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Land Capability Evaluation Using Remote Sensing and GIS in Communal Areas of North West Province, South Africa.

Tabaro H Kabanda

(22638326)

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Faculty of Agriculture, Science and Technology, Department of Geography and Environmental Studies.

Supervisors: Prof A.S. Oyekale & Prof C. Munyati

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Declaration

I, Tabaro Hashim Kabanda, hereby declare that the thesis for the Doctoral degree of Environmental Science at North West University hereby submitted has not previously been submitted by me for a degree at this university or any other university, that it is my own work in design and execution and that all material contained herein has been duly acknowledged.

SIGNED: ______________________ DATE: ______________________

Tabaro Hashim Kabanda (22638326)

Declaration by Supervisor

The undersigned declares: that the candidate attended an approved module of study for the relevant qualification and the work for the course has been completed.

SIGNED: ______________________ DATE: ______________________

Supervisor: Prof A.S. Oyekale

SIGNED: ______________________ DATE: ______________________

Supervisor: Prof C. Munyati

Acknowledgments

In the Name of Allah

The Most Beneficent, The Most Merciful

After praising Allah and praying for the bestowal of blessings and peace upon our master, the Messenger of Allah, Muhammad. I would like to thank Allah, for the spiritual guidance and good health to complete my study.

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Abstract

This study sought to develop a framework as a tool for land capability evaluation using remote sensing, GIS and geostatistical techniques for communal areas, where the results can be duplicated in other geographical areas with similar biophysical conditions. The relationships and interactions between components and parameters that are necessary for analysing the capability of agricultural land were investigated for an effective management system. The parameters taken into consideration were biophysical environment (soil texture, organic matter content, soil depth, etc.), socio-economic and policy. The primary data were obtained from climatic data and soil samples collected from depths 0–100 cm; the secondary information were acquired from the remotely sensed data (SPOT 5 HRG), toposheet, ancillary data, and agricultural statistics.

Crop requirement information of three different crops that were selected as representative of summer crops in North West province, namely maize, sorghum and sunflower were compared with the land resources parameters available in the four sites. The thematic layers of the land resources were then overlaid using a GIS to select areas that satisfy the crop requirements. The resulting maps showed that the study areas have moderate to very high capability for all crops and that the land capability assessment developed, is adaptable, flexible and applicable in arid and semiarid environments. It was concluded that Agricultural Impact Assessments (AIA) as part of land capability should be integrated in land reform policy prior to acquisition of land to beneficiaries. Land with high degree of agricultural capability (based on soil properties, terrain characteristics and present land use) should be identified to produce economical yields under specific uses over a long period of time and without degradation to the land.

Keywords: Remote sensing, GIS, land capability, land reform

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Abbreviations

DEM – Digital Elevation Model

DWAF – The Department of Water Affairs and Forestry

ET – Evapotranspiration

FAO – Food and Agriculture Organisation

GCP – Ground Control Point

GIS – Geographic Information System

ISRIC – International Soil Reference and Information Centre

NDVI – Normalised Difference Vegetation Index

RMSE – Root mean square error

SAWS – South African Weather Services

TD – Transformed Divergence

TM – Thematic Mapper

USDA – United States Department of Agriculture

Definition of terms

The following terms will be taken to have the following meanings throughout this proposal

1. Remote sensing – acquisition of information about objects through analysis of data collected through instruments that are not in physical contact with the objects of investigation (Jensen, 2006).

2. Land capability evaluation – process to evaluate land potency according to its capability for sustainable land uses (Al-Mashreki et al., 2011).

3. Image Enhancement – improving visual interpretability of an image by increasing the apparent distinction between features in the scene (Lillesand et al., 2014).

4. Image Classification – extraction of different classes or themes, land use and land cover categories from raw remotely sensed digital satellite data (Gorham, 1999).

5. Accuracy assessment – a measure of how many ground truth pixels were classified correctly.

Chapter One

Introduction

1.1 Background

Soil is a precious, non-renewable resource that occurs all over the world in a wide-ranging diversity, and these diverse kinds of soil display varied characteristics. It offers vital support to the environment and human life. It is thus necessary to preserve soil functions and qualities to sustain the environment and human life (Aksoy *et al.*, 2009). Soils are affected by landforms, and through their developmental stages and features, they in turn influence geomorphic evolution (Agidew, 2015; Al-Mashreki *et al.*, 2011; Schaetzl and Anderson, 2005). Land is also an essential natural resource that has to be exploited according to its potential. The land capability evaluation is controlled by various land characteristics such as the types of soil, its depth, texture, landscape, hydrology, and climate among others (Panhalkar, 2011). Hence, the predominantly old-fashioned foundations of land evaluation are soil resource portfolios, usually recognised as soil surveys. According to Bibby *et al.* (1991), land evaluation was originally intended to support land use decision making, especially linking the different production features such as crops, fertilisation and other land use practices to soil types. The level of capability for a land use, not considering financial state of the region, is demonstrated by a physical capability evaluation (Rossiter and Van Wambeke, 1997). Hence, the approach of land capability evaluation is the categorisation of specific areas of land in terms of their capability for specified uses (Al-Mashreki *et al.*, 2011). This study establishes the potential role of remote sensing and GIS in land capability evaluation for mixed farming using available biophysical information in a communal setting.

The ever-growing need for expanding food grain cultivation can be done through systematic survey of the soils, evaluating their ability for wide range of land use options and developing land use strategies that are financially feasible and ecologically suitable (Sathish and Niranjana, 2010). Numerous capability evaluation techniques used are versions of the Framework for Land Evaluation (FAO, 2007) and centre on the seriousness of land restrictions connected to crops and land use. The distinction between the classes (soil type, texture, landscape etc.) is based on the costs of reducing or eliminating these limitations

(Madrau *et al.*, 2009). These classes are used in a geographic information system (GIS) to produce diverse thematic information for use in land capability evaluation.

Remote sensing has become essential in describing and understanding modifications in the environment using an array of satellite-derived datasets such as the Landsat Thematic Mapper imagery (Al-Mashreki *et al.*, 2010; Baniya, 2008). Remote sensing techniques such as reclassification have also helped to improve landscape visualisation and database generation, and are thus cost effective and reliable. The old-fashioned approaches of survey are time-consuming, laborious and costly. As land capability evaluation considers a variety of land characteristics, a GIS provides a more adaptable and formidable tool compared to traditional data processing techniques. GIS offers the ability to integrate large volumes of different datasets into new datasets which can be displayed in the form of thematic maps (Meghdadi and Kamkar, 2011).

The land subject is a dominant issue in South Africa. It is against this background that the first democratic government announced the Land Reform Programme in 1994. Land reform is the transfer of land ownership from existing land owners to new land owners with the aim of addressing the skewed land ownership patterns (Sekoto and Oladele, 2012; Dlamini, 2014). As a result of previous racially divisive land laws, 28% of South Africa's rural population (a large proportion of who are farm workers and their dependants) live on 88% of the agricultural land. (Sekoto and Oladele, 2012; Simbi, 1998). Thus the remaining 12% of agricultural land supports 72% of the rural population in the overcrowded former homelands which lack the infrastructure for successful agriculture (Sekoto and Oladele, 2012; Simbi, 1998). Also, owing to a 32% population growth since 1994 and only a 9% increase in agricultural production, South Africa needs to produce at least 44% more food than it produced in 1994 (Hall, 2004). Redistributive land reform in South Africa is based on the necessity to create both direct profits for recipients and knock-on profits to the rural economy. The Minister of Rural Development and Land Reform conceded that minimal efforts have been made with regard to the support that should see the redistributed farms coming into production, which is also sustainable (Hebinck and Shackleton, 2011). Thus, there is need for a complete reorganisation of the agricultural sector, with successful black commercial farmers making profits on their newly acquired land by producing economical and quality food.

Prosperous rural development and land reform is vital for South Africa's economic and social future. Possession of a vibrant and sustainable rural sector can encourage development in other areas of economy, especially when a country is undergoing a rapid urbanisation. As proven in countries like Bangladesh and Kenya, rural development is a strong option for spurring overall economic growth, poverty reduction, and enhancing food security (World Bank, 2008). In South Africa, rural development and land reform programmes are of great importance. They are tools for achieving a higher degree of economic and social equity, creating more employment and building stronger social cohesion-objectives which, to date have largely not been achieved (Lahiff and Li, 2012).

South African agriculture is of a greatly dualistic nature, where a developed commercial sector which creates significant employment and export earnings, but 'contributes moderately little to gross domestic product' coexists with large numbers of small farms on communal lands (OECD, 2006; DAFF, 2014 (a)). The land reform programme thus intends to attain goals of both equity (in terms of land access and possession) and productivity (greater land use), while also contributing to the expansion of the rural economy. In terms of overall achievements, land reform in South Africa has consistently fallen far behind the targets set by the state, and behind popular expectations (Binswanger-Mkhize *et al*., 2009).

Land reform in South Africa to date comprises of allocation of fairly large commercial farms to individuals or groups of recipients. Generally, would-be recipients of land reform would rather have access to relatively small areas of land on a household basis, but more often than not they have found themselves owning large farms as part of a sizable collective i.e. as a group farming operation (Lahiff and Li, 2012).

The past two decades have seen a major reduction in the overall state services available to farmers (Lahiff and Li, 2012). While commercial growers are generally able to prevail under these conditions through their access to a range of commercial and cooperative services (savings and investments), land reform beneficiaries and other small-scale farmers are largely left to fend for themselves (Byamugisha, 2014; Vink *et al*, 2008). To improve the path of a small farmer to success in communal areas, a fundamental reorganisation of current farm units to make family-size farms and more accurate agricultural land planning is required.

1.2 Problem statement

To guarantee food security, job creation and elevate small scale farmers to commercial status, unproductive farms in the North West province that have resulted from the land reform programme need to be restructured and evaluated for agricultural productivity. Agricultural land is generally essential for agricultural production, the environment, human habitation and welfare, and therefore has direct impacts on human life (Tin, 2011). Thus the improper use of land, especially agricultural land, results in inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems (Rossiter, 1996).

Agricultural land use planning is one of several solutions suitable for sustainable agricultural development. However, this exercise requires the analysis of a large variety and amount of spatial data. Using the conventional approach of land surveying is time-consuming, laborious and costly, especially for planning authorities with budgetary constraints. This study develops a methodology for land capability evaluation using remote sensing, GIS and geostatistical techniques for communal areas. The results can be duplicated in other geographical areas with similar biophysical conditions, with a view to improve the accuracy of land evaluation. Agricultural land capability evaluation is an important procedure in agricultural planning, for purposes of detecting the environmental limits in sustainable land use planning.

In North West province of South Africa there are reclaimed farms which include the former Pienaars Nature Reserve in Ngaka Modiri Molema District, Barberspan 309 and Antwerp farms in Ngaka Modiri Molema District and Rietfontein 464 farm in Bojanala District. These farms are used as study sites in the use of GIS and remote sensing for land capability evaluation in this research.

Land tenure targets are to blame for the country's struggling land reform programme, and 25% of the national Department of Agriculture's budget in 2012 was spent on recapitalising 595 claimed farms (Farmers weekly, 2012). In 2012, the national Minister for Agriculture announced that this amounted to R900 million that went into rehabilitating collapsed farms handed to claimants since 1994 (Dardagan, 2012). The government had found that almost 80% of farms handed to land claimants since 1994 were lying fallow (Dardagan, 2012). Generally, South African soils are usually susceptible to deterioration and have low recovery potential and it is approximated that 25% of South Africa's soils are highly susceptible to wind erosion (DAFF, 2014 (a)). Therefore, the slightest mistakes in land management can be catastrophic. This research aims to assess the land capability of redistributed land for arable agriculture and to suggest the implementation of land capability study as part of land reform policy prior to acquisition of land to land claimants/beneficiaries as part of post-transfer support.

In brief, the research attempts to answer the following questions:

Question 1: What are the main issues to be considered for an effective agricultural land capability system?

Question 2: Can a GIS based agricultural management system be established to successfully measure the capability of agricultural land in the research areas?

Question 3: Who are the main beneficiaries of present research?

Question 4: Can a GIS based agricultural management system be implemented in a land reform policy?

1.3 Aim and Specific Objectives

The aim of this research is to establish the potential role of remote sensing and GIS in spatial planning for arable agriculture in a communal land use setting. This study comprises the incorporation and analysis of geographically referenced socioeconomic and physical attributes relating to the study areas in North West Province.

The specific objectives are as follows:

a) To develop a land information system or database of the basic land resources which influence the production capacity of sustainable agriculture within the study areas,
b) To determine which land attributes in an agricultural setting can be discriminated on optical remotely sensed imagery,
c) To assess capability by incorporating multi-dimensional analysis and making use of a geo-database in a GIS as an aid to decision making in agricultural land capability,
d) To create an agricultural land capability map for a given crop,
e) To develop policy framework that could efficiently sustain agriculture for land reform beneficiaries.

1.4 Expected outputs

The presentation of computer based agricultural land use tools and geographical analysis tools help in the understanding of the features influencing the capability of agricultural land. This study produces local soil databases and land information systems such as soil fertility, topography and climate to end users such as Department of Agriculture and farmers. The study generates current agricultural land capability classification maps and offer essential solutions and external inputs to help increase land management in the study areas. The study offers the theoretical and observed evidence connected to agricultural land capability study to policy makers and rural development planners as a base for programme development and policy building.

1.5 Potential contribution

This study develops a framework as a tool for agricultural land capability evaluation using remote sensing and GIS for communal areas. The results can be duplicated in other geographical areas with similar biophysical conditions, to improve the accuracy of capability evaluation. Contribution is also to be made to literature for future studies when capability classifications from different sources are compared.

1.6 Overview of the thesis

This thesis is organised into eight chapters as follows:

Chapter one presents an overview of the research objectives and aims, connection of the different chapters, and a general introduction about the different parts of the thesis are presented.

The background of the study areas is part of chapter two. This chapter introduces the background of the study area including climate and land conditions, agricultural production and several main socioeconomic characteristics.

Chapter three provides literature applicable to the land capability evaluation compiled by other academics on limitation and potentiality of different methodological approaches of land capability evaluation, land reform, geostatistical methods for soil mapping, etc.

The purpose of chapter four is to describe all the datasets and methods used to answer research objectives. Two main types of data used are: primary (e.g. climatic and soil data) and secondary (e.g. agricultural statistics and satellite imagery).

A land information database is generated in chapter five and so are land units using the SPOT satellite imagery. Methodology includes the following concepts: image processing, vegetation mapping and GIS analysis.

Chapter six presents results of land capability evaluation done in previous chapters. Output of this chapter are land capability maps depicting capability degrees and limitations involved for each study area.

Chapter seven presents the general discussion. This chapter highlights and summarises the major parts of the land capability evaluation and represents an overview about the knowledge obtained from the present and a number of other studies.

Chapter eight presents a summary of the thesis, conclusions and recommendations.

Chapter Two

Background of the study area

2.1 Introduction

The main purpose of this chapter is to briefly describe the study area's characteristics. These will have a marked effect on the methodology that is to be used in the next chapters. The significant information in the current chapter focuses on climate, soil type, topography, socioeconomic factors and other issues relevant to agricultural land capability evaluation.

2.2 Study area

The province is geographically positioned between 25 - 28 degrees south (latitude) and 22 - 28 degrees east (longitude). The province occupies a total area of 116320 km^2 and is the sixth largest province in South Africa (Thorn *et al.*, 2012). Figure 2.1 shows the four study sites found in North West Province. In the province, only the mining and agriculture sectors provide a comparative advantage over the other provinces. Agricultural sector generates 13% of provincial GDP and creates work for 18% of working people in the province (Sekoto and Oladele, 2012). The population in the province is about 3.5 million people, this accounts for 9.5% of the South Africa's total population, and 65% (of 3.5 million) of this population live in rural areas (Sekoto and Oladele, 2012).

Four large farms serve as study sites. They were chosen for their accessibility and current status of land use (natural vegetation). The sites are:

In Ngaka Modiri Molema District:

- Barberspan 309 IQ in Delareyville
- Antwerp 187 farm near Matloding
- The former Pienaars Nature Reserve, near Zeerust

And in Bojanala District:

- Rietfontein 464 farm near Lichtenburg.

These farms were transferred to the communities in 2008, except for the former Pienaars Nature Reserve (in 2011), under the Restitution of Land Rights Act 22 of 1994. The sites are shown in Figure 2.1B.

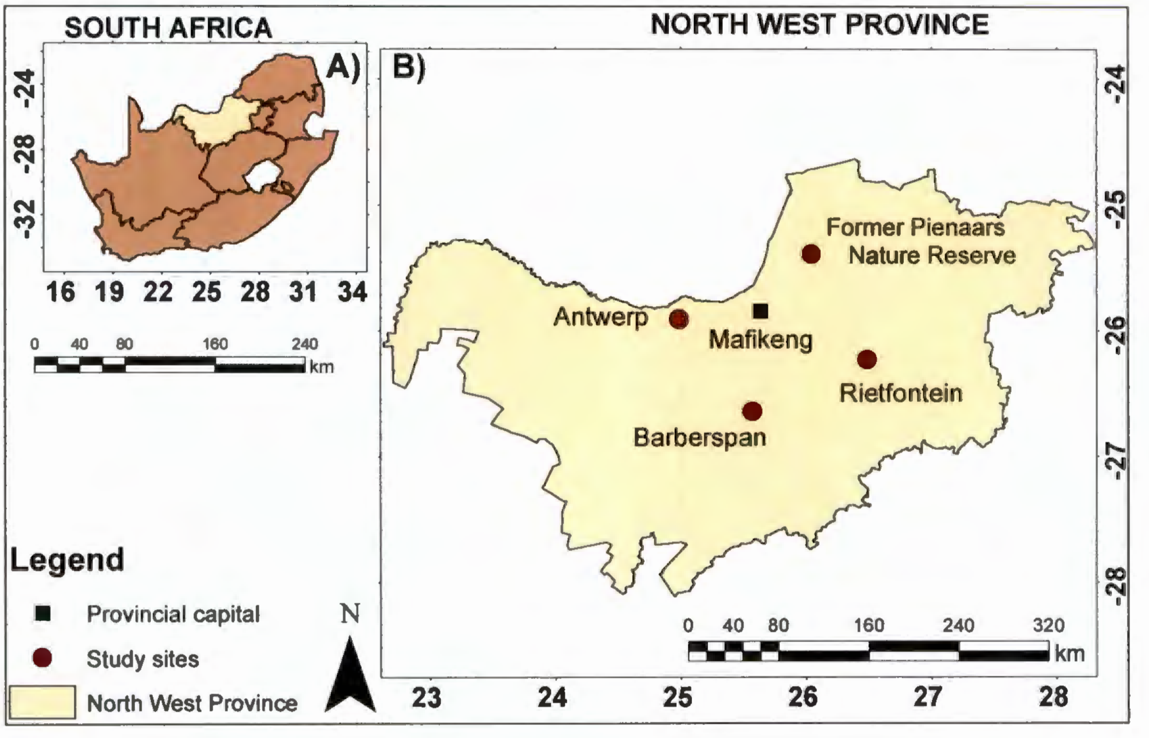


Figure 2.1: Location of the study area

2.2.1 Environmental setting of the study area

2.2.1.1 Climate

Climatic conditions in the far western region are generally dry, getting less than 300 mm of rainfall per year (Desmet *et al.*, 2009). Semi-arid conditions prevail in the central area of the province while the eastern areas are predominantly temperate. Great seasonal and daily variations in temperature occur. Summers are very hot, with daily average temperatures of 32°C (Desmet *et al.*, 2009). Winters are cold with an average daily minimum of 0.9°C (Desmet *et al.*, 2009). Seasonal variations in mean temperatures between the warmest and the coldest months exceed 15°C in the western region, while the central and eastern regions experience a range between 12°C and 15°C (Desmet *et al.*, 2009).

2.2.1.2 Soil type

Owing to the active nature of soils, they are continually changing and degrading by means of natural and man-induced practices. The low rainfall commonly occurring in the province, results in soils in the North West to be only marginally leached over much of the western region (De Villiers and Mangold, 2002). Vast extents of yellow shifting sands exist in the north-western areas; plinthic catena of yellowish-brown sandy loams dominate the south and eastern areas and the central area by red or brown non-shifting sands with rock (De Villiers and Mangold, 2002).

2.2.1.3 Vegetation

Large parts of the province (71%) occur within the Savannah biome (Desmet *et al.*, 2009). Vegetation types include sourish mixed bushveld (open savannah dominated by *Acacia caffra* and grasses of the *Cymbopogon* and *Themeda* species), turf thornveld and isolated pockets of Kalahari thornveld and shrub bushveld (Desmet *et al.*, 2009). The rest of the province occurs within the grassland biome and is characterised by a variety of grasses typical of arid areas.

2.2.1.4 Geology

The north-eastern and north-central regions are characterised by igneous rock formations due to the intrusion of the Bushveld Complex within the Earth's crust that has been slanted and eroded (De Villiers and Mangold, 2002). Ancient igneous volcanic rocks characterise the western, eastern and southern areas of the province while sedimentary rocks dating back to the Quaternary period (65 million years) occur in the north-western areas (De Villiers and Mangold, 2002).

2.2.1.5 Topography

Topography (elevation, slope, and aspect) is a vital feature which has an important influence on the environmental factors, such as spatial patterns of vegetation and climate. Among the topographic factors, elevation is the most influential on the ecosystem as it creates micro-climate (Desmet *et al.*, 2009). The province is claimed to have the most unvarying topography in the country, with elevation ranging between 920 - 1782 metres above sea level (Desmet *et al.*, 2009). The central and western regions are characterised by flat or gently undulating plains. The eastern region is of a more variable topography (Desmet *et al.*, 2009).

2.3 Land use patterns in the province

The total potential available arable land in the province is 30.8%, cultivated land makes up 20.9% and 2.9% land is put into other uses such as housing (SOER, 2008). The Central District municipality with an area of 8400 km^2 has bulk of the agricultural land and is double the figure of Bophirima District municipality at approximately 4700 km^2 (Masigo and Matshego, 2002). Commercially cultivated land in the province is generally found in the Central District, Southern District and Bophirima District municipalities (Masigo and

Matshego, 2002). Semi commercial and subsistence farming in North West Province is mainly located in the Central and Bojanala District Municipalities (Masigo and Matshego, 2002).

2.4 Socioeconomic conditions

The North West Province contributes largely to the South Africa's economic development, with mining, agriculture and community services being the biggest contributors to provincial financial growth and employment. Challenges of joblessness, poverty and disparity are still high although there is a general positive economic development at both national and provincial level (Koma, 2014).

2.4.1 Demography

The North West provincial population contribution to the country's total population in 1996 was 7.2%; 6.7% in 2001 and declined further to 6.3% in 2007 (NW Provincial Treasury, 2014). The recently published census data by Stats-SA indicated a slight increase in population share of the province from 6.3% in 2007 to 6.8% in 2011 (NW Provincial Treasury, 2014). In terms of population size, the province is the third smallest province in South Africa with a population size of 3509953 (3.5 million) and of the 3509953, women constitute a total population of 1779903 (50.7%) and 1730049 (49.3%) being men (NW Provincial Treasury, 2014).

In the province, there is a positive association among poverty and joblessness for both men and women. The association between jobless women and poverty is marginally larger than that of men. This could be due to a presence of large number of jobless women in the province thereby implies that more women are trapped in poverty. Education is vital for financial development and growth. Educational level in North West province has demonstrated some progress. The number of people with some secondary schooling has increased since 1996 (214927 men, 236025 women) to 2011 (353654 men, 344254 women). However, more men still access education compared to women (NW Provincial Treasury, 2014

North West is the only province that had a negative annual average growth rate (-0.2%) from 1996 to 2011 (NW Provincial Treasury, 2014). In the past, the province had experienced the changes in municipal and provincial borders that were applied by the Municipal Demarcation Board. The consequence was it lost a considerable amount of its population to other provinces like Northern Cape Province. The province is generally a net out-migrating province and this net loss of population through interprovincial migration and the redistribution of boundaries have produced the negative growth rate (NW Provincial Treasury, 2014).

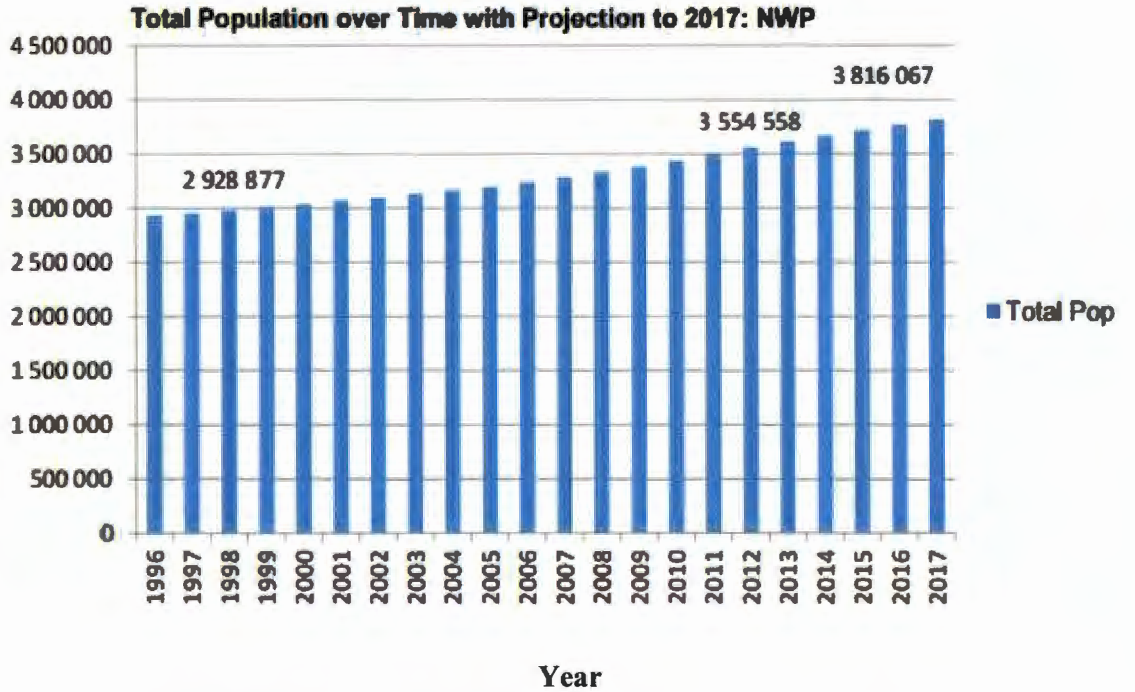


Figure 2.2: Total Population over time with projection to 2017 in NWP (Source: IHS Global Insight (2013))

Good health is a critical factor of welfare. However, developments in well-being status may be warranted on purely financial grounds as a logical hypothesis is that better health increases human capital levels and consequently the financial output of individuals and a nation`s financial growth rate. Improved wellbeing helps to improve workforce efficiency by decreasing incapacity and days lost to sick leave, and increase the prospects of people earning better paid work, (Guillem and Berta, 2007). North West medical aid membership increased from 13.7 per cent in 2009 to 14.7 per cent in 2010; and saw a decline to 13.6 per cent in 2011 (NW Provincial Treasury, 2014). The health services required by the public are likely to increase which then requires more resources from government into the health sector in order to meet the public needs (NW Provincial Treasury, 2014). Access to health is still the important challenge in the province, more particularly for the unemployed and rural populations. Figure 2.2 displays the total population over time with projection to 2017 in North West Province (NWP).

2.4.2 Labour and employment

Generally, employment decreased from 7853 in the 3rd Quarter to 7461 in 4th quarter of 2012 (NW Provincial Treasury, 2014). Decrease in occupation was documented in private household and agricultural sector and this can be vindicated by the fact that its occupation is periodic. Trade industry had also recorded a decline from 151 to 142 in 3rd to 4th quarter of 2012 respectively (NW Provincial Treasury, 2014). Utilities also recorded a decrease in employment in the same period from 8 to 5 in Q4:2012 compared to Q3:2012, the biggest decrease in the unemployment rate was observed in Limpopo (2.6% points), North West (1.7% points) and Mpumalanga (1.7% points) (NW Provincial Treasury, 2014).

For both official and expanded labour force participation rate, North West remains in the same region as Mpumalanga and Free State following Western Cape and Gauteng provinces and various factors are likely to have contributed in the North West fairly high participation (55.3%) which is above 50% margin (NW Provincial Treasury, 2014). There could be new participants to the labour market such as increased employment of females or it could be that some of the economically active residents are entering into the province. Figure 2.3 displays the total employment (formal and informal) per sector from 1996 to 2012.

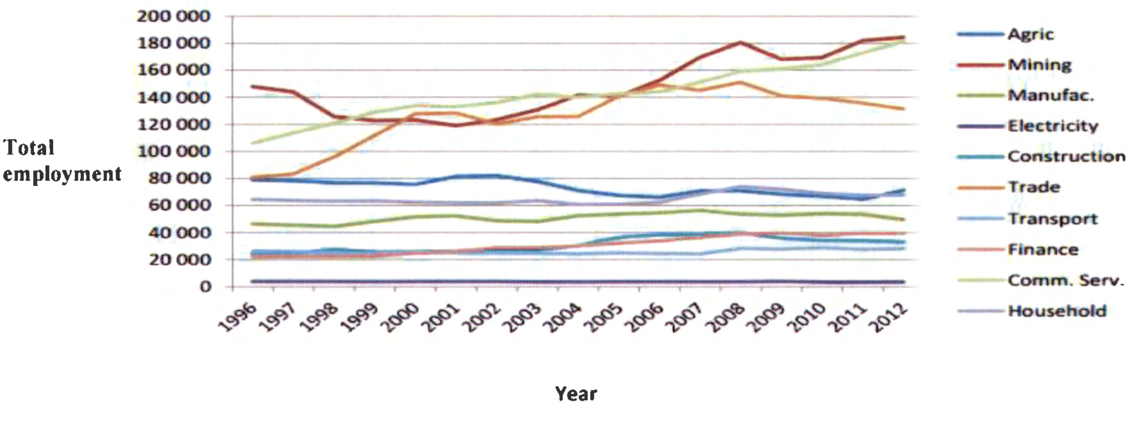


Figure 2.3: Total employment per sector, 1996-2012 (Source: IHS Global Insight (2013))

2.4.3 Household income

Household income is reliant on numerous sources of revenue such as employment, business, social grants and yield on investments. Employment forms the largest source of household income, which therefore means an increase in unemployment will result in high decrease in household income (NW Provincial Treasury, 2014). Generally, between 2001 and 2012 there was a significant increase in household disposable income in the North West Province although the household disposable income remained the third smallest in South Africa, with its average household disposable income increasing from 20112 in 1999 to 97958 in 2012 (NW Provincial Treasury, 2014). In 2013, Gauteng and Western Cape were two provinces with the highest disposable income, Limpopo and Free State were the only two provinces performing below North West Province, which placed North West in third place from the bottom (NW Provincial Treasury, 2014). This evidently shows the development prospective that exists in rural or underdeveloped provinces such as North West, Limpopo and Free State. Appropriate organisation, application and effective and efficient use of resources can result in additional growth in household salary in the future. Household income is one of the most significant elements of wellbeing in most nations. The ability to meet basic needs, such as adequate food, clothing, shelter and other basic amenities, is largely determined by the level of income earned by the household, Meintjies (2001). Poverty is regularly described as the absence of resources to meet these requirements. On these foundations, an increase in household income can be expected to result in reducing poverty and improve living standards.

The North West economy, with the omission of the mines, is categorised by small, medium and micro enterprises (SMMEs). The economy is characterised by primary industries and strategies for growth are aimed at adding value with the objective to move the economy from not just being a resourced-based economy, but to also be a knowledge based economy (NW Provincial Treasury, 2014).

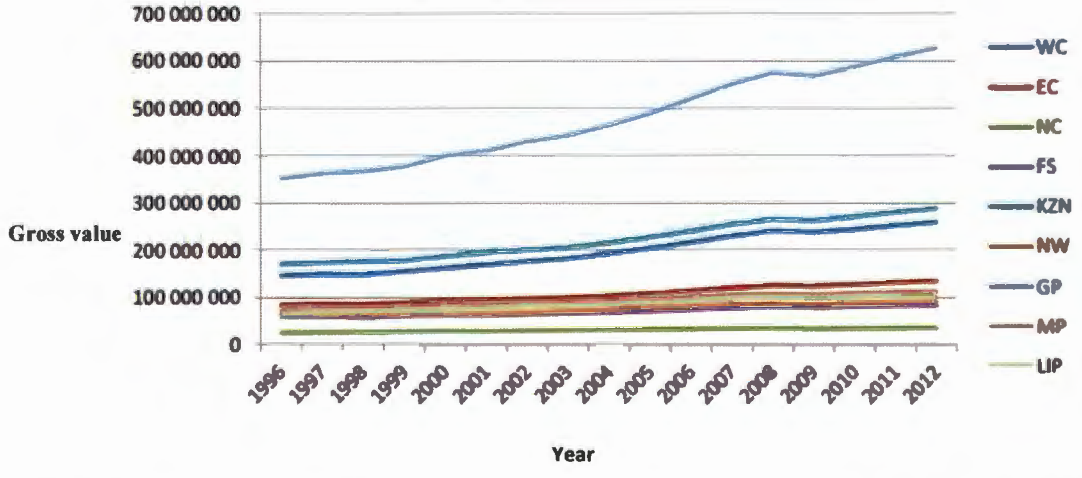


Figure 2.4: Gross value added by province, 1996 to 2012 (Source: IHS Global Insight (2013))

Due to the sensitivity of the province's economy to world mineral prices, the provincial government had planned to minimise its dependence on the mining sector, with an increased broadening to agri-business, tourism and non-mining related manufacturing sectors, evident in the recent year-on-year growth in this sector (NW Provincial Treasury, 2014).

Figure 2.4 clearly shows that the North West Province has been one of the lowermost performing provinces in South Africa when considering economic activity. It remains critical for this province to focus on developing its competitive advantage such as in agriculture and processing; venture into manufacturing and other economic sectors that can unleash the potential of the economy (NW Provincial Treasury, 2014). Investment in infrastructural expansion is still one of the important features in developing the economy of the province through attraction of investment.

2.4.4 Agriculture and Rural Development

In the province, agricultural potential extends from the lush irrigation areas of Brits and Rustenburg, past the grain producing areas of the central and southern parts of the province and ending in the dry and generally grazing areas of Vryburg and Molopo. Majority of the study sites in this research occur in Ngaka Modiri Molema District which comprises of the Local Municipalities of Ratlou, Tswaing, Mafikeng, Disobotla and Ramotshere. The District in 2012 had a population of 842699 (413399 males and 429300 females with 75974 unemployed and 149334 employed) residents (STATSSA, 2012). The main economic activity in the District is agriculture, mainly crops and cattle production with many communities within the district depending on agriculture as a source of food security and employment.

In 2009, there were only 4689 homes in the North West that depended only on subsistence farming as a main source of food (3181 households) or non-salary income (1508 households). 72.83% of agricultural households derived more than 50% of their household income from employment within the agricultural sector, while households involved with only subsistence farming, comprised 9.64% (Elsenburg, 2009). As of 2011, the number of households involved in agricultural activities accounted to 214049 while 847965 were not involved (STATSSA, 2012).

2.5 Gross value of agricultural production – Socioeconomic suitability

Infrastructure and other investments such as marketing have noticeable result on the output and financial benefit from the crops. The proper channel for crop marketing and market information is important to the farmers as it allows them to make an informed decision over selection of type, time and variations of crop to be produced. The physical factors in this study are considered very important in the agricultural land capability evaluation in multi-criteria analysis. It is also important to integrate the socioeconomic factors especially in developing countries like South Africa as it encourages sustainable agriculture production.

World food prices increased dramatically in 2007/08 (Chandrasekhar and Ghosh, 2012) and this renewed the argument on the importance of agriculture in social and economic development. Agriculture has an important role in the improvement of society as it can induce industrial growth and a structural transformation of the economy (Byerlee *et al.*, 2009; Timmer and Akkus, 2008). According to Vink *et al.* (2008), from 2002 the return created from agricultural production in the world had been well above the opportunity cost of the investment and thus farming as a sector is now more profitable. Maize, sunflower and sorghum have been chosen as promising crops in this study based on existing cropping systems, social acceptance of crops and economic status of the society, and from farmers' long experience.

2.5.1 Maize

Maize is the main grain crop in South Africa and is essential as a major feed grain for both animals and humans. The gross value of maize for 2012/13 amounted to R23814 million. North West Province contributed the second most at 14% to the national maize production during the 2012/13 production season with 2574 tons. The average producer price of maize during the 2012/13 season was R214414/ton. South Africa consumes majority of the maize it produces and the domestic market is vital to the industry (DAFF. 2014 (a)).

In October 2013, the intended maize plantings of South African farmers was 2.7 million ha for the 2013/14 production season, which was 3.5% less than the 2.8 million ha planted during 2012/13 (DAFF. 2014 (a)). Growers indicated that the drought of 2015 in the western parts of the country contributed to the decrease. This scenario usually encourages farmers to plant more oilseeds such as sunflower seeds at the expense of maize.

2.5.2 Sorghum

Sorghum is indigenous to Africa. During the 2013 season, North West Province produced the fourth most sorghum with 10.1% of the national production. South Africa produces on average 203700 tons of sorghum per annum. Like maize, sorghum also serves two markets – for human consumption and for animal feed. Local producer prices of sorghum decreased by 1.0%, from R2675.01/t in 2012 to R2649.02/t, for the 2013 season as the area planted decreased in the country (DAFF. 2014 (a)). In 2013, the average gross income per hectare of sorghum was better compared to maize due to drought. Deep root penetration and high proportion of roots in the subsoil allow sorghum to tolerate drought conditions.

The need to resort to clean and renewable fuels means using agricultural crops can be used for the production of energy. Sorghum is a fast growing crop that can be harvested twice a year and can produce both food (grain) and energy (bioethanol). The development of bioethanol production could double the size of the current sorghum market and provide the highest yields per hectare.

2.5.3 Sunflower

Maize and sunflower seed can generally be planted in the same area, so this allows farmers to switch to sunflower if the prime time for maize production has passed. During the 2013 production season, North West produced 35% of the national crop. The contribution of sunflower seed to the gross value of field crops during the season is approximately 5.6%, compared to the 46.1% of maize and 1% of sorghum (DAFF, 2014 (b)). The average producer price increased by 10.3%, from R4397/ton in 2012 to R4850/ton in 2013. In South Africa, sunflower seed is used almost exclusively (an estimated 98% or 580000 tons in 2013) for oil and oilcake production. The estimated domestic demand of seed for the 2013 marketing year was approximately 591300 tons (DAFF, 2014 (b)).

2.6 Summary

An introduction to the study area is necessary as it clarifies and aids in the understanding about the methodology to be used. Furthermore, information provided in this chapter is valuable indication for the clarification and explanation of results in the later chapters (results and discussion). The chapter highlighted the soil conditions, topography, agricultural production and socioeconomic characteristics of the study area. Generally, North West

Province is still faced with various socioeconomic challenges which definitely require proper resource allocation and investment to overcome.

Chapter Three

Literature review

3.1 Introduction

Studying earlier works connected to the approaches, practices and support tools for land evaluation is important. This chapter explains the methods and procedures used for land evaluation and their implementation. Specific focus is on two original systems provided by FAO and the USDA. Common standards, application measures, and land capability classification structures are included in the chapter. Firstly, the chapter looks at land reform programme in South Africa, as land allotted to people should have a detailed land capability investigation carried out. The chapter discusses the common contributions of the agricultural sector to socio-economic development of a region and country. Finally, support tools for land capability evaluation encompassing GIS and remote sensing are discussed.

3.2 Land reform

Land reform plays an important part in the national development strategies, and is designed to reduce rural disparity, refine agricultural efficiency, provide food security and grow revenues and general wellbeing of the rural inhabitants. The methodology and inspiration for land reform has differed from nation to nation and overtime. In some parts of Southern Africa, particularly the former settler colonies of Namibia, Zimbabwe and South Africa, land reform debates were mainly influenced by colonial histories, with the three countries sharing a similar profile of racially skewed land distribution owing largely to dispossession of the black rural population, which was confined to overcrowded communal lands (Maisela, 2007). Land reform in these countries was intended to reduce over-congested areas, to encourage reasonable distribution of agrarian land, to de-racialise commercial agriculture, and to transfer and protect land tenure of the dispossessed.

3.2.1 South African land reform programme

Land reform is the transfer of land ownership from existing land owners to new land owners with the aim of addressing the skewed land ownership patterns (Sekoto and Oladele, 2012). Since 1994 in South Africa, land reform has played an important part of the rebuilding and growth plan of the new African National Congress (ANC) administration. The South African land reform policy intends to mainly address the ethnically slanted land ownership, which sprang from the 1913 Land Act and subsequent legislation. Land reform aims to decrease poverty and encourage economic growth, particularly in areas that were marginalised through apartheid laws, and securing land and tenure rights of the marginalised people (DLA, 1997). Thus the South African land reform programme had three main elements, namely land redistribution, land restitution and land tenure reform.

a) Land Redistribution is a broad programme which aims to provide the disadvantaged and the poor with land for residential and productive purposes. The government developed a single, yet flexible, grant mechanism to embrace the wide variety of land needs of applicants (DLA, 1997).
b) Land Restitution aims to restore land and provide other compensation to people dispossessed by the 1913 Land Act. This is being done in such a way as to support the process of reconciliation and development, and with regard to the over-arching consideration of fairness and justice for individuals, communities and the country as a whole (DLA, 1997).
c) Land tenure reform aims to provide security of tenure. In the constitution, the administration is indebted to initiate laws which set out the types of interests in land which were undermined by discriminatory laws and ensure that such interests in land are legally secure (DLA, 1997).

Sekoto and Oladele (2012) analysed support service needs and constraints facing farmers under land reform agricultural projects in the Central District Municipality (Ngaka Modiri Molema) of the North West Province and found that the size of farms ranged from 6.6 – 1300 hectares. They suggested that the size of a farm should be dependent upon the financial goals of the producer. The study found that the project beneficiaries were faced with severe constraints such as lack of finance, poor building infrastructure, lack of fencing, and poor input supply. Prominent support services needed by farmers were agricultural land planning, funding, building infrastructure, capital funds, farming infrastructure and inputs.

3.2.2 Post-transfer support

Both the Mid-term Review (DLA, 1997) and the Review of the Land Reform Pilot Programme (DLA, 1999) pointed out that post-transfer backing is vital for the general achievement of land redistribution, yet it has been ignored by almost all the important role players. Support structures, or complementary development support, specified in the White

Paper include assistance with productive and sustainable land use, infrastructure support, farm credit, agricultural inputs and access to markets for farm outputs (DLA, 1997).

Only 12% of the country (14.6 million ha) is suitable for the production of rain-fed crops, and only 3% (3.6 million ha) is considered truly fertile land (World Wildlife Fund, 2009). By under-emphasising variables such as quality of land, proximity to markets and the enormous differences in the economic potential of land in different regions, land reform goals are rendered essentially meaningless (DA, 2013).

The fight of land reform recipients usually continues and does not end with the reception of land, as post-settlement backing is the next encounter to deal with. Thus for many land reform recipients, access to the essential support is still a major problem. There has never been a well-structured support package that is comprehensive (i.e. inclusive of training, finance, access to production inputs, appropriate technology and extension service) either from government or the private sector (Maisela, 2007). Support that is available is in many instances not adequate to meet all the needs of the farmers and has not been available to all the projects (Bradstock, 2005).

Lahiff and Li (2012) argued that failure to provide post settlement support is due to the disjuncture between land reform policies and development intentions of government, and failure to conceptualise land reform beyond land transfer stage. Kepe and Cousins (2002) noted that land reform will only be effective if embedded within broader programmes to restructure the agrarian economy, with beneficiary access to support mechanisms including finance, markets and agricultural land planning. A similar view was put forward by Windfuhr (2002), who argued that agrarian reform is central to land reform, which should also be integrated into broader rural development.

It is increasingly apparent that land reform will not single-handedly realise rural development or poverty reduction effectively, it must be accompanied with other agricultural reforms, such as access to education, training, capital and adequate market access.

3.3 The agricultural sector's role and agricultural land use distribution

3.3.1 Contribution to economic growth

Agriculture is a key economic component for many countries, as it promotes national economic development, provides opportunities and an investment environment for the private sector and state economic organizations, as well as driving agriculture related industries and the rural non-farm economy (World Bank, 2008). Estimates for 2013 put gross farming income from all agricultural products at R182966 million (an 8.6% increase over the previous year), and from field crops, R47744 million (a 6.1% increase) (DAFF, 2014(a)). The income from horticultural products rose by 13.4%, from R42126 million to R47785 million and the prices received by farmers for agricultural products increased on average by 4%, while prices paid by farmers for farming requisites rose by 7.1%, resulting in the terms of trade weakening from 0.86 to 0.84 during the period under review (DAFF, 2014 (a)).

The estimated volume of agricultural production during 2013 was 2.7% higher than in 2012 and the volume of field crop production increased by 2.3%, mainly as a result of an increase in the production of summer grains (especially sorghum), oilseeds (especially soya beans and sunflower seed), dry beans, as well as other food crops (DAFF, 2014 (a)). The estimated value of imports during 2013 came to approximately R57307 million, from R53071 million in 2012 – an increase of 8.0%. The estimated value of exports showed an increase of 13.1%, from R55188 million in 2012 to about R72493 million in 2013 (DAFF, 2014 (b)). Figure 3.1 shows the import and export values of agricultural products between 2009 and 2013 (January to December).

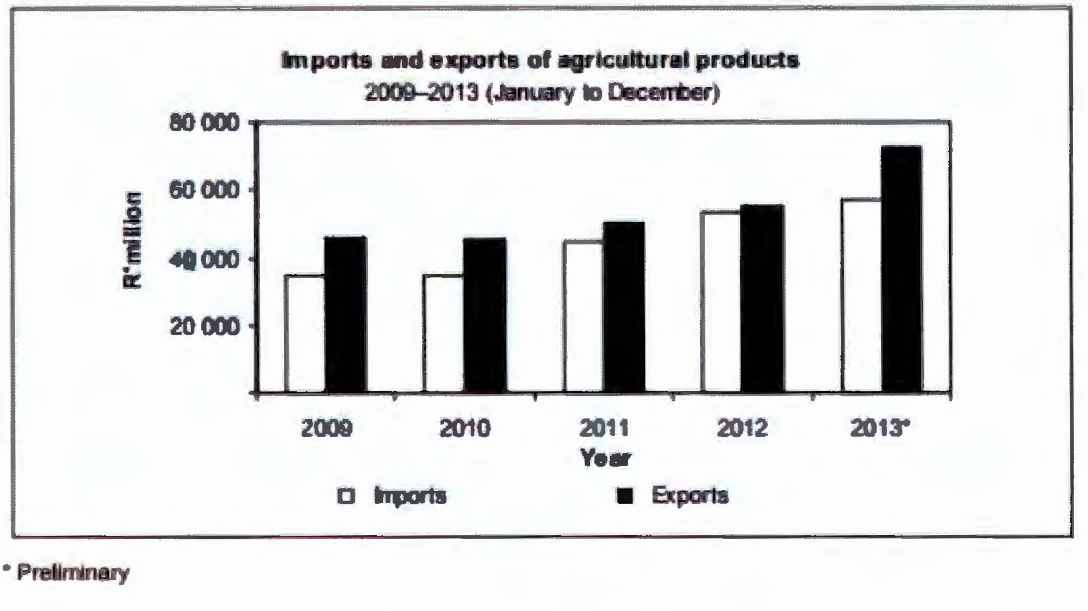


Figure 3.1: Imports and exports of agricultural products 2009–2013 (Source: DAFF, 2014).

Agriculture is a major source of income and employment for more than the 70% of the world's poor in rural areas. It provides job opportunities for 1.3 billion small landholders and forms a foundation for viable rural communities (World Bank, 2008). Agriculture has been the backbone of many rural societies, providing employment for the labour force. Labour productivity growth in agriculture impacts upon the level of employment and hence it is a concern in agriculture-based countries. The labour force in agriculture is estimated to have increased from 32000 in Oct-Dec of 2012 to 42000 Oct-Dec 2013 in North West province (STATSSA, 2014). Farm crop and livestock income together with agricultural salaries contributes between 55 and 75% to rural income in agriculture-based countries, such as those in sub-Saharan Africa (World Bank, 2008).

In 2006, the North West Province was estimated to cover 10.6 million ha, of which 8.8 million ha (81.1%) was agricultural land, which can be further subdivided into 3.1 million ha (34.9%) of arable land, 4.6 million ha (56.3%) of veld and 700791 ha (7.9%) of conservation land (LCSA, 2006). North West Province has a dualistic agricultural economy, comprising a well-developed commercial sector with approximately 7600 farms, and a predominantly subsistence sector with approximately 147000 small-scale farmers in communal areas (SOER, 2008). The cultivation levels in the communal regions of the province can be approximated to be 16% of the normal cultivation potential, demonstrating extraordinary development potentials (LCSA, 2006). Over the years this percentage has not improved greatly and shows that there is a relatively unexploited resource base which could assist in expanding and emerging the agricultural sector in the province. Though, many rural farmers still encounter difficulties, from the price of transport/fuel, infrastructure and a lack of knowledge, often due to inaccessibility or illiteracy.

Large-scale crop cultivation initiatives under dry land environments in the commercial sector mainly involve maize, sorghum, sunflower, groundnuts and dry beans, while irrigated crops include tobacco, paprika, citrus, wheat, pepper, cotton and sunflowers, cut flowers and vegetables, which are cultivated on a smaller scale. The Crocodile and Vaal rivers are the main source for irrigation and smaller irrigation schemes include Manyeding, Bodibe and Thlaping -Thlaro rivers. Irrigation in the province is limited to areas adjoining river systems (Brits, Rustenburg, Taung and Molopo), although irrigation from groundwater sources is practiced in isolated areas such as Ventersdorp, Ottosdal, Marico and Vryburg/Louwna (Mangold *et al*., 2002).

3.3.2 Emerging sector – Bio-fuels

The North West Provincial Government in association with the Barolong Bo-Ratshidi Development Company, Mafikeng Bio-Technologies, Clean Air Nurseries and the Mafikeng Industrial Development Zone company, launched the Mafikeng Biodiesel pilot project in May 2006 as an initiative aligned with the ASGISA (Accelerated and Shared Growth Initiative for South Africa) objectives for economic growth in the agricultural sector (SOER, 2008). The purpose of the pilot venture was to develop into a full scale, R850 million initiative, employing 10000 people to commercially cultivate oilseed trees for the production of biofuel (Engineering News, 2007).

The North West Provincial Government had added R10 million into the initiative for the construction of the tree nursery at the Setumo Dam outside Mafikeng with the nursery employing people as part of learnership programme (SOER, 2008). The trial project is still in an investigational stage and involves the growing of the *Jatropha curcas* and *Moringa oleifera* oilseed crops, the crops are tested for viability in biofuel applications.

Maize farmers' project was abandoned when the government banned the use of maize and wheat as feedstock for biofuels because of a possible threat of food insecurity. Thereafter, sorghum gained favour because it is a drought-resistant crop and because it has previously been a crop produced extensively by black farmers (Payne, 2013). Whereas 10 years ago South Africa was producing about 700000 tonnes of sorghum a year, because of the continuous decline in sorghum-beer consumption, that fell to about 80000 tonnes in 2013 (Payne, 2013).

3.4 Land resources

3.4.1 Land use planning

FAO (2001) defined land as an area of the earth's surface, including all elements of the physical and biological environment that influences land use. Land comprises the physical environment including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use (FAO, 2001). Land is a crucial natural resource, essential for the existence of humankind and all terrestrial ecologies.

Land and soil are two quite distinct concepts, though they are sometimes conflated in discussion of agricultural activities. Land has a much broader meaning than soil; soil is part of the land and soil quality is a subset of land quality (Kavetskiy *et al.*, 2003). Capability primarily begins with soil while land use planning uses soil classification. Land use is characterised by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO, 1993).

For local, regional and macro level planning and management, land use plays an important role. By using RS (remote sensing) and GIS it is possible to make planning and decision process more realistic and effective (Vibhute and Gawali, 2013). Land use planning has been defined as the systematic evaluation of land and water potential, for the purpose of selecting and implementing land use options which are most beneficial to land users without degrading the resources or the environment, together with the selection of measures most likely to encourage such land uses (FAO, 2007). Agricultural land use planning is fundamental to the process of natural resource management and sustainable development. This involves the analysis of a large variety of spatial data and GIS and RS provide the tools for these purposes. Agricultural land use planning should consider the sustainability, social impact and an evaluation of what the land is capable of supporting and sustaining into the future and in the interests of the wider community (van Gool and Vernon, 2005). While in some places the land can only support a limited range of uses, in other areas there are many potential uses, and balancing these competing demands can be a complex and demanding challenge. A fault in early efforts of land-use planning was to focus too narrowly on land resources without enough thought given to how they might be used; good agricultural land is usually capable of other competing uses (FAO, 2001).

Land use planning can be used to assist land users, policy and decision makers to use land sustainably, reducing current land use problems while achieving socioeconomic and environmental aims (such as food self-reliance, revenue, ecological preservation) are attained (Baniya, 2008). Land evaluation is a component of land use planning (FAO, 2001) and is a necessary basis for rational land use planning (FAO, 2001). Land use decisions are not determined solely by land capability, but the demand for products and the extent to which the use of a particular area is critical for a particular purpose should also be considered.

3.4.2 Description of land mapping units and land qualities

A land mapping unit (LMU) is a mapped area of land with specified characteristics and is defined and mapped by natural resource surveys, e.g. soil survey and forest inventory (FAO, 2007). Agricultural land capability classification starts with the land mapping units, which is the core of the system. A number of land evaluation studies involve physical resource surveys, although sometimes there may be adequate information already present. The surveys will frequently include a soil or soil-landform survey, and sometimes such work as pasture resource or other ecological surveys, and surveys of surface-water or groundwater resources (FAO, 2007). The objectives of such surveys are to define and determine the boundaries of the land mapping units and to determine their land qualities (FAO, 1985). The demarcation of LMU's is built in part on land features most readily mapped, common landforms, soils and vegetation. Land is thus a wider concept than soil or terrain. Variation in soils, or soils and landforms, is often the main distinguishing characteristic between LMU's within a local area, and soil surveys are sometimes the main basis for definition of LMU's (FAO, 1985). Though, the quality of soils for land use cannot be evaluated in isolation from other features of the environment; it is land, and not just soil, which is the basis for capability evaluation. The basic mapping units are the foundation for all informative groupings of soils as they provide the information required for developing capability units.

For the purposes of this study, important datasets for LMU's includes soils, landform, climate and vegetation. Generally, a GIS is used to store and overlay the datasets in order to develop LMU's (George, 2001). A land unit must be drawn on the map outlined by a polygon of specific area, must ensure the homogeneous characteristics of the land, and must be supported specifically by the description of attribute data (Baniya, 2008). Land units can be established by simple methods based on features that are found directly on the field, remote sensing imagery and other sources.

3.5 Land capability

3.5.1 Trends of land capability evaluation

Land evaluation has usually been predominantly based on soil resource inventories, commonly called soil surveys. They were initiated mainly as support for rural land use decision making, in particular the matching of production systems (crops, varieties, rotations, fertilization and other agricultural practices, conservation measures) to soil types. This support became systematised in the land capability approach (Baniya, 2008), where soil types were categorised by their ability to sustain general classes of land use. Starting in the 1950's, multi-purpose soil survey interpretations for non-agricultural uses became increasingly important (Baniya, 2008; Bacic, 2003). In the early 1970's, there was growing dissatisfaction with then-existing land classification systems insofar as their ability to support rational land-use planning (Rossiter, 1996), as the existing land classification systems were mostly or completely based on physical factors and ignored socioeconomic aspects of land use. To address this shortcoming, FAO's Land and Water Development Division, in approximately 1973, sponsored working groups, leading to publication of the Framework for Land Evaluation in 1976, Rossiter (1997). The land evaluation method of FAO is used by many nations and proves to be widely practical and significantly improved.

3.5.2 Concepts of land capability evaluation

Globally, several studies have been undertaken to assess land capability. Land use capability has been studied from topography, soil, land cover and the interrelationships among landform, soil and vegetation (Mahmoud *et al*., 2009). Land evaluation is the evaluation of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation, (FAO, 2001). Land capability evaluation can also be defined as the prediction of land quality for specific use. This process includes identification, selection and description of land use types relevant to the area under consideration; mapping and description of the different types of land that occur in the area; and the evaluation of the capability of the different types of land for the selected land use types (FAO, 2001). The modern era of land evaluation began with the publication of the FAO "Framework for Land Evaluation" in 1976 and subsequent guidelines for land evaluation of general kinds of land use (Rossiter, 1996).

Land capability evaluation is generally done for particular varieties of land use. Land use can be possibly defined at an overall level (such as rainfed arable cropping) or for a specific crop at a specified level of inputs. The level of physical inputs is defined in the evaluation, as are land enhancements such as soil management or drainage, and their general influence is taken into account in forecasting crop outputs. Recommended land uses must not cause soil erosion but must conserve the land for long-term production; improving the productivity of land use systems (FAO, 1993).

3.6 Land capability evaluation systems

Generally the method of determining the land feature from soil characteristics is largely by evaluating and alignment of soil types in orders and classes according to their ability which may range from capable (that symbolises a land with a sustainable usage) to inappropriate (which specifies a piece of land quality not allowing the considered agricultural use), or are not enough for sustainable outcomes. There are many kinds of land evaluation systems, of varying precision, objectives, requirements and assumptions. Beek *et al.,* (1998) identified three approaches to land evaluation based on whether the evaluation is for a general or specific purpose, physical or integral, and qualitative or quantitative.

General-purpose land evaluation is a standardised procedure for evaluating the capability to support a given land use. The capability classification depends on the links between broadly defined kinds of land use and qualities of the physical environment expressed in terms of limitations or hazards (Ebrahim, 2007). This land evaluation system is relatively straightforward because it relates to physical land variables and land use requirements only; it is relatively unaffected by social, economic and technological changes.

Specific-purpose land evaluation, evaluates land capability for specific purposes based on relevant physical and socio-economic data; the data requirements are not predetermined, but must be chosen to suit the specific requirements (Ebrahim, 2007). Physical land evaluation deals with the physical ecological aspects of land, and is used within a general socio-economic context (Masahreh *et al.*, 2000). This approach identifies and compares potential land use alternatives, and therefore follows from the recognition of the need for some changes in the use of land (FAO, 2006).

Integral land evaluation is a combination of physical land evaluation and socio-economic analysis (Beek *et al.,* 1998). It addresses the critical importance of land for specific uses in order to meet basic social goals such as economically acceptable production levels and the need for goods and services (Masahreh *et al.*, 2000).

Qualitative land evaluation deals with the evaluation of land capability for alternative purposes that are expressed as highly, moderately or marginally capable or not capable for a particular use (Dent and Young, 1981) without specific estimation of inputs and outputs such as production costs, yields and profits (FAO, 2006).

Quantitative land evaluation distinguishes between capability classes that are based on common numerical terms, which allow objective comparisons between classes that relate to different kinds of land use (Ebrahim, 2007). It can also be categorised into physical and economic evaluations according to whether results are expressed in yields or in economic terms (FAO, 1985).

The degree of quantification in which the capability criteria are expressed depends on the purpose and detail of land evaluation (Ebrahim, 2007). In this research, quantitative evaluation using the USDA's land capability classification system is used.

3.6.1 The USDA system of land capability classification

Before the adoption of the Framework for Land Evaluation formed by the FAO in 1976, the land capability technique developed by the U. S. Department of Agriculture (USDA) founded land evaluation activities, and this is still the main technique adopted globally, either directly or in modified methods (Hanson *et al.*, 2001; FAO, 2007). The latest version of the National Soil Survey Handbook (NSSH) was restructured in 2009 by the USDA. In the NSSH, land potential is evaluated based on soil properties using soil potential ratings related with other resource data, as a basis for making land use decisions (USDA, 2010).

The soil potential ratings help users to make informed decision regarding the capability of soils for a specific use as compared with other soil types in an area. They often focus on yield or performance aspects, the comparative cost of using modern technology to reduce the impacts of any soil limitations, and the adverse impacts of continuing restrictions, on socioeconomic or environmental values (USDA, 2010).

Definition of soil potential rating (USDA, 2010; Tin, 2011), includes five classes:

a) Very high potential: production/performance is at or above local standards because soil conditions are exceptionally favourable, installation or management costs are low;
b) High potential: production/performance is at or above the level of locally established standards, the cost of measures to overcome soil limitations are judged locally to be favourable in relation to the expected performance or yields, and soil limitations that continue after corrective measures are installed do not detract appreciably from environmental quality or economic returns;
c) Medium potential: production/performance is somewhat below locally established standards, the costs of measures to overcome soil limitations are high, or soil

limitations that continue after corrective measures are installed detract from environmental quality or economic returns;

d) Low potential: production/performance is significantly below local standards, measures that are required to overcome soil limitations are very costly, or soil limitations that continue after corrective measures are installed, detract appreciably from environmental quality or economic returns, and

e) Very low potential: production/performance is much below locally established standards, severe soil limitations exist for which economically feasible measures are unavailable, or soil limitations that continue after corrective measures are installed seriously detract from environmental quality or economic returns.

The USDA method measures primary land potential through consideration of physical parameters such as soil depth, soil structure, soil texture, landform, altitude, rainfall, temperature and growing season. The technique utilises the parametric approach to land classification, which gathers specific physical parameters independently and then combines them to form land capability classes (Land Capability Classification-LCC) (Hanson *et al.*, 2001).

Land capability classification for agriculture shows the vulnerability to soil and water erosion, water logging, land degradation etc. These hazards limit the use of land for particular purposes only, according to specific USDA guidelines for land capability classification (Panhalkar, 2011). Land capability classes reflect degrees of capability. The system contains classes of land in sequence of decreasing degrees of capability within the order from I to VIII, as follows (FAO, 2007):

a) Class I land has slight limitations that restrict their use. They are capable of most rural land uses and land management practices, and the few minor limitations can be very readily managed. They may be used for a wide variety of agricultural uses that involve regular cultivation, including vegetable and fruit production, grain and oilseed crops, and fodder and forage crops in specific areas. No special land management practices to control water and wind erosion are required. Some land management practices that will preserve soil structure and chemical fertility are required.

b) Class II land has moderate limitations and short, gradual slopes (1–3%, less than 500 m in length). This gently sloping land is capable of a wide variety of agricultural uses that involve cultivation, such as vegetable and horticultural production. This land can be subject to sheet, rill and gully erosion as well as wind erosion and soil structure decline. However, these limitations can be controlled by land management practices that are readily available and easily implemented, such as conservation tillage and conservation farming practices.

c) Class III land has limitations that must be managed to prevent soil and land degradation. However, the limitations can be overcome by a range of widely available and readily implemented land management practices. Included are sloping lands (3–10%) with slopes longer than 500 m that will require earthworks to control runoff and erosion if used for regular cultivation. Land includes sloping land that is capable of sustaining cultivation on a rotational basis. This land can be readily used for a range of crops including cereals and oilseeds.

d) Class IV land has moderate to severe limitations for some land uses that need to be consciously managed to prevent soil and land degradation. The limitations can be overcome by specialised management practices with high levels of knowledge and expertise. The land can be cultivated occasionally for sowing of pastures and crops, but has a high potential as grazing land. Essential cropping practices include retaining stubble, reducing tillage and sowing with minimum disturbance. Minor drainage depressions with low flows are included in this class. Windbreaks and ground cover should be retained in areas prone to wind erosion.

e) Class V land has severe limitations for high impact land management uses such as cropping. There are few management practices generally available to overcome these limitations. However, highly specialised land management practices can overcome some limitations for high value crops or products. This land is generally more capable for grazing with some limitations or very occasional cultivation for pasture establishment.

f) Class VI land has very severe limitations for a wide range of land uses and few management practices are available to overcome these limitations. Land generally is capable only for grazing with limitations and is not capable for cultivation. Land includes steeply sloping lands (20–33% slope) that can erode severely even without cultivation or land that will be subject to severe wind erosion when cultivated and left exposed. Other limitations can include shallow soils (less than 50 cm deep), stoniness and rock outcrop. Rotational grazing systems with adequate recovery time for plant regrowth are essential.

g) Class VII land has extremely severe limitations for most land uses. It is incapable for any type of cropping or grazing because of its limitations. Use of this land for these purposes will result in severe erosion and degradation. It may be too steep, rocky, swampy or fragile for grazing. The land may be capable for commercial timber plantations or for native timber on undeveloped land. Soil erosion control is difficult because of site limitations. Fertility varies with geology, soil depth and type. These limitations prevent most land uses.

h) Class VIII land has limitations that preclude their use for commercial plant production and limit their use to recreation, wildlife, or water supply or for aesthetic purposes. Land includes precipitous slopes (>50% slope) and cliffs, areas with a large proportion of rock outcrop (>70% area), or areas subject to regular inundation and waterlogging (swamps, lakes, lagoons, stream beds and banks).

The first four classes are appropriate for agricultural practices in which the constraint on their usage and requirements of management methods necessitates a cautious administration rise from I to IV. The last four classes, V to VIII, cannot be used for cultivation, but can be used for fallow, range, woodland, foraging and wildlife purposes.

Capability subclasses are soil groups within one class. They are designated by adding a small letter, *e, w, s,* or *c,* to the class numeral, for example, 2e (USDA, 1961). The letter *e* shows that the main hazard is the risk of erosion unless close-growing plant cover is maintained; *w* shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage); *s* shows that the soil is limited mainly because it is shallow, droughty, or stony; and *c,* used in only some parts of the United States, shows that the chief limitation is climate that is very cold or very dry (USDA, 1961).

Capability units are soil groups within a subclass. The soils in a capability unit are enough alike to be suited to the same crops and pasture plants, to require similar management, and to have similar productivity (USDA, 1961).

Table 3.1 Structure of land capability orders and classes (FAO, 1985)

Order	Class	Description
Capable (C)	C1 (Highly capable)	Land having no, or insignificant limitations to the given type of use
	C2 (Moderately capable)	Land having minor limitations to the given type of use
	C3 (Marginally capable)	Land having moderate limitations to the given type of use
Not-capable (N)	N1 (Currently not capable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 Permanently not capable)	Land with so severe limitations which are very difficult to overcome

Further categories namely orders and classes are recognised in land capability evaluation. Land capability orders specify whether land is evaluated as capable or not capable for use. A Land capability order is generally symbolised in maps by the symbols C and N respectively. Within orders, there are land capability classes. Table 3.1 presents land capability orders and classes.

Capability units are soil groups within a subclass. The soils in a capability unit are likely to be suited to the same crops and pasture plants, to require similar management, and to have similar productivity (USDA, 1961).

3.6.2 The FAO method for land evaluation

A number of studies indicate that there are limitations to the USDA land capability approach. The studies done by Hanson *et al.*, 2001; Moss, 1985; Rowe, 1981 and Bouma *et al.*, 1993, all provide similar criticisms of the method: they highlight biased assumptions about suitable land utilisation strategies (such as undertaking permanent annual cropping on high potential land); inadequate identification of permanent and temporary land use constraints; and the qualitative and often unverifiable nature of data processing methods (Tin, 2011).

The Framework for Land Evaluation was a pioneering document on land evaluation as it not only addressed the USDA limitations but the Framework set out principles and procedures of land evaluation. The basic principles that are fundamental to the approach and methods employed in land evaluation are based on FAO (1976) and are as follows:

a) Land capability is assessed and classified with respect to specified kinds of use. This principle embodies recognition of the fact that different kinds of land use have different requirements. Thus the land itself and the land use are equally fundamental to land capability evaluation.

b) Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. Land in itself, without input, rarely if ever possesses productive potential. Capability for each use is assessed by comparing the required input, such as labour and fertilizers, with the goods produced or other benefits obtained.

c) A multidisciplinary approach is required. The evaluation process requires contributions from the fields of natural science, the technology of land use, economics and sociology. In particular, capability evaluation always incorporates economic considerations to a greater or lesser extent.

d) Evaluation is made in terms relevant to the physical economic and social context of the area concerned. Such factors as the regional climate, standard of living of the population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable, and availability of capital, form the context within which evaluation takes place.

e) Capability refers to use on a sustained basis. The risk of environmental degradation is taken into account when assessing capability. What is required is that for any proposed form of land use, the probable consequences for the environment should be assessed as accurately as possible and such evaluations taken into consideration in determining capability.

f) Evaluation involves comparison of more than a single kind of use. This comparison could be, for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing uses.

The FAO method utilises ecological parameters and is focused on providing levels of capability for predefined land use types based on complex land characteristics in terms of land qualities, such as water availability, nutrient availability, oxygen availability, rooting conditions and erosion hazard (FAO, 2007). Using the FAO framework to classify land on the basis of capability for crop cultivation, Halder (2013) ranked classes in order to assess land capability for crop cultivation by using remote sensing and GIS in West Bengal, India. The classification scheme of land capability and their rating values had been adopted from proposed classification system of FAO, and the results indicated that only 12.71% of agricultural land was highly suitable for rice cultivation and 7.78% of agricultural land as highly suitable for wheat cultivation in the study area. Messing *et al.* (2003) also utilised FAO to develop criteria for land capability evaluation in a small catchment on the Loess Plateau in China. The study incorporated land users, land evaluation and soil erosion modelling into a united system to identify an approach for land use planning. The results of the study showed that biophysical factors can be integrated with socio-economic factors using a participatory method and soil erosion modelling to create settings for a more sustainable use of the land.

For more than 25 years, the FAO method has been used in many countries. In South Africa, many land classification studies have been conducted in Kwa-Zulu Natal (KZN), and these were mostly ecological and agro-ecological classification. Pentz (1945) classified KZN into three farming districts abased on their similarity in soil, climate, vegetation, topography, crop, pasture, livestock and timber potential suitability for each farming region that was based on the requirements of each land utilization type. Guy and Smith (1995) undertook a land potential classification for KZN using a combination of soil and climatic land capability classifications. Their land potential classification, classified KZN into eight climate potential classes and used the ratio of the average rainfall, average annual precipitation and to Class APAN measurements, average mean annual rainfall and the mean June, September and annual temperatures as indices to provide a good indication of the climatic agricultural potential and limitations.

Today, most land evaluators favour combining advanced features of the USDA LCC and the FAO, and offer alterations (where appropriate) associated with support tools to make a flexible method for land evaluation appropriate for different specific sites worldwide (Tin, 2011; FAO, 2007; Hossain *et al*., 2007; Corona *et al*., 2008; Hossain *et al*., 2010). A case of this flexible arrangement is the evaluation of the land capability for different crops related with the generation of cropping patterns using quantitative land evaluation procedures. This study combines the USDA LCC and FAO Land Evaluation Procedure for land capability evaluation.

3.7 The procedure of land capability evaluation

The methodology developed by FAO in 1976 presented two critical approaches. The two key approaches in land capability evaluation are: for any given land, what kinds of land use are possible; and for any specific kind of land use, which areas of the land are capable (FAO, 1976). The procedure consists of six basic steps adopted by the FAO. These are:

3.7.1 Defining the alternative land uses: land use types or farming systems

A land unit was defined by the FAO in 1976 as an area of land, possessing specified land qualities and land characteristics, which can be demarcated on a map. The FAO (2007) recognizes two levels of detail at which land use is defined. This is called a land utilisation type, and is a kind of land use defined in more detail as a farming system.

According to FAO (1985), land use types (LUTs), or farming systems, comprise of the following:

a) Single LUT: only one kind of use undertaken on an area of land (e.g. irrigated maize).

b) Multiple LUT: consists of more than one kind of use simultaneously undertaken on the same area of land, each use having its own inputs, requirements and produce. An example is a timber plantation used simultaneously as a recreational area

c) Compound LUT: consists of more than one kind of use undertaken on areas of land which for purposes of evaluation are treated as a single unit. The different kinds of use may occur in time sequence (e.g. as in crop rotation) or simultaneously on different areas of land within the same organizational unit.

The final result of this step is to find favourable LUTs based on specific purposes and objectives of the land evaluation in a particular area and objectives of the study.

3.7.2 Defining land use requirements

Land use requirements are described by the land qualities needed for sustained production, and land quality is a complex attribute of land that has a direct effect on land use (Tin, 2011). Most land qualities are determined by the interaction of several land characteristics – measurable attributes of the land (FAO, 1993).

This step determines the land properties needed for land quality, such as physical and chemical soil properties, seeds and labour for each LUT. The land properties are then classified as a range of capabilities with relevant indices corresponding to the performance of each LUT (Beek *et al.,* 1998).

3.7.3 Describing land mapping units

Land units are identified and form the basis for the diagnosis of problems. In this step, a survey is conducted to map land units and to describe their characteristics – e.g. climate, slope and soils – relevant to requirements of each land use type (FAO, 1993).

3.7.4 Matching land use requirements and land conditions

This step compares the requirements of each land use type and the land qualities of each land unit. The comparison is done by examining the measured values of each land quality against the class limits, and assigning each land unit to its land capability class based on the most severe limitation.

3.7.5 Presenting the results of land capability evaluation

The results of land capability evaluation are presented and the main outputs are land capability maps. The maps display the capability of each land unit for each land-use type, and descriptions of these land-use types, including required techniques or management for land improvement (West and Turner, 2014).

3.7.6 The notable points in land capability evaluation

While land is immovable and – in many ways – unchangeable asset, money, workforce, organisational skills are moveable and can be used to improve the land capability (FAO, 1993). The land conditions that are appropriate for crop growth and LUTs differ in different areas, and different farming systems, irrigation methods and management systems have differing requirements, and therefore the specification of land capability classes in terms of a few universally applicable land characteristics is not a sound approach (FAO, 1985).

Hence, the following key points in land evaluation exist in most studies:

a) Land uses and LUTs differ from area to area and thus their definitions and levels of detail do not have an identical framework. The acceptance of a suitable framework is contingent on the goals, development strategies, and locally specific conditions of the area.

b) When developing class specifications it is more appropriate to specify the land capability classes in terms of land use requirements and limitations rather than directly in terms of land characteristics (FAO, 1985).

c) The linkage between land use requirements and land qualities is important in land evaluation. Thus the matching process, associations, connections and the importance of these land qualities, considerably impact on the improvement of class-determining criteria (FAO, 1985). In cases where one limitation is enough to render the land incapable for the use, the most severe limitation method is valid, and for less severe limitations, alternative methods of combining ratings can be used (Tin, 2011).

d) Linking land use to land capability comprises a larger procedure than the simple evaluation of land use requirements with the land qualities. If the initial comparison shows certain land units cannot support a given land use, the specification of the land-use type can be reconsidered and the capability of those land units can be raised (Tin, 2011). Land cannot be graded from "best" to "worst" independently of the kind of use and management practice, as each kind of use has special requirements (FAO, 1993).

e) Land qualities can cause the land to be unusable for a particular LUT but usable for another. A new LUT could be introduced, or solutions for land improvement introduced, in order to achieve a higher overall land capability (FAO, 1993).

3.8 Basic soil properties

The theory of soil quality considers the evaluation of soil properties and development in terms of the capability of soil to function efficiently as an element of a healthy ecosystem. The concept of soil resource management for supporting the productivity of crop systems is necessary to guarantee sustainable agriculture practices and environmental protection. Measuring soil quality, if properly characterised, should serve as an indicator of the soil's capacity to produce safe and nutritious food, enhance human and animal health, and overcome degradative processes (Papendick and Parr, 1992).

3.8.1 Chemical properties as indicators of soil quality

Papendick and Parr (1992) and Schoenholtz *et al.* (2000), suggested pH, salinity, cation exchange capacities (CEC) and organic matter to be included as first order soil quality indicators. Soil organic matter (SOM) is generally acknowledged as one of the vital chemical parameters of soil quality, yet quantitative evaluation of its contribution to soil quality is often lacking (Kay and Grant, 1996). SOM has a role in aggregate stability and influences soil porosity, and thus gas exchange reactions and water relations. It is a critical factor in the carbon cycle and a repository of nutrients, and through its influence on many fundamental biological and chemical processes it plays a pivotal role in nutrient release and availability (Schoenholtz *et al.*, 2000)

Several chemical reactions that impact nutrient availability such as chemical form and adsorption are influenced by soil chemical environment and soil pH in particular. Therefore, pH is included as a key chemical indicator, particularly since it is normally included in soil surveys as it is easily and accurately measured. Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H+) in the soil (Ali, 2010). A high amount of H+ corresponds to a low pH value and vice versa. The pH scale ranges from 0 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline (basic). The pH of a soil is dependent on the parent material, the climate, the native vegetation, the cropping history (for agricultural soils) and the fertilizer or liming practices (Ali, 2010).

Cation exchange capacity (CEC) is the ability of the soil to hold onto nutrients and prevent them from leaching beyond the reach of crop roots. The more cation exchange capacity a soil has, the more likely the soil will have a higher fertility level (Ali, 2010). When combined with other measures of soil fertility, CEC is a good indicator of soil quality and productivity.

The cation exchange capacity of a soil is simply a measure of the quantity of sites on soil-particle surfaces that can retain positively charged ions by electrostatic forces. Cations retaining electrostatically are easily exchangeable with other cations in the soil solution and are thus readily available for plant uptake (Ali, 2010). Thus, CEC is important for maintaining adequate quantities of plant-available calcium, magnesium and potassium in soils. Other cations include Aluminium (when pH< 5.5) and Sodium. Cation Exchange Capacity can be expressed in two ways:

a) The number of cation adsorption sites per unit weight of soil or,
b) The sum total of exchangeable cations that a soil can adsorb (Ali, 2010).

Soil CEC is normally expressed in units of charge per weight of soil. Two different, but numerically equivalent, sets of units are used: meq/100 g (milliequivalents of element per 100 g of dry soil) or cmolc/kg (centimoles of charge per kilogram of dry soil). Normal CEC ranges in soils would be from < 1 meq/100 g, for sandy soils low in OM, to >25 meq/100 g for soils high in certain types of clay or OM (Ali, 2010). Soil organic matter will develop a greater CEC at near-neutral pH than under acidic conditions. Additions of an organic material will likely increase a soil's CEC. Soil CEC may also decrease with time through acidification and OM decomposition (Ali, 2010).

3.8.2 Physical properties as indicators of soil quality

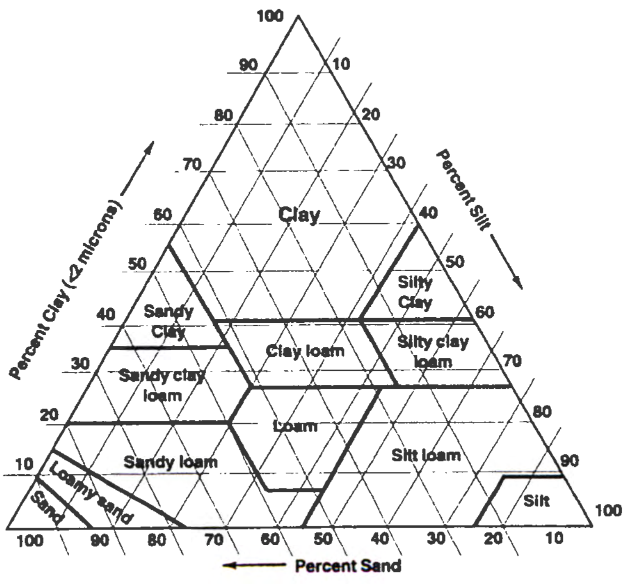


Figure 3.2: Soil texture triangle (Source: Brady, 1990)

Productive soils have attributes that (1) promote root growth; (2) accept, hold, and supply water; (3) hold, supply, and cycle mineral nutrients; (4) promote optimum gas exchange; (5) promote biological activity; and (6) accept, hold, and release carbon (Burger and Kelting, 1999). All of these attributes are a function of soil physical properties and processes.

Simple soil quality indicator like soil texture is valuable for linking soil quality among soil types and within a soil type before and after some management practice has been imposed (Schoenholtz *et al.*, 2000). Soil texture is the most essential qualitative soil physical property, governing water, nutrient, and oxygen exchange, retention, and uptake. It is a chief soil property that encourages most other properties and processes. The soil particles have the following size ranges, sand = <2 to 0.05 mm, silt = 0.05 to 0.002 mm, clay = <0.002 mm and for all mineral soils, the proportion of sand, silt, and clay always adds up to 100 percent (Schoenholtz *et al.*, 2000). These percentages are grouped into soil texture "classes", which have been organised into a "textural triangle" (Figure 3.2).

Indicators of water infiltration, retention, availability, drainage, and water/air balance are generally significant for all soil purposes. Available water holding capacity and saturated hydraulic conductivity are the two measures most frequently found in minimum data sets of soil quality indicators (Schoenholtz *et al.*, 2000). Existing water holding capacity measures the relative capacity of a soil to supply water, and saturated hydraulic conductivity is an indicator of the rate of soil drainage that can be used to judge water/air balance in soils.

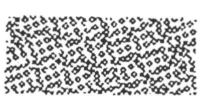
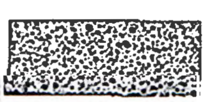
Graphic Example	Description of Structure Shape
	**Massive** – compact, coherent soil not separated into peds of any kind. Massive structures in clayey soils usually have very small pores, slow permeability, and poor aeration.
	**Single grain** – in some very sandy soils, every grain acts independently, and there is no binding agent to hold the grains together into peds. Permeability is rapid, but fertility and water holding capacity are low.

Figure 3.3: Soil structure (Source: Brady, 1990)

Soil structure refers to the size and shape of soil aggregates held together by organic matter and other chemical precipitates. Like soil texture, it influences a myriad of soil physical, chemical and biological properties Aggregate stability describes the ability of the soil to retain its arrangement of solid and void space when exposed to different stresses (Kay, 1990). Stability characteristics are generally specific for a structural form and the type of stress being applied. A measure of aggregate stability could serve as a surrogate for soil structure, which is critical for development of root systems (Kay and Grant, 1996).

3.9 Identification of decisive factors

A variety of factors are considered in land capability evaluation like soil properties, landform and climate. There are however some factors that are more dominant than others for particular crops. According to FAO (2006) guidelines for land capability evaluation, classification of capable land considers land characters in relation to crop requirements. The parameter method is used to classify the land for agricultural production. This is a method that considers ranking or grading through adding points and multiplying by percentage. This method allows the process of ranking land capability to easily identify the dominant factors. The dominant factors are significant and fixed factors in the land such as soil type and soil depth, while ordinary factors are soil fertility and soil texture. According to FAO (1985) and Baniya (2008), it is necessary to classify the dominant factors in the process of ranking land capability and these are called as class-determining factors (criteria). The criteria allow the land capability results to be characterised as classes from high to low capability.

Classifying criteria (FAO, 1985; Baniya, 2008):

a) If a dominant factor has the highest limitation level, the capability is ranked in accordance with that level. For example: if a dominant factor is at C3 and the other factors are at C2 and C1, then the capability level is ranked C3.
b) If an ordinary factor has the highest limitation level while the other factors (dominant and ordinary) are at lower ones, the capability is ranked one level higher. For example: if an ordinary factor is at C3 and the other factors are at C2 and C1, then the capability level is ranked C2.
c) If two ordinary factors are at C3 whereas all dominant factors are at C1 and C2, the capability level is ranked C2, or from N to C3, and from C2 to C1.
d) If more than three ordinary factors are at the same level, the capability level remains the same.

Through literature survey (compiled by South Africa Department of Agriculture) and field work, the study has recognised a list of land and climatic factors which are then categorised as the dominant and ordinary factors using the classifying criteria (FAO (1985); Baniya, 2008). Relationship with crop type and degree of influence is an important consideration for the categorisation into dominant and ordinary factors.

Table 3.2: Category of dominant and ordinary factors for crops in the study sites

Land quality/characteristics	Unit	Characteristics	
		Dominant	**Ordinary**
WEATHER CHARACTERISTICS			
1.Temperature	° C	_	
2. Rainfall	mm	_	
LAND CHARACTERISTICS			
1. Soil type		_	
2. Soil depth	cm	_	
SOIL CHARACTERISTICS			
1. Soil texture			_
3. Soil reaction (pH)			_
4. Organic Matter (OM)	%		_

Most of the land and climatic factors presented in Table 3.2 are rated as dominant factors. Different climatic features such as temperature, precipitation and sunshine hours are characterised as dominant. Similarly soil type and depth are also classified as dominant factors while land aspect is not included in the ratings as this can affect climatic factors such as temperature and sunshine durations.

Most of the land factors are rated as dominant factors, such as land use/type, soil type and soil depth, because they have substantial influence and relate closely to managing and providing sustainable land capability. The general flat characteristics of North West Province mean slope is an ordinary factor. Pedological factors such as soil texture and pH also carry more weight in land capability classification while other factors such as organic carbon and fertility are weighted less as they can be enhanced during the cultivation. Kalogirou (2002) suggested that the improvement of the physical evaluation by involving climate characteristics and the development of a complete economic evaluation brings valuable results. The dominant and ordinary factors are ranked on the basis of agronomical requirements of the selected crops using FAO (2006) guidelines.

Most crops are seasonal as the North West Province is a summer rainfall area with hot summers and cold winters with frost in some parts. There are some factors (such as soil type, temperature, etc.) that limit best growth condition and improvement of the crop. These factors reduce the production potential and are thus known as the limiting factors. Existence of one or more of these limiting factors can affect the capability rating of the land. For crop cultivation practices, on the basis of presence of limiting factors, physical land capability has popularly been identified as (a) current physical land capability, and (b) potential land capability (Sayed, 2012).

In the case of current land capability, the existing condition is considered i.e. the type of land, prevalence of soil characteristics, diversity of crop used and ways of land preparations are prevailing act to effect limiting factors and all of these have marked effects on the physiological functioning of the crop (Baniya, 2008). Capability classification of the land mapping unit with the current condition of physical factors for potential crop is known as current physical land capability.

The current land capability evaluation is very important as it allows land users to identify the current limitations of the land area for a given land utilisation. It provides an opportunity to take necessary steps for the further improvement and attaining higher level of capability in potential capability evaluation (Alebachew, 2012). The features from soil, land and climate are the main factors of capability evaluation and are rated into high, medium and low value for a crop while the agronomical requirements are rated on into highly capable, medium capable, low capable and non-capable.

3.10 Remote sensing and GIS for land capability evaluation

3.10.1 GIS Application for land capability evaluation

Geographical Information Systems (GIS) includes numerous mechanisms, beginning with the assimilation of geographical data from remote sensing sources or maps which are then transformed into a computer-readable form. This data can be manipulated and various data subjects such as land cover and soil types can be overlaid for analytical processes. Agricultural capability mapping encompasses categorising land use patterns and evaluating whether the existing use is the most practical both economically and environmentally. The GIS required to support such research has to integrate high functionality and a capability to work efficiently with both raster and vector data arrangements. Tabular information from various sources such as census and agricultural statistics, raster image data and vectorised output field data all add supplementary features to the overall study. Crop modelling, including soil/water requirement and geostatistical analysis, is critical at this stage to identify and make sense of complicated spatial relationships and, ultimately, substantiate trends and theories (Baniya, 2008). Merging GIS and Multi Criteria Decision Analysis (MCDA) on a computer is also the dominant tool for land capability valuations.

The strength of GIS lies in its ability to integrate different types of data into a common spatial platform. This information should present both opportunities and constraints for the decision maker (Ghafari *et al.*, 2000). Some limitations to the use of GIS technology are as follows (FAO, 2001):

a) "The inadequate analysis of real-life problems as they occur in complex land management and sustainability issues at the household level, and as they involve the integration of biophysical, socio-economic and political considerations in a truly holistic manner;
b) The limitation in data availability and data quality at all scales, especially those that require substantial ground truthing (process of verifying a satellite image with what appears on the on the ground);
c) The lack of common data exchange formats and protocol;
d) The inadequate communication means between computer systems, data suppliers and users due, for instance, to poor local telephone networks."

GIS helps link a digital map with a database where features on the map are linked to records in the database, comprising many characteristics and values and serving as a storehouse of information. The map stores physical factors and the database stores data about them. Decisions on land use for crop production depend on many spatially linked features (such as microclimate and vegetation) and location-specific characteristics (such as land areas and the prices of inputs and outputs), combined with production technologies that relate inputs and outputs. In the progression of land capability evaluation, it can be said that components of land unit, inquiries on land use for each agricultural crop are input data of this process; spatial allocation, boundary, area and scale of each capability level for each crop are output data of land evaluation process (Baniya, 2008).

The construction of a GIS is a chain of procedures that leads us from planning data observation and collection, to their storage and analysis, to the use of the derived information in some decision making process (Chuong, 2007). The integration of multi-criteria evaluation method with GIS has considerably advanced the conventional map overlay approaches to land-use capability analysis (Eastman, 1997). GIS-based multi-criteria evaluation can be thought of as a process that combines and transforms spatial data (input) into a resultant decision (output) (Malczewski, 2004).

3.10.2 Mapping land qualities using remote sensing

Over the last three decades, remote sensing has been found extremely useful for assessing soil characteristics (Zribi *et al.*, 2011). Diverse methods have been used for the evaluation of soil factors, built on various remote sensing sensors and practices (passive and active). For passive remote sensing, four principal types of sensors can be considered (Zribi *et al.*, 2011).

These are:

a) Optical remote sensing with a limited number of bands (e.g., SPOT, ASTER, LANDSAT etc.) particularly adapted for vegetation cover description and land use analysis.
b) Optical remote sensing based on hyperspectral sensors, particularly adapted for soil texture description.
c) Optical remote sensing with thermal infrared band, adapted for soil temperature estimation.
d) Passive microwave remote sensing adapted to soil moisture and vegetation estimation.

A variety of sensors have been launched in recent years to allow the use of various methods for recovering surface factors. For example, Pasolli *et al.* (2011) proposed a technique for estimating soil moisture based on the support vector regression algorithm and the integration of ancillary data, using active remote sensing (RADARSAT 2 data), while Liu *et al.* (2011), investigated the impact of soil moisture on gross primary production (GPP), chlorophyll content, and canopy water content represented by remotely sensed vegetation indices (VIs) in an open grassland and an Oak Savannah in California.

Using Landsat Enhanced Thematic Mapper (ETM) and GIS for soil mapping and capability evaluation, Ali and Kotb (2010) evaluated the soils adjacent to El-Manzala Lake east of the Nile Delta, Egypt. The landform units in the study were delineated from high spatial resolution images of Landsat ETM+ enhanced through the data merge process, performed using multi-spectral bands (28.50 m) as a low spatial resolution with panchromatic band 8 of ETM+ satellite image as a high spatial resolution (14.25 m) resulting in multi-spectral data with high spatial resolution (14.25 m). The Landsat ETM+ and Digital Elevation Model (DEM) from the Shuttle Radar Topographic Mission (SRTM) image were grouped and processed in ERDAS Imagine software to extract the different landforms of the studied area to obtain a geomorphologic map. A soil survey was done in the study area to get more detailed information of the soil patterns. The data obtained were imported in a GIS database; the digital geomorphologic map was used as base map in the database. The data obtained from the thematic layers indicated that the main limiting factors in the studied area were soil depth, drainage conditions, soil salinity, soil texture, alkalinity and calcium carbonate content.

In the north-western coast of Egypt, Mahmoud *et al.* (2009) used SPOT imagery and soil data in combination with GIS tools for sustainable land use analysis (SLU). The SLU was established based on various factors such as land capability, water resource availability, economic return from water and financial return from land and water. Laboratory analysis for soil samples and soil properties were stored as attributes in a geographical soil database linked with the soil mapping units. Results indicated that the area lacks high capability and moderate capability classes.

3.10.3 Landform mapping

Remote sensing can provide options for extending current soil survey data sets. The data it offers can be used in several ways. Firstly, it may help in segmenting the landscape internally into more or less homogeneous soil–landscape units for which soil composition can be assessed by sampling using classical or more advanced methods (Mulder *et al.*, 2011). Secondly, remotely sensed data can be analysed using physically based or empirical methods to derive soil properties. Moreover, remotely sensed imagery can be used as a data source supporting digital soil mapping (Ben-Dor *et al.*, 2008; Slaymaker, 2001). Finally, remote sensing techniques assist mapping remote regions by reducing the need for laborious and costly field surveys. Traditionally, landform mapping is done by visually interpreting aerial photographs (Dent and Young, 1981). Now, with the advent of fast computers and digital sources such as digital elevation models (DEMs) – typically acquired by remote sensing – it can be done digitally. Typically, the surface is parameterised by attributes such as elevation, slope, aspect, plan and profile curvature, and flow accumulation (Moore *et al.*, 1993) to obtain relief or surface topography units. These attributes quantify the role of topography in redistributing water in the landscape and in modifying the amount of solar radiation received at the surface, which may affect the pedogenesis and thereby the soil characteristics (Wilson and Gallant, 2000).

The grouping of a DEM with spectral data can improve landform classification in difficult landscapes. The combination of SRTM and Landsat Thematic Mapper+ (TM+) sources has resulted in better classification of landform types which are dominated by slope processes (Ehsani and Quiel, 2009; Martin and Franklin, 2005; Taramelli and Melelli, 2009). Other satellites whose data have been used for landform recognition in combination with a DEM include ASTER (Glasser *et al.*, 2008; Saadat *et al.*, 2008; Schneevoigt *et al.*, 2008) and Satellite Pour l'Observation de la Terre (SPOT) (Hansen *et al.*, 2009). These studies established that spectral data improved classification because of improved distinction between topographically related landforms.

The most widely used sources of DEM data are Light Detection and Ranging (LIDAR) and SAR and stereo-correlation of images. Dependent on the sensor flight altitude, LIDAR allows highly accurate and very densely sampled elevation points (Woolard and Colby, 2002). Compared to typical LIDAR data sets, Shuttle Radar Topography Mission (SRTM) has much poorer spatial resolution, but unlike the former, SRTM data is easily accessible and even available for free (Farr, 2000). Recently, the ASTER Global Digital Elevation Map (GDEM), created by stereo-correlation of ASTER imagery, has been made available for free to the public. The ASTER GDEM has a spatial resolution of 30 m and has near global coverage (METI/ERSDAC *et al.*, 2009). ASTER is useful for an interpretation of the macro- and meso-relief, and provides the opportunity for mapping especially at medium scales of 1:100000 and 1:50000 (Forkuor and Maathuis, 2012; Mousavi *et al.*, 2011).

Schmidt and Hewitt (2004) used various satellite sensors (Landsat TM, NOAA AVHRR and SPOT imagery) for sugarcane identification and mapping, monitoring harvesting programmes, estimating crop production and monitoring crop condition for precision farming in South Africa. The study found that remote sensing provides a powerful tool for integrating information about a target land use. SPOT imagery was used to monitor areas harvested between satellite scenes in a target area dominated by small scale farmers, while Landsat TM was shown to be useful for sugarcane identification and mapping on a broad regional scale. Landsat TM image were geo-referenced and classified into land use classes, and training areas of known land use were used to identify the spectral signatures corresponding to each land use. A farm boundary map was overlaid on the classified image in the GIS system. Statistical analyses were performed to compare the area under sugarcane, estimated from the classified satellite image, with the database of known area under sugarcane for each farm. Across the 46 farms studied, the study found that the sugarcane area estimates derived from the satellite image were within 5% of the total area recorded by growers.

3.10.4 Vegetation patterns and indices

The digital numbers (DNs) recorded in a raw image are not an accurate measure of change over time, because they are a function not only of surface conditions but also of the diurnally variable atmospheric conditions, the seasonally variable Earth–Sun distance, the solar zenith angle (θ_Z), θ_V, and the sensor calibration (Clark *et al.*, 2010). It is thus essential to calibrate the pixel values before any analysis is done on them and this process is also needed before any assessment of pixel spectrum between several images from the same sensor. Sensor calibration can be achieved utilizing the supplied gain and offset coefficients to convert DN to top-of atmosphere at-satellite radiance (L_{SAT}, in $W{*}m^{-2}{*}sr^{-1}{*}\mu m^{-1}$). It is then possible to convert these radiances to at-satellite reflectance (ρ_{SAT}), which normalizes for variations due to the Earth–Sun distance and θ_Z. This then leaves the effect of the atmosphere and off-nadir θ_V to be accounted for. Removing the atmospheric effects allows for easier evaluation of images over time, thus surface reflectance products are useful in change detection and monitoring applications. A variety of geospatial analyses work better with surface reflectance products such as vegetation indexes, albedo, Leaf Area Index (LAI) and land cover change.

Vegetation indices (VIs) looks at the vegetation's reflective disparity in the near infrared (NIR) and visible red (VIS) wavelengths. Spatial and temporal variations in vegetation indices have been found to be linked to prevailing climate, ecosystem, terrain and physical soil properties (Singh *et al.*, 2004). The Normalized Difference Vegetation Index (NDVI) is one of the most common indicators of crop growth characteristics and, indirectly, of specific site qualities (Sommer *et al*., 2003; Sumfleth and Duttmann, 2008). Tucker (1979) introduced NDVI and the Global Inventory Modelling and Mapping Studies (GIMMS) data set, the latter of which provides a time series of NDVI data (Julien and Sobrino, 2009; Los *et al*., 1994). Dobos *et al.* (2000) found that the use of spectral indices such as NDVI in combination with a DEM often produced soil pattern delineations comparable to existing regional scale soil and terrain data.

Prior to computation of NDVI values, Munyati and Mboweni (2013) converted the DN values in bands 2 and 3 on the original 10 m-resolution SPOT HRG image to at-sensor radiance (Lλ) values (expressed in $W*m^{-2}*sr^{-1}*\mu m^{-1}$). The study examined NDVI values for land cover types of savannah areas at Mafikeng, North West Province of South Africa. Following radiometric calibration and geometric pre-processing, the 10m pixel size of the image was aggregated to 250 m and 1000 m to simulate imagery at these pixel sizes, and then NDVI images at the spatial resolution scales of 10 m (NDVI 10 m), 250 m (NDVI 250 m), and 1000 m (NDVI 1000 m) derived from the respective images. The simulation of the NDVI 250 m image was validated against a concurrent 16 day MODIS NDVI composite (MOD13Q1) image, and the accuracy derived from the validation was generalised to the NDVI 1000 m image. The results indicated that vegetation monitoring using low spatial resolution imagery in semi-arid savannah may only be indicative and needs to be supplemented by higher spatial resolution imagery. The study demonstrated the importance of high spatial resolution for vegetation mapping and showed the scales at which vegetation can be studied, using SPOT imagery.

3.11 GIS, remote sensing and geostatistics as essential partners for spatial analysis

Generating high precisions soil maps is essential in landscape ecology, rangeland rehabilitation and management. Among various methods that have been used for mapping soil features, geostatistics and remote sensing are more efficient and cost-effective (Hosseini, 2013). Geostatistics is a powerful method that considers spatial variance, location and distribution of samples to determine spatial variability using mathematical and statistical functions (Sauer et al., 2006). Generating a precise soil map is very challenging when analysing a huge number of samples. Hence, the use of cost effective variables such as elevation and satellite images is recommended as secondary data for soil mapping in large areas (Eldeiry & Garcia, 2008). A number of authors (Hosseini, 2013; Isaak and Srivastava, 1989; Goovaerts, 1994) have pointed out that remote sensing data is an ideal tool for mapping soil properties with a reduced number of samples. GIS serves geostatistics by assisting in the geo-registration of data, allowing spatial data analysis, offering a spatial context for interpolation and modelling, and offering simple and functional tools for data display and visualization. The value of geostatistics for GIS lies in the provision of reliable interpolation methods with known errors, methods of upscaling and generalization, and for supplying multiple realizations of spatial patterns that can be used in environmental modelling (Burrough, 2001). The conclusion is that the connection between GIS, remote sensing and geostatistics offers a great and complementary collection of tools for spatial analysis in the agriculture and environmental sciences.

3.12 A comparative study of interpolation methods for mapping soil properties

The quality, quantity and type of vegetation is usually affected by soil properties and since soil mapping is a critical step in land capability evaluation, there is an increasing need to measure and map soil properties in natural ecosystems. Soil properties can vary at markedly different spatial scales within sites of interest, such as fields. The variation comprises that over short distances of a few metres and over longer distances of tens or hundreds of metres. For most environmental and agricultural management, it is variation over tens or hundreds of metres that managers want to resolve, and we can regard the short-range variation as 'noise' or a sampling effect (Goovaerts, 1994). Many soil attributes have to be determined from samples taken in the field, therefore there is a need to predict accurately at places where there are no data. Geostatistics, which is based on the theory of regionalised variables (Goovaerts, 1994), is increasingly preferred because it allows one to capitalize on the spatial correlation between neighbouring observations to predict attribute values at unsampled locations.

The interpolation techniques commonly used in agriculture include inverse distance weighting and Kriging (Weisz *et al.*, 1995). Kriging requires the preliminary modelling step of a variance-distance relationship, while IDW does not require such a step and is very simple and quick. Both methods estimate values at unsampled locations based on the measurements from the surrounding locations with certain weights assigned to each of the measurements. Inverse distance weighting is easier to implement, while Kriging is more time-consuming and cumbersome; however, Kriging provides a more accurate description of the data spatial structure, and produces valuable information about estimation error distributions (Kravchenko and Bullock, 1999).

The accuracy of these two procedures has been compared in a number of studies. Tabios and Salas (1985) compared Kriging with several other interpolation techniques, including IDW, for annual precipitation distributions, and found Kriging to be superior to IDW. In some cases, the performance of Kriging was generally better than IDW (Kravchenko and Bullock, 1999; Kravchenko, 2003; Reinstorf *et al.*, 2005). Warrick *et al.* (1998) also reported Kriging to be better than inverse distance weighting for mapping potato yield and soil properties, such as percent of sand, calcium content and infiltration rate. In other studies, IDW generally out-performed Kriging (Weisz *et al.*, 1995; Nalder and Wein, 1998). Gotway *et al.* (1996) observed the best results in mapping soil organic matter contents and soil NO_3^- levels for several fields when IDW was used as an interpolation technique. Often, however, the results have been mixed (Schloeder *et al.*, 2001; Mueller *et al.*, 2001; Lapen and Hayhoe, 2003). Kriging performance can be significantly affected by variability and spatial structure of the data (Leenares *et al.*, 1990) and by the choice of variogram model, search radius and the number of the closest neighboring points used for estimation. As might be expected, the performance of Kriging improved relative to IDW when spatial structure was known. Comparing Kriging with inverse distance weighting revealed that Kriging with the optimal number of neighbouring points, a carefully selected variogram model, and appropriate log-transformation of the data produces more accurate estimations than the inverse distance method for the majority of the data (Kravchenko and Bullock, 1999).

3.11.1 Kriging

Kriging is an optimal interpolation procedure which uses the description of soil variability with distance as provided by the semivariogram to obtain estimates for the soil property at non-sampled locations (Journel and Huijbregts, 1978). Kriging provides a sound basis for prediction leading to accurate digital mapping for managing soil attributes (Goovaerts and Kerry, 2010). This method is becoming an important tool in geostatistics because of the availability of many covariates at high spatial resolution with the advancement in proximal and remote-sensing with positioning technologies (Sun *et al.*, 2012). The Kriging equations guarantee the two main characteristics of un-biasedness and minimum errors in estimations. To achieve the mentioned weights for this estimation, semivariogram models are required

(Miller *et al.*, 2007). A semivariogram is calculated for each soil property as follows (Kerry *et al.*, 2010):

$$\Upsilon(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad \text{(Equation 3.1)}$$

where $Z(x_i)$ represents the measured value of the soil property at location x_i, $\Upsilon(h)$ is the semivariogram for a lag distance h between observations $Z(x_i)$ and $Z(x_i + h)$, and $N(h)$ is the number of data pairs separated by a lag distance equal to *h*.

To obtain reliable semivariograms, which are the main tools of geostatistics, a map of soil properties initially requires about 100 sampling points, which is costly in developing countries (Kerry and Oliver, 2003). However, to solve these budget limitations, some authors have reported accurate prediction maps from sparsely sampled observations of a primary attribute, for example rainfall erosivity (Goovaerts, 1994), rainfall distribution (Goovaerts, 2000), and evapotranspiration maps (Vanderlinden, 2001). These are complemented by the digital elevation models as exhaustive secondary attributes are more densely sampled and used with different interpolation techniques (Emadi *et al.*, 2010).

Providing an approach for land capability evaluation, Emadi *et al.* (2010) used geostatistics, remote sensing and GIS in arid and semiarid ecosystems. The primary data were obtained from 85 soil samples collected from depths of 0 to 90 cm, and the secondary information was acquired from the remotely sensed data from the linear imaging self-scanner (LISSIII) receiver of the IRS-P6 satellite. Ordinary Kriging and simple Kriging with varying local means (SKVLM) methods were used to identify the spatial dependency of important soil parameters. It was observed that using the data collected from the spectral values of band 1 of the LISSIII receiver as the secondary variable applying the SKVLM method resulted in the lowest mean square error for mapping the pH and electrical conductivity in the 0–30 cm depth. On the other hand, the ordinary Kriging method resulted in a reliable accuracy for the other soil properties with moderate to strong spatial dependency in the study area for interpolation in the unsampled points. Overlaying the information layers of the data was used with the GIS for preparing the final land capability evaluation. The study found that changes in land characteristics could be identified in the same soil mapping units over a very short distance. This approach was recommended for future studies when capability classifications from different sources are compared.

3.13 Summary

Considering prior studies on land evaluation is necessary to provide a theoretical framework for agricultural land capability evaluation, which is the main objective of the study. In this chapter, the idea of land capability and the purposes of land evaluation were explained. The chapter presented two original important systems for land evaluation – the FAO and USDA methods. A theoretical framework for land evaluation and applicable land capability evaluation developments, like the combination of qualitative and quantitative approaches, incorporating scientific and local knowledge, and several disciplines of evaluation, have been discussed.

This chapter, importantly, explained common required implementation methods, classification systems, and synopses of earlier studies on land evaluation globally and in the study area setting. Support tools for land evaluation like GIS and remote sensing were also reviewed. The review discussed the importance of the agricultural sector to socio-economic growth and human well-being, as it contributes to economic growth, jobs, food security, and poverty reduction, especially in the rural areas of a developing country.

Chapter Four

Materials and methods

4.1 Introduction

This chapter presents the required materials and methods used to acquire and analyse the essential data from relevant sources. The methodological approach defines the strategy implemented to answer the research questions.

4.2 Data sources

- The net return for each land use type figures are based on the Agricultural Statistics 2013/14. This report contains the detailed results on commercial and non-commercial agriculture, undertaken in the Republic of South Africa.
- Soil inventory is based on the Soil and Terrain database (SOTER) for South Africa. It was compiled from the SOTER database for Southern Africa (SOTERSAF, 1:2 M).
- Soil descriptions are according to the FAO guidelines while classifications are based on the USDA system.
- The climatic data is obtained from the South African Weather Services (SAWS). The data is based on major rainfall season for the study area which is from October to April of the following year. The methodological approach used in this study is summarised in Figure 4.1.

4.3 Remote sensing application

4.3.1 Selection of satellite images

SPOT 5 HRG images for the four study sites were obtained from the South African National Space Agency (SANSA). The images have a spatial resolution of 10 m in bands 1 (green, 0.50–0.59 μm), 2 (red, 0.61–0.68 μm), and 3 (near-infrared, 0.78–0.89 μm), and a spatial resolution of 20 m in band 4 (mid-infrared, 1.58–1.75 μm). An image covers an area sized approximately 60 km × 60 km and images are taken in the rainy season. The rainy season is chosen as natural vegetation is in prime leaf condition, which is ideal for computation of representative NDVI values. Table 4.1 shows the detailed description of the four SPOT 5 HRG images that were obtained for use in the study.

1. Identify major crops grown in the area

2. Identify requirements of the crops

- Rainfall, Soil depth, Soil texture, Topography/slope/aspect, Soil fertility

3. Identify GIS and RS sources/roles:

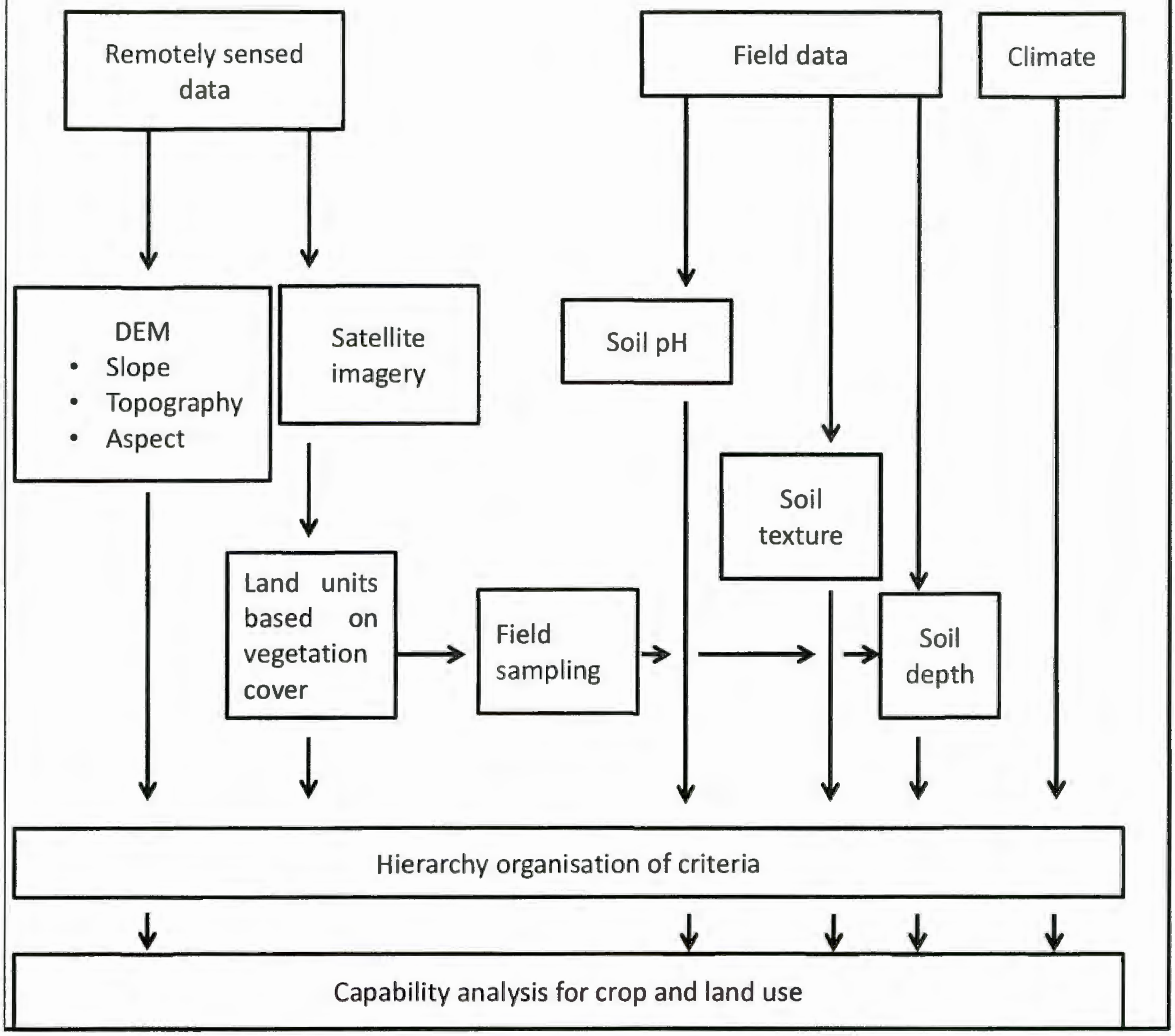


Figure 4.1: Agricultural land capability framework

Table 4.1: Characteristics of satellite images

Acquisition Date	Farm	Row	Column	Resolution
2013-03-04	Barberspan	128	403	10m
2013-03-15	Former Pienaars Nature Reserve	128	401	10m
2013-02-11	Antwerp	126	402	10m
2013-02-17	Rietfontein	129	402	10m

4.3.2 Image processing and NDVI computation

The SPOT 5 HRG images were obtained at a preprocessing level (Level IA) at which radiometric and geometric corrections are required. The SPOT 5 images underwent radiometric correction by computing the reflectance at the Top of the Atmosphere (TOA) for each image, in order to account for the variation in the relative positions between the sun, the earth and the satellite (Updike and Comp, 2010).

Radiance $(L\lambda) = \frac{DN}{G} + B$ (Equation 4.1)

$$\rho = \frac{\pi L\lambda d^2}{Esun_{\lambda} \cos \theta_S}$$ (Equation 4.2)

Where ρ is the reflectance, Lλ is the spectral radiance at the sensor's aperture (W m^{-2} sr^{-1} μm^{-1}), d is the date corrected earth–sun length, Esunλ is the SPOT sensor- and band-specific equivalent solar irradiance (SPOT 5 HRG 2 band 2: Esunλ = 1575 W m^{-2} μm^{-1}, SPOT 5 HRG 2 band 3: Esunλ = 1047 W m^{-2} μm^{-1}), and θ s is the solar zenith angle.

Converting the Digital Numbers (DN) to Top of Atmosphere reflectance (ρ) is done using Equation 1 and 2 (Clark *et al.*, 2010). Radiance ($L\lambda$) values (expressed as W $m-2$ $sr-1\mu m-1$) were computed using Equation 4.1, with gain (G) and offset (B) values that are supplied in the image metadata. Then reflectance (ρ) values were computed for the two bands using Equation 4.2.

Geometric rectification of the imagery resamples the pixel grid; that is, it changes the pixel grid to fit that of a map projection or another reference image. To conform the pixel and remove any geometric distortions in the SPOT 5 imagery, the images were registered to a UTM (Universal Transverse Mercator) map projection (zone 35 South, datum WGS84) using a nearest neighbour resampling routine. The nearest neighbour resampling algorithm was utilised as it does not alter the digital number (DN) values in the output image, in comparison to resampling algorithms that utilise distance-weighted DN averages (Lillesand *et al.*, 2014). Based upon thirty-six ground control points collected from topographical map (1:50000) and field work using a hand-held global positioning system (GPS) with an accuracy of 4 m, a sub-pixel root mean square error was attained for each image.

NDVI (Normalized Difference Vegetation Index) was used to analyse the extent of reflectance in the near infrared (NIR) and red portions of the electromagnetic spectrum.

NDVI = (NIR – Red) / (NIR + Red) (Equation 4.3)

NDVI indicates values from –1.0 (no vegetation) to +1.0 (abundant vegetation). NDVI was computed using an in-built model within the ERDAS image processing software.

4.3.3 Subset of study area

In some cases, SPOT 5 HRG images are much larger than the study area. It is thus necessary to decrease the area of the image and only retain the area of interest. The decrease of image file is known as subsetting. It cuts out the preferred study area from the image scene into a smaller more manageable file (ERDAS, 1999).

In order to subset the study area, vector files defining the boundary of the study areas with the same georeferenced coordinates as the SPOT 5 HRG images (UTM zone 35 South, datum WGS84) was imported into ERDAS. The Land Redistribution for Agricultural Development (LRAD) Department provided the vector files.

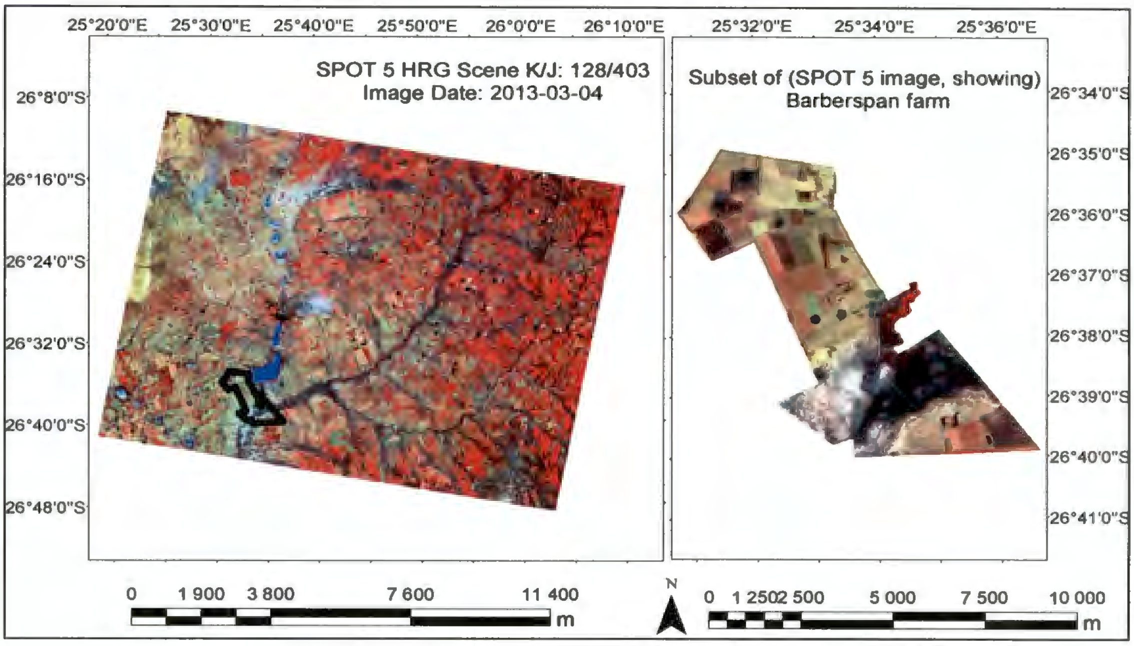


Figure 4.2: Subset of SPOT 5 imagery to focus on study area

The vector files were used to create an "Area of Interest" file and overlaid onto each of the SPOT 5 scenes. Figure 4.2 shows the subset of Barberspan farm SPOT 5 imagery.

4.3.4 Image classification

Image classification is described as the extraction of different classes or themes, land use and land cover classes from raw remotely sensed imagery (Lu and Weng, 2007). This study made use of hybrid classification as it uses both supervised and unsupervised methods to classify an image. With this combination, the output obtained is often more accurate than the individual classifications (Gonçalves, 2011).

Initially the images were classified each into seven classes by unsupervised classification using EDRAS Imagine software. Then supervised classification with the knowledge of topography and cluster-busting reduced the classes to five – cropland, dense woodland, sparse woodland, water and bare land. Training sites were located and circumscribed by polygonal boundaries as shown in Figure 4.3. For each class delineated, mean values and variances of the digital numbers (DNs) for each band used to classify are determined from all pixels within the site. The training points are proportionally distributed for each cover type using a 2014 topographical map (1:50000) and training sites taken from the field using a GPS. Training samples were collected from 30 points as signatures for each image for the supervised classification. A signature is a set of data that defines a training sample or cluster and corresponds to a class in a classification process (ERDAS Field guide, 2005). Signature classes were created using the signature editor of ERDAS, and this process was performed on all four images.

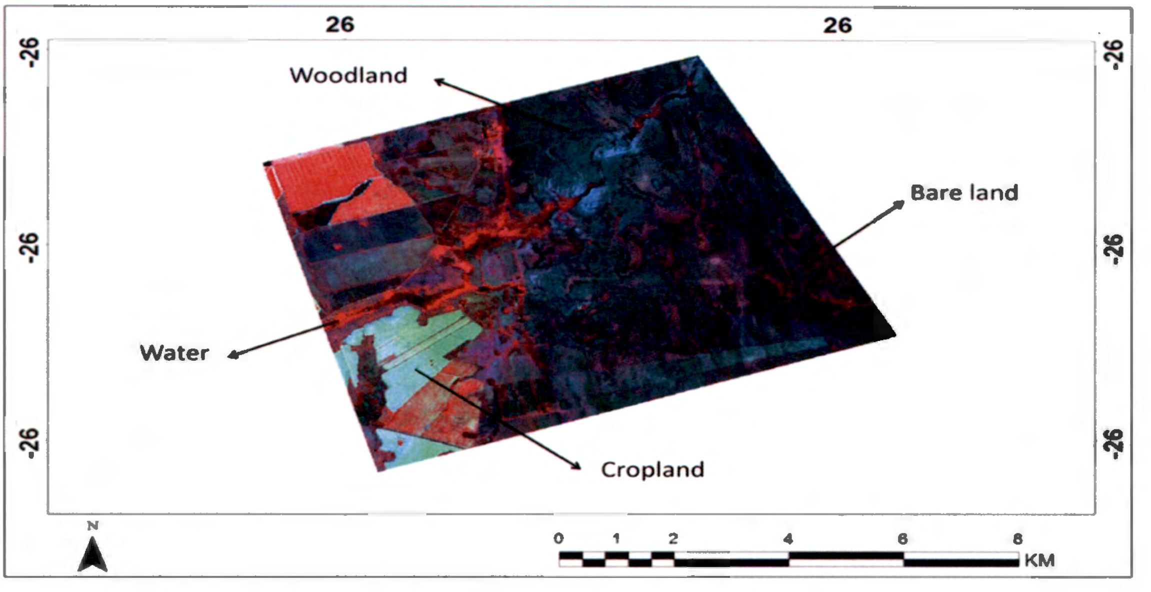


Figure 4.3: Classes on SPOT 5 HRG of Rietfontein farm

Following signature creation, the signature separability among the classes was assessed using a Transformed Divergence measurement and observed in a feature space plot. Signature separability calculates the spectral distance between two signatures or combination of bands used in a classification, allowing bands not suitable in a classification to be dismissed (Bourne and Graves, 2001). Transformed Divergence (TD) is commonly used to measure spectral separability. TD gives an exponentially decreasing weight to increasing distances between classes and scales the divergence values to lie between 0 and 2000 (Jensen, 1996). A TD value of 1500 or greater generally indicates an acceptable separability between classes (Haack, 2007). All the images showed good separability, with average and minimum separability measure of 2000 for three of the images (2013-03-04 Barberspan farm; 2013-03-15 former Pienaars Nature Reserve; 2013-02-17 Rietfontein farm) and an average of 1995 and minimum of 1985 for the fourth (2013-02-11 Antwerp farm). The low spectral measure in the fourth image is due to the NDVI being susceptible to the spectral influence of the soil in gaps between vegetation as the vegetation canopies in arid and semi-arid environments do not achieve complete coverage (Weiss *et al.*, 2004). A maximum likelihood classifier was applied to each image to define land cover classes into five classes using the signature with the best separability measure.

4.3.5 Post classification filtering

After classification, classified data usually has a salt-and-pepper appearance as a result of inherent spectral instability faced by the classifier when utilised on a pixel-by-pixel basis (Lillesand *et al.*, 2014). Applying a majority filter helps to "smooth" the classified output and only display the dominant classes. A majority filter involves a moving window passed through the classified data set to determine the majority classes within the window (Lillesand *et al.*, 2014). If the centre pixel in the window is not the majority class, its identity is changed to the majority class. If there is no majority class in the window, the identity of the centre pixel is not changed (Lillesand *et al.*, 2014). In this study, a 3*3 pixel majority filter was used to clean the classified images to the generalisation.

4.3.6 Classification accuracy assessment

Errors usually arise after classification of images. This is due to numerous elements such as the classification techniques used and methods of satellite data capture. Thus analysing the classification results is a necessary step in the classification process. An error matrix was used to evaluate the accuracy of an image classification and can also be used to refine the classification (Lu and Weng, 2007). The error matrix works by relating two sources of information: (i) pixels or polygons in a remote sensing-derived classification; and (ii) ground reference test information (Jensen, 2006). ERDAS Imagine Accuracy Assessment tool was used to conduct an accuracy assessment in this study. To assess the accuracy of each land-cover classification, a set of reference points were generated to compare their classification in the final thematic map. A total of 300 reference data points were generated for each year. The ERDAS Imagine Accuracy Assessment tool was used to select stratified random reference points; a minimum of fifty points were selected in each of the five land cover categories of interest. More than 250 reference pixels are needed to estimate the mean accuracy of a class to within plus or minus five percent (Congalton, 1991). Topographical map (1:50000) of 2014 and field work data using a hand-held global positioning system with an accuracy of 4 metres were used as a reference for the images. Visual interpretation of various features on the topographical map was done based on the shade, shape, size and location of the features.

Table 4.2: Error matrix for the classification of the Barberspan farm (2013-03-04)

		REFERENCE DATA					
		WO	C	WA	B	Total	User accuracy (%)
CLASSIFICATION DATA	WO	32	12	2	2	48	66.67
	C	8	128	0	4	140	91.43
	WA	0	5	13	0	18	72.22
	B	5	3	1	45	54	83.33
	Total	45	148	16	51	260	
Producer accuracy (%)		71.11	86.49	81.25	88.24		Overall accuracy = 83.85%
Overall Kappa Statistics = 0.7380							

Legend: WA-Water, C-Crop land, B-Bare land, WO-Woodland

Table 4.3: Error matrix for the classification of the former Pienaars Nature Reserve (2013-03-15)

		REFERENCE DATA			
		B	WO	Total	User accuracy (%)
CLASSIFICATION DATA	B	28	4	32	87.50
	WO	14	214	228	93.86
	Total	42	218	260	
Producer accuracy (%)		66.67	98.17		Overall accuracy = 93.08%
Overall Kappa Statistics = 0.7173					

Legend: WO-Woodland, B-Bare land,

Table 4.4: Error matrix for the classification of the Antwerp (2013-02-11)

		REFERENCE DATA				
		WO	WA	B	Total	User accuracy (%)
CLASSIFICATION DATA	WO	166	2	21	189	87.83
	WA	1	7	0	8	87.50
	B	8	0	55	63	87.30
	Total	175	9	76	260	
Producer accuracy (%)		94.86	77.78	72.37		**Overall accuracy = 87.69%**
Overall Kappa Statistics = 0.7195						

Legend: WA - Water, WO - Woodland, B - Bare land

Table 4.5: Error matrix for the classification of the Rietfontein (2013-02-17)

		REFERENCE DATA					
		WO	C	WA	B	Total	User accuracy (%)
CLASSIFICATION DATA	WO	138	4	0	6	148	93.24
	C	6	27	0	3	36	75.00
	WA	0	4	8	0	12	66.67
	B	4	3	0	57	64	89.06
	Total	148	38	0	66	260	
Producer accuracy (%)		71.05	62.50	100.0	86.36		**Overall accuracy = 88.46%**
Overall Kappa Statistics = 0.8050							

Legend: WA-Water, C-Crop land, B-Bare land, WO - Woodland

Tables 4.2, 4.3, 4.4 and 4.5 show the error matrices for the 4 sets of SPOT 5 images. The results show an accuracy of 83.85% for the Barberspan image, 93.08 % for FPNR, 87.69% for Antwerp and 88.46 % for Rietfontein image. The overall Kappa Statistics were 0.7380 for the Barberspan image, 0.7173 for FPNR, 0.7195 for Antwerp and 0.8050 for the Rietfontein image.

4.4 Field work and soil sampling

Field work was undertaken between March and May of 2014 to determine the location of representative sites for the main land-cover types in the image scenes and to collect soil samples. The land-cover types identified in the image scene were dense vegetation, cropland, built-up land, water, and bare soil. The GPS positions of sample sites representative of these land-cover types were recorded. The sites were selected so as to be widely distributed within the image scenes.

Soil sampling in this study was done during the late summer. The best time to collect soil samples for fall-seeded crops (e.g. cereals and grains) is when the field is idle, and in the summer works well (FAO, 2007). Soil auger bores were drilled to 1 m depth (or to bedrock), sampling to 1 m soil profile depth is satisfactory for most soils (Soil Survey Division Staff, 1993). Samples were taken from the auger bores to determine physical and chemical parameters related to soil classification. The soil classification was carried out according to the guidelines edited by FAO (2007) such as profile description, texture and parent material information. Sample locations were on a systematic grid. Sampling on a grid is often used because it provides an even cover of values and minimizes the maximum estimation variance (or error) for a given grid interval and it is efficient for sample collection in the field (Goovaerts and Kerry, 2010).

4.5 Soil sample interpolation

Geostatistical interpolation using the Kriging technique was used to estimate continuous properties within the sampled locations using the Geostatistical extension of ArcGIS. Kriging depends upon a semivariogram which considers spatial relationship and distance. The semivariogram ϒ (h) is described in Equation 4.4 (Kerry *et al.*, 2010).

$$\Upsilon\,(h) = \frac{1}{2\,N\,(h)} \sum_{i=1}^{N\,(h)} [z\,(xi) - z\,(xi + h)]2 \qquad \text{(Equation 4.4)}$$

Where Z(*xi*) is the computed value of the soil feature at a site *xi*, ϒ(h) is the semivariogram for a lag distance h between observations Z(*xi*) and Z(*xi* +*h*), and N(*h*) is the number of data pairs divided by a lag distance equal to *h*.

The interpolation predictions from Kriging are relatively accurate compared to other interpolation techniques like Inverse Distance Weighting (Gotway *et al.*, 1996). Ordinary Kriging is used in this research because it has remarkable flexibility to handle different types of trends in the mean (Leuangthong *et al.,* 2008). Ordinary kriging can also use either semivariograms or covariances, use transformations and allow for measurement error.

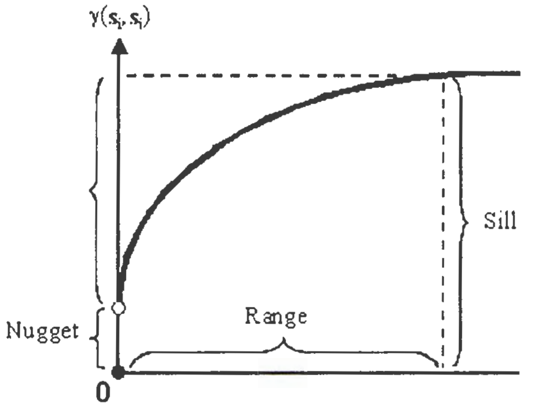


Figure 4.4: A theoretical semivariogram and its characteristics (Source: ESRI)

Figure 4.4 shows the theoretical semivariogram and its characteristics. The range is a certain distance where the model begins to flatten or level out and signifies a distance where there is no autocorrelation between properties. The sill is the value on the y-axis that the semivariogram model reaches at the range. Generally, the semivariogram value at the beginning is zero, but if it is considerably different from zero for lags very near to zero, then this semivariogram value is known as the nugget. For instance, if the semivariogram model intercepts the vertical axis at 0.5, then the nugget is 0.5. The nugget effect is usually due to miscalculations or spatial sources of variation at lengths lesser than the sampling interval or both (Gholam *et al.*, 2011).

4.6 Laboratory analysis of soil samples

4.6.1 Soil texture

The Wentworth grade scale is commonly used for soil particle size distribution analysis and this is shown in Table 4.6, together with the grade names and lithified equivalents (Selley, 2000). A common variation of the Wentworth scale is the phi (Φ) scale proposed by Krumbein (1934): $\Phi = -\log_2 d$ - where d is the diameter.

The particle size distribution of a soil sample can be determined by sieve analysis, in sieve analysis the soil sample is separated by the sieves with different aperture size.

4.6.1.1 Procedure for coarse sediment analysis

Samples of sediments were first dried for 24hrs at 60°C and mass of the sample was then recorded. The sieve stack was set up from coarsest to finest and sediments shaken gently for an average of 10 minutes. Lastly, each sieve was removed separately and the mass of sediment retained in each sieve recorded

The following can be obtained from the masses of sediment in each sieve:

- The percentage dry mass (of the total mass) for each sieve.
- The cumulative percentage retained in the sieves, working from coarse to fine.
- A line graph, plotting the cumulative percentage retained verses sieve size phi units.

In addition, the following descriptive statistics was calculated from information that can be read from the cumulative percentage graph:

Phi median: Value which divides the distribution into two equal halves: Φ50 (phi value at 50%)

Phi mean: The Phi mean (Φ) represents the average grain size (Table 4.6), where 75, 50, and 25 represent the size at 75, 50, and 25 percent of the sample by weight

$$\bar{\phi} = \frac{\phi 75 + \phi 50 + \phi 25}{3} \qquad \text{(Equation 4.5)}$$

Phi skewness: A non-regular spreading is made by the dissimilarity between the median and the mean. The irregularity is known as skewness.

$$\text{skewness} = \frac{(\phi 84 - \phi 50)}{(\phi 84 - \phi 16)} - \frac{(\phi 50 - \phi 10)}{(\phi 90 - \phi 10)} \qquad \text{(Equation 4.6)}$$

4.6.2 Soil pH

Soil pH was calculated using the potentiometric method. Soil suspension was done with purified water in 1:1 ratio. The pH was then measured using a Lamotte 1741 pH Tracer meter.

The measuring tool was a voltmeter and is usually graduated in pH units and has sensitivity such that discrimination of at least 0.05 pH units or at least 0.003 V may be achieved (European Pharmacopoeia, 2002). The Tracer can be calibrated at 1, 2 or 3 points. The device was standardised with a buffer mixture of potassium hydrogen phthalate (primary standard).

Table 4.6: Phi values

Values from	To	Equal
$-\infty$	$-\Phi$	Gravel
-1	0Φ	very coarse sand
0	1Φ	coarse sand
1	2Φ	medium sand
2	3Φ	fine sand
3	4Φ	very fine sand
4	8Φ	Silt
8	$\infty\ \Phi$	Clay

4.6.3 Organic Matter

Grahm colorimetric method was used to measure organic matter in the soil. The method comprised oxidising of readily oxidisable soil organic matter using potassium dichromate solution (K2Cr2O7) and measurement of reduced chromium ion calorimetrically. The reaction between carbon and $K_2Cr_2O_7$ which occurs in sulphuric (H_2SO_4) solution is represented by equation 4.7:

$$3C + 2Cr_2O_7^{2-} + 16H^+ \longrightarrow 3CO_2 + 4Cr^{3+} + 8H_2O \qquad \text{(Equation 4.7)}$$

A soil sample was added in a flask to a potassium dichromate solution where it was swirled and allowed to stand for 30 minutes for settling of soil particles. 20 ml of sulphuric acid was added, a 100 ml of tap water was also added to the flask and a measure of sodium fluoride powder, shaken until dissolved. A pipet was used to add 10 drops of diphenylamine indicator and swirled until the colour changed from dark brown through blue to a deep green; the colour was matched with organic matter endpoint colour standard.

Table 4.7: Size grades of sedimentary particles

Phi size	Millimetres (mm)	Micrometres (µm)	Wentworth Grade	
-6.0	64	64000	Cobbles	
				------ 60.0mm ------
-5.5	44.8	44800		
-5.0	32	32000	Coarse gravel	
-4.5	22.4	22400		
				------ 20.0mm ------
-4.0	16	16000		
-3.5	11.2	11200	Medium gravel	
-3.0	8	8000		
				------- 6.0mm -------
-2.5	5.6	5600		
-2.0	4	4000		
-1.5	2.8	2800	Fine gravel	
-1.0	2	2000		
				------- 2.0mm -------
-0.5	1.4	1400		
0.0	1	1000	Coarse sand	
0.5	0.71	710		
				------- 0.6mm -------
1.0	0.5	500		
1.5	0.355	355	Medium sand	
2.0	0.25	250		
				------- 0.2mm -------
2.5	0.18	180		
3.0	0.125	125		
3.5	0.090	90	Fine sand	
4.0	0.063	63		
				------ 0.06mm ------
4.5	0.045	45		
5.0	0.032	32	Coarse silt	
5.5	0.023	23		
				------ 0.02mm ------
6.0	0.016	16		
6.5	0.011	11.0	Medium silt	
7.0	0.008	8.0		
				----- 0.006mm -----
7.5	0.0055	5.5		
8.0	0.004	4.0	Fine silt	
8.5	0.00275	2.75		
				----- 0.002mm -----
9.0	0.002	2.0		
9.5	0.00138	1.38	Clay	
10.0	0.001	1.0		

Table 4.8: Conditions required for maize

Maize	Capable	Moderate	Incapable
Texture	Sandy	Clay - clay loam	Silty clay
pH	6.5 -7.5	5 to 6	<4.5
Drainage	Good	Moderately well	Imperfectly drained
Clay (%)	>30	30-Oct	<10
Depth (cm)	>100	80 – 100	<80
Temp (°C)	19 -25	25 – 32	>32
Rainfall (mm)	500 to 750	350 to 450	<350

4.7 Selection of promising crops

Promising crops were selected based on existing cropping systems, social acceptance of crops and economic status of the society, and from farmers' long experience.

Table 4.9: Conditions required for sorghum

Sorghum	Capable	Moderate	Incapable
Texture	Clay	Loam	Sandy
pH	5.5 - 7.5	7.5 - 8.5	<4.5
Drainage	Well drained	Moderately well	Imperfectly drained
Clay (%)	10% - 20	10% - 30	>30
Depth (cm)	>100	80 – 100	<80
Temp (°C)	27 – 30	7 - 10 °C	<7
Rainfall (mm)	300 - 750	200 – 300	<200

Summer field crops are better suited for the North West Province climatic conditions. Maize has the largest crop size, followed by sunflower, sorghum and groundnuts (DAFF (a), 2010).

Table 4.10: Conditions required for sunflower

Sunflower	Capable	Moderate	Incapable
Texture	Sandy loam	Clay - clay loam	Silty clay
Ph	6.0 - 7.0	7.0 - 7.5	<5
Drainage	Good	Moderately well	Imperfectly drained
Clay (%)	15 – 30	30 – 55	>55
Depth (cm)	>100	80 – 100	<80
Temp (°C)	23 – 28	14 -21	<5
Rainfall (mm)	500 - 1000	400 – 500	<400

Knowledge on the growth conditions of maize, sorghum and sunflower were obtained from local researchers and in combination with information from the literature (Department of Agriculture, Forestry and Fisheries, 2010). The information resulted in the construction of climatic and soil requirements tables (Table 4.8, 4.9 and 4.10).

4.8 Evaluation of topographic features

Topographic features such as elevation, slope, aspect and orientation are important factors of land evaluation (Ebrahim, 2007). Topographic features can also impact on soil properties and soil erosion hazard. Evaluation of topographic features and attributes is necessary in land evaluation, and the topographic evaluation in these study areas was based on Digital Elevation Model (DEM).

In terms of agricultural planning, the slope is classified as 0-4%, 4-8%, 8-12%, 12-16%, 16-20% and greater than 20% in order to determine the best slopes for agriculture (Ebrahim, 2007). Table 4.11 shows slope classification as percentages into 6 equal intervals, these are derived from the Soil Conservation Act Recommendations (FAO, 1985). The FAO

Framework for Land Evaluation (2006) land capability classes was used to correlate the slope classes in Table 4.11 to the land capability of the study areas.

Table 4.11: Slope classification

Slope %	Classification	Description	Land Use
0-4%	S1	Highly capable	Crops
4-8%	S2	Capable	Crops
8-12%	S3	Moderately capable	Crops
>12%	N1	Limited capability	Pastures and trees

4.9 Climatic data

4.9.1 Mean

Statistical analysis is one of the approaches for presenting the data in a simplified and understandable form. In this study the mean was used to average rainfall and temperature data between October and April of each year from1983 to 2013. A 30 year period was used, as it is long enough to filter out any inter-annual variation or anomalies, but also short enough to be able to show longer climatic trends (Davenport, 2014). Basic statistical techniques used here for computation of rainfall and temperature included mean, standard deviation and standardisation.

The mean is usually denoted by $(\overline{X})$. The statistical formula used to calculate the mean is:

$$\overline{X} = \frac{\sum x_i}{n} \qquad \text{(Equation 4.9)}$$

Where:

$\overline{X}$= Historical mean, x_i= Individual data point, n = Number of values

North West Province has a unimodal rainy season centred in January. Rainfall generally starts in October and ends in April of the subsequent year. Numerous studies (Kabanda, 2004; Makarau, 1995; Preston-Whyte and Tyson, 1988) have identified unimodal characteristics of summer rainfall in southern Africa rainfall.

4.9.2 Standard deviation

The standard deviation is computed using the following formula:

$$\sigma = \sqrt{\frac{\Sigma(x-x_i)^2}{n-1}} \quad \text{(Equation 4.10)}$$

Where:

σ = Standard deviation, Σ = Sum

x = Mean , x_i = Individual data point

n = Number of values

4.9.3 Standardisation

Standardisation (Z) of the data was calculated using mean and standard deviation. The mean was subtracted from every data point (x_i) value to locate the distribution of data at zero mean value (normalisation).

Standardized formula:

$$Z = (x_i - x) / \sigma \quad \text{(Equation 4.11)}$$

Where:

Z = standardised anomaly index

x_i= individuals data points

σ = historical sample standard deviation.

x = historical sample mean

The (xi -x) values were then divided by the standard deviation (σ) to obtain (Z) (Equation 4.11). Standardisation of data results in anomalies above and below the normal (zero mark).

4.10 Crop water requirement analysis (CWR)

The amount of water required to compensate for the evapotranspiration loss from the cropped field is defined as the crop water requirements (FAO, 2006). Equation 4.12 shows the CWR for the crop evapotranspiration under standard conditions i.e. no restrictions are placed on crop development like lack of water or diseases.

$$ETcrop = Kc \times ETo \quad \text{(Equation 4.12)}$$

Where:

ETcrop = crop evapotranspiration in mm/day

Kc = crop coefficient, dimensionless

ETo = potential crop evapotranspiration in mm/day

Calculation of the crop water requirement was carried out in the CROPWAT model that integrates climatic datasets, soil data and crop planting dates. CROPWAT is a decision support tool established by the Land and Water Development Division of FAO, and was used in this study for calculation of crop water requirements. It can provide suggestions for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the evaluation of production under rain fed conditions or deficit irrigation (Saravanan and Saravanan, 2014). The input climatic data required by the model includes monthly temperature (maximum and minimum), relative humidity and sunshine hours.

The crop data input includes the length of initial, development, mid-season and late-season crop growth stages, crop coefficient values for these four stages, and planting date. The algorithm for the measurement of CWR in the model is based on approximation of the probable evapotranspiration (ETo) by means of Penman Montieth equation and the crop factors. The equation uses standard 30 years of climatological records of air temperature, solar radiation (sunshine), humidity and wind speed for the current ETo. It was used in this study on the basis of acceptable performance under variable conditions throughout different locations in the world (Diakhate, 2014; Iyanda *et al.,* 2014; Adeniran *et al.,* 2010).

4.11 Capability evaluation procedure

The Spatial Analyst function in ArcGIS was used to generate thematic maps of textural class, soil depth, drainage condition and clay percentage. The Weighted Sum technique was used to overlay several thematic maps using weights (see Figure 4.5) to create a final land capability map. The land capability classes were defined using the rating method after FAO (2006).

Each one of the classes of thematic layers for texture class, soil depth, pH and clay percentage was categorised into (i) good, (ii) fair, (iii) moderate, (iv) average, (v) poor and (vi) not capable with respect to land capability for agricultural purposes. Capability weights were given to each thematic layer after considering their characteristics.

Table 4.12: Weights assigned to factors for sorghum.

Factors	Classes	Ratings	Agricultural land capability
Land use/land cover (weight=0.2)	Water Agriculture land Bare land Wood land	2 10 8 10	Not capable Good Fair Good
Slope (weight=0.1)	0-4% 4-8% 8-12% >12%	10 8 4 2	Good Fair Poor Not capable
Depth (weight=0.2)	>100 cm 80-100 cm <80	10 8 4	Good Fair Poor
pH (weight=0.2)	5.5-7.5 7.5-8.5 <4.5	10 8 4	Good Fair Poor
Texture (weight=0.2)	Clay loam Sandy loam Clay (light) Sandy clay loam Sandy	10 2 10 4 2	Good Not capable Good Poor Not capable
Clay (weight=0.05)	10-20% 20-30% >30%	10 8 6	Good Fair Moderate
Drainage (weight=0.05)	Well drained Moderately drained Imperfectly drained	10 8 4	Good Fair Poor

Below is the equation used in a GIS for the evaluation of agricultural land capability:

$$LSP = 0.2(LU)i=1\text{-}4 + 0.1(SL)i=1\text{-}4 + 0.2(D)i=1\text{-}3 + 0.2(T)i=1\text{-}5 + 0.2(pH)i=1\text{-}312 + 0.05(C)i=1\text{-}3 + 0.05(DR)i=1\text{-}3 \quad \text{(Equation 4.13)}$$

Where: LSP is the numerical index of the land capability, LU is the land use/land cover variable (with classes 1–4), SL indicates slope on (with classes 1–4), D indicates depth factor (with classes 1–3), pH indicates soil pH (with classes 1–3), T indicates texture (with classes 1–5), C indicates clay percentage (classes 1–3) and DR indicates drainage (with classes 1–3).

Weight allocation was determined with reference to expert opinion and the Department of Agriculture literature. The Weighted Sum technique in ArcGIS was used to carry out the overlay of all the factors. In this technique, the total weights of the final integrated polygons are derived as sums or products of the weights assigned to the different layers, according to their capability. Input factors favouring agriculture were changed from descriptive form into agricultural land capability ratings to allow for the calculation and other mathematical processes in GIS analysis. Also because these factors have different value scales and not all of them are equally important.

The influence of factors on agricultural land capability was arranged in the following order: pH, soil depth, soil texture, clay percentage, drainage, land use/land cover and slope. The different classes within the factors were given capability ratings where a greater rating specifies that the effect of the factor was great for agriculture. Various classes of each factor were placed into any one of the categories, and suitable weights were assigned based on the relative importance and shortcomings with respect to land capability for agriculture, shown in Table 4.12. An agriculture land capability map is then finally generated.

4.12 Summary

This chapter outlined the materials and equipment used and gave a detailed explanation of the various steps used to execute the land capability study. It discussed the software ArcGIS and ERDAS used for image processing and for producing thematic maps. Laboratory analysis of soil samples used in this study was discussed, as soil testing is an excellent way to assess soil productivity, and it offers valuable information for developing a comprehensive fertility database. Lastly, a capability evaluation procedure was discussed that helps to finally produce an agricultural land capability maps for each study area.

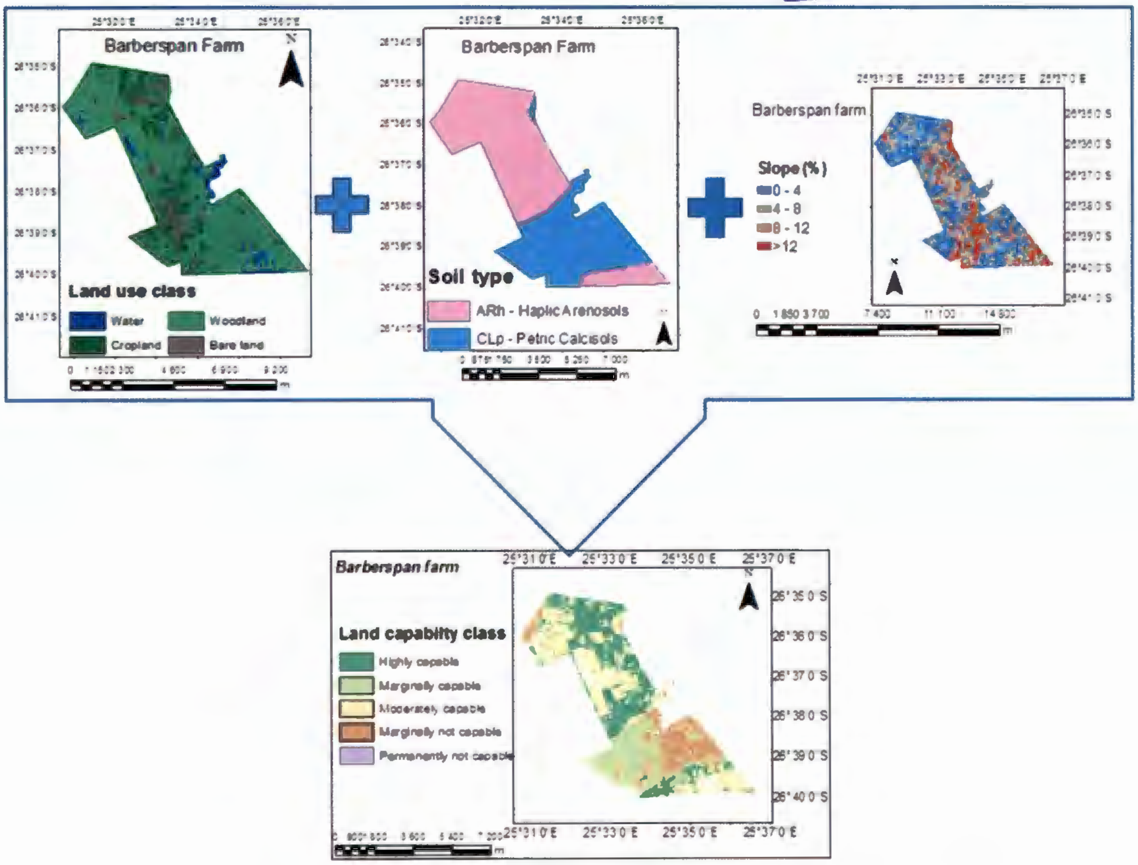


Figure 4.5: Pictorial representation combining land use class, soil and slope thematic maps into an overall agricultural land capability map.

Chapter Five

Spatial analysis on land capability for agriculture

5.1 Introduction

This chapter describes the development of a database that could be produced in similar geographic areas of South Africa. A database of spatial and non- spatial data helps to reproduce thematic layers to be overlaid and develop a land capability map for agriculture.

The land information database for communal areas in North West Province to be used for land evaluation is important as it can be used by a variety of participants such as farmers and environmental officials. Due to the complexity and time consuming of land capability studies, reliable land information to all its users need to be supplied at an affordable cost and at real time. This chapter considered the first three objectives of the study.

5.2 Preparation of land information (LI) database

Well-structured land information is necessary to deliver informed decisions on land use. Building a LI database for an area allows for tracking of progress and essential conservation goals. A LI system is an in-built component of a GIS. This has a tremendous impact on result output. LI system requires gathering, storing, managing and examining the land data. Spatial and non-spatial data are critical in LI system; GIS allows for easier interaction of spatial and non-spatial data (Dale and McLaren, 2005). Incorporating data from a variety of fields such as physical, social and economic of a region in a capability study allows for better results.

Comprehensive, relevant and accurate information should be provided by the land information database (Manakos and Braun, 2014), and its development is essential to evaluate accurately the evolution of environment over time. This can be done through prediction and analysis in models to encourage sustainable land use through better resource management. The database should be dependable and allow for retrieving and updating of figures. Examples of spatial data in this study include land use, soil properties and climate, while non-spatial data include agricultural statistics. The spatial data can either be in a vector or raster format and involves identifying the projection, co-ordinates and map scale to be consistent.

A vector data model represents features of the world such as land parcels using points, lines, and polygons. Raster data model symbolizes real-world phenomena as a set of cells arranged in rows and columns, with each cell storing a single value. Values can be continuous such as elevation models, discrete such as land use types or null, if no data is available. A land information database makes it possible to build an immediate, accurate, easy-to-use model for land evaluation (Baniya, 2008).

5.2.1 Generation of land mapping units

The present study used both raster and vector data models for land mapping units as physical features to produce a final land capability thematic map. A thematic map is made up of data distributed spatially in the units of the map itself and these units make up the land mapping unit (LMU). A land mapping unit is a mapped area of land with specified characteristics (Baniya, 2008; FAO, 2006; Loveland *et al*., 1995). From the farming perspective, each LMU is more appropriate for particular varieties of crops in the current land management circumstance (Baniya, 2008). Soil features such as soil type, texture, depth and fertility are examples of individual entities of an area within each LMU. A land unit survey allows effective survey of land features for land evaluation.

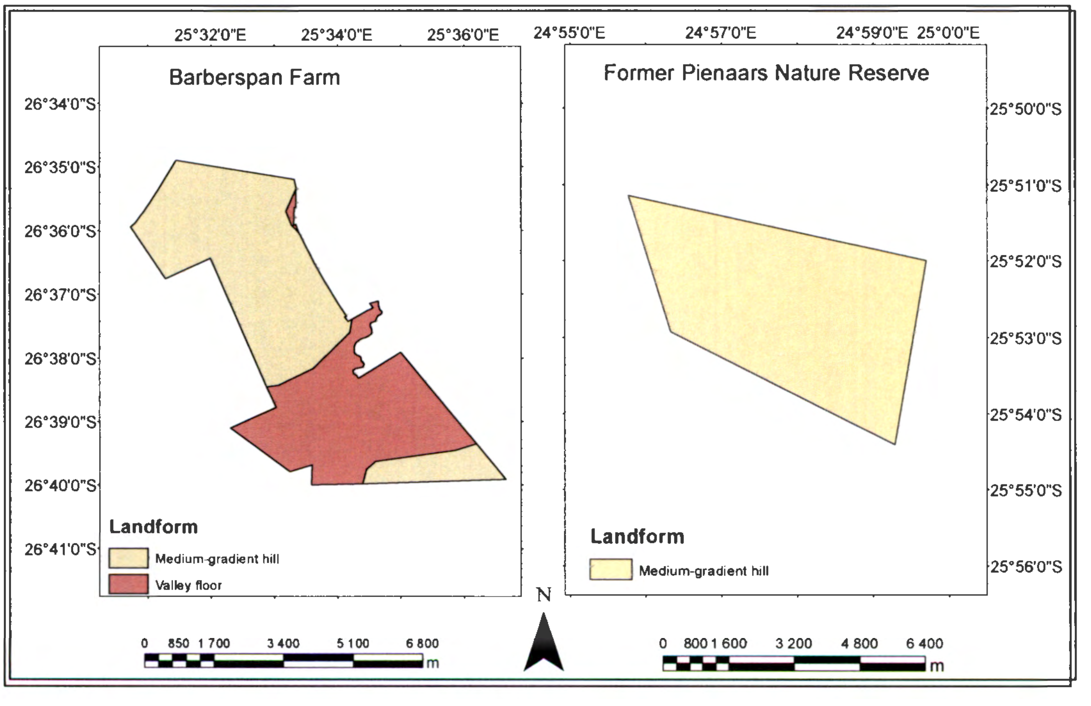


Figure 5.1: Landform classes of Barberspan farm and Former Pienaars Nature Reserve

As land features are the foundation of the evaluation process, landform and soil type carry more weight in LMU.

Factors considered in demarcating LMU (Baniya, 2008; FAO, 2006):

a. LMUs should be drawn with precise boundaries.

b. LMUs should be based on characteristics important for the type of crops to be considered.

c. LMUs should be established on characteristics and considering the land's capacity.

d. LMUs should be constant, so that they can be used for an extensive period for the evaluation of land capability.

Table 5.1: Legend of the physiographic characteristics of the studied areas

	Landscape	**Lithology**	**Relief**	**Land forms**	**Vegetation**	**Map unit**
FPNR	Plain (LP)	Shale (1)	Flat to gently undulating (1)	Mountainous highland (1)	Grassland to Thornveld	LP111
				Medium-gradient hill (2)		LP112
		Andesite, trachyte phonolite (2)		Medium-gradient hill (2)		LP212
Rietfontein	Plain (LP)	Andesite, trachyte phonolite (1)	Flat to gently undulating (1)	Medium-gradient hill (1)	Grassland	LP111
				Low-gradient footslope (2)		LP113
	Water bodies					
Barberspan	Plain (LP)	Andesite, trachyte phonolite (1)	Flat (1)	Medium-gradient hill (1)	Grassland	LP111
	Valley floor (LV)	Andesite, trachyte phonolite (1)	Flat (1)	Dried lake bed (1)	Grassland	LV111
	Water bodies					
Antwerp	Plain (LP)	Eolian unconsolidated rock (1)	Flat (1)	Medium-gradient hill (1)	Bushveld	LP111

Demarcation of the land mapping units within each study site is very important before conducting a soil survey. After classification (chapter 4), the rectified SPOT imagery was used as the primary base for the compilation of vegetation cover map. Topographical maps and the SOTER database also assisted in delineating land units based on topography, landforms and vegetation cover type.

Using Figure 5.1 and Table 1, LMU's were visited to conduct soil survey based on prominent biophysical features in the area. The quality of the land mapping unit is heavily reliant on the data available to be used to build a map. LMU method allows substantial liberty in the way in which the many land features are combined. Table 5.1 shows the physiographic characteristics of the studied areas.

The current study gathered up digital information from sources such as CROPWAT and SOTERSAF (Soil and Terrain Digital Database for Southern Africa). SOTER provides supplementary data on grander soil group diversity and land units. Combining the different land units with their identical attribute characteristics was performed and all the data produced eventually used to generate thematic maps. Topography is also very significant in demarcating land units within the study sites as most of the land attributes such as soil are influenced by the topographic element through the amount and intensity of solar radiation to which a location is exposed and consequently the temperature regime. Thus the physiographic detail of a study area is a controlling process of land unit building and this study recognised agro-ecological sub-areas as these are relatively consistent in natural and ecological conditions especially for cultivation, forestry, etc. (FAO, 2006).

5.3 Geostatistical analysis

In many instances it may be necessary to model a feature as a continuous surface but due to availability of only finite number of data values, it becomes necessary to interpolate (i.e. estimate) the values using the dominant points. Most interpolation methods are divided into global and local. Global interpolation method apply a single function to all the points in a study area, while local interpolation techniques apply the same function repeatedly to a small portion of the total set of sample points and then construct a surface by linking these regional observations together (Markus, 2010). Kriging is a certain type of local interpolation that uses advanced geostatistical techniques. Geostatistical interpolation using the Kriging technique is used to estimate continuous properties within the sampled locations in the study area using the Geostatistical extension of ArcGIS. A semivariogram function is based on the assumption that features nearby tend to be more similar than features that are farther apart. Geostatistical analysis of the sampled soil properties display a parabolic behaviour which shows that variability increases very slowly with distance. This can be seen in Figure 5.2, which shows the anatomy of a typical semivariogram; this example comes from Rietfontein farm where soil properties exhibited spatial dependency.

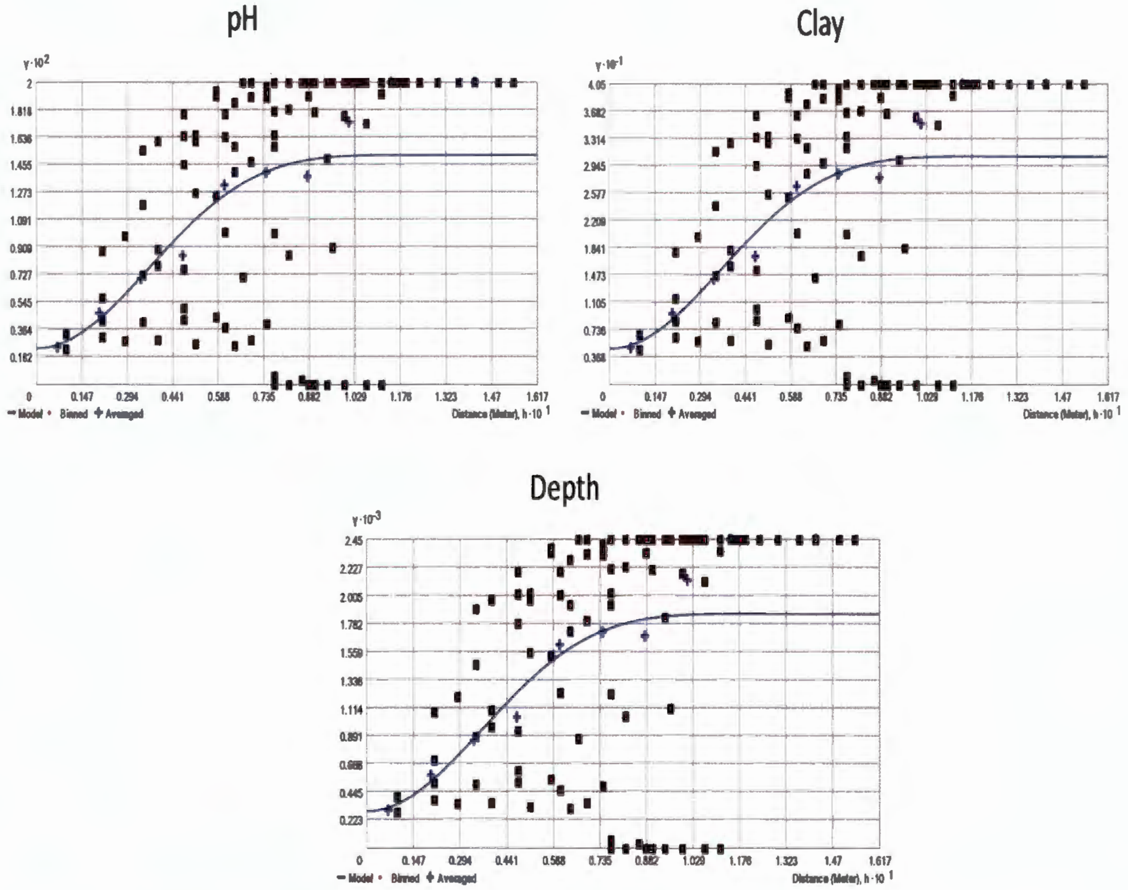


Figure 5.2: Semivariograms of pH, clay and depth in Rietfontein farm.

All the model variograms in Figure 5.2 exhibit large positive nugget values which are attributable to short scale variability between sampling points. The proportion of nugget to sill is used as a measure to categorise the spatial dependency of soil properties. According to Zhang (2002), a variable is considered to have strong spatial dependency if the ratio is less than 25%, moderate dependency if the ratio is between 25% and 75%, and weak dependency otherwise. The proportions of nugget to sill for soil properties in Rietfontein farm and other study sites were below 25%, with pH and clay content having 15% and soil depth at 14%. This research provides very useful information on the structure of the variability and the spatial dependence of soil properties even in a relatively small study area. The clay property in Barberspan farm (Figure 5.3) has nugget to sill ratio of 37% indicating that there is a moderate spatial dependence.

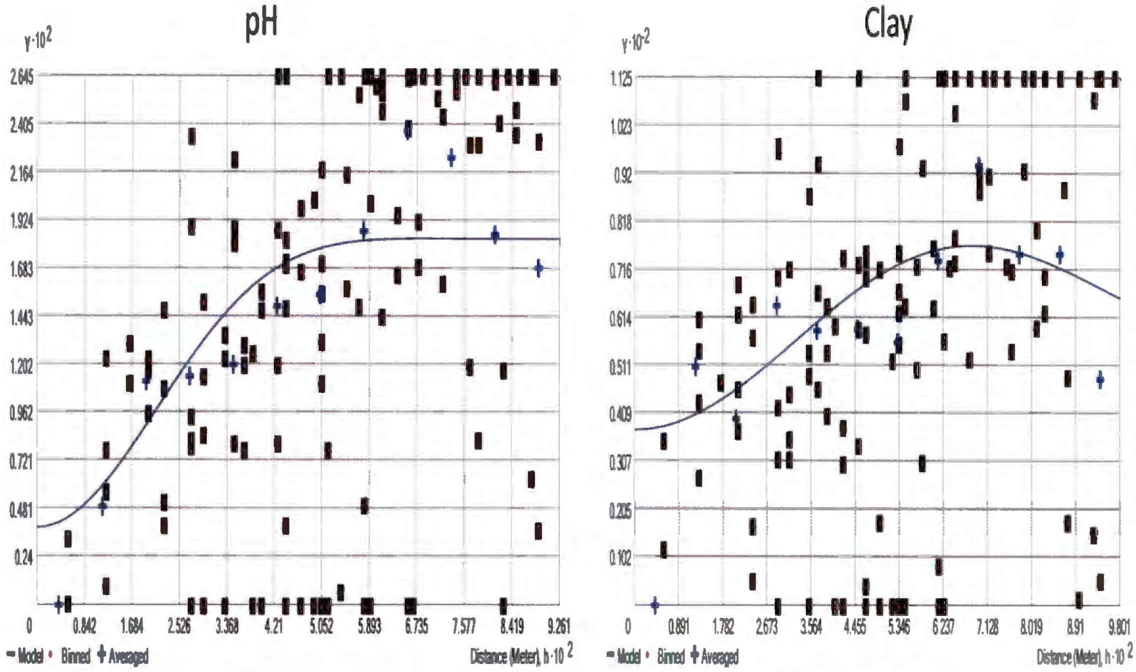


Figure 5.3: Semivariograms of pH and clay and depth in Barberspan farm.

These graphs show the existence of a highly homogeneous structure in distribution of these soil properties. It could be influenced by spatial distribution of vegetation cover which is consistent through many farms in the study. Analysis of spatial dependence of soil properties shows an isotropic behaviour, which might be caused by a low variability of soil formation factors (Gholam *et al.*, 2011). The variogram reveals the presence of spatial autocorrelation (Figure 5.2 and 5.3).

Goovaerts (1994) found a significant resemblance between the characteristics of semivariograms for eight soil chemical properties and six banana leaf contents calculated over a 100 km^2 site, he associated this common spatial pattern to the geographical spreading of soil types in the site.

In each of the study areas, pH values vary more continuously compared to other properties as shown by the smaller nugget effect and larger range of the resultant semivariogram. A discontinuity of the semivariogram at the origin is called the nugget effect and assumes that the difference between a sampled value and a potential repeat sample at the same location is actually zero (Samal, 2007). Soil properties show strong spatial variability, which highlights the need for soil sampling in every region of a site. Longstanding field management histories should be known, as even the same farming practices affect both spatial distribution and the level of spatial dependency of soil properties (Emadi *et al.,* 2010). Strong spatial dependency of soil variables may be caused by intrinsic variations in the soil characteristics (Cambardella *et al*., 1994). The results in Barberspan farm suggest that extrinsic factors such as the grass cover and drainage are important factors affecting the strong spatial dependency of soil properties.

5.4 Land information database

5.4.1 Accuracy assessment

Evaluation of classification outcomes is necessary after classification procedure. An error matrix was used to assess the classification outcomes as it is widely used for evaluating per-pixel classification (Congalton and Green, 1999). The accuracy was assessed with cross-examining against reference data such digital aerial photo maps, topographic maps and Google Earth images to create confusion matrices (Tables 4.2, 4.3, 4.4 and 4.5) for the four study sites. The resulting SPOT 5 land use/cover maps of the four sites had an overall map accuracy of 88.46% (Rietfontein), 87.69% (Antwerp), 93.08% (Former Pienaars Nature Reserve) and 83.85% (Barberspan farm). User's accuracy of individual classes ranged from 66% to 94% and producer's accuracy ranged from 63% to 100%. Kappa statistics were calculated for each classified map to calculate the accuracy of the results. Kappa values are categorised into three classes: a value higher than 0.80 signifies strong agreement, a value between 0.40 and 0.80 (40% to 80%) signifies moderate agreement and a value below 0.40 (40%) signifies poor agreement (Congalton, 1991). The overall Kappa Statistics were 0.80 (Rietfontein), 0.72 (Antwerp), 0.72 (Former Pienaars Nature Reserve) and 0.74 (Barberspan farm), showing strong agreement between the classified map and the ground reference information.

Crop land had good producer accuracy with values of 91.3 (Barberspan farm) and 75.0 (Rietfontein). This is possibly due to images being acquired during the wet season (February/March), eliminating spectral confusion predominantly between crop land and bare land.

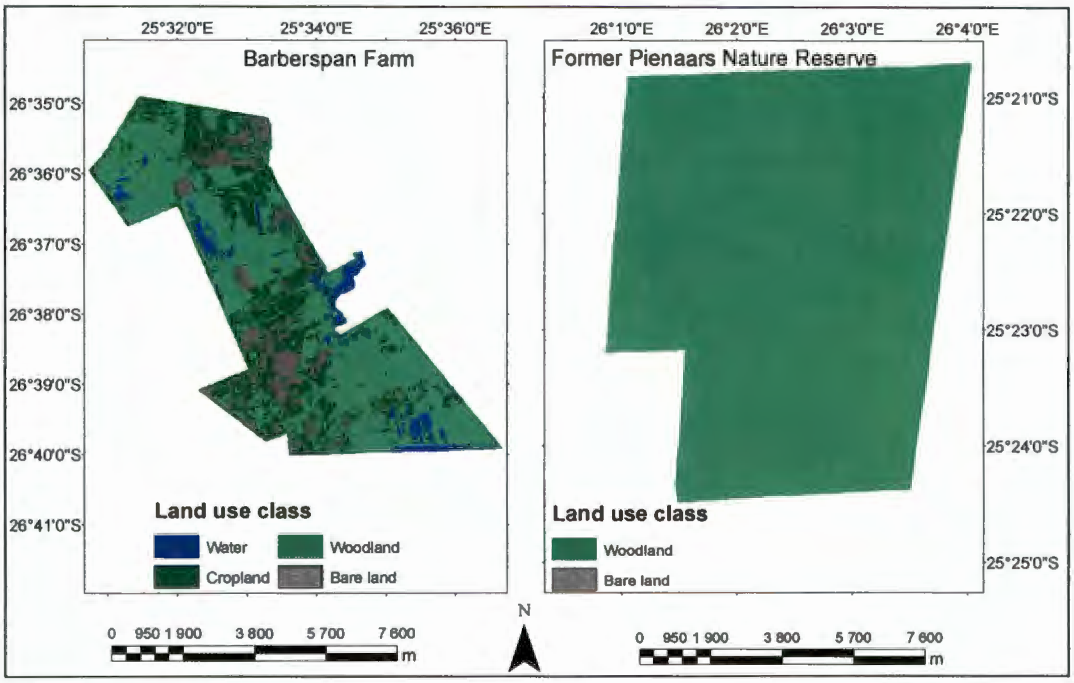


Figure 5.4: Land use classes of Barberspan farm and former Pienaars Nature Reserve

5.4.2 Land use structure

Barberspan farm, shown in figure 5.4, covers an area of 37.2 km^2, with woodland occupying almost half of that (48.7%). Cropland is the next largest class with 29.7% while bare land and water body occupies 15.1% and 6.5% respectively.

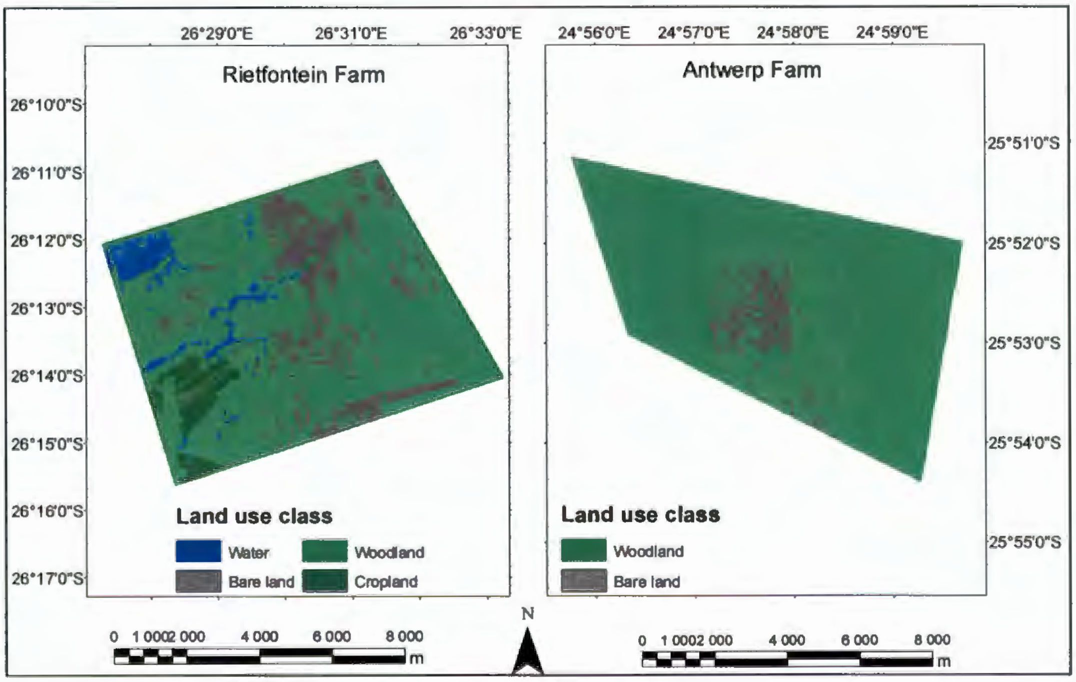


Figure 5.5: Land use classes of Rietfontein and Antwerp farm

Most of the surrounding farms are cultivated for summer crops, such as maize, sunflowers and groundnuts. The area is characterised by open savannah vegetation, prominently of Acacia species. The former Pienaars Nature Reserve (FPNR) covers an area of 29.8 km^2; the landscape is dominated by vegetation cover (92.7%) whilst bare land makes up 7.4%. The FPNR remains largely uninhabited, and a 2011 census recorded just three households, although surrounding communities do graze their livestock within FPNR (STATSA, 2012). Rietfontein farm covers an area of 53 km^2, with woodland accounting for 65.1% of the farm. Bare land covers 23.5% whilst cropland and water account for 5.3% and 6.2% respectively. Rietfontein farm is located in Lichtenburg, which forms the western corner of South Africa's 'maize triangle' and is the country's main maize growing region (FAO, 2012). The area also produces vast amounts of crops such as groundnuts and sunflower seeds. Antwerp farm consists of 88.4% of woodland and 11.6% is bare land (Figure 5.5).

5.5 Physical properties

5.5.1 Soil types

Soils in the study sites were classified according to soil classification methods from the FAO (2006) classification system. The study sites accounts for six major soil groups (Table 5.2). Distribution patterns of the soil groups are associated with the physiography of the valley and they are radially distributed.

Table 5.2: Soil types in the study areas

Soil Types	Count	% of land
Eutric Leptosols	1	72.8
Haplic Lixisols	1	27.2
Haplic Arenosols	1	58.8
Petric Calcisols	1	41.2
Haplic Arenosols	1	100
Lithic Leptosols	1	11.8
Ferric Luvisols	1	67.3
Rhodic Nitisols	1	20.9

Leptosols are by far the most extensive group of soils in the world. They are very shallow soils with minimal development, formed typically on hard rock or highly calcareous materials

(FAO, 2007). Eutric Leptosol (Figure 5.6) soils occur in the Rietfontein farm whilst Lithic Leptosols occur within the FPNR. The highest topsoil calcium carbonate in the study occurs within the Rietfontein farm and FPNR with 3.1 and 0.8 (% weight) respectively. Leptosols are generally found in areas where soil has been eroded to the extent that hard rock is exposed near to the surface (Zech and Hintermaier-Erhard, 2008). To combat the limitations of the soil, agro-forestry (combination of rotation of arable crops and plantations) is recommended as erosion is the greatest threat to Leptosol soils and potential to deliver greater volumes of biomass from the same land area (FAO, 2007).

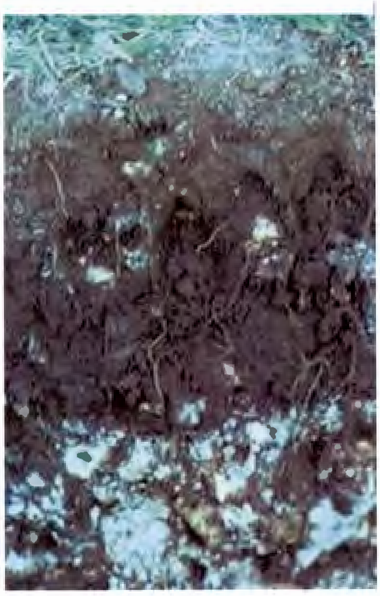


Figure 5.6: Eutric Leptosols profile

Figure 5.7: Arenosols profile

Arenosols (Figure 5.7) are sandy soils, developed on quartzose (and sometimes calcareous) sands of diverse origins, for example from weathering of acid rocks or from aeolian deposits (FAO, 2007). The soils have loamy sand or coarser texture to a depth of at least 100 cm from the soil surface and have less than 35% (by volume) of rock fragments or other coarse fragments within 100 cm from the soil surface (Zech and Hintermaier-Erhard, 2008).

Arenosols soils are found in Barberspan farm and Antwerp farm, their deep red at the surface horizon is due to accumulation of organic matter. The highest topsoil sand fraction in the study occurs within Barberspan and Antwerp farm with 89% and 93% respectively. Arenosols have low water storage but this can be deemed beneficial as the soils warm up early in the season and irrigation can be applied to avoid drought stress in dry spells (FAO, 2006).

Lixisols have very little leaching and occur in the Rietfontein farm, Figure 5.8. The soils have a subsurface horizon with distinct higher clay content than the overlying horizon which has a cation exchange capacity less than 24 cmol per kg (FAO, 2007). The high cation exchange capacity (CEC) is due to a low soil pH, as CEC is dependent upon the pH of the soil. Tillage of wet soil or use of (too) heavy machinery can compact the soil and cause serious structure deterioration. Erosion control methods such as terracing, contour ploughing, and use of cover crops aid in protecting the soil. The low absolute amount of plant nutrients and the low cation retention by Lixisols necessitates the usage of fertilizers as a requirement for frequent farming and chemically and/or physically deteriorated Lixisols rejuvenate very slowly if not actively reclaimed (FAO, 2007).

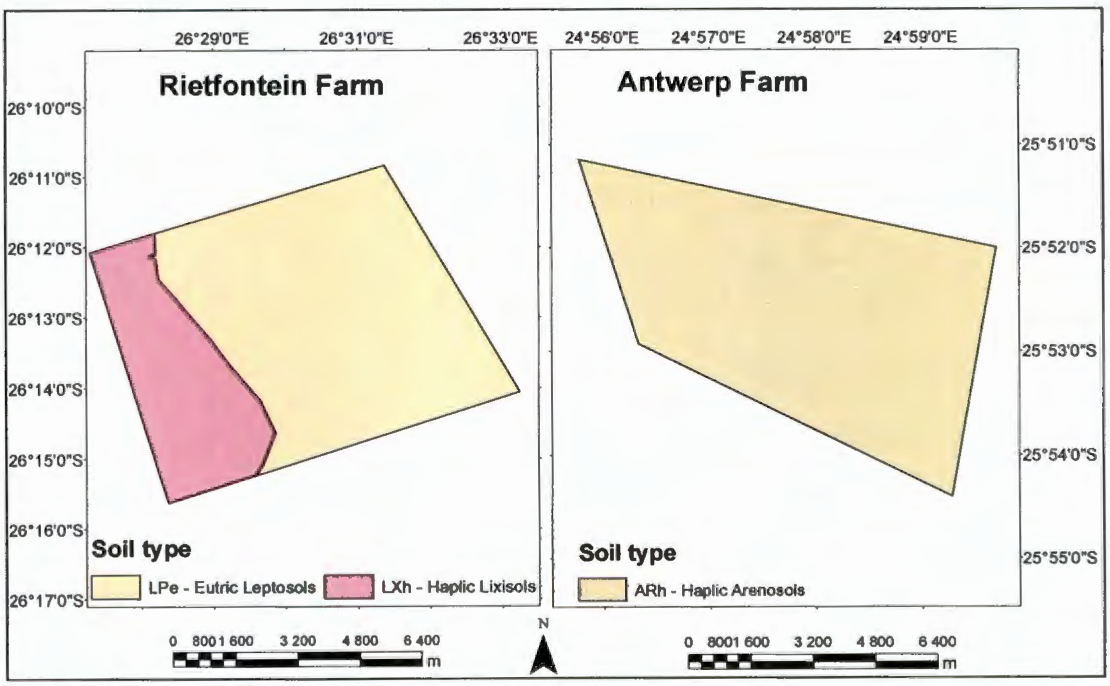


Figure 5.8: Soil types of Rietfontein and Antwerp farm

Luvisols (Figure 5.9) are base-rich soils with subsurface build-up of high activity clays washed down from the surface soil (FAO, 2007). The soils are common in flat or gently sloping land in regions with distinct dry and wet seasons, within the study area this soil group is found in the FPNR.

Luvisols are productive soils that are appropriate for a variety of agrarian practices. If it has high silt content it becomes vulnerable to degradation especially if cultivated in wet conditions and/or with weighty equipment (Zech and Hintermaier-Erhard, 2008).

Figure 5.9: Luvisols profile

Nitisols are rich in iron and are strongly weathered soils but far more productive than most other red tropical soils (FAO, 2007). Nitisols are predominantly found in level to hilly land under savannah vegetation, and within the study area this soil group is found in the FPNR, Figure 5.10. Nitisols are among the most productive soils and their deep and porous soil structure allow deep rooting and make these soils somewhat resilient to erosion (FAO, 2007).

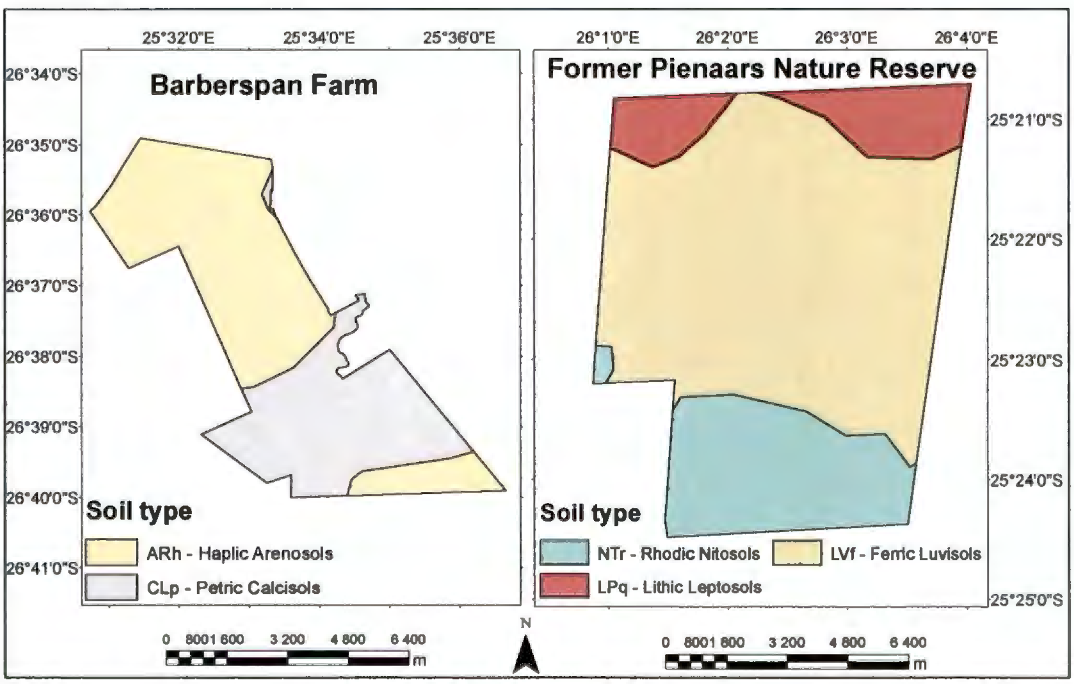


Figure 5.10: Soil types in Barberspan farm and Former Pienaars Nature Reserve

The good workability of Nitisols, their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favourably to those of most other soils (Zech and Hintermaier-Erhard, 2008). Calcisols are soils with a significant secondary accumulation of calcium carbonate resulting from precipitation from solution brought about by evaporation under arid or semi-arid conditions (FAO, 2007). The soil is found in level to hilly land in arid and semi-arid regions where the natural vegetation is scattered and dominated by xerophytic shrubs and trees and/or ephemeral grasses (Zech and Hintermaier-Erhard, 2008), within the study sites this group of soil is found in the Barberspan farm.

5.5.2 Soil texture

The examination of grain size in soils helps to determine the relative amounts of sand, silt and clay in a soil and these size fractions determine the soil texture. Sieve analysis laboratory procedure was conducted to determine the textural class of soil samples.

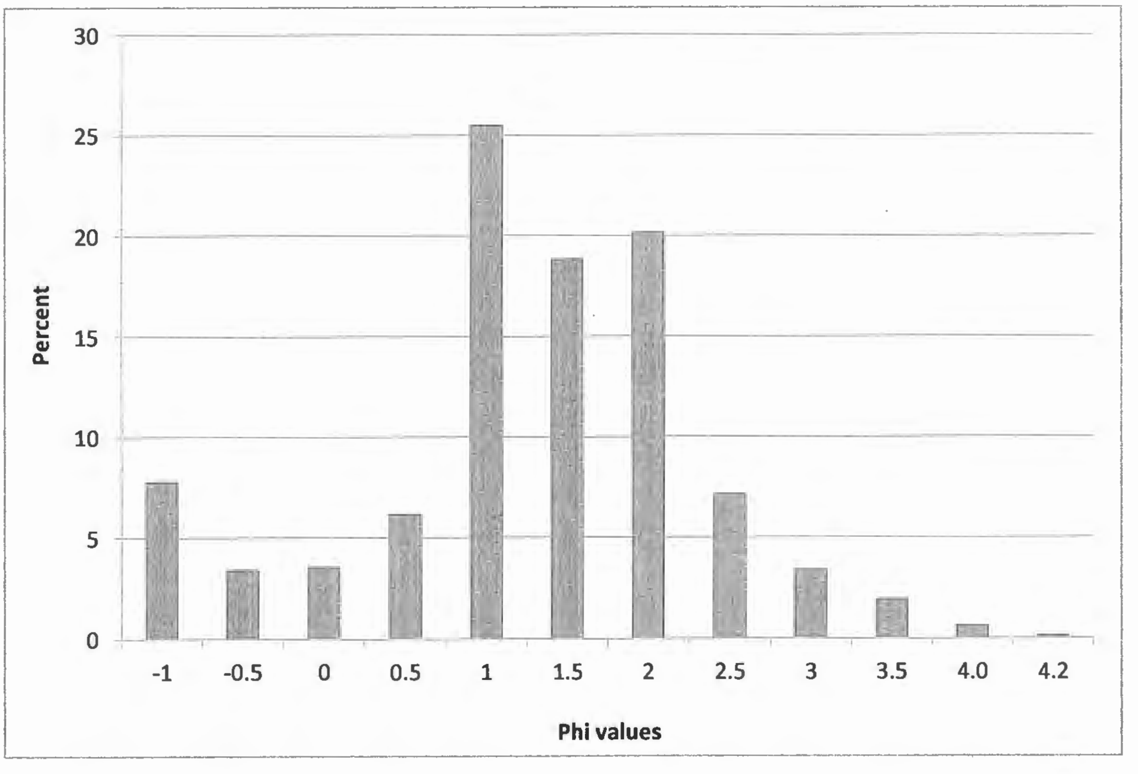


Figure 5.11: Percentage soil retained on each sieve from Barbespan farm

The grain size parameters: mode, mean, and sorting for the investigated 36 samples were evaluated in an attempt to find textural type of the soil. The cumulative percent retained was calculated by adding a percent retained on each sieve on the basis of the total mass of the initial dry sample. Figure 5.11 shows that majority of the soil settled at 1Φ (phi), according to the Wentworth grade this is regarded as medium sand.

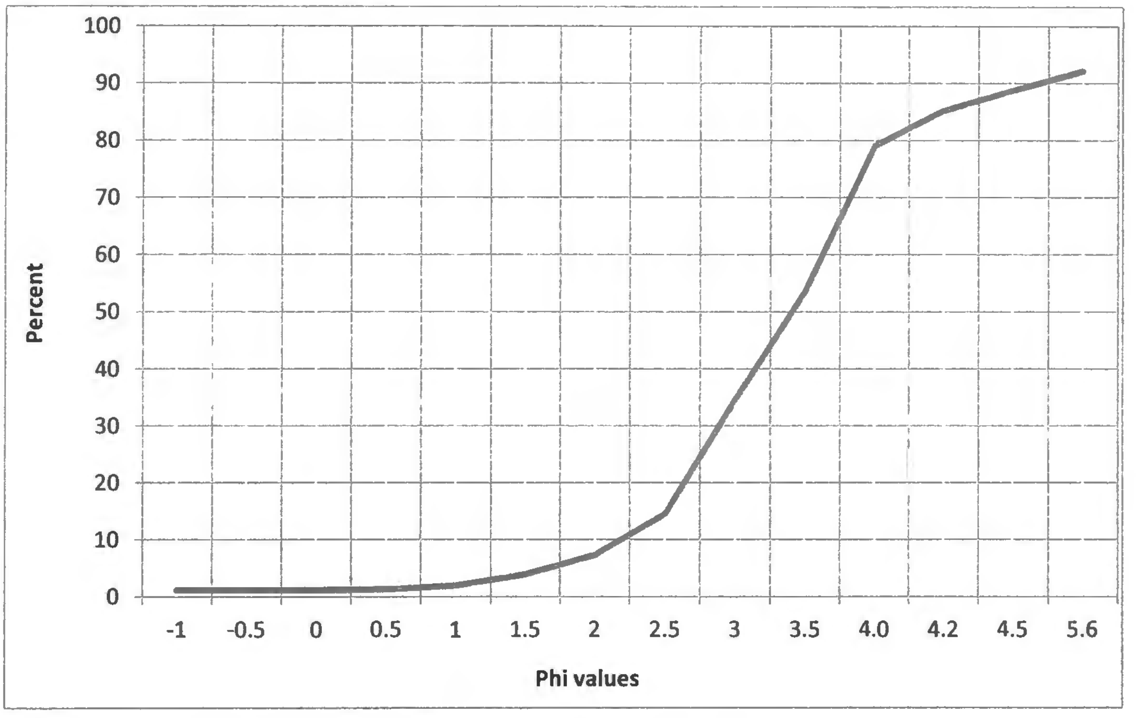


Figure 5.12: Cumulative arithmetic curve from Antwerp farm

For the evaluation of soil samples it is perhaps best to determine the curves directly by eye. Though, this is often problematic to properly determine whether a curve signifies a better sorted or finer soil sample. Thus to solve this problem one has to resort to several statistical measures which can better describe quantitatively definite structures of the curve. The slope of the central part of a cumulative curve reflects the sorting of soil in the sample. Figure 5.12 shows the cumulative arithmetic curve of a soil sample taken from Antwerp farm. The median grain size of the sample at 50 percentile is 3.2 phi units (Figure 5.12). The median displays the value at which half the particles by weight are larger and half are smaller.

There are several formulas used in calculating phi mean, but a common formula is the average of the 25, 50 and 75 percentile. The phi mean of the soil sample is 3.15; mean values ranging between three and four are classified as very fine sand, and this is true for the Antwerp farm. Sorting is how well the grains are separated out by size and is measured from a cumulative curve.

Table 5.3: Soil properties in the study areas

Soil texture	**Drainage**	**Area (km2)**	**%**	**Study site**
Clay loam	Imperfectly	3.49	11.75	Former Pienaars Nature Reserve
Sandy loam	Moderately Well	19.99	67.33	Barberspan Farm
Clay (light)	Moderately Well	6.21	20.92	
Sand	Somewhat Excessive	21.69	58.8	
Sandy clay loam	Moderately Well	15.2	41.2	Rietfontein Farm
Loam	Imperfectly	38.7	72.83	
Sandy clay loam	Moderately Well	14.44	27.17	
Sand	Somewhat Excessive	22	100	Antwerp Farm

Most of the physical characteristics of the soil depend upon texture class. The texture class of the soil is produced when the proportions of sand, silt and clay are compared and result in a texture triangle. Table 5.3 shows soil properties in the four study sites.

Soil texture shows the amount of the different size groups of individual soil particles and provides information regarding water holding capacity, porousness and irrigation requirement of soil. Growth and development of crops is heavily dependent on the soil texture type and root penetration and nutrition absorption of crops depends on characteristics of different texture type of soil particles. Farmers mostly prefers loamy to sandy loam soil as such soil are easier to work with and need moderate irrigation (FAO, 2007). Soils of the former Pienaars

Nature Reserve show 67% of the soil is categorised as sandy loam textural class (Figure 5.13).

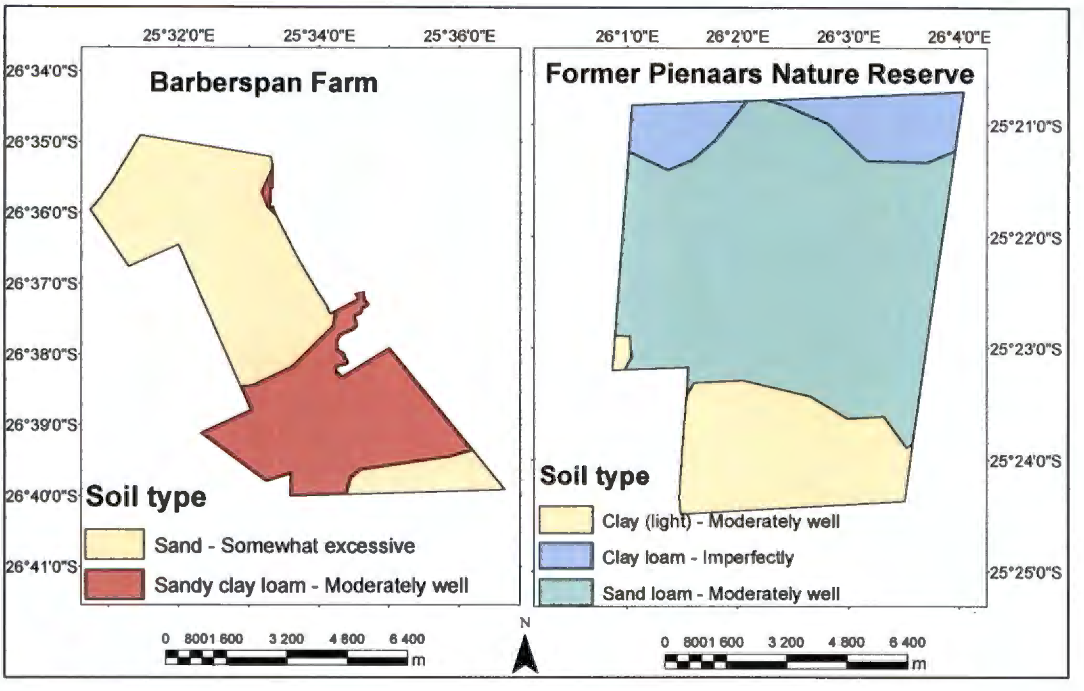


Figure 5.13: Soil texture and drainage in Barberspan farm and Former Pienaars Nature Reserve

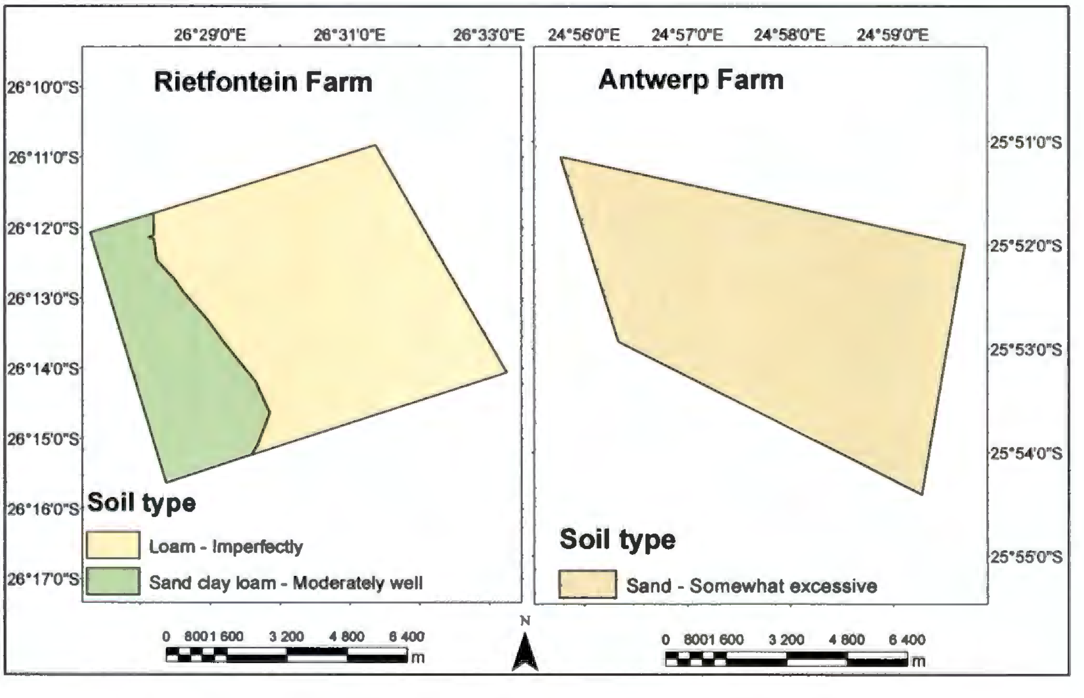


Figure 5.14: Soil texture and drainage of Rietfontein and Antwerp farm

Clay loam accounts for 11.75% of FPNR (Former Pienaars Nature Reserve), while sandy loam covers 67.33% and clay (light) at 20.92%. Clay loam soils are heavy as the soil mixture contains more clay than other types. The poor drainage that can stunt plant growth is due to the characteristic of swelling to retain water when it is very wet and cracking during very dry conditions. These drawbacks can be lessened by adding organic matter over time (Chesworth, 2008). Figure 5.14 shows that sandy soil texture covers the entire Antwerp farm. In sandy loam soils, sand particles are concentrated within sandy loam soils but contain enough clay and other sediments to provide some structure. Sandy loam structure is able to quickly drain excess water but this result in an inability to hold significant amounts of water or nutrients. Sandy clay loam soil covers 41.2% and 27.17% of Barberspan and Rietfontein farm respectively. Loam makes up 72.83% of Rietfontein farm. Figure 5.15 shows the clay fraction in FPNR, most of the summer crops such as maize and sorghum in North West Province require soils with a clay percentage between 10 and 30%.

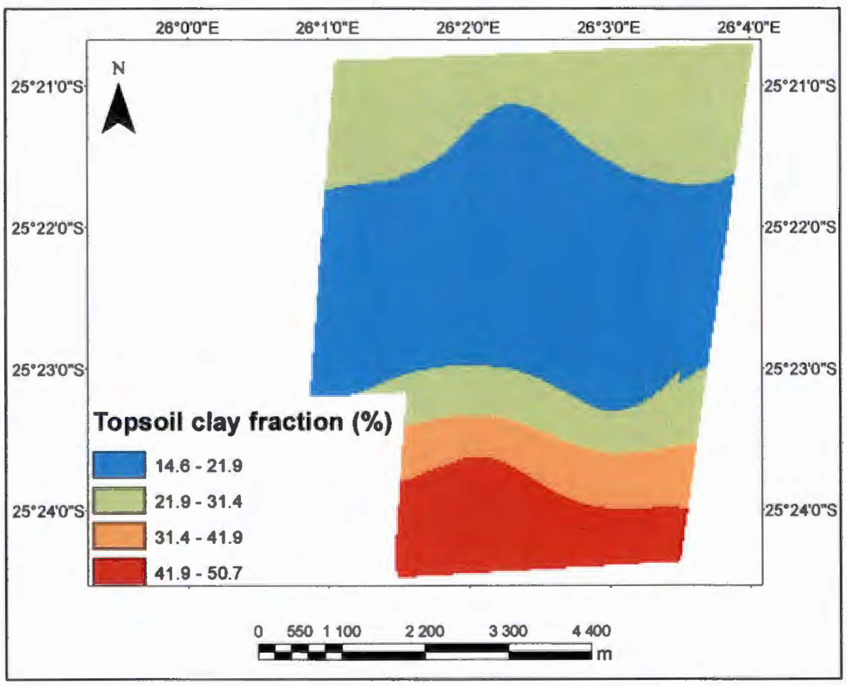


Figure 5.15: Clay fraction in Former Pienaars Nature Reserve

Sandy soils cover 100% and 58.8% of Antwerp (Figure 5.14) and Barberspan farm respectively. Sandy soils are characterised by a generally coarse texture and inability to retain nutrients and have a low water holding capacity. Surface application of organic manure to sandy soils does not last so the manure should be deposited deeper into the soil or a carpetlike layer spread of not less than one centimetre thick, which can improve water storage, biological activity, nutrient status and increase yields (FAO, 2006). Due to the high percentage of sandy soils in Barberspan farm, high proportion of clay fraction is less than 13% as seen in Figure 5.16.

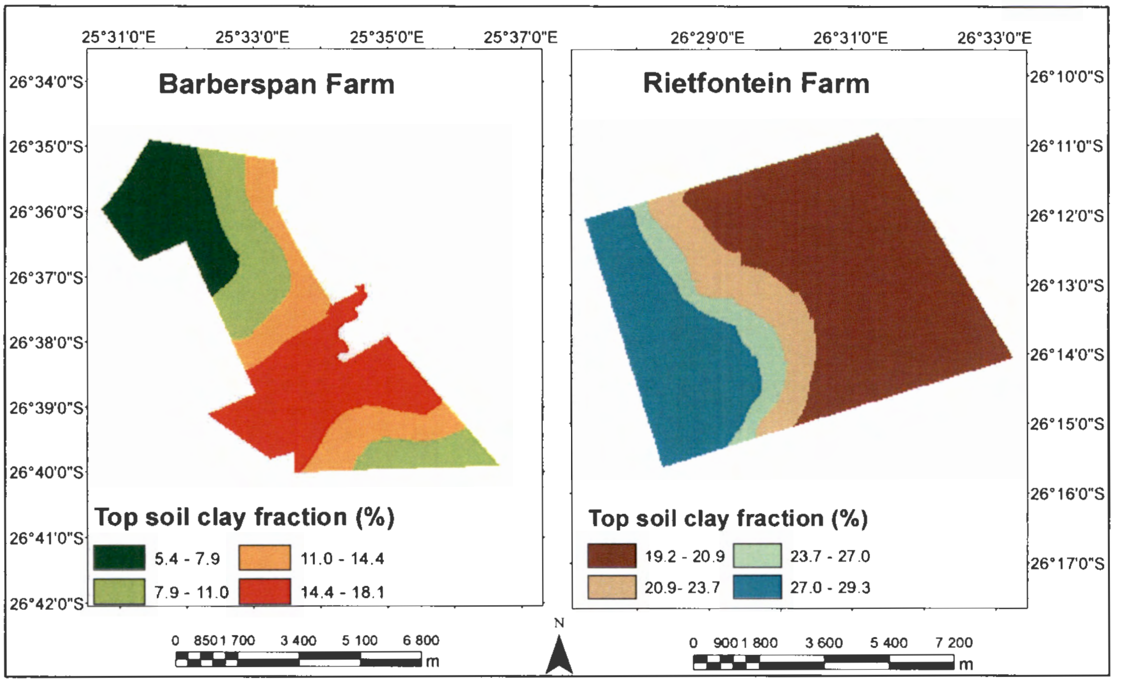


Figure 5.16: Clay fraction in Barberspan and Rietfontein farm

5.5.3 Soil drainage

Moderately well drained soil covers 88.25% of former Pienaars Nature Reserve (FPNR), 15.2% of Barberspan farm (Figure 5.13) and 14.44% of Rietfontein farm (Figure 5.14). In moderately well drained soil, water is removed from the soil at a lower rate and thus the soil is wet for longer periods. Periodically, the soil can be wet enough that mesophytic crops (examples are maize and many fruit trees and vegetables) are affected as wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided (Belt *et al.*, 2007). Sand texture class in Barberspan and Antwerp farm have somewhat excessive drainage class. Water is rapidly lost as the soil is pervious and can be susceptible to runoff, the soils are however free from mottling related to wetness (Fletcher and Veteman, 2014). Imperfectly drained soils are a result of slow removal of water from the soil in relation to supply. Excess water moves slowly if the source is precipitation and varies if groundwater is the source, but the soil generally remains wet during the growing season (Friske *et al.*, 2010).

The slow movement of precipitation is due to the general downward movement through the soil when available soil water storage capacity is high. Imperfectly drained soils make up 11.75% of FPNR and 72.83% in Rietfontein farm. As evidenced in the FPNR, when steepness in the area increases, land possesses less soil depth (Baniya, 2008).

5.6 Chemical properties

Agricultural productivity depends on the quality and capacity of soil to support crop growth. Soil fertility is the ability of soil to provide chemical elements in quantities and proportions for plant growth (Vodppl, 2015). Soil fertility is thus a decisive factor for the development of soil and for crops to grow.

5.6.1 Soil pH

Soil pH plays a role in the life and growth of crops and can affect the availability of nutrients and support microbial activity which influences fertility in turn (Baniya 2008). The pH of Haplic Arenosols soils ranges from 5.1 to 6.7 while Pertic Calcisols (CLp) soils from 7.5 to 8.1 within Barberspan farm respectively (Figure 5.17). CLp soils are common in calcareous parent materials and widespread in arid and semi-arid environments, as a result this explains the high base saturation (FAO, 2007). Fodder crops such as sorghum are tolerant of high calcium levels. Soil pH is less varied in Rietfontein farm with ranges from 6.3 to 6.5. Haplic Lixisols soils generally have low cation exchange capacity and thus a higher pH, in Rietfontein farm the pH is slightly acidic at 6.3 to 6.4. Eutric Leptosols (LPe) also display slightly acidic characteristic with a range from 6.4 to 6.5, LPe are generally basic because of the presence of calcium carbonate.

The soil pH ranging from 7.2 to 7.5 in FPNR (Figure 5.18) is due to the characteristics of Lithic Leptosols, where continuous hard rock between 10 and 25 cm is directly overlaid with a calcium carbonate equivalent of more than 40% (Chesworth, 2008). As a result less than 10% from the soil surface down to a depth of 100 cm by weight is soil material.

The pH range of 6.8 to 7.2 in FPNR is due to Ferric Luvisols soils, these have high cation exchange capacity (Chesworth, 2008). Cation exchange capacity (CEC) is dependent on soil pH, thus a high CEC means the soil is acidic as more cations are available. The Rhodic Nitisols soils with a pH range of 5.6 to 6.5 have the same characteristics as Ferric Luvisols, where a high cation exchange capacity means the soil is slightly acidic in nature.

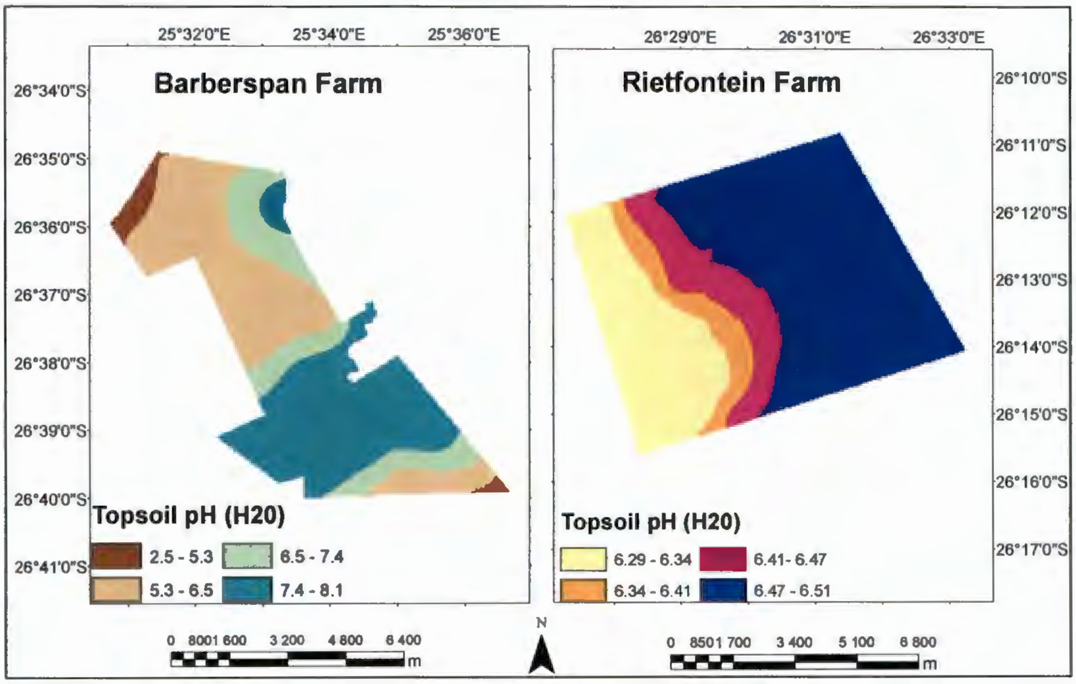


Figure 5.17: Soil pH in Barberspan and Rietfontein farm

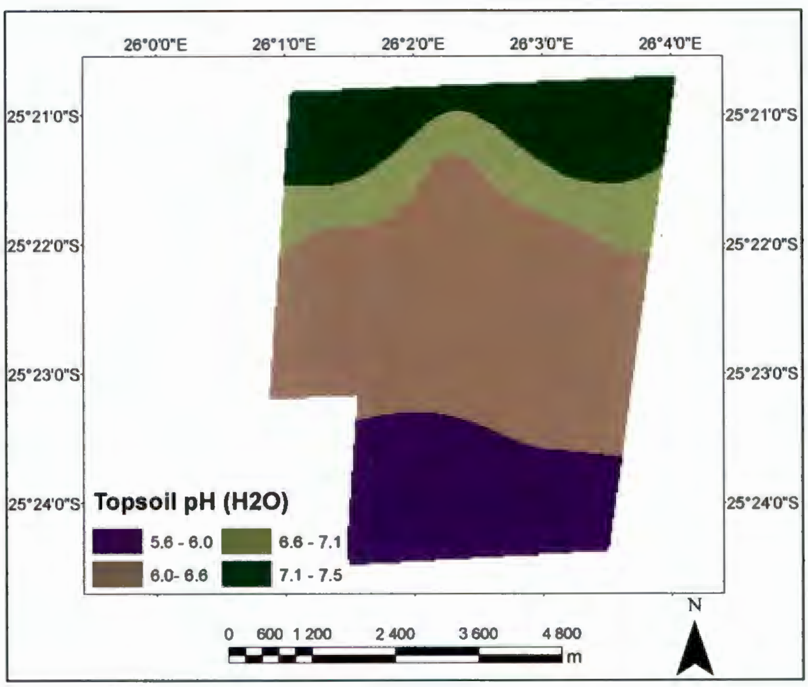


Figure 5.18: Soil pH in Former Pienaars Nature Reserve

5.6.2 Organic carbon

The influence to cation exchange from the organic fraction in soils with high clay content is usually less while in sandier soils the comparative influence of the organic fraction is higher due to less clay, even though the amount of total organic carbon present may be similar or less to that in clays (Pluske *et al.*, 2007). The percentage of organic carbon in the soil can affect the properties of the soil such as influencing colour and nutrient holding capacity, which in turn influence water relations and aeration. Organic matter in Rietfontein farm ranged from 0.59 to 0.73% while in Barberspan farm, from 0.22 to 0.47%. The organic matter is generally low within the study sites. The soils require improvements in organic carbon for increased and sustained agricultural yields.

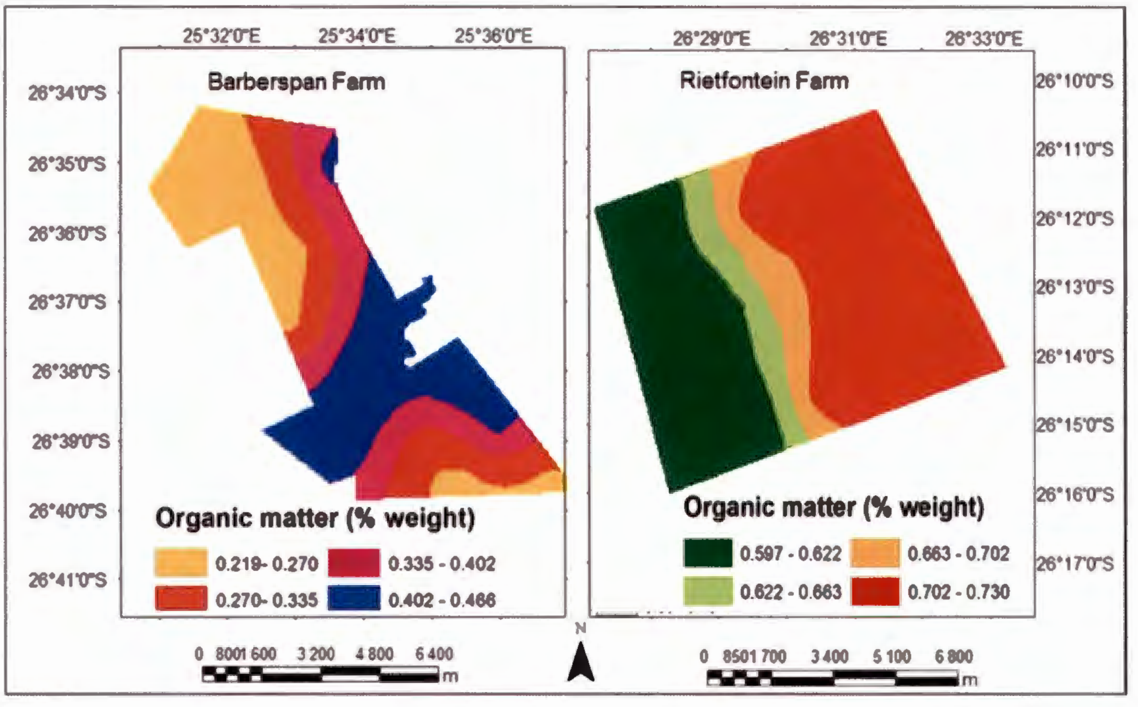


Figure 5.19: Organic matter in the Barberspan and Rietfontein farm

5.7 Topography

Topographic features result in the variation in micro-climate and soil properties such as soil temperature as the orientation of hill slopes can influence the amount and intensity of sunlight that is received at a location and this can affect the germination of seedlings, evaporation and crop growth in field crops. The topographic features of an area can also increase the risk of soil erosion hazard, sediment redistribution, but also local drainage capacity and thus evaluation of topographic features is necessary in land evaluation. Another significant effect is on water flow as the topographical features such as curvature and slope can influence the hydrological conditions of a location and generate different soil moisture conditions and flow patterns (Seibert *et al.*, 2007).

In terms of agricultural planning the slope is classified as 0-4%, 4-8%, 8-12% and greater than 12% in order to determine the best slopes for agriculture (Ebrahim, 2007). Land where the slope is less than 12% is ideal for agriculture, a 12% slope shows that a 12 m rise occurs in altitude over a distance of 100 m. Surface analysis in ArcGIS was used to calculate slope data using Digital Elevation Model (DEM) which consists of terrain elevations of ground positions. The topography of the North West Province is generally flat. Figure 5.20 and 5.21 illustrates slope ratings across Rietfontein and Antwerp farm was generally below 12%.

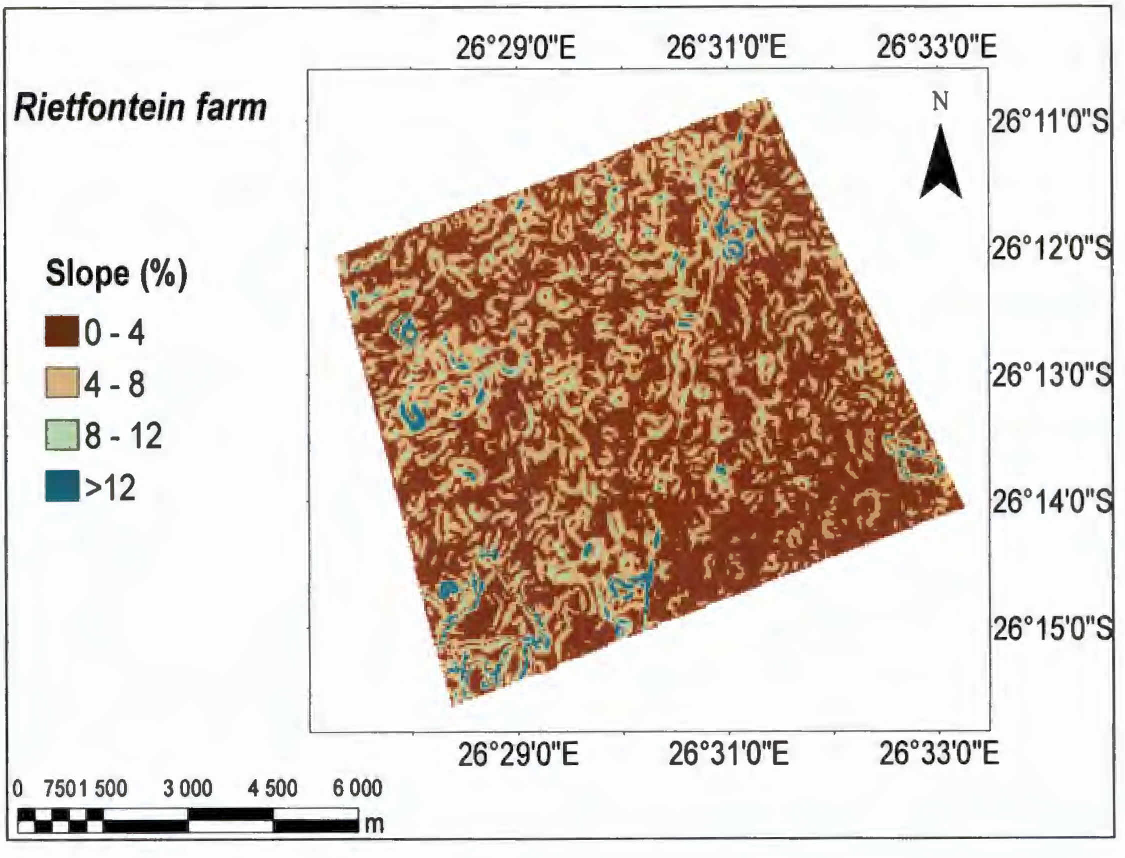


Figure 5.20: Slope ratings at Rietfontein farm

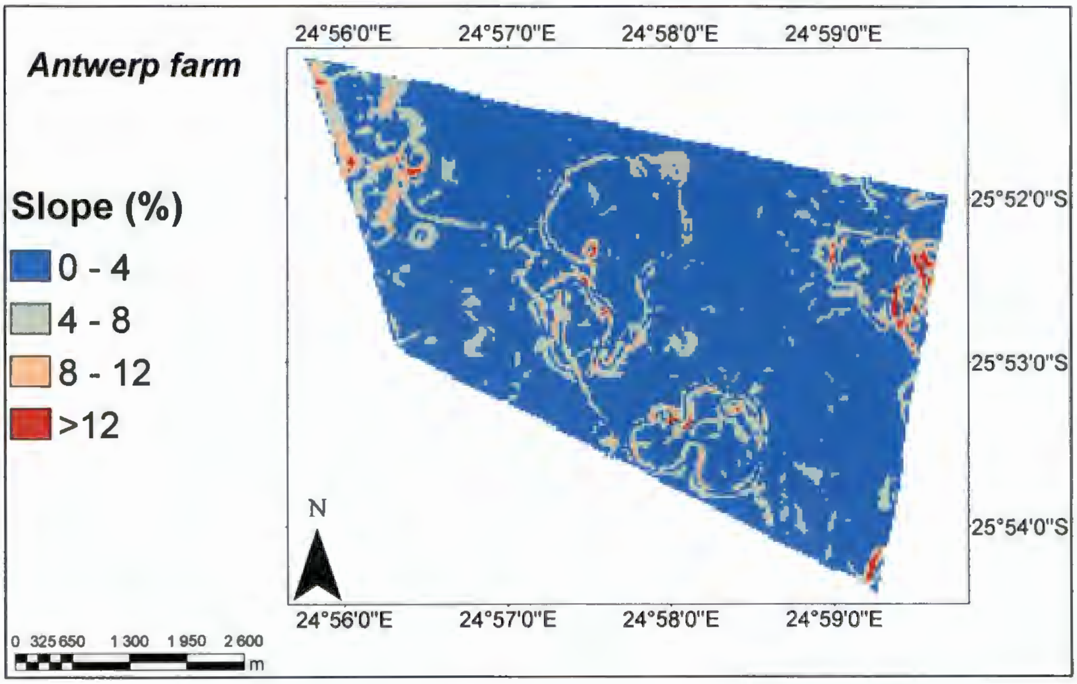


Figure 5.21: Slope ratings at Antwerp farm

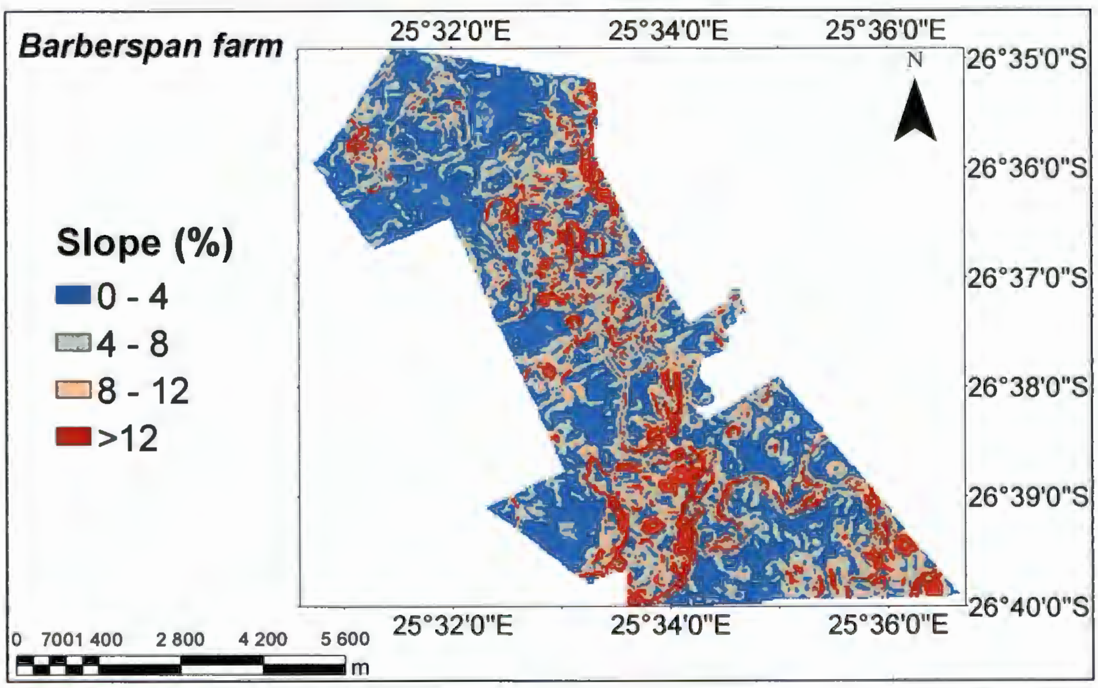


Figure 5.22: Slope ratings at Barberspan farm

5.8 Climate capability

5.8.1 Temperature and rainfall

Out of the three most important natural variables that dominate the earth's environment i.e. climatic pattern, plant distribution, and soil, climate is inevitably perceived as the principal dynamic component and obviously an independent variable shaping the other two on both meso and regional scales (Akin, 1991). Out of climatic variables, temperature, precipitation, and solar radiation are the major factors that govern the climatic adaptability and distribution (both in space and time) of crops (FAO, 2006).

Rainfall is the primary source of water for crop growth and its data is readily available in the study sites. Annual rainfall data for the period 1984 to 2014 was used to analyse annual rainfall trends. The data were standardised with respect to the long term mean and the standard deviation using Equation 4.11. The standardisation procedure was used to model extreme events such as floods and droughts by analysing rainfall and temperature time series. By so doing, rainfall and temperature anomalies were computed to define wet and dry spells and cold and warm extreme events over the study area respectively.

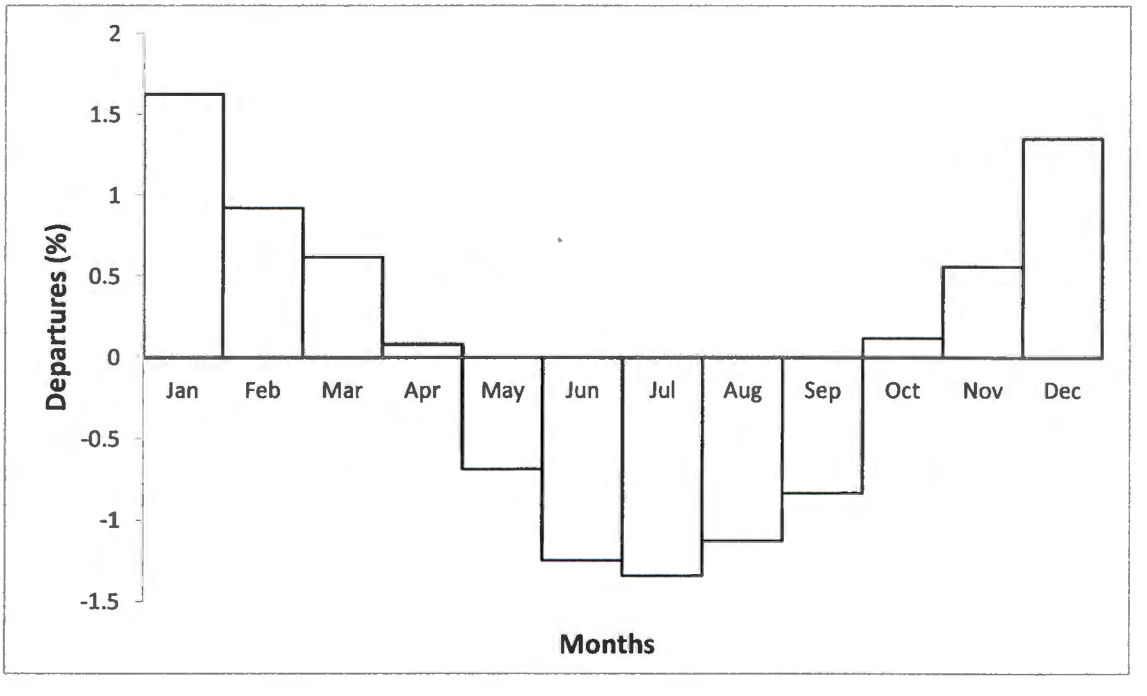


Figure 5.23: Monthly rainfall departures for the North West.

The months of October to April are generally used as growing periods of crops in North West province because these months have above normal departures (i.e. positive values indicating rainfall period) as seen in Figure 5.23. Thus, many parts of North West Province receive a unimodal rainy season centred on January, where rainfall start in October and end in April of the following year. The temperatures also follow the same pattern, where warmer months are from October to April with highest temperatures experienced during the month of January.

The Barberspan farm situated in Delareyville receives an annual amount of 489 mm in rainfall with the highest peak in January and experiences an average of 26.4°C in temperature. Rietfontein farm is situated near Lichtenburg and receives an annual amount of 512 mm in rainfall with the highest peak in December and experiences an average of 26.7°C in temperature. FPNR is located near Zeerust and receives an annual amount of 522 mm in rainfall with the highest peak in January and experiences an average of 30.1°C in temperature. Antwerp farm is located near Matloding and receives an annual amount of 365 mm in rainfall with the highest peak in January and experiences an average of 27.3°C in temperature. Figure 5.23 shows the average annual rainfall in the four study sites.

Temperature is vital and plays a role in the growth and development after germination of seeds. A general temperature range from 27°C to 30°C is required for optimum growth and development of crops, although this can be as low as 21°C, without a dramatic effect on growth and yield of crops (Du Plessis, 2003).

Rainfall in the study sites is highly variable with annual coefficient of variability (CV%) of 31% calculated using Equation 5.1 from the mean annual rainfall value of the areas, which is 500 mm. This indicates uncertainty of rainfall in the study areas as in two out of every three years the rainfall may fluctuate from 500 mm to around 700 mm. Rainfall in the study areas is also characterised by high seasonality, in which 75 - 85% of the total mean annual rainfall falls in the period October to April.

$$CV\% = 640/\sqrt{MAP}*100 \qquad \text{(Equation 5.1)}$$

Where: CV% is coefficient of variability of the rainfall; MAP is mean annual precipitation in mm

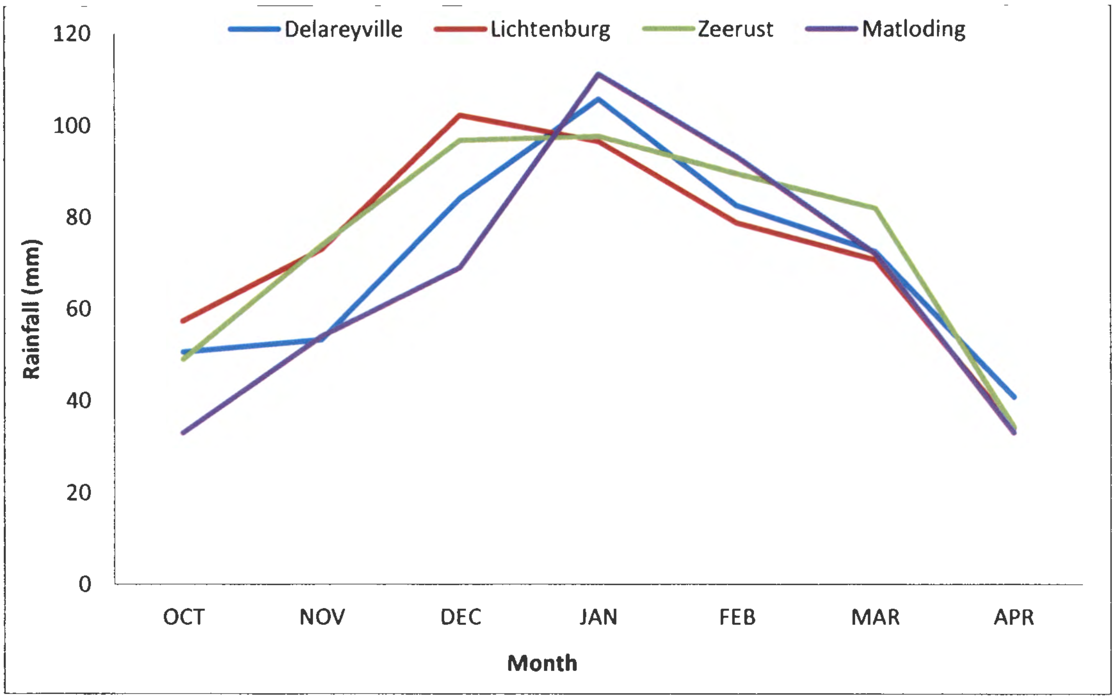


Figure 5.24: Average monthly rainfall in the study sites

5.8.2 Evapotranspiration

Large percentage of rainfall available in arid and semi-arid areas is lost through evapotranspiration to the atmosphere. This is particularly true in South Africa, where 91% of the mean annual precipitation (MAP) is lost by evaporation, which is considerably higher than the worldwide 65% of the MAP (Schulze, 1997).

Production of agricultural crops will then require greater amount of rainfall for optimum growth and exceed threshold value at which moisture deficit occurs due to evapotranspiration. In southern Africa this threshold is considered to be one-third of the evapotranspiration (Schulze, 1997). According to Figure 5.23 the threshold at which precipitation is greater than the one-third of the evapotranspiration starts in October and ends in April.

$$p \geq O.3E_r \qquad \text{(Equation 5.2)}$$

Where: p is median monthly precipitation (mm); Er is monthly reference evaporation (mm)

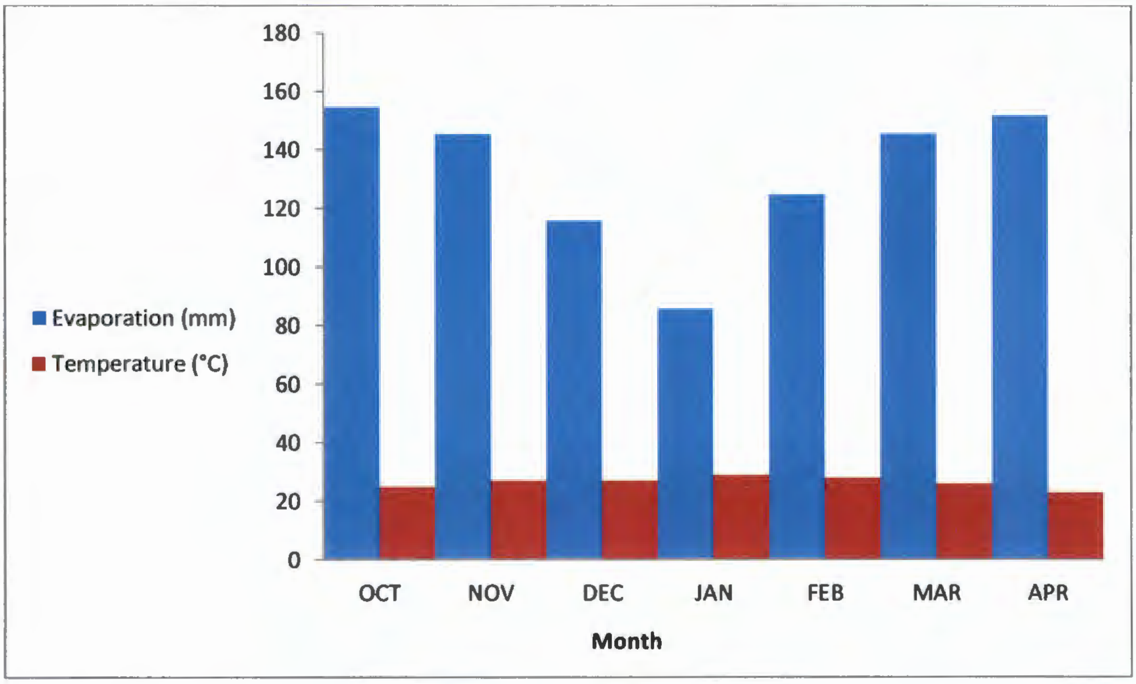


Figure 5.25: Mean monthly evaporation and temperature

Rainfall amount during this growing season allows for crop production as the soil moisture deficit due evapotranspiration is low. This period is referred to as the growing period (FAO, 2006). Normally, sorghum can endure heat and moisture stress better than maize as a result of its more fibrous root structure. The root structure allows sorghum to absorb more nutrient levels than maize (Wortmann e*t al.,* 2010).

5.9 Climatic requirements

5.9.1 Maize

Maize thrives in warm temperatures and is usually not cultivated in regions where the mean daily temperature is below 19°C or the mean of the summer months is below 23°C (Du Plessis (b), 2003). The minimum temperature for germination is 10°C, while at 20°C, sheathed ears should begin appearing within five to six days (Du Plessis (b), 2003). Temperatures of 32°C and above can adversely affect the yield. Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage (Obeng-bio, 2010).

Annual rainfall of 500 to 750 mm is essential for sufficient moisture as the lack of water is a yield-limiting factor. A yield of 3152 kg/ha requires between 350 and 450 mm of rain per annum (DAFF (b), 2010).

5.9.2 Sorghum

Sorghum needs high temperatures for good germination (minimum of 7°C to 10°C) and growth. 80% of seed sprouts within 10 to 12 days and is usually cultivated when there is sufficient water in the soil and the soil temperature is 15°C (Du Plessis (a), 2003). A temperature of 27°C to 30°C is required for optimum growth and development, but the temperature can be as low as 21°C without a dramatic effect on growth and yield (DAFF(c), 2010). Unusually high temperatures result in the decrease of yield. Flower initiation and the development of flower primordial are delayed with increased day and night temperatures (DAFF(c), 2010).

Sorghum is grown in a variety of soils in South Africa and under changing rainfall conditions. Sorghum can survive with an annual rainfall of about 400 mm in the drier western parts and is able to endure drought better than most other grain crops (DAFF(c), 2010). This is due to:

- An unusually strong and finely branched root system is effective in absorbing water.
- The leaves collapse better during warm environments than that of maize.

5.9.3 Sunflower

It can endure both low and high temperatures, but is more tolerant to low temperatures. Sunflower seedlings are very sensitive to high soil temperatures during germination and this is aggravated in the sandy soils of the North West (DAFF (a), 2010). Sunflower seeds will germinate at 5°C, though temperatures of at least 14°C to 21°C are necessary for better germination and the best temperatures for growth is between 23°C to 34°C (DAFF (a), 2010). Exceedingly high temperatures can reduce oil percentage and seed fill.

Approximately 500 mm to 1000 mm of annual rainfall is required for growth as it is an ineffective user of water, as measured by the volume of water transpired per gram of plant above-ground dry matter (DAFF (a), 2010). Sunflower does reasonably well under drought conditions but is not regarded as highly drought tolerant (DAFF (a), 2010). Its broadly branched taproot, penetrating to 2 m, allows the crop to endure periods of water stress and a critical time for water stress is the period 20 days before and 20 days after flowering (DAFF (a), 2010).

5.10 Summary

Development of the land information database in communal areas of North West was necessary to delineate lands for agricultural crops and provide sufficient and accurate information on land and soil characteristics. The information of soil and land parameters was converted into thematic map layer using a GIS application. The thematic layers are to be overlaid using the weight analysis to produce an agricultural land capability map in the next chapter. Database information included information related to biophysical resource and environmental.

Chapter Six

Findings from the land capability analysis

6.1 Introduction

Land capability evaluation study is an evaluation of the ability of a given type of land to support a defined land use. The capability map includes a capability degree and limitations involved. Crop water requirement of each crop within each study site is also investigated for sustainable land use.

6.2 Evaluation of natural land resource

The planning of appropriate agricultural crops begins with the selection of the appropriate crop type based on the ecological condition of the areas. Usually, local crop cultivars are selected for the production as the crop genetic has acclimatised over centuries to the local environment.

Improving the footprint of agriculture while increasing production needs a concerted effort in two areas: firstly by closing the uptake gap of existing best practices and technologies by focusing on knowledge sharing and creating supportive extension services networks; and secondly by investing in innovation and research to provide the solutions for tomorrow and ensure agricultural policies are science-based (Tasie *et al.,* 2015). The relationship among different influencing factors like physical environment, climatic, social conditions, economic infrastructure and agricultural input availability should be judged properly for selection of the land area (Baniya, 2008). All these measures are taken into account in the order of importance i.e. ratings in this study (explained in Chapter 4). Therefore, evaluation of rated elements produces land area which is capable for growing specific type of crop with degree of difficulty and limitations. Capability evaluation was done by assessing each component separately i.e. physical land capability, environmental sustainability and economic capability.

Crop water requirement for sustainable land use was also considered. Calculation of the crop water requirement was carried out using the CROPWAT model. The model integrates the appropriate climate and rainfall data sets, together with the crop files and the corresponding planting dates. It is used in this study due to satisfactory performance elsewhere throughout the world (Adeniran *et al.*, 2010; Al-Najar, 2011; Lassche, 2013). The four study sites generally allow for the cultivation of summer crops with regard to climatic requirements as all the sites average 500 mm of annual rainfall and a temperature range between 27°C to 30°C.

6.3 Land capability evaluation in Rietfontein farm

6.3.1 Sunflower cultivation

Under dry land conditions, sunflowers do best in deep soils with a good water-holding capacity (clays). Shallow soils can lead to stress and restrict growth; and in less developed roots, the shallow depth can reduce yields as warmer soil temperatures closer to the surface rapidly increase the emergence of seedlings (DAFF(c), 2010). Rietfontein farm is 25% highly to moderately capable for sunflower cultivation (Figure 6.1); the soil has a sandy clay texture and a depth of 100 cm. A large proportion of the farm (75%) is not capable for cultivation as the soil depth is insufficient, varying from 30 cm to 50 cm.

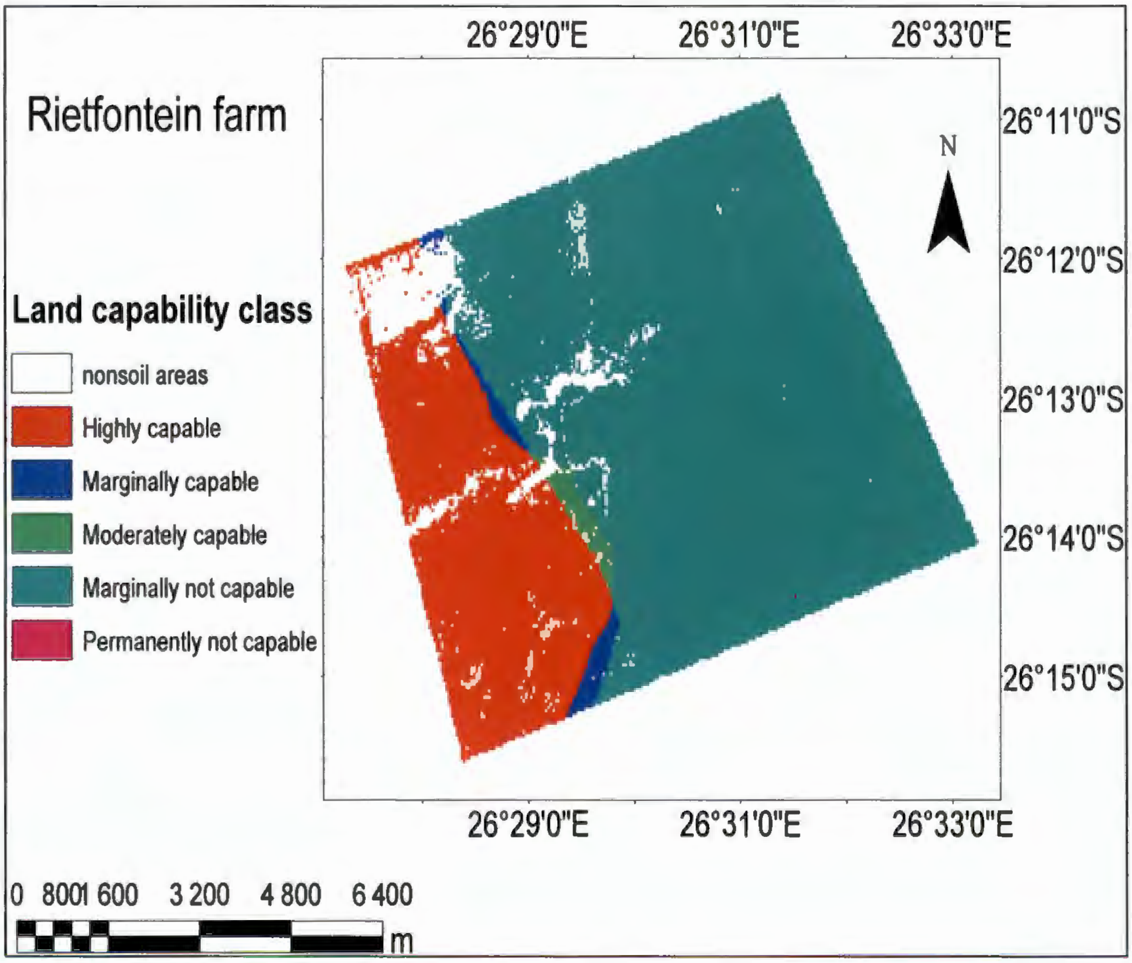


Figure 6.1: Land capability classified map for sunflower

6.3.2 Sorghum cultivation

Sorghum is mainly grown on low potential, shallow soils with high clay content. 48% of the study site is highly capable (C1) while 52% is marginally capable (C2) for sorghum cultivation (Figure 6.2). C2 soils are shallow with soil depth less than 50 cm and as sorghum is more tolerant of alkaline salts than other grain crops, it can therefore be successfully cultivated on soils with a pH between 5,5 and 8,5 (DAFF(c), 2010).

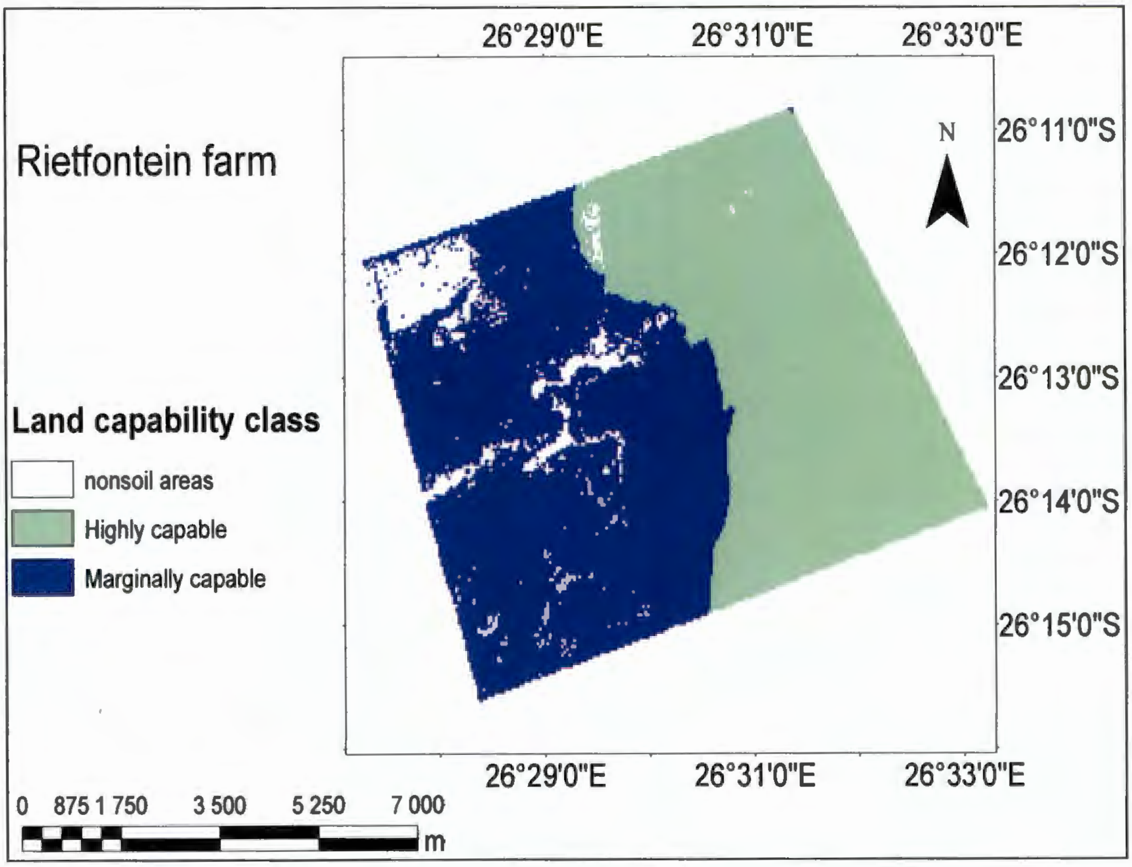


Figure 6.2: Land capability classified map for sorghum

6.3.3 Maize cultivation

Excessively shallow planting can cause slow, uneven emergence due to soil moisture variation, and rootless corn ("floppy corn syndrome") when hot, dry weather inhibits nodal root development in maize (Butzen and Jeschke, 2014). Even with the shallow soil depth in the farm, 74% of the farm is moderately capable for maize growth as the planting depth and germination of maize can still be accommodated at this depth. A smaller proportion of the farm is highly capable for maize at 24% while just 2.3% is marginal. Figure 6.3 shows the land capability map for maize.

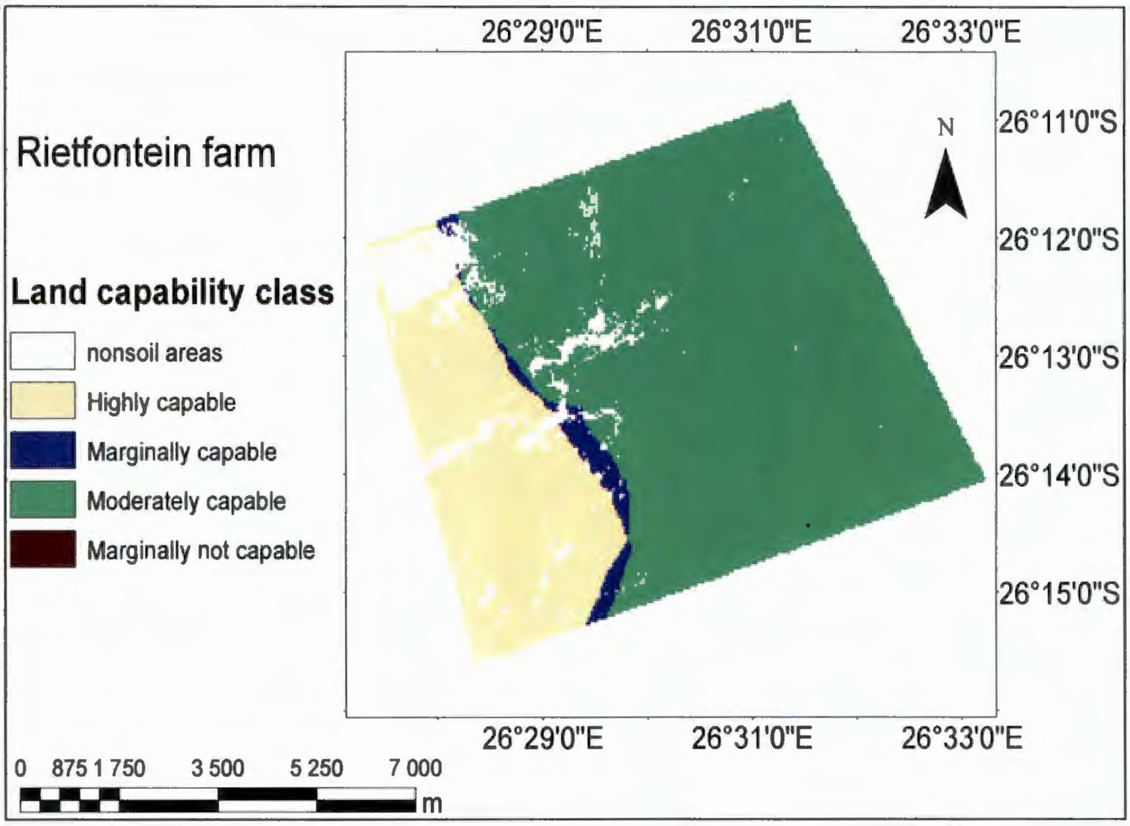


Figure 6.3: Land capability classified map for maize

6.3.4 Crop water requirement in Rietfontein farm

The crop water requirement generally peaked during mid-season and dropped during the late season. According to FAO (2007), this is because the maximum crop water need is reached at the beginning of the mid-season stage while during the late season stage dry harvested crops are allowed to dry out and sometimes even die and thus their water needs during the late season stage are minimal. A high value of 27.5 mm/dec was reached for sorghum during the initial stage, 33.6 mm/dec for maize during mid-season and 18.3 mm/dec during mid-season for sunflower.

As seen from Table 6.1, 6.2 and 6.3, the reference crop evapotranspiration (ETo) value varies greatly among these crops. Maize has the highest crop evapotranspiration at 609 mm/dec followed by sorghum at 527 mm/dec and sunflower with 469 mm/dec. Maize and sorghum indicated the highest value of irrigation requirement at 133 mm/dec and 143 mm/dec respectively and sunflower has the lowest at 73 mm/dec.

Table 6.1: Crop water requirement for sorghum

Crop Water Requirements

ETo station: Lichtenburg | Crop: Sorghum

Rain station: Lichtenburg | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.70	3.17	31.7	3.8	27.5
Nov	1	Init	0.70	3.35	33.5	14.8	18.6
Nov	2	Deve	0.74	3.71	37.1	21.5	15.6
Nov	3	Deve	0.81	4.15	41.5	25.2	16.3
Dec	1	Deve	0.87	4.61	46.1	28.1	18.0
Dec	2	Mid	0.93	5.03	50.3	31.9	18.4
Dec	3	Mid	0.94	5.08	55.9	37.5	18.4
Jan	1	Mid	0.94	5.09	50.9	46.1	4.8
Jan	2	Mid	0.94	5.10	51.0	52.9	0.0
Jan	3	Late	0.90	4.79	52.7	47.4	5.3
Feb	1	Late	0.75	3.90	39.0	41.5	0.0
Feb	2	Late	0.60	3.04	30.4	37.9	0.0
Feb	3	Late	0.50	2.44	7.3	11.0	0.0
					527.4	**399.8**	**143.0**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.2: Crop water requirement for maize

Crop Water Requirements

ETo station: Lichtenburg | Crop: Maize

Rain station: Lichtenburg | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.30	1.36	13.6	3.8	9.4
Nov	1	Init	0.30	1.43	14.3	14.8	0.0
Nov	2	Init	0.30	1.51	15.1	21.5	0.0
Nov	3	Deve	0.37	1.91	19.1	25.2	0.0
Dec	1	Deve	0.50	2.62	26.2	28.1	0.0
Dec	2	Deve	0.62	3.37	33.7	31.9	1.8
Dec	3	Deve	0.76	4.09	45.0	37.5	7.5
Jan	1	Mid	0.89	4.82	48.2	46.1	2.1
Jan	2	Mid	0.93	5.07	50.7	52.9	0.0
Jan	3	Mid	0.93	4.97	54.7	47.4	7.3
Feb	1	Mid	0.93	4.86	48.6	41.5	7.1
Feb	2	Mid	0.93	4.76	47.6	37.9	9.6
Feb	3	Mid	0.93	4.58	36.6	29.3	7.3
Mar	1	Mid	0.93	4.40	44.0	16.0	28.0
Mar	2	Late	0.87	3.94	39.4	5.9	33.6
Mar	3	Late	0.76	3.07	33.8	14.5	19.3
Apr	1	Late	0.64	2.31	23.1	28.9	0.0
Apr	2	Late	0.54	1.68	15.2	33.6	0.0
					608.7	**516.8**	**132.9**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.3: Crop water requirement for sunflower

Crop Water Requirements

ETo station: Lichtenburg | Crop: SUNFLOWER

Rain station: Lichtenburg | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.35	1.59	15.9	3.8	11.6
Nov	1	Init	0.35	1.67	16.7	14.8	1.9
Nov	2	Deve	0.38	1.89	18.9	21.5	0.0
Nov	3	Deve	0.53	2.71	27.1	25.2	1.9
Dec	1	Deve	0.69	3.66	36.6	28.1	8.5
Dec	2	Deve	0.86	4.66	46.6	31.9	14.7
Dec	3	Mid	0.94	5.08	55.8	37.5	18.3
Jan	1	Mid	0.94	5.09	50.9	46.1	4.7
Jan	2	Mid	0.94	5.10	51.0	52.9	0.0
Jan	3	Mid	0.94	4.99	54.9	47.4	7.5
Feb	1	Late	0.87	4.54	45.4	41.5	3.8
Feb	2	Late	0.64	3.28	32.8	37.9	0.0
Feb	3	Late	0.43	2.12	16.9	29.3	0.0
					469.4	**418.1**	**73.1**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

6.4 Land capability evaluation in Barberspan

6.4.1 Maize cultivation

The Barberspan farm allows for the cultivation of maize crop, as 62.4% falls under highly to moderately capable (Figure 6.4). The soil in these areas has favourable physical properties such as the absence of restrictive layers (hardpan) and a good effective depth of 100 cm. The soils also have sufficient and balanced quantities of plant nutrients and chemical properties. Marginal capability accounts for 19.2% of the farm. The land has limitations that can be severe if used without soil management, as sustained application can reduce productivity. Marginally not capable (N1) and permanently not capable (N2) land accounts for 18.3% and 0.1% respectively. The soils in N1 and N2 have low clay content (20% to 22%) for maize production.

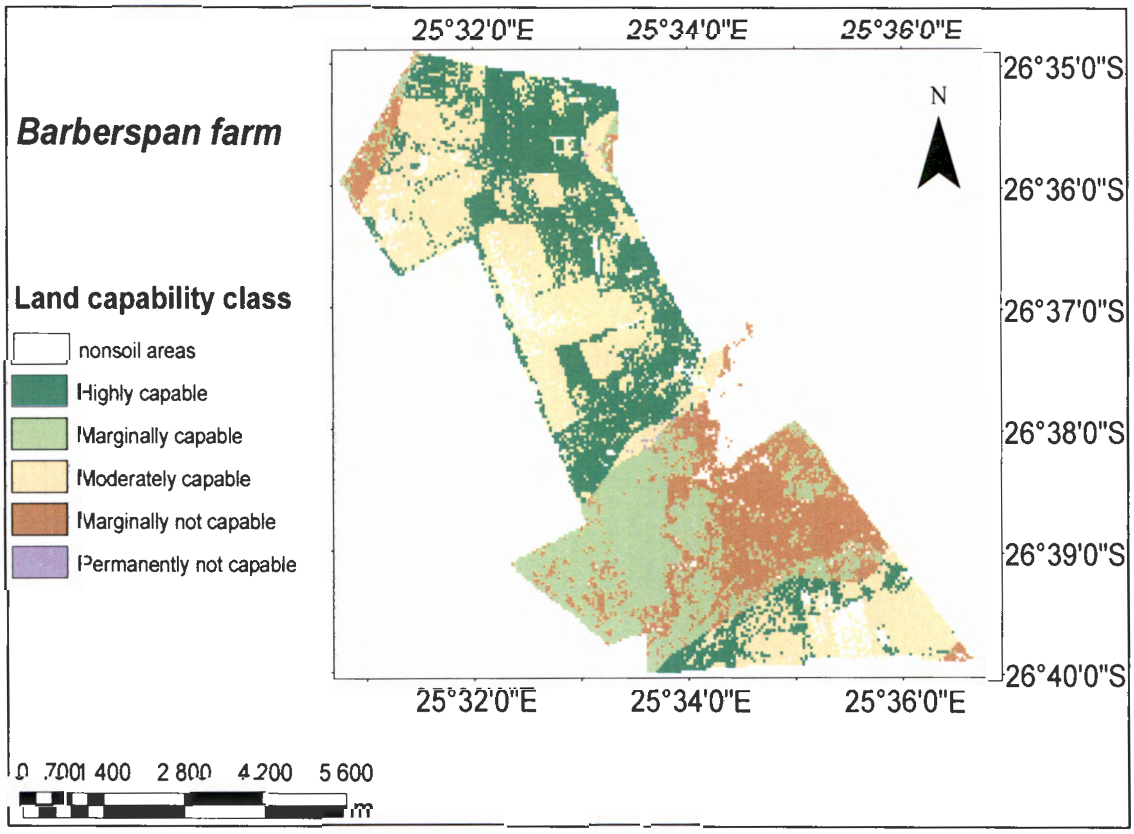


Figure 6.4: Land capability classified map for maize

6.4.2 Sorghum cultivation

Sorghum usually grows poorly on sandy soils, thus almost 55.5% of farm is marginally not capable for cultivation. Areas of high (C1) and moderate capability (C2) make up 44.5% as seen in Figure 6.5. The clay content of C1 and C2 soils ranges from 15.1% to 18.1% and although the pH is almost alkaline, sorghum is more tolerant of alkaline salts than other grain crops.

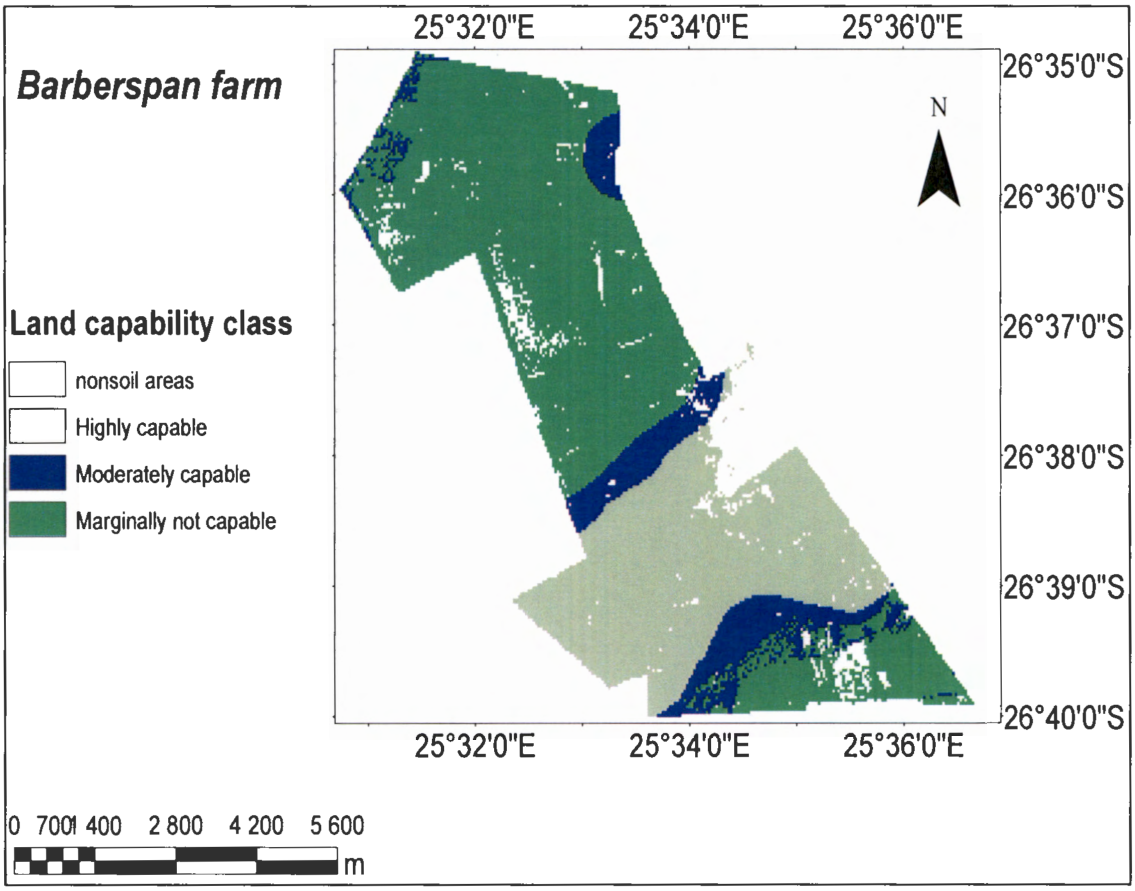


Figure 6.5: Land capability classified map for sorghum

6.4.3 Sunflower cultivation

High and moderate capability for sunflower cultivation accounts for 41.5%. The region within which the farm is located has a sandy clay loam texture and a clay fraction ranging from 12.5% to 18.1%. Traditionally, sunflower cultivation in South Africa has been limited to soils where the clay percentage varies between 15% and 55%, but at present the major planting areas are in soils with a clay content of less than 20% (DAFF (a), 2010). Marginal capability for sunflower covers 55.8%. The excessive drainage condition due to sandy textural type is not ideal but can be corrected by adding organic matter to improve the water holding capacity of the soil. Figure 6.6 shows the land capability classified map for sunflower.

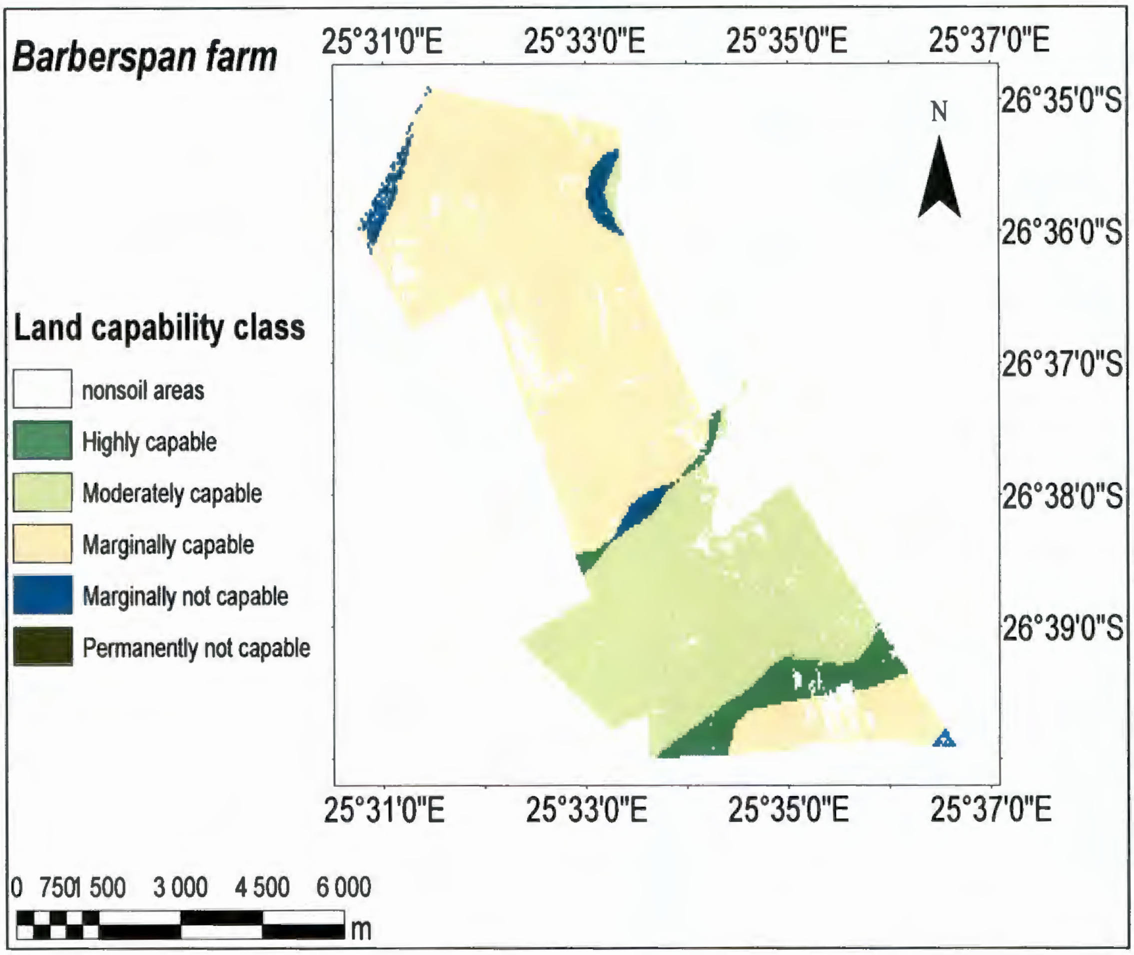


Figure 6.6: Land capability classified map for sunflower

6.4.4 Crop water requirement in Barberspan farm

The crop water requirement peaked during mid-season for maize and started relatively high for both sorghum and sunflower before dropping during the late season. A high of 27.5 mm/dec was reached for maize during the late season, 26.1 mm/dec for sorghum during mid-season and 14.4 mm/dec during mid-season for sunflower.

The reference crop evapotranspiration (ETo) value varies among these crops – Table 6.4, 6.5 and 6.6. Maize had the highest crop evapotranspiration at 560 mm/dec followed by sorghum at 495 mm/dec and sunflower with 440 mm/dec. Sorghum and maize indicated the highest value of irrigation requirement at 118 mm/dec and 97 mm/dec respectively and sunflower has the lowest at 51 mm/dec.

Table 6.4: Crop water requirement for maize

Crop Water Requirements

ETo station: Delarey - 04337913 | Crop: Maize

Rain station: Delarey - 04337913 | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.30	1.30	13.0	3.8	8.8
Nov	1	Init	0.30	1.37	13.7	14.8	0.0
Nov	2	Init	0.30	1.43	14.3	21.5	0.0
Nov	3	Deve	0.37	1.80	18.0	25.2	0.0
Dec	1	Deve	0.50	2.45	24.5	28.1	0.0
Dec	2	Deve	0.63	3.12	31.2	31.9	0.0
Dec	3	Deve	0.76	3.81	42.0	37.6	4.4
Jan	1	Mid	0.89	4.51	45.1	46.2	0.0
Jan	2	Mid	0.94	4.77	47.7	53.0	0.0
Jan	3	Mid	0.94	4.67	51.4	47.4	3.9
Feb	1	Mid	0.94	4.57	45.7	41.6	4.2
Feb	2	Mid	0.94	4.47	44.7	37.9	6.9
Feb	3	Mid	0.94	4.17	33.4	29.2	4.1
Mar	1	Mid	0.94	3.87	38.7	16.0	22.7
Mar	2	Late	0.88	3.33	33.3	5.8	27.5
Mar	3	Late	0.76	2.64	29.1	14.4	14.7
Apr	1	Late	0.64	2.02	20.2	28.7	0.0
Apr	2	Late	0.54	1.52	13.6	33.3	0.0
					559.6	**516.4**	**97.2**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.5: Crop water requirement for sorghum

Crop Water Requirements

ETo station: Delarey - 04337913 | Crop: Sorghum

Rain station: Delarey - 04337913 | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.70	3.03	30.3	3.8	26.1
Nov	1	Init	0.70	3.19	31.9	14.8	17.0
Nov	2	Deve	0.74	3.52	35.2	21.5	13.7
Nov	3	Deve	0.81	3.91	39.1	25.2	13.9
Dec	1	Deve	0.87	4.31	43.1	28.1	14.9
Dec	2	Mid	0.93	4.66	46.6	31.9	14.7
Dec	3	Mid	0.94	4.72	51.9	37.6	14.4
Jan	1	Mid	0.94	4.75	47.5	46.2	1.3
Jan	2	Mid	0.94	4.78	47.8	53.0	0.0
Jan	3	Late	0.90	4.49	49.4	47.4	1.9
Feb	1	Late	0.75	3.66	36.6	41.6	0.0
Feb	2	Late	0.60	2.86	28.6	37.9	0.0
Feb	3	Late	0.50	2.23	6.7	11.0	0.0
					494.7	**400.1**	**118.0**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.6: Crop water requirement for sunflower

Crop Water Requirements

ETo station: Delarey - 04337913 | Crop: SUNFLOWER
Rain station: Delarey - 04337913 | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.35	1.51	15.1	3.8	10.9
Nov	1	Init	0.35	1.59	15.9	14.8	1.1
Nov	2	Deve	0.38	1.79	17.9	21.5	0.0
Nov	3	Deve	0.53	2.56	25.6	25.2	0.4
Dec	1	Deve	0.70	3.42	34.2	28.1	6.1
Dec	2	Deve	0.86	4.32	43.2	31.9	11.3
Dec	3	Mid	0.94	4.72	52.0	37.6	14.4
Jan	1	Mid	0.94	4.75	47.5	46.2	1.3
Jan	2	Mid	0.94	4.78	47.8	53.0	0.0
Jan	3	Mid	0.94	4.68	51.5	47.4	4.1
Feb	1	Late	0.87	4.26	42.6	41.6	1.1
Feb	2	Late	0.65	3.08	30.8	37.9	0.0
Feb	3	Late	0.43	1.92	15.4	29.2	0.0
					439.7	418.3	50.7

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

6.5 Land capability evaluation in former Pienaars Nature Reserve

6.5.1 Maize cultivation

The FPNR is highly capable for cultivation of maize, with 83% being highly and moderately capable. This area consists of clay (light) and sandy loam soil texture. Maize production generally takes place on soils with clay content of less than 10% (sandy soils) or in excess of 30% (clay and clay-loam soils) (DAFF (b), 2010). Marginal capable soil covers 17% of the FPNR and the presence of clay loam prevents good internal drainage and optimal moisture regime. Figure 6.7 shows the land capability classified map for maize.

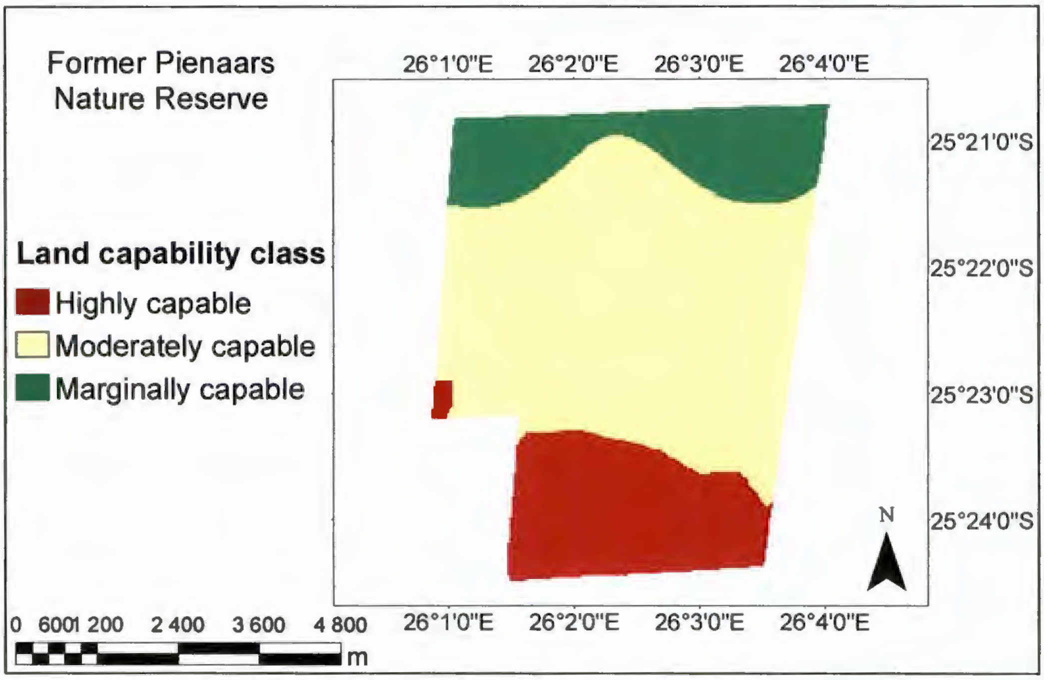


Figure 6.7: Land capability classified map for maize

6.5.2 Sorghum cultivation

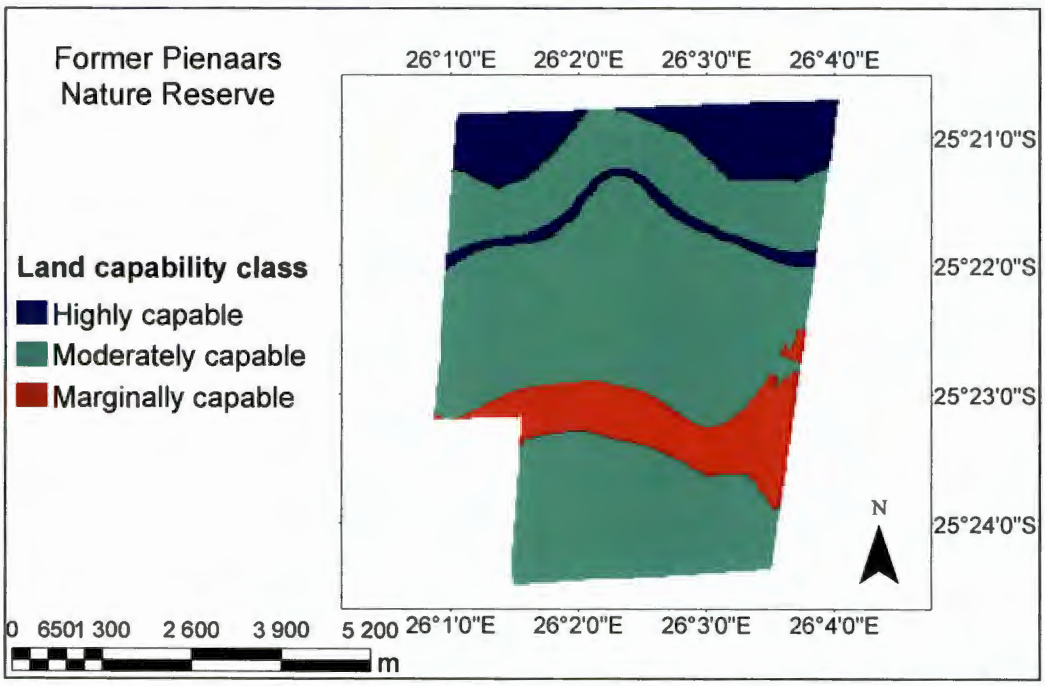


Figure 6.8: Land capability classified map for sorghum

Grain sorghum can be grown on many different soils and the presence of shallow soil depth and clay loam texture means that 15% of FPNR is highly capable for sorghum. Moderately capable area covers 74% of FPNR and consists both of sandy loam and clay (light) soil. The marginal capability in FPNR covers 11%. This area has a pH range from 5.9 to 6.2. Figure 6.8 shows the land capability classified map for sorghum.

6.5.3 Sunflower cultivation

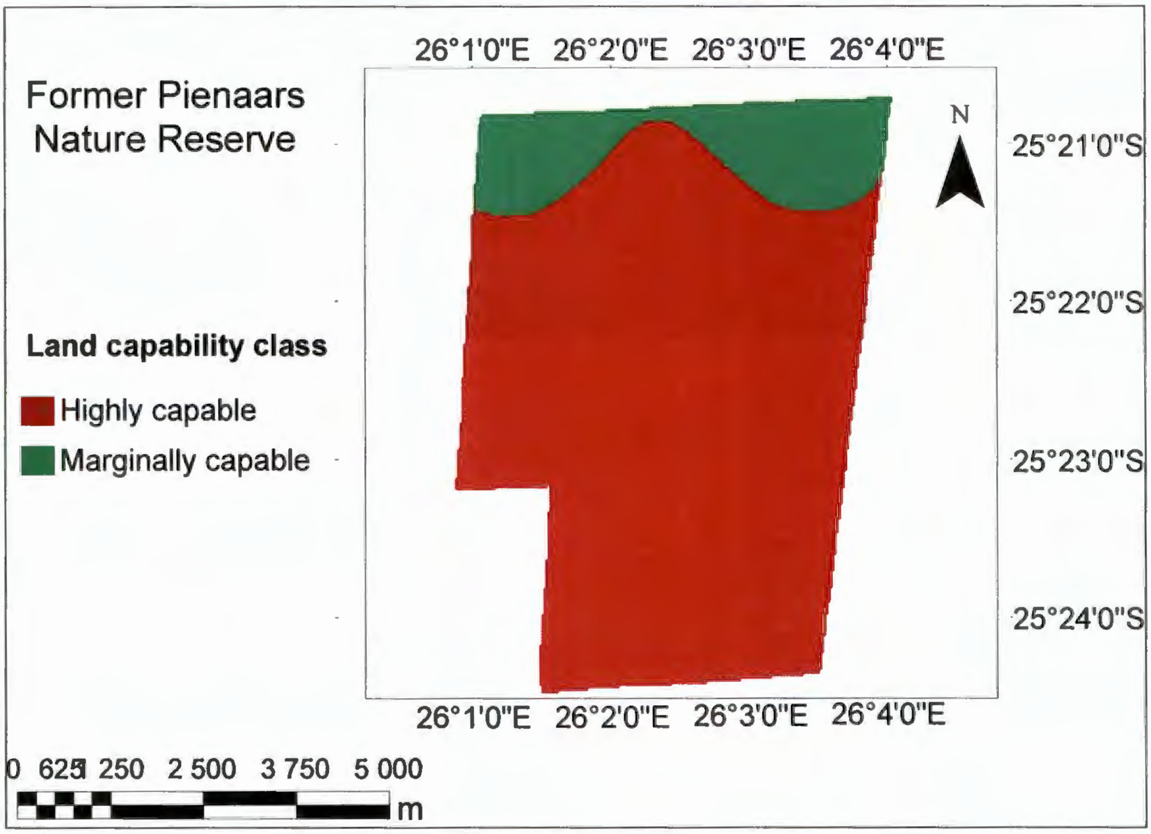


Figure 6.9: Land capability classified map for sunflower

High capability area for sunflower cultivation covers 85%. The sandy loam to clay texture provides ideal soil conditions and the area has over 100 cm soil depths. The low soil depth is a hindrance for cultivation and is thus marginally capable. Figure 6.9 shows the land capability classified map for sunflower.

6.5.4 Crop water requirement in former Pienaars nature reserve

From the results of data collected (see Chapter 4) specifically for this study, it was found that crop water requirement increased from initial stage of crop growth and is usually at its peak during mid and late season. A high value of 18.2 mm/dec was reached for sorghum during late season, 27.4 mm/dec for maize during mid-season and 24.2 mm/dec during mid-season for sunflower. This is called the "peak period" of their water needs as the crops have reached their maximum height; they optimally cover the ground; they possibly have started flowering or started grain setting and thus when the crops are fully grown their water need is the highest (FAO, 2007).

As seen from Table 6.7, 6.8 and 6.9, the reference crop evapotranspiration (ETo) value varies greatly among these crops. Maize has the highest crop evapotranspiration at 606 mm/dec compared to the relatively similar values of sorghum and sunflower with 424 mm/dec and 469 mm/dec respectively. Maize and sunflower indicated the highest value of irrigation requirement at 184 mm/dec and 115 mm/dec respectively and sorghum has the lowest at 87 mm/dec.

Table 6.7: Crop water requirement for sorghum

Crop Water Requirements

ETo station: Zeerust - 0509123 3 | Crop: SORGHUM (Grain)

Rain station: Zeerust - 0509123 3 | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.30	1.41	14.1	12.1	0.9
Nov	1	Init	0.30	1.48	14.8	24.4	0.0
Nov	2	Deve	0.39	2.00	20.0	33.1	0.0
Nov	3	Deve	0.55	2.86	28.6	34.8	0.0
Dec	1	Deve	0.71	3.76	37.6	36.9	0.7
Dec	2	Deve	0.87	4.67	46.7	39.9	6.8
Dec	3	Mid	0.94	5.06	55.7	37.8	17.8
Jan	1	Mid	0.94	5.06	50.6	35.8	14.8
Jan	2	Late	0.94	5.05	50.5	34.6	15.9
Jan	3	Late	0.84	4.40	48.4	30.2	18.2
Feb	1	Late	0.68	3.48	34.8	24.5	10.3
Feb	2	Late	0.54	2.71	21.7	15.9	1.8
					423.5	**360.2**	**87.0**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.8: Crop water requirement for maize

Crop Water Requirements

ETo station: Zeerust - 0509123 3 | Crop: Maize

Rain station: Zeerust - 0509123 3 | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.30	1.41	14.1	12.1	0.9
Nov	1	Init	0.30	1.48	14.8	24.4	0.0
Nov	2	Init	0.30	1.54	15.4	33.1	0.0
Nov	3	Deve	0.37	1.93	19.3	34.8	0.0
Dec	1	Deve	0.50	2.63	26.3	36.9	0.0
Dec	2	Deve	0.63	3.36	33.6	39.9	0.0
Dec	3	Deve	0.76	4.08	44.9	37.8	7.0
Jan	1	Mid	0.89	4.79	47.9	35.8	12.1
Jan	2	Mid	0.94	5.04	50.4	34.6	15.8
Jan	3	Mid	0.94	4.94	54.3	30.2	24.1
Feb	1	Mid	0.94	4.83	48.3	24.5	23.8
Feb	2	Mid	0.94	4.73	47.3	19.9	27.4
Feb	3	Mid	0.94	4.51	36.0	19.7	16.4
Mar	1	Mid	0.94	4.28	42.8	18.3	24.5
Mar	2	Late	0.88	3.81	38.1	16.8	21.2
Mar	3	Late	0.77	3.03	33.3	22.5	10.9
Apr	1	Late	0.66	2.34	23.4	32.3	0.0
Apr	2	Late	0.56	1.77	15.9	35.0	0.0
					606.2	508.8	183.9

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.9: Crop water requirement for sunflower

Crop Water Requirements

ETo station: Zeerust - 0509123 3 | Crop: SUNFLOWER

Rain station: Zeerust - 0509123 3 | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.35	1.65	16.5	12.1	3.2
Nov	1	Init	0.35	1.72	17.2	24.4	0.0
Nov	2	Deve	0.38	1.93	19.3	33.1	0.0
Nov	3	Deve	0.53	2.75	27.5	34.8	0.0
Dec	1	Deve	0.70	3.68	36.8	36.9	0.0
Dec	2	Deve	0.87	4.64	46.4	39.9	6.5
Dec	3	Mid	0.94	5.05	55.6	37.8	17.7
Jan	1	Mid	0.94	5.05	50.5	35.8	14.7
Jan	2	Mid	0.94	5.05	50.5	34.6	15.9
Jan	3	Mid	0.94	4.95	54.4	30.2	24.2
Feb	1	Late	0.88	4.50	45.0	24.5	20.6
Feb	2	Late	0.65	3.25	32.5	19.9	12.6
Feb	3	Late	0.43	2.07	16.6	19.7	0.0
					469.0	383.9	115.4

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

6.6 Land capability evaluation in Antwerp farm

6.6.1 Maize cultivation

The sandy soils of Antwerp farm (Figure 6.10) are capable for maize cultivation as it provides good internal drainage and an optimal moisture regime. The crop needs to be highly irrigated during the dry periods as the soil needs to be able to retain few weeks of water or the crop suffers. With a soil depth of 100 cm, it is free from restrictive layers (hardpan) and has a pH higher than 4.5.

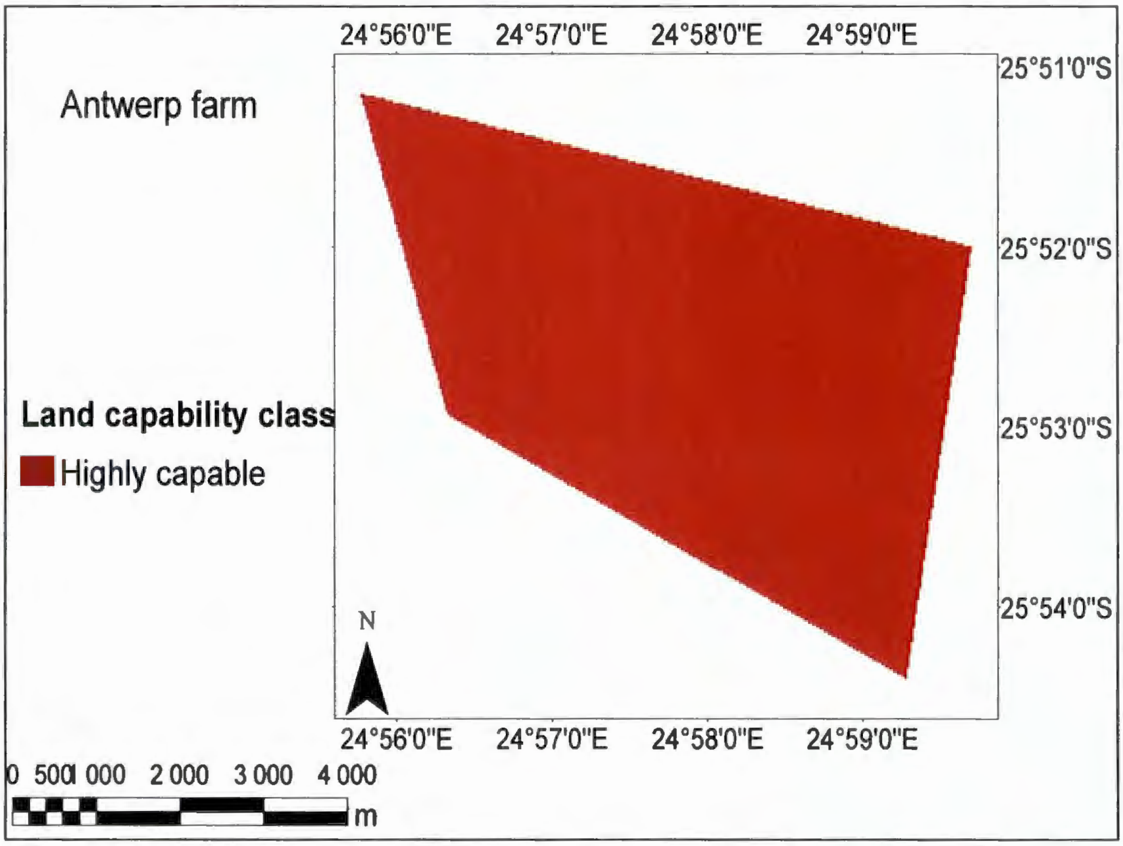


Figure 6.10: Land capability classified map for maize

6.6.2 Sorghum cultivation

Sorghum usually grows poorly on sandy soils and with Antwerp farm covered by sandy soil texture. The area is marginally capable for cultivation. All other factors such as pH of 6.1, a soil depth of 100 cm and a deep well-drained fertile soil are appropriate. Figure 6.11 shows the land capability classified map for sorghum.

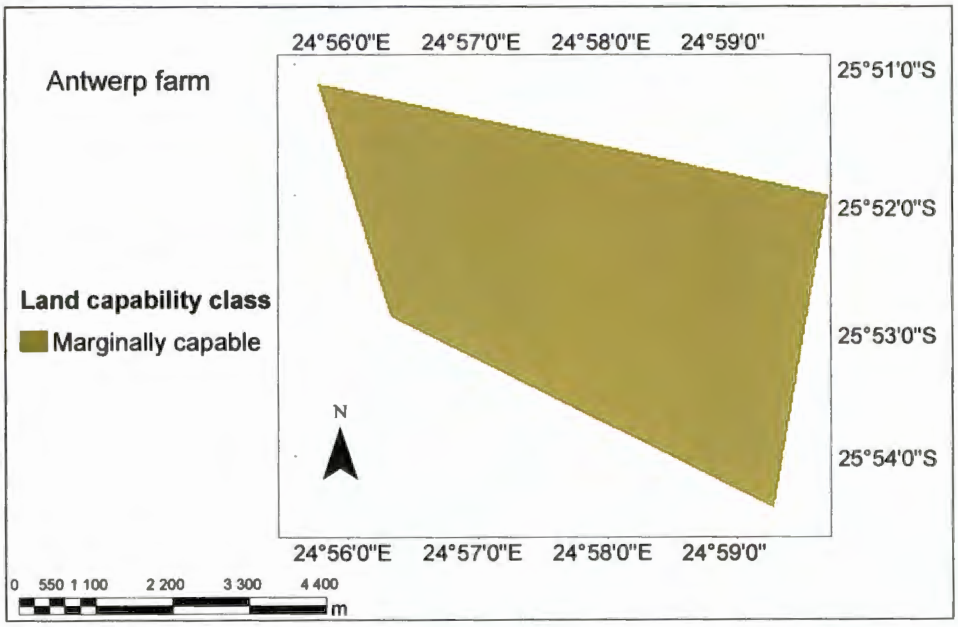


Figure 6.11: Land capability classified map for sorghum

6.6.3 Sunflower cultivation

Sunflower grows well in sandy loam to clays soil types and the 93% sand fraction in the farm means the crop is moderately capable for cultivation.

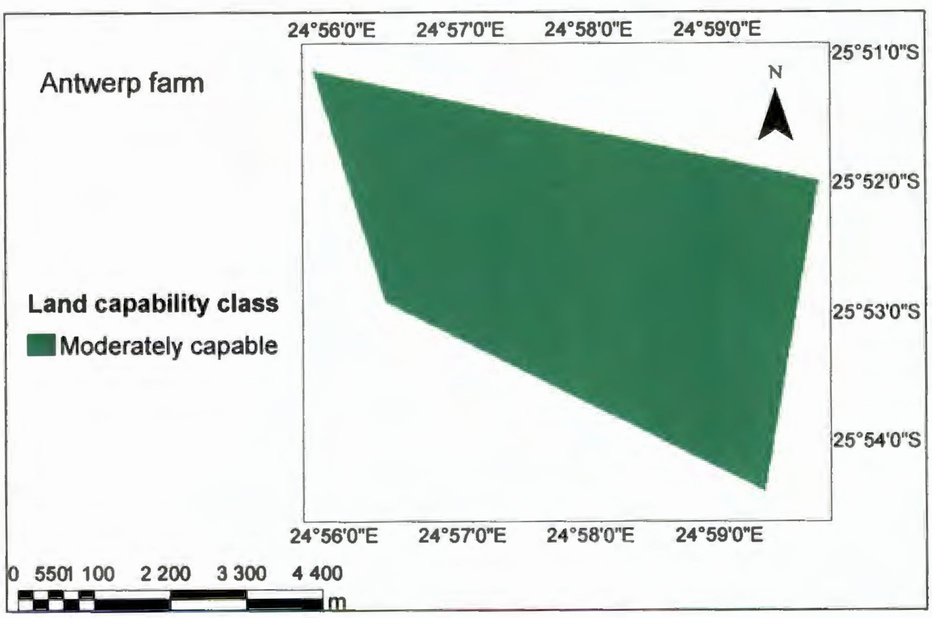


Figure 6.12: Land capability classified map for sunflower

Sunflower is not highly sensitive to soil pH and is grown on soils ranging in pH from 5.7 to over 8; with a pH of 6.1, the soil on this farm is capable. Figure 6.12 shows the land capability classified map for sunflower.

6.6.4 Crop water requirement in Antwerp farm

The crop water requirement was consistent throughout the growing period for sorghum, sunflower and maize, although initially maize had low values. A high of 44 mm/dec was reached for sorghum during the mid-season, 45.3 mm/dec for both maize and sunflower during mid-season.

The reference crop evapotranspiration (ETo) value varies among these crops – Table 6.10, 6.11 and 6.12. Maize had the highest crop evapotranspiration at 640 mm/dec followed by sorghum at 552 mm/dec and sunflower with 485 mm/dec. Sorghum and maize displayed the highest value of irrigation requirement at 435 mm/dec and 465 mm/dec respectively and sunflower has the lowest 364 mm/dec. The Antwerp farm is found in the far western region of North West Province which is arid and receives about 350 mm of rainfall per annum. Thus the irrigation requirement of any crop is the highest in the Antwerp farm.

Table 6.10: Crop water requirement for sorghum

Crop Water Requirements

ETo station: Matloding | Crop: Sorghum

Rain station: Matloding | Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.70	3.54	35.4	6.5	28.3
Nov	1	Init	0.70	3.81	38.1	7.1	30.9
Nov	2	Deve	0.74	4.27	42.7	7.4	35.3
Nov	3	Deve	0.81	4.56	45.6	8.8	36.8
Dec	1	Deve	0.88	4.80	48.0	10.7	37.3
Dec	2	Mid	0.94	5.02	50.2	12.2	38.1
Dec	3	Mid	0.95	5.08	55.9	12.0	43.9
Jan	1	Mid	0.95	5.09	50.9	12.0	38.9
Jan	2	Mid	0.95	5.11	51.1	12.2	38.9
Jan	3	Late	0.91	4.87	53.6	10.5	43.1
Feb	1	Late	0.76	4.05	40.5	7.8	32.7
Feb	2	Late	0.61	3.23	32.3	5.9	26.4
Feb	3	Late	0.52	2.62	7.9	3.0	3.9
					552.4	116.2	434.6

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.11: Crop water requirement for maize

Crop Water Requirements

ETo station: Matloding — Crop: Maize

Rain station: Matloding — Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.30	1.52	15.2	6.5	8.0
Nov	1	Init	0.30	1.63	16.3	7.1	9.2
Nov	2	Init	0.30	1.73	17.3	7.4	9.9
Nov	3	Deve	0.37	2.09	20.9	8.8	12.1
Dec	1	Deve	0.50	2.73	27.3	10.7	16.6
Dec	2	Deve	0.63	3.36	33.6	12.2	21.5
Dec	3	Deve	0.77	4.10	45.1	12.0	33.2
Jan	1	Mid	0.90	4.84	48.4	12.0	36.4
Jan	2	Mid	0.95	5.11	51.1	12.2	38.9
Jan	3	Mid	0.95	5.07	55.8	10.5	45.3
Feb	1	Mid	0.95	5.04	50.4	7.8	42.6
Feb	2	Mid	0.95	5.01	50.1	5.9	44.1
Feb	3	Mid	0.95	4.83	38.6	7.9	30.8
Mar	1	Mid	0.95	4.65	46.5	11.0	35.6
Mar	2	Late	0.89	4.19	41.9	12.9	29.0
Mar	3	Late	0.77	3.37	37.1	11.4	25.7
Apr	1	Late	0.66	2.64	26.4	9.8	16.6
Apr	2	Late	0.55	2.02	18.2	8.0	9.4
					640.3	**174.2**	**464.6**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

Table 6.12: Crop water requirement for sunflower

Crop Water Requirements

ETo station: Matloding — Crop: SUNFLOWER

Rain station: Matloding — Planting date: 22/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	3	Init	0.35	1.77	17.7	6.5	10.6
Nov	1	Init	0.35	1.90	19.0	7.1	11.9
Nov	2	Deve	0.38	2.17	21.7	7.4	14.3
Nov	3	Deve	0.53	2.98	29.8	8.8	21.0
Dec	1	Deve	0.70	3.82	38.2	10.7	27.5
Dec	2	Deve	0.87	4.65	46.5	12.2	34.3
Dec	3	Mid	0.95	5.07	55.8	12.0	43.8
Jan	1	Mid	0.95	5.09	50.9	12.0	38.9
Jan	2	Mid	0.95	5.11	51.1	12.2	38.9
Jan	3	Mid	0.95	5.07	55.8	10.5	45.3
Feb	1	Late	0.88	4.68	46.8	7.8	39.0
Feb	2	Late	0.65	3.43	34.3	5.9	28.3
Feb	3	Late	0.43	2.21	17.7	7.9	9.8
					485.2	**121.1**	**363.5**

Where: IR = Irrigation Requirement (mm/dec), Kc = Crop Coefficient and ETcrop = Crop Evapotranspiration (mm/day), Eff rain = Effective rain (mm/dec) and ETcrop = Crop Evapotranspiration (mm/dec).

6.7 Summary

This chapter presented the land capability results of each study site for agricultural production. Analysis of results showed that the land capability varies greatly between areas for sorghum and areas for both maize and sunflower. This chapter showed the advantage of GIS, the ability to generate output maps in a moderately short time with less effort and lower cost than from traditional methods and conventional map updating.

Chapter Seven

General discussion

7.1 Introduction

This chapter discusses the research findings and their relationship to the existing relevant theories described in the literature review (Chapter 3). The previous chapter incorporated spatial data and related attributes such as soil properties and climate data into a database to analyse agricultural land capability.

7.2 Result of land capability evaluation

7.2.1 Physical land capability

The importance of components or factors in the framework in contributing to the agricultural land capability is indicated by their weighting. The weight of components varies between every administrative scale as well as between farming systems. Therefore, a component, or factor can be very significant at the district scale, but insignificant, or not considered at all at the commune and farm scales. Likewise, a factor may have a significant impact on the land capability for vegetables production, but may contribute less to the land capability for maize cultivation.

The main components of physical capability (soil, land and climate) in this study were ranked into high, medium, low and very low value for each crop group. Factors restricting crop growth and development may be reduced by making use of external factors such organic fertilizers to ameliorate organic matter deficiency. The ability to transform land from one capability level to another means all land is potentially fertile. This provides an opportunity for the farmers to take measures and improve the agricultural land production to enhance output.

Soil depth was generally not a problem as only 13% of all study sites was below 100 cm. Data analysis showed that only 21% of drainage was imperfect, and all crops had almost ideal drainage conditions. Sorghum, though, can better tolerate short periods of waterlogging compared to maize. 22% of the study areas had the high clay content ideal for sorghum. The remaining areas are capable for maize and sunflower production. The climatic factors during the growing period are not a constraint to crop production. Most of the study areas average 500 mm of annual rainfall and temperature ranges from 27°C to 30°C.

Soils in the study areas do not generally suffer from fertility deficiency. The soils can be termed "permanent" soils, as they can generally tolerate permanent crops over an extended period of time, or can recover fertility after a break period not much longer than the period of cultivation (if not overly extended). This of course is reliant on irrigation availability. Increase in organic matter through humus can massively elevate fertility ratings and improve capability levels for sorghum and benefit maize and sunflower crop. The ability of sunflower to perform well under dry conditions is perhaps the reason for the crop's popularity in the marginal production areas of South Africa. Sunflower and maize can be grown in the same area and as a result, farmers can simply change to sunflower if the optimum time for maize planting has elapsed. The two crops can be intercropped. Intercropping consists of cultivating more than one crop in the same area concurrently and the crops may be seeded concurrently (mixed intercropping) or they may be seeded at different times (relay intercropping) (UMANITOBA, 2004).

7.2.2 Crop water requirements

The type of crop can determine the everyday water needs of a mature crop, that is, the peak daily water needs of a fully grown crop (FAO, 2006). The crop type also influences the period of the total growing season of the crop. Maize generally has a lower daily water need than sorghum or sunflower, but it also has a longer growing period (up to 180 days, compared to 130 for sorghum and sunflower), leading to a higher seasonal water requirement and irrigation demand. The results showed that reference and crop evapotranspiration (ETo and ETc) were higher for crops with longer growing season than for those with shorter ones. Also, a study by FAO (2006), reported that crops grown in the summer season need more water than those grown during the winter season. Stress on water resources due to rising demand by competing users like mining is already leading to water scarcity in many places. Generally though, the crops chosen in this study can be grown solely on rainfall received during the rainy season (October to April). There is however a need for better management and planning of water resources to optimise water use and balance competing demands. The main purpose of irrigation for agriculture is to sustain crop evapotranspiration (ETc) when there is not enough rainfall. Hess (2005) defined CWR for a crop as the total water required for evapotranspiration, from cultivation to harvest in a specific climate environment. Fertile soil provides crops with nutrients and appropriate quantity of aeration and soil moisture. To maintain and improve fertility, soil management plays a very important role. Soil management is the entirety of all processes such as cropping practices, lime, fertilizer, and other managements to the soil for the cultivation of a crop (Eash *et al.*, 2008).

7.3.3 Natural and socioeconomic capability

Land capability analysis is a multi-dimensional approach and thus various factors are considered. Integration of non-spatial data allows factors such as cultivation attitude of the community, net irrigation requirement and gross value of agricultural production to be considered. Natural and socioeconomic capability affects the potential yield and thus the economic benefits of a crop.

The multi-criteria analysis that has made use of factors such as physical land and socioeconomic features can only proceed if the site is physically capable. The agricultural land capability framework provided in this study can be generalised and used in areas with similar geographic characteristics.

One of the main contributors to rural poverty is probably the shortage of access to agricultural land, but the poor condition of land in communal areas is a huge problem and a hindrance to agricultural development and lessening of impoverishment. Land deterioration intensifies poverty and poor farming methods can also induce poverty and create a sinking spiral of human and environmental collapse (UNCCD, 2012). Change from agricultural land to non-agricultural uses is an increasing worry in North West Province. The agricultural land is mostly converted to built-up land due to development pressure or left bare (DAFF, 2011). The result of this study could be useful to the stakeholder, state and community to recognise the agricultural capability of the land for better land use and management. The National Land Care Programme (NLP) had set importance on soil fertility studies mainly by incorporating crop nutrient organisation systems that include both organic and inorganic fertilisers (DAFF, 2011). Therefore management must come from the policy statements, which should inform working plans that aid the execution of land management activities.

Geospatial information technology is an essential tool for planning communal agricultural practices, yet it receives insufficient attention among planners and policymakers. It is also not attaining sufficient consideration of planners and policy creators for agricultural land management in communal areas. The current research work has showed the necessity of allround information examination for the expansion and improvement of agricultural farming at the community level. The result of this research can help improve the management of natural resources. Hence socioeconomic aspects should, along with land properties, be integrated as in the current study to provide valuable, broad and easy-to-update information systems. Due to the continual deterioration of natural resources, applicable natural resource management policy decisions are of utmost significance amid numerous policies employed in emerging nations (Babu and Roe, 2000). Soil fertility and nutrient availability in soils of the study sites requires reasonable external input. To preserve the soil productivity and sustain agriculture over an extensive period, fertilizer nutrient applications are essential although any over-application of external input can be wasteful and detrimental to the crop. Excessive use of fertilizer reduces fertility of soil and can also increase soil degradation through nutrient mining (Baniya, 2008).

7.4 Feedback from the land capability study implementation

The results of the land capability analysis presented in Chapter 5 showed that the theoretical framework is well accustomed and works well in the study sites. Land evaluation in this study involved a multi-sector approach to analysis using various components. This reflects the present trend in land evaluation (Tin, 2011). In the development of the framework for land capability evaluation, the land capability is simultaneously examined and balanced between land characteristics as in this method the outcomes of land evaluation are more dependable and applicable.

Table 4.12 shows that relationships and interactions exist within and between components and factors in the framework. Thus the impact of a certain component, or factor, on the land capability is always linked to, and relates with, the influence of other components, and factors, in the framework. This is the characteristics of the framework in that it uses interrelationships between components in the system to achieve a common purpose.

Weighting components and factors in the agricultural land capability framework are important as it shows which factors in the framework need to be enhanced to increase the land capability. This is one of the satisfactions and advantages of using visual input such as maps and tables when evaluating the agricultural land capability assessment through a framework. The land capability analysis not only examines the impact of the individual land characteristics, it also considers the impact of relationships and interactions between different land characteristics on the land capability. Founded on the land features that are stored in the agricultural land capability database, the land capability can effortlessly be determined and forecasted over an extended period. When data on land quality is accessible, it is placed into the land capability framework to generate a superior land capability output. The output can be stored in a GIS and used for prospective land management.

Together with the physical land capability evaluation, consideration of the socioeconomic parameters and environmental features in land evaluation is necessary. This multi-dimensional land evaluation method provides alternatives for land administrators to release stresses on land use as a result of agriculture production according to market positioning, varying farming structures, environmental pollution, and land degradation. Specifically, the strong point of such a method is that a GIS-founded agricultural management system can successfully measure and forecast the capability of agricultural land as well as map and observe agricultural production.

Also, the land capability in the study sites recognised the following points which need to be considered:

(1) Many features chosen in a database are not usually obligatory as often only very important features are necessary. If all features are incorporated then that means its impacts on the land capability will have less significance and this will produce a weak capability framework (Tin, 2011). Land development and land capability modelling cannot be completed when considering insignificant features for the reason that it reduces the results and the outputs from the framework resulting in the framework not being important and valued. This agrees with the theory on the hierarchy technique (Saaty and Vargas, 2001; Bhushan and Rai, 2004) where the number of features in the hierarchical order for weighting should be less than fifteen;

(2) To function efficiently, the framework needs a precise and reliable database structure i.e. quality data. The database consisting of primary and secondary data, which requires to be updated to the period when the land evaluation study is started as a lack of accessible and current data will result in imprecise outcomes in the land evaluation;

(3) Information provided into the database to determine the land capability at the community and farm levels are symbolic data for the whole community or farm. Thus, in some

circumstances the outcomes of the land capability evaluation are marginally different i.e. at district level, commune or on specific selected farms.

7.5 Land capability as part of land reform policy

The four study sites in this research are all redistributed land under the land reform programme. A number of articles, assisted by statements from prominent policy makers, have shown that land reform recipients are encountering several difficulties with access to amenities, such as credit, training, technology extension, transport, ploughing services, and marketing services (Lahiff and Li, 2012; HSRC, 2003; Hall, 2004; Wegerif, 2004; and Bradstock, 2005) and thus most new farmers are failing either to produce or realise positive use of the land. Land reform recipients and other small-scale farmers are then generally left to look out for themselves, resulting in land being used inadequately or not at all.

Most amenities that are offered to land reform beneficiaries are provided by the local provincial departments of agriculture and other small NGOs, but there are strong indications that suggest that these reach only a few claimants. In research conducted on LRAD projects in three provinces, the Human Sciences Research Council noted that "in numerous circumstances there is still no institutionalised alternative to laying the whole burden of training, mentoring and general capacitation on the provincial agricultural departments" (Byamugisha, 2014). Using nine LRAD projects as case studies in the Eastern Cape Province, Hall (2004) detected that no one had acquired any backing from the private sector and that the majority of claimants never interacted with the Department of Land Affairs after transfer of their land while, only two claimants had received any infrastructure support from the Department of Agriculture, and none was receiving any form of extension service.

In November 2005, the minister for agriculture and land affairs acknowledged that 70% of land reform projects in Limpopo Province were dysfunctional, and the minister attributes this to generally a lack of post-settlement support (Farmers Weekly, 2005). In 2010/11, 411 farms were served with 'functional agricultural infrastructure' under the Recapitalization and Development Programme, a low percentage of the total attained since 1994 (DRDLR, 2011).

At one point the state organisations approved an initiative that was meant to solve the commonly encountered difficulties experienced by newly resettled farmers, such as lack of investment, probably of skills and suitable support services, particularly in the context of PLAS (Proactive Land Acquisition Strategy). Under PLAS, beneficiaries are supposed to demonstrate their farming ability in the early period of leasehold; thereafter they are allowed possession of the land at the discretion of state official and reliant on access to redistribution grants and other investment (Lahiff and Li, 2012). There are, however, concerns that have been raised, as rejection of land title can affect the access to financial support especially during the preliminary settlement phase as there could still be indecision about long-term ownership of the land (Lahiff and Li, 2012). Also, this prerequisite that new agriculturalists exhibit profitability inside the given three to five years is thus generally understood as impractical for a farming start-up. Consequently, there are severe uncertainties that continue as the set circumstances enforced under PLAS will truly be able to provide more sustainable and productive land use.

There is generally no comprehensive policy that is intended to provide support for agricultural development to land claimants after land transfer. Also, the organisations that are assigned with this role have hardly made an impact in this respect. Over the recent years, huge attention has been concentrated on the formal aspects of property rights and little on land use. This study suggests the implementation of Agricultural Impact Assessments (AIA) as part of land reform policy prior to acquisition of land to land claimants. With the claimants, this would comprise building on current agricultural approaches and identifying farmer's requirements such as the provision of correct sized holdings.

AIA is based on a land capability study in the format as prescribed by DAFF (2010):

(a) The topography and hydrology of the site.

(b) The type and characteristics of the soil.

(c) Water availability: The quantity and quality of water for purposes of irrigation.

(d) Size: Tracts of high value agricultural land are considered to be agriculturally viable regardless of their size. Applications for the development of such land need to be accompanied by AIA reports that demonstrate the extent of the land concerned.

(e) Classification of neighbouring land use: Tracts of high value agricultural land adjacent to tracts of land with a different land use classification are considered agriculturally viable, unless demonstrated otherwise through the AIA.

Land capability study as part of post-settlement support is necessary for long-term success of beneficiaries, as post-settlement support is possibly the weakest feature of the South African land reform programme to date. The authorities will have available information on the physical aspects of the various soils and their distribution in the land as well as a classification of their relative capability for agriculture. Also, the risk of land degradation and the necessity to manage land within its capability should be acknowledged at the state level, the more that land is used within its capability, the more sustainable will be the land management practices.

Anecdotal evidence suggests that for a new farming start-up to be prosperous, individual relations between land recipients and local agricultural officials is important. It will offer recipients with extension services such as regular farm visits, setting up relations of trust, and assistance that is suitable to the level of skills and resources of the farmers concerned (Lahiff and Li, 2012).

Land reform is a vital issue of socio-economic revolution in South Africa, as a means both of rectifying historical injustice and of lessening the pressing problems of poverty and inequality in the rural areas (Binswanger-Mkhize, 2009). Land reform programme in the country is established on the country's laws and has the potential for far-reaching change through compensation, tenure reform, and redistribution (Binswanger-Mkhize, 2009). The land reform policies and other applications, though, have not produced anticipated outcomes and have fallen far short of their delivery objectives (Lahiff and Li, 2012). Even in instances where land has been handed over, it seems to have had insignificant influence on the living standards of recipients, mainly due to unsuitable project plan, absence of essential provision services, and lack of working funds, leading to widespread underutilization of land. There is no indication to show that land reform has led to developments in agricultural proficiency, income, occupation or profitability.

The indication of the last 18 years shows that the present method - founded on attainment of land through the open market, minimal backing to new farmers, and administrative burden of production models roughly founded on present commercial operators - is unconvincing to change the rural economy and lift people out of poverty (Lahiff and Li, 2012). A key feature which is noticeably absent from the governance practice is the continuous emphasis on resource utilisation and timely policy adjustment. Much more will be necessary if the land-based economy is to play-a-part in economic growth and to the restructuring of wealth and opportunities to the majority of the population (Binswanger-Mkhize, 2009).

7.6 Summary

A large part of this study was tied to the development of a framework intended to determine agricultural land capability. Capability standards were established for the research area, based on information from the literature and from local land specialists and land administrators.

Weighting components and features in the database exposes connections and interactions amongst principles for land evaluation, especially the inter-relationships within a component and between factors in the database in contributing to the land capability (Tin, 2011). The hierarchy process and GIS are two valuable tools in land evaluation. The latter was used to plan, display, and monitor the land capability while the former supported the identification of the importance of every feature in the database. Moreover, this study offers a methodical approach to agricultural production management in the study areas. The study also offers feedback about the restrictions and important issues related to applying the framework to the real surroundings in the study areas. The significance of the output from the operating framework is influenced by the quality of the data, such as accessibility, dependability, accuracy, capability, currency and consistency, which is entered into the system. The next chapter will conclude the thesis with recommendations for further study.

Chapter Eight

Conclusions, summary and recommendations

8.1 Conclusion

The accomplishment of land reform in South Africa is exceedingly reliant on sound pre-and post-transfer arrangement that will see manageable use of land after transfer. Land reform programme in South Africa is also important in diminishing rural disparity, enhancing nourishment, security and general welfare of rural population. To make land reform projects realise their agricultural potential, this study developed a methodology for land capability evaluation that uses GIS, remote sensing and geostatistics to improve the accuracy of land evaluation. Land capability evaluation as part of post-settlement support is necessary for long-term success of beneficiaries. It is thus extremely fundamental to comprehend land capability to support crop cultivation.

An important outcome of this research is the development of land information database for any land parcel to be assessed for crop cultivation. The land information database requires consistent information update to examine current status, to foresee changing patterns, deterioration and to assess land capability evaluation for crops accurately. The study has demonstrated GIS, remote sensing and geostatistics can be integrated to evaluate land capability of communal lands more accurately with supporting databases for individual crops. The results of this research could help the state in its desire to see new land beneficiaries add to the mainstream agricultural economy being met. Without immediate intercessions, the targets of changing the farming sector and enhancing rural populations through land reform are unlikely to be realised.

8.2 Summary of the thesis

This work incorporates various factors in an agricultural organisational system to determine the capability of agricultural land. Appropriate for various land use types, the land capability system is multi-dimensional, allowing interactions and connections between features affecting land capability to be determined and examined.

The general objective of the study was to develop an agricultural land capability management system (framework), appropriate for capability analysis. Results were based on modifying and testing the framework in the four study sites.

Some of the fundamental questions in this study were:

- What are the main components and features essential for an operational agricultural land capability evaluation and how are these components and features significant to the agricultural land capability?
- Can a GIS founded agricultural management system be established to successfully measure the capability of agricultural land?

Prior to this research there was no incorporation of the biophysical, technical, environmental, and socioeconomic features into an amalgamated structure to consider the land capability in communal areas of North West Province. There was a comparable absence of awareness and studies centred on the agricultural land capability in the study area. Agricultural production, organisation, and land use all depend on the agricultural land capability. Therefore, before the methodologies and the theoretical structure for land evaluation are offered, matters connected to the agricultural sector are reviewed.

Chapter two introduced briefly the study area characteristics. Information and attributes connected to agricultural organisation and production, agricultural land use, soil properties, land capability, climate, and socio-economic, were particularly highlighted. This chapter set out the basic facts to be included for the data analysis and interpretation of the results.

Chapter three began with a discussion on the part that agricultural sector plays in socioeconomic improvement. Agriculture contributes to national economic development and offers investment opportunities for both state and private sectors. It is a way of life for many in the world, as approximately 2.5 billion of 3 billion rural people are associated with agricultural activities such as food production. Agriculture provides employment, income and food security, and is a way of life for many, with approximately 2.5 billion of the 3 billion world rural population being involved with agricultural activities such as food production. The chapter also provided an introduction to agricultural land distribution at numerous levels, at the worldwide, national and down to the local study area setting.

The chapter also discussed concepts, methods, structures, and studies relating to land evaluation. The FAO and USDA are two essential methods normally used to determine the land capability. Improved versions have been created and used in many parts of the world, and we described and evaluated many examples of land evaluation studies globally. Specifically, many examples of land evaluation studies globally were summarised and evaluated. The use of common support tools in land evaluation, such as the hierarchy process and GIS, were also described in this chapter. The chapter discussed the importance to organise an agricultural management system, which encompasses multi-dimensional land features to determine the land capability.

Chapter four related to the structure and establishment of the framework development. The framework was built upon the information obtained from the literature review in Chapter 2. The chapter provided essential materials and methods applied to obtain the required data from various sources, and the research design described a procedural plan to answer the research questions. Calculating the percentage of vegetation cover in a given study area using NDVI method is a good indicator for identifying appropriate areas for soil sampling. In this study, ordinary Kriging as a geostatistical approach was used for mapping the soil properties. The aim was to increase the estimation accuracy by considering the spatial variability of soil properties and also the estimation uncertainty for these soil parameters.

Chapter five described the development of the land information system. The database must be consistent and suitable for retrieving and updating figures and transferring to the associated and dedicated software. The database included biophysical resource, environmental and socioeconomic data. The chapter described the use of geostatistical analysis, specifically Kriging, to model soil sample sites as a continuous surface by interpolating (from) a (finite) set of sample points. Geostatistical analysis of sampled soil properties showed variability with increased distance. Thematic layers of all soil properties showed fairly good soil quality across the study sites, with a moderate diversity of soil groups. The four sites had climatic conditions - hot wet summers - favourable for the cultivation of summer crops. Topographically, the study area is capable for agriculture, as it falls within the requirements of the arable slope classes.

In **Chapter six** the discussion was based around the general research findings and their relationship to the research objectives and existing relevant theories described in the literature review (Chapters 3). The chapter began with a discussion of the physical land capability evaluation in the four study sites. Soils within the study areas generally do not suffer from fertility deficiency, although an increase in organic matter through humus could massively elevate fertility ratings and improve capability levels for sorghum and benefit maize and sunflower crop. The chapter also discussed crop water requirement for sustainable land use. The results showed that crops with a longer growing season had a higher seasonal water need, with higher reference and crop evapotranspiration (ETo and ETc). The crops (maize, sunflower and sorghum) considered in this study are generally

Chapter seven began with a discussion of the selection of capable farming systems and consideration of the land capability in land evaluation. An examination into the choice of effective components and factors used in the land capability database followed. A discussion of feedback from the case study application was also done. Beside advantages provided, the study also commented on the limitations and related matters to contemplate when using the framework to practical environments. It was noted that the yields from the use of the framework depend entirely on the quality of data and are concerned with such variables as accessibility, updating, precision and reliability in the system. The chapter ended with a critical discussion of land capability as part of land reform policy. The discussion concluded that land capability study as part of post-settlement support is necessary to long-term success for beneficiaries, as post-settlement support is possibly the weakest feature of the South African land reform programme to date.

Chapter eight, the important deductions based on the findings and discussions above are presented. This chapter emphasises the contributions that the current study made to the appropriate fields of knowledge, and notes limitations in the theoretical framework application. Finally, the chapter gives recommendations for specialists in the field of land evaluation and guidelines for further research.

8.3 Answering the research questions

The primary output from this research is a framework for agricultural land capability determination. The framework provides a rational and methodical determination of how the land capability is measured based on attribute data sets organised within a spatial database that incorporates not only the biophysical features, but also land development and environmental and socio-economic factors. The principal output from the framework is a map that specifies the land capability classes for many agricultural types. The framework was effectively created, and put together on a sound theoretical base. The framework was efficiently applied in the four study sites, in North West Province. Conclusions in this section are presented in relation to the major research questions expressed at the start of the thesis.

In brief, the research attempted to answer the following questions:

Question 1: What are the main factors necessary for an effective agricultural land capability system?

Current trend in the field of land evaluation demonstrates that land capability evaluation must be a multi-disciplinary method. The agricultural land evaluation procedure necessitates not only the contribution from land specialists; it also needs involvement from other participants such as environmentalists and policy makers. Background information offered in Chapter 3 showed that land capability is connected to many features. Thus in this research, various comprehensive components were assembled into the framework for land capability evaluation, with each component comprising of numerous corresponding factors.

Question 2: Can a GIS be used efficiently to map and observe agricultural production in the research area?

As discussed in Chapter 3, the purpose of land evaluation is to increase long-term agricultural productivity and water quality use. Land capability evaluation in this study delivers data (results) on the foundation of which such decisions can be made through inspecting other potential forms of use created for each area of land. Such investigation comprises significances, benefits and the adverse impacts of such decisions. By this means the results of the land evaluation in the research permitted agricultural production patterns in the study areas to be planned and mapped using function of the GIS. Attributes and the spatial information, of the agricultural production systems were used and kept in the GIS, which can effortlessly be updated, altered and retrieved for future uses.

Question 3: Can an agricultural land capability study form part of land reform programmes?

Key features which are noticeably missing from land reform are the continuous emphasis on practical application of policy, resource utilisation, and timely policy adjustment. There is generally no comprehensive policy that is intended to provide support for agricultural development to land claimants after land transfer. The evidence of the last 18 years suggests that after the acquisition of land by beneficiaries, there is minimal support to new farmers. Land capability study as part of post-settlement support is necessary to long-term success for beneficiaries as the authorities can have available information on the physical aspects of the various soils and their distribution in the land as well as a classification of their relative capability for agriculture.

Question 4: Who are the main beneficiaries of the present research?

Farmers and governmental officers are important users of the current study output. The research methodology could be used as an additional resource to the land planners and agricultural extension workers. Consequently, the current study contains dimension from all the areas, of society and environment, capability evaluation can greatly assist farmers. At the same time, governmental officers associated with land reform can view the result so that agricultural land with high degree of capability is known and not left fallow. Results of agriculture capability evaluation can help the greater extent of land management and planning process for a particular area and thus all participants are supposed to use the results of the current study.

8.4 Contributions of the study

In modern times, food production structure has to meet three main necessities: (1) effectively provide safe, nutritive, and adequate food for the increasing global population, (2) help to alleviate rural poverty by increasing the rural household profits, and (3) lessen and mitigate natural resource depletion, particularly that of land (World Bank, 2008). Agricultural land use generally, face many challenges such as climate change, inundations, drought, land degradation, soil erosion, water and soil pollution, land desertification, and collapse of natural resources (Tilman *et al.*, 2002; Oosterberg *et al.*, 2005, Tin, 2014).

Land reform programmes have been subjected to poor planning, coordination and implementation of projects. Projects are generally arranged without the consideration of beneficiaries and the relevant stakeholders and are then imposed on farmers for implementation. These projects are not sustainable and it is almost impossible for farmers to succeed.

Land capability evaluation provides extremely powerful tools for analysing such issues, and is thus enormously significant for sustainable use of land resource. The current study applied a holistic method established after using a literature review, to develop a framework that incorporates various land features connected to land quality to define the capability of agriculture land. The study uses theoretical perspectives from system principles as defined by the FAO (1993; Haaf, 2002; Baniya, 2008) resulting in the recommendations that (1) a regional land information database should be organised, designed, and developed; (2) factors in the database, which contribute to the capability of agriculture land will be defined, comprising of bio-physical, land development, environmental, policy and socio-economic factors; (3) roles and purposes of every factor in the database should be determined and examined; (4) modelling should include the best projected scenarios of the capability of agriculture land; (6) the processed outcomes of the database yields a capability of agriculture land and the prosperity of farms is demonstrated.

Hence, the purpose of this study was to design a theoretical framework for agricultural land capability. The framework could be capable of being used in areas of similar geographic characteristics. The framework could be sufficiently flexible to be able to adapt to various conditions. The framework permits the evaluation of multidisciplinary capabilities for agriculture land, and the connections among land features can be considered. This permits the capability of agriculture land to be determined accurately and efficiently.

This method allows agricultural officers and administrators to benefit from the huge potential for improving the livelihoods of the land beneficiaries. The research defines the important features that influence upon the prosperity and capability of agricultural land, and the connections between those important features. The outcomes of the research offer theoretical and experimental indication which can be used by policy creators and rural development planners as a source for programme improvement and policy design as it relates to agriculture.

The study presented limitations connected with land features and discussed essential management methods to improve agriculture land capability. Lastly, the most significant result of this research is that it designs a framework for agriculture land capability determination. This was done by incorporating the results of the evaluation and analysis of related features in the database.

The land reform programme needs to place less emphasis on land acquisition and possession and more on land use. A better approach would involve strengthening societies' involvement. On the beneficiary side, this would include building on present farming practices and responding to visibly recognised needs, establishment of suitably sized holdings (created by portioning of large farms) and better flexibility on land use (e.g. cooperating both 'commercial' and 'subsistence' farming).

8.5 Recommendations

It is recommended to distribute that the outcomes of this study to land reform policy makers as identification of very capable and promising crop growing areas might be protected from incapable land use type or land degradation. It is also important that the result of agricultural land capability evaluation is brought into the reach of crop growers. Multidimensional method of present study has provided recommendations for stakeholders as follows:

1. It is necessary to produce the soil databases and land information system, containing soil types and fertility, present land use, climate, slope, vegetation cover, and land unit maps. The database system should be generated within a GIS that will permit editing, updating, overlay and analysis to generate a new thematic map which meets the requirements of the study problem. Use of additional sources such as satellite imagery and Global Positioning System (GPS) will help to provide real time change in land use and management strategy.

2. Additional research should be conducted to build a comprehensive database with close links among various data sources of natural environment, financial settings, infrastructure, and the society.

3. The framework of current research work must be used to determine land evaluation for other agricultural crops as well as other geographical places. In addition to land evaluation, feasibility studies and bankable business plans should also be developed.

4. Agricultural extension services offered in places like Mafikeng and Lichtenburg in North West Province should offer marketing skills, organic farming skills and knowledge on the potential of the land to land beneficiaries. Without this support, farmers are unable to increase food production and make a living out of farming.

5. Input funding policy, better irrigation amenities, quality agricultural inputs, improvement of market support structure, are essential steps to be employed. These improvements should be implemented based on a land capability evaluation.

6. Lastly, the result of the study has to be distributed among local crop farmers so that they are aware of the capacity and limitation in range of capability of their farm holding. Land use

potential and hindrances should be provided to land users, so that the actual usage of research results will be realised.

The research has been effective, as it is founded on past research knowledge, and using practical experience the framework has been developed to suit the local area. It is with this declaration that the author recommends further studies be built on this work.

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Appendix

Table 1: Weights and ratings assigned to factors and classes for agricultural land capability modelling for sunflower.

SUNFLOWER

Variables	Classes	Ratings	Land capability
Land use/land cover (weight=0.2)	Water	2	Not suitable
	Agriculture land	10	Good
	Bare land	8	Fair
	Wood land	10	Good
Slope (weight=0.1)	0-4%	10	Good
	4-8%	8	Fair
	8-12%	4	Poor
	>12%	2	Not suitable
Depth (weight=0.2)	>100 cm	10	Good
	80-100 cm	8	Fair
	<80	8	Fair
pH (weight=0.2)	5.5-7.5	10	Good
	7.5-8.5	6	Moderate
	<4.5	4	Poor
Texture (weight=0.2)	Clay loam	10	Good
	Sandy loam	8	Fair
	Clay (light)	10	Good
	Sandy clay loam	10	Good
	Sandy	8	Fair
Clay (weight=0.05)	10-20%	10	Good
	20-30%	10	Good
	>30%	8	Fair
Drainage (weight=0.05)	Well drained	10	Good
	Moderately drained	8	Fair
	Imperfectly drained	6	Moderate

Table 2: Weights and ratings assigned to factors and classes for agricultural land capability modelling for maize.

MAIZE

Variables	Classes	Ratings	Land capability
Land use/land cover (weight=0.2)	Water	2	Not suitable
	Agriculture land	10	Good
	Bare land	8	Fair
	Wood land	10	Good
Slope (weight=0.1)	0-4%	10	Good
	4-8%	8	Fair
	8-12%	4	Poor
	>12%	2	Not suitable
Depth (weight=0.2)	>100 cm	10	Good
	80-100 cm	8	Fair
	<80	4	Poor
pH (weight=0.2)	5.5-7.5	10	Good
	7.5-8.5	6	Moderate
	<4.5	4	Poor
Texture (weight=0.2)	Clay loam	10	Good
	Sandy loam	8	Fair
	Clay (light)	10	Good
	Sandy clay loam	10	Good
	Sandy	10	Good
Clay (weight=0.05)	10-20%	10	Good
	20-30%	10	Good
	>30%	8	Fair
Drainage (weight=0.05)	Well drained	10	Good
	Moderately drained	8	Fair
	Imperfectly drained	4	Poor

Table 3: Semivariograms paramaters in Barberspan farm

Variable	Major range	Partial sill	Lag size	Nugget	Type
Organic carbon	0.052	0.015	0.008	0.004	Ordinary
Clay	0.065	40.17	0.008	35.86	Ordinary
pH	0.051	0.015	0.008	0.004	Ordinary
Depth	0.143	0	0.011	2619	Ordinary

Table 4: Semivariograms paramaters in Rietfontein farm

Variable	Major range	Partial sill	Lag size	Nugget	Type
Organic carbon	0.129	0.008	0.013	8.249	Ordinary
Clay	0.087	26.47	0.013	4.722	Ordinary
pH	0.087	0.013	0.013	0.002	Ordinary
Depth	0.087	1601	0.013	285.6	Ordinary

Table 5: Semivariograms paramaters in the former Pienaars Nature Reserve

Variable	Major range	Partial sill	Lag size	Nugget	Type
Clay	0.042	276.6	0.010	0.276	Ordinary
pH	0.121	0.599	0.010	0.127	Ordinary
Depth	0.121	985.7	0.010	1073	Ordinary