unit area. Canopy cover was not determined in this study.

4.1.3 Methods to quantify woody species

For this study, the woody structure and composition were recorded per species and height class at different height levels in all three sites (Lekung, Masutlhe 1 and Masutlhe 2, Figure 4.1). The quadrant size was thus determined independently at each sampling site for each tree height class and thus recorded (Figure 4.1). Figure 4.1 illustrates the procedure for 1 m high plants. The procedure by Coetzee and Gertenbach (1977) was

repeated at each site to determine a suitable quadrant size for each height class. Thus, for each height class four test squares were determined and recorded on a data sheet.

The total densities of woody plants was determined as tree equivalents per hectare (TE ha⁻¹) (Hagos and Smit, 2005). According to Hagos and Smit (2005), a tree of 1.5 m meters tall, represents 1 tree equivalent (TE) (Hagos and Smit, 2005). It is important to note that the total of each class was thus calculated separately.

The data collected by using the variable quadrant method (Coetzee and Gertenbach, 1977) were used as training data to confirm the remote sensed data to so as to identify and map the different categories of bush encroachment (Chapter 5). The guidelines adopted by the Department of Agriculture used to describe the extent of bush encroachment are shown in Table 4.3 adapted from (Moore and Odendaal, 1987; Bothma, 1989; National Department of Agriculture, 2000).

Table 4.3: Indication of the extent of bush encroachment TE ha⁻¹ (Moore and Odendaal, 1987; National Department of Agriculture, 2000).

Tree equivalents per hectare TE ha ⁻¹	Extend of bush encroachment
200-457	Encroached (grass production declines linearly)
458-714	Highly encroached (Grass suppressed further)
715-1099	Severely encroached (More grass suppression)
>2000	Grass growth almost suppressed

4.2 Data analysis

4.2.1 Ground truthing

Data collection by recording the woody species in each site per height class was undertaken during ground truthing. The data were analysed using bush equivalent factors at different height classes by multiplying the number of individuals recorded by the factor

for the individual height classes (1 TE = 1 tree of 1.5 m; therefore 2 TE = 1 tree of 3 m, etc.) (Tainton, 1999).

According to Tainton (1999), the tree equivalent factor of $f = 0.33$ was used for species at height classes of less than 0.5 m and a factor of $f = 0.59$ was used for species height at 0.5 – 1.0 m. Moreover, a bush factor of $f = 1.00$ was used for species height of 1.0 – 2.0 m. Factor of $f = 1.67$ used for species at heights of 2, 0 – 3.0 m, $f = 2.33$ used for bush heights of 3.0 – 4.0 m and lastly $f = 3.00$ was used for bush heights of more than 4 m (Tainton, 1999).

4.3 Remote sensing methods

4.3.1 Selection of satellite images

SPOT images were selected for this study primarily because of the requirement for high spatial resolution and availability. SPOT has a number of benefits over other space borne optical sensors. Its fine spatial resolution and pointable sensors are the primary features for this popularity. Moreover, SPOT allows applications requiring fine spatial detail to be addressed while retaining the cost and timelines applications of SPOT data. The potential applications of SPOT data are numerous. Applications requiring frequent monitoring are well served by the SPOT sensors (Huang and Seigert, 2006).

4.3.2 Image processing

4.3.3 Pre-processing

Pre-processing is aimed at correcting degraded or distorted data to create a more truthful representation of the original scene. This typically involves the initial processing of raw image data to correct for geometric distortions, atmospheric correction or normalization, image registration, and masking and to eliminate noise present in the data (Cheng *et al.*, 2004).

4.3.4 Geometric rectification

Geometric correction or rectification is critical for performing a digital change detection procedure. The SPOT image imagery of 2004 was used as a reference because it had already been orthorectified and georeferenced to the UTM map projection. Thus, image-

to-image registration was done to co-register all the images to the base image with a Root Mean Square (RMS) error of less than 30 meters. The RMS is the error term used to determine the accuracy of the transformation from one coordinate system to another. It is the difference between the desired output coordinate for a ground control point (GCP) and the actual (Sharma *et al.*, 2010). Using ground control points (GCP's) that were visually identifiable on the images, the SPOT images were geometrically registered to a common projection (UTM WGS 84) using the geometric correction function in ERDAS Imagine 2015. Pixel sizes varied slightly so that before analysis, the 2014 imagery was resampled, degrading from 5m to 20m resolution using nearest neighbour resampling, this ensured that the resolution of all imagery was equal, and therefore comparable.

4.4 Image processing

Image processing was undertaken using ERDAS Imagine 2015 software with additional mapping and processing undertaken using Arc GIS 10.3.1. The images were subset to the size of the study area in order to include only the area of interest for all the three images. It is always beneficial to reduce the size of the image file in order to include only the area of interest. This reduction of data is known as sub-setting. Sub-setting the study area eliminates the extraneous data in the file and speeds up the processing. This process cuts out the preferred study area from the image scene into a smaller more manageable file (Fernandez-Manzo, 2015).

Texture analysis was employed in delineating the woody cover. According to Haralick *et al.*, (1973), image texture characteristics can be defined as a function of the spatial variation in pixel intensities contained in an image, which is often signified as grey scales. In addition, image texture response describes the fineness, coarseness, contrast, regularity, directionality and periodicity in an image (Haralick *et al.*, 1973). For the remote sensing investigations, the image texture response therefore contains important information about the spatial and structural arrangement of the remotely sensed objects (Tso and Mather, 2001).

Moreover, texture analysis is used to retrieve spatial information contained in the section that is related to the different object types in the scene for evaluation. For semiarid

savanna studies, researchers have demonstrated that, structural and spectral information can lead to significant improvement in woody cover assessment. The output texture image generated can be correlated directly or used together with other multispectral raw or transformation land cover classification (Puissant *et al.*, 2005). In this regard, the role remote sensing plays in dry land savanna environments can be enhanced when texture information is incorporated in the analysis (Fisher, 2013)

Texture analysis was used in this research as it proved to be a good indicator of woody plant density in savannas. Thus texture analysis was employed in delineating the woody cover. The smallest size window 3×3 was judged to be optimal so as to detect small crown woody vegetation. The Mean Euclidean Distance operator was judged to be the most suitable option. Woody vegetation was then delineated on the resulting texture images, by automated clustering using the K-means algorithm in ERDAS. An unsupervised classification with three classes (woody vegetation, grass and bare land) was carried out on the three images following the maximum likelihood classification algorithm. Unsupervised algorithms compare pixel spectral signatures to the signatures of computer-determined clusters thus assigning each pixel to one of these clusters (Jensen, 1996).

The resulting texture analysis unsupervised classification was then used to assess the differences in woody cover across the acquired imagery. The spatial overall trend in area of the image classification classes was examined. Since much concern within the study areas is regarding woody vegetation, this analysis was limited to woody cover.

CHAPTER 5

WOODY PLANT ENCROACHMENT IN STUDY AREA

5.1 Encroachment and expansion of woody plants in Masutlhe and Lekung

5.1.1. Bush encroachment in the benchmark sites of Masutlhe and Lekung

According to Tainton (1999), a benchmark site is one whose veld is in an excellent condition in terms of management objectives. A veld benchmark is thus veld with the best possible botanical composition and cover (excellent condition) in relation to the prevailing climate (Tainton, 1999). A benchmark is used for comparison or rating with veld in the same ecological zone or experiencing the same macroclimatic conditions to differentiate between the influences of climate and management (Tainton, 1999; De Klerk, 2003). According to Tainton (1999), the selection of survey sites (benchmark) must represent the veld unit which is to be assessed.

Two benchmark sites were selected in this study where two different management regimes were practiced (Figure 3.2). One benchmark was in Masutlhe Village (benchmark 1) (communally managed) while another was in close proximity of the Mafikeng Airport (benchmark 2) (commercially managed) to detect any relationship between encroachment and land tenure. The two benchmarks were selected as the most feasible options on the basis of their vegetation component as they were situated within the same ecological setting, as the research site (study sites). A second benchmark site was chosen because to locate a benchmark site in a communally managed area that was still in an excellent condition, was hard to find.

Benchmark site 1 was, therefore, compared with study site 1 (Lekung) while benchmark 2 was compared with study site 2 and 3 respectively (Masutlhe 1 and Masutlhe 2) (Figure 3.2, Chapter 3). The benchmark sites were chosen according to the similarities of species composition in the study sites. Moreover, the second benchmark site was chosen due to the distance between the second and third study sites. It was therefore important to locate a second benchmark site for accuracy and as a point of reference in order to establish the extent of the encroachment of species and the variety or similarity of species present in both

the study sites and the benchmark site. A suitable and ideal benchmark site is imperative when dealing with the extent of woody plant species within the area. Therefore, to effectively get the desired results, two benchmark sites were chosen for this study. Species diversity within this benchmark site (benchmark 1) and study sites (1) (Figure 5.2) is dependent on a variety of biotic (e.g. competition, symbiosis, predation) as well as abiotic factors, such as rainfall, temperature, fire, soil type and nutrients (Dye and Spear, 1982; Smit and Swart, 1994; Tainton and Hardy, 1999).

5.1.2 Bush encroachment in Benchmark 1

The benchmark was chosen as a suitable benchmark (reference site) (Section 3.2) and was kept away from human and animal influence. This area was communally managed (under communal land tenure) and in close proximity to the research sites in Lekung (Refer to Figure 3.2). The reference site 1 (benchmark 1) was used to serve as a reference for study site 1 (Lekung).

There was evidence of species variation within this benchmark site (benchmark 1) as compared to study site 1 (compare figures 5.1 and 5.5). This benchmark (1) site (Lekung Village) was unique in that it was characterized by a thick grass layer (*Eragrostis lehmanniana*) and an even distribution of trees which was not the case within the two study sites. Though the species occurrence within the benchmark site was similar to that of the two study sites, the density and distribution differed substantially (compare figures 5.1 and 5.5).

The most prominent woody species within this reference site (benchmark site) was *Vachellia tortilis* (Figure 5.1). *Vachellia tortilis* dominates extensive regions of semi-arid ecosystems in Africa and the Middle East (Zohary, 1973; Ross, 1981). Milton and Dean (1995) stated that ecological studies focusing on such ecosystems have shown that *Acacia* trees play a role in structuring associated plant communities by modifying solar radiation, soil moisture and nutrient concentration available to understory plants. This implies that *Acacia* trees will eventually have an effect on the herbaceous development. *Vachellia tortilis* is an important species in the pre-Saharan Tunisia zone (Maslin *et al.*, 2003). According to Maslin *et al.* (2003), *Acacia* is a large genus with approximately 1 350 species. Four subspecies of *Vachellia tortilis* are recognized in arid and semi-arid Africa and the Far East (Wickens *et*

al., 1995). According to Abdullah *et al.* (2008), *Vachellia tortilis* is a species that is able to tolerate extreme drought (in the range 20 to 200 mm), through special adaptations such as deep lateral roots and partial shedding of leaves in the dry season.

The woody plant population locally (Benchmark 1) was dominated by *Vachellia tortilis*, that was present at a density of 322 TE ha⁻¹ (Figure 5.1). *Ziziphus mucronata* was the only other woody encroacher present (Figure 5.1). *Ziziphus mucronata* is identified as a species that grows in areas dominated by thorny vegetation in both temperate and tropical climates (Gedda, 2003).

Woody species density within the 0.5 height class (woody species with a maximum height of 0.5 meters) occurred at a density of 15 TE ha⁻¹ (Figure 5.2). Large (5-6 m high) trees were widely distributed and occurred at a density of 202 TE ha⁻¹ (Figure 5.2). According to Treydte *et al.* (2007), the stronger effect of large trees compared to medium-sized trees, reduces herbaceous biomass that increases soil moisture. Soil nitrogen is higher under large trees than under medium-sized trees and large trees improve the quality of the herbaceous layer in terms of grass digestibility, nitrogen, phosphorus and gross energy. *Acacia* trees do not compete directly with the grasses for water and nutrients because of their deep tap root systems, which would then explain the high presence of grasses in the benchmark site as compared to the research sites (Treydte *et al.*, 2007).

The benchmark was similar to the benchmark used by Mogodi (2009), in a communally managed benchmark site, showed both benchmark sites having similar natural veld with large scattered trees and a thick grass layer. Moreover, the species composition within both benchmark sites, were similar with species such as *Vachellia tortilis* and *Ziziphus mucronata* being the two common woody species observed. Although the species occurrence within the benchmark sites was similar, the densities differed substantially. Mogodi (2009) recorded densities of 44 TE ha⁻¹ for *Ziziphus mucronata* and 46 TE ha⁻¹ for *Vachellia tortilis*. Woody plants with similar heights were recorded by Mogodi (2009) in Disaneng and the Masutlhe benchmarks (Figure 3.3) with large trees (with a maximum height of 6 m) being the most abundant. Mogodi (2009), recorded 6 metre high trees at a density of 407 TE ha⁻¹ and 0.5 m high woody shrubs at a density of 200 TE ha⁻¹. Woody species within the 0.5 m height class was limited in benchmark 1 and occurred at a density of 15 TE ha⁻¹ (Figure 5.2). According

to Scholes and Walker (1997) and Stuart-Hill *et al.* (1987), large trees are able to promote grass growth beneath their canopies but the net result is dependent on tree density.

Research done by Comole (2014), in Tshidilamolomo, indicated that trees were scattered at a density of 1 110 TE ha⁻¹, while grasses were limited. The non-encroacher and slow growing, *Vachellia erioloba* was the most abundant species present (Comole, 2014). These findings were not consistent with the results found in Benchmark 1 (Figure 3.2, Chapter 3) of this research (Figure 3.2, Chapter 3), where *Vachellia tortilis* was the dominant encroacher. Moreover, woody plant invasion in Makgori Village (benchmark) (See Figure 3.2, Chapter 3) (Comole, 2014) recorded a limited woody plant population at a density of 297 TE ha⁻¹. Although *Senegalia mellifera* contributed the most to bush encroachment in the sites surveyed by Comole (2014), species such as *Vachellia tortilis* and *Ziziphus mucronata* were more obvious locally. The mutual occurrence of *Vachellia tortilis*, *Ziziphus mucronata* and *Grewia flava* was thus the common trend in the Molopo District.

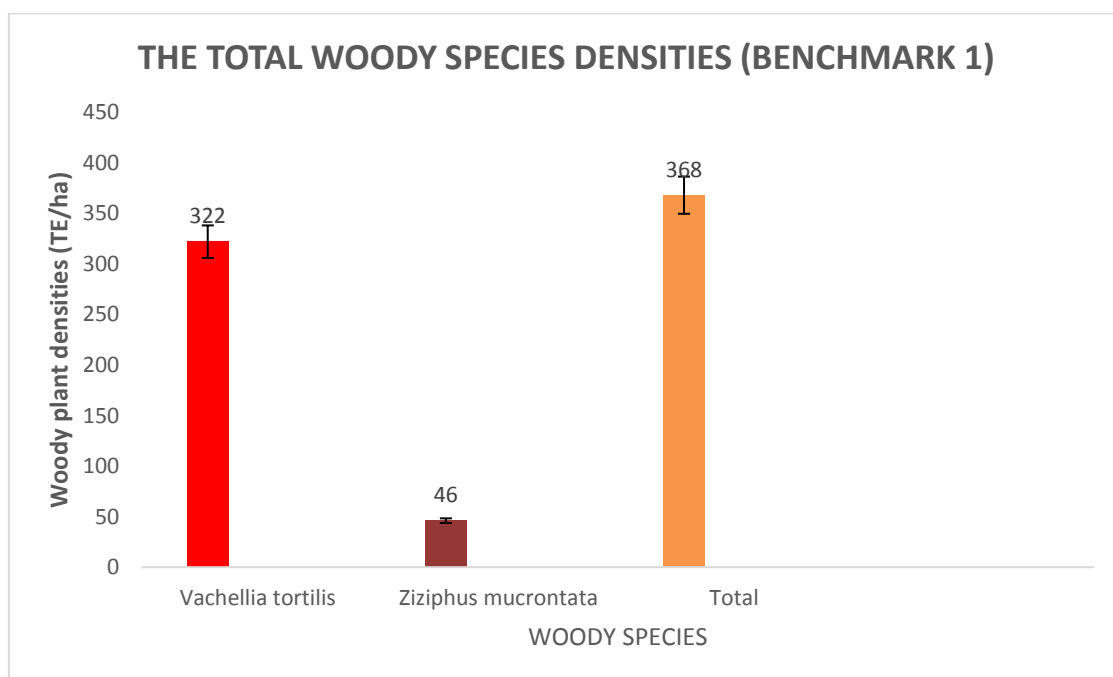


Figure 5.1: Woody species densities in the Benchmark 1

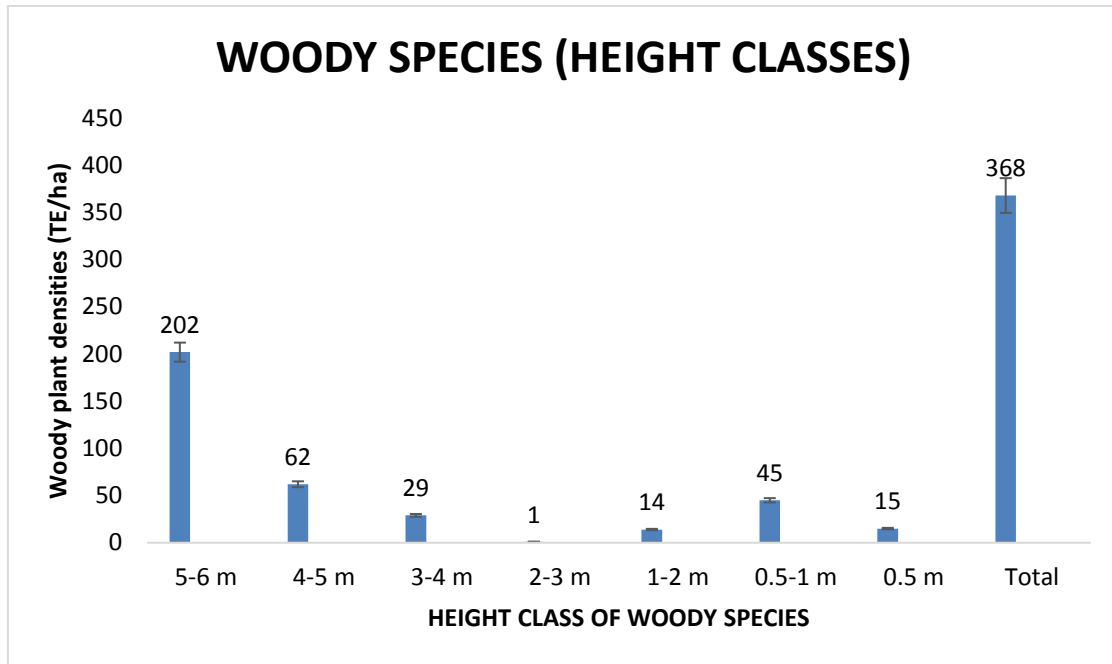


Figure 5.2: Woody plant densities in Benchmark 1 according to height classes

5.1.3 Bush encroachment in Benchmark 2

This reference area (benchmark 2) was situated within a commercially managed area (Figure 3.2). This benchmark site was compared with study site 2 and 3 Masuthe 1 and 2 (Figure 5.7 and 5.9).

Vachellia tortilis and *Ziziphus mucronata* were the only two woody species present with densities of 909 TE ha⁻¹ and 146 TE ha⁻¹ respectively (Figure 5.3). Of significance here, was the absence of grazing by cattle and human interference. The total bush density, however, was recorded at 1 055 TE ha⁻¹ (Figure 5.3).

Four to five metre (4-5 m) high *Vachellia tortilis* trees were the most abundant and occurred at a density of 790 TE ha⁻¹ followed by the 5-6 m tall trees and 3-4 m tall trees at respective densities of 250 TE ha⁻¹ and 201 TE ha⁻¹ (Figure 5.3). *Acacia* species are distinct distinguished by characteristics such as their ability to re-sprout and their investment in defensive characters such as spines and dense, hardwood impregnated with resins and crystals (Nakafeero *et al.*, 2007). According to Nakafeero *et al.* (2007), *Vachellia tortilis* inhibits the germination and seedling growth of a number of crop species. *Ziziphus mucronata* occurred at a higher density of 146 TE ha⁻¹ (Figure 5.3). *Ziziphus mucronata* is

usually a shrub or a medium-sized tree of up to 9 m tall. It grows in areas dominated by thorny vegetation in both temperate and tropical climates (Nakafeero *et al.*, 2007). According to Tefera *et al.* (2007) the grass layer on government ranches (commercial) which is commercial is in relatively good condition while in traditional grazing reserves (communal rangelands), the grass layer is in a poor condition (limited). The overall growth patterns of grass species indicated that a government ranch (commercial) had a better grass species composition (*Eragrostis lehmanniana* and *E. rigidior*) in land-uses such as grazing lands, fuel-cutting and habitation by humans (Tefera *et al.*, 2007). These changes reduced current availability of natural resources and will continue to reduce resource production in the future.

This reference area (benchmark 2) was characterized by large trees (5-6 m and 4-5 m tall, Figure 5.4) and the presence of grasses when compared to that of study site 2 and 3. Smith (2004) hinted that an increase in woody plant abundance is primarily brought by the increase in the biomass of already established plants (vegetative growth) and by an increase in density, mainly from establishment of seedlings (production). Four to five meter high trees (trees with a maximum height of 5 meters) were the most abundant in this benchmark site and this was significantly different from study site 2 and 3 (Figure 5.10). A survey done by Molatlhegi (2008), in a benchmark site near Disaneng (Figure 3.2) in the Molopo Area demonstrated that only two *Vachellia* species were the prominent encroachers, namely *Vachellia hebeclada* at a density of 450 TE/ha and *V. tortilis* at a density of 100 TE/ha. The only other woody species present locally included *Ziziphus mucronata*. However, research done by Mogodi (2009), (commercially managed area) recorded a total woody density 2 244 TE ha⁻¹. *Ziziphus mucronata* was the only common species found in the Loporung (See Figure 3.2) (Mogodi, 2009) and this reference site.



Figure 5.3: Woody species densities in Benchmark 2

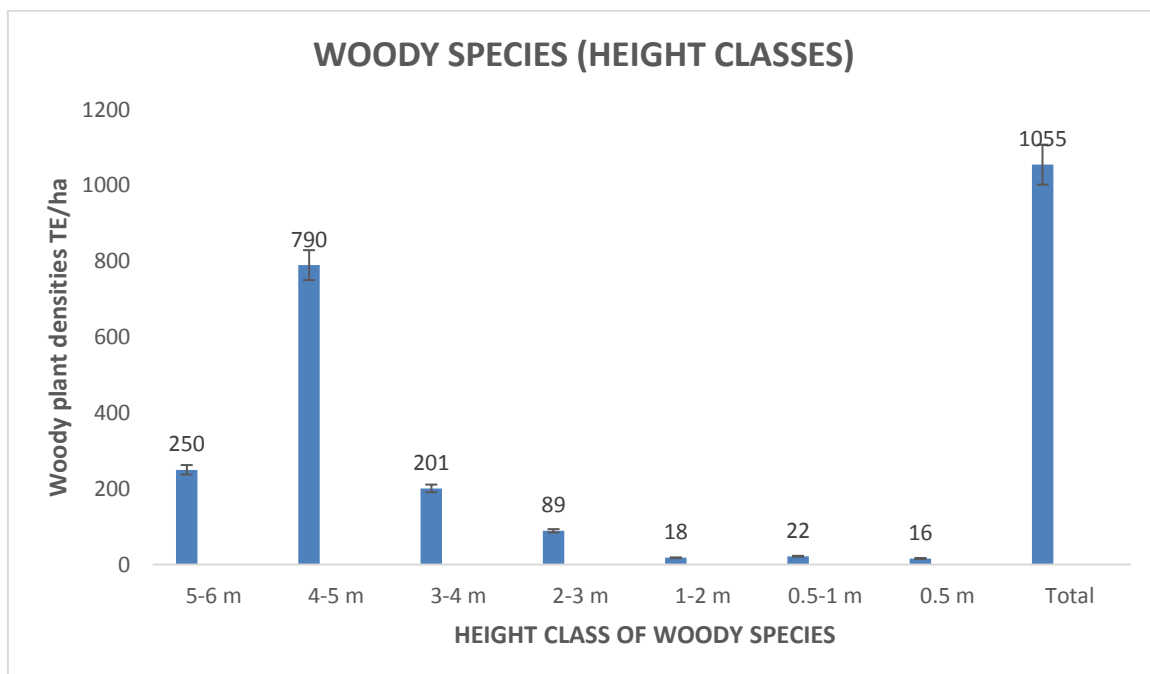


Figure 5.4: Woody plant densities in Benchmark 2 according to height classes

5.2 Bush encroachment in Lekung and Masutlhe villages

The extent of woody plant encroachment in the savanna has been a subject of several studies in southern Africa (Gram, 2004).

The presence of encroachment of woody species in the Lekung and Masutlhe villages has been highlighted by Ross (1979) and *Vachellia tortilis* was documented as the most widespread, drought-resistant and heat-tolerant species in arid and semi-arid rangelands (Fagg and Stewart, 1994). The survival of *Vachellia tortilis* and its existence in arid and semi-arid Northern Africa and Arabian Peninsula is due to its ability to endure harsh conditions. Therefore, it generally forms pure open stands in those drylands (Abdelrahman and Krzwinski, 2008). Wherever it grows, it plays an important role in human, animal and other plant species existence. Woody plants play important roles in ecosystem functioning and services. For instance, woody species can reduce soil erosion and slow down desertification (Young, 1989) by covering the soil surface.

Leguminous trees, such as *Acacia* species, improve soil nutrient availability (Gedda, 2003) and improve the environment for the growth of highly palatable grasses (Gedda, 2003). According to Hagos and Smit (2005) cognizance must be taken of the potential role of *Acacias* in enhancing and maintaining elevated levels of soil nutrients on these nutrient poor sandy soils. Woody encroachers such as *Senegalia mellifera* hold an advantage to the soil nutrient status and must be considered to be controlled partially in order to maintain some positive effects it has on the soil nutrient status (Hagos and Smit, 2005). According to Abdullah *et al.* (2008), *Vachellia tortilis* subsp. *raddiana* acts on the structure of the herbaceous vegetation by modifying its composition and cover. According to Akpo and Grouzis (2004), species richness is higher under the tree canopies than in the open. *Vachellia tortilis* population is considered as a pseudo-savanna with scattered tree - or shrub individuals of *V. tortilis* associated with several grass species, shrub and ligneous species. Abdullah *et al.* (2008) hypothesized that *Vachellia tortilis* could facilitate the growth of its understory vegetation by improving ecological conditions beneath its canopy. Moreover, *Vachellia tortilis* was expected to enhance soil nutrient content and improve soil structure by adding organic matter to the soil (Abdullah *et al.*, 2008). Abdullah *et al.* (2008) further suggested that *Acacia* trees reduce water loss by soil evaporation, mainly in spring, when plants are in maximum growth period.

5.2.1. Bush encroachment in Lekung village (study site 1)

This area at large is characterised by wide distributed vegetation, probably due to overgrazing, and where *Vachellia tortilis* encroachment was evident. Thus this site differs significantly from the benchmark site (benchmark site 1, Figure 3.2), as it was subjected to overgrazing by cattle and human interference such as chopping of wood and littering. According to Wigley *et al.* (2009) and Yusuf *et al.* (2011), bush encroachment is especially evident in communal areas as compared to commercial areas, but the encroachment is considered to be an advantage by local residents because of the fodder production for browsers and the increase in woody material that can be used as firewood, for kraal and house building purposes.

Surface erosion within this site had varying levels of trampling by cattle ranging from moderate to high. Moreover, the absence of fencing of the study site renders it vulnerable to over-exploitation, mismanagement and overutilization of resources which was not the case in the benchmark site (1) (Figure 3.2). Prevalent woody plants in Lekung, included *Vachellia tortilis*, *Ziziphus mucronata* and *Grewia flava* (Figure 5.5).

The reference site was chosen due to the same geographical setting and vegetation similarity as compared to the study site. The fenced off area was ideal, as it had previously been subjected to the same disturbances (such as trampling and resource exploitation) and was undergoing rehabilitation which included the reference site being fenced off.

According to Bothma (2002), heavy grazing leads to soil compaction and this lowers the soil water content due to runoff and causes ‘difficulties’ for seedlings of many herbaceous species to emerge from the soil, while Wiegand *et al.* (2002), suggested that without grazing, both grass and tree biomass increase linearly with increasing rainfall.

The presence of perennial grasses such as *Eragrostis lehmanniana* and *E. rigidior* in the benchmark site was evident, however, this was not the case within this study site where dense bushes completely suppressed the grass cover. Kraaij and Ward (2006) and Joubert *et al.* (2008), argued that a vigorous perennial grass cover may reduce bush seedlings and saplings through competition for water, but whether it prevents the establishment of young bushes or not is still debatable. According to O’Connor *et al.* (2014) severe livestock grazing

or wildlife could promote bush encroachment by reducing the fuel load and grass competition. Historical changes in grazing pressure are central to understanding bush encroachment, specifically the effect of disease pandemics and the pattern of increase in livestock numbers, through their impact on grass competition and fire suppression and seed dispersal (O'Connor *et al.*, 2014).

Overgrazing is the most likely reason why these woody species and especially *Vachellia tortilis*, encroached in the study site (See Figure 5.5) as compared to the benchmark site (Figure 3.2). *Vachellia tortilis* is one of the most common species in arid and semi-arid regions across Northern Africa and the Arabian Peninsula (Wickens, 1998; Anderson, 1999; Shaltout and Al-Sodany, 2002). According to Ayyad and Gharbhour (1986), *Acacia* species are well adapted to anthropogenic pressures they are the sole source of animal fodder, firewood and shelter for nomads. The effect that herbivores can have on the herbaceous layer, which ultimately leads to the encroachment of woody species, is well documented (Anderson and Walker, 1974; Guy, 1981; Barnes, 1985; Lewis, 1991; Styles, 1993). Recent studies show that plant-herbivore interactions also depend on the community context, in the way that herbivores, for example, optimize their forage intake in relation to plant species composition and food distribution (Baraza *et al.*, 2006).

Fire suppression was evident within this site. Fire suppression was reported or considered to have been frequent and widespread across the savanna and grassland areas of South Africa during the 19th century (Grout, 1861; Brooks, 1876; Brynand, 1971). According to O'Connor *et al.* (2014), fire suppression would include any instances of a reduction in the frequency or intensity of fire compared with the natural historical burning regime. In general, fire has a strong negative impact on the survival, growth, adult recruitment and seedling regeneration of woody plants (Bond and Van Wilgen, 1996). According to Trollope (1980), bushes flourish because of fewer hot fires at the start of the rainy season, when grasses are more sensitive. Fire may be infrequent in semi-arid savannas, but a single fire can have a pronounced negative impact such as 31% tree mortality of *Senegalia mellifera* and 35% mortality of adult *Vachellia erioloba* in the Kalahari (Van der Walt and Le Richie, 1984). According to Tiver and Andrew (1997), long-term browsing of taller shrubs and trees by goats was reported to have a significant negative effect on their recruitment and regeneration. During the two years (2013-2014) of observation during this study, the adult

population of trees and shrubs had declined considerably. This is due to a combined result of drought and tree-cutting and to a lesser extent overgrazing and mobility (Kenneni and Van der Maarel, 1990). In the site under prolonged combination of drought and exploitation, the local population of *Vachellia tortilis*, at least on drier soils, may be exterminated within a few decades. However, the establishment of *Vachellia tortilis* seedlings, therefore, do not require an initial wet season for seed production (Coe and Coe, 1987). Certain woody plant seedlings increase because large herbivores browse the pods and disperse the seeds. This implies especially in the dry season when palatable grasses are in short supply as compared to bush species with tasty pods.

The experimental sites differed in species diversity and woody plant density as compared to the reference site (benchmark 1, Figure 3.2). Roques *et al.* (2001), revealed that bush encroachment on communal land with subsistence cattle and goat farming has increased from approximately 3% to 40% in 50 years. By comparing this study site 1 to the benchmark site (Compare, figures 5.1 and 5.5), it is evident that bush encroachment, may be seen as a form of land degradation (Donaldson, 1966). This is mainly because of a decrease in grass development and an increase in woody plant density, especially *Vachellia tortilis*.

Study site 1 was dominated by thorny species, *Vachellia tortilis*, *Ziziphus mucronata* and *Grewia flava* (Figure 5.5). *Grewia flava* was absent in the reference site (Figure 5.1). This site had a more woody appearance than the reference site (Benchmark 1) due to prominence of *Vachellia tortilis* and *Ziziphus mucronata*. There were no traces of a grass cover, while the reference site had a dense layer of *Eragrostis lehmanniana*. The reduction in grass biomass makes room for shrubs to grow and reduces the probability of fire hot enough to kill shrub seedlings (Buffington and Herbel, 1965). Moreover, bush encroachment leads to suppression of palatable grasses by encroaching woody species, often unpalatable to domestic livestock (Lamprey, 1983; Scholes and Archer, 1997).

The total woody plant density was recorded at 3 650 TE ha⁻¹ (Figure 5.5), which will almost completely suppress grass growth. This was substantially higher than the woody plant density of 368 TE ha⁻¹ in the reference site (Figure 5.1). *Vachellia tortilis* was the sole dominant woody encroacher at a density of 1 899 TE ha⁻¹, followed by *Ziziphus mucronata* at 1 384 TE ha⁻¹. The reference site (Benchmark 1) recorded a density of only 322 TE ha⁻¹ for

Vachellia tortilis while *Ziziphus mucronata* was present at a density of only 46 TE ha⁻¹ (Figure 5.1). According to Bothma (1989), the indication of the extent of bush encroachment will result in the grass growth almost being suppressed.

Research done by Molatlhegi (2008), in Tshidilamolomo Village (See Figure 3.2) recorded *Grewia flava* at a density of 750 TE ha⁻¹ and declared it to be amongst the most prominent species in the area. Moreover, similar results within the Molopo area were recorded by Mogodi (2009). According to Mogodi (2008), *Vachellia tortilis* was the second most prominent woody species in the Setlhabaneng Village (See Figure 3.2), occurring at a density of 818 TE ha⁻¹ in an area dominated by *Senegalia mellifera*. Noteworthy were the presence of other common woody species such as *Grewia flava* and *Ziziphus mucronata*. The three common occurring woody species in Setlhabaneng Village (Mogodi, 2009) and in Lekung Village were notably *Vachellia tortilis*, *Grewia flava* and *Ziziphus mucronata*. *Vachellia tortilis* is adapted to dry conditions (Coates Palgrave, 1990). According to Coates Palgrave (1990), *Vachellia tortilis* is often one of the first woody plants to establish on disturbed (overgrazed) areas such as old lands. Total woody plant density in Setlhabaneng Village was recorded at 3 104 TE ha⁻¹ (Mogodi, 2009) while the total woody plant density locally was recorded at 4906 TE ha⁻¹ (Mogodi, 2009).

Research done by Comole (2014) in nearby Loporung Village (Figure 3.2) recorded a total woody plant density of 2 791 TE ha⁻¹ which almost totally suppressed grass growth. *Vachellia tortilis* dominated in Loporung and was present at a density of 1 693 TE ha⁻¹. The common trend of the occurrence of *Ziziphus mucronata* and *Grewia flava* was also evident with *Z. mucronata* recorded at a density of 479 TE ha⁻¹ and *Grewia flava* at a density of 100 TE ha⁻¹ (Comole, 2014). *Vachellia tortilis* trees within the 0.5 m and 4 m tall classes contributed the most to woody plant encroachment in Loporung (Comole, 2014).

According to Howaida *et al.* (2008), *Vachellia tortilis* is drought resistant, can tolerate strong salinity and seasonal waterlogging, has an ability to endure harsh conditions such as drought and trampling and generally forms open forests in pure stands or mixed stands in drylands. In this site, woody species with a maximum height of 4 meters (3-4 m height class) were the most abundant at a density of 1 783 TE ha⁻¹ (Figure 5.6) while 6 metre tall trees were evident in the reference site (Benchmark 1, Figure 5.1). Large trees were limited in this site and

occurred at a density of 202 TE ha⁻¹ (Figure 5.1). This is a clear characteristic of woody plant encroachment, where smaller trees are competing more intensively for resources, thus permitting them to grow larger (Tainton, 1999). It is apparent from many studies globally that the degree to which shrub encroachment leads to degradation and desertification can be influenced by the type of the particular shrub species involved (Ludwig and Tongway, 1995; Houeahanou, 2001; Cheng *et al.*, 2004; Peters and Havstadie, 2006). Maestre *et al.* (2009), hypothesized that the effect of woody species on ecosystem function was dependent upon traits of the encroaching shrubs (and trees), relative to those of the perennial grasses that they replace.

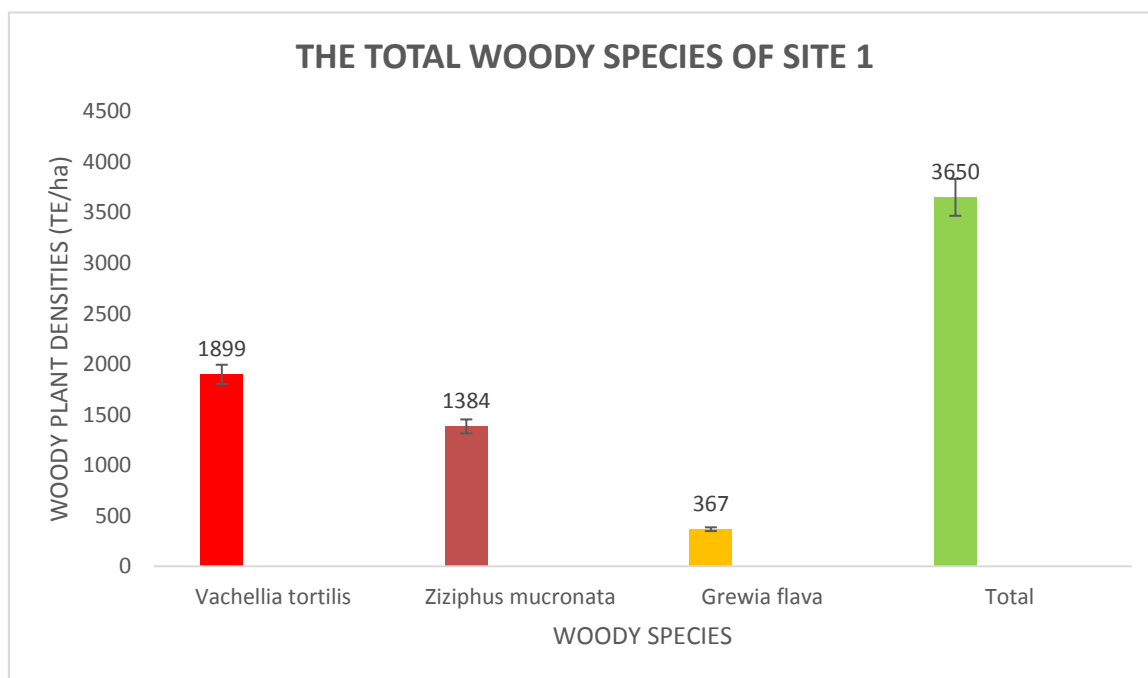


Figure 5.5: Woody species densities in study site 1 (Lekung village)

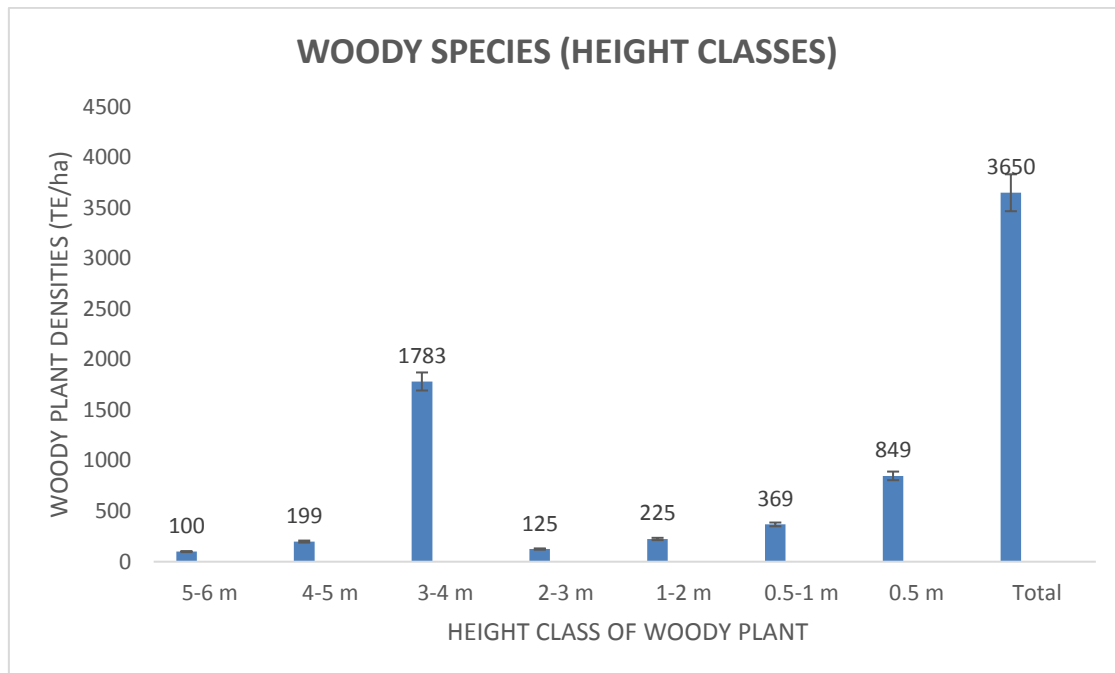


Figure 5.6: Woody plant densities in study site 1 (Lekung) according to height classes

5.2.2 Bush encroachment in Masutlthe 1 (study site 2)

Figure 5.7 indicates that, together with *Vachellia tortilis*, and *Ziziphus mucronata*, *Grewia flava* was also present at a density of 1 009 TE ha⁻¹. The latter was absent within the benchmark site (Figure 5.3). There were marked differences in both the cover and density of woody vegetation between this site and the fenced off benchmark. The total woody plant density in this site, was recorded at a density of 4 906 TE ha⁻¹ (Figure 5.7) as compared to the reference site with a woody plant density of only 1 055 TE ha⁻¹ (Figure 5.1). Due to the dense bushes, grasses were absent in this site.

According to Moore *et al.* (1988), competition experiments have shown that mature trees are competitively superior to grasses while grasses tend to out-compete immature trees. This asymmetry of competition between trees and grasses creates a pattern that outlines the dynamics of bush encroachment in the savanna (Moore *et al.*, 1988). According to Yusuf *et al.* (2008), the pattern and relative abundance of herbaceous and woody life forms in savanna-grassland ecosystems are governed by the interactions between climatic variables (e.g. rainfall amount and seasonality), topo-edaphic factors (e.g. texture, depth, soil fertility, run-off or run-on) and disturbance regimes (e.g. grazing, browsing, and fire). Moreover,

Scholes and Archer (1997), suggested that grazing effectively weakens the suppressive effect of the grass layer on young trees in a patch of a few hectares, leading to the conversion of an open savanna into a tree-dominated thicket (bush encroachment). This can be seen in the dense occurrence of 1 - and 3 m high trees which recorded a density of 2 337 TE ha⁻¹ and 2087 TE ha⁻¹ respectively (Figure 5.7), whereas in the benchmark site, large trees (5-6 m high trees) were the most evident (Figure 5.2). According to Eldridge *et al.*, (2011), bush-encroached plots also supported a lower cover of herbaceous vegetation than grassland plots. Plots where bush encroachment occurred had a lower woody species diversity than the non-encroached plots (Eldridge *et al.*, 2011). This was also found by Mogodi (2009), Wigley *et al.* (2009), Yusuf *et al.* (2011) and Comole (2014).

Soil erosion was evident in this site and was probably caused by long-term trampling by livestock. Bothma (2002) suggested that severe trampling by cattle leads to soil compaction, which increases soil surface erosion, especially by water runoff. The soil had a fine sandy texture and no rocks on the soil surface were noted. Overgrazing by livestock has a negative impact on soil structure through trampling and compaction of soil, thus reducing infiltration and increasing the rate of runoff. According to Coheen *et al.* (2007; 2010), cattle promote reproduction and regeneration of *Acacia* trees in Kenya. Most importantly, sheep were responsible for containing an increase of the invasive *Acacias* on rangeland in Queensland, Australia which proliferated on properties grazed only by cattle (Tiver *et al.*, 2001).

Cutting of trees was evident in the area. Cutting of trees in South African savannas is consequently a common practice, either for direct use or during bush control measures, often without herbicides being applied. Wood of *Vachellia tortilis* was generally used for fire wood and kraal building. Wigley *et al.* (2009) reported that communal residents preferred woody areas to open rangelands because of the availability of wood resources for house – and kraal building.

Knoop (1982), observed that on a site dominated by *Vachellia tortilis*, large numbers of seedlings germinated and survived in the site cleared of herbaceous vegetation, while few were found in a control plot. According to Smith and Goodman (1986) and Milton (1995), *Acacias* and other woody savanna plants are canopy intolerant. As a result competition between adult bushes and seedlings will prevent establishment of new bushes when the adult

bushes are still alive in a closed (bush encroached) savanna. These considerations show that the size of bush-encroached patches is determined by the size of the area within which the rainfall was sufficient for germination, seedling survival and the distribution of open savanna within this site (Smith and Goodman, 1986; Milton, 1995). Tree growth and inter-tree competition over time may convert bush-encroached patches to an open savanna (Smith and Goodman, 1986; Milton, 1995). This, however, will only happen if more browsers are introduced to the area and proper management mechanisms (camp system) are introduced.

Human influence within the area was significantly high with land-use and cattle grazing regularly unsupervised. According to Andrew (1984) and Halwagy (1962 a, b), human and animal interference may modify the performance and growth forms of many species involved in natural regeneration. This, therefore, explains the absence of grasses in this site as compared to the benchmark site.

The high density of *Vachellia tortilis* in this site (3 897 TE ha⁻¹, Figure 5.7) was due to the large clumps of species that were almost unpalatable and unreachable to cattle due to the thorns that restricted cattle from grazing. According to Scholes and Walker (1993), savannas are home to most of the human population in Africa. It is in these areas in which population growth is most rapid (Scholes and Walker, 1993). The rapid growth of the population, including livestock, within this area, is the main driver of dispersal and establishment of woody species. This is due to the fact that more grazers are introduced to the area and improper management due to the communal farming system ensues.

Although not part of this study, interviews with the residents within the site on a day-to-day basis, revealed that fire frequencies were almost totally suppressed. According to Van Auken (2000), lower fire rates promote woody plant recruitment and in the long run, may lead to shrub encroachment, which is evident in the site. Moreover, it should be noted that the benchmark area was under constant fire monitoring. It is obvious that suppression of fire frequencies through intensive grazing, reduces the risk of juvenile shrubs being killed by the fire. This does explain the varying differences in species diversity in this site (Figure 5.7), as compared to the reference site (Figure 5.2).

The woody plant density in the site Masutlhe 1, (Figure 3.2) was recorded as 4 906 TE ha⁻¹ (Figure 5.7) and was the highest recorded woody plant density in the entire study. Woody plants occurring at these densities will almost totally suppressed grass growth. This eventually will lead to soil erosion which was evident in the encroached sites. Archer *et al.* (1998) indicated that, introduction of woody vegetation, leads to an increase in the complexity of the local habitat structure and eventually a transition from a single to multiple-stratum environment. In general, shrub lands are likely to have a greater diversity of microhabitats than grasslands. As woody shrubs are shade intolerant (Hagos and Smit, 2005), shrub thickening will take place.

Over time, nutrients and water accumulate beneath the encroaching shrubs and allow shrub generation while a lack of suitable topsoil, nutrients and water in inter-shrub areas, prevents grass re-growth (Bhark and Small, 2003). Hagos and Smit (2005) reported that woody plants such as *Senegalia mellifera* play an important role in soil enrichment and that this must be kept in consideration when a bush clearing programme is initiated. Although soil analysis did not form any part in this project, *Vachellia tortilis* may also play a significant role in soil nutrient enrichment.

Vachellia tortilis was recorded at a density of 3 897 TE ha⁻¹, *Ziziphus mucronata* at 72 TE ha⁻¹ and *Grewia flava* at 1 009 TE ha⁻¹ (Figure 5.7). *Grewia flava* typically grows beneath the dominant tree species whereas, under cattle grazing, it may eventually encroach in tree interspaces (Skarpe, 1990). *Grewia* recruitment is associated with ‘good’ rainfall years and may outnumber mortality events and bad environmental conditions associated with bad rainfall years (Tews *et al.*, 2004). The palatable shoots and foliage of *Grewia* are important fodder for domestic livestock, however, when it reaches encroaching stage, it can prove to be a problem (encroachment) to the environment (Watt and Breyer-Brandwijk, 1962).

Grewia flava has been reported to severely encroach and form dense shrub thickets in savanna regions (Skarpe, 1990). *Grewia flava* grows beneath canopies of large *Acacia* trees (Schlesinger *et al.*, 1990). One possibility to increase *Grewia* encroachment is to isolate livestock from areas with high *Grewia* densities during the fruiting period. Cattle consume large quantities of *Grewia flava* seeds, but only when grasses are limited and spread them effectively via their dung (Tews *et al.*, 2004). According to Tews *et al.* (2004), changes in

precipitation pattern through climate change may alter *Grewia flava* populations, because of the strong link between rainfall and important life stages such as emergence and adult survival.

Vachellia tortilis is a keystone species, growing across arid ecosystems in Africa and the Middle East. According to Odendaal *et al.* (2010), in Africa, species of the genus *Acacia* often act as encroaching species, for example in Zanzibar, *Acacia auriculiformis* (Earleaf *Acacia*, Coates Palgrave, 1990) has been identified as a heavy encroacher. *Vachellia tortilis* and *V. erubescens* have been reported to increase in rangelands in Botswana (Odendaal *et al.*, 2010). In Namibia, *Senegalia mellifera* and *Vachellia reficiens* are among the main encroacher species (Joubert *et al.*, 2008). The roots of *Acacia* seedlings can reach depths of up to 1.2 m after 2 months in dry conditions as a strategy to effectively reach the fluctuating alluvial water table (Stave *et al.*, 2003).

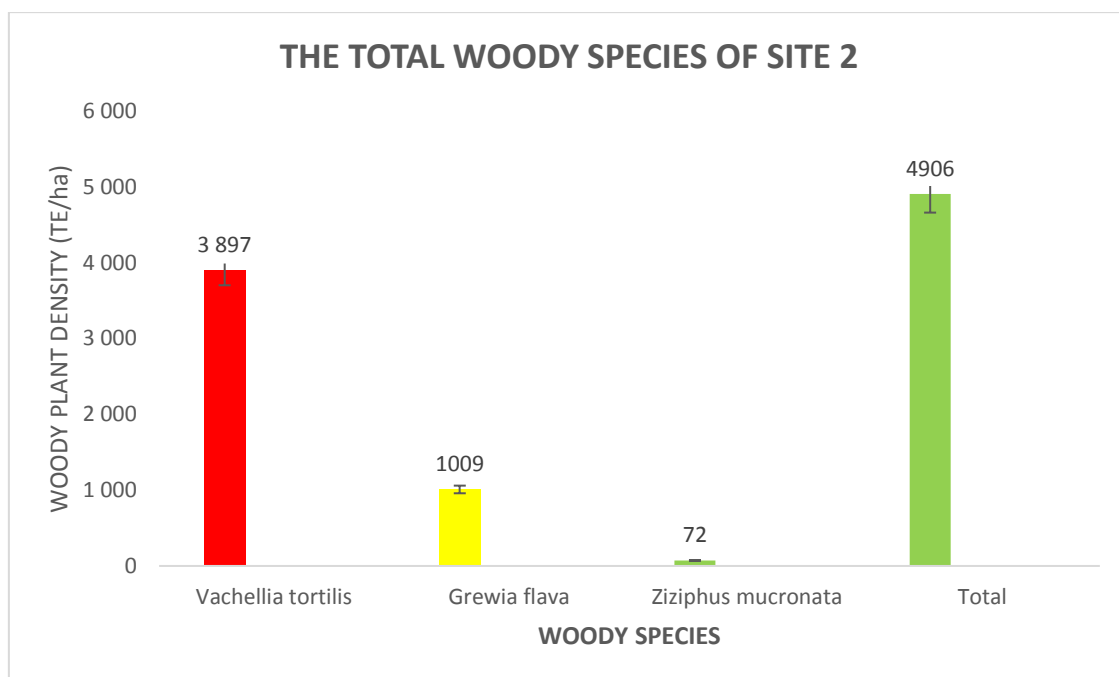


Figure 5.7: Woody species densities in study site 2 (Masutlhe 1)

One metre high woody plants (0.5-1 m height class) and 3 m high plants (2-3 m height class) were the most abundant in this study site II (Figure 5.8) as compared to the benchmark site where 4 to 5 m high trees were the most prominent (Figure 5.4). Young (1989), stated that,

under normal circumstances, woody plants play an important role in ecosystem functioning and services. Moreover, woody species can reduce soil erosion and slow down desertification (Young, 1989). Leguminous trees, such as *Acacia* species in particular, improve soil nutrient availability (Gedda, 2003; Hagos and Smit, 2005) and provide favourable environments for the growth of palatable grasses (Eldridge *et al.*, 2011). Archer (1995) and Roques *et al.* (2001) argued that, when woody plant density and cover increases beyond a threshold level, the problem outweighs the usefulness and the ecosystem degrades in the long term.

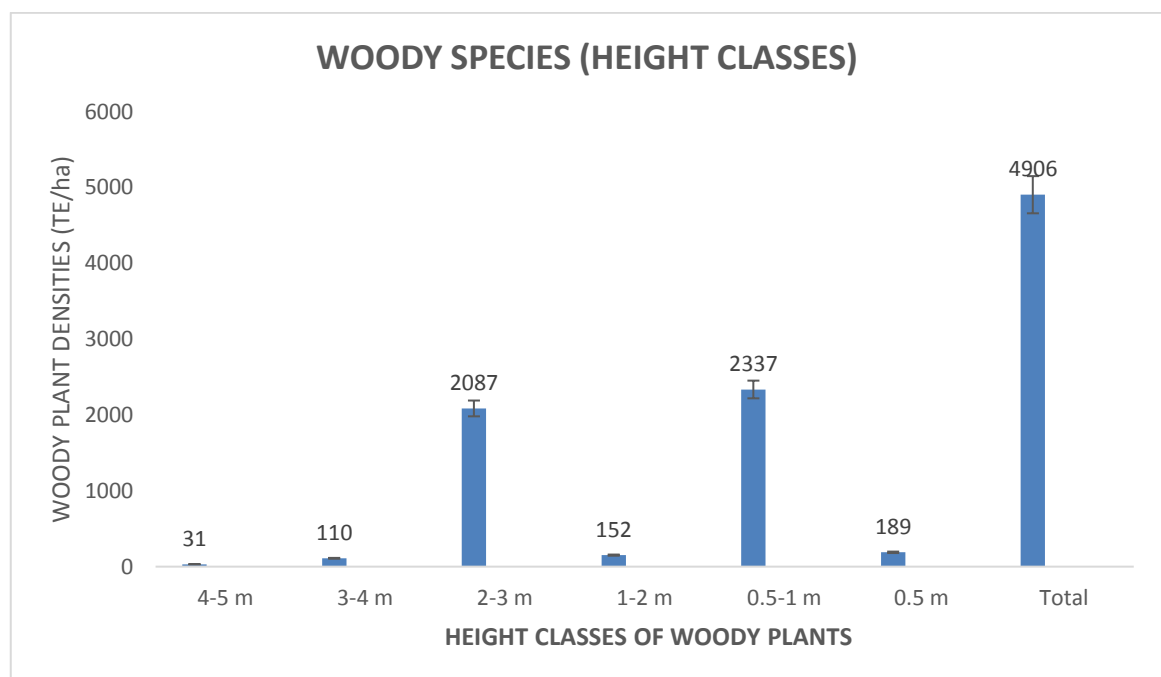


Figure 5.8: Woody plant densities of study site 2 (Masutlhe 2) according to height classes

5.2.3. Bush encroachment in Masutlhe 2 (study site 3)

Vachellia tortilis was the dominant species in Masutlhe 2 (3 999 TE ha⁻¹, Figure 5.9), compared to the occurrence of *Vachellia tortilis* and *Ziziphus mucronata* at lower densities in the reference site (Benchmark 2, Figure 5.3). The total woody plant density in this site (3 999 TE ha⁻¹) was substantially higher than in the reference site (1 055 TE ha⁻¹ Figure 5.3). In the two-metre high (1-2 m height class) and 4 metre high classes, *Vachellia tortilis* trees were found to be dominant in this study site (Figure 5.10). This was in contrast with the reference site (benchmark site 2) where 5 m high trees (4-5 m height class) were the most evident (Figure 5.4). This indicated that there were numerous

young woody encroachers in the study site, implying a more recent encroachment. The reference site also recorded 6 m high trees at a density of 250 TE ha⁻¹ (Figure 5.4), while large trees (taller than 5 meters) were limited in Lekung (Figure 5.9).

Findings by Mogodi (2009), within Selosesha Village, (Figure 3.2, Chapter 3) revealed *Senegalia mellifera* as the sole dominant encroacher, occurring at a density of 6 967 TE ha⁻¹ while within Masulthe 2 Village (study site 3, Figure 5.9), *Vachellia tortilis* was the dominant species occurring at a density of 3 999 TE ha⁻¹. The occurrence of *Senegalia mellifera* (Mogodi, 2009) and *Vachellia tortilis* in this survey site as dominant encroachers could be a result of intra species competition that suppresses growth of other trees (Tainton, 1999). It is important to note that inter - and interespecies competition have been regarded as significant determinants of the structure of woody plant communities in African savannas (Fowler, 1986; Shackelton, 2002). Mogodi (2009) reported that 1 m- and 2 m high *Senegalia mellifera* trees were the most abundant, whereas 2 m – and 4 m high *Vachellia tortilis* trees were in the majority in Lekung (Figure 5.10).

This area is being operated under free land tenure and, as a result, the land-users have no property rights and therefore take no particular interest in the securing the area and properly managing the natural resources. According to Bhenke (1997), in African pastoral land tenure systems, the natural landscape frequently is not carved into neat territorial packages owned by distinct groups or individuals, instead any defined area is likely to be used by a host of different ownership groups of variable size and composition with overlapping claims to territory derived from different categories of resources within it.



Figure 5.9: Woody species densities in study site 3 (Masutlhe 2)

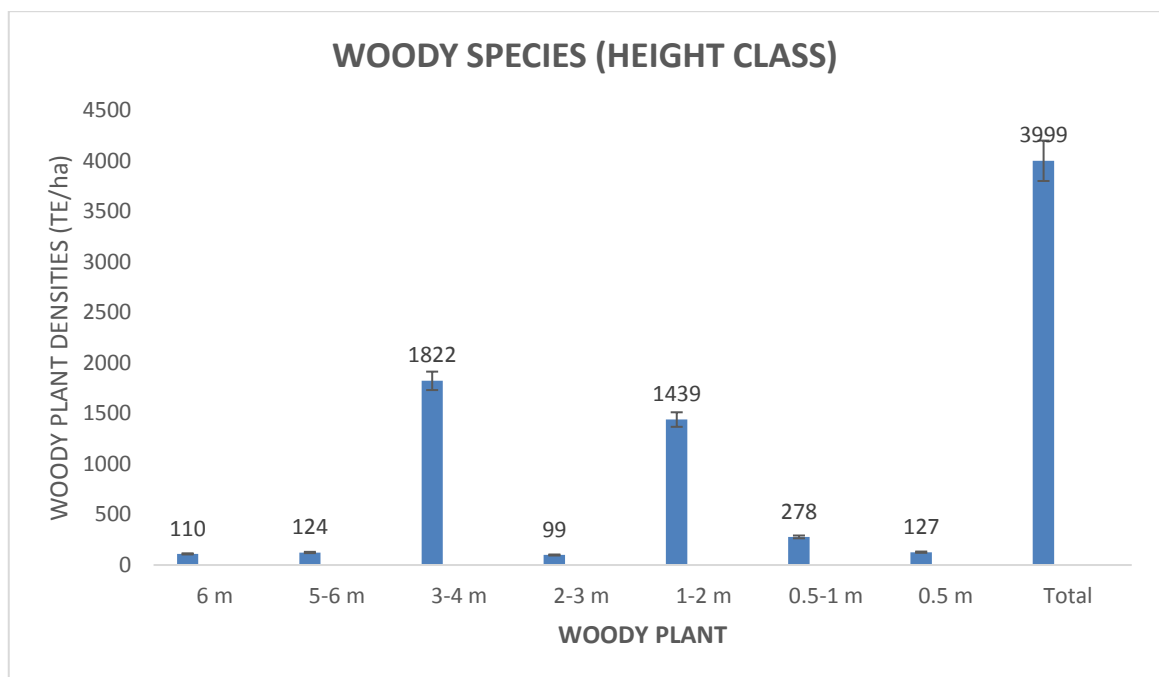


Figure 5.10: Woody plant densities in study site 3 (Masutlhe 2) according to height classes

Study site 3, in comparison to the benchmark, had a low species diversity (Figure 4.9). This is due to the dense coverage of *Vachellia tortilis*. West (1951) observed that overgrazed and

eroded hill slopes supported a thick growth of young *Acacia* trees because fire had been eliminated. In comparison to the other sites, this site was situated in close proximity to the benchmark site (Refer to Figure 3.2).

Human interference was prevalent in Lekung. Humans have been identified as the most powerful agent of changes in the ecosystem (De Korte, 1984). They are responsible for abiotic and artificially caused environmental changes such as cutting down of trees for wood, trampling of soil and overgrazing by cattle and footpaths caused by constant movement within the site. Many of their activities result in the modification of the actual soil surface by trampling and overgrazing by unmonitored animals. Their impacts can be accidental (such as acting from a point of ignorance and lack of education regarding conservation of natural resources) or deliberate (carelessly exploiting the soil for personal gain without any long-term consideration), direct (trampling and neglect of natural environment) or indirect (grazing of animals without herders present to facilitate rotational grazing). In some instances, human activities have altered the volume, composition and structure of the organic components and consequently the nature of the physical habitat (De Korte, 1984).

Browsers such as goats were present but due to the density of woody species in this site, movement by browsers was restricted, however goats were still the major contributors towards seed dispersal. According to Grunow (1980), browse being available does not necessarily mean that it will be eaten because of food preferences. A preferred food species is defined as one which is proportionally more frequent in the diet of an animal than it is in the available environment and food preference as the extent to which food is consumed in relation to its availability (Petrides, 1975). Browsers select among plant species as markedly as grazers do (Grunow, 1980). The plant's defence to browsing can take the form of chemical defences (compounds that are toxic or have digestibility-reducing effects) or mechanical defences (e.g. spines and thorns), which make food intake more difficult by reducing the bite size and biting rate (Bergstrom, 1992). Plant defences can make a species so unpalatable that it is totally rejected, or more commonly, that it is less preferred. Moreover, chemical defences of plants may include chemical substances which may be poisonous (Smith, 1992; Taylor and Ralphs, 1992), or reduce palatability (Robbins *et al.*, 1987; Bryant *et al.*, 1992).

Other animals noticed in the area include cattle, sheep and donkeys. Cattle are kept for milk production and meat, providing a ready source of household protein in a region where poor nutrition and high infant mortality are common. Bush encroachment refers to colonization of species in new or pre-existing ecosystems and dominates otherwise intact pre-existing native ecosystem (Dyke and Knick, 2003). This indicates the vast differences between the benchmark and the study site (Figure 3.10) and that woody species almost totally suppress grass development. Two metre and 4 m high trees were the most prominent in this site (Figure 3.10). This eventually leads to the lowering of the production potential of the area and thus has a direct effect on the well-being of residents.

The productivity and biodiversity richness in the study site is thus lower than that of the benchmark site. Accumulating evidence indicates that, in the past 50 years, savannas throughout the world are being altered by this phenomenon, known as bush encroachment (Ward, 2005). In general, these studies indicated that woody plant encroachment has been increasing over time. Ritcher *et al.* (2001), also showed that bush encroachment had a negative influence on grass biomass production and consequently decreased potential grazing capacity. Moreover, Ludwig *et al.* (1997) demonstrated that the shifts between tree-grass states are caused by disturbances such as heavy grazing pressure that diminishes perennial grasses.

Vachellia tortilis is adapted to dry conditions and is often one of the first woody species to establish on degraded areas like old lands (Coates Palgrave, 1990). It has a wide distribution and also occurs along dry riverbeds and is cold tolerant (Coates Palgrave, 1990; Smit, 1999); Grice (1996); Brown and Carter (1998) and Redford *et al.* (2001) stressed that, in the Kalahari, cattle may acts as dispersal agents of this species and thus contributing to seed distribution.

An important determinant of woody seedling establishment is competition from other plants (Smith and Goodman, 1983; Smith and Walker, 1983). Many researchers are of the opinion that seedling regeneration is a potential bottleneck of encroaching species that can negatively impact grass competition (Kanz, 2001; Ward and Elser, 2008). Smith and Goodman (1986) indicated that certain trees establish well beneath canopies of others, while others established better between canopies in open areas. Thus, sustained heavy grazing should therefore

promote woody seedling regeneration through reduction of grass competition, provided that seedling mortality is not increased through consumption and trampling (Joubert, 1966; Sweet, 1982). However, Eldridge *et al.* (2011) indicated that *Acacias* are canopy intolerant, implying that young trees do not grow beneath older trees. Moreover, in some regions, woody plant encroachment is associated with a decline in livestock carrying capacity (Rappole *et al.*, 1986; Bester, 1996).

According to Zaghloul *et al.* (1999), age structure showed that *Vachellia tortilis* populations growing in South Senai, are healthy and are shrinking with a sharp decline in the last 25 to 50 years. It has been suggested that changes in the abundance of *Vachellia tortilis* populations may have been significant in impacts on ecosystem functioning and biodiversity (Dean *et al.*, 1999).

The soil of the study site was severely eroded when compared to that of the benchmark site. Bardgett and Wardle (2003) outlined three key mechanisms by which herbivores potentially influence soil properties:

- Alteration in the quality of resource input into the soil and
- Long-term alterations in plant community composition

The significant impact of herbivores on the soil leads to soil erosion and thus affects the biodiversity.

5.3. Conclusion

The differences in the woody densities within Lekung and Masutlhe villages were reflections of different habitats influenced by various abiotic and biotic factors. It was found that *Vachellia* was associated with deeper, sandy soil, while the other woody species such as *Ziziphus mucronata* and *Grewia flava* OR *Senegalia mellifera* were associated with shallow, gravelly soil. *Acacia* species dominate large regions of arid and semi-arid ecosystems in Africa and the Middle East (Zohary, 1973; Ross, 1981). It was also found that the most widespread plants were mostly forbs and grasses that are associated with degraded areas.

From this study, it became apparent that a diverse number of aspects related to the encroachment of woody species in savannas are complex and received substantial attention

in the literature. *Vachellia tortilis* was the most prominent encroaching woody species in this study. *Ziziphus mucronata* and *Grewia flava* were the only other encroachers in Masutlhe. The study site in Masutlhe 2 (study site 3) was completely dominated by *Vachellia tortilis*. Noteworthy was the absence of *Grewia flava* in the reference site (figures 5.2 and 5.9), while it was present in the two study sites examined by Skarpe (1990), who did a similar investigation in Botswana. Skarpe (1990) showed that, in areas with no and or moderate grazing, shrub densities fluctuated but showed no consistent change. Thus, grazing favoured annuals over perennial plants and prostrate over erect (Rutherford and Powrie, 2011). Moreover, management changes had not reached the same advanced level in Botswana, neither followed the same sequence as was the case during this study where communal farming practices is at the order of the day. Exclusion of grazing is suggested as one of the rehabilitation techniques to restore vegetation biomass and composition (Kauffman *et al.*, 2001; Mekunia *et al.*, 2007).

Research by Molatlhegi (2008), Mogodi (2009) and Comole (2014) provided insights into the dynamics and the existing differences in vegetation components within the Molopo District under similar climatic conditions. There were distinct similarities between the climatic conditions and land-use practices (such small- scale farming, grazing of cattle and cutting of trees for fire-wood and kraals, unsupervised grazing practices and harsh drought and climatic conditions) reported by Molatlhegi (2008), Mogodi (2009) and Comole (2014). The similarity could be due to the fact that all the three study projects were undertaken within the same geographical settings thus, subjected to the same environmental conditions and influences. The methodology also played a huge contributing in the obtained results.

Vachellia tortilis was the dominant woody encroacher recorded in this study at densities of 1 899 TE ha⁻¹, 3 897 TE ha⁻¹ and 3 999 TE ha⁻¹ respectively in the 3 study sites. According to Mogodi (2009), *Vachellia tortilis* was the most prominent woody species in Setlhabaneng Village occurring at a density of 818 TE ha⁻¹. Comole (2014), recorded *Vachellia tortilis* as the dominant encroacher in the Loporung Village at a density of 1 693 TE ha⁻¹. Noteworthy was the occurrence of other woody species such as *Ziziphus mucronata* and *Grewia flava*. It thus seems that *Vachellia tortilis* is dominant, not only in the surveyed sites, but also in other areas within the Molopo area.

The Benchmark sites surveyed by Molatlhegi (2008) and Mogodi (2009), displayed the same pattern as that of the benchmark sites recorded in this research in the constant occurrence of *Vachellia tortilis*. The results obtained by Molatlhegi (2008) and Mogodi (2009) recorded a significant relationship between *Vachellia tortilis*, *Ziziphus mucronata* and *Grewia flava*, similar to our findings this study. These findings were of woody species that could almost be found growing in the same area within the different sites however recorded at different densities and height classes (namely *Ziziphus mucronata*, *Vachellia tortilis* and *Grewia flava*). These findings support and validate the findings of this research. Both Molatlhegi (2008) and Mogodi (2009) concluded that the encroachment of woody plants jeopardises grassland biodiversity and threatens the sustainability of pastoral subsistence and communal and commercial livestock. Therefore, the early detection of shrub encroachment is essential for assessing the possible drivers and implementation of effective management strategies. The benchmark sites surveyed by Comole (2014), yielded varying results with *Senegalia mellifera* and *Vachellia tortilis* recorded as the dominant encroachers, however noteworthy were the reoccurring patterns of *Ziziphus mucronata* and *Grewia flava*, especially in the sandy soils.

The results were also consistent with a similar study by Bester (1996), where it was established that woody encroachment can reduce local cattle carrying capacities by up 80%. While it is possible to remove the undesirable woody vegetation, treatment may have to be repeated every 2 to 15 years (Rappole *et al.*, 1986). In order to do this, the local inhabitants must be involved in gaining advantages from the woody abundance, such as selling of fire wood, wood for fencing, house building etc. The results were also consistent with Moore *et al.* (1985) where it was found that dense woody trees resulting from overgrazing, rainfall patterns and other factors have competitive advantages over grasses (Moore *et al.*, 1985). An almost total absence of grass cover was observed in the study sites except for the benchmark sites. Similar findings were reported by Mogodi (2009) and Comole (2014). Moreover, these results also showed that the environmental variables did contribute to the expressed morphological variables presented by *Vachellia tortilis* (Stebbins, 1952). Stebbins (1952) suggested that this is an indication that, along with climatic change, plants are forced to modify their characters so as to be able to adapt to the new environment, in arid lands, such rate of evolution is speeded up. Exclusion of grazing is suggested as one of the rehabilitation techniques to restore vegetation biomass and composition studied (Kauffman

et al., 2001; Mekunia *et al.*, 2007). Higher than average rainfall years can lead to the spread of woody vegetation (Fensham *et al.*, 2005). Droughts during the 1960's, followed by the high rainfall of the 1970's coincided with a pulse of bush encroachment across semi-arid and mesic savannas in southern Africa (Ward *et al.*, 2014). According to Frost *et al.* (1986), rainfall and soil type are considered to be the primary determinants, of African savanna functioning. Furthermore, fire may appear to override the effects of climate in that many areas which should support more woody vegetation do not (Bond *et al.*, 2003). General consensus on the primary causes of bush encroachment is not apparent, either globally (Archer *et al.*, 1995; Van Auken, 2009), or in southern Africa (Hoffman *et al.*, 1999; Ward, 2005; 2012; Buitenwerf *et al.*, 2012). O' Connor *et al.* (2014), however, suggested that there have been multiple causes of bush encroachment of which fire application early in the twentieth century, followed by changing livestock grazing, indirect fire suppression during the mid-twentieth century, and gradual increase in atmospheric CO₂, followed by directional changes in temperature and rainfall are the drivers of bush encroachment in southern Africa.

The human population in communal areas comprises a significant element of communal rangeland ecosystems, making it imperative to understand how their activities influence and affect ecosystem functioning. For rangeland resource management policies and practices to be efficacious and effective, knowledge and socio-cultural practices should be taken into consideration (Oba and Kaitira, 2006).

Moreover, climate is a primary determinant of fire frequency and intensity (Archibald *et al.*, 2009, 2010). Succession has also provided a conceptual framework for interpreting changes in woody composition as bush encroachment proceeds (Van Auken and Bush, 2012).

The human population in communal areas comprises a significant element of communal rangeland ecosystems, making it imperative to understand how their activities influence and affect ecosystem functioning. For rangeland resource management policies and practices to be efficacious and effective, knowledge and socio-cultural practices should be taken into consideration (Oba and Kaitira, 2006).

Further management and rehabilitation procedures are to be implemented with the involvement and engagement of the local residents. Idso (1992), argued that, due to these

differences in their photosynthetic pathways, many woody plant species (C3 plants) may benefit more and subsequently grow faster and accumulate more biomass than many of the grass (C4) species found in semi-arid regions. Special mechanisms to eradicate these encroaching species thus need to be implemented. The involvement of the land-users is of critical importance in the rehabilitation and management of the natural resources present in the study site. An appropriate model of vegetation is an important prerequisite for effective and predictive management of rangelands. Milton and Hoffman (1994) concluded that flawed or incoherent conceptual models may result in rangeland mismanagement that results in declining productivity and biodiversity.

In order to control the adverse effects of bush encroachment in grazing lands, control methods widely applied must include fire (Luken and Shea, 2000; DiTomaso *et al.*, 2006) and tree cutting (Smit, 2003) and the combination thereof. Many researchers are of the opinion that fire suppresses bush growth by killing and reducing the abundance of encroaching woody species (Hoffman, 1988; Ruthven *et al.*, 2003; Ansley and Castellano, 2006), as does cutting at least in the short-term (Clark and Wilson, 2001). The combined effects of fire and grazing (Nolte *et al.*, 1994) and cutting inhibit the recovery of woody species (Nolte *et al.*, 1994; Scholes and Archer, 1997; Sawadago *et al.*, 2002), while grazing alone might promote bush encroachment (Hadar *et al.*, 1999).

The evaluation and the response of individual woody species to different treatments is useful in understanding potential management strategies for controlling the growth of woody cover and expansion. By monitoring the performance of individual woody species in response to bush encroachment methods, it is to show that the different treatments have varied consequences for encroaching species in terms of management and policy implications. The policy of banning the use of fire in savanna ecosystems has been largely responsible for the expansion of bush encroachment worldwide (Angassa and Baars, 2000). Angasa and Baars (2000) further stressed that the combined use of fire with other disturbances substantially increased mortality of woody species.

Control of bush encroachment requires changes in the overall policy for the management of savanna ecosystems that combine the use of fire with alternative management options. Most importantly, bush encroachment or woody plant control methods should be supported by

public education. Property rights and collective action are important for the technological innovation and adoption and thus sustainable grassland management due to the incentives they provide.

In conclusion, woody species or bush encroachment management strategies have not been successful because of the lack of public discussions on bush encroachment control methods (particularly in communal areas), that can be used to create awareness to the public on rehabilitating bush encroached savanna ecosystems. Primary attention should be given to protecting open grasslands not to be encroached with bushes. The use of the indigenous knowledge supported by scientific methods and communities participation is crucial to control the expansion and encroachment in open grasslands and savannas.

CHAPTER 6

REMOTE SENSING

6.1 Results and discussion

Change assessment was performed to determine how much change had occurred in woody cover over time. Change detection was used to compare images after classification and mapping. Following image sub-setting and texture analysis, all the images (2004, 2006 and 2014) were classified using unsupervised classification. Classification of land cover in the Lekung, Masutlhe 1 and Masutlhe 2 was categorized into three major groups namely: woody vegetation, grass and bare area.

The results of the image classification are displayed in Figures 6.1, 6.2 and 6.3. A comparison of the three maps was undertaken in order to establish the encroachment and expansion of woody species, in order to fulfil the objectives set in Chapter 1. For the purpose of this study the main interest was based on expansion of the woody vegetation by bush encroachment. The results were considered in terms of actual progression and regression of woody vegetation in previously grass dominated savanna. The graphical representation of the various tree groups coverage, as seen over the years, in the study area is shown in figure 6.4. Graphical differentiation of the study area of the classified images in terms of the tree coverage classes groups in the study area is shown in Figure 6.4.

Texture analysis enhanced images from the three dates (2004, 2006 and 2014) were classified by unsupervised classification into three major classes namely: woody vegetation, grass and bare area. An examination of the graph and the classified images showed evidence of a gradual increase of woody plant encroachment and expansion at the study sites. The strong association between trees and grasses is quite evident.

The 21 August 2004 image (Figure 6.1) shows a modest coverage of woody vegetation with a slight domination of grass cover and minimal indication of bare areas. The total area under woody cover was 844.4 ha (17.91%) as shown in Figures 6.4 and 6.5. The 4 September 2006 image showed that there had been a large change since 2004, with some

substantial increment in woody vegetation which increased from 844.4 ha to 1 123.76 ha. There was substantial increase in grass also. The explanation of the high values can be attributed to the normal rainfall in the years prior to the image acquisition (e.g. 1995-2001) (Figure 6.3).

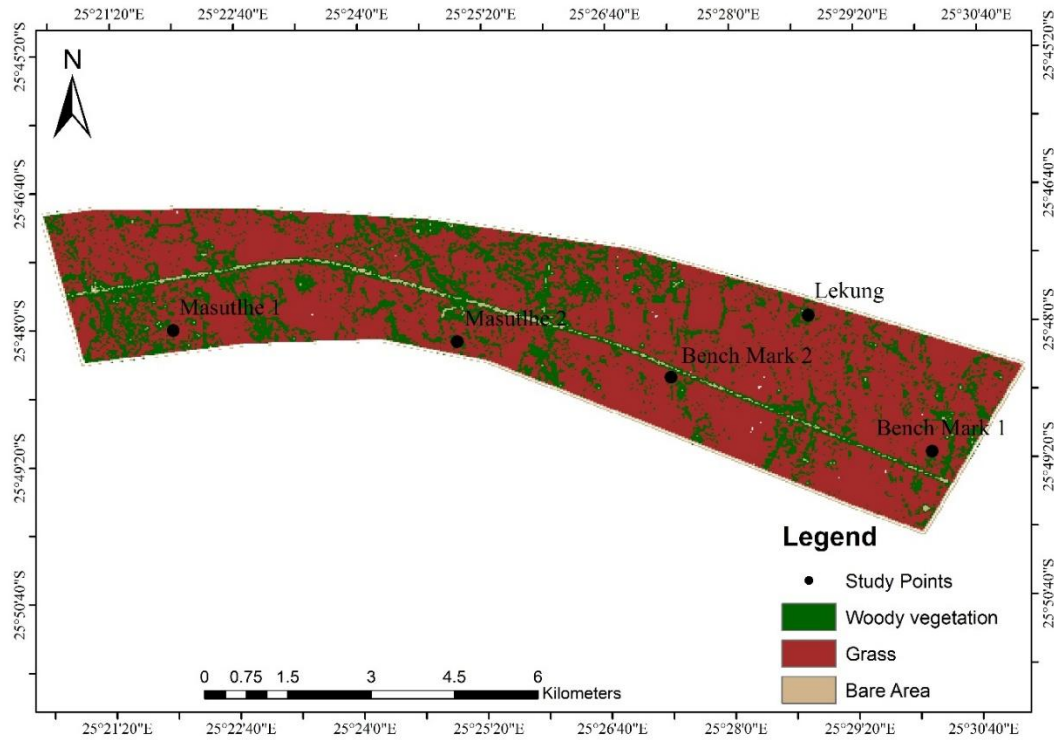


Figure 6.1: Classified 21 August 2004 image

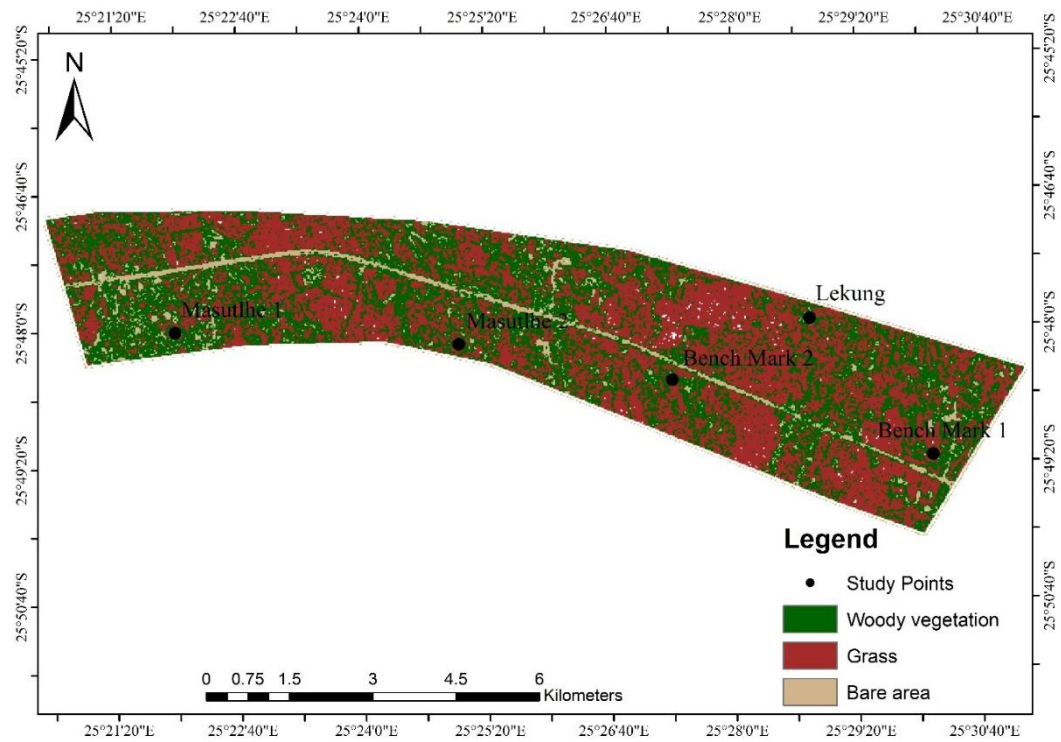


Figure 6.2: Classified 4 September 2006 image

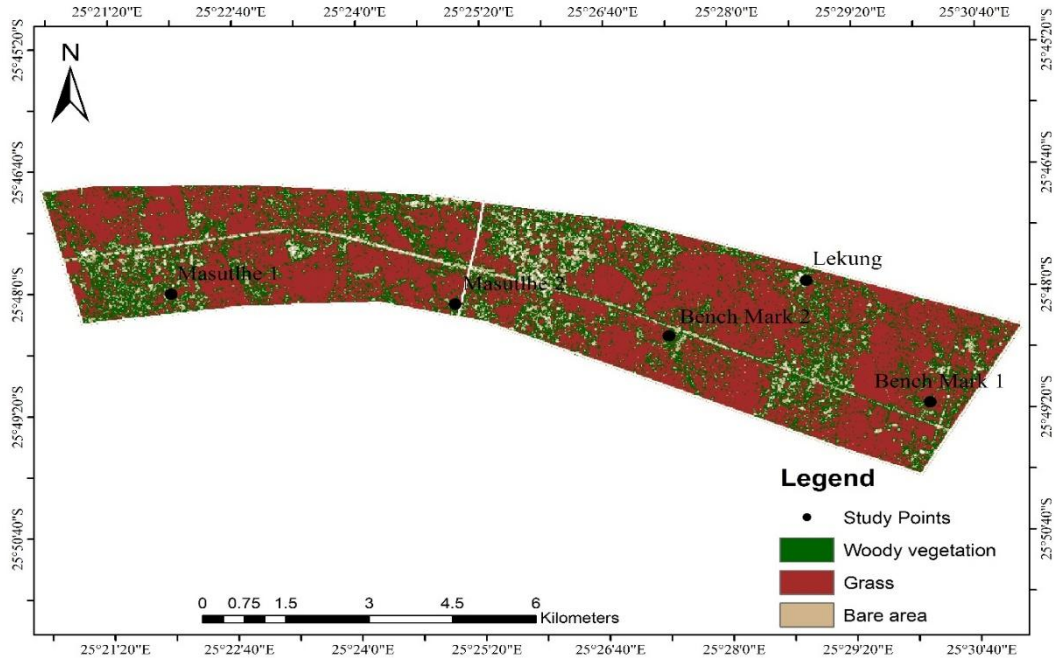


Figure 6.3: Classified 14 July 2014 image

Results from the unsupervised classification revealed that in 2014, woody vegetation density decreased slightly as compared to the 2004 and 2006 images resulting in 12.44 % (583.56

ha). The 2014 image also showed a marked increase in bare area. A decrease in woody vegetation could have been due to a fire before the image date.

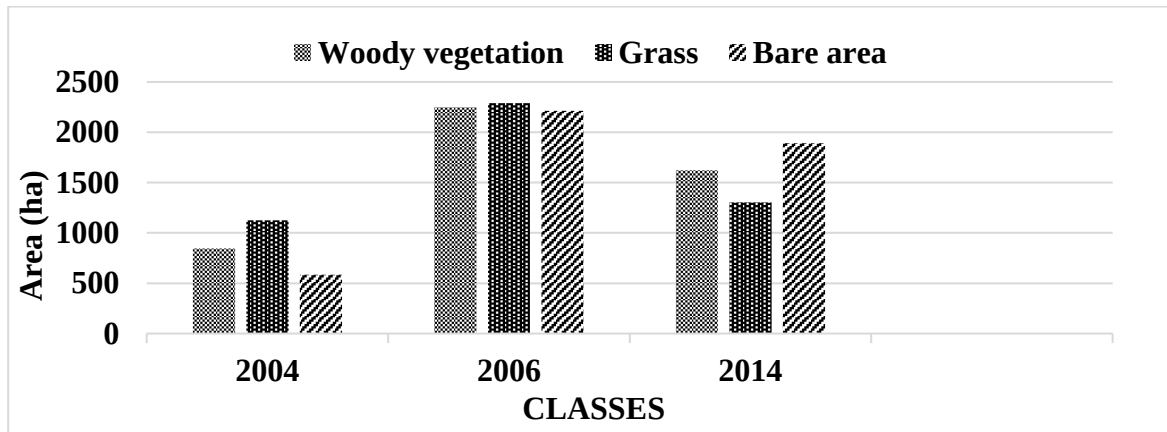


Figure 6.4: Overall trend in image classification per area in hectares

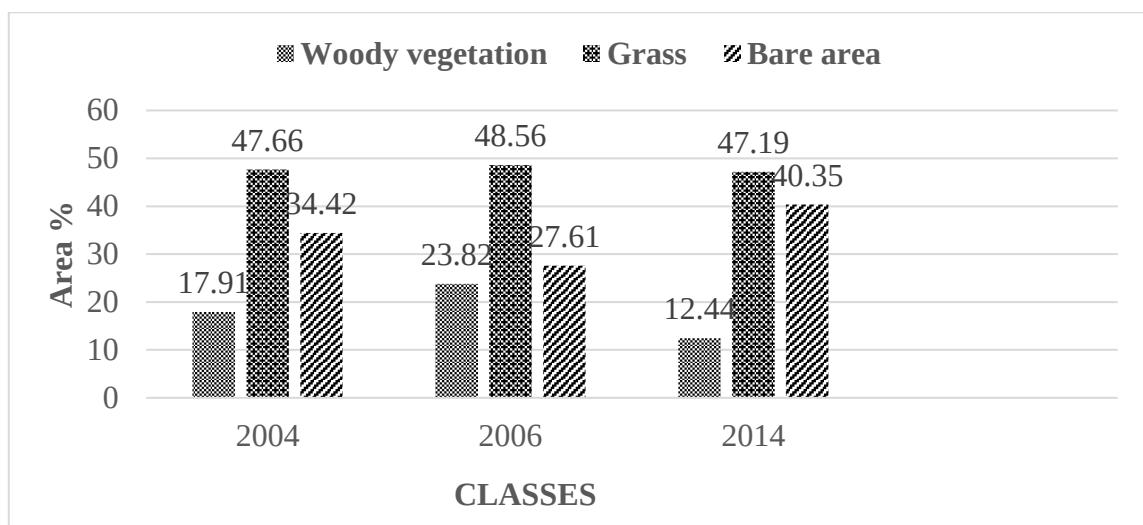


Figure 6.5: Overall trend in image classification class area in percentages

6.1.1 Accuracy assessment

To assess the accuracy of each classification, a stratified random sample of 50 pixels was generated using ERDAS Imagine 2015. The coordinates of the random points were exported to a spreadsheet (Microsoft Excel), and a shapefile was then created using ArcCatalog 10.3. In ArcMap 10.3 a KML file was then created from the shapefile. The KML file was then displayed on a Google Earth image in order to assess accuracy of the classes. The high spatial

resolution image dated 29th March 2016 in Google Earth served as the reference data. An error (confusion) matrix was then constructed. The error matrices (Tables 6.1, 6.2 and 6.3) showed the User's accuracy, Producer's accuracy, Overall accuracy, as well as the Kappa coefficient. The overall accuracy of classification of the SPOT 4 (2004) image was 84%, SPOT 2 (2006) image was 82% and the SPOT 5 was 90% (2014). Therefore, the classification accuracies were quite high, which makes the classified images useful for assessing the encroachment and expansion of woody vegetation and the spatial resolutions useful for subsequent analyses. In general the user's accuracy values for both classifications were very high (over 75%). Table 6.1 implies that 68.60% of classification errors which would have resulted from a randomly unsupervised classification were avoided.

Table 6.1: Error matrix for the 21 August 2004 SPOT 4 image classification

Reference data	Classification data			Row total	User's accuracy
	Grass	Woody vegetation	Bare Area		
Grass	29	3	4	36	80.56%
Woody vegetation	0	11	1	12	91.67%
Bare Area	0	0	2	2	100%
Column total	29	14	7	50	
Producers accuracy	100%	78.57%	28.57%		
Overall Accuracy= 84%					
Overall Kappa = 0.6860					

Table 6.2: Error matrix for the 04 September 2006 SPOT 2 image classification

Reference data	Classification data			Row total	User's accuracy
	Grass	Woody vegetation	Bare Area		
Grass	20	1	4	25	80 %
Woody vegetation	3	18	1	22	81.82%
Bare Area	0	0	3	3	100%
Column total	23	19	8	50	
Producers accuracy	86.96%	94.74%	37.50%		
Overall Accuracy= 82%					
Overall Kappa = 0.6966					

Table 6.3: Error matrix for the 14 July 2014 SPOT 5 image classification

Reference data	Classification data			Row total	User's accuracy
	Grass	Woody vegetation	Bare Area		
Grass	20	1	4	25	80 %
Woody vegetation	3	18	1	22	81.82%
Bare Area	0	0	3	3	100%
Column total	23	19	8	50	
Producers accuracy	86.96%	94.74%	37.50%		
Overall Accuracy= 82 %					
Overall Kappa = 0.6966					

6.2 Discussion and conclusion

The results from the images showed an increase in vegetation density between the years 2004 and 2006 on average across all sites. The study area thus experienced the highest annual rate of woody encroachment between the year 2004 and 2006. For the purposes of this study the main interest was on woody vegetation and their expansion. According

to Figure 6.1 and 6.2 an examination of differences in woody vegetation distribution across the area for the years 2004 and 2006 indicates that there was a steady increase of woody cover and thus an increased woody cover. Thus there is a clear indication of an emerging competition pattern between woody trees and grasses. This pattern is most pronounced when looking at the 2014 trend of grass and woody density.

According to Moore *et al.* (1988), competition experiments have shown that mature trees are competitively superior to grasses while grasses tend to outcompete immature trees. This asymmetry of competitive effects creates instability in interactions between trees and grasses (Scholes and Archer, 1997).

The key informant interviews indicated that the drastic difference of decrease of woody cover in the year 2014 is likely the result of different management practices utilized in the unprotected areas and communities. The community cleared the land for agriculture or homesteads and collected timber resources reducing the number of trees. Thus, this contributed to the significant decline of tree cover in the year 2014. The active practice of historical fire application in the community areas likely contributed to the ambiguous trends of woody vegetation and grasses.

The location of tree clusters is probably the result of both historical community development, processes and the influence of variations in either biotic parameters (such as herbivory or trampling) which influence tree growth. Despite the modest observation of woody cover on the spatial imagery it can be concluded that there is an increase in the encroachment and expansion of woody species across the research site. The data suggests that an increase in human population and thus disturbance, would lead to a rapid decrease in woody cover (Banks *et al.*, 1996). Thus, the disturbance develops due to increasing clearing for fields and this intensifies with time as the population grows.

CHAPTER 7

GENERAL DISCUSION AND CONCLUSION

7.1 General Discussion

This study offered a detailed insight on the encroachment and expansion of woody species in savanna areas of Masutlhe and Lekung in the North West Province, South Africa.

The total woody plant density in Lekung was recorded at 3 650 TE ha⁻¹. This was substantially higher than the woody plant density of 368 TE ha⁻¹ in the reference site. This site was dominated by thorny species, *Vachellia tortilis*, *Ziziphus mucronata* and *Grewia flava*. *Vachellia tortilis* was the dominant woody encroacher at a density of 1 899 TE ha⁻¹, followed by *Ziziphus mucronata* at 1 384 TE ha⁻¹. There were no traces of a grass cover, while the reference site had a dense layer of *Eragrostis lehmanniana*. Bush encroachment leads to suppression of palatable grasses and herbs by encroaching woody species, often unpalatable to domestic livestock. Four metre high woody plants, especially *Vachellia tortilis* were the most abundant in the Lekung area.

The total woody plant density in Masutlhe was recorded at a density of 4 906 TE ha⁻¹ as compared to the reference site with a woody plant density of only 1 055 TE ha⁻¹. Due to the dense bushes, grasses were absent in this site. *Vachellia tortilis* was present at a density of 3 897 TE ha⁻¹ and was the sole dominant woody encroacher species. *Vachellia tortilis* is unpalatable to livestock and thickens in areas where there is lack of browsers. Three metre and 4 m high *Vachellia tortilis* trees were dominant in this area. The results are in agreement with findings of previous field studies in the Molopo Area in the North-West Province by Molatlhegi (2008), Mogodi (2009) and Comole (2014) who also recorded high densities of *Vachellia tortilis*. Inter – and intra species competition has led *Vachellia tortilis* to be the sole dominant encroacher in this study.

Browsers such as goats were present but due to the density of woody species in this site, movement by browsers was restricted.

The results demonstrate the usefulness of remote sensing in detecting, quantifying and monitoring woody plant species in communal areas of the savanna region in the North-West Province. Remote sensing making use of high resolution SPOT images of the years 2004, 2006 and 2014, supported by ground-truthing, is shown to be a useful tool for quantifying and comparing the land and woody vegetation cover over the years. Thus there is a clear indication of an emerging competition pattern between woody trees and grasses. Communal farmers do not own the land and are often forced to over utilize available grazing lands. As the people increase in these areas, there will be more pressure on the available grazing and would favour the development of woody encroachers at the expense of a herbaceous stratum, especially grasses.

7.2 Conclusion

The results show that extensive land and tree cover changes exist through woody plant encroachment. Extensive areas of woody species are replacing natural vegetation, especially grasses.

The main findings in this study show that remote sensing identification of woody plant species using high resolution multispectral satellite imagery is beneficial in detecting and quantifying woody plant species. The results of spatial analysis strongly implicate cattle grazing, resources mismanagement as the major cause of savanna change, while direct human influence is a primary cause of savanna change in the Masutilhe and Lekung villages. Thus, increasingly large areas of woodland, grassland and shrub land will be transformed to areas intensely encroached by woody species. Moreover, smaller areas particularly in the villages and communal areas are in danger of being completely encroached because of anthropogenically induced pressures.

As per change detection results, for the years 2004, 2006 and 2014, there had been substantial grassland and woodland losses owing the advancement to severe bush encroachment. Thus, the impact of bush expansion on the overall rangeland condition is definitely adverse. In conclusion, the findings of the study were that the substantial change in vegetation densities has occurred in the area. Long-term information is required to

establish the main causes, drivers and impact of bush encroachment particularly in the savanna.

This replacement of grasses by woody plants represents a major natural resource loss as both grazing and browse are reduced in terms of both quality and quantity. Although, climate (rainfall, temperature), increased atmospheric [CO₂] and anthropogenic factors such as mismanagement (overgrazing and the replacement of browsers by grazers) had a significant impact on woody changes, the pattern demonstrates that anthropogenic activities are the main drivers of change. Thus, areas encroached by woody vegetation appear to be predominantly anthropogenic in origin, with local people as the land managers, appear to be causing vegetation depletion, resulting in the expansion and encroachment of woody species in previously grass dominated areas. Woody species are unpalatable to livestock and browsers such as Boer goats have to be introduced to these areas. However, the communal farming system has to be addressed first, before any programme is initiated. Farmers have to own the land they are farming on. In this way, they will “treat” it as an asset and appropriate farming techniques (camp system and rotational grazing) will only then be implemented.

7.3 Recommendations

In view of the findings, this study recommends the following:

- Monitoring and analysis of woody species is important to understand the drivers of change and the positive and negative impacts likely at larger spatial scales especially in the savanna areas of the North West Province
- These studies will make important advances in further understanding the encroachment and expansion of woody plant species and the impact of natural and human ecosystems
- Change detection studies are valuable especially for woody cover change. Much research needs to be done to improve the results of vegetation and change detection studies in the Ecology and Environmental field
- Village inhabitants must be educated and engaged about the encroachment of woody plant species

- More research must be done especially on the expansion of woody plant species

REFERENCES

- Abdallah F. 2008. The influence of *Acacia tortilis* (Forssk) subspecies *raddiana* (Savi) and livestock grazing species composition, yield and soil nutrients in and environments of South Tunisia. *Flora* 203 (2): 116-125.
- Abdelrahman HF and Krzwinski K. 2008. Environmental effects of morphology of *Acacia tortilis* group in the Red Sea Hills, North-Eastern Sudan and South-Eastern Egypt. *Forest Ecology and Management* 225 (1): 254-263.
- Abdullah F, Noumi Z, Touzand B, Belgacerm AO and Chaieb M. 2008. The influence of *Acacia tortilis* (Forssk) subsp. *raddianna* (Savi) and livestock grazing on grass species composition yield and soil nutrients in arid environments of south Tunisia. *Flora – Morphology, Distribution, Functional, Ecology of plants* 203(2): 116-125.
- Abil A and Bucker EH. 2001. Overgrazing and soil carbon dynamics in the western Chaco of Argentina. *Applied Soil Ecology* 16: 243-249.
- Acocks JPH. 1988. Veld types of South Africa. *Memoirs of the botanical survey of South Africa*. No. 57. 3rd Edition 57: 1-1146, Government Printer: Pretoria. South Africa.
- Adjorlolo C. 2008. Estimating woody vegetation cover in an African savanna using Remote Sensing and Geostatistics. University of Kwazulu Natal. Pietermaritzburg.
- Akpo LE and Grouzis M. 2004. Interactions between tree and grass under semi-arid bio climates: Influence of grazing. *Secheresse* 15: 253-261.
- Amiri F and Tabatabaie T. 2004. Operational monitoring of vegetative cover by remote sensing in semi-arid lands of Iran. *Advanced Technology for Cadastre and Land Management*. (7th Ed). Regional Conference, Hanoi, Vietnam.
- Andersen GI. 1999. Change and variation in a hyper-arid cultural landscape: a methodological approach using remote sensing time series (Landsat MSS and TM, 1973-1996), from the Wadi vegetation of Eastern Desert of Egypt. M.Sc Thesis. Botanical institute, University of Begern. Nowerg.
- Anderson E. 1999. Seed dispersed by monkey and the fire of dispersed seed in Pervian rain forest. *Biotropica* 31: 145-158.
- Anderson GD and Walker BH. 1974. Vegetation composition and elephant damage in the Sengwa wildlife research area, Rhodesia. *Journal of Wildlife Management: Assessment* 4: 1-14.

- Anderson LJ, Jackson RB and Brumbaugh MS. 2001. Water and tree understory interactions: a natural experiment in a savanna with oak wilt. *Ecology*. 52: 33-49.
- Andrew FW. 1984. The vegetation of the Sudan In: Tothill JD. (Ed.). Agriculture in the Sudan p. 114-120. Oxford University Press, Oxford.
- Angassa A and Baars RMT. 2000. Ecological condition of encroached and non-encroached rangelands in Borana, Ethiopia. *African Journal of Ecology* 38: 321-328.
- Ansley RJ and Castellano MJ. 2006. Strategies for savanna restoration in the Southern Great Plains effects of fire and herbicides. *Restoration Ecology* 14: 420-428.
- Archer D. 2005. Fate of fossil fuel CO₂ in geologic time. *Journal of Geophysical Research* 110: 6-9. DOI: 10.1029/2004JC6026525.
- Archer DE, Eshel G, Winguth A, Broecker W, Pierrehumber R, Tobis M and Jacob R. 2000. Atmospheric CO₂ sensitivity to the biological pump in the ocean. *Global Biogeochemical Cycles* 14: 1219-1230.
- Archer MS. 1981. Successful and unsuccessful development of colonies of *Vespula vulgaris* (Lim) (Hymenoptera Vespidae). *Ecological Entomology* 6: 1-10.
- Archer S. 1989. Have southern Texas savannas been converted to woodlands in recent history? *American Naturalists* 34: 545-561.
- Archer S. 1990. Development and stability of grass or woody mosaics in a subtropical savanna parkland, Texas, USA. *Journal of Biogeography* 17: 453-462.
- Archer S. 1994. Woody plant encroachment into southwestern grasslands and savannas: rates, patterns and proximate causes. In: Varva M, Laycock WA and Pieper RD (Eds.). Ecological implications of livestock herb ivory in the West. Society for Range Management Denver, Colorado. Pp. 13-68.
- Archer S. 1995. Tree-grass dynamics in *Prosopis* thorn scrub savanna parklands: Reconstructing the past and predicting the future. *Ecoscience* 2: 83-99.
- Archer S. 2002. Proliferation of woody plants in Grasslands and Savannas: A Bibliography. Texas. A and M University, College Station, Texas.
- Archer SR. 2010. Rangeland conservation and shrub encroachment: new perspectives on an old problem. In: Du Toit JT, Kock R, and Deutsch JC. (Eds.). 2010. Wild Rangelands: Conserving wildlife while maintaining livestock in semi-arid ecosystems. John Wiley and sons. Ltd, Chichester, UK. Pp. 53-97.
- Archer S, Boutton TW, Hibbard KA. 2001. Trees in Grasslands: Biogeochemical Consequences of woody plant expansion. In: Schulze ED, Harrison SP, Helmann M,

- Hollard ER, Llyod JL, Pientre IC, Schimel D. (Eds.). 2001. Global Biogeochemical cycles in the Climate System. Academic Press, San Diego.
- Archer S, Schimel DS and Hollard EA. 1995. Mechanisms of shrub land expansion: land use, climate or CO₂. *Climatic Change* 29: 91-99.
- Archer S, Scifres CJ, Bassham CR and Maggio R. 1998. Autogenic succession in a subtropical savanna: Conversion of grassland to thorn woodland. *Ecological Monographs* 58: 111-127.
- Archibold S, Nickless A, Govender N, Scholes RJ and Lehsten V. 2010. Climate and the inter-annual variability of fire in southern Africa: a meta-analysis using long-term field data and satellite-derived burnt area. *Global Ecology and Biogeography* 19: 794-809.
- Archibold S, Roy DP, Van Wilgen BW and Scholes RJ. 2009. What limits fire? An examination of the drivers of burnt area in southern Africa. *Global Change Biology* 15: 613-630.
- Asner GP, Elmore AI, Olander LO, Martin RE and Harris AT. 2004. Grazing systems, ecosystems responses and global change. *Annual Review of Environment and Resources* 29: 1-39.
- Asner GP and Martin RE. 2008. Airborne spectranomics: Mapping canopy chemical and taxonomic diversity in tropical forests. *Frontiers in Ecology and the Environment*. DOI: 10. 1890/070152.
- Atkinson PM and Curran PJ. 1997. Choosing an appropriate spatial resolution for remote sensing investigations. *Photogrammetric Engineering and Remote Sensing* 63: 1345-1351.
- Augustine DJ and Mcnaughton SJ. 1998. Ungulate effects of the functional species composition of plant communities: herbivore selectivity and plant tolerance. *Journal of Wildlife Management* 62: 1165-1183.
- Austin MP, Smith TM, Van Niel KP and Wellington AB. 2009. Physiological responses and statistical models of the environmental niche: a comparative study of two co-occurring Eucalyptus species. *Journal of Ecology* 97:496–507.
- Ayyad MA and Gharbbour SI. 1986. Hot deserts of Egypt and the Sudan. In: Evenani M, Noy-meir I, Goodall DW. (Eds.). *Ecosystems of the World*. Vol. 12 B. Hot Deserts and Arid shrublands. 149-202. Elsevier, Amsterdam.

- Babykalpana Y and Thanushkodi K. 2010. Classification of land use cover change detection using remotely sensed data of Coimbatore City, India. *Journal of Computing* 2: 150-157.
- Badi KM 1989. The forests of the Sudan. The Agricultural Research Council, The national Council of Research, Khartoum, Sudan.
- Bagachi S, Ritchie ME. 2010. Introduced grazers can resist potential soil carbon sequestration through impacts on plant community composition. *Ecology Letters* 13(8): 959-968. DOI: 10.1111/j.1461-0248.2010.01486.x.
- Bainbridge DA. 1996. Vertical mulch. *Restoration and Management Notes* 14 (1): 72.
- Bainbridge DA. 2007. A Guide for Desert and Dryland Restoration: New Hope for Arid Lands. Society for Restoration Ecology International. Washington DC: Island Press. Pp.391
- Banks DI, Griffin NJ, Shackelton CM, Shackelton SE and Mavrandonis JM. 1996. Wood supply and demand around two rural settlements in a semi-arid savanna, South Africa. *Biomass and Bioenergy* 11(4): 319-331.
- Baraza E, Zamora R and Hodar JA. 2006. Conditional outcomes in plant-herbivores interactions: neighbours matter. *Oikos* 113(1): 148-156.
- Bardgett, RD and Wardle DA. 2003. Herbivore-mediated linkages between aboveground and belowground communities. *Ecology* 84: 2258–2268. DOI: 10.1890/02-0274.
- Barnard CJ. 1987. Time constraints and prey selection in common shrews *Sorex araneus* L. *Animal Behaviour* 35: 1827-1837.
- Barnes RFW. 1985. Woodland changes in Ruata National Park (Tanzania) between 1976 and 1983. *African Environment* 23: 215-221.
- Beck PSA, Wang TY, Skidmore AK and Liu XH. 2008. Display remotely sensed vegetation dynamics along natural gradients for ecological studies. *International Journal of Remote Sensing* 29: 4277-4283.
- Bernhard-Reversat, F. 1982. Biogeochemical cycles of nitrogen in a semi-arid savanna. *Oikos* 38: 321 – 332.
- Beinart W. 2000. African history and environment history. *African Affairs* 99: 269-302.
- Bellefontaine R, Gaston A and Petrucci Y. 2000. Management of natural forests of dry tropical zones, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

- Bellone T, Boccardo P and Perez F. 2009. Investigation of vegetation dynamics using long-term Normalized Difference Vegetation Index time series. *American Journal of Environmental Sciences* 5: 460-466.
- Belsky AJ. 1994. Influences of trees on savanna productivity: tests of shade, nutrients and tree-grass competition. *Ecology* 72: 922-932.
- Belsky AJ, Amundson RG and Duxbury JM. 1989. The effects of trees on their physical, chemical and biological environments in a semi-arid savanna in Kenya. *Journal of Applied Ecology* 26: 1005-1024.
- Bergstrom R. 1992. Browse characteristics and impact of browsing on trees and shrubs in African savanna. *Journal Vegetation Science* 3: 315-324. DOI: 10.2307/3235756.
- Bertness MD and Callaway RM. 1994. Positive interaction in communities. *Trends in Ecology and Evolution* 9(5): 191-193.
- Bester F. 1996. Bush encroachment: a thorny problem. *Namibia Environment*. 1: 175-177.
- Bhark EW and Small EF. 2003. Association between plant canopies and the spatial patterns of infiltration in shrubland and grassland of the Chinahuan Desert. New Mexico. *Ecosystems* 6: 185-196.
- Bhenke HD. 1997. Sarcobataceae: A new family of *Caryophyllales*. *Taxon* (46): 495-507. ISSN: 004.
- Bond WJ. 2008. What limits trees in C₄ grasslands and savannas? *Annual Review of Ecology, Evolution and Systematics* 39: 641-659.
- Bond WJ and Midgley GF. 2000. A proposed CO₂ – controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology* 6: 865-869.
- Bond WJ and Midgley GF. 2012. Carbon dioxide and the uneasy interaction of trees and savannah grasses. *Philosophical Transactions of the Royal Society Biology. Biological Sciences* 367: 601-612.
- Bond WJ, Midgley GF and Woodward FL. 2003. What controls South African vegetation-climate fire? *South African Journal of Botany* 69: 79-91.
- Bond WJ and Van Wilgen BW. 1996. Fire and plants. Chapman and Hall, London.
- Bongonko M. 2005. Hyperspectral remote sensing of soil moisture gradients in the Millingerwaard. Unpublished M.Sc Thesis, Vrije Universiteit Brussel. The Netherlands.

- Bosch OJH and Van Wyk JJP. 1970. The influence of Bushveld trees in the productivity of *Panicum maximum*: A preliminary report. *Proceedings of the Grassland Society of southern Africa* 5: 67-69.
- Bothma J. du P 1989. Game Range Management. Van Schaik Pty. (Ltd.). Pretoria. Pp. 672. ISBN: 0 627 015891.
- Bothma J du P. 2002. Game Ranch Management, Fourth edition Centre for Wildlife Management, University of Pretoria.
- Bothma J du P, Van Rooyen N, Theron GK and Le Riche EAN. 1994. Quantifying woody plants as hunting cover for southern Kalahari leopards. *Journal of Arid Environments* 26 (3): 273-280.
- Bovey RW. 2001. Woody plants and woody plant management: Ecology, Safety and environmental impact, New York: Marcel Dekker. ISBN: 0-8247-0438-x.
- Burton H and Mueller-Dombois D. 1984. Response of *Metrosideros polymorpha* seedlings to experimental canopy opening. *Ecology* 65: 779-791.
- Britton CM and Sneva FA. 1981. The effects of *Tebuthiuron* on western *Juniper*. *Journal of Range Management* 34: 30-32.
- Britz ML and Ward D. 2007. Dynamics of woody vegetation in a semi-arid savanna with a focus on bush encroachment. *Italian Journal of Range and Forage Science* 24: 131-140.
- Brooks H. 1870. Natal, a history and description of the colony. London: L. Reeve and Co.
- Brooks H. 1876. Natal, a history and description of the colony London: L Reeve and Company.
- Brooks ML, D' Antonio, Richardson CM, Grace JB, Keeley JE, Di'tamaso JM, Hobbs RJ, Pellant M and Pyke D. 2004. Effects of invasive alien plants on fire regimes. *Bioscience* 54 (7): 677-687.
- Brown JR and Carter J. 1998. Spatial and temporal patterns of exotic shrub invasion in an Australian tropical grassland. *Landscape Ecology* 13: 93-102.
- Brown JR, Scalan JC and McIvor JG. 1997. Competition by herbs as a limiting factor in shrub invasion in grassland: A test with different growth forms. *Journal of Vegetation Science* 9: 829-836.
- Bruce J and Fortmann L. 1989. Tenure and Incentives. *Agroforestry*. LTC. Paper 135. Madison: Land Tenure Centre, University of Wisconsin.

- Brynard AM. 1971. Controlled burning in the Kruger National Park- a history and development of the veld burning policy: In: Komarek EV (Ed.). *Proceedings of the 11th Annual Tall Timbers Fire Ecology Conference*, Tallahassee, Florida. Tall Timbers Research Station 219-231.
- Bryant JP, Reichardt PB and Clausen TP. 1992. Chemically mediated interactions between plants and browsing mammals. *Journal of Range Management* 45: 18-24.
- Buffington LC and Herbel CH. 1965. Vegetation changes on a semi dessert grassland range from 1858 to 1963. *Ecological Management* 35: 139-164.
- Buitenwerf R., Bond WJ, Stevens N and Trollope SW. 2012. Increased tree densities in South African savannas: 750 years of data suggests CO₂ as a driver. *Global Change Biology* 18: 675-684.
- Buyantuyev A, Wu J and Gries C. 2007. Estimating vegetation cover in an urban environment based on Landsat ETM+ imagery: A case study in Phoenix, USA. *International Journal of Remote Sensing* 28: 269-291.
- Callaway RM. 1994. Facilitative and Interfering Effects of *Arthrocnomum subterminale* on Winter Annual. *Ecology* 75(3): 681-686.
- Campbell BD, Grime JP and Mackey JML. 1991. A trade-off between scale and precision in resource foraging. *Oecologia* 87: 532-538.
- Campbell JB. 1996. Introduction to remote sensing 2nd Edition, Guilford Press, New York. ISBN: 978-1609181765.
- Campbell JB. 2002. Introduction to Remote Sensing, Guilford Press, New York. ISBN: 978-1572306400.
- Campbell JB. 2006. Introduction to Remote sensing, Guilford Press, New York. ISBN: 978-3642142116.
- Carter GA and Knapp AK. 2001. Leaf optical properties in higher plants: Linking spectral characteristics to stress and chlorophyll concentration. *American Journal of Botany* 88: 667-684.
- Carter JD. 1964. Effects of drought on mesquite. *Journal of Range Management* 17: 275-276.
- Carter JO. 1994. *Acacia nilotica*: A tree legume out of control. 338-351. In: Gutteridge RC, Shelton HM (Eds.). 1994. Forage tree legumes in tropical agriculture, pp 338-351, CAB, International, Wallingford, Oxford UK.
- Carter TR. 1994. IPCC technical guidelines for assessing climate change impacts and adaptations: part of the IPCC special report to the first session of the conference of the

- parties to the UN framework. ISBN: 0904813118. Pp. 45-51. London. Department of Geography. University College of London.
- Castellanos J, Maass M and Kummerow J. 1991. Root biomass of a dry deciduous tropical forest in Mexico. *Plant and Soil* 131: 225-228.
- Chambers PG, Raubenheimer D and Simonson SJ. 1997. The selection of nutritionally balanced foods by *Locusts migratoria*: The interaction between food nutrients and added flavours. *Physiological Entomology* 22: 199-206.
- Cheng XI, An SQ, Liu SR and Li GQ. 2004. Micro scale spatial heterogeneity and the loss of carbon, nitrogen and phosphorus in degraded grassland in Ordos Plateau, north-western China. *Plant and Soil* 259: 29-37.
- Chica-Olmo and Abarca-Hernandez F. 2000. Computing geostatistical image texture for remotely sensed data classification. *Computers and Geoscience* 26 (4): 373-383.
- Clark DL and Wilson MV. 2001. Fire, moving and hand removal of woody species in restoring a native wetland prairie in the Willamette Valley of Oregon. *Wetlands* 21 (1): 135-144.
- Clement A. 2008. Estimating woody vegetation cover in an African savanna using remote sensing and Geostatic. M.Sc thesis. University of KwaZulu-Natal. Pietermaritzburg.
- Coates Palgrave K. 1990. Trees of Southern Africa. Struik Publishers. ISBN. 1868251713.
- Coe M and Coe C. 1987. Large herbivores, *Acacia* trees and bruchid beetles. *South African Journal of Science* 106: 1-9.
- Coetzee BJ and Gertenbach WPD. 1977. Technique for describing woody vegetation composition and structure in inventory type classification, ordination and animal habitat surveys. *Koedoe* 20: 67-75.
- Coheen JR, Young TP, Keesing F and Palmer TM. 2007. Consequences of herbivory by native ungulates for the reproduction of a savanna tree. *Journal of Ecology* 95: 129-138.
- Coheen JR, Palmer TM, Keesing F, Riginos C and Young TP. 2010. Large herbivores facilitate savanna tree establishment via diverse and indirect pathways. *Journal of Animal Ecology* 79: 372-382.
- Collingwood A, Franklin SE, Guo X and Stenhouse GB. 2009. A medium resolution remote sensing classification of agricultural areas in Alberta grizzly bear habitat. *Canadian Journal of Remote Sensing* 35: 23-36.
- Comole AA. 2014. Extent of woody plant invasion along a riparian zone of the Molopo River, North-West Province, South Africa. M.Sc. Thesis. North West University. Mafikeng.

- Conchard R. 2004. Epilogue: some myrmecophilic thoughts patterns and dynamics of secondary *Acacia zanzibarica* woodlands at Mkwaja Ranch, coastal Tanzania. Ph. D Thesis. Geobotanical Institute, Swiss Federal Institute of Technology.
- Coops N and Culvenor D. 2000. Utilizing local variance of stimulated high spatial resolution imagery to predict spatial pattern of forest stands. *Remote Sensing of Environment* 71: 248-260.
- Csurches S. 1996. Mesquite (*Prosopis* species) in Queensland, Pest status review series land protection branch. ISBN 0724269703: Pp. 1-19.
- Dean WRJ and Macdonald IAW. 1994. Historical changes in stocking rates of domestic livestock as a measure of semi-arid rangeland degradation in the Cape Province, South Africa. *Journal of Arid Environments* 26: 281-298.
- Dean WRJ, Milton SJ and Jeltsch F. 1999. Large trees fertile islands and birds in an arid savanna. *Journal of Arid Environments* 41: 61-78.
- De Bryun TD. 1998. The condition, productivity and sustainability of communally grazed rangelands in the central Eastern Cape Province. Department of livestock and Pasture Science, University of Fort Hare. [WEB:] <http://www.ais.up.ac.za/vet/goat/documents/sec18.pdf> (Accessed on 13 October 2012).
- De Bruyn TD and Scogings PF. 1998. Conclusions of symposium and workshop. In: De Bruyn and TD Scogings PF. (Eds.). 1999. Communal Rangelands in southern Africa: A synthesis of knowledge. *Proceedings of a Symposium on Policy-making for the sustainable use of Southern African Communal Rangelands*: 290-291. Fort Hare University Press, Alice.
- De Klerk JN. 2003. Bush encroachment in Namibia. Report 1 on the bush encroachment research, monitoring and management project for the Namibian Ministry of Environment and Tourism. Ministry of Environment and Tourism, Government of the Republic of Namibia.
- De Klerk JN. 2004. Bush environment in Namibia. Report on phase 1 of the bush encroachment Research, Monitoring and Management Project. John Meinert-Printing, Windhoek.
- De Korte J. 1984. Ecology of the long-tailed Swua at Scoresby Sund, East Greenland. Park two: arrival, site tenacity and departure. *Beaufortia* 34: 1-14.
- Dembele F, Dicard N, Karembe M and Birnbaum P. 2006. Tree vegetation patterns along a gradient of human disturbance in the Sahelian area. *Ecology* 93: 596-606.

- Department of Agriculture, Conservation and Environment and Tourism. 2002. In: Walmsley D, Walmsley J, Mangold S and Kalule-Sabiti. (Eds.) 2002. North-West Province State of the Environment Report. North-West Province, Mmabatho.
- De Villiers B and Mangold S. 2002. The biophysical environment. In: D Walmsley, J. Walmsley, S. Mangold and Kalule-Sabiti (Eds.) 2002. North West Province State of the Environment Report. Directorate of Environment and Conservation Management, North West Department of Agriculture, Conservation and Environment, Mmabatho.
- Department of Agriculture, Conservation, Environment and Tourism. (DACET). 2002. State of the Environment Report. Megaphase 122 cc Printing, Mafikeng, South Africa.
- Dickie M, Agrawal AA and Bruin J. 2005. Plants talk, but are they deaf? *Trends in Plant Science* 8: 403-405.
- Dikeni L, Mooihead R and Scoons I. 1996. Land-use and environmental policy in the rangelands of South Africa: Case studies from the Free State and Northern Province. Working paper 38: 59. LAPC, Johannesburg.
- DiTomaso JM, Brooks NL, Allen EB, Minnich R, Rice PM and Kyser GB. 2006. Control of invasive weed with prescribed burning. *Weed Technology* 20: 535-548.
- Donaldson CH. 1966. Control of blackthorn in the Molopo area with special reference to fire. *Proceedings of the Grassland Society of southern Africa* 1: 57-62.
- Dreber N, Harmse CJ, Götze A and Trollope WSW. 2014. Quantifying the woody component of savanna vegetation along a density gradient in the Kalahari Bushveld: a comparison of two adapted point-centred quarter methods. *The Rangeland Journal* 36: 91-103.
- Drying E. 1973. Principles of Remote Sensing. *Ambios* 3: 57-69.
- Dunn AT. 2001. Sierra Nevada Vegetation. [WEB:] <http://www.sierranevadaphotos.com/geography/vegetation.asp>.
- Dye PJ and Spear PT. 1982. The effects of bush clearing and rainfall variability on grass yield and composition in south-west Zimbabwe. *Journal of Agricultural Research* 20: 103-188.
- Dyke DA and Knick T. 2003. Plant invaders, global change and Landscape management (Paper 541).
- Eastman JR. 2003. IDRISI Kilimanjaro: Guide to GIS and Image Processing, Clark Labs, USA.
- Edwards D. 1983. A broad-scale structural classification of vegetation for practical purposes. *Bothalia* 14: 705-810.

- El Amin HM. 1976. Geographical distribution of the Sudan *Acacias*. Bulletin of the Forest Research Institute. Khartoum, Sudan.
- Eldridge DJ, Bowker MA, Maestre FT, Roger E, Reynolds JF and Whitford WG. 2011. Impacts of shrub encroachment on ecosystem structure and functioning: towards a global synthesis: *Ecology* 14: 709-722.
- Eldridge DJ and Wong VNL. 2005. Clumped and isolated trees influence soil nutrient levels in an Australian temperate box woodland. *Plant and Soil* 270: 331-342.
- Elhleringer JR, Sage RF, Flanagan LB and Pearcy RW. 1991. Climate change and the Evolution of C₄ Photosynthesis. *Trends in Ecology and Evolution* 6: 95-99. DOI: 10.1016/0169-5347 (91) 90183-2.
- Fagg CW and Stuart JOL. 1994. The value of *Acacia* and *Prosopis* in arid and semi-arid environments. *Journal of Arid Environments* 27: 3-25.
- Fensham RJ, Fairfax RJ and Archer SR. 2005. Rainfall, land-use and woody vegetation cover change in semi-arid Australian savanna. *Journal of Ecology* 93: 596-606.
- Fensham RJ and Holman JE. 1999. Temporal and spatial patterns in drought related tree dieback in Australian savanna. *Journal of Applied Ecology* 36: 1035-1050.
- Fisher JT. 2013. People, parks and rangelands: An analysis of 3-dimensional woody vegetation structure in a semi-arid savanna. Ph.D. thesis. University of the Witwatersrand Johannesburg, South Africa.
- Foody GM. 2002. Status of land cover classification accuracy assessment. *Remote Sensing of Environment* 80: 185-201.
- Fowler N. 1986. The role of competition in plant communities in arid and Semi-Arid regions. *Annual Review of Ecology and Systematics* 17: 89-110.
- Frost P, Menaut J, Walker B, Mendia E, Solbrig O and Switt M. 1986. Responses of savannas to stress and disturbance: A proposal for a collaborative programme of research. *Biology International Special Issue* 10. Paris: International Union of Biological Sciences.
- Furley PA, Rees RM, Ryan CM and Saiz CM. 2008. Savanna burning and the assessments of long-term fire experiments with particular reference to Zimbabwe. *Progress in Physical Geography* 32: 611-634.
- Gabriel HW and Talbot SS. 1984. Glossary of landscape and vegetation ecology for Alaska. BLM-Alaska. Technical Report No. 10. Anchorage: US. Department of the Interior Bureau of land management.

- Gao J. 2009. Digital Analysis of Remotely Sensed Imagery, McGraw Hill, New York.
- Gedda AE. 2003. Rangeland evaluation in relation to pastoralists' perceptions in the Middle Awash Valley of Ethiopia. Ph.D Thesis, University of Free State, Bloemfontein, South Africa. 297pp.
- Geist HJ and Lambin EF. 2001. What drives tropical deforestation? Land use and Cover Change International Project Office, Louvain-la-Neuve. Belgium.
- Gemedo DT, Maas BL and Tisselstein J. 2006. Environment of woody plants and its impact on pastoral livestock production in the Borana Lowlands. Southern Oromia. Ethiopia. *African Journal of Ecology* 44: 237-246.
- Gibbs-Russell E, Watson L, Koekemoer M, Smook L, Barker NP, Anderson HM and Dallwitz MJ. 1991. Grasses of southern Africa: In: *Memoirs of the Botanical Survey of South Africa* No. 58. Botanical Research institute, Pretoria. South Africa.
- Gibson PJ and Power CH. 2000. Introductory Remote Sensing- Digital Image Processing and Applications, Routledge, New York. ISBN: 0 415 170249.
- Goheen JR, Young TP, Keesing F and Palmer TP. 2007. Consequences of herbivory by native ungulates for the reproduction of a savanna tree. *Journal of Ecology* 95: 129-138.
- Goodchild MF. 1994. Integrating GIS and remote sensing for vegetation analysis and modelling: methodological issues. *Journal of Vegetation Science* 5: 615-626.
- Goncalves CS and Batalha MA. 2011. Towards testing the "honeycomb rippling model" in Cerrado, Brazil. *Journal of Biology* 71: 401-408.
- Gram FP. 2004. Application of a Total Station in savanna vegetation surveys. *Dinteria* (29): 41-53. Windhoek. Namibia.
- Grice AC. 1996. Seed production, dispersal and germination in *Cryptostegia grandiflora* and *Ziziphus mauritiana*, two invasive shrubs in tropical woodlands of Northern Australia. *Australian Journal of Ecology* 21: 324-331.
- Grime JP. 1994. Defining the scope and testing the validity of C-S-R theory: a response to Midgley, Laurie, and Le Maitre. *Bulletin of the Southern African Institute for Ecologists and Environmental Scientists* 13: 4-7.
- Grossman D, Crunow JO and Theron GK. 1980. Biomass cycles, accumulation rates and nutritional characteristics of grass layer plants in canopied and uncanopied sub habitats of *Burkea* savanna. *Proceedings of the Grassland Society of southern Africa* 15: 157-161.

- Grout L. 1861. Zululand, or Life among the Zulu Kaffirs of Natal and Zululand London: African Publication Society.
- Grunow JO. 1980. Feed and habitat preferences among source large herbivores on African veld. *Proceedings of the Grassland Society of southern Africa* 5: 141-146.
- Guy PR. 1981. Changes in the biomass and productivity of woodlands in the Sengwa Wildlife Research area, Zimbabwe. *Journal of Ecology* 18: 507-519.
- Hadar L, Noy-Meir and Perevolots A. 1999. The effect of shrub clearing and grazing on the composition of a Mediterranean plant community: functional groups versus species. *Journal of Vegetation Science* 10: 673-682.
- Hagenah NH, Munkeut GK and Olff H. 2009. Interacting effects of grass height and herbivores on the establishment of an encroaching savanna shrub. *Plant Ecology* 201: 553-566.
- Hagos MG and Smit GN. 2005. Soil enrichment by *Acacia millifera* subsp. *detinens* on nutrient poor sandy soil in a semi-arid southern African savanna. *Journal of Arid Environments* 61: 47-59.
- Halwagy R. 1962 a. The impact of man on semi-desert vegetation in the Sudan. *Journal of Ecology* 50: 263-273.
- Halwagy R. 1962 b. The incidence of biotic factors in northern Sudan. *Oikos* 13: 97-117.
- Hardin G. 1968. Tragedy of the commons. *Science* 162: 1243-1248.
- Hardy MB, Hurt CR and Bosch OJH. 1999. Veld condition assessment. In: Tainton NM (Ed.). 1999. Veld Management in South Africa. University of Natal Press, Pietermaritzburg.
- Harmer R. 2001. The effect of plant competition and simulated summer browsing by deer on tree regeneration. *Journal of Applied Ecology* 38: 1094-1103.
- Harper JL. 1977. The population biology of plants. Academic Press, New York, New York, USA.
- Harralick RM, Shanmugan K and Dinstein I. 1973. Textural features for image classification. *IEEE Transactions on Systems, Man and Cybernetics*. SMC 3: 610-612.
- Harrison YA and Shackleton CM. 1999. Resilience of South African communal grazing lands after the removal of high grazing pressure. *Land Degradation and Development* 10 (3): 225-239.
- Hasmadi M, Pakhariazad H and Shahrin M. 2009. Evaluating supervised and unsupervised techniques for land cover mapping using remote sensing data. *Malaysian Journal of Society and Space* 5: 1-10.

- He Y, D'Odirico P, De Wekker P, Fuentes SFJ and Litvak M. 2010. On the impact of shrub encroachment on microclimate conditions in the northern Chihuahuan desert. *Journal of Geophysical Research* 115 (D21). Wiley and Sons. DOI: 10.1029/2009JD013529.
- Higgins SI, Bond WJ and Trollope WSW. 2000. Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. *Journal of Ecology* 88: 213-229.
- Higgins SI, Shackelton CM and Robinson ER. 1999. Changes in woody community structure and composition under contrasting land-use systems in a semi-arid savanna, South Africa. *Journal of Biogeography* 26: 619-627.
- Higgins SI, Scheiter S and Sankaran M. 2010. The Stability of African savannas, Insights from the indirect estimation of the parameters of a dynamic model. *Ecology*. 91: 1682-1692.
- Hill MJ, Hanan NP, Hoffmann W, Sholes R, Prince S, Ferwerda J, Lucas RM, Baker I, Arneth A, Higgins I, Barrett SI, Disney M and Hutley L. 2010. Remote Sensing and Modelling of Savannas: The state of the Dis-Union. Keynote address. Workshop held at Colorado State University.
- Hoffman MT and Ashwell A. 2001. Nature Divided: Land Degradation in South Africa. University of Cape Town Press. ISBN: 987- 1- 9197- 135- 4- 0.
- Hoffman MT, Todd S, Ntshona Z and Turner S. 1999. Land degradation in South Africa. Cape Town: National Botanical Institute.
- Hoffman WA. 1988. Post-burn reproduction of woody plants in a neotropical savanna: the relative importance of sexual and vegetative reproduction. *Journal of Applied Ecology* 38: 422-433.
- Hoffman WA, Otto W and Solbrig T. 2003. The role of top kill in the differential response of savanna woody species to fire. *Forest Ecology and Management*. 180(1): 273-286. DOI: 10.1016/50078-1127 (02) 00566-2.
- Holling CS. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1-23.
- Homewood KM and Rodgers WA. 1991. Masailand Ecology: Pastoralist Development and Wildlife Conservation in Ngonongoro, Tanzania. Cambridge University Press. Pp.1-298, Cambridge, UK.
- Houehanou DT, Glele KR, Assagbadjo AE, Kindomihou V, Houinato MW, Wittig R and Sinsin B. 2013. Change in woody floristic composition, diversity and structure 1 from

- protected to 2 unprotected savannas in Pendjari Biosphere Reserve (Benin, West Africa). *African Journal of Ecology* 51(2): 358-365. DOI: 10.1111/aje. 12030.
- Howaida F, Abdelrahman K and Krzywinski. 2008. Environmental effects on morphology of *Acacia tortilis* group in Red Sea Hills, North-Eastern Sudan and South-Eastern Egypt. Department of Biology, University of Bergen, Allegaten, Norway.
- Huang S and Seigert F. 2006. Land cover classification optimized to detect areas at risk of desertification in North China based on SPOT vegetation imagery. *Journal of Arid and Environment* 67: 308-327.
- Hudak AT. 1999. Rangeland Mismanagement in South Africa: failure to apply ecological knowledge. *Human Ecology* 7: 65-78.
- Hudak AT and Brockett BH. 2004. Mapping fire scars in a southern African savannah using Landsat imagery. *International Journal of Remote Sensing* 25: 3231-3243.
- Hudak AT and Weissman CA. 1998. Textual analysis of historical aerial photography to characterize woody plant encroachment in South African savanna. *Remote Sensing of Environment* 66: 317- 330.
- Hudak AT and Weissman CA. 2001. Textural analysis of high resolution imagery to quantify bush encroachment in Madikwe Game Reserve, South Africa, 1965-1996. *International Journal of Remote Sensing* 14: 2731-2740.
- Hudak AT, Weissman CA and Seastedt TR. 2003. Woody over story effects on soil carbon and nitrogen pools in South African savanna. *Australian Ecology* 28; 173-181.
- Huete AR, Liu HQ, Batenily K and Luenen VW. 1997. A comparison of vegetation indices over a global set of TM images for EOS-MODIS. *Remote Sensing of Environment* 59: 440-451.
- Hulme MS, Melanie AH, McGlore MS and Duncan RP. 2009. Are treelines advancing? A global meta-analysis of treeline response to climate warming. *Ecology Letters* 12: 1040-1049. DOI: 10.1111/j.1461-0248.2009.01355.
- Hulme PE, Nentwig W, Pysek P and Villa M. 2010. Are the aliens taking over? Invasive species and their increasing impact on biodiversity. In: Settele J, Pereu L, Georgiev T, Grabaum R, Grobenik V, Hammen V, Klotz S, Kotirac M and Kurin I. (Eds.) 2010. Atlas of Biodiversity Risk. Perisoft, Sofia and Moscow.
- Huxman TE, Wilcox BP, Scott R, Snyder KA, Breshears D, Small EE, Huttme KR, Pockman WT and Jackson RB. 2004. Woody plant encroachment and water cycles: *An Eco hydrological Framework Ecology* 86: 308-319.

- Idso SB. 1992. Shrubland expansion in the American southwest. *Climate Change* 22: 85-86.
- Intergovernmental Panel on Climate Change (IPCC). 2011. Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press. Cambridge, United Kingdom and New York, USA. ISBN: 9789291691319.
- Jachmann H and Croes T. 1991. Effects of browsing by elephants on *Combretum/ Terminalia* woodland at the Nazinga Game Ranch, Burkina Faso, West Africa. *Biological Conservation* 57: 13-24.
- Jacobs N. 2000. Grasslands and Thickets: Bush Encroachment and herding in the Kalahari Thornveld. Environment and History 2000. African-American Studies Program.
- Jeltsch F, Milton SJ, Dean WRJ and Van Rooyen N. 1996. Tree spacing and coexistence in semi-arid savannas. *Journal of Ecology* 84: 583-595.
- Jelstch F, Milton SJ, Dean WRJ, Van Rooyen N and Moloney KA. 1998. Modelling the impact of small-scale heterogeneities on tree-grass co-existence in semi-arid savanna. *Journal of Ecology* 86: 780-793.
- Jeltsch F, Weber GE and Grimm V. 2000. Ecological buffering mechanisms in savannas: A unifying theory of long-term tree-grass coexistence. *Plant Ecology* 161: 161-171.
- Jensen JR. 1983. Biophysical Remote Sensing. *Annals of the Association of American Geographer* 1: 111-132.
- Jensen JR. 1986. Introductory Digital Image Processing. Prentice Hall, New Jersey.
- Jensen JR. 1996. Introductory Digital Image Processing: A remote sensing perspective. Prentice Hall, Saddle River New Jersey. Pp 316.
- Jin XM, Zhang YK, Schaepman ME, Clevers JGPW and Su Z. 2008. Impact the elevation and aspect on the spatial distribution of vegetation in the Qiluian mountain area with remote sensing data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 37: 1385-1390.
- Joubert DF, Rothauge A and Smit GN. 2008. A conceptual model of vegetation in the semi-arid Highveld savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. *Journal of Arid Environments* 72: 2201-2210.
- Joubert DF, Smit GN and Hoffman TM. 2013. The influence of rainfall, competition and predation on seed production, germination and establishment of an encroaching *Acacia* in an arid Namibian savanna. *Journal of Arid Environments* 91: 7-13.

- Joubert JGV. 1966. Die invloed van verskillende behandelings op die verhouding van swarthaak tot gras in die Damaralandse doringboomsavanne in Suidwes-Afrika. *Annals of the University of Stellenbosch. Series A* 41: 435-463.
- Jupp DLB and Walker J. 1997. Detecting structural and growth changes in woodlands and forests: the challenge for remote sensing and the role of geometric-optical modelling. In: Gholz HL, Nakane K, Shimoda H. (Eds.). 1997. The use of remote sensing in the modelling of forest productivity Dordrecht. Kluwer Academic Publishing. Pp. 75-108.
- Justice C, Huete A and Liu H. 1994. Development of vegetation and soil indices for Modis-EOS. *Remote Sensing of the Environment* 49(3): 224-234.
- Kamaruzaman J, Hasmadi I and Hidayah MA. 2009. Spectral separability of tropical forest tree species using airborne hyperspectral imager. *Journal of Environmental Science and Engineering* 3: 37-41.
- Kambataku JR, Creamer MD and Ward D. 2013. Overlap in soil water sources of savanna woody seedlings and grasses. *Ecohydrology* 6: 464-473.
- Kanz WA. 2001. Seed and seedling dynamics of certain *Acacia* species as affected by herbivory, grass, competition, fire and grazing system. M. Sc thesis. University of Natal. Pietermaritzburg, South Africa.
- Kassas M. 1957. On the Ecology of the Red Sea Coastal Land. *Journal of Ecology* 45(1): 187-201.
- Kauffman JB, Thorpe AS and Brookshire ENJ. 2001. Livestock exclusion and belowground ecosystem responses in riparian meadow of Eastern Oregon. *Ecological Applications* 14: 1671-1679.
- Kellman M. 1979. Soil enrichment by Neotropical savanna trees. *Journal of Ecology* 67: 565-577.
- Kennard DG and Walker BH. 1973. Relationship between tree canopy cover and *Panicum maximum* in the vicinity of Fort Victoria. *Rhodesia Journal of Agricultural Research* 11: 145-153.
- Kenneni L and Van der Maarel E. 1990. Eddy-populations Ecology of *Acacia tortilis* in the semi-arid region of the Sudan. *Journal of Vegetation Science* 1: 419-424. © IAVS; Opulus Press. Sudan.
- Kent M and Coker P. 1992. Vegetation description and analysis. A practical approach. Belhaven, London. UK.

- Kgope BS, Bond WJ and Midgley GF. 2010. Growth responses of African savanna trees implicate atmospheric (CO₂) as a driver of past and current changes in savanna tree cover. *Austral Ecology* 35: 451-463.
- Kidron GJ. 2009. The effect of shrub canopy upon surface temperatures and evaporation in the Negev Desert. *Earth Surface Processes and Landforms* 34: 123-132.
- Knoop WT. 1982. Interactions of woody and herbaceous vegetation in two savanna communities and Nylsvei. M.Sc thesis. University of the Witwatersrand, Johannesburg.
- Knoop WT and Walker BH. 1985. Interactions of woody and herbaceous vegetation in southern African savanna. *Journal of Ecology* 73: 235-253.
- Kochy M and Wilson SD. 2001. Nitrogen deposition and forest expansion in the northern Great Plains. *Journal of Ecology* 89: 807-817.
- Kotze IJDF and Fairall N. 2006. Using Landsat TM imagery to map fynbos plant communities: a case study. *South African Journal of Wildlife Research* 36: 75-87.
- Kraaij T and Ward D. 2006. Effects of rain, nitrogen and grazing on tree recruitment and early survival in bush-encroached savanna. *Plant Ecology* 186: 235-246.
- Kutiel P, Kutiel H and Laveee H. 2000. Vegetation response to possible scenarios of rainfall variations along a Mediterranean extreme and climate transect. *Journal of Arid Environments* 277-290.
- Laliberte AS, Rango A, Havstad KM, Paris JF, Beck RF, McNeely R and Gonzalez AL. 2004. Object-oriented analysis for mapping shrub encroachment from 1937-2003 in southern New Mexico. *Remote Sensing of the Environment* 93: 198-200.
- Lamprey HF. 1983. Pastoralism yesterday and today the overgrazing problem. In: Bourliere F (Ed.). 1983. Living with uncertainty: New directions in Pastoral Development in Africa.
- Land Type Survey Staff. 1989. Land types of the map 2530 Baberton. *Memoirs of the Agricultural Resources of South Africa* 13: 1-390.
- Lark RM. 1996. Geostatistical description of texture on an aerial photograph for discriminating classes of land cover. *International Journal of Remote Sensing* 17: 2115-2133.
- Le Houerou HM. 1969. The vegetation of steppe Tunisia with reference to Morocco, Algeria and Lybia. Vol.42.

- Le Houerou HM. 2001. Biogeography of the arid steppeland north of the Sahara. *Journal of Arid Environments* 48: 103-128.
- Lesoli MS, Gxasheka M, Solomon TB and Moyo B. 2013. Integrated Plant Invasion and bush encroachment Management on *Southern African Rangelands*. [WEB:] <http://dx.doi.org/10.5972/56182>.
- Lett M and Knoop AK. 2003. Consequences of shrub expansion in mesic grassland: Resource alterations and graminoid responses. *Journal of Vegetation Science* 14: 487-496.
- Levin N. 1999. Fundamentals of remote sensing, a book compiled using internet resources, articles and personal knowledge. [WEB:] [http://gepgraphy.huji.ac.il/personal/Noam% 20 Levin/1999-Fundamentals-of-remote-sensing pdf](http://gepgraphy.huji.ac.il/personal/Noam%20Levin/1999-Fundamentals-of-remote-sensing.pdf). (Accessed on 09 May 2011).
- Lewis DM. 1991. Observations of tree growth, woodland structure and elephant damage on *Colophospermum mopane* in Changwa Valley, Zambia. *African Journal of Ecology* 29: 207-221.
- Lewis GP. 2005. *Acacieae*. In: Lewis GP, Schrine BD, Mackinder B and Lock JM (Eds.). 2005. *Legumes of the World*. Pp. 187-191.
- Lillesand TM and Keifer RW. 1994. *Remote sensing for image Interpretation*. John Wiley and Sons. Pp. 750.
- Lillesand TM, Keifer RW and Jonathan WC. 2004. *Remote sensing and image Interpretation*. John Wiley and Sons. ISBN: 0471451525.
- Liu JG and Mason PJ. 2009. *Essential Image processing and GIS for remote sensing*, John Wiley and Sons Ltd. Singapore.
- Low AB and Rebelo, AG. 1996. *Vegetation of South Africa, Lesotho and Swaziland*. South African National Biodiversity Institute (SANBI). DEAT, Pretoria. ISBN: 9780620345689.
- Lu D, Mausel P, Brondizio E and Moran E. 2004. Change detection techniques. *International Journal of Remote Sensing* 25: 2365-2407.
- Luckow M, Miller JT, Murphy DJ and Livschultz T. (Eds.). 2003. A phylogenetic analysis of the Mimosideae (Leguminosae) based on chloroplast DNA sequence data. In: Klitgaard BB, Bruneau A, (Eds). 2003. Kew: Royal Botanic Gardens. Pp. 197-220.
- Ludwig JA, Coughenour MB, Liedloft AC and Dryer AR. 2001. Modelling the resilience of Australian savanna systems to grazing impacts. *Environment International* 27: 167-172.

- Ludwig JA and Tongway DJ. 1995. Spatial organization of landscapes and its function in semi-arid woodlands, Australia. *Landscape Ecology* 101: 51-63.
- Ludwig JA, Tongway D, Freudeneberger D and Noble IR. 1997. Landscape Ecology Function and Management Principles from Australian Rangelands, CSIRO, Collingwood. Australia. Pp. 158.
- Luken JD and Shea M. 2000. Repeated prescribed burning at Dinsmore Woods State Nature Preserve (Kentucky, USA): responses of the understory community. *Natural Areas Journal* 20: 150-158.
- Lunetta RS and Elvidge CD. 1999. Remote Sensing Change Detection. *Environmental Monitoring Methods and Applications*. Sleeping Bear Press Inc., USA.
- Lurk RM. 1996. Geostatistical description of texture on an aerial photography for discriminating classes of land cover. *International Journal of Remote Sensing* 17: 2115-2133.
- Mac Vicar CN, De Villiers JM, Loxton RF, Vester E, Lambrechts JJN, Merry Weather RF, Le Roux J, Van Rooyen JA, Harmse HJ and Van M. 1977. Soil classification: A binomial system for South Africa. (1st Edition) Pretoria: Soils and Irrigation Research Institute. Pp. 150. ISBN: 090835682X.
- Maestre FT, Bowler MA, Puche MD, Hinojosa MB, Martinez I and Garcia P. 2009. Shrub encroachment can reverse desertification in semiarid Mediterranean grasslands. *Ecology Letters* 12: 930-941.
- Manger LO and Abd Elati H. 1996. Survival on Meagre Resources: Hadendowa Pastoralism in the Red Sea Hills, Nordiska Afrikanstitutet: Distributed by Almquist and Wiksell International, Uppsala. Sweden.
- Martin
- Martyn JT. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. *Journal of Conservation Biology* 4: 1626-1632.
- Maselli F, Amparo G and Conese C. 1998. Integration of High and Low Resolution NDVI data for monitoring vegetation in Mediterranean Environments. *Remote Sensing of Environment* 63: 208-218.
- Masike S and Urich P. 2008. Vulnerability of traditional beef sector to drought and the challenges of climate change: The case of Kgatleng District Botswana. *Journal of Geography and Regional Planning* 1 (1): 12-18.

- Maslin BR, Miller JT and Seigner DS. 2003. Overview of the generic status of *Acacia* (Leguminosae Mimosoideae). *Australian System. Bothalia* 16: 1-18.
- Maslin R and Macdonald MW. 2004. *Acacia* search. Evaluation on *Acacia* as a woody crop option for southern Australia. RINDC. Union Offset Printers. Canberra. Australia.
- Mc Naughton SJ and Banyikwa FF. 1995. Plant communities and herbivory. In: Sinclair ARE and Arcese P (Eds.). 1995. Dynamics, Management and Conservation of an ecosystem. Chicago: Chicago Press. Pp. 49-70.
- McPherson GR and Wright HA. 1990. Effects of cattle grazing and *Juniperus pinchotti* canopy cover on herb cover and production in western Texas. *American Midland Naturalists* 123: 144-151.
- Mekunia W, Veldkamp E, Laile M, Nyssen J, Muys B and Gerbrehiwot K. 2007. North West Province South Africa, North West Province Department of Agriculture, Conservation and Environment.
- Menaut JC, Gignoux J, Prado C and Clobert J. 1990. Tree communities' dynamics in a humid savanna of the ivory-coast-modelling the effects of fire and competition with grass and neighbours. *Journal of Biogeography* 17: 471-481.
- Meurer M, Raff K, Starm HJ and Will H. 1994. Savannebrande in Tropischwestafrika. *Petermanns Geographische Mitteilungen* 138(1): 35-50.
- Midgley JJ and Bond WJ. 2001. A synthesis of the demography of African *Acacias*. *Journal of Tropical Ecology* 17: 871-886.
- Milchunas DG, Varnamkhasti AS, Lauenroth WK and Goetz H. 1995. Forage quality in relation to long-term grazing history- current- year defoliation and water resource. *Oecologia* 101: 366-374.
- Miller JT and Bayer RJ. 2003. Molecular phylogenetic of *Acacia* subgenera *Acacia* and *Aculeiferum* (Fabaceae: Mimosoideae), based on the chloroplast matK coding sequence and flanking trnK intron spacer regions. *Australian Systematic Botany* 16: 27-33.
- Miller JT, Grimes JW, Murphy DJ, Bayer RJ and Ladigo PY. 2003. A phylogenetic analysis of the *Acacieae* and *Ingeae* (Mimosoideae: Fabaceae) based on tmK, matK, psbA-trnH and trnL/ trnF seqa data. *Australian Systematic Botany* 28: 558-566.
- Miller JT and Seigler DS. 2012. Evolutionary and taxonomic relationships of *Acacia s.l.* (legumenosae: Mimosoideae). *Australian Systematic Botany* 25: 217-224.
- Milton MF. 1994. The costs and benefits *Acacia* seed consumption by ungulates. *Oikos* 71 (1): 181-187.

- Mills AJ and Fey MV. 2004. Declining soil quality in South Africa: Effects of land use on soil organic matter and surface crusting. *South African Journal of Plant and Soil* 21: 388-398.
- Milton SJ. 1995. Effects of rain sheep and tephtirid flies on seed production of two arid karroo shrubs in South Africa. *Journal of Applied Ecology* 32: 137-144.
- Milton SJ and Dean WRJ. 1995. How useful is the keystone species concept and can it be applied to *Acacia erioloba* in the Kalahari Desert. *Okologie* 4: 147-156. ISSN : 0940-5178.
- Milton SJ and Hoffman MT. 1994. The application of state-and-transition models to rangeland research and management in arid and semi-arid grassy Karroo. *African Journal of Range and Forage Science* 11: 18-24.
- Miranda FP, Fonseca LEN and Carr J. 1998. Semi variogram textural classification JERS-1 (Fuyo-1) SAR data obtained over a flooded area of the Amazon rainforest. *International Journal of Remote Sensing* 19: 549-556.
- Mogodi PP. 2009. The extent of woody plant invasion in selected sites of the communally managed Molopo District, North West Province. M.Sc. thesis. North West University. Mafikeng.
- Molatlhegi KS. 2008. The extent of woody plant invasion in selected areas of the former Molopo Magesterial District. M.Sc thesis. North-West University. Mafikeng.
- Moleele NM and Perkins J. 1998. Encroaching woody plant species and boreholes: Is cattle density the main driving factor in the Olifants Drift communal grazing lands, Botswana. *Journal of Arid Environments* 40: 245 – 253.
- Moleele NM, Ringrose S, Matheson W and Vanderpost C. 2002. More woody plant? The states of bush encroachment in Botswana's grazing areas. *Journal of Environmental Management* 64: 3-11.
- Moore A, Van Niekerk JP, Knight IW and Wessels W. 1985. The effect of Tebuthiuron on the vegetation of the Thorn Bushveld of the Northern Cape: a preliminary report. *Journal of Grassland Society of southern Africa* 2: 7-10.
- Moore A and Odendaal A. 1987. Die ekonomiese implikasie van bosverdigting en bosbeheer soos van toepassing op 'n speenkalfproduksiestelsel in die doringbosveld van die Molopo gebied. *Journal of the Grassland Society of southern Africa* 4: 139–142.

- Moore A, Van Euk JAJ, Van Niekerk JP and Robertson BL. 1988. Evapotranspiration in 3 plant communities of a *Rhigozum trichotomum* habitat at Uppington. *Journal of the Grassland Society of southern Africa* 5: 80-84.
- Mopipi K, Trollope WSW and Scogings PF. 2009. Effects of moisture, nitrogen, grass competition and simulated browsing on the survival and growth of *Acacia karroo* seedlings. *African Journal of Ecology* 47: 680-687.
- Moyo D, Dube S, Lesoli M and Masike PJ. 2008. Communal area grazing strategies: institutions and traditions practices. *African Journal Range and Forage Science* 25: 47-54.
- Mucina L and Rutherford MC. 2006. The vegetation of South Africa, Lesotho and Swaziland. Streltzia – 19. South African National Biodiversity Institute, Pretoria. ISBN-13. 978-1-919976-21-1.
- Mueller-Dombois D and Ellenberg V. 1974. The count-plot method and plot less sampling techniques. In: Aims and Methods of vegetation Ecology. John Wiley and Sons New York Pp. 96-108.
- Munyati C and Kabanda TA. 2009. Using multitemporal Landsat TM imagery to establish land-use pressure induced trends in forest and woodland cover in sections of the Soutpansberg Mountains of Venda region, Limpopo, South Africa. *Regional Environmental Change* 9: 41-56.
- Munyati C and Ratshibvumo T. 2010. Differentiating geological fertility derived vegetation zones in Kruger National Park South Africa, using Landsat and Modis Imagery. *Journal of Nature Conservation* 18: 169-179.
- Munyati C, Shaker P and Pasha G. 2011. Using remotely sensed imagery to monitor savanna rangeland deterioration through plant proliferation: A case study from communal and biodiversity conservation rangeland sites in Mokopane, South Africa. *Environment Monitoring and Assessment* 176 (1-4): 293-311. DOI: 10.1007/s10661-010-1583-4.
- Mutanga O, Prins HHT, Skidmore AK, Huizig H, Grant R, Ped MJS, Biggs H and Van Wieren S. 2004. Explaining Grass- Nutrient Patterns in a Savanna Rangeland of southern Africa. *Journal of Biogeography* 31: 819-829.
- Mutanga O and Rugege D. 2006. Integrating remote sensing and spatial statistics to model herbaceous biomass distribution of tropical savanna. *International Journal of Remote Sensing* 27: 3499-3514.

- Myeni RB, Los S and Tucker CJ. 1996. Satellite-based identification of linked vegetation index and sea surface temperature anomaly areas from 1982-1990 for Africa, Australia and South America. *Geophysical Research Letters* 23: 729-732.
- Nakafeero AL, Reed NS and Moleele NM. 2007. Allelopathic potential of fire agroforestry trees, Botswana. *African Journal of Ecology* 45: 590-593.
- National Department of Agriculture. 2000. Declared bush encroachers. In Conservation of Agricultural Resources Act.43 of 1983. South Africa. [Wed:] <http://www.nda.agric.za/docs/Act43/Table%204.htm>. [Access date 2005/07/28].
- Ndou N. 2013. Relating vegetation condition to grazing management systems in the central Keiskamma Catchment, eastern Cape Province, South Africa. M.Sc thesis. Nelson Mandela Metropolitan University. Port Elizabeth.
- Neilson RP. 1986 High-resolution climatic analysis and southwest biogeography. *Science* 232: 27-34.
- Nelder J. 2006. Why is vegetation condition important to government: A case study from Queensland. *Ecological Management and Restoration* 7: 5-7.
- Nix HA. 1983. Climate of tropical savannas in ecosystems of the world. In: Bourliere F. (Ed.). 1983. Tropical Savanna. Pp. 37–62, Elsevier, New York.
- Noble JC. 1997. The delicate and noxious scrub CISRO studies on native tree and shrub proliferation in the semi-arid woodlands of eastern Australian Canberra, ACT: CSIRO.
- Noble IR and Dirzo R. 1997. Class system for South African indigenous forests: An objective classification for the Department of Water Affairs and Forestry. *Science* 277: 522-525.
- Nolte KR, Gabor TM, Hehman WM, Asteson MA, Fulbright TE and Rutledge JC. 1994. Long-term effects of bush management on vegetation diversity in ephemeral drainages. *Journal of Range Management* 47: 457-459.
- Oba G and Kaitira LM. 2006. Herder knowledge of landscape assessments in arid rangelands in northern Tanzania. *Journal of Arid Environments* 66: 168-186.
- Oba G, Post EE, Syvertsen PO and Steinseth NC. 2000. Bush cover and range condition assessments in relation to landscape and grazing in Southern Ethiopia. *Landscape Ecology* 15: 535-546.
- O'Connor TG. 1993. The influence of rainfall and grazing on the demography of some African savanna grasses: a matrix modelling approach: *Journal of Applied Ecology* 30: 119-132.

- O'Connor TG. 1995. *Acacia karroo* invasion of grasslands environmental and biotic effects influencing seedling emergence and establishment. *Oecologia* 103: 214-223.
- O'Connor TG and Crow VRT. 1999. Rate and pattern of bush encroachment in Eastern Cape savanna and grassland. *African Journal of Range and Forage Science* 16: 26-31.
- O'Connor TG, Puttick JR and Hoffman MT. 2014. Bush encroachment in southern Africa: Changes and causes. *African Journal of Range and Forage Science* 31(2): 1022-1029.
- Odendaal J, Porigo W, Wesuls D and Jurgens N. 2010. Mapping bush encroaching species by seasons differences in hyperspectral imagery. *Remote Sensing* 2(6): 1416-1438.
- Parkes D and Lyon P. 2006. Towards a national approach to vegetation condition assessment that meets government investor's needs: A policy perspective. *Ecological Management and Restoration* 7: 53-55.
- Partel M, Helm A. 2007. Invasion of woody species into temperate grasslands: Relationship with abiotic and biotic soil resource heterogeneity. *Journal of Vegetation Science* 18: 63-70.
- Pearson RL and Muller LD. 1972. Remote sensing of standing crop biomass for estimation of the productivity of the short grass prairie, *Pawnee National Grasslands*, Colorado. *Proceedings of the 8th International Symposium on Remote Sensing of the Environment*, Ann Arbor, Michigan: Pp. 133-140.
- Peijum DU, Xingli L, Wen CAO, Yan LUO and Huaperg Z. 2010. Monitoring urban land cover and vegetation change by multi-temporal remote sensing information. *Mining Science and Technology* 20: 922-932.
- Perumal K and Bhaskaran R. 2010. Supervised classification performance of multispectral images. *Journal of Computing* 2: 799-807.
- Peters DDC and Havstadie KM. 2006. Nonlinear dynamics in arid and semiarid systems, interactions among drivers and processes across scales. *Journal of Arid Environments* 65: 196-206.
- Petrides GA. 1975. Principle foods verses preferred foods and their relation to stocking rate and range condition. *Biological Conservation* 7: 161-169.
- Pluess T, Jarosik V, Pysik P, Cannon R, Pergl J, Breukers A and Bacher S. 2012. Which factors affect the success or failure of eradication campaigns against alien species? *Plos One* 7 (10): 157- 248. DOI: 10.1371/journal.pone.0048157.

- Puissant A, Hirsch J and Weber C. 2005. The utility of texture analysis to improve per-pixel classification for high to very high spatial resolution imagery. *International Journal of Remote Sensing* 26: 733-745.
- Polley HW, Johnson HB and Mayeux HS. 1992. Carbon dioxide and water fluxes of C₂ annuals and C₃ and C₄ perennials at sub ambient CO₂ concentrations *Functional Ecology* 6: 693-703.
- Poorter H and Navas ML. 2003. Plant growth and competition at elevated CO₂: on winners, losers and functional groups. *New Phytologist* 157: 175-198.
- Prince SDE, Colstoun BD and Kravitz LL. 1998. Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. *Global Change Biology* 4(4): 359-374.
- Pyke DA and Knick T. 2003. Plant invaders, global change and landscape management (Paper 541) [WEB:] <http://www.ruoo.za./Institutes/rgi/irc2003/93/invited/htm>.
- Rappole JH, Russell CE, Norwine JR and Fullbright TE. 1986. Anthropogenic pressures and impacts on marginal, Neotropical, semiarid ecosystems. The case of south Texas. *Science of Total Environment* 55: 9-99.
- Ravi S, D'Odorico P, Wang L, White CS, Okin GS, Macko SA and Collins SL. 2009. Post-fire resource redistribution in desert grasslands: A possible negative feedback on land degradation. *Ecosystems* 12: 434-444.
- Rebello S, Milchunas DG, Noy-meir I and Chapman PL. 2002. The role of a spiny plant refuge in structuring grazed shortgrass steppe plant communities *Oikos* 98: 53-64.
- Redford IJ, Nicholas DM, Brown JR and Kriticos DJ. 2001. Paddock-scale patterns of seed production and dispersal in the invasive shrub *Acacia nilotica*. (Mimosaceae in northern Australian rangelands. *Australian Ecology* 26: 338-384.
- Reed MS. 2008. Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141: 2417-2431.
- Rejmanek M and Pitcairn MJ. 2002. When is eradication of exotic pest plants a realistic goal? Section of Evolution and Ecology. University of California, Davis, CA.USA.
- Richter CGF, Snyman HA and Smit GN. 2001. The influence of tree density on the grass layer of three semi-arid savanna types of southern Africa. *African Journal of Range and Forage Science* 180: 103-109.
- Rietkerk M, Kether P, Burger J, Hoorens B and Diff H. 2000. Multiscale soil and vegetation patchiness along a gradient of herbivore impact in a semi-arid grazing system in West Africa. *Plant Ecology* 148: 207-224.

- Riginos C, Milton SJ and Wiegand T. 2005. Context dependent interactions between adult shrubs and seedlings in a semi-arid shrubland. Department of Conservation Ecology. University of Stellenbosch.
- Ringrose S, Vanderpost C and Matheson W. 1996. The use of integrated remotely sensed and GIS data to determine causes of vegetation cover change in southern Botswana. *Applied Geography* 16: 225-242.
- Ritcher BD, Matthews D, Harrison DL and Wigington R. 2003. Ecologically sustainable water management: Managing River flows for river integrity. *Ecological Applications* 13: 206-224.
- Ritcher CGF, Synman HA and Smit GN. 2001. The influence of tree density on the grass layer of three semi-arid Savanna types of southern Africa. *African Journal of Range and Forage Science* 18 (2-3): 103-109.
- Robbins CT, Moles S, Hagerman AE and Hantley TA. 1987. Roles of tannins in defending plants against ruminants: reduction in dry matter digestion. *Ecology* 68: 1606-1615.
- Ross JH. 1979. A conspectus of the African *Acacia* spp. Botanical Research Institute, South Africa. 21-58.
- Ross JH. 1981. An analysis of the African *Acacia* species, their distribution, possible origin and relationship. *Bothalia* 13: 389-413.
- Roques KG, O' Connor TG and Watkinson AR. 2001. Dynamics of shrub encroachment in an African savanna: Relative influences of fire, herbivore, and rainfall and density dependence. *Journal of Applied Ecology* 38: 268- 280.
- Rouse JW, Haas RH, Schell JA and Deering DW. 1974. Monitoring vegetation systems in the Great Plains with ERTS. Paper presented at the 3rd ERST Symposium, Washington DC.
- Roux PW. 1966. Die uitwerking van seisoenrenewal en beweiding op gemengde karooveld. *Proceedings of the Grassland Society of southern Africa* 1: 103-110.
- Roux PW. 1986. Grondbewaring. Ongepubliseerde Referaat. Departement Landbou en Watervoorsiening. Middelburg. South Africa.
- Russell J and Ward D. 2014. Vegetation change in northern KwaZulu Natal since Anglo-Zulu War of 1879: local/ global drive. *African Journal of Range and Forage Science* 31: 89-105.

- Rutherford MC. 1978. Primary production ecology in southern Africa. In: Werger MJA (Ed.). 1978. Biogeography and ecology of southern Africa. W. Junk. The Hague. Pp. 623-652.
- Rutherford MC. 1980. Annual plant production-precipitation relations in arid and semi-arid regions. *South African Journal of Science* 76: 53-56.
- Rutherford MC. 1981. Survival, regeneration and leaf biomass changes in woody plants following spring burns in *Burkea africana*-*Ochna pulchra* savanna. *Bothalia* 13: 531-552.
- Rutherford MC. 1983. Growth rates, biomass and distribution of selected woody plant roots in *Burkea africana*-*Ochna pulchra* savanna. *Vegetatio* 52: 45-63.
- Rutherford MC. 1984. Relative allocation and seasonal phasing of woody plant components in a South African savanna. *Progress in Biometeorology* 3: 200-221.
- Rutherford MC. 1991. Diversity and photosynthetic responses in the mesic and arid Mediterranean-type climate region of Southern Africa: In: Esser G and Overdieck D. (Eds.). 1991. Modern Ecology and applied aspects. Elsevier. New York.
- Rutherford MC and Powrie LW. 2011. Can heavy grazing on communal land elevate plant species richness levels in the Grassland Biome of South Africa? *Plant Ecology* 212: 1407-1418. DOI: 10.1007/511258-011-9916-0.
- Rutherford MC and Westfall RH. 1994. Biomes of southern Africa: An objective categorization. *Memoirs of the Botanical Survey of South Africa* 63. Government Printer. Pretoria.
- Ruthven DC, Braden AW, Knutson HJ, Gallagher JE and Synatzske DR. 2003. Woody vegetation response to various burning regimes in South Texas. *Journal of Range Management* 56: 159-166.
- Sabins FF. 1987. Remote Sensing: Principles and Interpretation 2nd Edition. ISBN: 1577665074.
- Sagar R, Roghubanshi AS and Singh JS. 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *Forest Ecology and Management* 186: 61-71.
- Sankaran M, Niaw P, Hanan RJ, Scholes J, Ratmam DJ, Augustine DJ, Brian S and Cade JD. 2005. Determinants of woody cover in African savannas. *Nature* 438: 846-849.

- Sankaran M, Ratman J and Hanan NP. 2004. Tree-grass co-existence in savannas revisited – insight from examination assumption and mechanism invoked in existing models. *Ecology Letters* 7: 480-490.
- Sawadago L, Nygard R and Pallo F 2002. Effects of livestock and prescribed fire on coppice growth after selective cutting of Sudanian savannah in Burkina Faso. *Annals of Forage Science* 59(2): 185-195. DOI: 10. 1051/ *Forest*: 2002005.
- Schaltout KH and Al-Sodany NM 2002. Phytoecology of Omayed site. Mediterranean West Coast Project. Egyptian Environmental Affairs Agency. *Cairo* p 89.
- Sharam G, Sinclair ARE and Turkington R. 2006. Establishment broad-leaved thickets in Serengeti, Tanzania: the influence of fire, browsers, grass competition and elephants. *Biotropica* 38: 599-605.
- Sharp BR and Bowman DMJS. 2004. Patterns of long-term woody vegetation change in sandstone-plateau savanna woodland. *Journal of tropical Ecology* 20: 259-270.
- Scheiter S and Higgins SI. 2009. Impacts of climate change on the vegetation of Africa: an adaptive dynamic vegetation modelling approach. *Global Change Biology* 15: 2224-2246.
- Van Auken J, Meyer KM, Wiegand K, Schurr FM and Ward D. 2011. Distangling facilitation and seed dispersal from environmental heterogeneity as mechanisms generating associations between savanna plants. *Journal of Vegetation Science* 22: 1038-1048.
- Schlesinger WH, Reynolds JF, Cunnungham GL, Huenekke LF, Jarell WF, Virginia RA and Whitford WG. 1990. Biological feedbacks in global desertification. *Science* 247: 1043-1048.
- Schmidt H and Gileton A. 2000. Temporal and spatial vegetation cover changes in Israeli transition zone: AVHRR-based assessment of rainfall impact. *International Journal of Remote Sensing* 21(5): 977-1010.
- Scholes RJ. 1988. Response to Three Semi-arid savannas on contrasting soils to removal of the woody component. Ph.D thesis. University of Witwatersrand. Johannesburg.
- Scholes RJ. 2009. Syndromes of dryland degradation in southern Africa. *African Journal of Range and Forage Science* 26: 113-125.
- Scholes RJ and Archer SR. 1997. Tree–grass interactions in savannas. *Annual Review of Ecological Systems* 28: 517-544.
- Scholes RJ and Walker BH. 1993. An African savanna – Synthesis of the Nylsvley study. Cambridge. University Press. Cambridge, UK.

- Schulze ED, Caldwell MM, Canadell J, Mooney HA, Jackson RB, Parsons D, Scholes R, Sala OE and Trimborn P. 1998. Downward flux of water through roots (i.e. inverse hydraulic lift) in dry Kalahari sands. *Oecologia* 115: 460-462.
- Schulze RE. 1997. South African Atlas of Agrohydrology and Climatology. Report TT82/96. Water Research Commission, Pretoria.
- Scogings P, De Bruyn T and Vetter S. 1999. Grazing into the future; policy making for South African communal rangelands. *Development of southern Africa* 16: 403-414.
- Scogings P and Macanda M. 2005. *Acacia karroo* responses to early dormant season defoliation and debarking by goats in a semi-arid subtropical savanna. *Plant Ecology* 179: 193-206.
- Seigler DS, Ebinger JE and Miller JT. 2006. The genus *Senegalia* (Fabaceae: Mimosoideae) from the New World. *Phytologia* 88: 34-94.
- Sepehry A and Lui GJ. 2006. Flood induced land cover change detection using of Land surfaces. [WEB:] <http://www.2H.uniborn.de/earsel/papers/399-406.sepehry.pdf>. (Access date: 2007-04-12).
- Shackleton CM. 1993. Fuel wood harvesting and sustainable development in a communal grazing land and protected area of the Eastern Transvaal Lowveld. *Biological Conservation* 63: 247-254.
- Shackleton CM. 2002. Growth and fruit production of *Sclerocarya birrea* in the South African Lowveld. *Agroforestry Systems* 55: 175–180
- Shackleton CM, Shackleton SE, Buiten E and Bird N. 2007. The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics* 9 (5): 558-577.
- Shackleton JH and Gambiza J. 2008. Social and ecological trade-offs in combating land degradation: the case of invasion by a woody shrub (*Euryops floribundus*) at Macubeni, South Africa. *Land Degradation and Development* 19: 454-464.
- Shaltout KH and Al-Sodany YM. 2002. Phytoecology of Omayed Biosphere Reserve. Medwestcoast Global Environmental Facility (GEF) and Egyptian Environmental Affairs (EEAA). Cairo. Egypt.
- Sharma CM, Badu NP, Gairola S, Ghildiya SK and Suyal S. 2010. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya India. *Forest Ecology and Management* 260: 2170-2179.

- Shouten SA. 1982. Analysing spontaneous cases: A replication based on the Rhine collection. *European Journal of Parasychology* 4: 113-158.
- Simonson JT, Johnson EA. 2005. Development of the cultural landscape in the forest-grassland transition in southern Alberta controlled by topographic variables. *Journal of Vegetation Science* 16: 523-532.
- Sidiyasa K and Samsuudin I. 2003. Exploring biological diversity, environment and local people's perspectives in forest landscapes: Methods for a multidisciplinary land assessment. 2003. ISBN: 979-8764-88-9. [Web:] <http://www.cifor.cgiar.org>
- Skarpe C. 1986. Vegetation ecology in the western Kalahari in relation to large herbivore grazing. Ph.D. thesis. Upsalensis NO. 33, Uppsala University.
- Skarpe C. 1990. Shrub layer dynamics under different herbivore densities in arid savanna, Botswana. *Journal of Applied Ecology* 27: 873-885.
- Skarpe C. 1991. Impact of grazing in savanna ecosystem. *Ambios* 20: 351-356.
- Skarpe C. 1991. Spatial patterns and dynamics of woody vegetation in arid savanna. *Journal of Environmental Science* 2: 565-572.
- Skarpe C. 1996. Plant functional types and climate in southern African savanna. *Journal of Vegetation Science* 7: 397-404.
- Smit GN. 1989. Quantitative description of woody plants communities. Part 1: An Approach. *Journal of the Grasslands Society of Southern Africa* 64: 186-191.
- Smit GN. 1999. Field Guide to the Acacias of South Africa. Briza Publishers. Pretoria. ISBN: 1875093923.
- Smit GN. 2003. The coppicing ability of *Acacia erubescens* and *Combretum apiculatum* subsp. *apiculatum* in response to cutting. *African Journal of Range and Forage Science* 20: 21-27.
- Smit GN. 2004. An approach to tree thinning to structure southern African Environmental Management 71: 2: 179-191.
- Smit GN. 2005. Tree thinning as an option to increase herbaceous yield of an encroached semi-arid savanna in South Africa. *BMC Ecology* 5 (4), published online on May 28, 2005.
- Smit GN and Rethman NFG. 1998. Root biomass, depth distribution and relations with leaf biomass of *Colophospermum mopane*. *South African Journal of Botany* 64: 38 - 43.
- Smit GN and Rethman NGF. 2000. The influence of tree thinning on the soil water in a semi-arid savanna of the southern Africa. *Journal of Arid Environments* 44: 41-59.

- Smit GN, Richter CGF and Aucamp AJ. 1999. Bush encroachment: An approach to understanding and managing the problem: In Tainton (Ed.). 1999. *Veld management in South Africa* Pietermaritzburg: University of Natal Press. Pp. 246-260.
- Smit GN and Swart JS. 1994. Influence of leguminous and non-leguminous woody plants on the herbaceous layer and soil under varying competition regions in Mixed Bushveld. *African Journal of Range and Forage Science* 11: 27-33.
- Smit J. 2012. A spatial and temporal analysis of elephant induced thicket degradation in Addo Elephant National Park. M.Sc thesis. Nelson Mandela Metropolitan University. Port Elizabeth.
- Smith GS. 1992. Toxification and detoxification of plant compounds by ruminants: an overview. *Journal of Range Management* 45: 25-30.
- Smith JM. 2004. *Trends in Ecology and Evolution* 19 (7): 345-346.
- Smith TM and Goodman PS. 1986. The effect of competition on the structure and dynamics of *Acacia* savanna in Southern Africa. *Journal of Ecology* 74 (4): 1031-1044.
- Smith TM and Goodman PS. 1987. Successional dynamics in an *Acacia –nilotica-eucleadivinatorum* savannah in southern Africa. *Journal of Ecology* 75: 603-610.
- Smith TM and Grant T. 1986. The role of competition in the spacing of trees in a *Burkea africana – Terminalia sericia*. Savanna. *Biotropica* 18: 219-233.
- Smith TM and Walker BH. 1983. The role of competition in the spacing of savanna trees. *Proceedings of the Grassland Society of southern Africa* 18: 159-164.
- Smith TM and Walker BH. 1992. Browse characteristics and impact of browsing on trees and shrubs in African savanna. *Journal of Vegetation Science* 3: 315-324.
- Smith TM and Walker BH. 1993. The role of competition in the spacing of savanna trees. *Procedures of the Grassland Society of southern Africa* 18:159-164.
- Snyman HA. 1998. Dynamics and sustainable utilisation climates of Southern African. *Journal of Arid Environments* 39: 645-666.
- Snyman HA. 2002. Short-term response of rangeland botanical composition and productivity to fertilization (N and P) in a semi-arid climate of South Africa. *Journal of Arid Environments* 50: 167-183.
- South African Weather Services (SAWS). 2008. [Web:] www.weathersa.co.za (Access date: 2008/05/19).

- Squires VR, Mann TL and Andrew MH. 1992. Problems in implementing range management on common lands in Africa: An Australian perspective. *Journal of the Grassland Society of southern Africa* 9: 1-2.
- State of the Environment. 2002. State of the Environment Report. 2002. North West Province, South Africa. North West Department of Agriculture, Conservation and Environment: Directorate Environment and Conservation Management, South Africa. [CD-ROM].
- Stave J, Oba G, Broja CS, Mengistu Z, Nordal I and Stenseth NC. 2003. Spatial and temporal woodland patterns along the lower Turkwel River, Kenya. *African Journal of Ecology* 41: 224-236.
- Stebbins GL. 1952. Aridity as a stimulus to Plant Evolution. *Annual National* 80: (826): 33
- Sternberg M, Brow VK, Masters GJ and Clarke IP. 1999. Plant community dynamics in a *calcareous* grassland under climate change manipulated. *Plant Ecology* 143: 29-37.
- Stevens GC and Fox FJ. 1991. The cause of treeline. *Annual Revision of Ecological Systems* 22: 177-191.
- Stevenson FJ and Cole MA. 1999. Cycles of soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients, second edition. John Wiley and Sons Incorporation. New York.
- Stuart N, Barratt T and Place C. 2006. Classifying the Neotropical savanna of Belize using remote sensing and ground survey. *International Journal of Biogeography* 33: 476-490.
- Stuart-Hill GG. 1985. Competitive interactions between herbaceous and woody vegetation in semi-arid *Acacia* savanna in the Eastern Cape. M.Sc Agric thesis. University of Natal, Pietermaritzburg.
- Stuart-Hill GG, Tainton NM and Bernard HJ. 1987. The influence of *Acacia karroo* trees on grass production in its vicinity. *Journal of Grassland Society of southern Africa* 3(1): 83-88.
- Styles CV. 1993. Relationship between herbivores and *Colophosphorum mopane* of the northern Tuli Game Reserve. M.Sc. thesis, University of Pretoria.
- Sunar F. 1998. An analysis of changes in a multi-date data set: A case study in the Ikitelli area, Istanbul, Turkey. *International Journal of Remote Sensing* 19(2): 225-235.
- Sweet RJ. 1982. Bush control with fire in *Acacia nigrescens* / *Combretum apiculatum* savanna in Botswana. *Proceedings of the Grassland Society of southern Africa* 17: 25-28.
- Tainton NM (Ed). 1999. Veld management in South Africa. University of Natal Press. Pietermaritzburg. ISBN: 0 86980 947 4.

- Tainton NM (Ed). 2000. Pasture management in South Africa. *African Journal of Range and Forage Science* 18: 67-68. DOI: 10.2989/10220110109485758. ISSN: 1022-0119.
- Tainton NM and Hardy BM. 1999. Introduction to the concepts of development of vegetation. In Tainton NM (Ed.). 1999. Veld Management in South Africa. Pp. 1-21. University of Natal Press, Pietermaritzburg. ISBN: 0-86980-948-2.
- Taylor CA and Ralphs MH. 1992. Reducing livestock losses from poisonous plants through grazing management. *Journal of Range Management* 45: 9-12.
- Teague WR and Smit GN. 1992. Relations between woody and herbaceous components and the effect of bush clearing in southern African savannas. *Journal of the Grassland Society of southern Africa* 5(2): 85- 95.
- Tefera S, Snyman HA and Smit GN. 2007. Rangeland dynamics of southern Ethiopia: (2) Assessment of woody vegetation structure in relation to land use and distance from water in semi-arid Borana rangelands. *Journal of Environmental Management* 85: 443-452.
- Tews J, Schurr F and Jeltsch F. 2004. Seed dispersal by cattle may cause shrub encroachment of *Grewia flava* on southern Kalahari rangelands. *Applied Vegetation Science* 7: 89-102.
- Thomas RJ. 2008. 10th Anniversary Review: Addressing land degradation and Climate change in dryland agro ecosystems through sustainable land management. *Journal of Environmental Monitoring* 10: 592-603. [WEB:] <http://dx.doi.10.1039/b801649f>.
- Thompson D. 2002. Geographic information. Systems tools. Training for Disaster Management. Presentation for the UN Regional Workshop on the use Space Technology for Disaster Management in Africa. Addis Ababa. Ethiopia.
- Tiedemann AR and Klemmenson JO. 1973. Nutrient availability in desert grassland soils under mesquite (*Prosopis juliflora*) trees and adjacent open areas. *Soil Science Society of American Proceedings* 37: 107-110.
- Tiver F and Andrew MH. 1997. Relative effects of herbivory by sheep, rabbits, goats and kangaroos on recruitment and regeneration of shrubs and trees in eastern South Australia. *Journal of Applied Ecology* 34: 903-914.
- Tiver F, Nicholas M, Kriticos D and Brown JR. 2001. Low density of prickly pear *Acacia* under sheep grazing in Queensland. *Journal of Range Management* 54: 382-389.

- Treydte AC, Heitkonig MA, Prins HHT and Ludwig F. 2007. Trees improve grass quality for herbivores and species composition in savannahs. *Biodiversity Conservation* 18: 3989-4002.
- Trollope WSW. 1980. Controlling bush encroachment with fire in the savanna areas of South Africa. *Proceedings of the Grassland Society of Southern Africa* 15: 173-177.
- Trollope WSW. 1982. Ecological effects of fire in South African savannas. In: Huntley BJ, Walker BH (Eds.). 1982. *Ecology of Tropical savannas* 293-306. Springer-Verlag, New York, NY. US.
- Trollope WSW and Aucamp AJ. 1981. Veld Management in the semi-arid bush grass communities of Eastern Cape. *Proceedings of the Grassland Society of southern Africa* 16: 23-28.
- Trollope WSW, Hobson FO, Donckwerts JE and Van Niekerk JP. 1989. Encroachment and control of undesirable plants. Pp. 73-89: In: Danckwerts JE and WR Teague (Eds.). 1989. *Veld management in the Eastern Cape*. Department of Agriculture and Water Supply. Pretoria. Pp. 73-89.
- Trollope WSW and Tainton NM. 1986. Effects of fire intensity on the grass and bush encroachment of the Eastern Cape thornveld. *Journal of the Grassland Society of southern Africa* 3: 37-42.
- Trotter CM. 1998. Characterising the topographic effect at red wavelengths using juvenile conifer canopy. *International Journal of Remote Sensing* 94 (9, 11): 2215-2221.
- Tso B and Mather PM. 2001. Classification methods for remotely sensed data. Taylor and Francis, New York.
- Tucker CJ, Vanpraet CL, Sharman MJ van Ittersum G. 1985. Remote sensing of land use and rangeland for mesoscale hydrological studies. *International Journal of Remote Sensing* 21(2): 213-233.
- Tucker CJ, Vanpraet CL, Boerwinkel E and Gaston A. 1983. Satellite remote sensing of total dry matter production in the Senegalese Sahel. *Remote Sensing of Environment* 13: 461-474.
- Twine W, Moshe D, Netshiluvhi T and Siphungu S. 2003. Consumption and direct- use values of savanna grasses environmental and biotic effects influencing seedling emergence and establishment. *Oecologia* 103: 214-223.
- UNEP. 1992. World Atlas of Desertification London: Edward Arnold: Pp. 1-25.

- Van Auken WO. 2000. Shrub invasions of North American semi-arid grasslands. *Annual Review of Ecology and Systematics* 31: 197-216.
- Van Auken OW. 2009. Causes and consequences of woody plant encroachment into western North America grasslands. *Journal of Environmental Management* 90: 2931-2942.
- Van Auken OW. 2010. Thicket expansion in South African savanna under divergent land use: local and global drivers? *Global change Biology* 16: 964-976.
- Van Auken OW and Bush JK. 2012. Invasion of woody Legumes. Springer. New York.
- Van Carter, Kerley GHI and Cowling RM. 2005. The consequence of inaccuracies in remote-sensed vegetation boundaries for modelled mammal population estimates. *South African Journal of Wildlife Research* 35: 155-161.
- Van Til M, Bijlmer A and De Langer R. 2004. Seasonal variability in spectral reflectance of coastal dune vegetation. *Proceedings EARsel* 3: 154-165.
- Van der Meulen F. 1979. Plant sociology of the western Transvaal Bushveld, South Africa, a syntaxonomic and syneological study. Vazu: J. Cramer.
- Van Rooyen N. 2002. Veld management in the savannas. In: Bothma J du P (Ed). Game Ranch Management. Pretoria, Van Schaik pp. 571-617.
- Van der Walt PT and Le Richie GAN. 1984. The influence of veld fire on *Acacia erioloba* comm, in the Kalahari Gemsbok National Park. *Koedoe* (27): 103-106.
- Van Oudtshoorn, F. 1999. Guide to the grasses of southern Africa. Briza Publications, Pretoria. ISBN: 9781920217358.
- Van Vegten JA. 1981. Man-made vegetation changes: an example from Botswana's savanna. Working Paper. No. 40. Botswana: National Institute of Development and Cultural Research. (NIR).
- Van Vegten JA. 1983. Thornbush invasion in a savanna ecosystem in eastern Botswana. *Vegetatio* 56(1): 85-86.
- Van Wilgen BW. 2009. The evolution of fire management practices in savanna protected areas in South Africa. *South African Journal of Science* 105: 335-342.
- Venter F and Venter JA. 1996. Making the most of indigenous trees. Briza Publications, Pretoria. South Africa.
- Verstaete MM. 1986. Defining desertification: A review. *Climate change* 19: 5-18.
- Vetter S. 2007. Soil erosion in the Herschel District of South Africa: changes over time, physical correlates and land user's perception. *African Journal of Range and Forage Science* 24(2): 77-86.

- Vetter S. 2013. Development and sustainable management of rangeland commons- aligning policy with the realities of South Africa's rural landscape. *African Journal of Range and Forage Science* 30: 1-9.
- Vila M and Ibanez I. 2011. Plant invasions in the landscape. *Landscape Ecology* 26: 461-472. DOI: 10.1007/s10980-011-9585-3.
- Von Maltitz G. 1998. Institutions for sustainable land management: reflections on institutional aspects of implementary in the UNCCD in South Africa. *African Journal of Range and Forage Science* 26: 159-168.
- Von Maltitz G. 2009. Institutions for sustainable land management: reflections on institutional aspects of implementary the UNCCD in South Africa. *African Journal of Range and Forage Science* 26: 159-168.
- Vrieling A. 2006. Satellite remote sensing for water erosion assessment: A review. *Catena* 65: 2-18.
- Walker BH, Ludwig C and Peterman RM. 1981. Stability of semi-arid savanna grazing systems. *Journal of Ecology* 69: 473-498.
- Walker H. 1971. Ecology of Tropical and Subtropical vegetation Oliver and Boyd, Edinburg UK ISBN: 0 05 002130 3.
- Walters S. 1994. Proceedings of Namibia's National workshop to combat desertification Research Foundation of Namibia. Windhoek.
- Ward D. 2005. Do we understand the causes of bush encroachment in African savannas? *African Journal of Range and Forage Science* 22: 101-105.
- Ward D. 2010. A resource ratio model of the effects of changes in CO₂ on woody plant invasion. *Plant Ecology* 209: 147-152. DOI:10.1007/s11258-010-9731-2.
- Ward D and Elser KJ. 2008. What are the effects of substrate and grass removal on recruitment of *Acacia mellifera* seedlings in a semi-arid environment? *Plant Ecology*.
- Ward D, Hoffman MT and Collocott SJ. 2014. A century of woody plant encroachment in the dry Kimberly savanna of South Africa. *African Journal of Range and Forage Science* 31: 107-121.
- Ward D and Russell JM. 2011. Vegetation change in Zululand, KwaZulu-Natal since the Anglo-Zulu War of 1879. Local or global drivers? *African Journal of Range and Forage Science* 31 (2): 89-105. DOI: 10.2989/10220119.2013.827740.

- Watt JM and Breyer-Brandwijk MG. 1962. Medicinal and Poisonous Plants of Southern and Eastern Africa. E and S Livingstone Ltd, London.
- Weiss JL, Gutzler DS, Allfred C and Dahm CN. 2004. Long-term vegetation monitoring with NDVI in a diverse semi-arid setting Central New Mexico, USA. *Journal of Arid Environments* 58: 209-272.
- Weltzin JF, Archer S and Heitschmidt RK. 1997. Small mammal regulation of vegetation structure in temperate savanna. *Ecology* 78: 751-763.
- Wessels KJ, Prince SD, Zambatis N, Macfadyens, Frost PE and Van Zyl D. 2006. Relationship between herbaceous biomass and 1-km². Advanced Very High Resolution Radiometric (AVHRR) NDVI in Kruger National Park, South Africa. *International Journal of Remote Sensing* 27: 951-973.
- Wessels W, Anderson P and McNeil L. 1992. A model of southern African rainfall. *South African Journal of Science* 88: 103-109.
- West O. 1951. The vegetation of western country. Natal. *Memoirs of the Botanical Survey of South Africa* 23: 1-183.
- White E. 1980. The vegetation of Africa. Natural Resource XX. UNESCO, Paris, France.
- Whitford WG. 1990. Biological feedbacks in global desertification. *Science* 247: 1043-1048.
- Wickens GE. 1998. Ecophysiology of Economic Plants in Arid and Semi-Arid Lands. Springer. London.
- Wickens GE, Self EL, Gunko D and Nahal I. 1995. Role of *Acacia* species in the rural economy of dry Africa and the near East FAO, Conservation guide No. 27, FAO. Rome.
- Wickens RT. 1988. The productivity of Sahel goats and sheep under transmutnant manage in northern Burkina Faso. *Bulletin of Animal Health and Production in Africa* 36: 348-355.
- Wiegand K, Saltz D and Ward D. 2006. A patch-dynamics approach to savanna dynamics and woody plant encroachment-insights from an arid savanna. *Perspective in Plant Ecology Evolution and Systematics* 7: 229-242.
- Wiegand K, Ward D and Shcultz D. 2002. Approach to savanna dynamics and woody plant encroachment- Insights from arid savanna. *Perspective in Plant Ecology, Evolution and Systematics* 7: 229-242.
- Wiegand TS, Milton J and Wissel C. 1995. A simulation model for a shrub ecosystem in the semiarid karroo, South Africa. *Ecology* 76(7): 2205-2221.

- Wigley BJ, Bond WJ and Hoffman MT. 2009. Bush encroachment three contrasting land-use practices in mesic South African savanna. *African Journal of Ecology* 47: 62-70.
- Wigley BJ, Bond WJ and Hoffman MT. 2010. Thicket expansion in a South African savanna under divergent land use: local vs Global drivers? *Global Change Biology* 16: 964-976.
- Wilson JRU, Ivey P and Nanni I. 2013. A new national unit for invasive species detection, assessment and eradication planning. *South African Journal of Science* 109: 5-6. DOI: /10.1590/sajs.2013/20120111.
- Wilson SD. 1998. Competition between grasses and woody plants. – In: Cheplick, GP. (Ed.). 1998. Population biology of grasses. Cambridge University. Press. Pp. 231–254.
- Wolfson MM and Tainton NM. 1999. The morphology and physiology of the major forage plants: In: Tainton, NM. (Ed.). 1999. Veld Management in South Africa. University of Natal Press. South Africa. Pp. 54-90.
- Wu H, Sharp PJH, Walker J and Peridge LK. 1985. Ecological field theory: A spatial analysis of resource interference among plants. *Ecological Modelling* 29: 215-243.
- Wulder MA, Cohen WB, Loveland TR and Woodcock CE. 2008. Landsat continuing issues and opportunities for land cover monitoring. *Remote Sensing of Environment* 112: 955-969.
- Yang J and Prince SD. 2000. Remote sensing of savanna vegetation in Eastern Zambia 1972-1989. *International Journal of Remote Sensing* 21: 301-322.
- Yichum X, Zongyao S and Mei YU. 2008. Remote sensing imagery in vegetation mapping. A review. *Journal of Plant Ecology* 1: 9-23.
- Yongxue Q, Gong P and Clinton N. 2006. Object-based detailed vegetation classification with airborne high spatial resolution remote sensing imagery. *Photogrammetric Engineering and Remote Sensing* 72: 799-871.
- Young A. 1989. Agroforestry for soil conservation. CAB International, Wallingford, UK, and International Centre for Research in Agroforestry, Nairobi, Kenya. Pp. 276.
- Yusuf AA, Ayedun H and Sanni LO. 2008. Chemical composition and functional properties of raw and roasted Nigerian benniseed (*Sesamum indicum*) and Bambaragroundnut (*Vigna subterrean*). *Food Chemical* 111: 277-282.
- Yusuf H, Treydte AC, Demissew S and Woldu Z. 2011. Assessment of woody species in the grasslands of Nechisar National Park, Ethiopia. *Journal of Ecology* 49 (4): 397-409.

- Zaghloul, MS, Abdel-Wahab RH and Moustafa, AA. 2008. Conservation of *Acacia tortilis* subsp. *raddiana* populations in Southern Sinai, Egypt. III- Population Structure and Dynamics. *Bulletin Assuit University* 37(1):85-113.
- Zaghloul ZM, Elgamal MM, El Araby H and Abdel Wahab WW. 1999. Evidences of neotectonics and ground motions in the northern Nile Delta. In: Zaghloul ZM, Elgamal MM. (Ed.). 1999. *Deltas-Modern and Ancient*. Proceedings of Mansoura University, first international symposium on the deltas, Egypt. Pp. 207-217.
- Zavoianu F, Zhou C and Qi KL. 2001. Study and accuracy assessment of remote sensing data for environmental change detection in Romanian Coastal Zone of the Black Sea. *International Archives of Photogrammetry* 35: 778-785.
- Zohary M. (Ed.). 1973. *Geobotanical Foundations of Middle East*. Gustav Fischer. Verlag, Amsterdam. The Netherlands.