MODELLING AND MAPPING THE SUITABILITY OF LAND FOR CROP PRODUCTION USING A COMBINATION OF GIS AND REMOTE SENSING IN THE EASTERN CAPE
A CASE STUDY OF MBASHE AND MQUMA LOCAL MUNICIPALITIES-SOUTH AFRICA

University of Fort Hare
Together in Excellence

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A Case Study of Mbashe and Mnquma Local Municipalities

Solly Vuso

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By

Solly Vuso

Thesis submitted to the University of Fort Hare in partial fulfillment of the requirements for the degree of Master of Science in Geographic Information System (GIS) Department

Thesis Assessment Board

Supervisor: Caryll Tyson

External Examiner

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I certify that although I may have conferred with others in preparing for this assignment, and draw upon a range of sources cited in this work, the content of this report is my original work

Signed..............................
Date: ......22-07-14......

Disclaimer

This document describes work undertaken as part of a programme of study at the University of Fort hare. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institution.

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Abstract

In order to achieve sustainable agriculture, decision makers require appropriate and fully detailed spatial information on land resources. Crop-land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agriculture rural production (T.R. Nisar Ahamed et al., 2000). It is indeed of paramount importance to identify suitable land for cropping while causing minimum impact to the environment. The Food and Agriculture Organization (FAO, 1976), recommended an approach of land suitability evaluation for crops in terms of suitable land based on climatic and terrain data and soil properties.

In this study, an attempt was made to identify suitable areas for massive crop production using remote sensing and GIS methodologies and the knowledge from extension officers. The primary method aims at generating land cover data using SPOT 5 satellite imagery and modeling with the existing land capability. The research purpose was to map the number hectares suitable areas for crop production.

Spatial modeling techniques were utilized to model land suitability model in an effective and efficiently way. The spatial modeling extension from ESRI product was used to model the crop suitability areas. The model run on ArcGIS platform and due to the fact that modeling only uses raster formats, all the data sets were projected and converted to raster format. The weighted overlay model was used to create land suitability map.

The model results revealed that 4046251.79 hectares were suitable for cropping in the study area. The final outputs of suitable areas were calculated and each ward was given a value of suitable area as well as unsuitable area. The validation of the final maps compliments the 500 000 hectares that were mapped by Dept of Agriculture EC using 8% slope as the best potential areas. The method provides a cheap, effective and efficient way to map suitable areas over a large area and it also uses remote sensing data. It is hoped that decision makers will make use of the information produced in this paper as the whole world is in crisis of food security.

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Acronyms and Abbreviations

AHP:	Analytic Hierarchy Process
FAO:	Food and Agriculture
GIS	Geographic Information System
ISODATA:	Iterative Self-Organizing Data Analysis Technique
LANDAST:	Land Remote Sensing Satellite
SPOT5:	Systeme pour l'Observation de la Terre 5
TM:	Thematic Mapper
PGDP:	Provincial Grown and Development Plan
IDP:	Integrated Development Plan
MCE:	Multi Criteria Evaluation
LSA:	Land Suitability Analysis
ARC:	Agricultural Research Council
AGIS:	Agriculture Geo-Referenced Information System
CES:	Coastal& Environmental Services
ADM:	Amatole District Municipality
ISODATA:	Iterative Self-Organizing data Analysis Technique
NDA:	National Department of Agriculture
ASGISA-EC:	Accelerated and Shared Growth Initiative –Eastern Cape
UTM:	University Transverse Mercator
ECBCP:	Environmental Systems Research Institute Eastern Cape Biodiversity Conservation Plan
ESRI:	Environmental Systems Research Institute
SANIB:	South African National Biodiversity Institute

Chapter 1

Introduction

This Chapter starts by introducing the topic and the present scope of the study. This chapter outlines the research aims and offers a justification for its relevance.

1. Introduction

1.1 General Background

Land has always been a productive force that rural societies rely upon for production of crops to sustain and improve household and community livelihoods. The population of the planet is growing dramatically and in order to meet the increase demand for food security, the farming communities have to increase their production (Prakash, 2003).

South Africa has a large agriculture sector and is a net exporter of farming products. There are a number of agricultural cooperatives and agribusinesses throughout the country. Agricultural exports have constituted 8% of South African total exports for the past five years. The agricultural industry contributes 10% of formal employment, relatively low compared to other parts of Africa, as well as providing work for casual laborers and contributing around 2.6% of GDP for the nation. However, due to the aridity of the land, only 13.5% can be used for crop production, and only 3% is considered as land with high potential.

1.2 Overview of the Eastern Cape

Eastern Cape has the third largest population in the country with a population of 6.3 million people: 2.9 million are male and 3.3 million are female. Food insecurity and poverty is one of the major challenges in the Eastern Cape 75 % of the population of the Eastern Cape lives in poverty, the highest percentage of any province (Eastern Cape Provincial Government, 2004).

In the Eastern Cape the agrarian transformation initiative under the Provincial Growth and Development Programme has stated the need for massive food production. The Massive Food Programme is a flagship intervention of the Provincial Growth and Development Programme that aims to develop and consolidate food security, provide a growth stimulus and momentum for socio-economic growth and strong conservation agricultural practice within this growing agriculture economy (Mtero, 2012).

The Department of Agriculture in the Eastern Cape has a mandate to identify arable land that will be used for crop production (PGDP Eastern Cape, 2004). This mandate has two objectives, firstly to identify suitable land for crop production and secondly to avoid the use of agriculture land for other purposes like housing. Determining and assessing the suitability of an area for crop production requires considerable land use accuracy in land mapping. GIS is a powerful tool to assist in solving the two objectives, as it provides means for manipulating and combining datasets. To meet the challenges stated above, Land capability and Land use are the most important factors.

1.3 Agriculture and Land Suitability

Agriculture is important as a source of food and income, but how, where and when to cultivate are the main issues that famers, communities and land owners have to face day to day. To overcome this concern the farming community has to produce more and more, high quality food using eco-friendly practices. This requirement for eco-friendly practices has paved a way for the concepts like precision farming, sustainable farming, organic farming etc. The high productivity, profitability and health of mankind as well as environment are the main fears of the present agriculture. Hence much attention is shifted on selecting suitable areas for crop production.

Land suitability analysis is a prerequisite for sustainable agriculture production (Prakash, 2003). Land suitability analysis is a multicriteria evaluation involving soil, climate, and terrain to socio-economic, markets, crop requirements and infrastructure (Prakash, 2003). Since the mapping of land cover and land suitability involves lot of data sets and different methodologies, it is necessary to develop our applications of Geographic information System (GIS) and especially Remote Sensing so as to enhance regional mapping and modeling suitability of arable land for a better production. Remote Sensing in combination GIS will be a very powerful tool to integrate (spatial and non special data) and interpret real world situation in most realistic and transparent way. Research by Leingsakul et al.

(1993) shows that integrated GIS and Remote Sensing technology apart from saving time and yielding good data quality they have an ability to locate potential new cropland sites.

1.4 Problem statement

For the next decade South Africa will be facing a great challenge of increasing food production to ensure food security for the steadily growing population, particular in provinces with limited land resources. The issue of arable areas that are being used for other developments like forestry, housing and squatercamps are a grave problem in this province.

Consequently, there is a need to develop an optimal method for mapping land suitability to identify which areas of the province could grow crops successfully. A number of questions can be developed to investigate this need further, such as:

- Which methodology for mapping land that could suits the Eastern Cape environment?
- What criteria are appropriate to the Eastern Cape environmental conditions taking into account the available data?
- Which tool will be appropriate for this application?

Effective land suitability mapping is a prerequisite to achieving optimum utilization of available land resources for agriculture production. The principal purpose of land suitability is to predict the potential and limitations of land for changing land use. The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined specific use.

Land suitability systems are based on the local conditions and the level of data available for locations where they have been developed. Consequently, the land suitability criteria and their associated threshold values are intended solely for those locations. Therefore, these land suitability methods may not perform adequately in different environments.

However, some of those methods can be described as a framework for land evolution, such as FAO methods for land suitability (Bashir, 2005)

A number of new technologies have been developed to facilitate the implementation of the land suitability principles. One of the most significant developments has been spatial analysis using Geographic Information Systems (Bashir, 2005). GIS facilitates the storage and analysis of wide range of spatial data, and is used as tool for land suitability through the world. With GIS, the results of the analysis of alternative scenarios can be produced as maps. This graphical presentation capability allows ready communications of the outcome in formats useful for guiding decision making at various spheres of administrative or technical levels.

In the light of these needs, possibilities and limitations, this research project will develop a land suitability model for selected food crops in the Eastern Cape, in particular Mbashe and Mnquma local municipalities. The two local municipalities have been selected as a study area, and aims to show how a land suitability model can be developed and applied to assist regional planers in other arid and semi-arid regions.

1.5 Research problem

In the study area, rangeland has been converted on a large scale into rainfed cropland areas during past five decades. Unfortunately, this conversion took place without proper consideration of the capability and suitability of the land. As a result, soil erosion including topsoil removal became a major problem and the communities decided to convert some grazing areas into cropping areas. This reduction of grazing land resulted in a shortage of food for the farmer’s animals.

Inhabitants of the study area were faced by these resource problems:

1) Low crop production and low farm income,
2) Indiscriminate conversion of rangeland in to rainfed cropland without due consideration of the suitability of the land leading low yields,

3) Overgrazing on remaining rangeland areas leading to grassland degradation and soil erosion,
4) Lack of appropriate conversion practices on above lands has aggravated the soil erosion.

Clearly, current land use and land suitability developments in the area are lacking a firm sustainable basis. ZEL (2001:44) noted, in the context of rural planning that there are pieces of land (land unit) more or less suitable for a specific uses (e.g. agriculture, housing, tourism etc.) while others are more or less vulnerable to degradation (erosion, salinization, desertification etc). A systematic inventory and analysis of present land cover and land use patterns are therefore required to be followed by sound land suitability per ward. In this way, land suitability can be optimized on a sustainable basis with due consideration of government policy objectives and farmer's priorities in the area.

1.6 Objectives

The general aim of this research is to model and map the suitability of land for crop production in Mbashe and Mnquma municipalities using a combination of Remote Sensing and GIS. This will include:

- Generating a land cover of the study area using a satellite image (SPOT 5) ,
- Developing a land suitability assessment model for the key crops of rainfed maize, sorghum and vegetables in the local municipality of Mbashe and Mnquma and
- Calculating suitability of land for the key crops per ward.

1.7 Research Questions

The research objectives of the study will be achieved by answering the following important questions:

- How can a combination of remote sensing and GIS data be used to find suitable areas for crop production?

- Which areas are regarded as restricted for crop production?
- How many hectares are suitable for cropping?

1.8 Justification of the Study

In the Eastern Cape, the needs and demands of a rapidly increasing population have been the principal driving force in the allocation of land resources to various kinds of uses, with food security as the primary aim. Population pressure and increased competition among different land users have emphasized the need for more effective land –use planning and policies. In the Eastern Cape rational and sustainable land use is an issue of great concern to the government and communities to preserve the land resources for the benefits of the present and future populations. An incorporated approach to planning and management of land is the key factor to implementing a solution, which will ensure that land is allocated according to its potential to provide the greatest benefits.

The contribution of agriculture to gross domestic products (GDP) at market price is 8.2%, which could increase with utilization of land for cropping pattern. Therefore the identification of suitable land areas for specific types of crops is a pre-requisite to realizing the objectives of this paper. The research outcomes are expected to benefit the decision makers, policy makers and the agricultural sector in the following ways:

a. Identification of the suitable areas for crop production,
b. Identification of the role of government as to where they should manage agricultural land area.

1.9 Role of GIS and Remote Sensing

Remote sensing and GIS are playing a rapidly increasing role in field of land suitability development.

GIS is the tool for input, storage and retrieval, manipulation and analysis, and output of spatial data (Marble et al.1984). GIS capability can play a major role in spatial decision-making. Significant effort is involved in information collection for suitability analysis for crop production. This information should present both opportunities and constraints for the decision maker (Ghafari et al.2000). GIS has the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. The use of GIS tool will assist in data integration problems caused by the different geographic units to which different data sets are related. GIS will allow the overlaying of maps with different data (e.g. Soil, land use, climate, slope, villages, and wards) and thereby facilitate the integration and modeling analysis. GIS modeling makes it possible to assess the interaction of (potential) land uses, and physical infrastructure.

Remote Sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface (Choudhury, 1999). It also has an ability to generate information in a spatial and temporal domain, which is very crucial for successful analysis, prediction and validation. Remote Sensing will be used to derive the information like land cover and land use and also to validate the other data that will be used in this study e.g. infrastructure.

Chapter 2

Literature reviews

This Chapter reviews the related works conducted in this field to gain insight on key methodologies that may be applicable to this research.

2 Literature Review

This chapter explains the concept and general overview for land suitability. The first part deals with a list definitions/glossary used in this thesis. The second part gives a brief discussion of possible approaches/methodologies that were previously used for Land Suitability, Land cover, Land Capability, Land Use Type, Biodiversity and Analytic Hierarchy Process (AHP).

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2.1 Definitions

Land Suitability is the fitness of a given type of land for a defined use. Suitability indicates in the simplest form whether land is suitable or not for a specified use. Whereas S = Suitable, N = Not suitable for the land use

Land Capability is used for a ranked system based on the severity of the land limitations for a general agriculture use and refers in particular to the quality of the land to produce common cultivated crops and pastures without deterioration over a long time.

Land Use Types is a kind of land use to define in more detail, according to a set of technical specification in a given physical, economic and social setting (FAO, 1983; Rossiter and van Wambeke, 1995; Sys et al., 1991).

Land Cover refers to directly observable features of land surface (Kassaye 2006), and these features can be natural, semi-natural or total man-made.

Biodiversity is the combination of two words “biological” and “diversity”. It refers to all variety of life that can be found on Earth (plants, fungi and micro-organisms) that form and habitats in which they live.

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Saaty (1977) and 1994). It uses a multi-level structure of the objectives, criteria, sub criteria and alternatives. Using a set of pair- wise comparisons derives the pertinent data. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion.

2.2 Land Suitability

Land suitability is the fitness of given types of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is an appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Land Suitability Analysis (LSA) is a Geographic Information Systems (GIS) tool for evaluating the relative suitability of land for different purposes. The end results are a generalized map showing areas of suitability that are categorized according to classes, low, moderate or high suitability for development.

The framework for land evaluation (FAO, 1976) recognizes four levels of generalization in classification of land suitability:

- Land suitability orders: A suitability order is simply a statement as to whether an evaluation unit is at all fit for use or not. It gives no information about limitations or characteristic. ‘S’= Suitable and ‘N”= Not suitable for the land use
- Land suitability classes, signifying the degree of suitability within an order. The following are land suitability classes:
    - S1 (highly suitable) - land having no significant limitations to sustained application of a given use.
    - S2 (moderate suitable) - land-having limitations, which aggregate, are moderately severe for a sustained application of a given use.
    - S3 (marginally suitable) - land-having limitations which in aggregate are saver for sustained application of a given use and will reduce productivity or benefits.

    - N1 (currently not suitable) - land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.
    - N2 (permanently not suitable) - land having limitations, which appear as a severe as to, preclude and possibilities of successful sustained use of the land of a given land use.
  - Land suitability subclasses, specifying the kind(s) of limitation or kinds of required improvement measures within classes.
  - Land suitability subclasses indicating differences in required management within subclasses.

The Department of Agriculture in the Western Cape has done a similar study, Modelling the potential for Lupin and Canola Production in the Western Cape by Mike Wallace, 2000. The following methodology was used:

- Development of a soil-water balance model framework and literature review of similar work.
- Conversion and “cleaning” existing land Type data into a form usable in GIS.
- Synthesis of a digital terrain model (DTM) from elevation point data.
- Derivation of rainfall grids using the Schäfer interpolation method.
- Interpolation of evaporation grid data.
- Development of a GIS-model for the delineation of terrain units from the DTM.
- Refinement of the land type database to terrain unit level.
- Development of the soil water-balance crop model. The model process, briefly is as follows:
  - Calculate distributed soil water balance based on soil properties (texture, water holding capacity, and wetness), monthly mean/median climatic data and terrain unit position.
  - Apply crop specific weighting factors to determine potential.
  - Exclude or penalize known unsuitable areas e.g. salinity, waterlogging-susceptibility, slope, stony soils.

  - Exclude unavailable regions such as metropolitan areas, conservation areas and mountain reserves.
- Establish a model to determine lupin and canola potential.
- Produce a report.
- Run a model to produce maps.

The model was written in the AVENUE GIS programming language. The model has a subroutine for waterlogging susceptibility- particularly important in some lupin species. The ability of the available resources to support such requirements is then evaluated, and a yield potential map produced. A particular need was for accurate crops factors appropriate to dry land conditions in the Western Cape, as this information appears to be unavailable.

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- Establish model to determine lupin and canola potential.

- Produce report.
- Run model to produce maps.

The results of a GIS model were proved to be a useful aid to strategic regional planning and to agriculture advisors. The GIS environments were proved exceptionally useful in work of this nature due mainly to the visual impact of thematic maps-that can fundamentally improve the understanding, communication, and didactics involved in the efficient management of agriculture resources (Wallace, 2000).

2.2 Land Cover

Land cover mapping is one of the most important and typical applications of the Remote Sensing data. Firstly, the land cover classification system should be established, which is usually defined as levels and classes. These levels and classes are designed in consideration of the purpose of use (national, regional and local), the spatial and spectral resolution of the remote sensing data and user's request.

Land cover information is essential for associations and individuals involved in the management and monitoring of land resources. The South African National Land Cover products from 1994 and 2000 both provided information of every class. However the information is relatively out dated and in addition to this, the resolution for each of these products was relatively poor, which makes planning challenging on finer scales. In 2006, South Africa acquired SPOT2 and SPOT 4 with the resolution of 20m, which was used to produce a Land Cover map. The South African land cover classification scheme comprising 31 classes of land cover was applied. These land cover classes are based on those developed by Thompson (1996) for Southern Africa and it has been designed to conform to international accepted standard and conventions in order to ensure cross-border compatibility and integration with existing national and international land cover classification systems and datasets. The results using SPOT were much better compared to previous classification. One of the reasons for better SPOT classification than Landsat TM

30m is more efficient for geologic structural features extractions compared with 10m images resolution that are found to be the best for automatic lineament extraction especially in tropical area as well it could be also best for lineament extraction

Since the study area has dense vegetation and settlements, the manual and automated mapping and classification techniques need to be refined. The shared or overlapping spectral characteristics with alternate cover types can be mapped using a semi-automated approach compared to a fully automated approach as used for non-overlapping class-types. The semi-automated approach involves the delineation of user-defined, generic area of interest (AOI), vector boundaries around each specific cover type, and then using an automated spectral classifier to delineate the actual class boundary within these analyst defined" mask" areas. In this manner the final class boundaries will be defined automatically by spectral characteristics. In the case where specific feature spectral characteristics are not unique, class boundaries will be captured (digitized) directly off the image using conventional on-screen photo interpretation.

2.3 Land Capability Classes

The concept of land capacity developed in the United States where the authoritative work of Klingebiel and Montogometry was published in 1961. Subsequently, in South Africa, land capability concept was addressed in a number of studies and some brought meaningful progress. The following local developments were judge to be relevant.

THE E.C.M. CODE (LOXTON, 1962)

Land capability concept was first documented by Loxton (Loxton, 1962). He includes a simplified soil survey procedure for farm planning, a capability code, the E.C.M. code, referring to erosion hazard, soil climate and mechanical limitations. It is not known to what extent the E.C.M code was applied in practice and it certainly contained elements found in later land capability system

DEVELOPMENTS BY THE FORMER TRANSVAAL AGRICULTURAL REGION

Middle 1980s Resource Section of the Transvaal Agriculture Region derives land capability from land type data. History reveals the system was not documented and it was lost in the subsequent division of the data, materials and responsibilities between the three provinces constituting the former Transvaal Agricultural Region

DEVELOPMENTS BY VAN DER WALT ET AL. (1995)

A poster was produced by Van der Walt, Haarhoff, Olivier and Kuschke (1995) entitled "Land capability classification by means of GIS technology: testing of methods in the Gauteng ". Their aim was to test a computerized version of the land capability system proposed by the Task Team (1987). The logic development by these authors for estimating average slope classes from land types data was used and refined in the present study

NATIONAL DEPARTMENT OF AGRICULTURE SCHOEMAN ET AL., (2000)

Through the Directorate of Agricultural Land Resource Management of the National Department of Agriculture the ARC- Institute for Soil, Climate and Water was commissioned to develop and implement a workable land capability system for South Africa, taking previous developments into account.

For purposes of international and national technology transfer and simplicity, the methodology was aimed at reflecting the classic concepts of land capability, as established by Klingebiel and Montgomery (1961) as far as possible. Schoeman et al., (2000) brought this concept under parameters suited to South African conditions, particularly the local availability of data. In the original form, this system deals with concepts rather than with hard threshold values of parameters.

Taking into account the local availability of data, the following criteria was selected by Schoeman et al., (2000) for use at all levels of scale:
Terrain: Flood hazard, erosion hazard, and slope.
Soils: Depth, texture, erodibility, internal drainage, mechanical limitations, acidity.

Climate: Moisture availability, Length of moisture season, length of the temperature season, frost hazard, wind hazard, hail

A land capability class is an interpretive grouping of land units with similar potentials and continuing limitations or hazards. Land Capability, determined by the collective effects of soil, terrain and climate features, show the most intensive long-term use of land for rain-fed agriculture and at the same time indicate the permanent limitations associated with the different land-use classes.

Land Capability			Intensity of use for rain-fed agriculture								
Orders		Classes	Wildlife	Grazing & Forestry				Crop Production			
				Forestry	Veld	Veld reinforcment	Pastures	Limited	Moderate	Intensive	Very Intensive
Arable	A	I	.	.	.	.	.	.	.	.	.
		II	.	.	.	.	.	.	.	.	
	B	III	.	.	.	.	.	.	.		
		IV	.	.	.	.	.	.			
Non arable	C	V	.	.	.	.	.				
		VI	.	.	.	.					
		VII	.	.	.						
	D	VIII	.								

Table 1.1 South African Land Capability classes. (Schoeman et al., 2000)

Order A: Arable land – high potential land with few limitations (Classes I and II)

Order B: Arable land – moderate to severe limitations (Classes III and IV)

Order C: Grazing and forestry land (Classes V, VI and VII)

Order D: Land not suitable for agriculture (Class VIII)

Further brought the parameters were brought by Schoeman et al., (2000) to suit South African conditions, especial looking on the availability of data. The following methodology was applied by Schoeman et al., (2000) to reach the results:

Assigning of class limits to criteria

Class limits were identified by Schoeman et al., (2000) as per criterion in accordance with what, in practice, would constitute none, few, moderate, severe and very severe limitations. As far as possible, best available knowledge was incorporated by this team. Individual criteria differ with respect to the number of classes required to present them and the way they affect land capability.

The Schoeman et al., (2000) system was to be used, with appropriate adaptations, at all scales. As soils in the land type database are classified in terms of the Binomial soil classification system, class limits are given in relation to that system. At large scale, however, soils data are being collected using the Taxonomic soil classification system. Class limits were also given in a relation to that system. The standards (criteria and class limits of the land capability system) were remaining the same at all scales. Data sources and data quality, however, were vary between scales and individual applications of the system.

Schoeman et al., (2000) used modelled 1 x 1 km temperature grids, for basic calculations at small scales and were generally preferable as individual temperature stations, even at larger scales. The scarcity of the temperature stations and the close link between temperature and terrain features were rendered as surfaces preferred data sources. More exact rainfall data, however, were substituted at larger scales.

Development of queries for the identification of qualifying land types and land types soil components.

Queries were written to assign classes to all soil entries in the land type database.

Production of soil capability map

A South African soil capability map was produced from the flooding, erodibility and other soil criteria.

This map was used to assess the potential for irrigation, should water be available

The heterogeneity of land types creates difficulties to present the data. Different methods of presenting the data gave different results. Two methods of presentation were tested by Schoeman et al., (2000) and resulted in a dominant soil capability map and soil capability map. In the first method, when a particular class occupies more than 40% of a land type, the land type is assigned to the class. This method leaded to employing an undifferentiated class to accommodate polygon with no clear dominance.

In the second method, land types in which a particular class more than 50% are assigned to the class, starting with Class I. Components belonging to lower to the next class in the sequence. When components occupy 50%, the land type is assigned to the class. The main advantage of this method is that it gives a good gradation from high capacity (unit 1) to low capacity (Unit 8). The main disadvantage is the possibility that a polygon assigned to a particular class (although only from high classes), rather than be dominated by the class coinciding with the number.

Incorporation of the climate data

Raster coverage of the values for the climate criteria were superimposed on land types. For each criterion, the median value for all the cell coinciding with a land type polygon were obtained and classified by Schoeman et al., (2000).

Production of land capability map

Schoeman et al., (2000) produced a South African land capability map using the methods as described under soil capability.

Checking of maps against local and best available knowledge

With respect to locally well-known situation, the questions were asked "is this what wanted? Is the class tag congruent with the classic concept of the particular class?". Class limits were adjusted on basics of available evidence on land productivity where necessary.

The draft final products are being made available to knowledgeable natural resource and extension workers with the request to evaluate the validity in those areas they are familiar with.

Results

The study that was done by Schoeman et al., (2000) resulted in a parametric, GIS-compatible land capability system, congruent with local data availability but adhering to classic concepts.

Application of the system with its current class limits to land type data leaded to the identification of 10% of the country as being dominated by soils that have little or no limitations (soil capability Class I, occupying 2% and Class II, occupying 8%). The bulk of the country's arable soils were shown to suffer from moderate or severe limitations (soil capability Class III, occupying 25% and Class IV, occupying 13%), often due to limited depth or moderate or severe erosion hazard, caused by sandy textures, other soil properties or steep slopes.

Superimposing climate with the soil capability map showed that almost nowhere in South Africa is it found that both the best soil and best climate classes coincide. The bulk of the arable land was classified as land capability Class III (occupying 9.5%). This class, together with Class I and II (occupying only 1.7%) represents rain-fed arable land of acceptable quality. Class IV, representing marginal rain-fed cropland, occupies a further 11.5%).

Valuable unique farmland in the Western Cape was classified as Class IV and VI due to shallow natural soil depth. Extremely valuable land in the seaboard areas of the former Transkei (valuable due to favorable climate) with moderately steep slopes and shallow soils (Class IV and VI) were also regarded as unique farmland. Its value was be unlocked by best practice technologies.

2.5 Land Use Types (LUT)

Land Use Types is the synonym for the FAO's land utilization type, which is defined as a specific manner of occupying and using the land, with specified management methods in a defined technical and socio-economic setting (Chizumba, 2002). It may involve any number of activities and products, as long as they form part of one system of management (Rossiter, 2001b). The FAO distinguishes between simple land types and compound land use type. A simple land type has one use at a time. In agricultural LUTs this simply means one crop species per cycle. A compound LUT refers to several uses at a time (intercropping) or more than one activity per cycle (relay or multiple cropping).

Considering the availability of data in South Africa and the lack of high spatial resolution images the methodology was slightly shift to accommodate the conditions. In determining the land use types, a number of determinants need to be considered. Taking into consideration the limited amount of time, simple land use types needed to be preferred. The LUT is defined by utilizing the land cover, SPOT 5 panchromatic band and other determinants that are obtained through fieldwork, farm managers and other agricultural experts. The selection of land use requirements were based on the following criteria: (Rossiter, 2001b).

- Importance (relevance) for the use.
- Existence of sub-optimal values in the study zone.
- Availability of knowledge with which to evaluate the corresponding land quality.
- Availability of data with which to evaluate the corresponding quality.

- Areas of Land Use Types were residential, industrial, transportation and others.

2.6 Biodiversity

A number of slightly different definitions of the term ‘biological diversity’ or in shot ‘biodiversity’ exist in literature. According to McNeely et al. (1990), it includes all species of living organisms and ecosystems and ecological process of which they are part. It includes both the number and frequency of ecosystems, species, or genes in a given assemblage. WRI-IUCN-UNEP (1992) has defined biodiversity as the totality of genes, species and ecosystems in a region. A simple, comprehensive and fully operational definition of biodiversity is unlikely to be found (Noss, 1990).

Biodiversity is the variability among living organisms from all sources including, amongst others, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. It covers the composition, structure and functions of living organisms, and includes diversity within species at a genetic level, between species and of ecosystems, as defined by the Convention on Biological Diversity (1992). Since biodiversity is under treat on the globe, and some of these treats include ecosystem destruction and accompanying species extinction through human activity, climate change and invasive species. The use of biodiversity data arises after South African National Biodiversity Institute (SANBI) joint venture with Government Department identifying critical biodiversity areas (CBAs) through a systematic conversation planning process and land use guidelines. The study involves biodiversity data to protect different species. The biodiversity data was used to avoid critical biodiversity areas (protected areas). The biodiversity data guides which areas are protected and the ecosystem must not be disturbed. In those areas no development must take place. It also shows areas that are less sensitive (not protected areas), in those areas any development can take place.

2.7 Analytic Hierarchy Process (AHP)

The integration of multi-criteria decision making methods (MCDM) with GIS has considerably advanced the conversional map overlay approaches to the land-use suitability analysis (Malczewski, 2004).

Analytic hierarchy process (AHP) is one of a GIS based MCDM that combines and transform spatial data (input) into a resultant decision (output). The procedures involve the utilization of geographical data, the decision maker's preference and the manipulation of the data and preference according to a specific decision rules referred to as factors and constraints.

There are two key considerations that are of critical importance in decision making as outlined by Malczewski (2004):

i. The GIS capabilities of dada acquisition, storage, retrieval, manipulation and analysis, and
ii. The MCDM capabilities for combining the geographical data and decision maker's preference into uni-dimentional values of alternative decisions.

AHP is key decision-making tool that was used in this study to assist in obtaining an appropriate solution for land suitability. The process involved the structuring of factors that are selected in a hierarchy starting from the overall goal to criteria, sub-criteria, and alternatives in successive levels (Saaty, 1990).

Saaty (2008) outlined four steps that are key in undertaking AHP in an organized way in order to make a decision over alternatives. These are; definition of the problem or issue to be considered, I identify the goal which is the criteria that the other elements usually the alternatives will depend on which should be at the top of the decision making tree, develop a pairwise comparison matrix, weigh priorities for each element with priorities obtain a global priority that will form the basis of decision making for alternatives at the bottom of hierarchy.

This study integrated various data such as land use, land capability and biodiversity to create land suitability. The suitability is determined by assigning weights and AHP is applied as a decision support system to arrive at the final decision to arrive at the final decision.

Integrating AHP in a GIS environment can be used to make decisions based both on expert and indigenous knowledge and choose between alternatives. The weighting assigned to the thematic layer vary from one site to the other hence may not be replicated.

Chapter 3

Description of the study area

This Chapter describes the study area with respect to its location, climate, soil and land cover.

3.1 Study Area

This research was undertaken in the province of the Eastern Cape, South Africa. The Study area comprise of two municipalities, Mbashe and Mnquma, which fall within the Amatole District Municipality (ADM). The study area is located along the coast in the former Transkei area (Figure 3.1). Both Municipalities were established after South Africa’s re-organization of municipal areas that took place in 2000.The main town of Mnquma is Butterworth, also with the small towns of Ngqamakwe and Kentani, and numerous peri-urban and rural settlements and Mbashe municipality contains the towns of Idutywa, Elliotdale and Willowvale, and numerous peri-urban and rural settlements.

Both municipalities are characterized by 70% rich fertile soil such as alluvial and brown soils that are combined with high temperature weather conditions in summer, to create prime agriculture land. The area grows a variety of crops: dry beans, maize, sorghum, soya, and sunflower. There are multiple growing seasons (winter and summer) producing two crop types per year in a certain regions due to warm winters. The study area however is under increasing pressure due to the extreme lack of social wealth and the desperate need for the upliftment of poor communities. Both municipalities are constrained largely by the levels of poverty, unemployment, poor infrastructure and the widespread need for basic services. Large rivers and estuaries that are ecologically important also characterize the study area, and they offer great economic opportunities to the communities of the study area in the form of tourism. The poor land management and unwise development upstream, however continues to threaten the communities and decision makers.

Economically, there is comparatively little formalized economic activity within the study area, but a broad informal trading sector exists. The spatial distribution of the population coupled with poor road infrastructure considerably limits access to potential work force by potential investors and access to markets by farmers (Coastal& Environmental Services, 2007).

Figure: 3.1: Study area located in the Eastern Cape

See the attached A3 size map

3.2 Climate

The study area climate ranges from cool, humid and subtropical at the coast to hot and sub-arid inland. Maximum temperatures in summer fall mainly within the 25-27 ºC range, with the areas on the coast and the north western regions of the study area reaching up to 29 ºC. Small isolated regions in the study area have maximum temperatures of less than 25 ºC in summer (Coastal& Environmental Services, 2007). The minimum temperatures in winter for the coastal region are generally above 8ºC while inland the minimum temperature can drop down to between 2-4 ºC in winter.

Rainfall varies from more than 1000mm per annum in the northern and southern coastal regions, to between 600-800mm per annum in the entire inland regions (Figure 3.2). Most of the rainfall approximately (70%) occurs during summer months (October- March).

Figure 3.2: The annual rainfall

See the attached A3 size map

3.3 Topography and Soil

The study area is 900 meters above sea level and is characterized by a topography that rolls into watercourses that dissect area. The slope of the area varies from 2 to 30 percent. The geology is derived from the Karoo sequence and Ecca group (Grenfell, 2005). Besides water and temperature, soils are an important determining factor in identifying potential crops as well as potential yield, and thus, sustainability.

The soil of the study area is limited to soils derived from mudstone and sandstone, which gives rise to soil that are structure-le) with a high water table. Topsoils are generally 300 to 400 millimeters deep (Grenfell, 2005). According to Grenfell, (2005) the underlying sub-soils are either impenetrable rock or high clay layer which do not allow the penetration of water, and thus, restrict the development of roots to the top 300 to 400 millimeters of top soil. During high rainfall periods, these soils become waterlogged and essences drown the crops by limiting the air within the soil. Other climatic resources generally being good, with an average annual rainfall that is relatively high and stable, the limitations of the soils restrict the production potential of the most crops and reduce the achievable long term yield.

3.4 Land cover

The predominant land cover of the area is unimproved grassland and scattered thicket. The northern unimproved grasslands are degraded, as a result of poor management practices that have led to overgrazing and thus a decrease in the species diversity and plant cover. The second most abundant land cover in the area is scattered farming areas that are primarily adjacent to watercourses. Semi-commercial and subsistence dry land farming primarily influences these agricultural activities and there are very few commercial farmers in the area.

3.5 Land Capability

Land capability takes into consideration all levels of data from terrain (flood hazards and erosion hazards), soils (depth, texture, erosion, internal drainage, mechanical limitations, and acidity) and climate (moisture availability, length of moisture season, length of temperature season, frost hazards, wind hazards and hail). Each land types are assigned a land capability index based on the features mention above. The classifications range from 1 (good capability) to 8 (poor capability). While the classification is designed to show the capability of land for crop production, it infers the capability for less intensive agricultural uses (e.g. pasture and natural grazing). All the areas that are not suitable for cropping are also grouped according to pasture or natural grazing depending on the results of the criteria.

According to Schoeman et al., (2000) results, the land with the highest capability is distributed in the coastal strip, around the mouth of the major river. Land with high capability predominates in the area south and southwest of the Idutywa, Kentani and many of the river basins.

3.6 Current Land use in communal areas and informal settlements

The 2.5 m mosaic of SPOT 5, Land Cover data, knowledge about the area and household surveys done by Statistic South Africa indicates that the current land use is a diversified strategy involving cultivation, livestock farming and the harvesting of natural resources (including wood, thatching grasses, wild food plants, medical plant parts and shellfish/fish) (Coastal& Environmental Services, 2007). Maize is the most cultivated crop in the area. This maize is processed into maize meal, samp and traditional beer (Mqombothi).

Eastern Cape has more livestock than any other province. Even though the meat has a high value as do the skins, which are exported on a daily basis. In addition skins (sheep, cows and goat) are processed into ropes/strops/whips, skirts and blankets. Milk is also converted into amasi (sour milk). Land use is supplemented by off-farm sources of income such as wages, remittance, business incomes and pensions (Coastal& Environmental Services, 2007).

3.7 Population

According to National Census 2001 the total population of the whole district in 2001 was 1. 65 million .The distribution of the population across the study area is as follows:

Local Municipality	Population	Percentage	Wards no
Mbashe	256,395	15.3%	24
Mnquma	286,707	17.1%	31

Table: 3:1: Population of the study area (CES, 2007)

Chapter 4

Material, research methods and techniques

This Chapter presents the material and the methodology used to accomplish the results. It also includes the technical techniques involved.

4 Materials and Methods

4.1 Material used

This section provides the description of the data used and the software used for research.

- The five spectral bands of the SPOT 5 satellite sensor.
- Land cover class definitions (Thompson, 1996).
- South African Land capability shape file scale of 1:2500 000(Schoeman et al., 2000).
- Biodiversity shape file scale of 1:10 000.
- Microsoft office (Word and Excel), Erdas Imagine 9.1, ArcGIS 9.2 and GPS Trimble.

4.2 Data Used

Most of the data used were collected from National Department of Agriculture, South Africa.

4.2.1 SPOT 5 Satellite Sensor data

In the study area the multispectral satellite image that was taken between 30/08/2005 and 01/04/2006 by a Sensor of the French satellite system: *Satellite Pour Observation la Terre* (SPOT), was utilized to produce a land cover classification map. The images were already radiometric corrected and geo-referenced (Fig 3.2). The different dates for the capturing of the images were as follows:

- Scene 3127D, 3127C, 3128D, 3129C, 3227D, 322A, 3228B, 3229A (30/08/2005)
- Scene 3227D, 3228C, 3228D(01/04/2006)

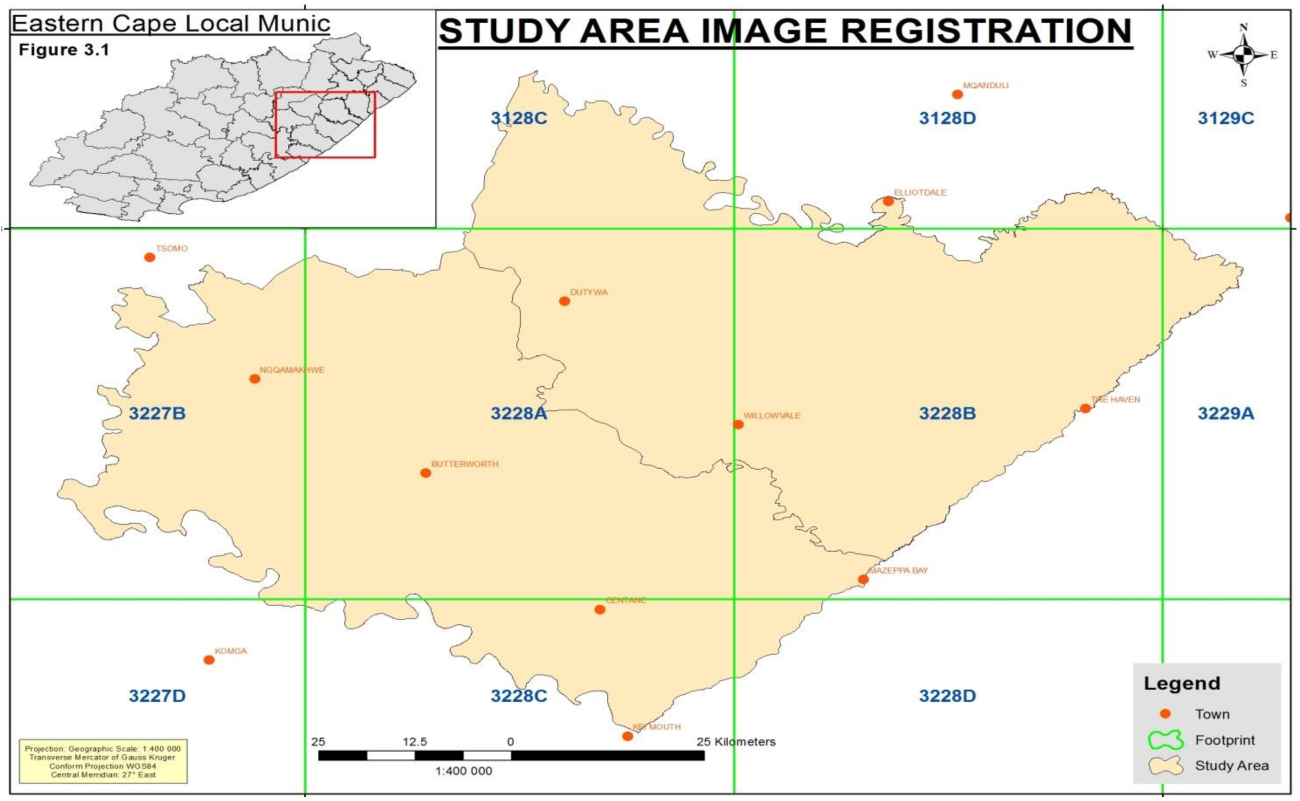

Figure 4.1: Study area SPOT 5 image coverage

The SPOT 5 satellite sensor has five spectral bands with different spectral ranges that assist in identifying different features (Table 3.1)

Sensors

Spectral bands	Ground pixel size	Spectral range
Panchromatic	2.5 meters	0.48-0.71um
B1: green	10 meter	0.50-0.59um
B2: red	10 meters	0.61-0.68 um
B3: near infrared	10 meters	0.78-0.89um
B4: short-wave infrared (swir)	20 meters	1.56-1.75um

Table 4.1The five spectral bands of the SPOT 5 satellite sensor.

B1= this band corresponds to the green reflectance of healthy vegetation.

B2= this band is used for discriminating between plant species. It is also useful for soil boundary and geological boundary delineating

B3= this band is especially responsive to amount of vegetation biomass

B4= this band is particular sensitive to soil moisture content, leaf moisture content and vegetation cover.

4.2.2 Land Cover Class Definitions

The standard hierarchical framework for the classification of remote sensing data, designed to suit the South Africa environment (Thompson, 1996) was applied in the research.

Level I	Level II
Forest and woodland	Forest Woodland Wooded grassland
Thicket, bushland, shrub forest and high fynbos	Thicket Scrub forest Bushland Bush clumps Hi fynbos
Shrubland and low fynbos	Shrubland Low fynbos
Herbland	
Grassland	Unimproved grassland Improved grassland
Forest plantation	Pine species Eucalypt species Wattle

	Indigenous species
Waterbodies	
Wetlands	
Barren lands	Bare rock/soil Degraded land
Cultivated land	Permanent crops Temporary crops
Urban/built up land	Residential Commercial Industrial
Mines and quarries	

Table 4.2: Standard land-cover classification for remote sensing applications in South Africa: class summary (Thompson, 1996).

4.2.3 Land Capability

The land capability shape file that was prepared was obtained from National Department of Agriculture (NDA) offices in Pretoria. The shape file covered the whole Eastern Cape, and the local municipality shape file was used to extract the information about the study area only. In the extracted information of the study area there were only six classes that were found. The class ranges were: Class II, III, IV, VI, VII, and VIII. These classes were grouped according to the specific type of land in terms of their absolute or relative suitability for a specific kind of use, class II, III, IV (Arable), Class VI, VII (Grazing) and Class VIII (Wilderness).

Arable	***Class II*** soils have moderate limitations that restrict the choice of plants or that require moderate conservation practices. ***Class III*** soils have severe limitations that restrict the choice of plants or that require special conservation practices, or both. ***Class IV*** soils have very severe limitations that restrict the choice of plants or that require very careful management, or both.

Grazing	***Class VI*** soils have severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat. ***Class VII*** soils have very severe limitations that make them unsuitable for cultivation and that restrict their use mainly to grazing, forestland, or wildlife habitat.
Wilderness	***Class VIII*** soils and miscellaneous areas have limitations that preclude commercial plant production and that restrict their use to recreational purposes, wildlife habitat, watershed, or esthetic purposes.

Table 4.3 Land Capability Classes

Suitable areas for different kinds of use were measured, and the resulting measurements were: Arable 41 % (262777 hectares): Grazing 52 % (330154 hectares) and Wilderness 7 % (41705 hectares) (Figure 4.2).

Figure 4.2: The land capability of the study area

See attached A3 Land capability map of the study area

4.2.4 Biodiversity

Since biodiversity is so closely intertwined with human needs, its conversation should rightfully be considered an element of national security (WRI, IUCN and UNEP 1992). The Biodiversity data for the study was acquired from South African National Biodiversity Institute (SANBI). The data comprise of protected and non-protected fields. The data was used to ensure that biologically rich sites are not left under or un-represented in the network of protected areas.

4.3 Methods

Within the scope of this research, the following steps were employed to complete the research. The steps are: data preparation, and pre-processing GIS and Remote Sensing data, land cover, land use, land suitability and field survey as well as accuracy assessment.

4.4 Data Collection

According to Conglaton (1991), image classification is incomplete without accuracy assessment. The field data was done for the accuracy assessment of the land cover. Land suitability was validated using the soil information and ASGISA cropping maps and expects knowledge.

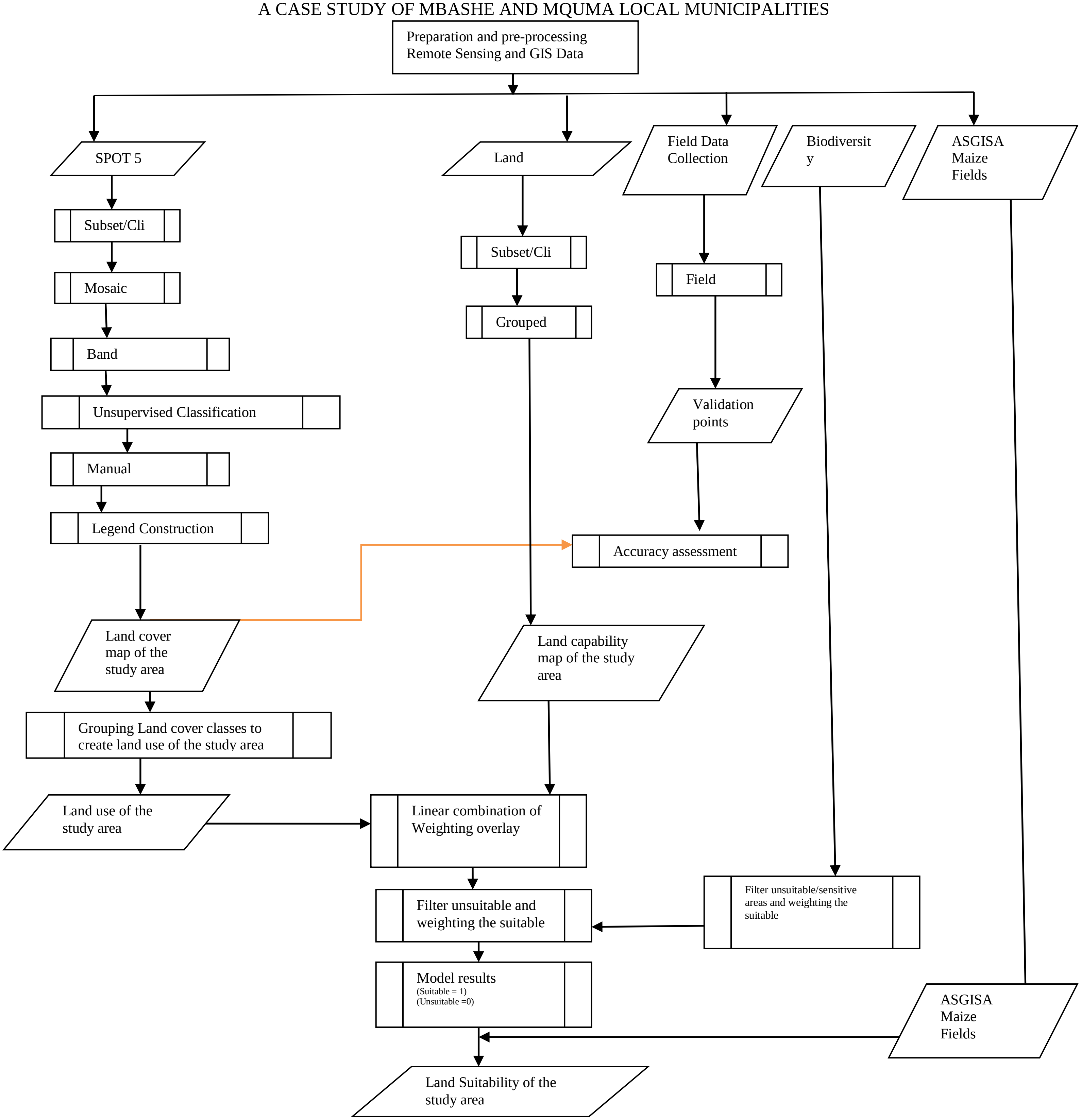

Figure 4.3 Flow chart of the methods used to execute the study.

4.5 Preprocessing

The pre-processing steps were done for the preparation of the data the steps were subset/clipping, mosaic, band combination, manual digitizing and unsupervised classification.

4.5.1 Subset/Clip

Subset is the process of cropping/clipping a specific area on the images. SPOT 5 images were stacked and clipped to retain only the study area composite layers.

4.5.2 Mosaic Images

Mosaic is the process of combing different scenes into one image. The SPOT 5 images were grouped according to their acquisition dates. Finally, there were two stacked layers. This was done to ensure that land cover classification such as unsupervised classification was possible.

4.5.3 Band Combination

Determination of the 'best' bands combination in the context of image statistical analysis is very important. This technique is commonly used for combining high-resolution single images with colour images for interpretation purposes and accurate classification. In this study, ERDAS software was used to perform digital classification of SPOT 5 image using colour composite band 3, 4 and 2. In this false colour composite, vegetation appears in shades of red, urban areas cyan blue, and soils vary from dark to light brown. This is a very popular band combination and it is useful for vegetation studies. Generally, deep red hues indicate broad leaf and or healthier vegetation while lighter reds signify grassland or sparsely vegetated areas. Settlements areas are shown in light blue. This band combination gives results similar to traditional color infrared aerial photography. This band combination contains one band from each of the two spectral zones: the visible (bands 2, 3), near infrared (band 4) (Figure 4.4). The 3,2 and 4-band combination was used in the manual digitization and SPOT 5 panchromatic band was also used for to verify those digitized features from band combination.

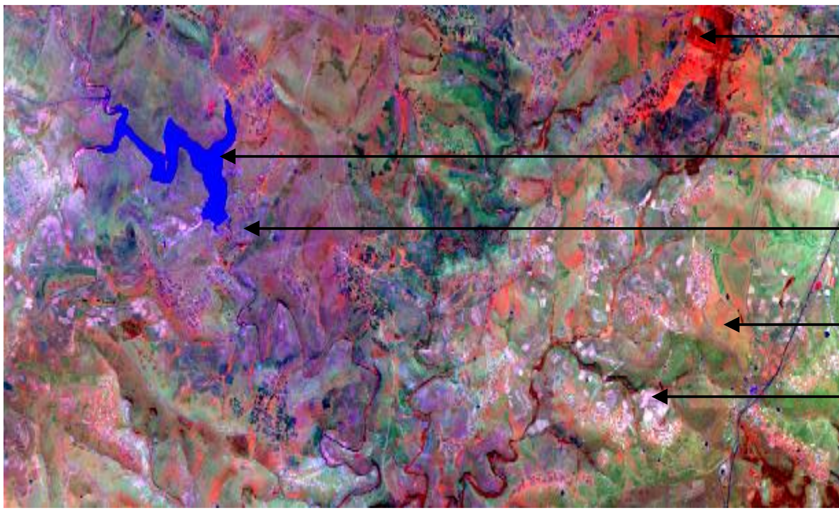

Figure 4.4: Image showing band combination of 342.

4.5.4Unsupervised Classification

Unsupervised classification technique, classifies the image automatically by finding the clusters based on certain criterion. The most common unsupervised classification algorithm in ERDAS is ISODATA (An Iterative Self-Organizing data Analysis Technique) (Duda and Hart, 1974) cited in Campbell (2002). The ISODATA is a clustering unsupervised method that uses minimum spectral distance formula to form clusters (Campbell, 2002, ERDAS, 2003). Unsupervised indicates that there were no expert guidance employed during the process of classification (Campbell, 2002). ISODATA algorithm has been developed with empirical knowledge gained through experimentation and requires relatively little in the way of human interaction. An ISODATA divides all pixels within an image into a corresponding class pixel by pixel. Typical, the only input ISODATA needs is the number of classes of the scene. An ISODATA unsupervised classification method was performed on the 4 bands. According to Herkt (2007), the number of iterations must be slightly higher than a half of the number chosen for classes.

The bands were classified into 50 classes or clusters and 100 maximum iterations and the convergence threshold of 0.950. After the classification process was finished, the attribute table was opened and there were 50 classes with different colors (Figures 4.5)

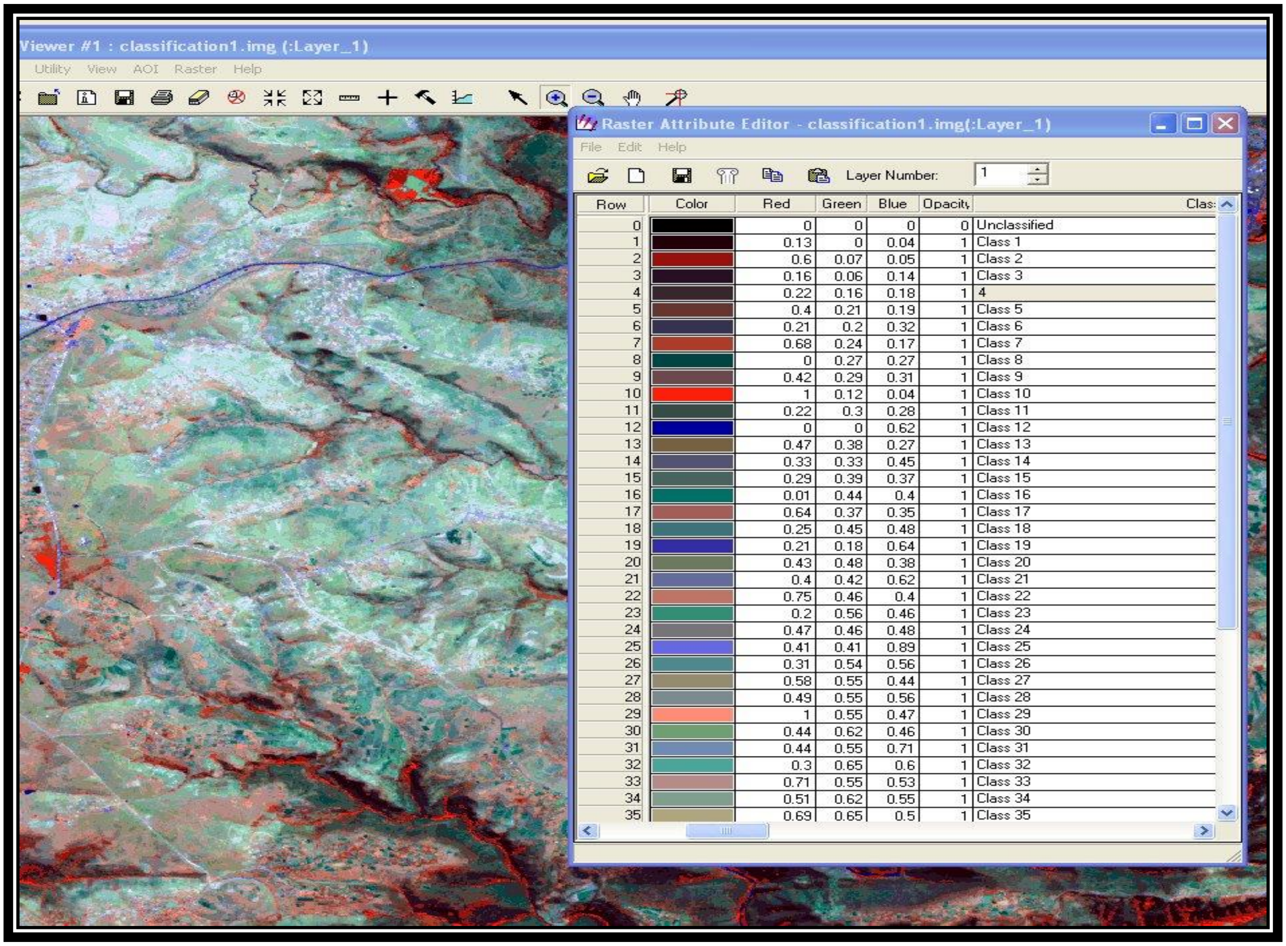

Figure 4.5 Unsupervised classifications with 50 classes

Similar classes were identified and given names and colors were grouped into one color i.e. all the areas that were identified as water bodies were labeled and their class names were changed to water bodies. For areas that were not identified clearly, the selection process was done class by class and the color of the selected class was changed so that it can be identified on the image view. Some classes were still not easily identified even after this selection and there was a need to overlay the panchromatic band to the classified image. A swipe tool was used. A swipe is a tool that allows the user to view two overlapping images at the same time. The panchromatic band was swiped behind the classified image and all the classes were named and the colors were grouped according to the class name (Figure 4.6).

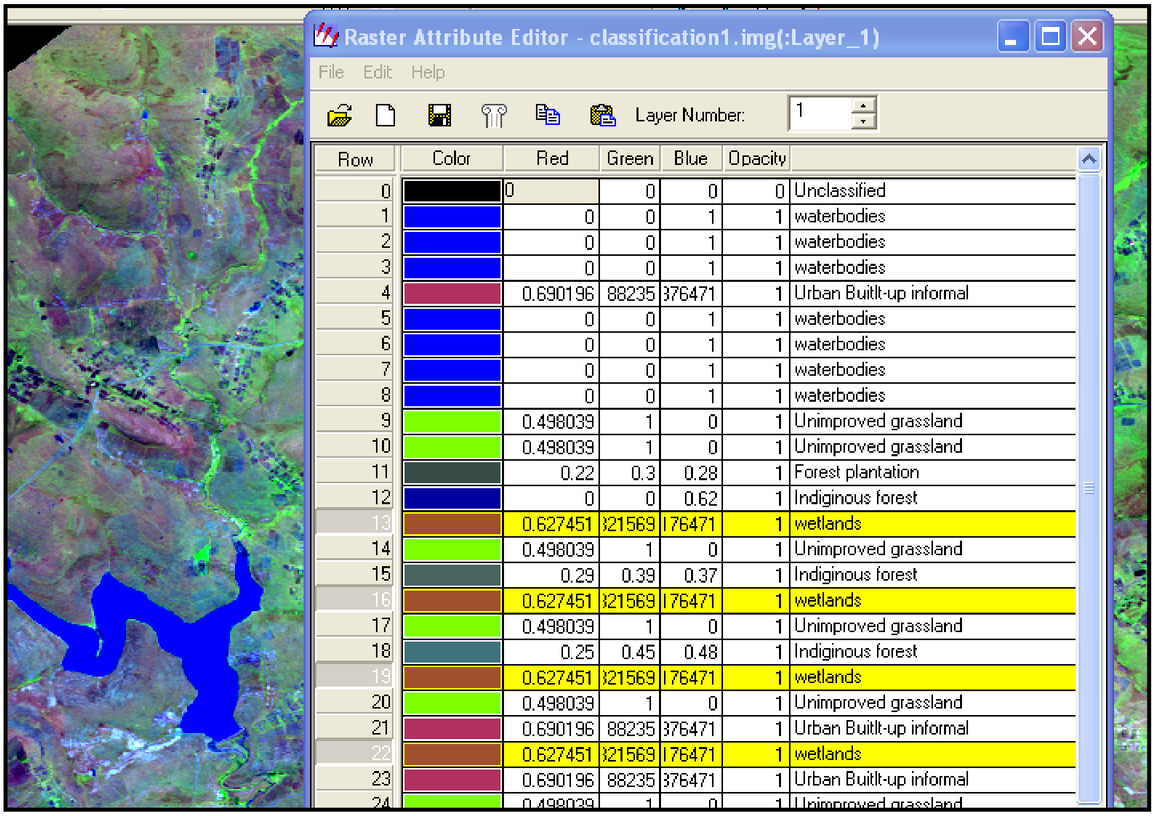

Figure 4.6 Unsupervised classifications with class name and colors.

4.5.5 Manual Digitizing

The manual screening digitizing was used after unsupervised classification could not identify all the classes. In order to identify all the similar classes that were picked up by unsupervised classification, the 3, 4 and 2-band combination was used. The combinations of 3, 4 and 2 has an advantage of showing bare grounds, water bodies and vegetation from sparsely to dense vegetation and on the later stage the manual photo interpretation was used to digitize some features that were so difficult to be identified. The urban, settlements, waterbodies and bare ground features were digitized using DEM, 4, 3 and 2 band combinations and the 2.5m panchromatic band.

4.5.6 Urban and Rural settlements

The Eastern Cape is mostly rural and the colour image resolution is not sufficient to differentiate between the houses and the kraals or garden close to the houses. Different band combinations were tested but the settlements were still not easily identified. Since the settlements were difficult to be identified, the SPOT 2.5 meter panchromatic band was used to digitize the settlements (Figure 4.7), mask it and assign it a separate class called settlements.

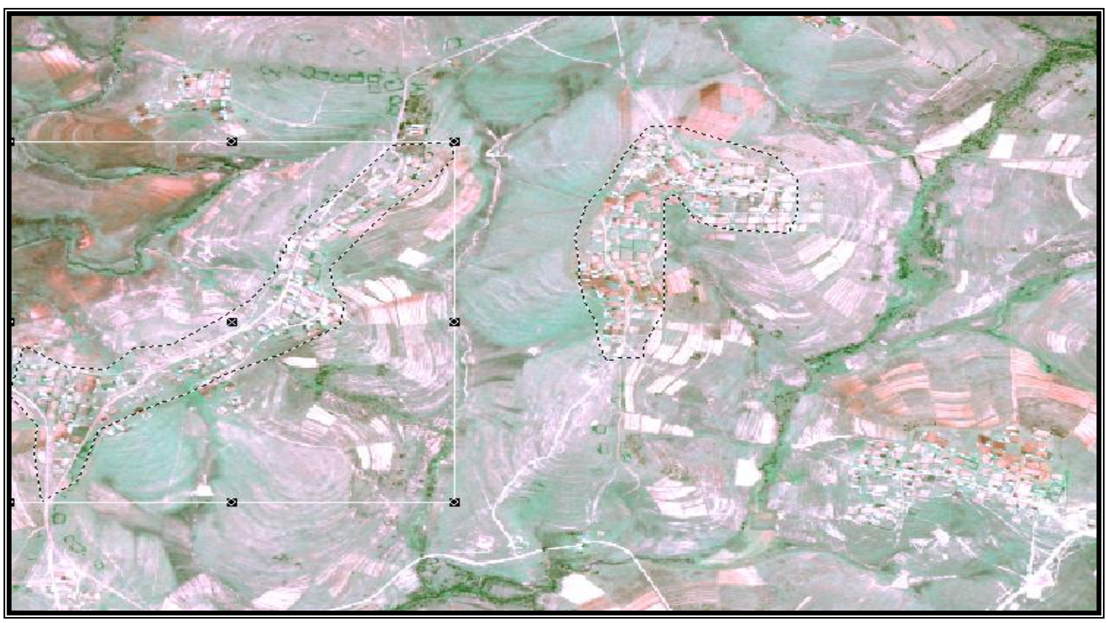

Figure 4.7 Digitizing settlements

4.5.7 Water bodies

Manually the different band combinations were explored to identify water bodies. In the combination of band 3, 4 and 2 the water bodies were clearly identified, but there are also areas that were confused with shadows. In those areas that were not clearly distinguished whether its water or shadows, the 30m contour lines were overlain and the height from sea level was utilized to separate shadows and water. All the water bodies that were digitized using area of interest (AOI) were merged with the other results obtained.

4.5.8 Bare ground

The results of the unsupervised classification identified most classes but in other classes such as bare ground and bare scars and settlements, an alternative method was required. To solve that problem, the SPOT 2.5 panchromatic band, dams shape file and settlements shape file were overlapped to verify and digitize those areas using the AIO that at the later stage were merged with the other results obtained.

4.5.9 Legend Construction

A land cover classification scheme can be defined as the combination of a set of independent diagnostic attributes, or classifiers, that are arranged to assure a high degree of map ability (Lotham, 2000). The construction of the legend was based on the South African Land Cover Database project (Thompson 1999). The 50 classes were assigned colours and their respective names and the recode tool was used for legend construction.
Recoding is the process of grouping all the classes that represent one feature i.e. all the water bodies from different rows were recorded to class waterbodies and all the digitized features were merged to create a legend. The recode process minimized the classes from 50 to 13 classes (Table 4.4).

Land Cover Classes
Forest plantations
Forest (Indigenous)
Urban/Built-up (Residential)
Urban/Built-up (Residential, formal township)
Urban/Built-up (Residential, Informal township)

Wetlands
Cultivated, temporary, subsistence, dry land
Cultivated, temporary, subsistence, irrigated
Thicket, bushland, bush clumps, high fynbos
Bare rock and Soil (natural)
Degraded unimproved grassland
Unimproved grassland
Waterbodies

Table 4.4 Land Cover Classes for the study area

Figure 4.8: The land covers of the study area

See attached A3 Land cover map of the study area

<u>4.5.10 Land Use Types</u>

Land Use Type is defined as a specific manner of occupying and using the land, with specific management methods in a defined technical and socio-economic setting. It may involve any number of activities and products, as long as they form part of one system of management (Rossiter, 2001b). For the benefit of the model there was a need to group all the land cover classes for land use purposes. This grouping of the land cover classes was done to simplify all the classes of the land cover that can be grouped into one class of level I (Table 4.4) i.e. residential, formal and informal township and industries were grouped into Built-up land (Table 4.5). After the grouping there were only seven classes that were classified as land use classes (Table 4.4) and (Figure 4.9).

Class name from land cover	**Land use**
Forest Plantation	FORESTRY
Forest (Indigenous)	FORESTRY
Urban/Built-up (residential)	BUILT-UP-LAND

Urban/Built-up (residential, formal township)	BUILT-UP-LAND
Urban/Built-up (residential, informal township)	BUILT-UP-LAND
Wetlands	WETLANDS
Cultivated, temporary, subsistence, dryland	CULTIVATED LAND
Cultivated, temporary, subsistence, irrigated	CULTIVATED LAND
Thicket, Bushland, Bush clumps, High Fynbos	GRAZING
Bare Rock and Soil (natural)	BARREN LAND
Degraded Unimproved Grassland	BARREN LAND
Unimproved grassland	GRAZING
Waterbodies	WATERBODIES

Table 3.4 Grouping of land cover classes for a land use map

4.5.11 Land use

In the study area seven types of land use were identified. These are described below.

Class	Description
Urban/Built-Up	Include all residential, commercial and industrial development.
Forestry	All forest vegetation types
Wetlands	Predominately wetlands or marsh features
Grazing	Includes all vegetation features that are not of typical forest or cultivated land, including pasture grassland, recreational grasses, scrub or shrub, thicket, bushland, bush clumps, and high fynbos
Waterbodies	All water bodies including freshwater lakes, rivers, and stream as well as marine water environments
Barren Land	Barren or sparsely vegetated areas most often representative of bare soil
Cultivated Land	Includes all agricultural fields

Table 4.6: The seven classes of land use and description

Figure 4.9 Land use of the study area

See attached A3 size map of land use

4.5.12 Land Suitability Analysis (Modeling)

In the current study, the Analytic Hierarchy Process (AHP) method was applied to describe the land suitability analysis.

4.5.13 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) method commonly used in multi-criteria decision-making exercise was found to be a useful method to determine the weights (Saaty, 1998; Dutta, et al., 1998; Siddiqui et al., 1996 Kamal Alharbi, 2001, Weerakoon, 2002, Yesilnacar and Doyuran, 2000). Compared with other methods used for determining weights, e.g. Delphi method, the AHP method is superior because it can deal with inconsistent judgment and provides a measure of inconsistency of judgment of the respondents. AHP means the separation of an entity into its constituents. This method decomposes the complex decision problems into simple groups and hierarchies. The AHP is based on three basic principles and four (Sharif and Herweijnen 2003):

- Decomposition: speak: is to structure a complex problem into different clusters at various hierarchies
- Pairwise Comparison: is to create Pairwise Comparison matrices (PCMs) for all the elements or criteria under evaluation to derived the weights or preferences, and
- Hierarchical composition, to aggregate these local comparisons over the hierarchy to arrive at the final evaluation

And the four simple axioms those constitute the theory of AHP are,

- Reciprocal axiom: If the pairwise comparison between two elements A and B with respect to an element c is Pc (xab), then the comparison between b and c must be 1/Pc (xab).

- Homogeneity axiom: Elements clustered and arranged under a hierarchy must be homogeneous i.e. they must be comparable with an order of magnitude. It means that elements within a cluster should preferably be compared within the AHP scale, 1 to 9.
- Independency of judgment at each level: judgment at one level of hierarchy should be independent of the elements under it. One should carefully consider this axiom while making decisions, as the human tendency force one to look at the elements under the hierarchy during evaluation.
- One should make sure that their ideas are adequately represented in or incorporated into process of decision making so that the results match their expectation.

The AHP weighted linear combination; factors were combined by applying a weight to each, followed by a summation of the results to yield a suitable (1) and unsuitable (0) map. The criterion used in the study area was resulted in two categories: Suitable and Unsuitable. The unsuitable areas were defined under these circumstances:

- Settlements- are areas that are already occupied by people and it's not possible to remove people.
- Water bodies and wetlands are areas that are not suitable in any way for cropping due to the level of water.
- Restricted areas are areas that are no go areas, either land or sea, that are spatially dedicated to the protection and maintenance of biological diversity, associated culture resource, and managed through legal or other effective mean.

The suitable areas were defined under these circumstances:

- Cultivated land –are those areas that were classified as cultivated land in the land use.
- Grazing-
- Barren land and

- Forest- The forest was included in the list after the community of Tholeni (community in the study area) decided to cut the forest that existed for the purpose of doing cropping in that area.

4.5.14 Assigning Weights for the Criteria

The purpose of weighting in land suitability analysis for agriculture crops is to express the importance or preferences of each factor relative to other factors on crop yield and growth rate. The weightings in the study area were determined by using AHP, which was first proposed by Saaty (1980) for usage in multi-criteria decision-making. The relative importance of each criteria, i.e., the weights **W1 (i),** for I = 1 to 7 and those of the sub-criteria, i.e. those of W0 (i, j) for i = 1 to 7 and j=1 to 9(ni)

Simplify

i =main criteria and each with

n= sub criteria

According to Saaty the weighting was as follows:

Numerical Ratings	**Verbal judgment of preference**
7	Extremely preferred
6	Very strongly to extremely
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred (restricted)
2	Equally to moderately (restricted)
1	Equally preferred (restricted)

Table 4.7 Pair-wise comparison scale for AHP preferences (Saaty 1980)

4.5.14 Aggregating the Criterion Weights

GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets (Malczewski, 2003). The data was manipulated and analyzed in order to obtain information and the ranking was done according to Saaty, (1980). All the areas that were not suitable for cropping i.e. Water bodies, Wetlands, Built-up areas, and etc were treated as restricted areas and the forest was treated as moderate to strong since it is possible to cut the trees and do cropping. In AHP, the ratio scale for pair-wise comparisons range from 1 to 7 representing judgment entries where 1 is equally important and 7 is absolutely more important (Alam & Shrabonti, 2002).

Raster	**% Influence**	**Field**	**Scale Value**
Land Capability	85	Arable (II)	7
		Arable (III)	7
		Arable (IV)	7
		Gazing (VI)	Restricted
		Gazing (VII)	Restricted
		Wilderness (VIII)	Restricted
Biodiversity	5	Not Protected area	7
		Protected area	Restricted
Land Use	10	Forestry	4
		Urban/Built-Up	Restricted
		Wetlands	Restricted
		Cultivated area	7
		Grazing	6
		Barren land	5
		Waterbodies	Restricted

Table 4.8 Weighted overlay criteria for the study area

4.5.15 Data Preparation and criteria

Since the model uses raster, all the vector data was converted to raster i.e. land capability, protected areas. All the data was grouped according to Saaty, (1980) weighting and all the areas that no cropping can be done were grouped as restricted areas. All the layers received an influence weight and the overlay weights were based on 100 percent (see equation below). The land capability receives 85 percent 10 percent land use and 5 percent protected areas (Figure 4.8).

Equation

Lu - Land Use = 0.10

Lc - Land Capability = 0.85

Bd - Biodiversity = 0.50

Ls - Land Suitability

$$Ls = (Lc * Lu * Bd)$$
$$=0.10*0.85*0.50 = 0.0425$$

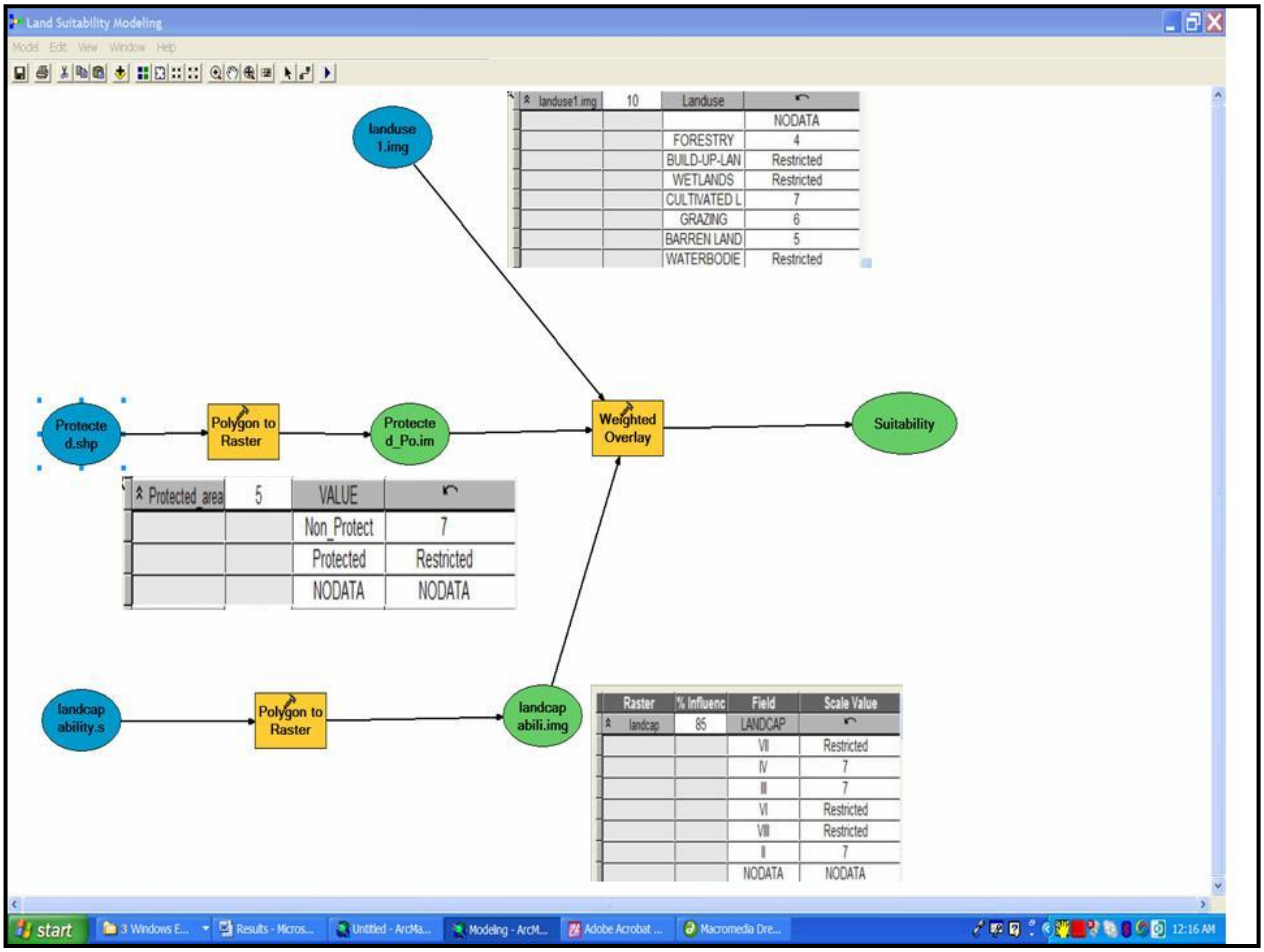

Figure 4.10 Snapshot of the weighted overlay tool

The weighted overlay tool of spatial analyst creates the final output for potential land suitability for cropping. The whole data was integrated and the criteria was defined according to Saaty weighted overlay and lastly the entire model was ran as one operation, (Figure 4.10) taking into consideration that the model should be interactive, enabling decision-makers to modify factors used in the analysis and can be re-run to evaluate the new results. Inside the model, all the areas that are suitable for cropping (land capability) that are not overlapping the restricted areas (Protected areas and land use areas) were given a value of 1 and all the areas that are restricted from land capability ,land use and protected land were given a value of 0 on the results stage.

4.5.16 Field Data Collection and Accuracy Assessment

Field data collection was done for accuracy assessment of the land cover products and most areas in the study area were covered. The stratified random method was used for data collection in this study area. For this approach, the area of study was divided into strata: and the random sampling was applied (Bigig et al., 1999, Campbell, 2002, Lunneta and Elevidge, 1999). The stratification was based on each land cover type (Campbell, 2002, Liang, 2004). This approach allowed for a necessary randomness and overcomes chances for underestimating or overestimating of reference points among the category maps (McCoy, 2005). The sample unit of 0.5 km² was adopted so that it corresponds to image pixel size. After 0.5 km² a sample point was collected using GPS and the points were labeled by the land cover in that area.

Sample points were used for accuracy assessment. Accuracy of the land cover interpretation is a complex issue, both in its definition and measurement e.g. an area delineated and classified as a particular category may be in an error for one or more of the three reasons: (1) Classification error, (2) boundary reason (Hord and Brooner, 1976), and (3) control location point error. The image classification is said to be incomplete without accuracy assessment (Congalton, (1991). The study used a confusion or error matrix to calculate accuracy descriptive techniques such as kappa statistics, user, producer and overall accuracy. In the confusion matrix, map (classified) points are normally presented as rows and ground truth points are presented as columns (Congalton, 1991, Hudson, 1997, Jensen, 1996, Kerle et al., (2004). Kappa (KHAT) statistics can be used to test if two data sets have statistical different accuracy. The results presented in an error matrix are significantly better than the random results .i.e. the Null hypothesis is KHAT = 0. The KHAT results value ranges between -1 to 1, where -1 indicate no agreement, 0 is random agreement and 1 is a perfect agreement (GIS –Centre, 2004).

The producer accuracy is a probability of a reference points being correctly classified and, it is derived by dividing total number of correctly classified pixels in a category or a class by total number of points in the corresponding row or column (Congalton, 1991). The user accuracy is the probability that a randomly chosen point on the map is the same on the ground, which is derived by dividing total number of correctly classified on the same category (Congalton, 1991, Jensen, 1996). The overall accuracy was derived from dividing total number of points used for assessment (GIS-Centre, 2004, Jensen, 1996, Kerle et al., 2004).

Chapter 5

Results and discussion

This Chapter presents the overall results analysis and Discussions.

5. Land cover and land use mapping

SPOT 5 data was classified to create land cover types. The results of accuracy of land cover classification will be discussed based on Confusion matrix. The major land use types were derived from major land cover types.

5.1 Land cover

The study encompasses thirteen major land cover types.

Land Cover Classes	**Percentages %**
Forest plantations	02
Forest (Indigenous)	11.6
Urban/Built-up (Residential)	0.2
Urban/Built-up (Residential, formal township)	8.6
Urban/Built-up (Residential, Informal township)	0.5
Wetlands	0.2
Cultivated, temporary, subsistence, dry land	3.6
Cultivated, temporary, subsistence, irrigated	2.4
Thicket, bushland, bush clumps, high fynbos	23.9
Bare rock and Soil (natural)	4.9
Degraded unimproved grassland	4.1
Unimproved grassland	39.3
Waterbodies	0.4

Table 5.1 Present land cover types with percentages

5.2 Land Use Type

The outcomes of creating the land use by grouping land cover classes resulted in seven classes (Table 4.6). In the grouping of land cover classes, it was clear that half of the study area is grazing land, followed by forestry and urban/built-up area (settlement).

Land Use	**Percentages %**
FORESTRY	11.6
BUILT-UP-LAND	9.4
WETLANDS	0.2
CULTIVATED LAND	6.0
GRAZING	63.5
BARREN LAND	8.9
WATERBODIES	0.4

Table 5.2: The Land Use table with percentages

5.3 Land suitability

After categorization, all the thematic layers were integrated with one another in the GIS using weighted aggregation method. The resultant map (Figure 5.1) shows the extent distribution of the land suitability classes. The most suitable locations are in dark green and the unsuitable lands are in orange. The percentages for two municipalities were calculated for both suitable and unsuitable (Table 5.3).

	Suitable %	Unsuitable%
Mbashe	11.5	88.5
Mnquma	23.4	76.6

Table 5.3 Land suitability per local municipality

After the suitability of each local municipality, the following step was to calculate the suitable areas per ward (Table 5.6 and Table 5.7), this exercise was assisting the ward councilors as to know which area can be reserved for agriculture since the housing development is the major problem in rural areas.

See attached A3 Size (Figure 5.1)

Figure 5.1 Land suitability with wards numbers.

Ward	Suitable (ha)	Unsuitable (ha)	Total (ha)	Suitable %	Unsuitable %
1	104240.85	332615.27	436857.12	23.9	76.1
2	104240.85	332636.69	436879.53	23.9	76.1
3	104287.91	333222.19	437513.09	23.8	76.2
4	104287.91	333206.50	437498.41	23.8	76.2
5	104240.85	705.80	104951.64	99.3	0.7
6	104240.85	612.71	104859.56	99.4	0.6
7	104333.02	333535.09	437875.11	23.8	76.2
8	104251.59	332897.21	437156.80	23.8	76.2
9	104262.02	332744.22	437015.25	23.9	76.1
10	104304.92	332604.53	436919.45	23.9	76.1
11	669.86	332604.53	333285.39	0.2	99.8
12	104282.42	332811.27	437105.69	23.9	76.1
13	104260.94	333201.63	437475.57	23.8	76.2
14	104240.85	333063.66	437318.51	23.8	76.2
15	104723.18	332625.31	437363.49	23.9	76.1
16	104727.27	332614.57	437357.85	23.9	76.1
17	104287.91	356551.40	460856.31	22.6	77.4
18	104240.85	356678.88	460937.72	22.6	77.4
19	112395.60	356296.85	468711.45	24.0	76.0
20	112438.50	356495.02	468953.51	24.0	76.0
21	112427.51	356389.73	468838.24	24.0	76.0
22	106910.44	335087.21	442019.66	24.2	75.8
23	104722.50	333055.29	437800.79	23.9	76.1
24	146651.60	333163.02	479838.62	30.6	69.4
25	164536.41	333643.66	498205.07	33.0	67.0
26	40897.68	333787.40	374711.08	10.9	89.1
27	54103.17	341544.30	395674.47	13.7	86.3
28	40050.85	336659.69	376738.53	10.6	89.4
29	39802.62	334011.73	373843.35	10.6	89.3
30	40870.24	332949.02	373849.25	10.9	89.1
31	145525.04	332767.53	478323.57	30.4	69.6
Total	**2995456.20**	**9790781.89**	**12786238.09**	**23.4**	**76.6**

Table 5.6 Mnquma Land Suitability per ward

Wards	Suitable (ha)	Not Suitable (ha)	Total (ha)	Suitable %	Not suitable %
1	104533.54	332604.53	437138.07	23.9	76.1
2	104535.28	332604.53	437139.81	23.9	76.1
3	104838.15	333232.37	438070.52	23.9	76.1
4	25001.54	356919.64	381921.18	6.5	93.5
5	19101.03	24048.37	43149.40	44.3	55.7
6	17080.49	24044.77	41125.26	41.5	58.5
7	20768.85	356251.46	377020.31	5.5	94.5
8	111888.70	333996.43	445885.13	25.1	74.9
9	112083.43	332755.07	444838.50	25.2	74.8
10	108630.72	332760.16	441390.88	24.6	75.4
11	116411.23	332939.23	449350.47	25.9	74.1
12	20169.60	332999.33	353168.93	5.7	94.3
13	1972.40	332746.21	334718.62	0.6	99.4
14	7055.31	332797.32	339852.64	2.1	97.9
15	3906.66	332673.80	336580.46	1.2	98.8
16	0.00	332604.53	332604.53	0.0	100.0
17	0.00	332604.53	332604.53	0.0	100.0
18	0.00	332604.53	332604.53	0.0	100.0
19	341.26	332604.53	332945.79	0.1	99.9
20	1385.71	332604.53	333990.24	0.4	99.6
21	2760.54	332630.96	335391.50	0.8	99.2
22	15965.19	332679.44	348644.63	4.6	95.4
23	15016.66	339373.97	354390.63	4.2	95.8
24	17314.18	332677.15	349991.33	4.9	95.1
25	119541.71	332636.05	452177.76	26.4	73.6
26	493.41	332604.53	333097.94	0.1	99.9
Total	**1050795.59**	**8088997.97**	**9139793.56**	**11.5**	**88.5**

Table 5.7: Mbashe Land Suitability per ward

Municipality	Suitable (ha)	Not Suitable (ha)
Mbashe	1050795.59	8088997.97
Mnquma	2995456.20	9790781.89
Total (ha)	4046251.79	17879779.86
Percentage %	18.45	81.55

Table 4.7: Land Suitability hectors per municipality

5.4 Accuracy Assessment

For accuracy assessment, 130 sample points were collected using stratified random sampling. The results for assessment are presented in table 4.1, where kappa and overall kappa, producer, user and overall accuracies are reported. Land cover groups such as 1, 2, 3, 6 and 12 are the most accurately mapped classes with more than 75% user and producer. In contrast, a land cover group such as No 4 has a user and producer of 100% and 50% respectively; same applies to No 5 with 100% and 14% of producer and user accuracy respectively. In generally 1,2,3,6 and 12 have a comparatively higher accuracy than 4,5,7,8,9,10 and 11. The overall accuracy is 64% and overall kappa (KHAT) statistics is 0.54 %.

Class name from land cover	Class numbers
Forest Plantation	1
Forest(Indigenous)	2
Urban/Built-up (residential)	3
Urban/Built-up(residential, formal township)	4
Urban/Built-up(residential, informal township)	5
Wetlands	6

Cultivated, temporary, subsistence, dryland	7
Cultivated, temporary, subsistence, irrigated	8
Thicket, Bushland, Bush clumps, High Fynbos	9
Bare Rock and Soil (natural)	10
Degraded Unimproved Grassland	11
Unimproved grassland	12

Table 4.1: Showing the number and the names of classes used in the confusion matrix.

		Field data												
Classes	1	2	3	4	5	6	7	8	9	10	11	12	Total	PA(%)
1	5	0	0	0	0	0	0	0	0	0	0	0	5	83
2	0	6	0	0	0	0	0	0	2	0	0	0	8	100
3	0	0	3	0	0	0	0	0	0	0	0	0	3	75
4	0	0	1	6	5	0	0	0	0	0	0	0	12	100
5	0	0	0	0	1	0	0	0	0	0	0	0	1	14
6	0	0	0	0	0	1	0	0	0	0	0	0	1	100
7	0	0	0	0	0	0	9	1	0	0	0	1	11	30
8	0	0	0	0	0	0	2	0	0	1	0	0	3	0
9	1	0	0	0	0	0	2	2	9	0	0	0	14	75
10	0	0	0	0	1	0	1	1	0	5	2	1	11	71
11	0	0	0	0	0	0	8	1	0	0	3	1	13	50
12	0	0	0	0	0	0	8	1	1	1	1	36	48	92
Total	6	6	4	6	7	1	30	6	12	7	6	39	130	
UA (%)	100	75	100	50	100	100	82	0	64	45	23	75		
Classes	Producer	User												
1	0.833333	1												
2	1	0.75												
3	0.75	1												
4	1	0.5												
5	0.142857	1												
6	1	1												
7	0.3	0.818182												
8	0	0												
9	0.75	0.642857												
10	0.714286	0.454545												
11	0.5	0.230769												
12	0.923077	0.75												
	Value													
Overall Accuracy	0.646154													
Overall Kappa	0.578487													

Table 5.10: The confusion matrix with accuracy assessment results in terms of User Accuracies (UA) and Producer Accuracies (PA). Overall Accuracy of 64% and Kappa of 54 % (0.54)

5.5 Model Validation

To validate this model, the soil data samples that were collated by ASGISA officials were overlain on the Land Suitability map (Figure 5.2). Since 2008 ASGISA has been doing dry land cropping in the former homelands of Transkei and the soil data was a pre-requisite whenever they were stating projects in those villages. Also these soil samples were determining how much chemicals and fertilizers suppose to be used in those villages and this was the way of saving their funds .i.e. if the village have bad soils or soils that will need more chemicals or fertilizers that areas was excluded.

The soil samples were collected using a GPS and were done per hector, this data was taken to the lab for analysis (Table 5.11) and according to the Agronomist the results showed good soil with less chemicals to apply in those villages. For the season of 2008, 2009 and 2010 ASGISA was still using those fields and getting high yields per hector.

See attached A3 Size (Figure 5.2)
Figure 5.2 Land Suitability with soil samples.

year	prefix	sample Number	ownID	density	P	K	Ca	Mg	Exch. Acidity	Total cations	Acid Sat	PH	Zn	Mn	Cu	Clay	Carbon	Nitrogen	CNratio	batch
2010	F	4720	Tanga 1	1.08	7	126	616	153	0.63	5.29	12	4	1.3	29	7.6	27	0.9	0.075	12	230
2010	F	4721	Tanga 2	1.19	16	47	767	222	0.26	6.03	4	4.17	2.3	21	4.6	20.5	0.65	0.105	6.19	230
2010	F	4722	Tanga 3	1.22	10	70	384	82	0.26	3.03	9	4.04	1.1	12	2	10	1.6	0.14	11.43	230
2010	F	4723	Tanga 4	1.18	10	196	312	73	0.4	3.06	13	3.95	1.6	31	3.7	13	0.5	0.07	7.14	230
2010	F	4724	Tanga 5	1.03	19	38	826	229	0.13	6.23	2	4.15	2.6	26	4	14.5	1.95	0.17	11.47	230
2010	F	4725	Tanga 6	1.24	18	187	614	141	0.11	4.81	2	4.24	1	33	6.9	18	0.35	0.04	8.75	230
2010	F	4726	Tanga 7	1.19	30	254	916	196	0.15	6.98	2	4.3	2	24	8.1	22.5	0.3	0.05	6	231
2010	F	4727	Qorha 1	1.08	1	78	617	220	0.09	5.18	2	4.63	0.5	7	4.2	14	1.25	0.15	8.33	231
2010	F	4728	Qorha 2	1.17	1	38	458	179	0.07	3.93	2	4.56	0.6	5	1.9	11	1.75	0.13	13.46	231
2010	F	4729	Qorha 3	1.16	1	46	843	377	0.04	7.47	1	5.11	0.6	5	3.9	11	0.65	0.1	6.5	231
2010	F	4730	Qorha 4	1.13	6	151	907	260	0.1	7.15	1	4.54	0.9	20	7.4	22.5	0.7	0.095	7.37	231
2010	F	4731	Zingqayi 1	1.18	19	65	316	149	0.28	3.25	9	4.26	0.6	4	1	13.5	1.45	0.165	8.79	231
2010	F	4732	Zingqayi 2	1.15	8	62	379	128	0.5	3.6	14	4.09	0.6	9	1.2	14.5	1.55	0.175	8.86	231
2010	F	4733	Zingqayi 3	1.17	10	74	305	126	0.24	2.99	8	4.18	0.4	5	0.8	14	1.7	0.165	10.3	231
2010	F	4734	Zingqayi 4	1.22	7	75	314	138	0.23	3.12	7	4.17	0.7	6	0.9	12	1.5	0.15	10	231
2010	F	4735	Zingqayi 5	1.12	3	103	443	193	0.15	4.21	4	4.23	1	5	1.2	14	1.65	0.18	9.17	231
2010	F	4736	Zingqayi 6	1.13	2	98	452	189	0.19	4.25	4	4.23	0.5	4	1.3	14	1.65	0.185	8.92	231
2010	F	4737	Nqadu 1	1.15	9	40	1377	154	0.03	8.27	0	5.76	1.2	9	5.4	21.5	0.4	0.14	2.86	231
2010	F	4738	Nqadu 2	1.1	1	54	1141	171	0.06	7.3	1	5.52	0.9	6	5.7	21.5	0.35	0.09	3.89	231
2010	F	4739	Nqadu 3	1.08	1	95	745	327	0.2	6.85	3	4.28	1.5	14	5.8	40.5	1.9	0.19	10	231
2010	F	4740	Nqadu 4	1.12	6	67	1535	262	0.07	10.06	1	5.1	3.8	7	7.2	27	0.95	0.165	5.76	231
2010	F	4741	Nqadu 5	1.09	4	170	927	258	0.31	7.49	4	4.18	3	34	9.6	35	1.35	0.105	12.86	231
2010	F	4742	Nqadu 6	1.1	10	100	1385	381	0.07	10.37	1	4.7	2.6	20	5.5	29	2	0.175	11.43	231
2010	F	4743	Nqadu 7	1.05	2	230	1425	427	0.04	11.25	0	4.87	2.1	5	8.5	38	2.3	0.195	11.79	231
2010	F	4744	Nqadu 8	1.04	1	71	1030	332	0.13	8.18	2	4.36	2.5	28	8.8	39	1.7	0.145	11.72	231
2010	F	4745	Nqadu 9	1.14	28	285	1789	337	0.04	12.47	0	5.28	4.8	10	10.5	33	1.3	0.135	9.63	231
2010	F	4746	Teko 2	1.04	10	91	877	348	0.32	7.79	4	4.15	9.5	80	8.9	33	1.9	0.145	13.1	231
2010	F	4747	Teko 3	1.08	8	90	858	327	0.34	7.54	5	4.15	8.9	80	9.2	34	2.15	0.155	13.87	231
2010	F	4748	Teko 4	1.08	28	214	889	236	0.7	7.63	9	3.91	5.3	90	11.2	32	2.2	0.155	14.19	231
2010	F	4749	Teko 5	1.13	3	102	849	279	0.18	6.97	3	4.25	3	19	7.5	25.5	1.35	0.11	12.27	231
2010	F	4750	Teko 6	1.11	8	269	836	301	0.17	7.51	2	4.28	4.6	14	6.9	27	1.4	0.12	11.67	231
2010	F	4751	Teko/Nkond1	1.08	8	92	1246	332	0.05	9.24	1	4.56	1.4	13	7.9	26.5	1	0.135	7.41	231
2010	F	4752	Teko/Nkond2	1.04	8	62	1733	538	0.05	13.28	0	4.54	2.9	12	8.8	30.5	1.8	0.2	9	231

Table 5.11 Soil sampling of Mbashe and Mnquma areas

5.6 Discussion

The multi criteria approach for land suitability was confirmed to be adequate by integrating database of climate, soil and the land cover. This integration has been successfully to meet all the objectives of the research. Most of the areas in the study area that were suitable for cropping were also the areas that the Department of Agriculture were working on before ASGISA took over. The soil information that was collected by the agronomist made it very clear to the project managers and extension officers that the model was successful. The suitability of the wards was also counted and many of those areas were 1.5 hectares in each household's gardens.

This model will also play a major role to government officials and decision makers. This model will also show and interpret the situation to the low level of communities since it shows the potential areas per wards and this will also make the ward councillors and the chiefs to know which areas to grow crops and also which areas can be identified for housing development and pastures. This will also reduce the money that the government spent on consultants to do this type of work. Furthermore, the results of this study could be useful for other researchers who could use our results for diverse studies.

5.8 Limitation

- The availability of the data is a major limitation.
- Another limitation of the system is the application of a single set of class limit for all criteria throughout the country. It can be argued, for example, the soil depth class limit can be relaxed in the eastern part of the country, where rainfall is relatively dependable and the water storage capacity of the soil is less critical

5.9 Recommendation

More research on Land use requirements for intercrops is required, to be investigated at field level in the given conditions. This investigation will give a better understanding of aspects such as crop water requirements, row spacing and plant population. Also the soil nutrients study must be taken, this soil nutrients study must take place every three years and it must be done per hectare, this will also increase the yield. The study of soil nutrient deficiency will also be required to be undertaken in order to determine the amount of and the type of fertilizers that need to be applied. One of the reasons why the soil nutrient research is so vital, many cropping areas in the EC have some limitations on different aspects and many areas fall between II to IV land capability classes (see appendix A). Therefore, knowledge of soil nutrients will avoid the risk and assist in high production that the country has been longing for.

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APPENDIX

Appendix A: South African Land capability classes and intensity of use (After Smith, 1998)

LAND CAPABILITY CLASS	LAND USE OPTIONS	LAND CAPABILITY GROUPS
I II II IV	W F LG MG IG LC MC IC VIC W F LG MG IG LC MC IC W F LG MG IG LC MC W F LG MG IG LC	Arable land
V VI VII	W F LG MG W F LG MG W F LG	Grazing
VIII	W	Wildlife

W – Wildlife
F - Forestry
LG - Light grazing
MG - Moderate grazing
IG - Intensive grazing

LC - Poorly adapted cultivation
MC - Moderately well adapted cultivation
IC - Intensive, well adapted cultivation
VIC - Very intensive, well adapted cultivation

<u>Appendix B</u>: This shows the weight and criteria done in terrain, soil and climate from Land Capability developed by Agriculture Research Council (ARC) and Agricultural Geo-referenced Information System (AGIS) (2000).

CLASS	FREQUENCY	DURATION	CLASS DESCRIPTION
F1	None	None	No reasonable possibility of flooding (near 0% chance of flooding in any year).
F2	Rare	Very brief	Flooding unlikely but possible under unusual weather conditions (from near 0 to 5% chance of flooding in any year, or near 0 to 5 times in 100 years). Flooding will last less than 2 days.
F3	Occasional	Brief	Flooding is expected infrequently under usual weather conditions (5 to 50 times in 100 years). Area flooded for a period of 2 to 7 days.
F4	Frequent	Long	Flooding is likely to occur often under usual weather conditions (more than a 50% chance of flooding in any year or more than 50 times in 100 years). Flooding commonly lasts from 7 days to 1 month.

F5	Common	Very long	Flooding is a regular feature under usual weather conditions and may last a very long time. Examples are vleis and active streambeds of rivers.

Flood hazard classes. Source: (Schoeman et al., 2000)

F1 None	F2 Rare	F3 Occasional	F4 Frequent	F5 Common
Kranskop	Arcadia	Bonheim	Rensburg	Champagne
Magwa	Wasbank	Inhoek	Willowbrook	Dundee
Inanda		Kroonstad	Katspruit	Streambeds
Nomanci		Longlands	Lamotte	
Tambankulu		Estcourt	Pans	
Milkwood		Cartref		
Constancia		Fernwood		
Shepstone		Sterkspruit		
Vilafontes		Valsrivier		
Houwhoek		Swartland		
Avalon		Oakleaf		
Glencoe				
Pinedene				
Griffin				
Clovelly				
Bainsvlei				
Hutton				
Shortlands				
Glenrosa				
Mispah				

Soil forms associated with flood hazard classes. Source: (Schoeman et al., 2000)

BASIC INDEX	CRITERION	CLASS LIMITS	VALUE SUBTRACTED FROM BASIC INDEX
10	Clay Content (%)	0-6	4
		7-15	3
		16-35	2
		36-55	1
		>55	0
	Leaching	Dystrophic	0
		Mesotrophic	1
		Eutrophic and	2
		Calcareous	3
	Structure and transition	Orthic A	1
		E horizon	1
		Neocutanic B	1
		Clear transition from A to B	1
		Abrupt transition from A to B	2
	Depth (m)	Soil depth >0.4	0
		Soil depth <0.4	1

Soil erodibility criteria and class limits to be used with the Binomial soil classification. Source: (Schoeman et al., 2000)

WATER ERODIBILITY GROUP	EROSION HAZARD	ERODIBILITY INDEX	SOILS
1	Low	8-10	Humic soils; non-duplex, non-calcareous clays; dystrophic or mesotrophic clays and sandy clays
2	Low to moderate	5-7	Calcareous clays; sandy clays not included above; dystrophic or mesotrophic sandy loams or loams
3	Moderate	4	Calcareous sandy clays; non-calcareous, non-duplex sandy or loamy soils not included above; dystrophic or mesotrophic sandy soils and sands
4	High	2-3	Calcareous sandy or loamy soils; sandy or loamy duplex soils; sandy or loamy E-horizon soils; eutrophic sands
5	Very high	0-1	Very sandy calcareous soils; very sandy duplex, neocutanic and shallow soils; stratified alluvium

Water erodibility groups. Source: (Schoeman et al., 2000)

WIND ERODIBILITY CLASS	CLAY PERCENTAGE	SAND GRADE	PARTICLE SIZE (mm)	WIND EROSION HAZARD
1	15-20	Very fine, fine	0.05-0.5	Low
	7-15	Coarse	>0.5	
2	7-15	Very fine, fine,	0.05-0.5	Moderate
	0-6 *	Coarse	>0.5	
3	0-6	Very fine, fine, medium	0.05-0.5	High

Wind erodibility classes. Source: (Schoeman et al., 2000)

CLASS	CLASS DESCRIPTION	SLOPE GRADIENT (%)	WATER ERODIBILITY INDEX	WIND ERODIBILITY CLASS
E1	Land with low water or wind hazard. Generally level to gently sloping. Soils have low erodibility.	0-5	8-10	1
		0-3	5-10	
E2	Land with low to moderate erosion hazard. Generally gently to moderately sloping. Soils have low to moderate erodibility.	5-8	8-10	1
		3-5	5-10	
E3	Land with moderate water or erosion hazard. Generally moderately sloping land. Soils have low to moderate erodibility.	8-12	8-10	1 2
		5-8	4-10	
E4	Land with moderate to high water or wind. Erosion hazard. Generally moderately to strongly sloping land. Soils have low to moderate erodibility.	12-20	8-10	1 2 3
		5-12	3-10	
E5	Land with low to moderate water or wind erosion hazard. Generally level to gently sloping land; soils may have low to very high erodibility.	0-5	0-10	1 2 3
E6	Very steep slopes with soils water erodibility; moderately to strongly sloping land with soils of low to to high water erodibility; moderately sloping land with soils of very high erodibility.	20-40	8-10	1 2 3
		12-20	0-10	
		5-12	0-2	
E7	Land with very steep slopes, causing severe erosion hazard or past erosion. Soils may have low to very high erodibility.	20-40	0-10	1 2 3
E8	Land with extremely steep slopes. Soils may have low to very high erodibility.	40-100	0-10	1 2 3

Erosion hazard classes. Source: (Schoeman et al., 2000)

SOIL FORM	SERIES	MAXIMUM DEPTH, CORRESPONDING WITH EFFECTIVE DEPTH (mm)
Rensburg	All	500
Willowbrook	All	500
Bonheim	30, 31, 40, 41	700
Katspruit	All	400
Swartland	All	500
Valsrivier	All	500
Sterkspruit	All	400
Estcourt	All	400
Kroonstad	All	800
Westleigh	All	600

Maximum effective depth values of poorly drained or duplex soil forms. To be applied to the Land type database when effective depth is to be indicated. Source: (Schoeman et al., 2000).

CLASS	CLASS LIMITS (mm)	
D1	>800	All soils except Av,
	>700	Av, Pn, Bv
D2	600-799	All soils except Av,
	500-699	Av, Pn, Bv
D3	400-599	All soils except Av,
	300-499	Av, Pn, Bv
D4	100-399	All soils except Av,
	100-299	Av, Pn, Bv, We
D5	<100	All soils

Soil depth classes. Source: (Schoeman et al., 2000)

CLASS	SOIL LEACHING STATUS	CLAY %
T1	Undifferentiated	15-30
	Dystrophic	15-45
T2	Undifferentiated	10-15: 30-35
	Dystrophic	45-55
T3	Undifferentiated	<10; >55

Soil texture classes. Source: (Schoeman et al., 2000).

W1 Excessively drained	W2 Well drained	W3 Imperfectly drained	W4 Somewhat poorly drained	W5 Poorly drained
Clovelly 10-12, 20-22, 30-32, 40-42 Hutton 10-12, 20-22, 30-32, 40-42	Kranskop Magwa Inanda Nomanci Arcadia Bonheim Inhoek Mayo Milkwood Houwhoek Griffin Clovelly 13-18, 23-28 33-38, 43-48 Hutton 13-18, 23-28 33-38, 43-48 Shortlands Oakleaf Dundee Glenrosa Mispah	Tambankulu Swartland Valsrivier Sterkspruit Constancia Shepstone Vilafontes Lamotte Westleigh Avalon Glencoe Pinedene Bainsvlei Fernwood 10-22	Cartref Wasbank Kroonstad Longlands Fernwood 30-42	Champaigne Katspruit Rensburg Willowbrook Estcourt

Internal drainage classes: Binomial soil classification system. Source: (Schoeman et al., 2000).

CLA SS	LIMITATION RATING	DESCRIPTION
C1	None to slight	Favourable for growing a wide range of adapted crops.
C2	Slight	Less favourable than C1 and may limit choice of crops or yields.
C3	Moderate	Water stress, extremes of temperature and/or damage from frost, wind or hail restricts choice of crops and yield potential.
C4	Moderate to severe	Less favourable than C3. Low and unreliable rainfall, extremes in temperature and severe damage from frost or wind restricts regular crop production. Risks in cropping are high.
C5	Severe	Unfavourable (mainly rainfall) for growing crops.
C6	Very severe	Unfavourable for plant production. One or more of the following extremes occur: - Severe aridity - Extremes in temperature

Climate classes. Source: (Schoeman et al., 2000)

CLIMATE CLASS	MOISTURE AVAILABILITY (R)-10.25 PET ·	LENGTH OF MOISTURE SEASON ·(Decadals with R 0.25 PET -1 >0.8)
C1	>34	>17
C2	27-34	13-16
C3	19-26	10-12
C4	12-18	6-9
C5	6-12	<6
C6	<6	

Moisture availability and length of moisture season: October to March. Source: (Schoeman et al., 2000).

CLIMATE CLASS	MOISTURE AVAILABILITY (R)-10.40 PET ·	LENGTH OF MOISTURE SEASON ·(Decadals with R 0.40 PET -1 >0.6)
C1	>34	>15
C2	25-34	13-15
C3	15-24	10-12
C4	10-14	7-9
C5	6-9	<7
C6	<6	

Moisture availability and length of moisture season: April to September. Source: (Schoeman et al., 2000)

CLIMATE CLASS	LENGTH OF TEMPERATURE GROWING SEASON	
	OCTOBER - MARCH (Decadals with Tave >15°C)	APRIL - SEPTEMBER (Decadals with Tave >10°C)
C1	15-18	15-18
C2		
C3	<15	<15
C4		
C5		
C6		

Temperature restriction on the summer and winter growing seasons. Source: (Schoeman et al., 2000)

CLIMATE CLASS	WIND HAZARD		HAIL	FROST HAZARD	
	OCT-MAR (Average windrun, km d-1)	APR-SEP (Average windrun, km d-1)	Hail occurrences per annum	OCT-MAR (Decadals with Tmin <10°C)	APR-SEP (Decadals with Tmin <6°C)
C1	<25	<20	<5	<2	<3
C2	∃ 25	∃ 20	5-6	2-3	3-6
C3			>6	>3	>6
C4					
C5					
C6					

Other climatic restrictions. Source: (Schoeman et al., 2000)

Appendix C: Shows the combination criteria between terrain, soil and climate

TERRAIN / SOIL FACTORS		SOIL FACTORS					SOIL CAPABILITY CLASS
Flooding Hazard	Erosion hazard	Soil depth	Soil texture	Internal drainage	Mechanical limitations	Other soil Properties	
F1, F2	E1; E5	D1	T1	W2, W3	MB0	P1	I
F1-F3	E1,E2; E5	D1,D2	T1,T2	W2, W3	MB0	P2	II
F1-F4	E1-E3; E5	D1-D3	T1-T3	W1-W4	MB0-MB1	P2	III
F1-F4	E1-E4; E5	D1-D4	T1-T3	W1-W4	MB0-MB1	P2	IV
F1-F5	E1-E5	D1-D4	T1-T3	W1-W5	MB0-MB1	P2	V
F1-F5	E1-E6	D1-D4	T1-T3	W1-W5	MB2	P2	VI
F1-F5	E1-E7	D4-D5	T1-T3	W1-W5	MB2-MB4	P2	VII
F1-F5	E1-E8	D4-D5	T1-T3	W1-W5	MB2-MB4	P2	VIII

Terrain and soil classes constituting soil capability classes I to VIII. Source: (Schoeman et al., 2000)

Appendix D: Shows the land capability classes

SOIL CAPABILITY CLASS	CLIMATE CLASS	LAND CAPABILITY CLASS
I	C1	I
I, II	C1,C2	II
I-III	C1-C3	III
1-IV	C1-C4	IV
1-V	C1-C5	V
1-VI	C1-C5	VI
1-VII	C1-C6	VII
1-VIII	C1-C6	VIII

Soil capability and climate classes constituting land capability classes I to VIII. Source: (Schoeman et al., 2000)