AGRO-ECOLOGICAL ZONE BASED FARM PLANNING AT THABA YA BATHO SMALL AGRICULTURAL HOLDINGS: PLANNING AND PRODUCTION PERSPECTIVES

By

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DEDICATION

This dissertation is dedicated to my late father and sister.
Johannes Mosesenyane ‘‘Joe Sample’’ Mabasa and Winnie ‘‘Ausi-Tsakane’’ Mabasa.
May their soul rest in peace. The race is on.

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DECLARATION

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I, Patrick Mickel Mabasa declare that this dissertation, **Agro-ecological zone based farm planning at Thaba Ya Batho Small Agricultural Holdings: Planning and Production Perspectives** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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ABSTRACT

This study assesses agricultural planning and production perspective on smallholder farms of Boschplaats 91 JR using an integration of a geographic information system (GIS) and remote sensing (RS). The main objective was to evaluate the use of agro-ecological zoning (AEZ) in planning and its role in promoting sustainable agricultural production on a smallholder farm. This was achieved through processing, analysis and interpretation of satellite images together with *in situ* spatial data for land suitability evaluation. SPOT-5 images, which were acquired from 2006 through to 2011 were used to detect change that took place in the study area. Agro-ecological parameters such as soil, climate and terrain are limiting factors that would have a negative impact on agricultural production. Soil degradation is also a major problem to food security in Thaba Ya Batho smallholder farms and presents environmental constraints to agricultural expansion. Suitable land that could increase food production was identified and mapped. This contributes to delineation of the suitability of the land and demarcating areas of high agricultural potential. The results show that a GIS and RS make it possible to plan and monitor the use of the environment on Thaba Ya Batho smallholdings. The analysis of climate, soil and terrain has shown that more than 80% of the study area is suitable for both irrigated and dryland production. A number of key constraints faced by smallholder farmers are presented. Lack of experience and poor agricultural planning were found to be among limiting factors to production. Despite the scale at which agro-ecological zones are generated, they still play significant role in planning of agricultural production.

Keywords: Geographic information system, Remote sensing, Agro-ecological zone, Suitability, Planning, Production, Smallholder farm

GLOSSARY OF TERMINOLOGY

Agriculture – Activities associated with the cultivation of land, producing crops and raising livestock that are useful to human beings.

Agro-ecological zoning – Division of an area of land into land resources and mapping units; having unique combination of landform, soil, and climatic characteristics and land cover that has a specific range of potential and constraints for land use.

Commercial farmers – Large scale farmers who primarily produce for the market and make a considerable living from farming.

Geographic Information System – A system for capturing, storing, checking, integrating, manipulating, analysing, and displaying data which is spatially referenced to the Earth.

Land cover – The vegetation and artificial construction covering the land surface.

Land use – Man's activities on land which are directly related to the land.

Planning – A basic management and decision support function involving formulation of one or more detailed plans to achieve optimum balance of resource needs.

Production – The process of producing goods and services.

Remote sensing – Obtaining information about objects or areas at the Earth's surface without being in direct contact with the object or area.

Smallholder farmers – Small scale farmers, mainly own communal land in former homelands, who produce for home consumption. They usually occupy an average area of about 7 hectares.

Soil auger – A tool for boring holes used for collecting soil samples for analysis.

Sustainable development – Development which meets the needs of the present without compromising the ability of future generations to meet their own needs.

ABBREVIATIONS

AEZ	-	Agro-Ecological Zoning
AOI	-	Area of Interest
ARC	-	Agricultural Research Council
CASP	-	Comprehensive Agricultural Support Programme
CBD	-	Central Business District
CBPWP	-	Community Based Public Works Programme
DAFF	-	Department of Agriculture, Forestry & Fisheries
DBSA	-	Development Bank of Southern Africa
DEA	-	Department of Environmental Affairs
DoA	-	Department of Agriculture
DN	-	Digital Number
DSMW	-	Digitised Soil Map of the World
EIA	-	Environmental Impact Assessment
EO	-	Earth Observation
ESRI	-	Environmental Systems Research Institute
FAO	-	Food and Agricultural Organisation of United Nations
GAEZ	-	Global Agro-Ecological Zoning
GLASOD	-	Global Assessment of Soil Degradation
GIS	-	Geographic Information Systems
GDP	-	Gross Domestic Product
GPS	-	Geographic Positioning Systems
ha	-	hectare
ha/lsu	-	hectare per livestock unit
IPCC	-	Intergovernmental Panel on Climate Change
IPGRI	-	International Plant Genetic Resources Institute
IR	-	Infrared
ISCW	-	Institute for Soil, Climate and Water

LADA	-	Land Degradation Assessment in Drylands
LGP	-	Length of Growing Periods
MLM	-	Moretele Local Municipality
NDA	-	National Department of Agriculture
NDVI	-	Normalised Difference Vegetation Index
NLC	-	National Land Cover
NW	-	North West Province
RS	-	Remote Sensing
SARD	-	Sustainable Agriculture and Rural Development
SDWG	-	Smallholder Development Working Group
StatsSA	-	Statistics South Africa
SOTER	-	Digitised Global Soil and Terrain Database
SPOT	-	*Système Pour l'Observation de la Terre*
WADSCO	-	Water and Dam Services Company
WCED	-	World Commission on Environment and Development

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This study explores the role and effectiveness of agro-ecological zoning (AEZ) in sustainable agricultural development as a planning tool within a rural setting. Cloete *et al*. (2009) demonstrate that sustainable agricultural development enhances agricultural planning and production. It describes effective ways of addressing agricultural planning problems experienced on small agricultural holdings. Sustainable agricultural production can only be achieved when agriculture meets the needs of the present generation without compromising the ability of the future generation to meet their own needs. Ngqangweni & Hendriks (2003) identifies rural agricultural development as a priority for the South African government.

Sustainable farming has the potential to improve human livelihoods. Petja *et al.* (2014) indicate that sustainable agriculture and rural development (SARD) practices have the potential to reduce hunger and poverty while sustaining the ecosystem that poor rural people rely on for livelihood. Schulte *et al.* (2014) emphasize that sustainable food production has re-emerged on top of the global policy agenda which is driven by the two contemporary challenges, namely the challenge to (1) produce enough food to feed a growing world population and (2) make more efficient and prudent use of the world's natural resources; including water, atmosphere, soil, nutrients and the natural heritage in the form of biodiversity. Food production is problematic in many parts of South Africa due to land degradation. As a result of water scarcity, yield decreases.

Geographic information systems (GIS) are mostly used to determine the relationship between soil, topography and land use/cover when assessing the land potential (Sivakumar & Hinsman, 2004). The use of remote sensing and GIS is limited in rural areas due to limited resources. SPOT-5 imagery is a suitable tool to be used in providing information on land cover and use. It produces the remote sensing images that could assist in assessing land cover changes across large areas at regular intervals (Simms, 2009). This study explores high-resolution satellite images from SPOT-5 in order to identify suitable areas for production potential for smallholder farms in Thaba Ya Batho.

1.2 Background

Farming is not only important in South Africa, human survival depends on it. It provides safe food every individual. Agriculture is the main source of income on smallholder farms. Baloyi (2010) emphasises that smallholder farms generate self-employment opportunities and improve the standard of living within the local community. Moreover, smallholder farming is important for food security.

This study was undertaken at Thaba Ya Batho smallholder farmers on the farm portion Boschplaats 91 JR. Like many other smallholder farmers in South Africa, Thaba Ya Batho smallholders have not performed well in terms of agricultural production. In recent years agricultural output has declined due to poor farm planning and management although the area is located on high potential agricultural land. Thaba Ya Batho smallholder farm under-perform due to lack of capacity for sustainable agricultural development. Other constraints faced by smallholder farmers include lack of access to markets, finance, communication, infrastructure, education, and skills training (Department of Agriculture, Forestry & Fisheries [DAFF] (2012). Low levels of education also impact on the agricultural sector in rural areas as it becomes difficult for the farmers to understand the environmental management needed in order to achieve high levels of agricultural production. Environmental factors such as water and land use have a considerable impact on agricultural production.

1.3 Research problem

A Thaba Ya Batho smallholder farm experiences environmental risks such as erosion, fire and waste, bush encroachment and land degradation which makes agricultural production difficult. There are many farm plots that are unproductive because of poor management. This results in the establishment of grass and bush encroachment. This condition is a result of lack of land use planning and poor farming practices that degrade the surrounding land. Other factors such as lack of experience in agriculture and environmental monitoring limit production. Currently agriculture provides little income for the households and subsistence agriculture dominates. Smallholder agriculture is diminishing over time as a result of poor planning which results in limited production. Consequently, other farming plots in Thaba Ya Batho are left unoccupied as a result of migration to urban areas. However, part of the study area is characterised by favourable and conducive agricultural environments. This study experimented with AEZ for use in farm-scale production planning. Many models of AEZ are based on provincial, national, and regional scales. The AEZ model is demonstrated in a site-specific (smallholder farm) area to examine its applicability.

1.4 Aim and Objectives

The main aim of the research is to evaluate the use of AEZ in planning and its role in promoting sustainability on a smallholder farm. The specific objectives are to:

1.4.1 Identify, classify and describe agro-ecological zones of the study area;
1.4.2 Use remote sensing technology to do spatial analysis of the change detection maps;
1.4.3 To identify and assess production limiting factors;
1.4.4 To encourage sustainable agricultural development as an important source of food production; and
1.4.5 To assess and characterise the agro-ecological potential of the study area.

1.5 Significance of the study

This study seeks to encourage agricultural planning for production on rural farms. Thaba Ya Batho smallholder farms are examples of such farmers that require a comprehensive agricultural plan for risk management and efficient production. In order to meet the demand for food, the zoning of sustainable agricultural utilisation of smallholder farms is very important. The objective of the zoning is to identify areas with different potential and assess constraints for development. This is done to enable sustainable utilisation of land. The study area is vulnerable to human impact, such as dumping, fire, fuel wood collection and inappropriate land use. For planning purposes, the outcomes of the study will transform farming on smallholder farms and increase sustainable production. The study will provide a unique means of understanding the state of agricultural planning through the use of geo-informatics. It will also create an agro-ecological zone map of Thaba Ya Batho. The AEZ provides an effective base to support land use, planning and management. Sustainable agricultural development is the critical issue to be addressed in order to revitalise smallholder farms.

1.6 Hypothesis

1.6.1 Agro-ecological zoning enables decision support for agricultural production and planning.

1.6.2 The AEZ approach could overcome existing agricultural problems in Thaba Ya Batho.

1.6.3 AEZ can be optimally determined by integrating GIS and RS to identify and map out potential sites for agricultural production.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides the literature review of key themes of relevance to the study. It starts with background and an explanation of AEZ. The background information about smallholder farming in both global perspective and South African context is presented in this chapter. This chapter also explores the concepts of sustainable development on smallholder farms. The challenges faced by smallholder farmers are discussed as well. The applications of GIS and RS on smallholder farm evaluation are also explained.

2.2 Background to agro-ecological zoning

Agro-ecological zoning (AEZ) refers to the division of an area of land into land resource mapping units, displaying a unique combination of landform, soil and climatic characteristics and/or land cover with a specific range of potential and constraints for land use. AEZ can be regarded as a set of core applications leading to assessment of land suitability and potential (Patel, 2004). According to Kurukulasuriya & Mendelsohn (2008), AEZ plays a vital role in dividing a heterogeneous landscape into a set of homogeneous zones. The Food and Agricultural Organisation of the United Nations (FAO) (2005) points out that AEZ has a great potential as a basis for policy-level decision making and could be used as a basis of a legal framework for land zoning. Studies have shown that AEZ as applied in the FAO methodologies, defines zones on the basis of the combination of soil, landform and climatic characteristics (FAO, 1993). Accurate zoning has the potential to assist in the site selection process (Rogan & Chen, 2004). Jensen (1996) describes AEZ as the strategy that can meet the challenges of poor planning and destruction or deterioration of the environment.

Araya *et al.* (2010) indicate that proper AEZ and classification help policy makers, investors and agriculturalist to drive crop suitability and amend the existing limitations to cropping, as well as to plan for better short- and long-term development strategies under climate change scenarios. Williams *et al.* (2008) indicate that AEZ identifies fundamental geographic units that provide information on location and extent of crop-relevant resources and their capabilities and potential for future use as part of strategic planning. It is very important for smallholder farms to understand the environmental factors and their impacts on production capacity.

Literature indicates that the AEZ methodology started in 1975 (FAO, 1996). The methodology has been used to address various questions related to soil inventory, land evaluation, land use planning and management, land degradation assessment and land use mapping at global, regional, national and subnational levels (FAO, 2005). Many models of AEZ are based on the FAO methodologies which characterise the physical factors associated with suitability of various crops in a specific environment.

Wandahwa & van Ranst (1996) indicate that sustainability can be expressed in terms of highly suitable; moderately suitable; marginally suitable; unsuitable with or without the possibilities for land improvements. In the case of this study, zoning aims to demarcate the high potential areas for future use. Collett (2008) finds that zoning for agricultural use provides the opportunity to create areas where farming would be the only land use allowed. Recently, there has been a major focus of AEZ methodology used for specific locations. The results from many studies show that agro-ecological innovations are necessary to develop a new and truly sustainable agriculture that reverses environmental deterioration and at the same time augments the supply of food (de la Rosa *et al*., 2009). Agro-ecological zoning was applied in land degradation assessment of dry lands (LADA). On this issue, it should be mentioned that land degradation affects the world's agricultural land, especially in developing countries (The National Department of Agriculture [NDA], 2005). On the other hand, there are major limitations to global agro-ecological zoning (GAEZ). Fischer *et al*. (2006) indicate that the Global Assessment of Soil Degradation (GLASOD) offers insufficient details and quantification for application within the GAEZ model. Therefore, Fischer *et al*. (2006) propose the need for further validation of the results underlying the databases. Xuegong *et al.* (2006) indicate that most of the existing studies deal with the general sustainable development for the whole country, and few focus on zoning of agricultural sustainability.

2.3 Agro-ecological zone: A global perspective

This review draws on experience from studies conducted in other countries. Several studies have shown the application of AEZ at global, national, district and sub-district levels. A review of the literature indicates that the FAO has been assessing various countries such as Mozambique, Kenya, Nigeria, Brazil, China and Nepal, applying and adapting the methodology to local level (FAO, 1996). The AEZ methodology was first applied on a global scale in assessing food production potential and population-supporting capacities in developing countries, using a 1:5 million scale FAO soil map of the world (Table 2.1). A global digital AEZ land resources database called global agro-ecological zones 2000 (GAEZ) was developed using the digitised soil map of the world (DSMW), the digitised global soil and terrain database (SOTER) and digitized global climate databases (FAO, 2005).

The study conducted by Fischer *et al*. (2006) finds that agro-ecological zoning follows an environmental approach which provides a standard framework for characterisation of climate, soil, and terrain conditions relevant to agricultural production. Crop modelling and environmental matching procedures are used to identify crop-specific environmental limitations under assumed levels of input and management conditions. It is, therefore, necessary to argue that the scale used by the FAO is not sufficient to make a decision at farm level. The FAO indicates that GAEZ provides a global inventory of agro-climates, soil and terrain conditions, and evaluations of land resources potential and constraints, and productivity possibilities for more than 250 combinations of crop and management level. The FAO has developed a technique for inventory, evaluation and planning of land resources, both at global level and in regions and developed countries.

Table 2.1: Scales of land use planning and management

Level of analysis	Scale	Issues
Field or production Unit (site-specific)	>1:50 000	Productive crops and animals; conservation of soil and water; high levels of soil fertility; low levels of soil and water pollutants; low levels of crop pests and animal diseases.
Farm or village (local)	1:1 000 - 1: 50 000	Viable production systems; satisfaction of food requirements, economic and social needs; awareness by farmers.
Country (national or subnational)	1:25 000 - 1:2 500 000	Judicious development of agro-ecological potential and use of irrigation water resources; drought and flood risks; food production and food security; conservation of natural resources and biodiversity, carbon sequestration; land degradation; public awareness.
Continent or world (regional or global)	1:1 000 000 - 1:5 000 000	Land degradation and desertification; preservation of biodiversity; water sharing; water pollution; population development and food security; climate change and agricultural potential and carbon sequestration of agricultural heritage systems; awareness of regional and global institutions.

Source: Adopted from FAO (2005)

2.3.1 Food and Agricultural Organisation of the United Nations (FAO) AEZ model

The FAO developed a GIS model, linking it with its agro-ecological zoning and similar models, to tackle issues of land, food and people at global, national and subnational levels. Much of the work on AEZ has been performed by the FAO to improve food security in developing countries (FAO, 2005). The zones were intended to capture the length of the growing season taking into account soil moisture (Kurukulasuriya & Mendelsohn, 2008). The first series output of the FAO AEZ project covered land suitability estimations for crops at three levels of inputs in five regions of developing countries (1996). Studies conducted show that land suitability evaluation includes the assessment of both land potential for selected crops and water potential of the area (Neamatollahi *et al*., 2012). The study conducted by Fischer *et al*. (2006) demonstrates that an AEZ approach is a GIS-based modelling framework that combines land evaluation methods with socioeconomic and multiple criteria analysis to evaluate spatial and dynamic aspects of agriculture. The study further highlights that the results of global agro-economic zoning include the identification of areas with specific climate, soil and terrain constraints to crop production; estimate of the extent and productivity of rain-fed and irrigation cultivable land and potential for expansion; and impacts of climate change on production, geographical shifts of cultivable land (FAO, 2005). The FAO (1996) shows that the GAEZ database has been used in global land productivity studies for estimation of arable land potential for agricultural expansion by country. Several studies indicate that more than three quarters of the global land surface area is unsuitable for crop cultivation with severe constraints such as cold climate, dry climate and steep topography (Neamatollahi *et al*., 2012).

It is therefore, not surprising that the FAO has used global agro-ecological zoning in regional and country studies on land use changes, population support capacity and land suitability for agriculture (FAO, 1993).

The key elements applicable to the AEZ proposed by the FAO (1996) can be summarised as follows:

- Land resources inventory;
- Inventory of land utilisation types and crop requirements;
- Land suitability evaluation;
- Potential maximum yield calculation; and
- Matching of constraints and requirements.

Reviewing the results of GAEZ, the FAO (1996) proposes that the methodology characterises tracts of land by quantified information on climate, soil, and other physical factors, which are used to protect the potential productivity of various crops according to their specific environmental and management needs. The methodology of the FAO is analysis of various problems of land resources for planning and management at national, regional and subnational levels (FAO, 1996). The results of many studies have shown that AEZ is used globally to assess crop suitability (Fischer *et al*., 2006). Many countries have carried out their own AEZ studies that deliver useful applications and results (Wandahwa & van Ranst, 1996).

2.3.2 AEZ in developing countries: Kenya and Uganda

Uganda and Kenya have similar smallholder farmers as South Africa. The AEZ national studies in Kenya and Uganda have used length of a growing periods (LGP) pattern as a means of capturing inter-annual variation (FAO, 1996). Kenya was used as a case study to develop and test the upgraded AEZ methodology for detailed country assessment. In Kenya the AEZ study involved analysis at district level. SPOT-5 imagery was used for vegetation data to determine the net primary production. The vegetation biomass was used to predict the cattle corridor (Makuma-Massa *et al*., 2012).

Kenya and Uganda are affected by water scarcity. The population relies on subsistence agriculture. Smallholder farmers in Kenya are affected by water scarcity and severe drought (FAO, 2005); these factors have an impact on food production. Farmers rely on seasonal rainfall. According to Makuma-Massa *et al*. (2012) drought affects the production potential of farmers. Vegetation biomass was determined by analysis of seasonal variation of the normalised difference vegetation index (NDVI). The NDVI vegetation analysis of 2000 to 2010 was used to assess the duration of drought events. The correlation between rainfall and vegetation was determined. The NDVI data modelled the time-based trends in land cover properties to assess seasonal variations in vegetation (Makuma-Massa *et al*., 2012).

2.4 Farming operations in South Africa

Agriculture is the cornerstone of the economy. Farming is important in South Africa because it provides food security. South Africa is divided into a number of farming regions according to climate, natural vegetation, soil types, and types of farming practises (Agricultural Research Council - Institute for Soil, Climate and Water [RC-ISCW], 2004). As a result of differences in agro-climatic zones, production is very diverse. Studies indicate that the Southern African subcontinent is characterised by enormous variations in the agro-ecological factors that affect the production system (Botsime, 2006). Water availability in South Africa limits production. According to Benhin (2006) more than 50% of South Africa's water is used for agricultural purposes. Agricultural land is sparse which makes it difficult for the land to be effectively utilised. Livestock farming also remains widespread. The communal areas of South Africa are faced with an excessive fuel-wood collection, inappropriate land use and overgrazing (Sekokotla, 2004).

2.4.1 Farming operations in South Africa

Commercial farming is dominated by white farmers. Schulze (2010) indicates that 40 000 commercial farmers in South Africa occupy 82 million hectares whereas smallholder farmers occupy 14 million hectares of agricultural land. Schulze further indicates that smallholder farms are situated mostly in former "homelands" or black rural areas. There are 147 400 smallholder farmers in former homelands of North West province of South Africa. Commercial farms are capital intensive and small-scale farms are mainly owned by subsistence farmers. The commercial sector produces 95% of the marketed agricultural output in South Africa. Agriculture is important in South Africa as it contributes to the gross domestic product (GDP). Table 2.2 shows the major land use types consisting of subsistence and commercial agriculture in South Africa.

Table 2.2: Major agricultural land-use types in South Africa per million (ha)

	Total Area	Farm land	Potential arable	Arable land used	Grazing land	Nature conservation	Forestry	Other
Developing agriculture /subsistence	17	14	2.5	N/A	11.9	0.78	0.25	1.5
Commercial agriculture	105	86	14.1	12.9	71.9	11	1.2	6.8

Source: Adopted from DBSA (1991), and Palmer & Ainslie (2000)

According to a survey done by Statistics South Africa (StatsSA) in 2013, a 12,8% increase in employment was observed in the agricultural sector during the period January to March 2013 (DAFF, 2013b). Nationally, a total of 54 000 jobs were created during this period. The sector presently employs 739 000 people, up from 656 000 in the previous year. On the other hand, smallholder farming is unable to meet the production expectations as a result of delivering low economic and financial returns which discourages investments.

Mudau (2010) further argues that smallholders in Africa have performed poorly in terms of achieving predicted production levels. High food-prices remain the greatest challenge in South Africa. South Africa exports products such as soya bean oil, sugar, sunflower oil, wheat, maize and apples. The exports have increased from R5,3 billion in 2007 to almost R15 billion in 2012 (DAFF, 2013a), with maize produced in North West being the largest export product in South Africa. Many farmlands plant maize crops, sugar cane and sunflower.

The NDA (2005) emphasises the importance of recognising sustainable development to farmers, to the environment and to people. The elements of sustainable agriculture comprise environmental, economic and social factors. Although unable to supplement the country's produce, smallholder farming aims to improve the standard of living in rural areas. Many smallholder farmers are found in a wide range of locations, including deep rural areas of former homelands, in townships, and cities, and on commercial farms, and mainly produce staple food for household consumption (Lahiff & Cousins, 2005). Studies show that lower rainfall will impact agricultural production more especially in developing countries (Schulze, 2010). A study by the NDA (2005) shows that approximately 40 per cent of the world's food is produced on the 260 million hectares of irrigated farmland. The International Plant Genetic Resources Institute (IPGRI, 2000) shows that millet crop yield in Africa is expected to drop by between 6% and 8% due to lack of rainfall.

2.5 The role of GIS and Remote Sensing

2.5.1 Geographic information system

A geographic information system is a computerised storage, processing and retrieval system that has hardware and software specifically designed to deal with geographically referenced spatial data and corresponding informative attributes (Sivakumar & Hinsman, 2004). Abah (2013) describes a geographic information system as an assemblage of computer equipment and set of computer programmes for the entry and editing, storage, query and retrieval, transformation, analysis and display and printing of spatial data. According to Kairo *et al*. (2002), GIS make it possible to store, retrieve and analyse various types of information very quickly.

The notable advantages of using GIS include the ability to update the information rapidly, to undertake comparative analytical work and generating this information as required (Kairo *et al*., 2002). Neamatollahi *et al*. (2012) demonstrate that GIS provide a powerful and flexible tool that combines large volumes of different kinds of data into new datasets and display these new datasets in the form of informative and accessible thematic maps. Sivakumar & Hinsman (2004) explain GIS as a tool used in organising and management of geographical data. Globally GIS and RS play a vital role as a decision-making means in a problem-solving environment. For example, GIS play a significant role in assessing sustainable water and food supply according to the environmental potential.

2.5.2 Remote sensing

RS was originally developed for military applications by Gaspard Felix Tournachon around 1850 (Konecny, 2003). RS is an acquisition of information about an object or phenomenon, by use of either recording or real time sensing devices that are wireless, or not in physical contact with the object such as by way of aircraft, spacecraft, satellite or ship (Neamatollahi *et al*., 2012). Remotely sensed data reduce time for mapping and field work. As shown by Simms (2009), satellite remote sensing uses reflected energy in the visible and infrared range to produce images. Belal (2011) points out that remote sensing has great capabilities to solve many land resource issues. For example, remote sensing data is used in agricultural research for location of problem areas. The use of satellite imagery monitors land cover changes over time. High-resolution remote sensing images provide good spatial representation of areas. IKONOS is the world's first commercial one-meter resolution colour Earth imaging satellite used for application in wetlands, agriculture and urban planning (Konecny, 2003).

RS allows for a homogeneous and easily-available high quality data over large regions. Benzer (2010) argues that RS is able to divide the land surface into many cells, which permits analysis to be performed on both large as well as small regions. The study by Raju (2004a) shows that RS allows for simple manipulation of objects in geographic space and to acquire knowledge from spatial facts. Moreover, it maximises the efficiency of planning and decision making. For example, satellite remote sensing provides reliable data on crop identification. Furthermore, a number of researches have been carried out to monitor degradation processes.

2.6 Integration of GIS and RS

An integration of GIS and RS provides information on monitoring possible changes in agricultural production. Using GIS and RS enables better understanding of the environment. According to Rawat *et al*. (2013), the applications of GIS and RS mapping provide detailed ways to improve the selection of areas designed to be agricultural, urban and industrial areas of a region. Therefore, GIS and RS techniques are useful tools to manage and map the environment. GIS and RS are successfully and widely applied to provide accurate results or observation over a large area. Alkharabsheh *et al*. (2013) show that the integrated use of GIS and RS helps to assess soil loss on various scales and also to identify areas that are at potential risk for degradation. The technology provides an opportunity for an integrated assessment of the resource development potential within a given time and scale (Abah, 2013). GIS and RS are used to perform planning tasks in different countries. The FAO (1996) argues that GIS serve as tools which overlay spatial data or data layers in order to produce the results in a form of maps and tables. The techniques manage, organise data and map it according to specific needs. Saha (2004) argues that these techniques produce images and tabular reports. Many studies reveal that a geographic information system is a technological tool for comprehending geography and making intelligent decisions (ESRI, 2009; Abah, 2013; Belal, 2011). The development of GIS and RS has allowed large scale synoptic views of the Earth from space (Raju, 2004a). The techniques have been used for data distribution and handling.

2.6.1 Applications of GIS and RS in agriculture

Applications of GIS and RS in agriculture help monitoring management and use of natural resources. Remotely sensed data contribute to sustainable water and food supply according to the environmental potential (Sivakumar & Hinsman, 2004). GIS are used to perform risk assessment (ESRI, 2009) and climate risk evaluation. Sivakumar & Hinsman (2004) demonstrate that agricultural planners use geographical data in order to decide on best zones for cash crops, combining data on soil, topography and rainfall to determine suitable zones. Abah (2013) indicates that agricultural development requires the use of GIS in planning to ensure effective coordination, implementation and monitoring to achieve the objective of sustainable production. Saha (2004) shows that RS mapping offers a unique source of information for many agricultural land evaluations. Experience has shown that the development of GIS and RS has allowed research in agro-climatic characterisation. For agricultural application, remotely sensed satellite data detect and map change in vegetated areas (Raju, 2004b).

GIS and RS tools are further used in crop estimations or predictions. GIS and RS are used in agriculture as a decision support tool in yield prediction. Caldiz *et al.* (2002) argue that GIS simulation models and yield gap analysis identify actual yield defining/yield limiting and yield reducing factors. The FAO (1996) indicates that with GIS the changes either in land-use suitability or environmental degradation can be estimated. RS data is effective in determining, identifying and mapping crop stress locations. GIS and RS provide periodic information on land use and land cover. GIS help farmers to increase production, reduce cost, and manage land more effectively (ESRI, 2009). ESRI further highlights that the use of GIS in South Africa has resulted in cost-effective, accurate, and objective grain estimation. In South Africa, GIS-based dataset maps help to improve market access for agricultural products.

2.6.2 Applications of GIS and RS in developed and developing countries

The results of many studies have shown that remote sensing technology provides accurate and reliable land use/cover information (Yuksel *et al*., 2008). Remote sensing and GIS technology is used for erosion mapping of dam watershed in Turkey. High-resolution satellite imagery provides NDVI for regional monitoring (Jeyaseelan, 2004). GIS and RS technology have been fully applied in developed countries for land evaluation. The techniques are fully used in the diverse fields of architecture, engineering, environmental management and mineral prospecting (Mellett, 1995; Reynolds, 1997). However, most of the GIS and RS research has been conducted in developed countries (Benzer, 2010; Belal, 2011; Baroudy, 2014). A recent study by Petja e*t al.* (2014) shows that in India land evaluation for agriculture was carried out, based on soil survey data incorporating GIS technology. GIS played a vital role in fertility assessment and land use suitability as a result of soil survey data. Dadhwal (2004) studied leaf area index and crop phenology using RS data. The RS data helped in identification and mapping of crop distribution and vigour.

The development of high resolution remote sensing in developed countries highlighted the biophysical assessment factors of land potential and other important factors of crop production such as socioeconomic factors and climate (Abah, 2013). GIS and RS help decision makers to develop effective plans for suitable management of land. High resolution satellite data in China is a useful tool to monitor floods. It is used for mapping post river configuration, flood control work, drainage-congested areas, bank erosion and floods hazards zones (Jeyaseelan, 2014). These techniques have been used in legal and planning issues (Veni, 1999). In fact, the vast majority of developed countries rely on GIS and RS technology for land management (FAO, 2005). In China GIS were applied to protect arable land and foster sustainable development.

China has adopted policies and laws aimed at strengthening the land rights of individual farmers (ESRI, 2009). Surveying technology is commonly used there to solve one of the most pressing land policy challenges. However, technology has enhanced China's ability to feed people by safeguarding the land right of its 800 million farmers (ESRI, 2009). GIS technology provided mapping solutions for rural land registration. Sylla *et al*. (2012) conducted research on GIS technology used to assess environmental problems for land use and land cover changes in Conakry. This study integrated GIS and RS to investigate the land cover and land use. US farmers in particular rely on remotely sensed data and GIS as a basis for visualisation of input and output (Konecny, 2003). According to Belal (2011), in the Nile Delta of Egypt RS provides information to planners. Remotely sensed data was used to track changes to urban expansion which led to loss of agricultural land. To this extent, it has been established that the results obtained using GIS and RS offer valuable opportunities in the decision making process of land management planning (Petja *et al*., 2014).

In the sub-Saharan African region, it was found that GIS and RS play an increasing role in agricultural planning and development (ESRI, 2009). GIS are used to indicate different types of soils useful for agricultural planning and production. Petja *et al.* (2014) indicate that GIS provide decision-makers with a unique view of a landscape that enables land managers to improve natural resource management. GIS and RS analyse and evaluate land use for management of natural resources. The FAO (1996) extensively developed a GIS model to determine land mismanagement in Kenya. This model was designed to generate a number of land units or classes in order to improve the land use. The model supported decision making in agricultural management.

Furthermore, other studies have shown that the interpolation capabilities of GIS and RS techniques can be used for soil erosion assessment (Benzer, 2010). GIS and RS have substantial benefits for developing countries. For example, GIS are currently used in the lower River Benue basin in Nigeria for mapping and evaluating agricultural land use patterns (Abah, 2013). In Kenya GIS and RS are used as a tool for the management of mangrove forest (Kairo *et al*., 2002). In both instances, the technique proves to be a valuable resource. Remote sensing makes it possible to identify loss of forest resources (Simms, 2009).

Currently, the GIS technique has been used for impact assessment of erosion. It has proven to be an effective approach for estimating the magnitude and spatial distribution of erosion (Alkharabsheh *et al*., 2013). A study indicated that GIS and RS have already been used for long-term drought management where action plan maps were generated at watershed level for implementation (Jeyaseelan, 2004). Jeyaseelan (2004) further mentions that RS provides data used to show intensity, estimated movement and expected duration of rainfall.

Recently, in Nigeria, an approach was followed to evaluate land suitability based on the FAO framework by overlaying maps with GIS technology for evaluation of land suitability classification (Abah, 2013). The FAO conducted a GIS-based approach study to assess the land water potential for irrigation in Africa (Urama, 2005). The technology has been used to provide regular images of regional crop distribution. RS has demonstrated a great potential as an ecosystem management tool (Sivakumar & Hinsman, 2004). One of the greatest challenges in developing countries is poorly developed technology. Access to affordable technology remains the greatest challenge.

2.6.3 Applications of GIS and RS in South Africa

The GIS and RS technology in South Africa is used in health, crime analysis, natural resources management, rural planning and agriculture (Mhangara & Odindi, 2013). The South African government uses the technology for planning purposes of human settlement, demarcation of municipalities, local government and environment. The study conducted by Pretorius (2009) shows that GIS are widely used for mapping land use systems on a national scale for land degradation assessment in South Africa. Most of the GIS and RS information in South Africa is applied for mapping land use and land cover (Mhangara & Odindi, 2013).

GIS and RS technologies are used in research and applications in various areas such as the following:

Health

In South Africa, as with other countries, remote sensing has been applied in public health care facilities and epidemiology. Mhangara and Odindi (2013) show that major applications of GIS and RS in public health care include assessment of spatio-temporal trends, disease vulnerability mapping, stratification of risk factors and intervention in resource distribution. GIS are used to improve the health profile in South Africa.

Crime hotspot

The applications of remotely sensed data in crime prevention may include crime events assessment, visibility analysis, situational awareness and movement control (Mhangara & Odindi, 2013). Remote sensing plays a significant role in identification of crime indicators and mapping crime risk areas. The technique is considered important because it determines crime hotspots.

Natural resources management

GIS and RS are effectively used to monitor and manage land resources for AEZ characterisation (Patel, 2004). For this reason, the application of remotely sensed data allows land use planning and optimisation of resources management. GIS display possible human activities that affect the resource availability in South Africa. Petja *et al*. (2014) indicate that RS has been used in South Africa as a tool for monitoring natural resources.

Human settlement

Remote sensing technology contributes to the key development priorities of the South African government. The technology is used to improve livelihoods and environmental quality. GIS and RS are increasingly used in studies on human population densities (Pretorius, 2009). GIS and RS in South Africa have the potential to support management of land administrative policies. For example, GIS and RS protect farming rights through documentation of land boundaries. GIS enhance South Africa's ability to ensure food security, farming rights and land registration (ESRI, 2009). Several studies have shown that in South Africa, SPOT-5 is used for analysing the evolution of informal settlement (Mhangara & Odindi, 2013).

Service delivery

In the poor rural communities of South Africa, the GIS and RS approach provide solutions to service delivery and planning in public institutions. GIS play a significant role in distribution and transmission of electricity, maintenance and strategic expansion of road and rail network and maintenance of bulk water infrastructure (Mhangara & Odindi, 2013). GIS and RS have been used for a policy-orientated approach to provide information to influence development decisions (Petja *et al*., 2014). GIS and RS are also applied to support sustainable socioeconomic strategic priorities set by the democratic government's objective of improving service delivery.

Land degradation

The technique has been used successfully to provide a soil erosion map for South Africa (Fischer *et al*., 2006). Satellite data were used for studying erosional features such as gullies, rainfall interception by vegetation and vegetation cover factors (Saha, 2004). Locally, by using satellite images, the vegetation change across the entire protected area can be monitored over time (Simms, 2009).

Disaster management

High-resolution satellite sensors from SPOT-5 are being used for drought study which involves decision support for water management, crop management and for mitigation and alternative strategies (Jeyaseelan, 2004). RS presents valuable information for flood disaster management. Remote sensing data has become useful to identify areas that are at greatest risk of floods. It is used to identify damage to buildings or infrastructure. The FAO (2005) suggests that GIS and RS improve early warning and contingency planning.

Geo-spatial information is used for disaster response planning. RS plays a significant role in predicting, detecting and assessing of fires (Mhangara & Odindi, 2013). The use of geographical data presents a valuable spatial coverage for early warning. Locally, this has led to the notable advantages in production planning and decision making. Currently, South Africa, like most of the world, relies on SPOT-5 in order to monitor active farms which aid food security. This could decrease factors that extensively damage agriculture (Katsch, 2005).

Risk assessment

GIS and RS are widely used for environmental impact assessment. Satellite remote sensing assesses water quality parameters: sediment concentration, turbidity, chemical contamination and temperature variability (Mhangara & Odindi, 2013). In South Africa GIS and RS are used in agricultural management to determine pest migration on farms. SPOT-5 imagery is able to identify environmentally sensitive areas. For example, RS data is used to detect waste pollution (Jeyaseelan, 2004). The application of GIS and RS plays a role in natural hazard monitoring and impact mapping (Veni, 1999). The technology used in South Africa is able to detect changes in land use patterns. Mhangara & Odindi (2013) demonstrate that SPOT-5 imagery can indicate human induced process such as deforestation and land degradation.

2.6.4 GIS and RS in smallholder agriculture

Remote sensing tools are used for evaluation of planning and land management. As a result of technology becoming much more advanced with time, the application of RS was extended to disaster management in agricultural research (Abah, 2013). According to Petja *et al*. (2014) RS data collection systems such as aerial photography and satellites provide periodic land use, land cover and other thematic information. GIS and RS increase the knowledge of planning and land management (Rogan & Chen, 2004). The advantages of remote sensing and GIS in agricultural planning and production are the following:

- Yield predictions;
- Crop production;
- Land management;
- Risk evaluation; and
- Decision support.

SPOT-5 imagery is suitable for smallholder farm planning because it provides information on land cover and land use. The use of remote sensing along with GIS in smallholder agricultural zoning is essential for planning (FAO, 2005). The main purpose of integrating GIS and remote sensing is to combine spatial varying inputs and outputs. The integration of both techniques provides for identification, monitoring and assessment of agricultural production (Simms, 2009). Topographic maps, land resources maps and contour maps with geographic information form the primary inputs in GIS for agro-ecological zoning (Patel, 2004).

2.7 Satellite images as a tool for agricultural planning

High-resolution satellite images are used to support complex decision making and problem solving. It is important to note that remote sensing enables an information base upon which planning decisions could be taken (Rogan & Chen, 2004). Satellite images allow for better prediction as they provide early warning systems. Simms (2009) indicates that remote sensing satellites are valuable tools for providing managers with data that is objective, reliable and economical. Petja *et al*. (2014) indicate that the increasing availability of remote sensing images, acquired periodically by satellite sensors in the same geographical area, makes it extremely interesting to develop a monitoring system capable of automatically producing and regularly updating land cover maps of the considered site. By using satellite images, the vegetation across the entire farm can be monitored over time. Abah (2013) confirms that ecological data can be effectively monitored using the applications and interpretations of satellite images.

Environmental problems in agriculture can be addressed by advisory information detected from satellite images. Simms (2009) proposes that the spatial component of satellite data allows any vegetation changes to be related back to specific ground coordinates, enabling field investigation to be more focused. Land use planning improves decisions taken for land use and agricultural management, indicates potential for agricultural expansion and minimises the deterioration of land (Collet, 2008).

Table 2.3: SPOT imagery features

Satellite	Launch	Sensor	Type	No. of Channels	Spectral Range (microns)	Resolution (meters)
SPOT-5	May 2002	HRS	Multi-spectral	4	0.5-0.59 (green) 0.61-0.68 (red) 0.79-0.89 (NIR) 1.58-1.75 (SWIR)	10 10 10 10
			Pan	1	0.61-0.68	5 m, combined to generate a 2.5 m product
		HRG	Pan	1	0.61-0.68	10 m (re-sampled at every 5 m along track)

Source: Adopted from Aggarwal (2004). HRS = high resolution stereoscopic, HRG = high resolution geometric, NIR = near-infrared band, SWIR = short-wavelength infrared and Pan = panchromatic band

Table 2.3 shows the characteristics of a SPOT-5 image which consists of four spectral bands (green, red, near-infrared, and short-wave infrared) and 10-meter pixel size. The spectral bands are used to discriminate vegetation. Lillesand *et al*. (2008) show that remote sensing has two modes of operations, active and passive. Passive remote sensing is capable of capturing the energy emitted by sun and reflected by objects on Earth's surface, in visible, near infrared and thermal infrared bands (Jensen, 1996). The energy that reaches back to the satellite sensor is subject to physical and chemical properties of the objects under observation. This provides passive remote sensing the opportunity to identify and map the objects under observation using thematic means of intelligent computing (Konecny, 2003). Simms (2009) shows that the chlorophyll pigment in green-leaf chloroplast absorbs radiation centred at about 0.65 µm (visible red) and also in the blue range (about 0.55 µm).

Planning for agriculture requires knowledge about socioeconomics, environment, crops and livestock management. Abah (2013) describes land use planning as the allocation of land to various categories of use according to criteria formulated during the land evaluation process. In determining land use options, it is important to consider management-related activities. It is important to know the environmental status of smallholder farms before embarking on any agricultural activity. Land use planning identifies land with production potential and identifies constraints to agricultural expansion. It also minimises the ecosystem conflict (Anderson *et al*., 2001).

Poor land use management and planning have negative implications for agriculture and environment. They limit production potential. According to the *White Paper on Spatial Planning and Land Use Management* (Department of Land Affairs DLA, 2001), spatial planning is planning of the way in which different activities, land uses and buildings are located in relation to each other, in terms of distance between them, and the way in which spatial considerations influence and are influenced by economic, social, political, infrastructural and environmental considerations. Land management increases the production in the area and overcomes environmental implications. An agro-ecological approach can be useful when formulating soil specific agricultural practices to assess environmental degradation based on spatial variability of soil and related resources (de la Rosa *et al*., 2009).

The constraints associated with poor land use planning includes: (1) poor compliance, (2) slow production growth and (3) lack of investment. To address these problems, land use planning improves decisions in agricultural planning and raises awareness of the dangers of poor planning. Land use planning is essential in managing natural resources and addressing threats to food security. It selects the best land use options. It may well be argued that land use planning is the first objective in achieving environmental sustainability. Soil management is the second objective (de la Rosa *et al*., 2009). Land use planning indicates the best zones for farming.

2.8 Sustainable agricultural management and production suitability on smallholder farms

Abah (2013) defines sustainable agriculture as:

> *An integrated system of plant and animal production practices having a site-specific application that will over the long term satisfy human food and fibre needs, enhance environmental quality and the natural resources base where appropriate, natural biological cycles and controls, sustain economic viability of farm operations and enhance the quality of life for farmers and society as a whole.*

Sustainable agriculture incorporates efficient and effective management of environmental, economic and social aspects (Petja *et al*., 2014). The goal of sustainable development is to emphasise development which enhances the quality of life in rural communities. Sustainability should be achieved without causing damage to the environment. Furthermore, Whiteside (1998) defines sustainable agriculture as agriculture which meets today's livelihood needs without preventing the needs of the future generations from being met. Sustainable smallholder agriculture enables an environment in which smallholder farmers sustain their business models. Sustainable agricultural production is an important goal in economic planning and human development worldwide (Xuegong *et al*., 2006). Schulte *et al.* (2014) suggest that sustainable intensification refers to increasing total food production from the current global agricultural land area, thus negating increased competition for land with ecological habitats, while reducing or at least decoupling the environmental impacts associated with agricultural production.

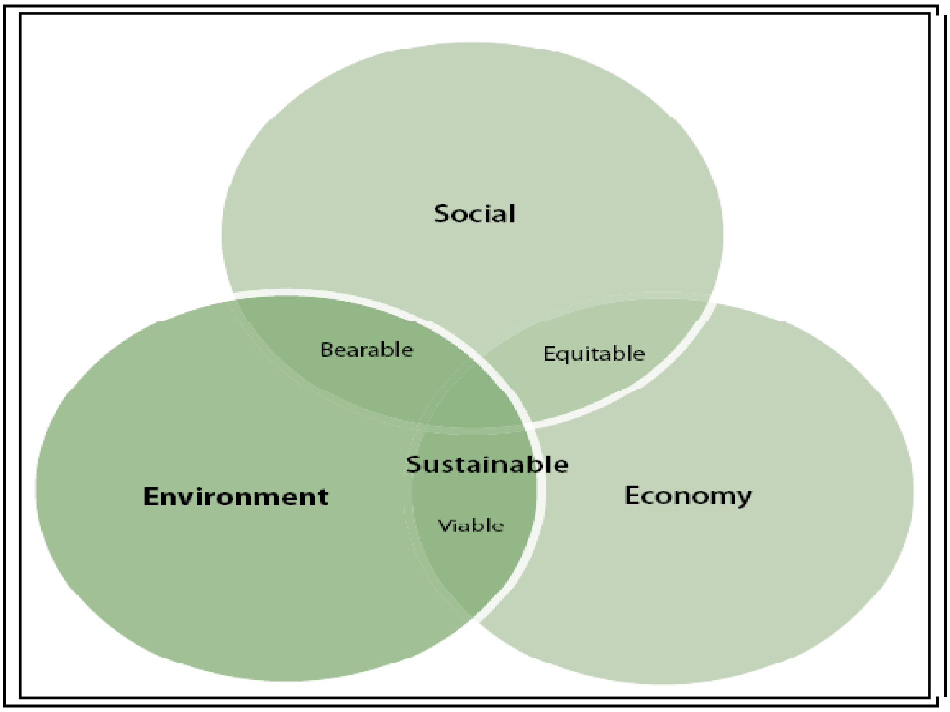

Figure 2.1: Three pillars of sustainable development
Source: Adapted from DAFF (2012)

A simplified presentation of the pillars of sustainable development is shown in Figure 2.1. Sustainable agricultural management considers economic tools in achieving the goals of smallholder farmers. The World Commission on Environment and Development (WCED) describes sustainable development "*as a development that meets the needs of the present without compromising the ability of the future generation to meet their needs and aspirations"* (WCED, 1987).

According to the DAFF (2012), there are three main elements or strategies to achieve the required goals of sustainable development, namely social, economic, and environmental (Figure 2.1):

- **Social pillar.** The key challenges are equity and transformation, implying equitable access to and participation in agricultural opportunities, so as to unlock the full entrepreneurial potential;
- **Economic pillar.** The key challenges are growth and competitiveness, implying enhanced profitability through sustained global competitiveness in the sector's input supply, primary production and agro-processing industry; and
- **Environment pillar.** This implies the sustainable use of natural resources by means of the careful management of the benefits to current and future generations.

All these factors interact and influence each other within sustainable development. These parameters are linked to the sustainability of the environment. Typically, concerns are often raised about the utilisation and protection of the environment as a result of development (DAFF, 2012). Xuegong *et al*. (2006) shows that an index of sustainable development consists of the following five support systems: agricultural resources; agricultural development; environmental and ecosystem; rural society; science, education and management. Clearly, more emphasis needs to be placed on sustainable utilisation of agricultural land.

Goodland (1997) asserts that the most fundamental requirement of environmental sustainability is that capital should remain intact. Sustainable agriculture must look at the above pillars at all levels of development. In order to promote the sustainability of smallholder farms, the farm owner must be prepared to ensure compliance with applicable environmental regulations as sustainable agriculture depends on sustainable development.

According to the DAFF (2012) sustainable smallholder agricultural management means:

- Appropriate land use;
- Economic development with low cost production;
- Management and conservation of natural resources;
- Socioeconomic and environmental benefits of AEZ;
- The protection of the agricultural land from negative impacts and land-use changes; and
- Ensuring the safe utilisation of the land in a sustainable manner.

Smallholder farms are areas of economic and social development. Sustainable agriculture should improve food security, eradicate hunger and be economically viable while conserving land, water, plant and animal genetic resources, biodiversity and ecosystem, and deal with climate change and natural disasters (Abah, 2013). Collett (2008) states that there are six possible factors that determine yield, namely physical (soil, climate), economic (capital and services) and human (labour and management) factors.

Smallholder farmers are individuals who farm on a traditional communal basis on a small plot of land (Whiteside, 1998). A smallholder farm remains a critical sector for employment and food security. In order to prevent food insecurity, smallholder farmers should be given necessary skills and resources. The DAFF (2013a) affirms that in analysing food security, three challenges can be identified, namely whether enough good food can be produced to meet the demand, whether the consumer can afford the food and if it is safe to eat. Smallholder farmers are subsistence producers. The smallholder farm has a potential to increase job creation. Poverty alleviation through job creation remains a critical factor in smallholder farming.

2.9 The impact of climate change on agricultural production

It is recognised that smallholder farming is less environmentally damaging than commercial farming in terms of its impact on climate change (DAFF, 2012). Generally, climate change leads to decreased yield production.

According to DAFF (2012) the effects of climate change on agricultural production are as follows:

- Increased heat affecting crops and livestock;
- A possible decline in precipitation;
- Increased evapo-transpiration rates caused by higher temperatures;
- Lower soil moisture levels;
- Concentration of rainfall into fewer discrete events, which will increase erosion;
- Floods risks; and
- Disruption of food production and supply by more frequent, severe and extreme climatic events.

According to Benhin (2006) climate change increases and reduces rain and changes the timing which puts increased pressure on the country's water resources. Climate changes have a negative impact on agriculture and compromise sustainability, particularly on smallholder farms. The Intergovernmental Panel on Climate Change (IPCC) predicts that the build-up of greenhouse gases in the atmosphere will cause global temperature to rise by 1-3.5°C during the next century, according to the International Plant Genetic Resources Institute (IPGRI) (2000). Moreover, studies show that lower rainfall will have an impact on agricultural production especially in developing countries. The IPGRI further predicts that millet crop yield in Africa are expected to drop by between 6% and 8%.

2.10 Constraints facing smallholder farms

A major challenge facing smallholder farmers is lack of infrastructure which makes food distribution difficult. Lack of transport prevents them to participate in agribusinesses. The majority of smallholder farmers are located in rural areas (DAFF, 2012). They often travel long distances to markets. In addition, smallholder farmers are poorly organised. Studies conducted indicate that some constraints relate to lack of access to land, and poor physical and institutional infrastructure (Lahiff & Cousins, 2005). Agriculture is the largest consumer of water in the country (IPGRI, 2000). About 70 percent of fresh water is used for agriculture (NDA, 2005). Production is limited due to water being more difficult to distribute on smallholder farms (DAFF, 2013b). Furthermore, production is affected by labour forces and capital. Studies conducted by the FAO (1996) have shown that smallholder farmers lack policy and technical support for farming system. Smallholder farmers are unable to achieve consistency due to the fact that they produce on a small plot of land. There is lack of collaboration amongst public and private institutions. This is partly because there is a lack of trust between farmers and government. The potential of the smallholder farmers is ignored by urban markets. Relatively few products of smallholder farms find their way into the local markets (Lahiff & Cousins, 2005).

The results of many studies show that smallholder farmers are unable to meet the quality standard. The problems of smallholder farms result from ecological disturbances, for example soil erosion. Poor land use management and planning impact negatively on the success of smallholder farmers. Petja *et al.* (2014) also state that because of a lack of research, rural farmers face challenges related to agricultural sustainability, natural resource management, business diversification, agriculture efficiency and long-term growth and planning.

The constraints facing smallholder farmers that are summarised by Baloyi (2010) include amongst others: limited resources, high transport costs, shortage of water, degradation, lack of proper roads, and lack of skills. The major challenge facing smallholder farmers is that there is no adequate access to market. According to the DAFF (2012), marketing skills and lack of markets force them to sell their products at the most unprofitable prices. The majority of smallholder farmers are illiterate and have poor technological skills. Agribusiness development investments focus more on commercial farmers.

2.10.1 Initiatives to support smallholder farmers

The aim of the government programme is to expedite support to the smallholder farmers through unlocking access to markets. Pre-1994 smallholder farmers in former homelands were neglected. Since 1994, the Integrated Sustainable Rural Development Programme tends to improve land-based livelihoods in general, and smallholder agriculture in particular (Lahiff & Cousins, 2005). However, it must be noted that the support offered by government departments is very limited because it only reaches a minority of smallholder farmers.

Despite the number of challenges faced by smallholder farmers, there has been a limited number of initiatives or government programmes in support of small-scale farmers. Baloyi (2010) argues that the challenges facing government programmes are due to lack of co-operation between the officials and spheres of government at national, provincial and municipal level. To date, little has been done to address problems faced by smallholder farmers.

The following initiatives have been supported by the DAFF:

2.10.1.1 Strategy for smallholder producers

The strategy for smallholder producers as a broader initiative is to give support to smallholder producers and increase the number of smallholder farmers. The strategy makes provision for a large number of distinctive functions, e.g. extension, co-operatives development, marketing, mechanisation, financial services, spatial planning, and benefitting women and youth (DAFF, 2013).

2.10.1.2 Co-operatives

It is often argued that co-operatives accelerate empowerment and also enhance the productivity of smallholder farmers. According to the DAFF (2012), co-operative development has been found to be one of the most effective interventions through which growth in smallholder farming could be enhanced, thereby creating long-term food security, job opportunities and income. In other words, unemployment has been reduced by co-operatives. The aim of the programme is to maximise the use of agricultural land through improving social relations between smallholder farmers. The initiative encourages co-operatives among smallholder farmers (Lahiff & Cousins, 2005).

2.10.1.3 Training through skills development

The programme creates and maintains training institutions which empower smallholder farmers. This is to ensure that qualified field extension officers support smallholder farmers. The programme promotes access to new technology, supports smallholder farmers with sufficient entrepreneurship skills and appropriate training (Collett, 2008). It is an essential element for training smallholder producers.

2.10.1.4 Comprehensive Agricultural Support Programme (CASP)

The programme gives financial support to emerging smallholder farmers and increases agri-business development. The main objectives of CASP are to assist on-farm and off-farm infrastructure and production input, particularly in former homelands (Baloyi, 2010). Collett (2008) argues that the main objective of the initiative is to redistribute 5 million hectares of land with the hope to increase agricultural production from 10 to 15%.

2.10.1.5 Community-Based Public Works Programme (CBPWP)

The programme secures the country's agricultural land through the provision of public social services. The purpose of the programme is to provide employment opportunities to unemployed youth (e.g. Working for Water, Fire and Land Care). Through community works programmes, agriculture provides temporary work opportunities to unemployed youth, many of whom are women and people with disabilities. The initiative promotes vegetable gardens with the aim of increasing food security and improvement of the quality of life in rural areas (DAFF, 2012).

2.10.1.6 The Smallholder Development Working Group

The initiative enhances collaboration among the stakeholders in national and provincial spheres of government towards support and development of smallholder producers (DAFF, 2013). The aim of such a programme is to reach smallholder farmers through decentralisation of decision-making and monitoring of individual projects (Collett, 2008). The programme promotes the growth of small businesses.

2.11 Summary

In this chapter, the broad overview of the basic concept of agro-ecological zone was given, it was defined and discussed. Application of GIS and remote sensing in agriculture were also reviewed. The chapter also reviewed the importance of farm production planning. A number of government programmes in support of smallholder farmers were highlighted. The chapter emphasised that some of the challenges in smallholder farms are due to poor management and lack of funding. However, little guidance is given to smallholder farmers by the government. A variety of factors were considered. For example, marketing was identified as a key constraint to smallholder farmers' development. This chapter also discussed interaction between the pillars of sustainable development (economic, social and environment).

CHAPTER 3

ENVIRONMENT OF THE STUDY AREA

3.1 Location

3.1.1 Description of the study area

The study area is situated in the North West Province (Figure 3.1) which is the fifth largest province in the country and covers 116 320km² or 9,5% of the total surface area of South Africa. According to Baloyi (2010,) agriculture is a critical economic sector in the province. It is important to note that 65% of people in North West live in rural areas.

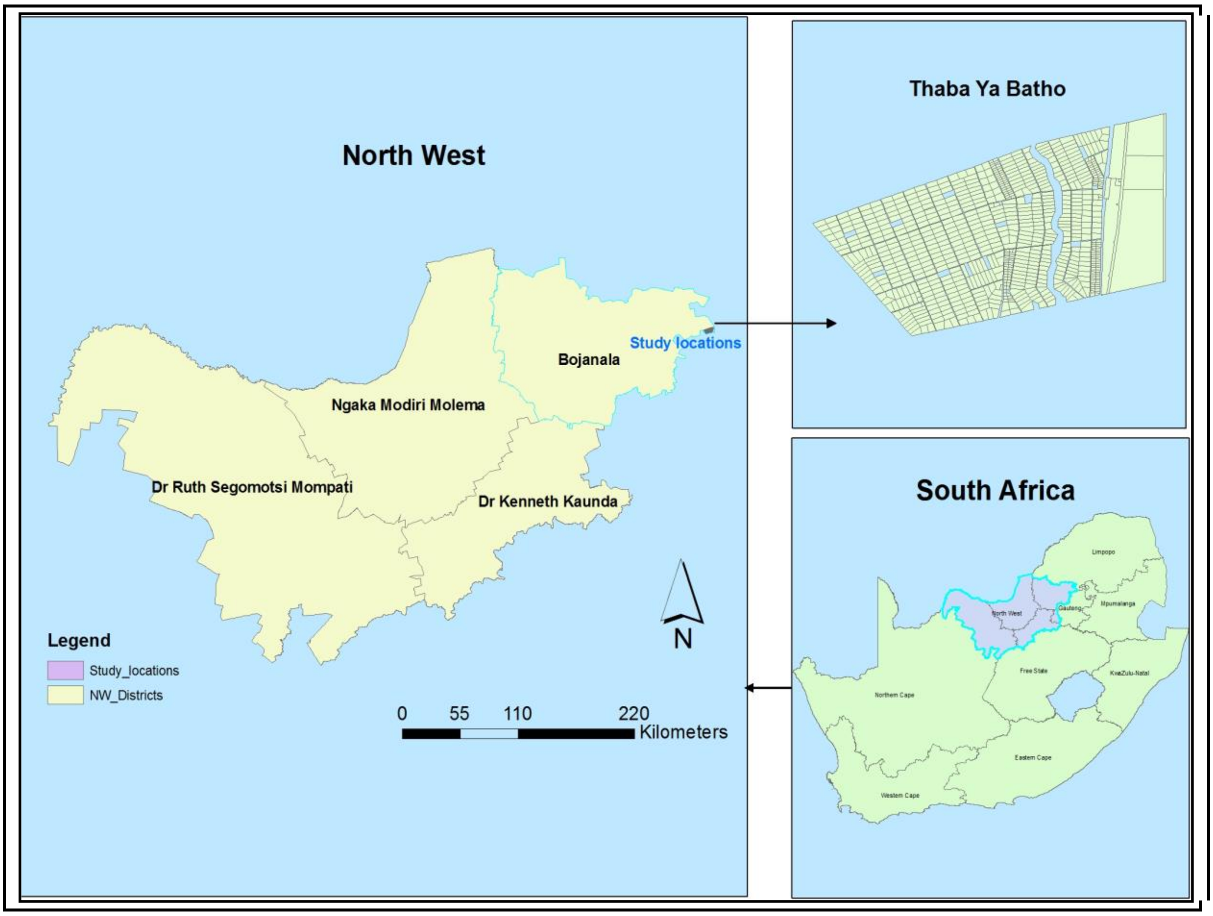

Figure 3.1: The geographic location of the study area in North West province, South Africa

The study area as shown in Figure 3.1 lies about 56km north of Pretoria. The farm Boschplaats 91 JR is a farmland that was divided into farm plots called Thaba Ya Batho Smallholding. The geographical coordinates of the study area are 28º 14' 59" E, and 25º 19' 27" S. The population is dominated by Tswana-speaking people, although other language groups are present. The vast majority of the population is regarded as poor (Cloete *et al.*, 2009). The capital city of the province is Mahikeng.

The province is divided in four districts, namely: Bojanala District, Ngaka Modiri Molema District, Dr Ruth Segomotsi District, and Dr Kenneth Kaunda District. For this research, the study was conducted in Moretele Local Municipality which falls under the Bojanala District (Figure 3.1).

3.2 Climatic conditions

Like in other small-holder farms in South Africa, rain is a major limiting factor on Thaba Ya Batho smallholder farms. The climate of the study area (ARC-ISCW, 2004) can be regarded as warm to hot with moderate rain in summer and dry conditions in winter. The climate makes it ideal for crop production. The area consists of large open spaces, with a large number of agricultural holdings. The rainfall varies from an average monthly maximum and minimum of 500 mm and 700 mm. Temperatures vary from an average monthly maximum and minimum of 21ºC for summer and 12ºC for winter. The extreme high temperature that has been recorded is higher than 35ºC and the extreme low -4ºC (ARC-ISCW, 2004).

Water is the limiting factor for agricultural development. Water supply is not reliable for production as a result of rainfall being seasonal. The bulk of water comes from the Vaal River. Smallholder farmers are unable to access underground water. This is partly because underground water is under pressure from mining, industries and settlements. However, agriculture and mining are major contributors towards economic growth in North West.

The location has two distinct seasons: warm summer and cool winter. Summer is the rainy season. More than 200km² of Moretele is used for farming activities (MLM, 2009). Thaba Ya Batho smallholder farms have been identified as one of the municipality's prime agricultural regions based on its soil potential.

3.3 Land use

North West is divided into four ecological zone including: Bushveld, Middleveld, Kalahari Desert, and Highveld. The major dams include the following: Buffelspoort, Hartebeespoort, and Klein Marico (MLM, 2009). Smallholder farmers on average occupy 7 ha plots. Smallholder farms are scattered throughout the province. North West houses about 147 000 smallholder farmers and most of them are not operating effectively (DBSA, 1991). The largest proportion of land is used for farming purposes. Table 3.1 shows that North West covers an area of 11 871 000 ha, 85% of the total area is farm land.

Studies conducted show that South African export products include soya bean oil, sugar, sunflower oil, wheat, maize and apples. South Africa's export has increased from R5,3 billion in 2007 to almost R15 billion in 2012 (DAFF, 2013). Maize, mainly produced in North West, is the largest export in South Africa. Many farmlands are planted with maize crops, sugar cane and sunflower.

Table 3.1: Land utilisation in North West Province (1991)

North West Province					
Total	Farm land (ha)	Potential arable land (ha)	Grazing land (ha)	Nature conservation (ha)	Other (ha)
11 871 000	10 098 473	3 360 459	6 738 014	764 500	1 008 027

Source: DBSA (1991)

Thaba Ya Batho smallholder farm is situated in the Moretele local municipality. It is characterised by a flat topography. The major rivers in Moretele are the Apies River and Moretele River. Figure 3.1 identifies the location and boundaries of the study area. The total area of Boschplaats 91 JR is about 4 000 ha referred to as Thaba Ya Batho Agricultural Holdings that is divided into 822 smallholdings. Thaba Ya Batho smallholder farmers farm in a traditional communal area. They farm on 4.5 ha plots on average for subsistence and production per plot is very low. Farmers are unable to utilise the whole farm portion; of 4.5 ha they only utilise less than 1 ha on average due to lack of water.

However, the climate is suitable for a range of vegetables. The vegetable production (spinach and cabbage) occurs mainly in winter in small gardens and on demarcated fields. Many smallholder farmers in Thaba Ya Batho have given up their farming activities to employment in Babelegi industries.

The area is serviced by the N1 Polokwane National Highway, the R101 Freeway joining Hammanskraal and Bela-Bela, a railway line also joining the two towns mentioned above. The area also has a perennial river (Apies River) running through it (Figure 3.2). Apart from the above-mentioned road infrastructure (freeways), about 80% of the road surface within Thaba Ya Batho is tarred. The main point of interest within the area is the Carousel Hotel and two petrol stations. The area is also very close to a belt of industries along the railway line through Hammanskraal.

3.4 Land cover

There is a homestead in the study area; occupation numbers vary. The study area is characterised by unimproved vegetation, which is used as grazing land for cattle and goats. Cultivation is in small areas scattered throughout the surrounding area (Figure 3.2).

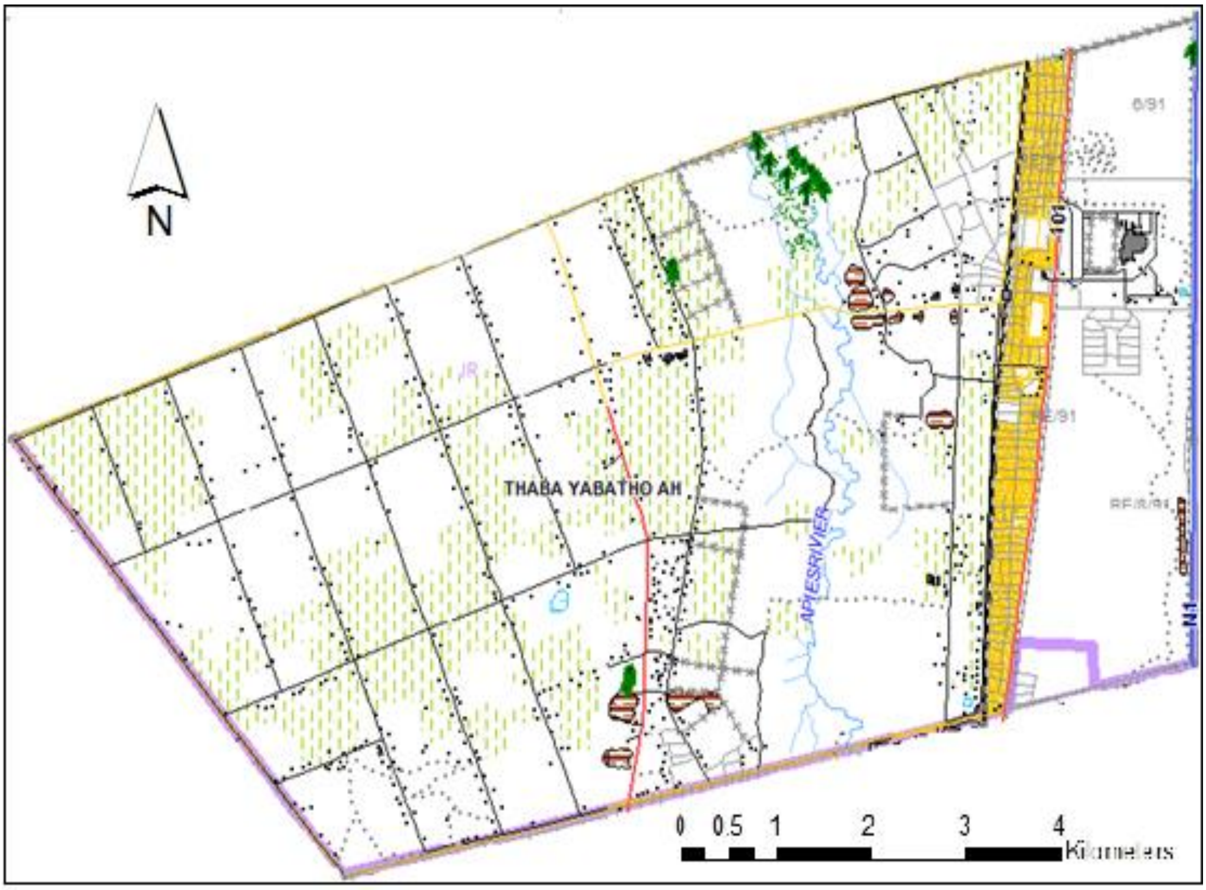

Figure 3.2: Topographical map of Thaba Ya Batho

Figure 3.3: Grass cover in *Eragrostis plana-Cyperus rupestris*

Approximately 69% of the study area is characterised by forest woodland. The topography is mainly level (flat) with no hills. The land cover is sparse consisting of bushes, trees, and grasses. A small section of the study area consists of herbaceous vegetation, *Eragrostis plana-Cyperus rupestris* with a cover ranging from 25%-95% (Figure 3.3) (Acocks, 1975). The climate has been linked to vegetation distribution. The farm is considered to be underdeveloped relative to its potential for planting crops. Maize and vegetables are common crops cultivated. This municipality is characterised by subsistence farming. Farmers rely exclusively on family labour. It has been established that maize is the largest produced field crop.

Table 3.2: Land use and land cover in Moretele Local Municipality

Description	**Size (km²)**	**% of total Municipal area**
Cultivated: temporary Commercial dry land	45.52	3.32%
Cultivated: temporary Commercial irrigated	0.05	0.00%
Cultivated: temporary semi Commercial /subsistence dry land	200.06	14.60%
Degraded: forest and woodland	563.41	41.60%
Forest and woodland	408.32	29.80%
Forest plantation	0.27	0.025
Thicket & bush land (etc)	32.4	2.36%
Unimproved grass land	5.65	0.41%
Urban/ build-up land: Commercial	0.31	0.05%
Urban /build-up land: residential	95.5	6.99%
Water bodies	0.63	0.05%
Wetland	17.83	1.30%

Sources: MLM – 1st draft IDP Review (2009)

The figures presented in Table 3.2 above illustrate land use/cover in Moretele. The area is dominated by degraded forest and woodland which constitutes 41.1% (563 km²) of the total area. Forest woodland covers 29.8% (408.3 km²) and urban build-up areas cover 7% (95.5 km²) (MLM, 2009).

3.5 Hydrology

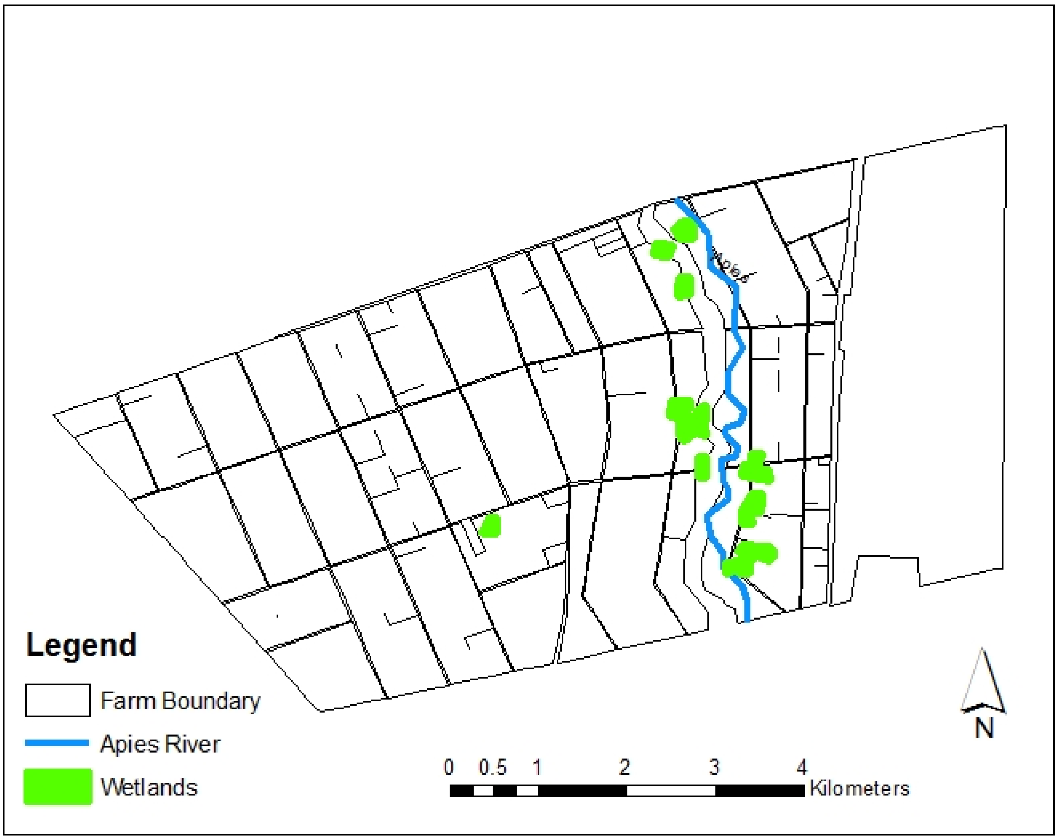

Figure 3.4: Water sources in Thaba Ya Batho

Figure 3.4 illustrates the locality of water sources. There is adequate underground water supply at approximately 80 meters deep (ARC-ISCW, 2004). The Apies River is the boundary that divides the study area into Boschplaats West and East. The Apies River runs through Thaba Ya Batho smallholder farms; even though it is not the main source of water supply for the farms, it is suitable for animals and household use. Boreholes and taps are the main sources of water supply for many plots. Tanks are used for collecting rainwater. Dumping has a significant effect on agricultural development. Chemicals cause major constraints to agricultural production. Field observations have shown that smallholder farmers have heavily overgrazed the land.

3.6 Socioeconomic factors

Many smallholder farmers in Thaba Ya Batho are pensioners (MLM, 2009). Lack of infrastructure and markets place a burden on agricultural expansion. The major sources of air pollutants are due to industries (Babelegi) and waste dumps. Livestock is mostly cattle. Only a few farmers have title deeds and most plots are registered to old age male pensioners. Many plots are still registered under names of deceased persons while some plot owners or beneficiaries are unknown. Over the past two decades some farms have not been used at all.

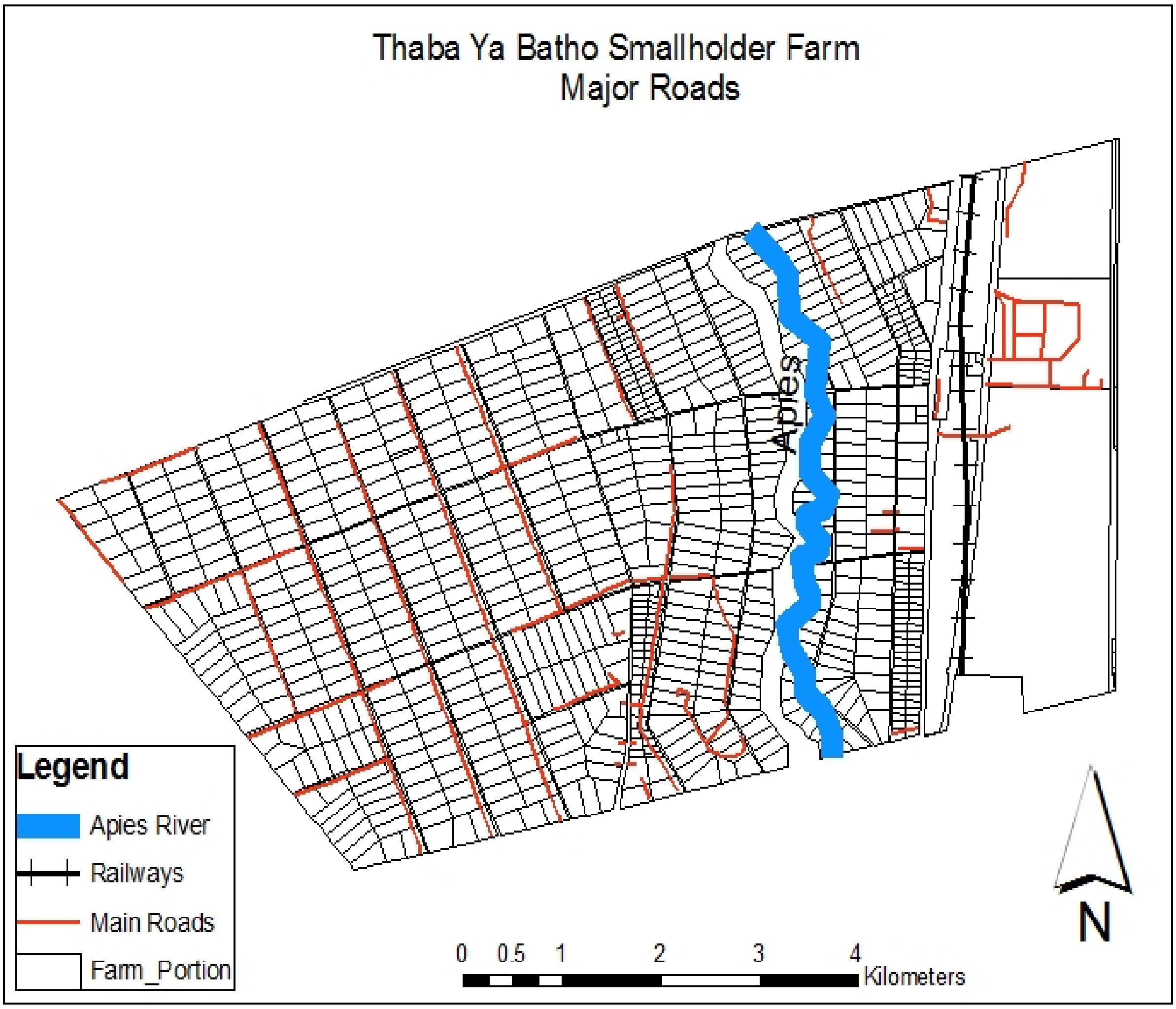

Figure 3.5: The presence of major roads in Thaba Ya Batho

Figure 3.5 shows the presence of major roads in Thaba Ya Batho. Thaba Ya Batho is privately owned by individuals under community authority and it is an agricultural holding. Smallholders in Boschplaats occupy approximately 4.5 ha per farmer with production primarily for subsistence farming.

Figure 3.6: (A) Waste disposal, (B) Red-yellow soils and (C) fresh vegetables

Figure 3.6 illustrates sources of waste, red-yellow soils and fresh vegetables in Thaba Ya Batho. Collet (2008) argues that the best soils that are able to withstand degradation are deep, permeable red or yellow loams.

3.7 Summary

This chapter described the environment of the study area in Moretele local municipality, North West Province. A geographical description of the study area was presented. Agro-climatic factors and socioeconomic issues on Thaba Ya Batho smallholder farms were highlighted. These factors negatively impact employment opportunities. Chapter 3 also provided relevant information regarding the land use and land cover.

CHAPTER 4

MATERIALS AND METHODS

4.1 Introduction

This chapter illustrates the methods and approaches used in this study. It includes primary and secondary data collection together with analytical methods. The basic data collection strategies include the use of geo-spatial information for agricultural planning and production purposes. For this study, data sources include GIS shape files of soil data, NLC2000, SPOT-5 imagery and field data. The land evaluation publication of the United Nations Food and Agricultural Organisation *Framework for Land Evaluation* in FAO Soils Bulletin 76 (1996) is used for land suitability, land productivity assessment and for land use analysis based on multi-objective land use optimisation.

4.2 Research design

This research study was utilised as quantitative approach to a post-test only design. Mapping of the study area and assessment of the environmental and agricultural status of smallholder farms were conducted after some agricultural activities failed over the years.

4.3 Sampling strategy and field data collection

The design of the sampling attempts to capture a representative distribution of agro-ecological zones in the study area. Thaba Ya Batho smallholder farms were purposively sampled for the purpose of this study. This was because of the many unproductive plots which could have been well utilised. Stratified random sampling was adopted for collection of data on the plots. Twelve soil samples (Figure 4.1) were collected for analysis, in this case using a simple random sampling technique comprising of at least 30% of the entire population. However, the results are extrapolated to the whole study area. The soil samples selected were based on the feasibility considerations. However, adding more soil samples was not sufficient to warrant the additional costs.

Field survey provided relevant data needed for the study. Physical observation was also conducted to collect relevant data in the field. Field data include a checklist of identifying key factors (Appendix A) limiting production and assessing environmental state. Images were validated during field visits. This was done before the actual survey was conducted.

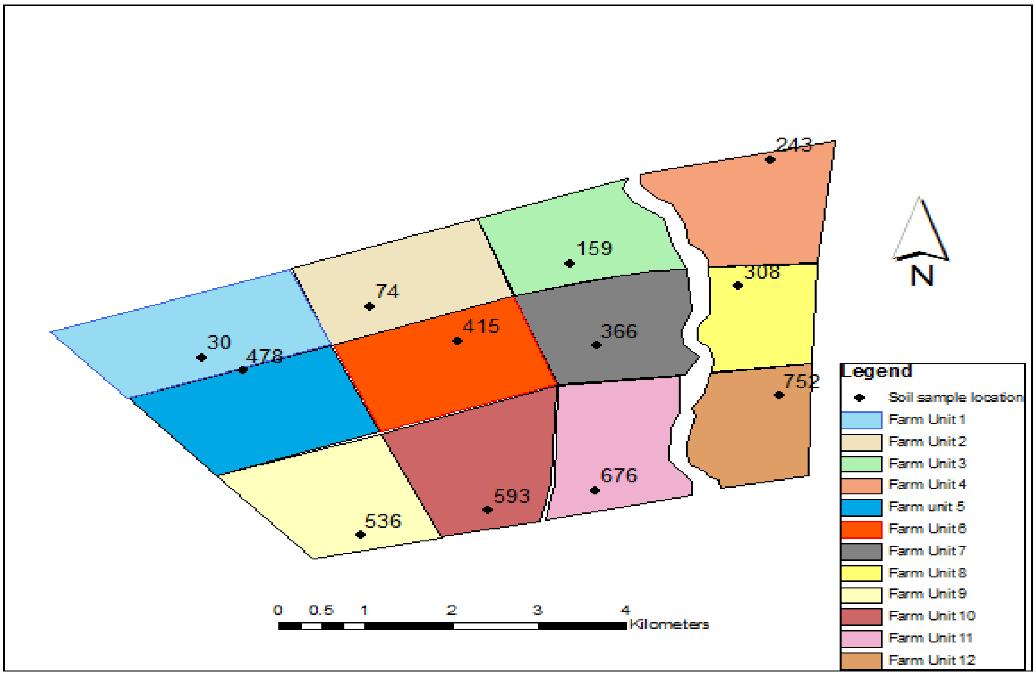

Figure 4.1: Location of soil samples and farm units

Figure 4.1 shows locations of soil samples within each farm unit. Soils were sampled at the soil depth of 0 to 20 cm topsoil and 30 to 60 cm subsoil and GPS coordinates were recorded at each sampling point.

4.3.1 Water holding capacity of soil

Table 4:1 Soil with beneficial water retaining layer

Water retaining layer_2003	
Class 3	Beneficial water retaining characteristics scarce or absent

Source: ARC-ISCW (2004)

Table 4.1 illustrates the water-holding capacity of Thaba Ya Batho soils determined from the land type data. Eight percent of the country's soils have favourable water retaining properties due to a deep rooting zone (ARC-ISCW, 2004). Class 1 is regarded as having beneficial water-retaining characteristics without risk of water-logging. Class 2 has some risk of water-logging. Class three is characterised by absence of water retaining characteristics (ARC-ISCW, 2004).

4.4 Laboratory analysis

The soil samples collected in the field were numbered, air-dried and later sent in plastic bags to the ARC-ISCW for laboratory analysis (Appendix B). This study used the same soil sampling and laboratory techniques as the Water and Dam Services Company (WADSCO) (1981) studies to analyse the results. Soil analysis was done to assess the physical and chemical properties of soils.

The following methods were applied to the samples. Soil chemical properties such as K, P, Ca, Mg, Na, pH and moisture were analysed in the Soil Laboratory (Appendix B). In the laboratory, samples were analysed for pH using soil: water solution method (WADSCO, 1981). P was analysed using Bray1 method. The determination of the total (Potassium, Ca, Mg and Na) were done using 1M ammonium acetate extraction (WADSCO, 1981).

4.5 Satellite data acquisition

The SPOT-5 imagery was used as the primary data for producing AEZ in Thaba Ya Batho smallholder farms. Images acquired at different dates and seasons were overlaid in order to determine the changes that had occurred over a period of 6 years.

Table 4.2: SPOT-5 data used in Thaba Ya Batho

Satellite Number	Designation Of scene	Acqu. Date JJ/MM/DD	Acqu. Time Hrs/Min/Sec	Spectral mode
5	133401	2006/05/10	08:26:12	j
5	133402	2007/02/05	08:15:23	j
5	133401	2008/04/27	08:13:50	j
5	133401	2009/04/26	08:13:32	j
5	133401	2010/03/09	08:23:21	j
5	133401	2011/12/03	08:28:26	j

Table 4.2 above shows the six images of pan-sharpened 2.5 m resolution orthorectified SPOT-5 containing green, red and NIR spectral bands acquired from 2006 to 2011. These images differ in terms of atmospheric and illumination conditions.

Table 4.3: Weather station

Weather Station No	Station Name	Latitude	Longitude	Altitude	Year Start	Year End
30901	Pienaarsriver: Waterburg	-25.24262	28.30701	1044	2009	2013

Source: ARC-ISCW (2004)

Table 4.3 shows the location of the meteorological station. Weather was observed from 2009 to 2013. The temperature was calculated from monthly minimum and maximum temperature data. The weather data was used for identification of growing season. The method used for primary data collection involved site visits with the objective of gathering data by means of field observation. The field work helped to obtain first-hand information throughout the study area, which was useful for understanding environmental constraints on smallholder farms. Temperature and rainfall was the main climate data used. This climate data comes from the ARC-ISCW presented in Appendix C.

Accurate spatial datasets such as National Land Cover_2000 (NLC), and Land Capability were obtained from the DAFF at a scale of 1:50 000 and 1:250 000. According to Collett (2008), the scale of these tools is sometimes very coarse and may differ from the situation on the ground. The NLC_2000 contains information on land use which is provided at national coverage in a much higher resolution (Pretorius, 2009).

4.6 Digital image processing

The objective of image processing is to process the digital image in order to allow the user to extract as much information as possible from it. Image analysis serves to describe image qualities, assisting in enhancement operations. Any resulting image is referred to as an image output. The image processing programmes used included ERDAS Imagine 2011 and ArcGIS 10.2.2.

4.6.1 Pre-processing

The pre-processing and analysis were carried out to enhance the quality of the images. The pre-processing technique is divided into the geometric rectification (Lillesand *et al.*, 2008). For this study, digital images were corrected for geometric and atmospheric distortions followed by value adding to image products. The suitability maps of the study area were generated by overlaying national soil layer, depth, and land capability layer (ARC-ISCW, 2004). The GPS points from the field survey were transferred to ArcMap 10.2.2.

4.6.1.1 Atmospheric rectification

Atmospheric rectification is a pre-processing step which focuses on the scattering and absorption of the radiation that occurs during the passage of radiation through the atmosphere. According to Cranknell & Hayes (1999), remote sensing usually uses radiation of wavelengths that are not within the absorption bands of the major constituents of the atmosphere. Atmospheric effects can be accounted for in thermal scanner calibration by using empirical or theoretical atmospheric models. Atmospheric effects are normally eliminated by correlating scanner data with actual surface measurements (Lillesand *et al*., 2008).

Scattering and absorption of optical and near-infrared radiation by aerosols is the major source of uncertainty in atmospheric correction (Ressom *et al*., 2005). The passage of the radiation through the atmosphere is described with the radiative transfer equation; the values of various parameters that appear in the radiant transfer equation are not sufficiently and accurately known to make direct and explicit solution of the radioative transfer equation a feasible approach (Rees, 1999). Digital Number (DN) depicts the average radiance of a relatively small area within the scene (Raju, 2004b). The DN to reflectance conversion was conducted in this instance using ERDAS for atmospheric correction.

4.6.1.2 Geometric rectification

Geometric transformation alters the image geometry to correct geometric distortions introduced by the data-collection system so that it meets the needs of the user. The intent of geometric correction is to compensate the corrected image so that it will have the highest practical geometric integrity (Konecny, 2003). The geometric correction process is implemented as a two-step procedure. First, those distortions that are systematic or predictable are considered. Second, those distortions that are essentially random, or unpredictable, are considered (Lillesand *et al*., 2008). The geometric correction allows for sizing, orientation, and movement of image. It implies image scaling, rotation and translation. All geometric operations are performed by moving pixels from their original spatial coordinates in the input image to new coordinates in the output image. A first-order polynomial equation was used to geometrically correct the image in ERDAS and nearest neighbour approach was applied for resampling.

4.6.2 Classification procedure

Classification was carried out during the years 2006 to 2011. Combinations of supervised and unsupervised classification were done to identify land use and land cover of the study area. ERDAS Imagine was used to classify images. Supervised classification assigned pixels to class bands. In supervised classification, the identity and location of some of the land cover types are known a *priori* through a combination of fieldwork, interpretation of the image, map analysis, and personal experience. The image subset was classified into fifteen distinctive groups and then assigned to meaningful informational classes. Five different classes were identified.

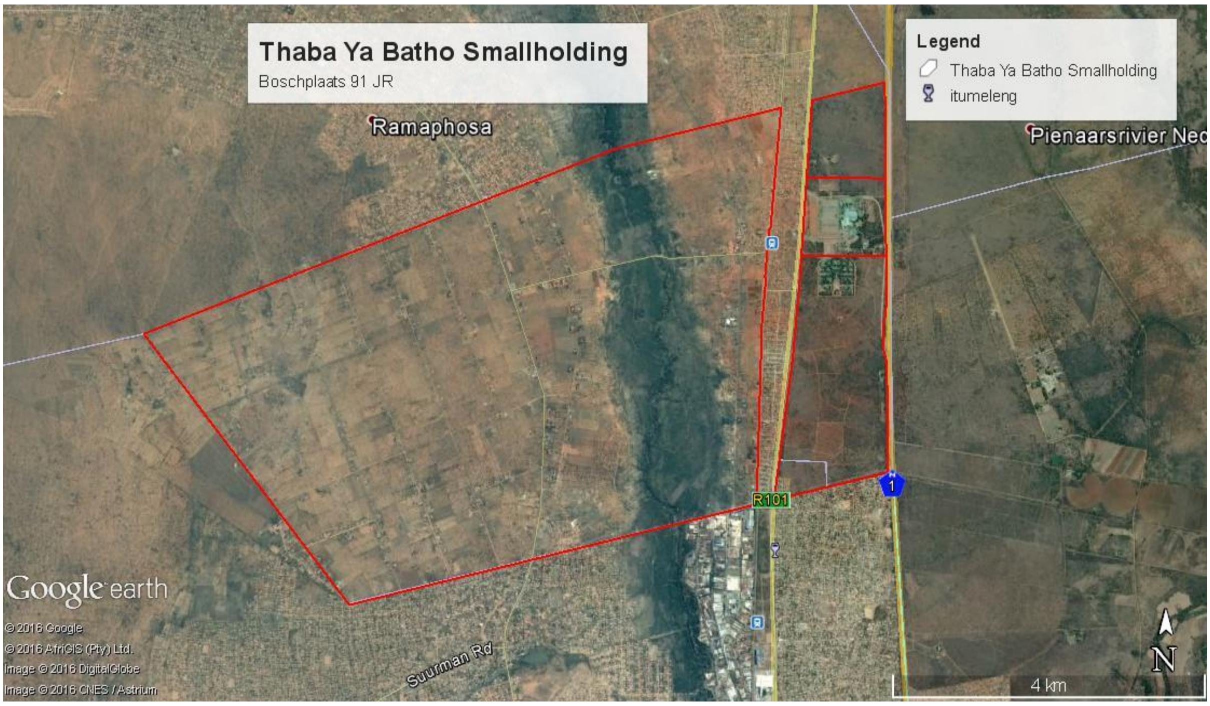

Figure 4.2: Google Earth imagery of Thaba Ya Batho Smallholder Farms

Areas that appeared to be related to the land types of interest were digitised using the Area of Interest (AOI) tool and added to a signature file (Figure 4.2). A polygon was drawn in the feature space image that corresponds to an area drawn as a specific type of land cover. A polygon was used to create an area of interest. Polygon AOI is an estimate extracted from rectified remote sensor data that is more accurate than an area estimate extracted from unrectified imagery.

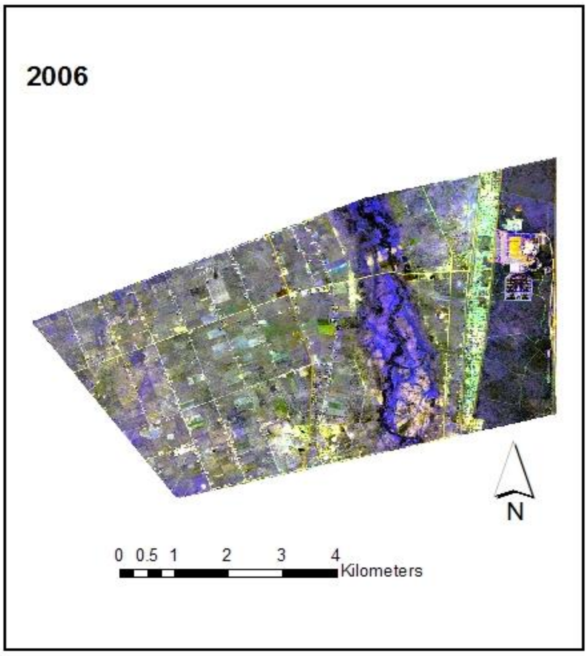

Figure 4.3: 2006 Subset imagery using SPOT

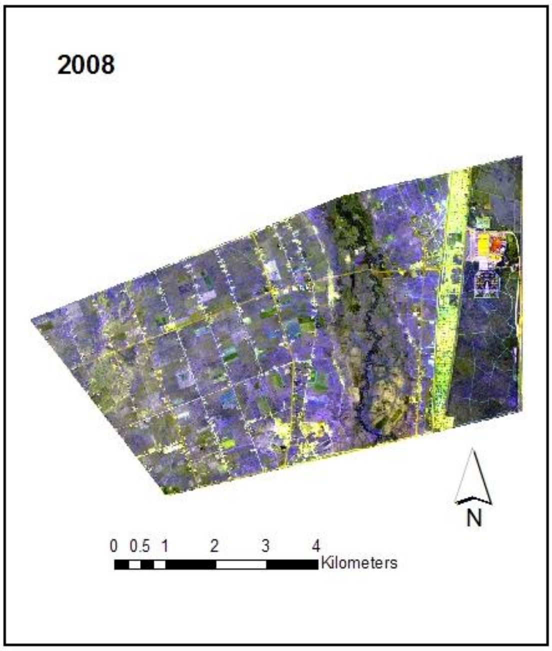

Figure 4.4: 2008 Subset imagery using SPOT

Figures 4.3 and 4.4 show the subset imagery. Each digitised area was added to the program's signature editor and checked to determine if the area had a unimodal leptonic distribution for its brightness signature. After sub-setting the image, areas of visually homogenous spectral response were chosen as AOI's and added to the spectral signature editor.

A subset (Figure 4.3) shows the 2006 SPOT image and the subset of the same area in 2008 (Figure 4.4). The study area was clipped out from a SPOT-5 scene by using the subset function in ERDAS Imagine 2011. Maps produced using satellite images during different years are compared in order to detect the changes that have taken place in land use.

4.6.3 Change detection

One of the basic methods applied was to calculate the changes in an image base on two dates. Satellite images captured during 2006 to 2011 were manipulated and analysed. This process involves a pixel to pixel comparison of the study year.

Change detection was applied in different applications so as to determine the extent of land cover changes (Avery & Berlin, 1992). Land cover change was identified through classification and change detection on SPOT imagery. The goal of change detection is to measure the degree of change through time in an amount or concentration of a variable such as vegetation. Differences between two image sets for the same area may thus reflect seasonal changes, changes due to antecedent weather conditions and apparent changes that are introduced by differences in sensor calibration, atmospheric effects and viewing/illumination geometry (Mather, 2011).

4.6.4 Normalised difference vegetation index (NDVI)

Lillesand *et al*. (2008) define the NDVI in terms of the NIR and red (R) bands using equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where, NIR represents near-infrared wavelength and Red represents red wavelength. Jensen (1996) shows that the NDVI equation produces values in the range of –1.0 to 1.0 where increasing positive values indicate increasing green vegetation, and negative values indicate non-vegetated surface such as water, barren land, or snow and cloud. The SPOT-5 imagery NDVI was used to monitor the conditions of vegetation and areas undergoing degradation. However, seasonal influence had to be taken into consideration. Images were taken during different seasons in order to determine land use changes in the study area. NDVI data was used to monitor plant growth status.

4.7 Data analysis

Results of laboratory data were analysed using comparison of means. A combination of GIS data layers (i.e. climate, soil and terrain), rainfall statistics, satellite imagery and soil data were spatially analysed and interpolated to produce agro-ecological zone maps. Soil analysis from the laboratory was used amongst others to determine the productivity of the area and as an input to determine the agro-ecological potential zones. Agro-ecological potential zones are classified into five classes including (1) highly suitable, (2) suitable, (3) moderately suitable, (4) marginally suitable, and (5) not suitable.

Areas suitable for irrigated crops were also classified as (1) optimal, (2) sub-optimal, and (3) not suitable. Agro-climatic analysis of seasonal rainfall and temperature also served as an input to determine crop suitability. Image products were analysed to spatially determine crop potential and classification of the zones. All GIS layers were integrated to determine production-limiting factors. The purpose of this analysis was to determine the overall suitability for agricultural production. Most spatial analysis was performed in ArcGIS. Bar graphs were analysed by means of descriptive statistics.

Table 4.4 Data types and parameters for agricultural land assessment in Thaba Ya Batho

Data type	Base source	Years	Parameter
Soil	Soil samples, soil data	2015	Type, texture, nutrient content
Slope	Topographic map	2001	Erosion
Vegetation	Topographic map, satellite image	2001	Types, coverage, development stage
Land use	Satellite imagery of study area	2006 – 2011	Existing land use type, land use potential
Rainfall	Monthly rainfall data	2009 – 2013	Monthly rainfall averages
Temperature	Monthly temperature data	2009 – 2013	Monthly temperature averages

Table 4.4 illustrates data types and parameters for agricultural land assessment in Thaba Ya Batho. Remote sensing, especially images derived from satellite sensors, provides land cover changes over time. The following software was used for this study:

- ArcGIS – for processing of data;
- ERDAS Imagine – used for development of land use, land cover classes, NDVI, and change detection for the study area;
- Microsoft Word – used for presentation of the research; and
- Microsoft Excel – used for producing the bar graphs.

4.8 Summary

The purpose of this chapter was to explain the methods and materials employed in this study. The methods used for data collection were explained. In this study, different image processing techniques were applied to determine the characteristics of the agro-ecological zone in Thaba Ya Batho.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter presents the results obtained and the discussion. The results of the study are divided into four sections: (1) Field survey (2) Soil analysis (3) Agro-climate analysis and (4) Image processing. The results present environmental and agricultural perspectives which help to inform planning of agricultural production in the study area.

5.2 Field survey

Field surveys revealed that agricultural environment faces the problems of bush encroachment, forest fire and waste disposal. Bush encroachment is ranked as the highest environmental risk. It affects productivity of the land. Farmers are unable to deal with the extent of bush encroachment. Water shortages pose a risk to farm crops. Appendix A shows that more than 50% of Thaba Ya Batho smallholder farms are prone to fire started by humans which triggers bush encroachment and alien plant invasion. Bush encroachment had deteriorated the land available for farming and grazing. It was found that most parts of the study area have low levels of production due to unavailability of infrastructure on the farms. Parts of the smallholder farms are also utilised as places of residence.

Table 5.1: Key priority factors for Thaba Ya Batho

Thaba Ya Batho Environmental Profile				
Activity	**Low**	**Medium**	**High**	**Category**
Land degradation			✓	Human impact
Chemicals			✓	Human impact
Water supply	✓			Bio-physical impact
Land use		✓		Socio-economic impact
Agricultural land			✓	Socio-economic impact
Commercial or industrial	✓			Socio-economic impact
Cultural resources	✓			Socio-economic impact
Access to public transport	✓			Socio-economic impact
Erosion		✓		Human impact
Fire risk			✓	Human impact
Dumping			✓	Human impact
Production diversity	✓			Socio-economic impact

Source: Key priority factors are based on physical observation.

Table 5.1 shows the key priority factors that affect productivity on Thaba Ya Batho smallholder farms. Production limiting factors which make the land unsuitable for crops were identified. The explanatory analyses of low, medium and high were used to create an accurate representation for analysis of key priority factors. The analysis allows for the natural description of the problem rather than in terms of the relationship. It clearly classifies certain land use classes which are unregulated.

The highest recorded land use is woodland. Field survey indicated that pastures dominate in the study area. It was also observed that the land is used for cultivation but there is little infrastructure and no agro-processing industries. Soil erosion has been increasing over a number of years. Land degradation is caused by fire. The types of water resources used for farming are shown in Appendix A.

Table 5.2: Types of water resources in Thaba Ya Batho based on 12 randomly selected plots

Water resources	Number of water resources (n=12)
River	1
Reservoir	0
Dam	0
Municipal tap	10
Bore hole	1

From Table 5.2 it is evident that municipal tap is the most used water source. None of the smallholder farms relies on a dam and reservoir.

5.2.1 Soil analysis

Table 5.3 Soil type description

Soil classes		
Freely drained, structure less soils	Favourable physical properties	May have restricted soil depth, excessive drainage, high erodibility, low natural fertility

Table 5.3 illustrates the description of soil types. However, the basic soil requirements for crops are summarised under the following soil properties:

- Geology;
- Soil moisture regime;
- Soil fertility;
- Effective soil depth;
- Slope/topography; and
- Soil texture (FAO, 1996).

Appendix B shows the soil analysis results which determine the suitability for agricultural production. Soil samples were tested for pH, and moisture. The results confirm that there are variations in pH and moisture properties of soils. It was observed that samples with pH levels above neutrality contained high concentrations of exchangeable cations (Ca and Mg) which also require fertilizer application (Urama, 2005). Concentrations of Ca and Mg ranged from 1123 mg/kg to 3972 mg/kg and from 499 mg/kg to 1121 mg/kg respectively. It was also observed that the concentration of sodium (Na) is directly proportional to soil pH. Thus, the soil that is slightly alkaline and alkaline soils show significantly higher concentrations of Na that vary from 2.1 mg/kg to 182.8 mg/kg.

The analysis shows that the availability of soil groups increases as soil pH approaches alkalinity. However, a contrasting trend was observed with phosphorus at higher concentrations. Furthermore, the lowest concentration (7.3 mg/kg) of P was contained at soil pH above 9. Low organic matter results in soil susceptibility to water and wind erosion (Caldiz *et al*., 2000). The analysis found that there was a significant variation in moisture content of the sample, varying from 0.524% to 2.703% (Appendix B). Field measurement demonstrates that when soil depth decreases, the moisture content in the soil also decreases. Moisture content varies tremendously during the season depending on rainfall. By means of soil laboratory analysis, favourable soils were determined. Soil samples reflect a steady accumulation of soil organic matter. Soil analysis results show that the soil in the study area is able to store sufficient water for productivity of crops.

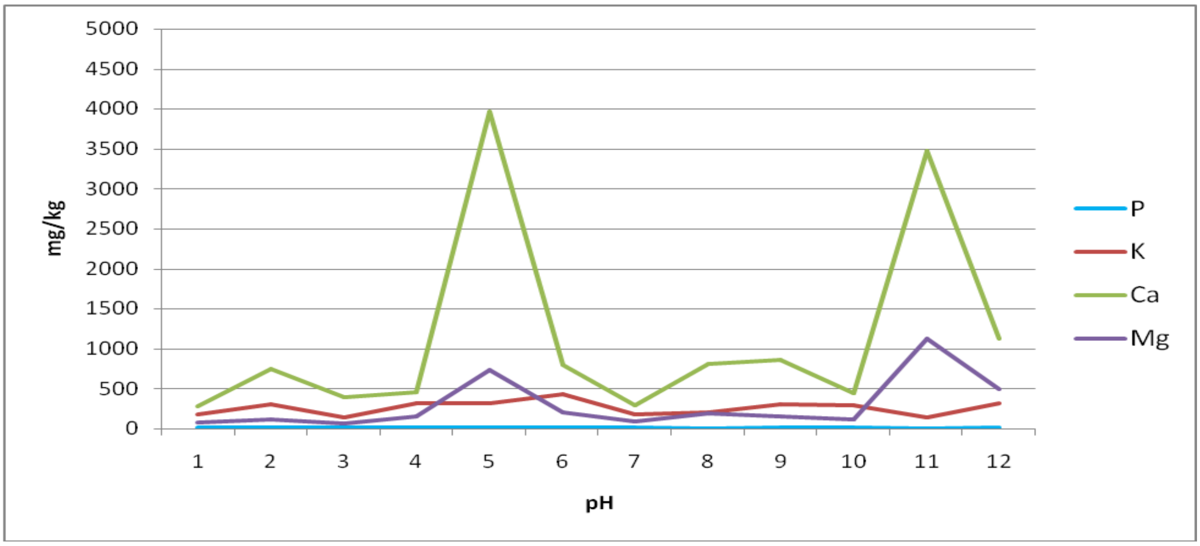

Figure 5.1: The effects of pH on soil nutrient availability (P, K, Ca, and Mg)

Physicochemical properties of a particular soil depend on hydrogen ions (H^+) of that particular soil (Pasquini & Alexander, 2004). The values of pH ranged from 5.49 to 9.04 and showed variations in physicochemical properties of the samples (Figure 5.1). It was observed that as the soil pH approaches neutral and alkalinity there is a gradual decrease in K.

The results (Appendix B) show that potassium concentration is inversely dependent on soil pH with a linear relation. Considering the averages, potassium content varied from 179 mg/kg to 314 mg/kg. On the other hand, the results showed an opposite trend in Ca concentration and suggested that Ca adsorption increases with the increase in soil pH. Similar observations were made for Mg concentration. Another observation is that all measured parameters dropped in sample 159 at soil pH 6.28 to low concentrations. The soil analysis indicates that the soil is rich in moisture content. Soil suitability determines production potential for crops. However, the soil analysis results indicate that there is limited high potential agricultural land available for farming purposes. Crop yield is influenced by topsoil depth; available soil moisture and slope position (Betts & De Rose, 1999). This land needs to be protected for food security. Figure 5.2, Figure 5.3 and Figure 5.4 shows the regression analysis to find out the relationship of exchangeable cations Ca, Mg and K (mg/kg) as to estimates approximate AEZ specific yield.

Figure 5.2 showing the trend line suggests that Ca distribution in soil starts increasing at 91.8 from 540 mg/kg in response to pH where R^2 = 0.0812 and for Mg the increase starts at 42.06 from 16.37 mg/kg where R^2 = 0..22 (Figure 5.3). The trend line also suggests that K distribution in soil starts increasing at 1.44 from 249 mg/kg in response to pH where R^2 = 0.003 (Figure 5.4). The results demonstrate a correlation between pH and distribution of Ca, Mg and K in the soil.

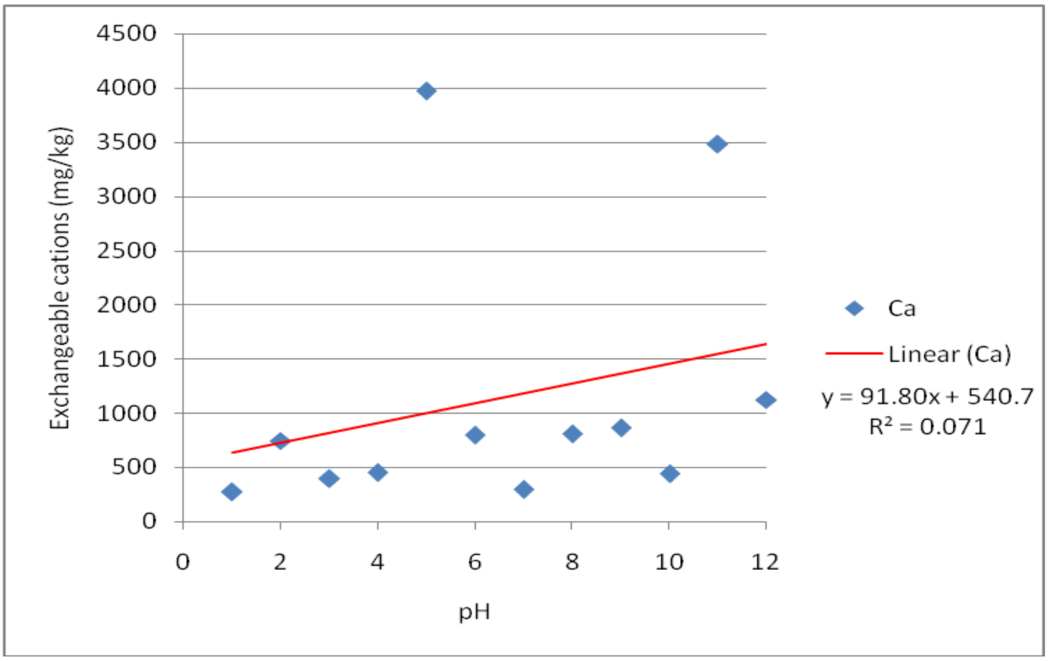

Figure 5.2: Data transformation depicting Ca (mg/kg)

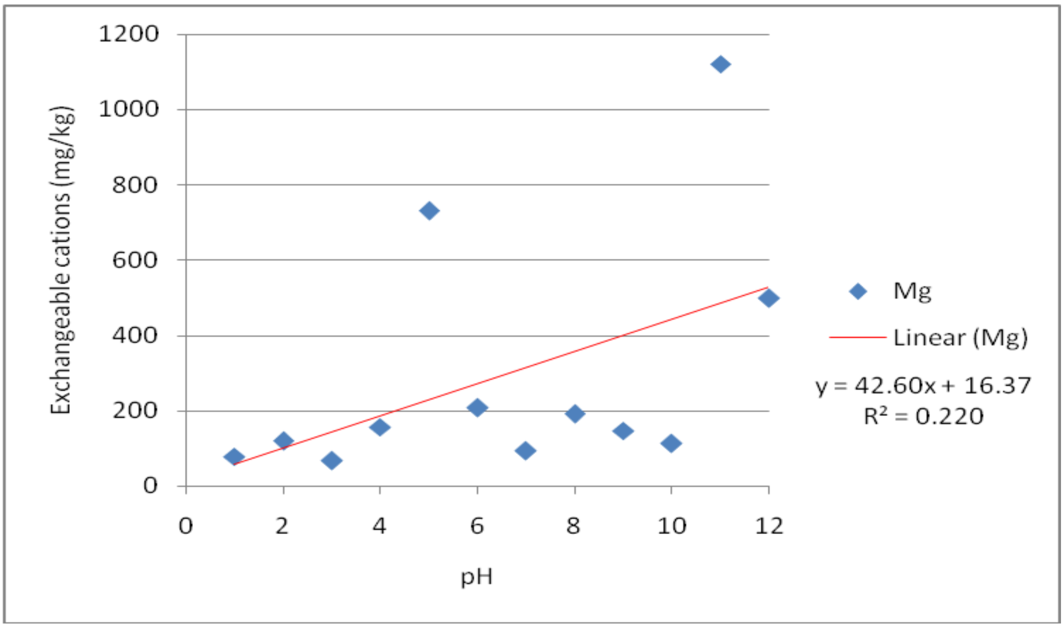

Figure 5.3: Data transformation depicting Mg (mg/kg)

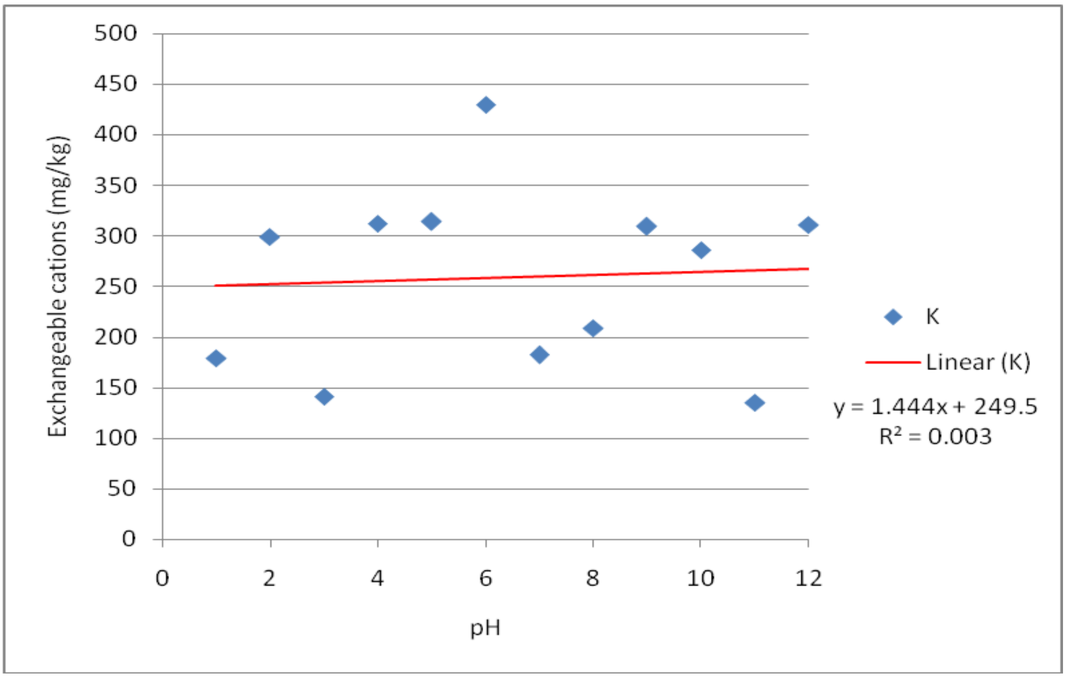

Figure 5.4: Data transformation depicting K (mg/kg)

5.2.2 Agro-climatic analysis

The agro-climatic suitability assessment for zoning crops comprises the following:

- Elevation;
- Precipitation;
- Temperature;
- Proportion of sunshine and cloud cover; and
- Relative humidity (FAO, 1996).

Temperature

The results obtained from the meteorological information are essential for food security (Kalsi, 2004). Table 5.3 shows that Thaba Ya Batho smallholder farms experience mild to cold winters. The area is also characterised by an average maximum temperature of 21°C and an average minimum temperature of 12°C. Summer temperatures as high as 31°C can be expected and may drop to lower than 1°C in winter. Temperature and rainfall data were obtained from weather station number 30901 located at Pienaarsriver over a period 2009 to 2013 (Table 4.2).

The lowest mean minimum temperature occurs during the driest periods of May, June, July and August; it ranges between 1- 4°C. The highest mean temperature occurs during November, December, January and February between 31- 33°C. The lowest recorded minimum temperature was in June (-2°C) and the highest average maximum temperature was in February (33°C). Summer periods have extreme temperatures higher than 33°C. Fenyes & Meyer (2003) indicate that temperature is a factor which influences agricultural potential and crop adaptability.

Table 5.4: Monthly temperature (minimum and maximum) in °C for the period 2009-2013

Pienaarsriver Weather Station: 30901

	2009		**2010**		**2011**		**2012**		**2013**		**Ave-min/max 2009-13**	
Month	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Jan	17	31	17	31	17	30	16	32	16	33	17	28
Feb	16	31	15	33	15	31	16	34	14	35	15	33
Mar	12	30	13	32	14	31	12	32	13	32	13	32
Apr	7	29	13	26	10	26	6	28	8	29	9	28
May	2	25	7	26	4	25	2	28	2	26	3	26
Jun	1	23	2	22	-3	23	-1	23	-2	24	-1	23
Jul	-4	21	0	23	-3	22	-2	24	-1	23	-2	23
Aug	0	25	0	26	0	25	2	27	1	25	1	26
Sep	6	31	7	31	5	30	7	29	9	31	7	30
Oct	13	31	12	33	10	31	12	30	11	31	12	31
Nov	13	29	14	32	14	32	13	32	13	32	13	32
Dec	15	32	16	31	16	31	15	32	16	30	16	31

Rainfall

The annual rainfall ranges between 500 mm and 600 mm (ARC-ISCW, 2004). The study area receives almost 96% of the annual rainfall during summer and 4% during the winter season.

This shows that the climate in the study area is suitable for a wide range of field crops. Figure 5.5 shows the rainfall trend over the five years on Thaba Ya Batho smallholder farms.

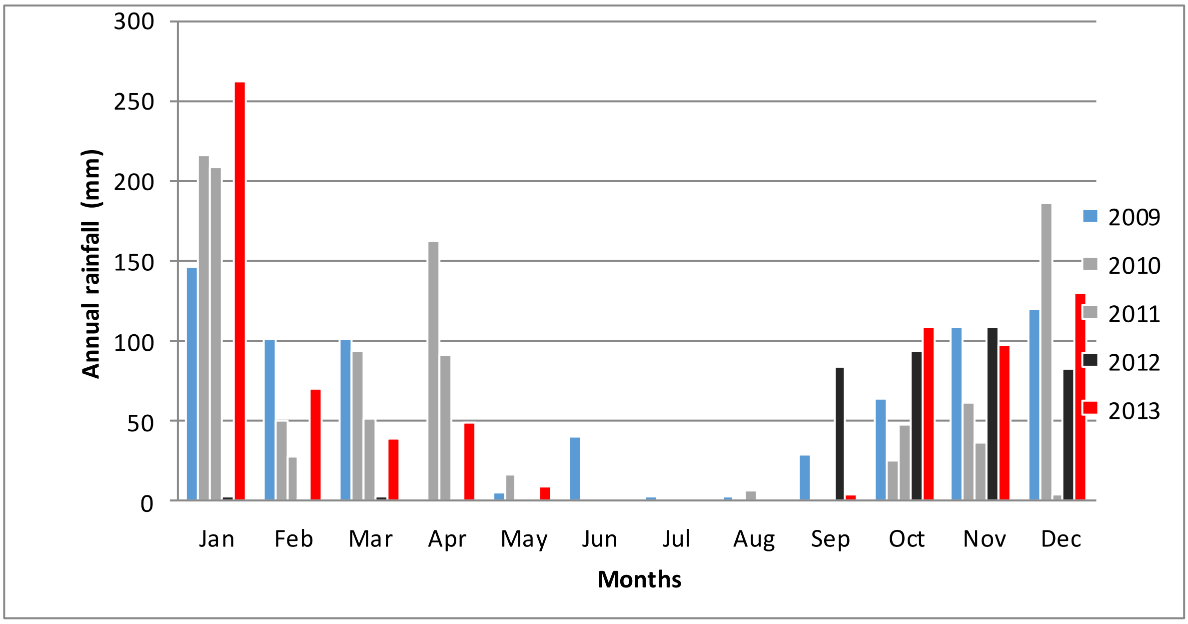

Figure 5.5: Monthly rainfall (mm) for the period 2009-2013 (Pienaarsriver Weather Station: 30901)

Table 5.5: Monthly rainfall figures (mm) for the period 2009-2013

Pienaarsriver Weather Station: 30901

Month	2009	2010	2011	2012	2013	Ave Monthly 2009-13
Jan	146	216	208	3	262	167
Feb	101	50	27	1	69	50
Mar	101	93	51	3	39	57
Apr	0	162	91	0	48	60
May	5	16	1	0	9	6
Jun	39	0	1	0	0	8
Jul	3	0	0	1	0	1
Aug	3	0	6	0	1	2
Sep	28	0	0	83	3	23
Oct	64	25	47	93	108	68
Nov	108	61	36	108	97	82
Dec	120	185	4	82	130	104

Table 5.5 illustrates monthly rainfall distribution. The monthly rainfall during November, December and January ranged between 82 mm and 167 mm.

The recorded monthly rainfall during the driest periods of July and August was between 0-6 mm. The results demonstrate that January and December have high rainfall. Higher rainfall occurred in 2010 and 2013 than in other years. Table 5.6 shows ranges in agro-climate indices. There is high potential evaporation (2200 - 2400 mm) which may not be suitable for dry land production. The average first frost date in the past 10 years occurred from 1- to 10 May and the last frost date from 21to 31 July. The long-term 33rd percentile annual rainfall received ranges from 400 – 500 mm with the long-term 66th percentile annual rainfall of 500 – 700 mm. Frost occurs most years on 21-31 days on average between May and June. The average evaporation is between 2200-2400 mm per year.

Table 5.6: Agro-climate indices in Thaba Ya Batho

Chill units from May to September	**Chill unit class (PCU)** 700-800
Long-term Average Annual Evaporation	**Annual evap (mm)** 2200-2400
Average First Frost Date (1 in 10 years)	**First frost date class** 1-10 May
Average First Frost Date (5 in 10 years)	**First frost date class** 21-31 May
Long-term Average Accumulation Heat Unit: Nov-April	**Heat unit class (GDD)** 2100-2400
Average Last Frost Date (5 in 10 years)	**Last frost date (5 in 10 years)** 21-31 July
Long-term 33rd Percentile Annual Rainfall	**Rainfall class (mm)** 400-500
Long-term 66th Percentile Annual Rainfall	**Rainfall Class (mm)** 500-700

Source: ARC-ISCW (2004)

5.3 SPOT-5 data classification

The land cover and land use classes were mapped in order to determine the magnitude of changes between years of interest 2006 to 2011.

5.3.1 Change detection

The processing of the SPOT-5 imagery produced the change detection image illustrated in Figure 5.6. The changes that have occurred over a number of years are presented. Rapid changes in land use and land cover are identified in satellite images. The basic results for change detection show unchanged vegetation cover, and increase and decrease in vegetation cover.

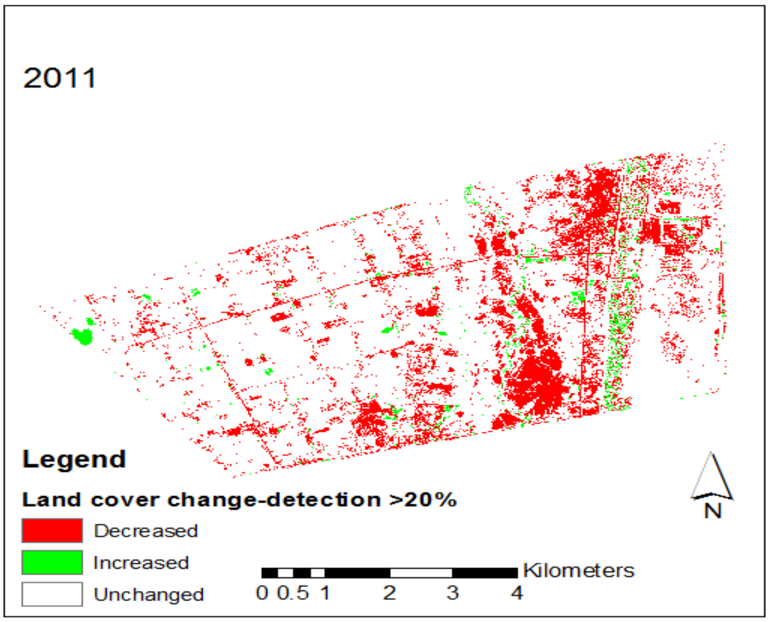

Figure 5.6: 2011-2006 (Land cover change-detection image >20%)

Figure 5.6 represents the imagery of areas where change has occurred over a period of six years. The red areas represent significant increase in vegetation, while green areas represent significant decrease in vegetation (Figure 5.6). Change detection was done using a 20% increase or decrease. The red colour highlights the areas of 20% decrease in reflectance value while green colour highlight areas show a >20% increase in reflectance value. An overall change is increase in vegetation. Red colour areas show a negative change whereas green colour show a positive change.

5.3.1.1 Normalised difference vegetation index (NDVI)

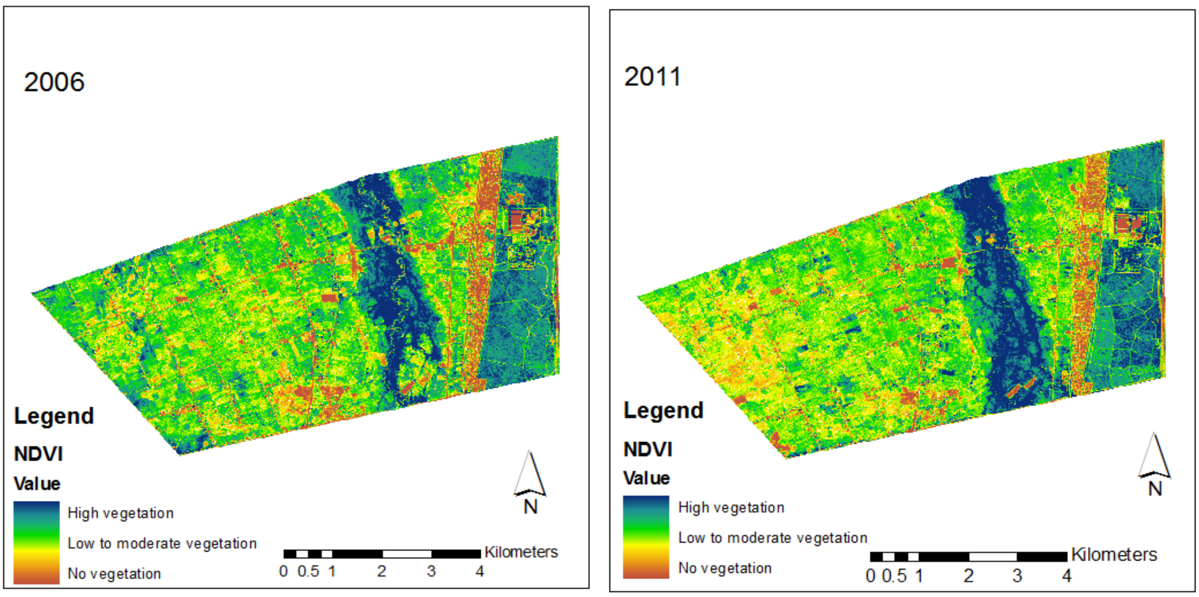

Figure 5.7: Satellite-derived NDVI in Thaba Ya Batho (2006 and 2011)

The satellite-derived NDVI (Figure 5.7) shows seasonal variations in vegetation productivity. The NDVI distinguishes vegetated area from the non-vegetated area. It also determines the health of vegetation (Mather, 2011). The results show that natural grasses decreased in the eastern section. The low value colours illustrate barren land or man-made structures (house, road, and other buildings). The dark colour in Figure 5.7 illustrates high vegetation features. The NDVI map shows increase in vegetation in 2011 compared to 2006 in some areas.

5.3.1.2 Classification

The forest types divide the western and eastern sections of the study area. The forest is spreading further along the western and eastern sections (Figure 5.8). Burning practices lead to resource degradation and cause reduction in agricultural production. Figure 5.8 below shows that dry grass has a higher coverage than other land cover types.

5.3.1.3 Supervised classification

Figure 5.8: Supervised classification created using SPOT imagery (2006 and 2009)

Soil degradation is a major problem to food security on Thaba Ya Batho smallholder farms. Degraded area is identified as an environmental constraint to agricultural expansion. The bare rock and soil shows the deterioration of soil due to erosion. The erosion is a result of forests that were cleared by fire and cutting of trees for fuel wood. The overexploitation of natural resources gives rise to loss of top soil. Figure 5.8 shows an increase in the amount of bare rock and soil from 2006 to 2009. Certain areas have started to be degraded.

The results presented in Figure 5.8 shows that the other dominant land cover is forest. The supervised classification shows the increase in natural forest in 2009. The results show that bush encroachment is uncontrollable. The results gathered from the SPOT images show bare patches of soil in 2009. The loss of agricultural land for production was due to overgrazing, forest fire, waste disposal sites, and fuel wood collection.

Images acquired in October 2006 and April 2009 (Table 4.1) determine changes in crop requirements for growth (e.g. grass dries up in April). Temperature influences the distribution of vegetation. The seasonal fluctuation determines the growth of veld. The land cover classes are grassland, forest woodlands, cultivated lands and bare rock and soil. Forest occupies a largest portion along the Apies River. The results show that in October, grass shows 100% ground cover. High rainfall occurred in this month and resulted in green areas illustrated in the image. The area changed from cultivated land to grassland. During the dry season, large areas of grassland changed from grassland to barren lands (Figure 5.8). Major attention should be focused in alleviating the spreading of forest woodland.

5.4 Land cover

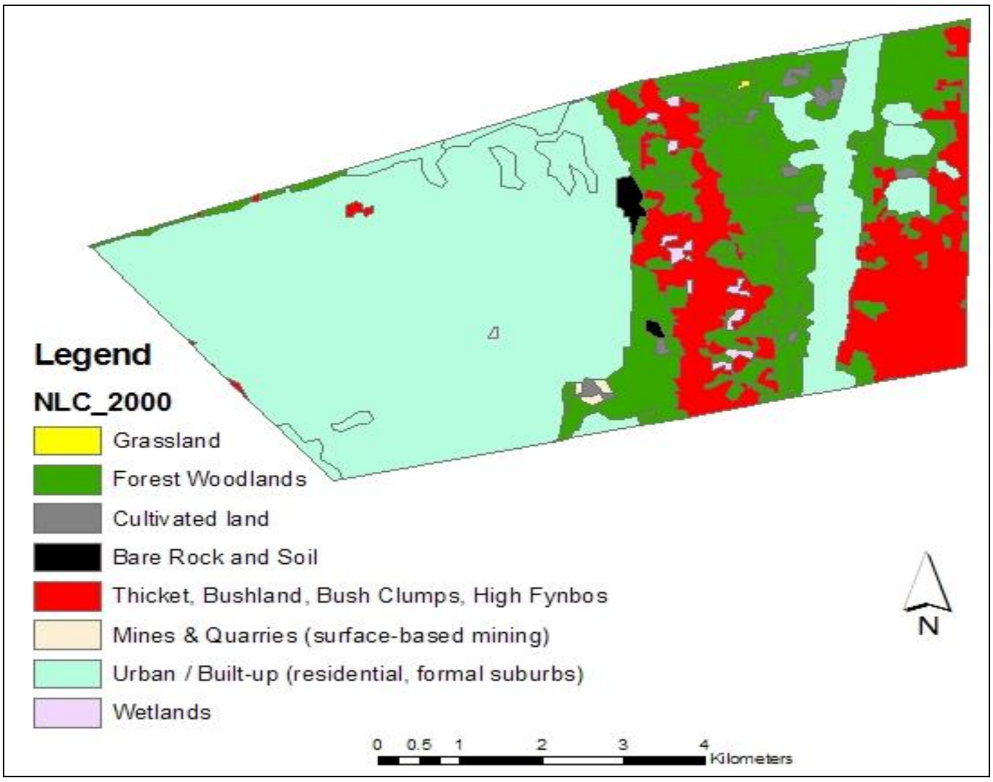

Figure 5.9: Land Cover Classification for Thaba Ya Batho, 2000

Figure 5.9 shows the distribution of land use/land cover across Thaba Ya Batho based on the 2000 National Land Cover (NLC) and verified in the field. A number of classes are merged to produce simplified land cover classes according to the 2000 (NLC) Classification.

Table 5.7: Land-cover characteristics of mapped areas in Thaba Ya Batho

Land-cover classes for Thaba Ya Batho	% of mapped area
Bare Rock and Soil (erosion: dongas / gullies)	2%
Cultivated, temporary, commercial, dryland	11%
Forest Woodland	69%
Mines & Quarries (surface-based mining)	3%
Thicket, Bushland, Bush Clumps, High Fynbos	13%
Unimproved (natural) Grassland	1%
Urban / Built-up (residential, formal suburbs)	14%
Wetlands	11%

Table 5.7 summarises the land-cover characteristics of mapped areas in Thaba Ya Batho. Features might differ on the ground because data was processed on a national scale. The NLC provides national coverage at a much higher resolution that distinguishes the land cover aspects. Buildt-up area occupies a vast land area in the west. The quarries from Babelegi industries situated in Thaba Ya Batho are included in Table 5.7. Mines and quarries occupy a small portion. The results indicate that about 3% of the study area is covered by mines and quarries. The study area shows a small portion of water bodies. Approximately 11% of the study area is covered by wetlands. The water bodies form part of the wetland data layer. Unimproved natural grassland covers 1% in Thaba Ya Batho. As illustrated above, land use is characterised by urban built-up areas, savannah, cultivated land, vegetation and wetlands.

However, some classes are more highly represented than others: 69% of the area is regarded as forest woodland: bare rock and soil covers 2% and unimproved grassland covers 1% of the land. The bare rock and soil are areas that are not suitable for crop production. The results show that agricultural land with a high potential will diminish over time as a result of forest woodland. Smallholder farms in Thaba Ya Batho are easily accessible due to level topography. The results of land use and land cover change as analysed using supervised classification shows vegetation change from 2000 to 2011 respectively. Anderson *et al.* (2001) argue that land use and land cover has become increasingly important to overcome the problems of uncontrollable development, deteriorating environmental quality, loss of prime agricultural land, destruction of important wetland and loss of wildlife habitat.

5.5 Integration of GIS products

5.5.1 Geo-database

The study was conducted with the use of a geo-database as a decision support tool. The scale of the data was refined to a 1:50 000 scale with more detail. The spatial representations through various layers support high resolution satellite images.

5.5.2 Suitability for agricultural production

Land suitability and potential are categorised for agricultural development. The focus is on suitability in terms of the parameters that determine the AEZ of Thaba Ya Batho smallholder farms as discussed below. This is partly because these factors determine agricultural production. Moreover, the mapping of the present agricultural status shows that the land area is classified as highly suitable and moderately suitable.

5.5.2.1 Soil

Table 5.8: Legend of generalised soil patterns of Thaba Ya Batho

Code	Group	Description
Red-yellow well drained soils generally lacking a strong texture contrast		
CM	RED-YELLOW WELL DRAINED, MASSIVE OR WEAKLY STRUCTURED SOIL	Red soils with high base status.

Source: ARC-ISCW (2004)

Table 5.8 shows a simplified generalised soil pattern of Thaba Ya Batho. The soil types identified are: red-yellow well drained, massive or weakly structured solids based on land type survey data (ARC-ISCW, 2004). The dominant soil type of the irrigated areas is red structure-less sandy loams or sandy clay loams.

The national land type survey at a scale of 1:250 000 is the source of information for the generalised soil patterns (ARC-ISCW, 2004). The land type survey provides soil information of each land type. The soils in the study area are considered to be suitable for a variety of crop production. Le Roux *et al*. (2013) show that red soils with high base status are popular for dry land cropping and irrigation.

Table 5.9: Soil potential for irrigation

Soil suitability for irrigation	
% (irrigation)	**Description**
Suitable_50	>50% of area suitable, slight limitations

Source: ARC-ISCW (2004)

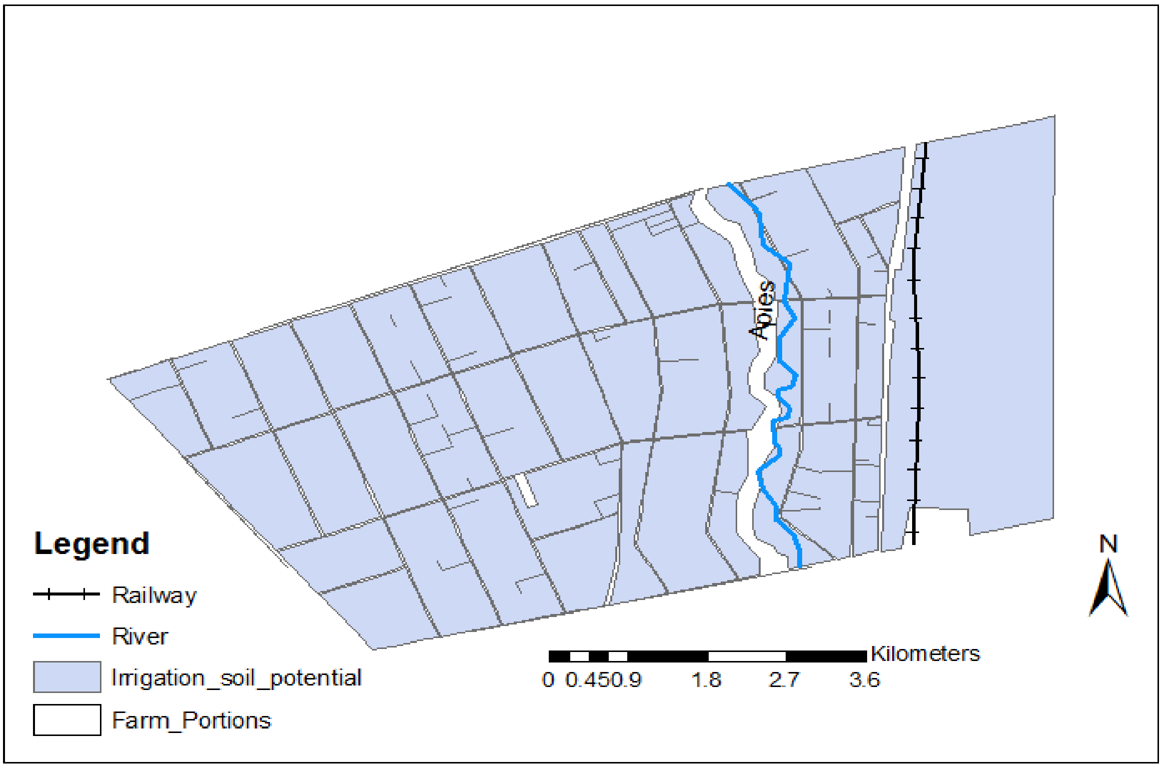

Figure 5.10: Soil suitability for irrigation

Figure 5.10 shows the irrigation potential in Thaba Ya Batho. Table 5.9 shows that more than fifty percent (50%) of the soil in the study area is regarded as suitable for irrigation purposes, based on land type information (ARC-ISCW, 2004). High potential areas are located along the Apies River and north-western part. More than 80% of the study area is high potential agricultural land. The best soils are permeable red or yellow loams suitable for cultivation. Thaba Ya Batho has good fertile soils good for production.

Table 5.10: Detailed description of soil suitability for irrigation

Suitability Class	**1**	**2**		**3**		**4**	**5**
Class description	Highly suitable; little or no limitation	Suitable; slight limitation		Moderately suitable; moderate limitation		Marginally suitable; severe limitation	Not suitable; very severe limitation
Soil class	2	2	3	2	3,4,5,6	2,3,4,5,6,7,8	All
Soil depth (mm)	>1000	>800	>750	>650	750	>500	All
Top soil clay (%)	15-25	10-25		10-30		6-30	All
Slope percentage	<5	<8		<12		<12	All

Source: ARC-ISCW (2004)

Table 5.11: The terrain of Thaba Ya Batho smallholder farms

	Class	Description	Local relief (m)
Terrain	A1	Level plains	0-30

Source: ARC-ISCW (2004)

Table 5.10 indicates soil different suitability classes. Table 5.11 illustrates the terrain of Thaba Ya Batho. For this study, the slope is determined based on 90 m digital elevation model (DEM) (ARC-ISCW, 2004). The surface area of the farms falls within a level plain making it favourable for crop production. There are no hills surrounding the farms. Terrain influences agricultural production potential. In the study area, flat landscapes feature with a slope less than 12%.

5.5.2.2 Water

Table 5.12: River

Name	Class	Description
Apies River	Perennial river	Has a continuous flow all year round

Table 5.12 indicates that the Apies River is a perennial river. As noted earlier, the Apies River flows in a North-South direction: it divides Thaba Ya Batho into Boschplaats east and west. Farmers in the area have no option but to depend on underground water pumped by boreholes. As a result of inaccessible water from the Apies River, water has become a major limiting factor in terms of production as a result of poor irrigation systems. Furthermore, water rights should be applied on high value labour intensive crops (Collett, 2008).

5.5.2.3 Agriculture

The vegetation suitability (Figure 5.11) was derived from 1:250 000 scale land type information (ARC-ISCW, 2004). The results indicate a large amount of under-utilised arable land of good quality. Vegetables, maize and groundnuts are intensively grown. Agricultural productivity relates directly to land use management or production techniques.

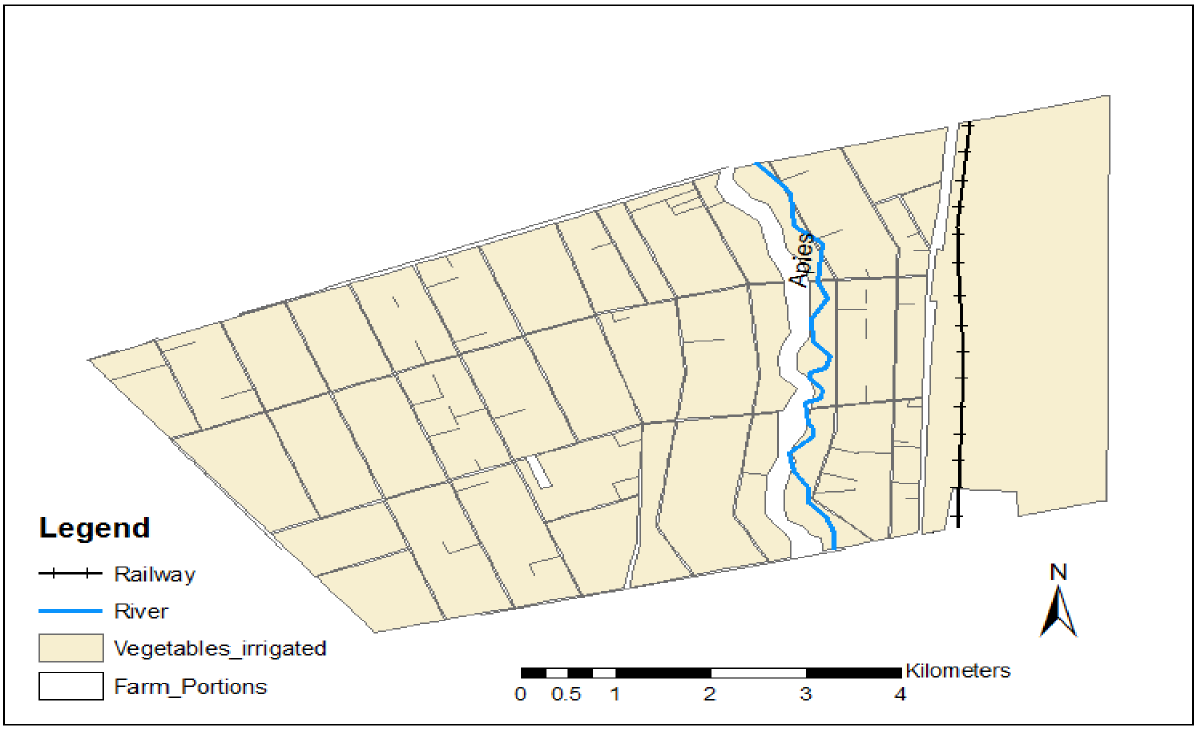

Figure 5.11: Suitability for irrigated vegetables

Table 5.13: Suitability for irrigated vegetables

Vegetable suitability		
Crop	Suitability class	Description
Vegetables – irrigated	Optimal_50	>100% of the area optimally suitable

Source: ARC-ISCW (2004)

The study area can potentially be irrigated under responsible land management. Table 5.13 shows that Thaba Ya Batho has more than 100% irrigation potential with slight limitations (ARC-ISCW, 2004). Table 5.13 above helps to explain the suitability for irrigated vegetables.

Table 5.14: Vegetation

Map code	Name	Hectares	Biome
SVcb15	Springbokvlakte Thornveld	3560.17	Savannah Biome

Source: Mucina & Rutherford (2006)

Table 5.14 indicates the savannah biome in Thaba Ya Batho which occupies 3560.17 ha. Vegetation data set such as Vegmap2006 was clipped for Thaba Ya Batho with a scale of 1:1 000 000. The vegetation in Thaba Ya Batho can be described as tree savannah consisting of fairly dispersed bushes and grass.

From the field observation, it is clear that fire and overgrazing are some of the major limiting factors that influence the species composition. Environmental parameters have a major impact on the occurrence of natural vegetation (Collett, 2008); for example, climate limits yield production. More plant species are found along the Apies River.

Table 5.15: Grazing capacity (ha/LSU)

ID	Grazing Capacity Class (ha/LSU)	Description
12	>10 ha/LSU	Controlled Extensive Agriculture

Source: ARC-ISCW (2004)

ha/LSU= hectare per livestock unit

Livestock unit determines the impact of stock numbers on the condition of the veld or the degradation thereof and the extent of economic recovery (DoA, 1998). Table 5.15 above shows the grazing for Thaba Ya Batho smallholder farms. The grazing capacity in the study area is greater than 10 ha/LSU (ARC-ISCW, 2004).

Collett (2008) indicates that livestock farming is the largest agricultural sector in the country. Livestock includes dairy and beef farming. Poultry production mainly features eggs and broilers. Poultry production is rapidly growing. The operating capital might negatively affect production. The study area has a potential carrying capacity to support livestock (cattle, sheep and goats). Inappropriate developments and bush encroachment might lead to declining grazing areas. The result of ha/LSU indicate that the study area has a grazing potential (Table 5.15).

5.6 Agro-ecological zone description

Table 5.16: Land cover classes and descriptions

No	Land cover type	Description
1	Bare rock soil (erosion)	Non-vegetated areas, or areas of very little vegetation cover (excluding agricultural fields with no crop cover, and open cast mines and quarries), where the substrate or soil exposure is clearly apparent.
2	Cultivated land	Areas of land that are ploughed and/or prepared for raising crops (excluding timber production). The category includes the areas currently under crop, fallow land, and land being prepared for planting.

3	Forest & Woodland	All wooded areas with greater than 10% tree canopy cover (1), where the canopy is composed of mainly self-supporting single stemmed (2), woody plants > 5m in height. Essentially indigenous trees species (3), growing under natural or semi-natural conditions (may include some localised areas of self-seeded exotic species).
4	Mines & Quarries	Area in which mining activity has been done or is been done. Includes both opencast mines and quarries, as well as surface infrastructure, mine dumps etc., associated with underground activities.
5	Urban/Build-up	An area where there is a permanent concentration of people, buildings, and other man-made structures and activities, from large village to city scale.
6	Wetlands	Natural or artificial areas where the water level is at (or very near the land surface) on a permanent or temporal basis, typically covered in either herbaceous or woody vegetation except for dry salt pans in arid regions.

Source: Adopted from (NLC_2000)

Table 5.16 provides a comprehensive description of land cover classes groups based on their description. The land cover classes were identified in Thaba Ya Batho and their description is given.

5.7 Delineation of agricultural potential zones

This section determines the agricultural potential in Thaba Ya Batho. The overall results show that remote sensing is able to detect suitable areas for crop and livestock production. Land capability plays an important role in determining the long-term agricultural potential and planning. The land suitability map was compiled based on the relationship between soil fertility, soil erosion risks and land evaluation inputs for crops. The map is obtained by combining various data layers, such as soil, terrain and climate. Land suitability evaluation involves overlapping maps with GIS and remote sensing techniques (Abah, 2013).

Figure 5.12 shows high potential agricultural land. Looking at Figure 5.12, it can be argued that the results show that Thaba Ya Batho smallholder farms have a high agricultural potential. In addition, Figure 5.9 identifies future development areas. Collett (2008) argues that high potential agricultural land is influenced and maintained by the principles of sustainable development, such as prevailing market factors, available infrastructure, possible additional water sources, socioeconomic factors, suitable crop selection and excellent management practices. The suitability map below was produced from combining different soil map layers.

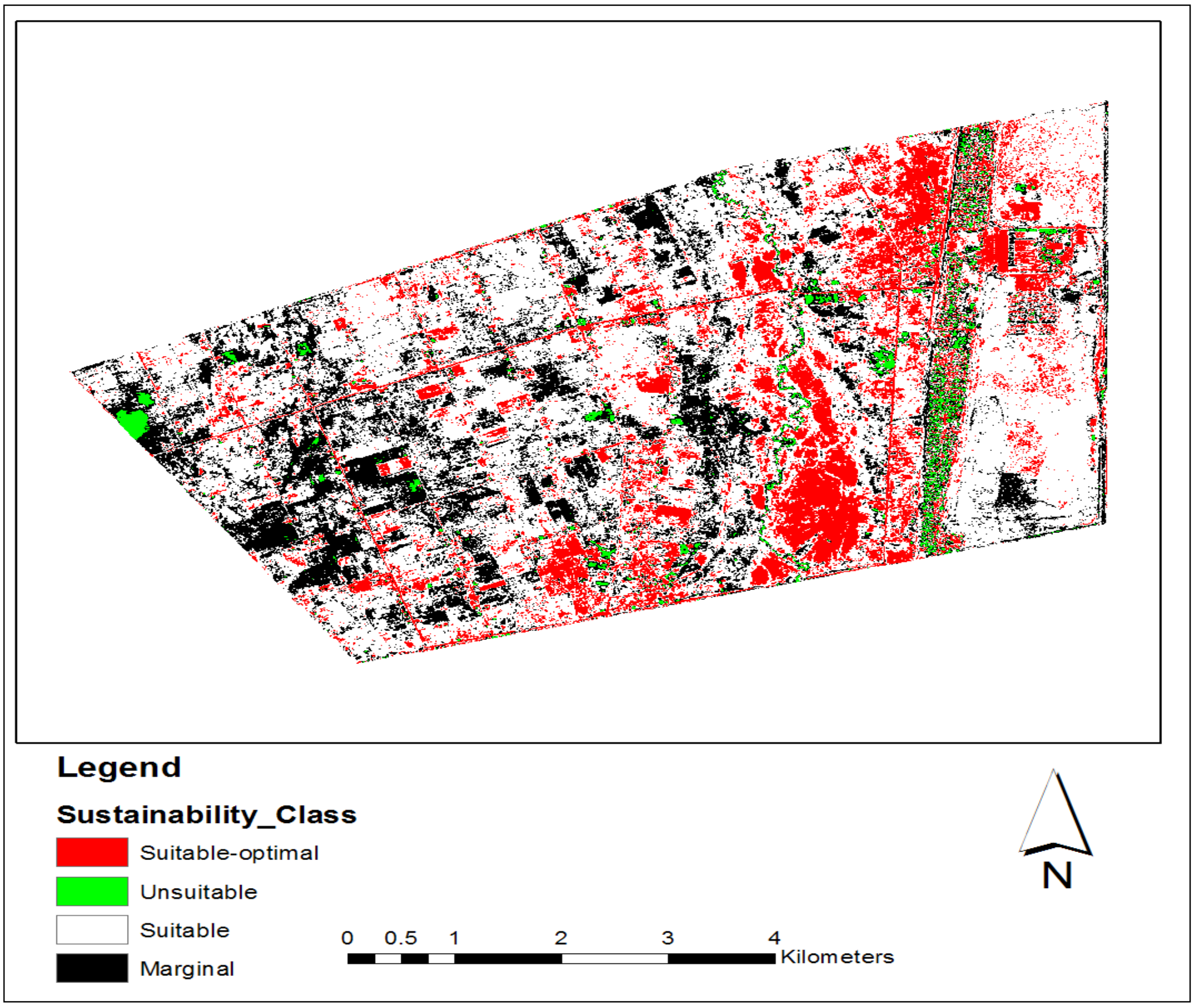

Figure 5.12: High potential agricultural land

Table 5.17: Land suitability for agriculture

Suitability	**Area (ha)**	**Area (%)**
Suitable-optimal	214	5.33
Unsuitable	328	8.2
Suitable	2654	66.35
Marginal	804	20.1
Total	4000	100

Table 5.17 illustrates the land suitability for agriculture. About 66% of the study area is highly suitable for agriculture. Approximately 8% of the area is not suitable. About 20% of the area is considered marginal (804 ha), with only about 5% regarded as suitable-optimal land with high agricultural potential. It is important to protect the high potential agricultural land in order to secure employment opportunities and food.

5.7.1 Land capability

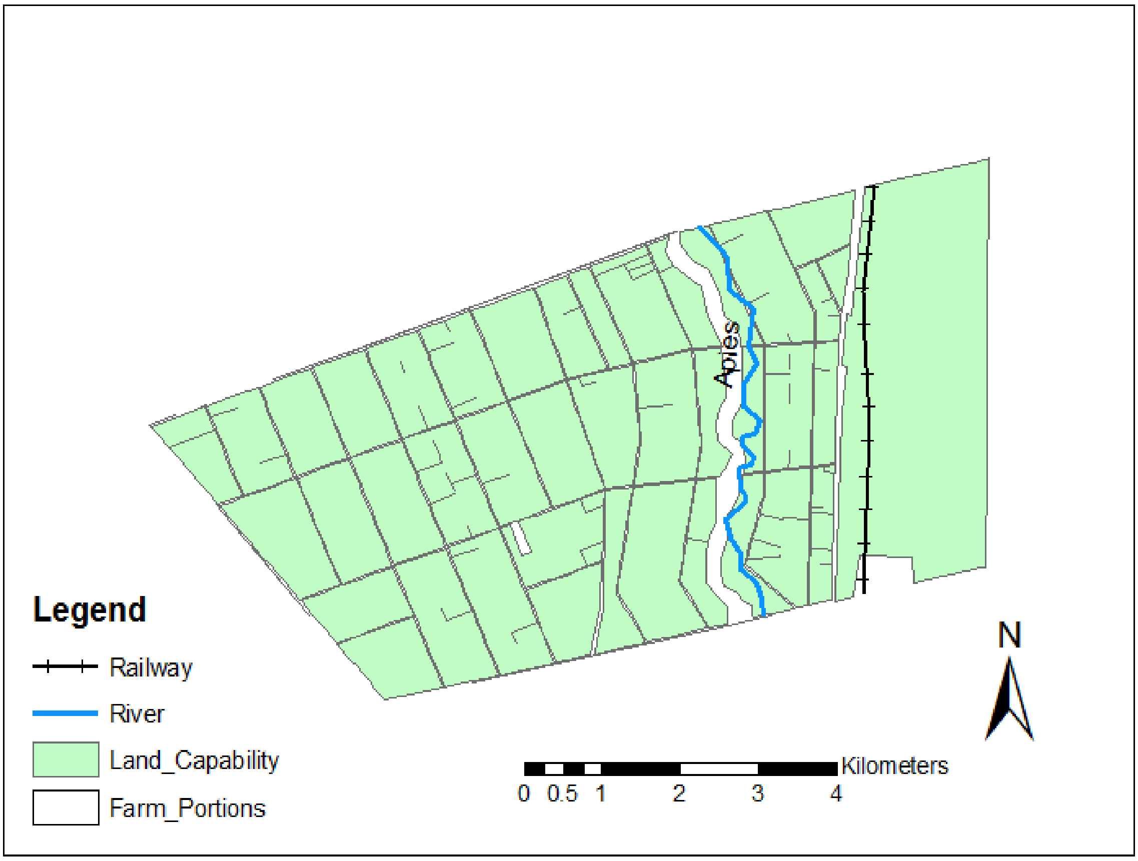

Figure 5.13: Land capability of the study area

Land capability map was used to determine crop suitability. Figure 5.13 depicts the land capability of Thaba Ya Batho. Land capability was determined at a scale of 1:1 000 000 in order to identify dominant land capability classes (ARC-ISCW, 2004). Arable land, is classified by Class I – IV, and covers 23,4% of the area of South Africa (Schoeman *et al.*, 2002). Thaba Ya Batho's land is suitable for crops such as maize, oranges, cabbage, potatoes and groundnuts.

Thata Ya Batho has moderate potential arable land. Thaba Ya Batho smallholder farms can be regarded as high potential agricultural land based on land capability (Figure 5.13). This is partly because 100% of the study area is suitable for various crops as a result of favourable climate, soil and terrain. This area is suitable for mixed vegetable farming due to its geographic location.

Table 5.18: Cropping patterns for field crops in Thaba Ya Batho

Thaba Ya Batho Smallholder Farms												
Month	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**
Maize												
Cabbage												
Butternut												
Lucerne												
Wheat												
Potatoes												
Oranges												
Sunflower												
Lemons												
Carrots												
Tomatoes												
Groundnut												
Dry beans												

	Planting period
	Growing period
	Harvesting period
	Perennial crops

Table 5.18 proposes the major cropping patterns for crop growth seasons from planting to harvesting, as outlined in Appendix C. The cropping patterns are derived from the land qualities, top soil properties, moisture storage capacity and related soil maps. These crops are selected due to the fact that they are produced in Thaba Ya Batho. This shows that growing seasons are Dec – Jan for maize crops. Harvesting for maize may extend for three months. Maize is planted from November to mid-December and harvested from February to March. Oranges and lemons are perennial. The oranges are usually harvested in bulk from July – August. Cabbage in Thaba Ya Batho requires low temperatures. The growing period for cabbage usually lasts for two months. Cabbage is planted in April. Groundnuts are mainly planted in August. As a result of early precipitation, wheat is grown in spring (November).

The classification of seasons according to months plays a vital role in crop management. Winter is cold and dry, whereas summer is hot and wet (Meng *et al*., Zhang, 2013). Batesman *el al*. (2013) indicate that seasonal management can be subcategorised as follows:

1) Dry season – periods without rainfall during which crops depend on irrigation water. Crops stop growing during the dry season. Grazing is very low in winter due to water shortages.
2) Wet season – rainfall stimulates growth of crops. Rainfall occurs during wet seasons. Planting of summer crops takes place; and
3) Harvest season – a period when a crop that is ripe is harvested.

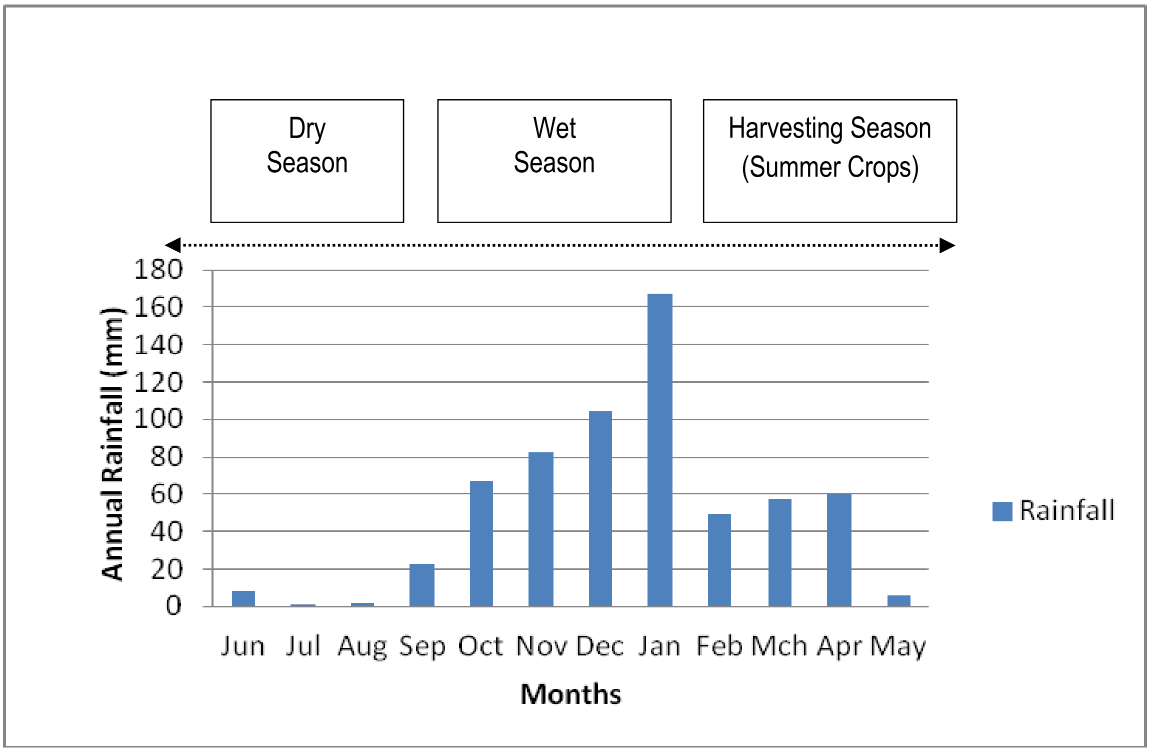

Figure 5.14: Growing season for most summer crops

Figure 5.14 indicates variations in growing season for most summer crops (selected in Table 5.18) using rainfall data from 2009 to 2013. Based on monthly average, the rainfall shows that the main farming season is in summer and no dryland farming takes place in winter. The rainfall pattern helps in planning crop farming. Annual precipitation is extremely variable; ranging from 400 mm to 900 mm. Crops can be harvested from February to April. There is enough rain to grow crops without irrigation in summer. Irrigation can be used during the dry season (winter) due to low rainfall. The climate is favourable which makes it ideal for crop production. Climate suitability helps farmers to make an informed decision on selection of crops or crop yield estimation.

Table 5.19: Plantation season in Thaba Ya Batho

Crops	
Cabbage, Beetroot, Carrots, Pumpkins, Dry beans, Maize, Sweet potatoes, Sunflower, Potatoes	
Growing season	**Month**
Early	October
Mid-early	November
Mid-late	December
Late	January

Table 5.19 shows the planting season for most summer crops. The crops can be grown during the mid-early (November) season due to high rainfall (Figure 5.14). A delay in planting might decrease yield. Late growing season delay can affect harvest index of the crop (Caldiz *et al*., 2002).

Table 5.20: Recommendations for pest control and fertilizers

Crop	Pest control	Fertilizer (kg/ha)	Kg/ha
Tomatoes	Alfathrin Endosulfan EC	Pot. Nitrate SG L.A.N (28)	100 250
Cabbage	Afox Cypermethrin	L.A.N (28) 2:3:4 (30) + 0.5% Zn	600 500
Butternut	Dithane M45 Benlate	L.A.N (30) 2:3:4 (30)	250 400
Carrots	Alfathrin	L.A.N (28 2:3:4 (30)	150 500
Onion	Oftanol Tronnic (Wetting)	L.A.N (28) 2:3:4 (30)	300 500
Beetroot	Nematodes, cutworm	2:3:4 (30) L.A.N (30)	400 100

Table 5.20 shows the recommendations for pest control and applications of fertilizers based on the results of soil samples, climate and farm survey. Soil conditions within the study area are considered to be satisfactory for crop production. Crops can be grown with the application of fertilizers as supplement. For optimum economic yield, 500 kg/ha of NPK fertilizer is recommended for high production yield of onion, carrot and cabbage. Fertilizers are normally applied after early rain for optimum growth (Yunju *et al*., 2012). Crops can be attacked by various diseases such as leaf spot or pests during warm conditions. The DAFF (2011) indicates that pests (cutworm, nematodes and American bollworm) attack plant roots causing galls to develop which reduce the size and efficiency of the roots system. Pest control increases crop production. The applications of fertilizer and pest control measure should be based on the principles of sustainable development. The principles of sustainable development emphasise development which enhances the quality of life.

5.7.2 Crop requirements

In summary, crop productivity is influenced by soil, climate and terrain. The study area receives almost 96% of the annual rainfall during summer and 4% during the winter season. The climate in the study area is suitable for a wide range of field and vegetable crops. Summer temperatures of Thaba Ya Batho are most suitable for growth of a variety of crops. The optimum planting date (Appendix C) can be during early wet season.

5.8 Crop production model

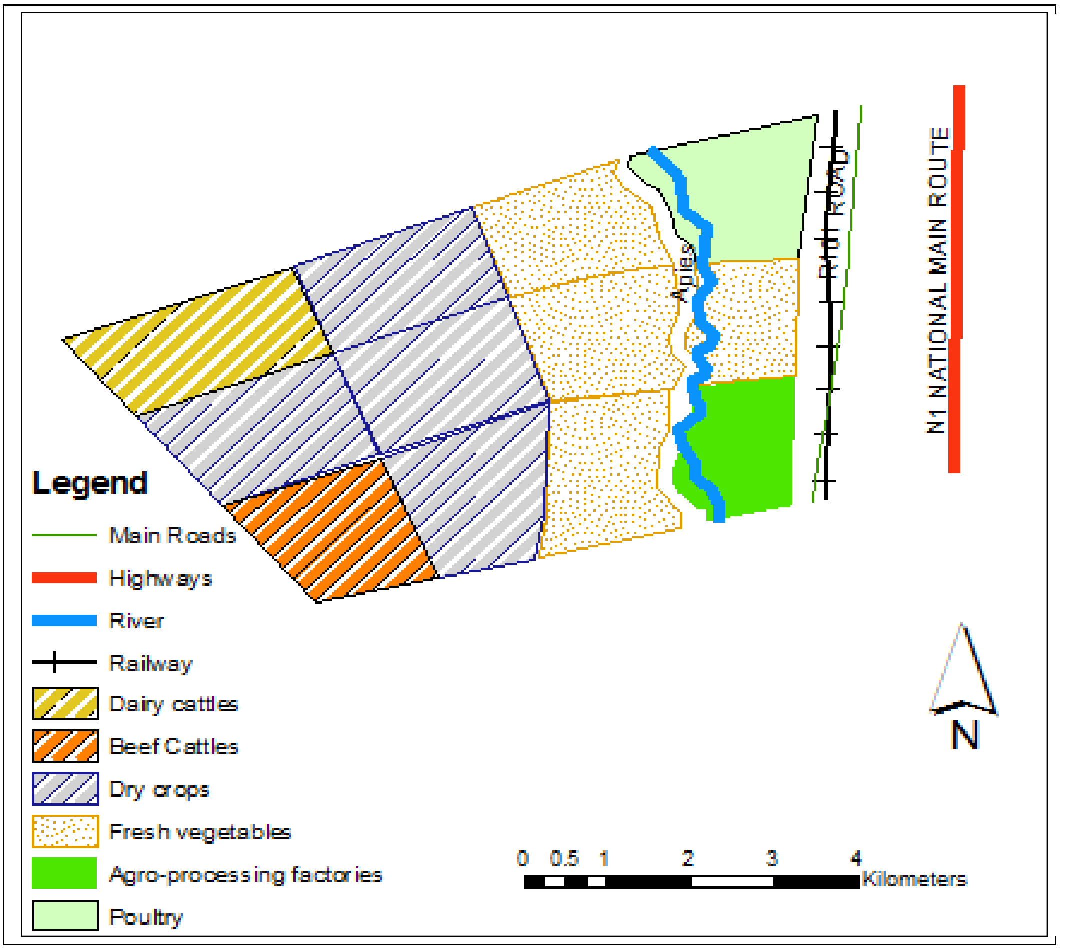

Figure 5.15: Division of land use

Figure 5.15 identifies possible division of land use for purposes of maximising agricultural production. The intent of the zoning model is to supply smallholder farmers with essential crop management information which will strengthen production and support land-use policy formulation. The crop production model is delineated using soil, climate and terrain suitability. The model is used to organise Thaba Ya Batho smallholder farms in order to improve agricultural production which will create job opportunities. In Thaba Ya Batho smallholder farm zoning is essential because it allows for future planning.

A multipurpose agricultural model may be used to increase agricultural output in Thaba Ya Batho. The proposed sustainable land management model enables smallholder farmers to create new business partnerships which will guide decision-making. The model aims to stimulate new ideas among smallholder farmers in Thaba Ya Batho and meet the demand for food security. The model maximises agricultural production and effectively addresses problems in agriculture. Thaba Ya Batho should not be used for residential development. Finally, the proposed production model will be integrated with the local hypermarkets, e.g. Spar, Pick n Pay and Checkers.

The production zoning model includes the following categories:

Poultry

This zone can be used for poultry production due to degraded lands. The uplands are characterised by extraction of natural resources (e.g. sand mining). Problems of water shortage are experienced. Therefore, this land can be used for intensive production of poultry and broilers in the long term. The pig production is concentrated close to a processing factory.

Dryland crops

This agricultural zone is planned for maize, sunflower, groundnuts and spring wheat production during summer rainfall. This zone will be used to feed animals during harvesting season. This area has a low volume of traffic.

Fresh vegetables

Fresh vegetables can be grown along the Apies River at lower elevations because of the fertile soils available and favourable climatic conditions. It is high potential agricultural land for production of vegetables such as cabbage, beetroot, tomatoes and carrots. There is a strong relationship between the zoning of vegetables productivity and the agro-processing industry. It is also close to a water source for irrigation.

Dairy and beef cattle

This zone is planned for livestock farming due to grassland of varying agricultural potential. In this zoning more pasture land is made available to support dairy and beef cattle. The dominance of livestock is based on high levels of rangeland. Sheep and goats can be allowed to graze. Livestock farming is zoned within this boundary for protection of water resources against rapid runoff related to animal waste during heavy rainfall. This zoning occupies 40% of the study area. The model is used to determine the availability of grazing for animals.

Agro-processing industries

This part of the study area is situated in close proximity to major roads such as N1, R101 and the railway line. It makes it possible to transport products. These major roads pass through Boschplaats before going to Pretoria and Limpopo. The road is heavily used for cargo transport. This will reduce distance to markets and it will create a business link. This zone is in close proximity to Babelegi industries, large shopping centres, hospitals and clinics which makes it ideal for processing and distribution to fresh produce markets. The market is approximately 9 kilometres from Thaba Ya Batho smallholder farm. This can be classified as a selling point of all farm products. The processing and distribution of milk will take place in this zone. This site is unsuitable for livestock production because of its proximity to Babelegi industries and existing excavations.

Table 5.21: Distribution of land use

Boschplaats 91 JR	Land use	Percentage (%)	Hectares (ha)
4 000 (ha)	Poultry	4	160
	Dry crops	37	1500
	Fresh vegetables	15	600
	Dairy and beef cattle	40	1600
	Agro-processing industry	4	160

Table 5.21 shows the distribution of major land use on Thaba Ya Batho smallholder farms proportioned at 4% of poultry, 37% of dry crops, 15% of fresh vegetables, 40% of dairy and beef cattle, and 4% occupied by the agro-processing industry. Dry crops and fresh vegetables account for nearly half of the total land use. The western portion of the farm is earmarked for dry crops and livestock production in the long term. Fresh vegetable production is planned for the eastern portion of the farm. The crop production model is used to prepare and manage agricultural land. This model has proved to be an effective approach for estimating the size and distribution of agricultural units. The crop production model is used to represent a unique view of the landscape in order to improve natural resources management. GIS and RS are used to justify the crop production model on a given object or area. The model determines the land use options important for production planning. A crop production model supports assessment of land capability which promotes sustainable recovery of natural resources. GIS and RS provide a decision-making tool for sustainable use of smallholder farms.

5.9 Summary

Image classification and analysis were used to determine the amount of change in Thaba Ya Batho. An accurate vegetation map was made using a supervised classification technique. Land use and land cover maps were produced at a scale of 1:50 000. The most notable change over the years is the increase of forest, grassland, mines and quarries. These changes are spreading across the study area. The unfavourable zones which might disturb agricultural production are found in the eastern part of the study area. Unsuitable agricultural practices are waste disposal and tailing dumps. Agro-ecological zones were delineated by means of GIS and RS. The study also identified the most suitable crops in Thaba Ya Batho.

The results from satellite derived images were compared with spatial datasets. The SPOT imagery output corresponded closely with the field observation. Furthermore, land suitability evaluation was carried out using GIS in order to increase yields to determine agricultural potential. Crop production divided the land into various land use categories based on their specific suitability. This chapter presented the results from field survey, laboratory analysis, image processing, AEZ mapping and land suitability evaluation.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The main focus of the study was to evaluate agro-ecological zoning using remote sensing and GIS integrating climate, soil, and terrain. The study emphasised the use of AEZ methodology to overcome the existing environmental constraints for better sustainable production and planning. Land use and land cover changes were mapped using high-resolution satellite sensors from SPOT-5 imagery. NDVI imagery was used to determine the amount of and improvement in distribution of vegetation cover.

The conclusion that can be drawn from this study is that smallholder farms cannot achieve high production without proper planning and management skills. GIS and RS techniques are recommended as important tools determining farm planning which contributes to high production. There is a need for all spheres of government and private sectors to support smallholder farmers to become productive in the future.

Unutilized smallholder farms contribute to exploitation of natural resources, because they are normally used as illegal dumping sites. There is also a challenge of overgrazing due to lack of control on the farms. The analysis presented shows that GIS and RS are fundamental tools used to extract information relevant to agriculture. The result of the study has revealed that there is poor agricultural production due to lack of knowledge about the potential benefits of farming. The best way to achieve sustainability is to encourage good agricultural practises. This could be achieved only when the provincial government and community work collectively towards common goals. Smallholder farmers need skills and knowledge in order to use the natural resources effectively. One of the primary requirements for smallholder farmers to improve the agricultural production and management perspective is that there should be an equitable distribution of farming resources. Satellite images dating back from 2006 to 2011 were compared to determine the loss of prime agricultural land. Climate data from 2009 to 2013 indicated that rainfall mostly occurs in summer (December to February). This suggests that mean monthly climate data determine the potential growing seasons of crops. As a result of high potential soils, high annual rainfall (500- 600 mm) and high summer temperature (21°C), Thaba Ya Batho smallholder farms are suitable for production of various crops. Maps of change in vegetation were produced from satellite imagery. This study has therefore achieved the objectives and the findings confirmed the hypotheses.

6.2 Recommendations

Smallholder farmers are unable to effectively and efficiently manage agricultural production, unless they are given extensive support. The results of this study can be used to manage future agricultural programmes as it recommends strategies to achieve sustainable production through good planning.

This research study makes a number of recommendations to enable successful smallholder production. The recommendations to address some of the problems facing smallholder farmers include the following strategies:

6.2.1 Skills development

In smallholder farms, skills development remains a major challenge for agricultural planning. Well-co-ordinated agricultural practice requires effective monitoring and provides a solution to environmental impacts. Training of smallholder farmers is essential for proper agricultural planning and production. It is important to empower smallholder farmers through skills development initiatives. More importantly, good planning, mapping and monitoring of the environment improve decision-making in agricultural planning. It is necessary to protect and enhance the environment and natural resources through increasing smallholder farmers' training and improving access to information technology. Skills training centres should be within the reach of smallholder farmers. The government's extension support should create a culture of learning. The skills development programmes should be designed in such a way that they focus on aspects of farming literacy like GIS, RS, mapping, and agronomy which will increase the standard of farming.

6.2.2 Access to markets

The DAFF (2012) aims to aid the existing smallholders to gain access to markets, by focusing less on primary co-operatives and more on secondary (e.g. marketing) co-operatives; and to improve the quality and accessibility of support systems and infrastructure in order that large numbers of producers may benefit. Baloyi (2010) shows that the expansion and intensification of agriculture on smallholder farms will enable access to agricultural markets.

6.2.3 Planning

Proper planning will ensure that some of the challenges facing smallholder farmers are effectively addressed. The most important goals to be adopted are speeding up growth and transforming the economy of smallholder farms in order to create decent jobs. The most effective strategy is to build a sustainable community which increases food production. In addressing planning challenges, the local community should be involved and play a major role in selection of sites for new farming establishment and dumping. More emphasis is also needed on land management for sustainable agricultural and environmental growth. For smallholder farms in Thaba Ya Batho to achieve sustainability, the environment should be protected. Sustainable agriculture is possible because the climatic conditions are favourable.

6.2.4 Conservation agriculture

Good farming practices should be emphasised in order to create sustainable jobs. A local planning forum should be established on smallholder farms in order to promote sustainable agriculture. The planning should be aimed at overseeing the implementation and monitoring of the development initiatives which promote crop diversity.

Production planning can help in evaluation of the environmental implications through integrating the environmental decision-making. The following is proposed in order to promote sustainable agricultural development and planning:

- Develop opportunities and access to information for small farm producers;
- Identify priority areas for farming in order to minimise environmental risks;
- Limit constraints that will have impact on agricultural production;
- Strive for a permanent organic soil cover; and
- Improve resource conservation or protect the environment.

6.3 Suggestions for further research

The findings of this research suggest that further research should attempt to address the most important socioeconomic factors which influence production levels related to this study and prevent smallholders from making substantive progress in primary farming. Socioeconomic information is needed for purposes of planning. Without this information it is difficult to draw sound conclusions. The socioeconomic factors should be investigated to maximise agricultural production.

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APPENDICES

APPENDIX A: FIELD SURVEY IN THE STUDY AREA

Lab/No	GPS points		Altitude (m)	Land use/cover	Main crops	Water supply	Limiting factors
	South	East					
030	25.32708	28.21728	1077	Grazing	Grass crop	Municipal tap	Fire and bush encroachment
074	25.32022	28.23459	1074	Cultivated land	Vegetables	Borehole	Fire and bush encroachment
159	25.31453	28.25550	1064	Cultivated land	Maize	Municipal tap	Bush encroachment
243	25.30058	28.27625	1063	Thicket	Grass crop	Municipal tap	Waste disposal
308	25.31756	28.27287	1059	Forest woodland	Grass crop	Apies River	Waste disposal
366	25.32553	28.25819	1060	Forest woodland	Grass crop	Municipal tap	Fire and bush encroachment
415	25.32490	28.24381	1073	Grazing	Grass crop	Municipal tap	Fire and bush encroachment
478	25.32708	28.22141	1077	Bare rock/soil	Grass crop	Municipal tap	Fire and bush encroachment
536	25.35099	28.23367	1088	Grazing	Grass crop	Municipal tap	Fire and bush encroachment
593	25.34761	28.24690	1084	Grazing	Grass crop	Municipal tap	Fire and bush encroachment
676	25.34497	28.25812	1074	Industry	Grass crop	Municipal tap	Waste disposal
752	25.33220	28.27711	1063	Forest woodland	Grass crop	Municipal tap	Fire and Bush encroachment

Source: Survey data January/October 2014

APPENDIX B: CHEMICAL SOIL PROPERTIES OCCURING IN THE STUDY AREA (SOIL DEPTH 20-60 CM)

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Page 1 of 1

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P.O.BOX 29039

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0409

Tel :

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Date / Datum :

RESULTS FOR REPORT No:
RESULTATE VIR VERSLAG Nr BOERE 201415 12422

Rep. / Verteenw.:

Farmer / Boer : **P MABASA**

Method Used / Metode Gebruik -->		P-Bray 1	Amm. Acetate									Water		
LabNo	**Sender ID**	**P**	**K**	**K**	**Ca**	**Ca**	**Mg**	**Mg**	**Na**	**Na**	**R**	**pH**	**T. Acid / T. Suur**	**SA/SV**
		mg/kg	mg/kg	me/100g	mg/kg	me/100g	mg/kg	me/100g	mg/kg	me/100g	ohm		cmol(+)/kg	%
V 1303	030	8.7	179	0.4578	274	1.3673	78	0.6420	2.1	0.0091	4340	5.59	0	
V 1304	074	8.8	299	0.7647	748	3.7325	119	0.9794	3.9	0.0170	1950	6.42	0	
V 1305	159	10.5	141	0.3606	398	1.9860	66	0.5432	3.3	0.0144	3660	6.28	0	
V 1306	243	9.6	312	0.7980	454	2.2655	157	1.2922	6.9	0.0300	2560	6.41	0	
V 1307	308	7.5	314	0.8031	3972	19.8204	731	6.0165	113.1	0.4920	530	7.87	0	
V 1308	366	8.6	430	1.0997	797	3.9770	207	1.7037	4.2	0.0183	2460	6.36	0	
V 1309	415	8.5	182	0.4655	296	1.4770	92	0.7572	2.9	0.0126	3240	6.06	0	
V 1310	478	7.4	209	0.5345	806	4.0220	191	1.5720	4.9	0.0213	2260	6.07	0	
V 1311	536	7.8	309	0.7903	862	4.3014	147	1.2099	2.7	0.0117	1920	6.25	0	
V 1312	593	8.5	286	0.7315	439	2.1906	112	0.9218	4.8	0.0209	2440	5.46	0.11	2.7821
V 1313	676	7.3	135	0.3453	3480	17.3653	1121	9.2263	182.8	0.7951	880	9.04	0	
V 1314	752	9.2	311	0.7954	1123	5.6038	499	4.1070	12.1	0.0526	780	7.33	0	

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Farmer / Boer : P MABASA

T	LabNo	SENDER_NR	Moist. (1)
			%
V	1303	030	0.524
V	1304	074	1.326
V	1305	159	0.551
V	1306	243	1.369
V	1307	308	2.703
V	1308	366	2.263
V	1309	415	1.205
V	1310	478	2.654
V	1311	536	1.956
V	1312	593	2.051
V	1313	676	1.767
V	1314	752	2.035

End of this farmer's analysis

METHODS USED FOR ANALYSIS :

Serial	Method	Serial	Method	Serial	Method
1	Moisture (105°C)				

Source: Soil analysis on soil samples (ARC-ISCW)

APPENDIX C: CROP REQUIREMENTS

Crops	Soil requirement			Climate		Elevation	Crop requirement		
	Soil depth	pH	Drainage	Rainfall	Temperature	Slope	Winter/Summer	Planting date	Harvesting date
Maize	50-100 mm	5,5-5	Well drained soils.	500-700 mm	12-24°C	Altitude ranging up to 1,200 m	Summer	When maximum temperature of 10°C is maintained	March-May
Cabbage	600 mm	5,3-8,5	Deep, well drained, loam soils.	500 mm	15-18°C	Altitude ranging up to 1,200 m	Winter	Early-March	June
Wheat	75-130 mm	6,0-7,5	Well drained fertile loam soils	600 mm	22-34°C 5-25°C	Altitude ranging up to 1,200 m	Summer Winter	mid-May to end of July	October
Tomatoes	600 mm	5,6-5	Fertile, deep, well drained.	550-600 mm	20-24°C	Altitude ranging up to1,200 m	Summer	September to November	February
Oranges	500 mm	6-6,5	Well drained soils.	450-600 mm	13°C	Altitude ranging up to 1,200 m	Winter	Early spring	Throughout the year
Sunflower	600-1000 mm	6,0-7,5	Fertile soils; sandy loam to clays	500-1000 mm	23-28°C	Altitude ranging up to 1200 m	Summer	November to December	April
Dry beans	300-500 mm	5.2	Cool, well drained, medium to heavy loams.	500-900 mm	Optimum temperature for growth is 25°C	Altitude ranging up to 1,200 m	Summer	November to December	February

Source: Allemann & Young (2008); DAFF (2010 & 2011)