A Land Suitability Evaluation for Improved Subsistence Agriculture Using GIS: The Case Study of Nkwezela, KwaZulu-Natal, South Africa.

FAZAL EBRAHIM

Submitted in fulfilment of the academic requirements for the degree of Master of Science in Applied Environmental Sciences

School of Environmental Sciences

University of KwaZulu-Natal, Pietermaritzburg.

Pietermaritzburg
June 2007

Declaration

This work described in this dissertation was carried out in the Discipline of Geography, School of Environmental Sciences, Faculty of Science and Agriculture, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Dr. Fethi Ahmed.

I hereby state that this thesis is the result of my original work and has not been submitted in any form for any degree or diploma at any other university. Where use has been made of the work of others, it is acknowledged in the text.

Fazal Ebrahim

June 2007:_____________.

Supervisor:

Dr. F. Ahmed:_____________________

Abstract

Rural farmers in the Nkwezela Area, with an average family size of 10 people, face a number of problems. The crops that are predominantly cultivated in the area, for subsistence (maize, dry beans, sorghum, potatoes, cabbages and turnips) have very low yields compared to the potential yield of the land. Natural resources in the area are increasingly deteriorating. In addition, arable land has shown remarkable signs of soil erosion that may lead to loss of soil fertility.

This study evaluates the current land suitability for subsistence agriculture in Nkwezela based on climatic, soil, topographic and crop requirement data collected from different sources. The spatial parameters of the land resources were digitally encoded into a GIS database to create thematic layers of the land resources which was then compared to the crop requirement data of the selected crops grown in Nkwezela namely, maize, sorghum, dry beans, potatoes, cabbages and turnips. A GIS was used to overlay the thematic layers of the resources to select areas that satisfied the crop requirements of the selected crops.

The results of the analysis of the land evaluation in the study area showed that the very hot summers, very cold winters together with the high clay content in the soils are the two limiting factors in Nkwezela. The land suitability maps indicate that sorghum is highly suitable in the area with dry beans and maize being relatively suitable. Cabbages are the least the least adapted crop with potatoes and turnips being not suitable due to the high temperatures during the growing season and the very cold winters.

In conclusion Nkwezela is in a high rainfall area that is suitable for subsistence agriculture where warm season crops like dry beans, maize and sorghum are used for daily consumption by the community and can be cultivated in a sustainable manner. In addition the correct farming methods, procedures, liming and fertiliser requirements must be implemented, adhered to and maintained in order to improve crop yields in a sustainable manner and to encourage subsistence agriculture by the community.

Acknowledgement

I am very appreciative of my friend and supervisor Dr. F. Ahmed, who motivated and inspired me to undertake this study using GIS to assist rural farmers to implement better and sustainable agricultural practices and hence improve quality of life.

I must also thank my very close friends, Riyad Ismail, Michael Gebraselasie and Khavin Sivananden whose motivation and support was a huge inspiration to me.

Thanks Mr Hannes DeVilliers and the Farming Systems Research staff for their help and support

Thanks to Rob Moolenschot of Starke Ayres for his technical help.

Many thanks to the Department of Agriculture and Environmental Affairs, Natural Resources Section for allowing me to carry out the research in the Nkwezela area.

Thanks to Mr. Richard Kunz for providing me with the climatic data. Mr. Kunz, the custodian of the climatic data originally created by the Computing Centre for Water Research (CCWR) at the University of KwaZulu-Natal, Pietermaritzburg Campus).

Thanks to the staff members of the Geography Department of the University of KwaZulu-Natal, PMB campus, for their unlimited support and in particular Professor B. Maharaj for his support and encouragement during the course of my studies.

I also owe the deepest appreciation to Sibusiso Madiba for his assistance with the soil survey.

Thanks to Dr. Shabnum Randeree for proof reading my thesis and to my wife for her support and encouragement.

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List of Acronyms

A-PAN	Annual Evaporation
AEZ	Agricultural Ecological Zone
BEEH	Bioresource Engineering and Environmental Hydrology
BR	Bioresource
BRG	Bioresource Group
BRU	Bioresource Unit
CCWR	Computing Centre for Water Research
DAEA	Department of Agriculture and Environmental Affairs
DC	District Council
DEM	Digital Elevation Model
DOT	Department of Transport
DTLGA	Department of Traditional and Local Government Affairs
DWAF	Department of Water Affairs and Forestry
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organisation
FSR	Farming Systems Research
GIMS	Geographical Information Management Systems
GIS	Geographical Information Systems
GPS	Global Positioning System
ICFR	Institute for Commercial Forestry Research
KZN	KwaZulu-Natal
L0	Longitude of nought
LUT	Land Utilization Type
MAP	Mean Annual Precipitation
MAT	Mean Annual Temperature
NRS	Natural Resources Section
RHFA	Reasonably Homogeneous Areas
SARD	Sustainable Agriculture and Rural Development
STATSSA	Statistics South Africa
USDA	United Nations Department of Agriculture
WRC	Water Research Commission

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Subsistence farmers contribute to the local economy in rural areas, where large numbers of the subsistence farmers live off the land. In South Africa, a large proportion of the population in KwaZulu Natal live in the rural areas (Erskine, 1998).

The rural population are poor and mostly depend on subsistence farming to supplement their food requirements. Incorrect farming methods and a lack of technical know-how lead to low yields that consequently do not satisfy the growing demand. Incorrect farming practices will result in barren lands. One of the major problems caused by the subsistence farmers is the endangerment of the natural habitat. Sustainability will encourage subsistence farmers to use the natural resources while preserving the natural habitat for future generations (Falconer, *et al.*, 2003).

The FAO in 1976 developed the "*Framework for Land Evaluation*", a land evaluation methodology in response to the rapidly increasing world population and the likely need for increased agricultural production and optimum use of the world's resources. The fundamental principle of this methodology is that for sustained agricultural production, the edaphic and climatic conditions of an area should be matched to specific crop requirements. This system has been adapted to local conditions by many countries to delineate areas of land as agro-ecological zones at different levels (FAO, 1996).

An agro-ecological zone in KwaZulu-Natal (KZN) is referred to as a "*Bioresource Classification*" (Camp, 1999). This is used as a basis for decisions on land use planning through the detailed matching of agricultural production and other forms of land use with the natural resources. The Bioresource Classification comprises of three levels of detail which depends on the criteria used to delineate homogeneous areas: vegetation, climate and soil. This classification will be discussed in section 2.4.3, Camp (1999) which classifies Nkwezela into two Bioresource Groups and into seven Bioresource Units classes. This classification is discussed in detail in section 4.1.5.

This study attempts to classify the suitability of Nkwezela into more detailed and specific land suitability classes for rural sustainable agriculture by selecting representative crops. The FAO *Framework for Land Evaluation* (FAO, 1976) land evaluation methodology has been adapted for this study.

The rural communities in South Africa have been dependent on subsistence agriculture for centuries and are still dependent on subsistence agriculture to supplement their earnings in order to survive. Nkwezela which is also representative of the impoverished rural areas in KZN was chosen as the study area because it is an impoverished area with an unemployment rate of 68.6%. Historically the existing land conditions in the area and the farmers' lack of correct agricultural practices showed that the land use has deteriorated the agricultural potential of the area in the past. In 2001 the Farming Systems Research Section and the Natural Resources Section of the Department of Agriculture and Environmental met with the communities and initiated programmes to assist them with correct agricultural practices and to educate them to improve farming methods in a sustainable manner that will preserve the natural resources and to improve crop yields in a sustainable manner. The average annual household income for the area is R5 935.00, which is dependant on subsistence agriculture to support their families and to supplement the earnings (Strategy & Tactics, 2003). Other mitigating factors include the topography, favourable climatic conditions and the unawareness of suitable agricultural practices and technical expertise. These factors and conditions are generally similar in all the rural communities of KwaZulu-Natal. In South Africa where 46% of national population live in rural areas, KwaZulu-Natal has the largest rural population of 57%. (Strategy & Tactics, 2003).

1.2 Historical Background

Agriculture was the first phase of South Africa's economic development. Through colonialism, agriculture moved from subsistence to commercial agriculture. The discovery of diamonds and gold in the nineteenth century created major economic development. Gold in particular played an important role in shaping the economic future in South Africa. In the process the agricultural potential of the country was neglected and prime agricultural land in the former homelands such as the Transkei were not exploited. Major foreign investment was made in the country. This led to economic boom with the production of mining equipment and a wide range of consumer goods until 1970 (Coetzee, and Oliver, 1990).

The apartheid policies of the previous government that controlled the movement of blacks were seen as an important and necessary method to develop the economy of the country. Blacks were subsistence farmers and the government used various laws and acts to force them into cheap waged labour for the mining industry. This forced the black males to work in the developed urban areas and cities. Although they worked in the cities and urban areas during their term of employment, they could not own property. The mineworkers were housed in hostels near the mines. Racial segregation was implemented with the introduction of the Group Areas Act (Dewar, 1996).

During this time the families in the rural agricultural areas survived on subsistence farming. In the rural areas laws such as the hut tax and poll tax forced people to give up excess land that they owned. Poor farming methods and natural disasters made it difficult to survive. Basically the rural population could not and still cannot afford mechanisation, fertilisers and water during droughts (Dewar, 1996).

1.3 Why Rural Subsistence Agriculture

A survey conducted by De Villiers and Letti, 2001 showed that maize and potatoes are the most commonly grown crops for consumption in rural areas in KwaZulu-Natal. In Nkwezela maize and dry beans are cultivated. The average price of maize is R95.00 for a 50kg bag and R129.00 for an 80kg bag. According to a survey conducted by the Farming Systems Research Section, (De Villiers and Letti, 2001) 18% of the households in Nkwezela depend solely on pensions. Approximately 43% indicated that a pension is the only source of income and only 10% indicated agriculture as a source of income. Generally the incomes of rural people are below the breadline. The rural subsistence farmers face the following problems:

- Low crop production.
- Farmers have to seek supplementary sources of income.
- Farm abandonment due to land degradation.

- Generally low quality of life.

These problems are generally brought about by one or a combination of the following:

- Lack of technical know-how.
- Use of inappropriate agricultural practices/implements.
- Cultivation of the wrong crop on unsuitable lands
- General land degradation.

According to the 2001 Census, KZN has the largest population in comparison to the other provinces in the country. The 1996 Census shows that KZN has a population of 8 417 021, which was approximately 20. 7%. Although the national average indicated that 46% of the population lived in rural areas, approximately 57% of KZN's population for 1996 lived in rural areas. (Statistics SA, 2001).

Approximately 54.4% of the households in the study area are headed by women and therefore this means that female-headed households are traditionally more disadvantaged and vulnerable. The 1996 Census showed that the unemployment rate was 62. 7% which was nearly double the national average unemployment of 33, and 9% respectively.

The province also had a higher proportion of females (53.1%) of the population partially as a result of labour migration to the other provinces in particular to Gauteng and Free State which is illustrated in Table 1.1 (Strategy Tactics, 2003).

Table 1.1: KwaZulu-Natal's population by race compared with national distribution

Race	South Africa (%)	KwaZulu-Natal
African	76.7	81.7
Coloured	8.9	1.4
Indian	2.6	9.4
White	10.9	6.6
Other	0.9	0.8

Land has to be managed in a sustainable manner in order to achieve a high quality of life and sustainability will encourage subsistence farmers to use the natural resources while preserving the natural habitat for future generations.

Rural land is characterised by agriculture and farming, low population density, low concentration of houses in scattered settlements, rural lifestyles and values with large open or undeveloped areas (Carter, 1999). In South Africa, the majority of the black population live in the rural areas, where agriculture is the main economic activity. Historically the post apartheid government controlled the movement of the blacks from the rural to the urban areas with various pass laws. In particular, the migrant mine labour system was used to control the labour force from the rural areas to urban areas with the implementation of various acts such as the hut tax and influx controls. Subsistence agriculture can be undertaken by a community or by an individual household to sustain themselves and their incomes.

A rural area characterised by the role it performs and the relationships that occurs between the interactions of its inhabitants. These two roles are closely interlinked to the function of rural areas and a community is formed. Although not all the households farm their lands, agriculture is a common activity practiced by in the rural areas. In the case of the South Africa cultural ties, common languages and tribal areas formed the basis of rural areas. This pattern also existed in the former residential for the different race groups that was enforced by the Group Areas Act of the previous government.

This investigation focuses on small scale farming, and in particular rural subsistence farming in order to understand how the small-scale farming by communities and the environment in which it operates is managed in a sustainable manner. To identify the agricultural constraints faced and to research potential solutions which can be implemented within the socio-economic environment and to increase the overall productivity of small scale farms by improving food security and farm income without reducing the potential of land for future generations.

1.4 Aim and Objectives

The main overall aim of this study is to use GIS in Nkwezela and precisely assess the suitability of land in the study area for growing selected crops and attempt to improve production of subsistence farmers, improve the quality of life and promote sustainable resource utilization.

The specific objectives of the study are:

1. To compile an inventory of the basic land resources which influence the production capacity of sustainable agriculture based on a land resources survey.

2. To map out the natural resources that are relevant to sustainable agriculture based on the land resources survey.

3. To determine the land use requirements of sustainable agriculture for soil, climate and topography and to identify the limits of the requirements on which sustainable agriculture is marginal.

4. To evaluate the suitability of the study area for sustainable agriculture of maize, dry beans, sorghum, potatoes, cabbages and turnips by comparing the land qualities with land use requirements.

Chapter two reviews the relevant literature including the land evaluation and land use planning approaches, methods and the role of GIS in Agriculture. Chapter three describes the study area in terms of location, climate, topography and demographics.
Chapter four discusses the materials and methodology used in this study and focuses on the data collection, data used and procedures. Chapter five discusses the results and discussions derived from the analysis of the data discussed in chapter four which results in the conclusions and recommendations detailed in chapter six.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

To improve the lives of the subsistence farmers in a sustainable way by maximizing the economic and environmental benefits of the land and to avoid or minimise the adverse effects on available limited land resources in rural areas, a comprehensive assessment of the land resources and farming methods and practices in relation to their effect on use of land is required (FAO, 1983).

Land evaluation is defined as a "process of assessment of land performance when used for specified purposes" (FAO, 1983), which is a process of predicting the performance of present and alternative land use systems representing different combinations of land units with land use types taking into account the similarities and differences between land units identified during land resource studies (Beek, 1978). According to McRae and Burnham (1981) land evaluation deals with opportunities and limitations of land resources and attempts to translate potential information accumulated about land into a form usable by land users and decision makers.

A particular use of land is dependent not on a single parameter of natural resource attribute, but on the interaction of a number or parameters of various attributes (Stewart, 1968). Land evaluation assesses the limiting resources parameters for the specified use. For agricultural use the most limiting resources are soil, climate, topography, infrastructure and land ownership (Stewart, 1968). A land evaluation based on the absence or presence of the observable or measurable land resources is not reliable for the fact that interaction between these land characteristics is more limiting (Beek, 1978). The land parameter based on the interaction of land characteristics is referred to as *land quality* and *land evaluation* is preferably based on this parameter. The concepts of *land quality* and *land characteristics* will be discussed in section 2.6.4

Although there is no single universal model for evaluating land suitability or standard criteria and critical values for crop production, which will be universally applicable, there is a systematic way of evaluating land suitability as set out in the *FAO's Framework for Land Evaluation* (FAO, 1976). The FAO *Guidelines for Land Evaluation* FAO (1983) provides the sequence of activities and procedures that can be summarized by the following three phases (Sys, 1985).

Phase I: Measurement and estimation of necessary land characteristics/qualities; having influence on the production capacity of the considered land use type. In the case of agricultural land use, the characteristics used in evaluation are: climate, topography, wetness, physical soil conditions, natural fertility, salinity and alkinity (Sys, 1985) points out that some of these characteristics are used as is while others are recalculated based on weighting factor on arbitrary basis.

Phase II: Determination of land use requirements; in this stage, the climatic topographic, soil and socio-economic requirements of the land are studied. This is done separately for each land characteristic. The data on land use requirement can be presented in different ways. In most cases evaluation of agricultural land, the requirements are prepared in tables for different crops (Sys, 1985).

Phase III: Matching land characteristics/qualities with land use requirements; this is the final stage of land evaluation in which land characteristics/qualities are compared with land use requirements. There are different methods used for comparisons. The most common method used was developed by the FAO (1976), which expresses the suitability of land in different degrees based on limitations of land characteristics/qualities. The four levels of classification are recognised: land suitability orders, classes, sub-classes and units (Dent and Young, 1981). This classification structure will be discussed in section 2.5.1.

2.2 The Need for Land Evaluation

The FAO *Framework for Land Evaluation* (FAO, 1976) states that decisions on land use have always been part of the evolution of human society. The *Framework* further argues that in the past, land use changes often came about by gradual evolutions as a result of many separate decisions taken by individuals. In the past few decades, the need for rational land use has become greater, because of rapid population growth and urban expansion making land a scarce resource (FAO, 1983). This calls for a thorough assessment and evaluation of land resources. Beek (1978) argues that increase in population and people's demand for land with different purposes has put areas, which were once considered marginal, for different land uses. The utilization of marginal areas is, however expensive, physically difficult and could be hazardous with regard to economic success and to the fragile environment (Purnell, 1986).

Scientists have been interested in the study of land resources and modifications of the methods of land evaluation (Beek, 1978). Purnell (1986) stated that land evaluation provides a systematic way of looking at various options and predicting the results of alternative courses of action. The inventory and survey of natural resources are essential parts of land evaluation. This helps land use planners to avoid costly mistakes and to improve investment efficiency (Camp, 1999; Young, 1998). Valid techniques of resource survey and land evaluation have helped to translate environmental data into land use potential (Young, 1998). Young (1998) argues that land evaluation was developed in response to the inadequacy of soil survey to provide managers and land use planners with information on the economic and physical suitability of an area. Land evaluation is an essential perspective for all-rational land use planning (Purnell, 1986). It forms the link between basic resource surveys and land use planning (FAO, 1983) and enables land use planners to make decisions on land use.

2.3 Land Evaluation and Land Use Planning

According to Beek (1978), there is no significant difference between land evaluation and land use planning because whoever is involved in land suitability is also involved in land use planning. Land evaluation helps land use planners to choose optimum land for each land resource unit based on a land use survey. The FAO *Guidelines for Land Evaluation* (FAO, 1983) states that land evaluation forms the link between land resource surveys and land use planning. A land use planner makes decisions based on the results of land evaluation. It provides a systematic way of analysing various options and to predict the results of alternative courses of action. Therefore, land evaluation is an important perspective for rational land use planning (Purnell, 1986). It also provides important information to the different stages of land use planning and it usually comes up with proposed changes and formulations on which land use planning can be made. Land use planning is the concluding stage that involves detailed analysis of preferred uses, their implementation and monitoring (FAO, 1976).

2.4 A Review of Land Classification Studies

Among the many different approaches and methods of land classification, the FAO *land suitability* classification and the USDA *land capability* classification methods are mainly used. These methods will be discussed in detail in section 2.5.2. The following sub-sections will focus on the different land classification studies that are conducted at global, regional and local scales.

2.4.1 The FAO Agro-Ecological Zoning

In 1976 the FAO initiated a study of potential land use by agro-ecological zones to achieve an initial estimate of the production potential of the world's resources because of the increasing world population and the probable need for increased agricultural production and optimum use of the world's resources. The agro-ecological zoning was based on the FAO *Framework for Land Evaluation* developed by the FAO in 1976.

This approach recommends that crop requirements should be matched to edaphic and climatic conditions for sustained agricultural production. The methodology is based in the six basic principles that are outlined in section 2.5.2.2. The overall methodology used to classify the world into agro-ecological zones was done in accordance with the agreed land evaluation procedures developed in the FAO *Framework for Land Evaluation* (FAO, 1976). This comprises of a series of activities that are outlined in section 2.5.2.2.

Although the FAO agro-ecological zones project was a land evaluation exercise which was developed for continental study of land potential, the methodology used in the assessment of land resources is the basis on which most large and small scale land classification studies depend. The FAO has been assisting developing countries in adapting the methodology to local conditions (FAO, 1996). The level of zoning can differ depending on the scale of the study. An example of this is an agro-ecological study in Kenya, which distinguishes between *agro-ecological cells*, which are smaller units of the AEZ's and basic units for land evaluation and data processing (FAO, 1996).

Later developments by the FAO has resulted in the development of computerized systems of land resources appraisal systems such as GIS where layers of spatial data on climate, soils, landform and other physical and socio-economic factors can be combined by the overlay process and matched to crop requirements (FAO, 1993b; FAO, 1996).

2.4.2 Agro-Ecological Zones in Southern Africa

This classification was carried out partially in South Africa (Scotney, 1987). An agro-ecological zone was defined as a “discrete area of land delineated at a 1:250 000 scale in which the environmental conditions such as soils, slope, landforms and climate are suitably similar to allow uniform recommendations of land use in which an adaptive agricultural research program can be carried out, and to assist land use planners to make correct decisions”. The following land characteristics were used as important criteria in the mapping of agro-ecological zones.

Rainfall including mean annual rainfall, median rainfall, mean monthly rainfall, likelihood of 80% rainfall and intensity of rainfall, the of growing period, pentades and decades analysis.

Temperature – monthly means of daily maximum and minimum temperatures, mean first and last dates of frost and heat units.

Soils – a soil association map showing dominant soil types, average profile texture, average effective depths, specific profile morphology, E-horizons and gleyed horizons (MacVicar, 1977).

Vegetation – the vegetation was not considered as an important criterion but was considered as an important feature of indicator significance (Camp, 1999).

Others - A-pan evaporation, frequency and intensity of hail, radiation and hours of sunshine, speed and direction of wind.

An AEZ can be described as a Reasonably Homogeneous Farming Area (RHFA’s) for many areas in the country since 1973 (Scotney, 1987). A RHFA is an unit of land that has a fair degree of uniformity in respect of possible agricultural pursuits, yield horizons and production techniques to be applied (Scotney, 1987), are delineated based on "land types", which are discussed under 2.6.3. They may include one or more land types. Special emphasis was given to micro-climates, soil pattern, adapted crops, yield potential and vulnerability to water and wind erosion in mapping RHFA's (Scotney, 1987).

2.4.3 Land Classification Studies in the KwaZulu-Natal (KZN) Province

In KZN many land classification studies have been conducted at a provincial level, which were mainly ecological and agro-ecological classification. These include the following:

a) The agro-ecological survey of Natal by Pentz (1945), classified KZN into three farming regions according to their homogeneity in soil, climate, vegetation, topography, crop, pasture, livestock and timber potential suitability for each farming region that was based on the requirements of each land utilization type.

b) Phillips (1973) classified the KZN into Bioclimatic groups based on a drainage basin of the Tugela River (Tugela Basin), which flows from the Drakesnberg Mountains to the Indian Ocean. This study was regarded as a valuable approach in land use planning except where there is a lack of information on soil and climatic data (Camp, 1999).

c) The Bioresource methodology developed by Camp (1999), to define agro-ecological zone for KZN, was initiated in 1998, introduced three levels of classification. A BRU is a demarcated area in which the environmental conditions such as soil, vegetation, climate and to a lesser degree, terrain form, are similar to allow uniform recommendations of land use and farm practices to be made, to assess the magnitude of crop yields that can be achieved, to provide a framework in which an adaptive research programme can be carried out, to enable land use makers to make correct decisions. This classification system comprises of 590 BRU's. These classification levels were based on homogeneity of the land units in terms of their natural resources, which are necessary to achieve optimal agricultural production in an environmentally sustainable manner with the other forms of land use. The BR classification differentiates between three levels of homogeneity in natural resources.

The first classification is the Bioresource Unit (BRU); this is a unit in which the environmental factors such as climate, soil, vegetation, and terrain are similar. The second classification is the BRG, this is a composition of the BRUs that have been grouped into ecological units characterised by the climate and vegetation. Thirdly, the soil form can vary in a BRG and these differences are defined at the ecotope level. The Bioresource groups were combined according to their homogeneity in terms of vegetation types to create a broader level of homogeneity, which are known as Bioresource Groups (BRG). KwaZulu-Natal is classified into a total of 23 Bioresource Groups (Camp, 1999).

A land potential classification for KZN has been undertaken by Guy and Smith (1995) of the KZN DAEA in Pietermaritzburg. The classification is a combination of soil and climatic land capability classifications using the framework of the BRU. This land potential classification, classifies KZN into eight climate potential classes, which later updated by Guy and Smith (1998). The ratio of the average rainfall, average annual precipitation and to Class APAN measurements, average mean annual rainfall and the mean June, September and annual temperatures was used. The combination of these indices provides a good indication of the climatic agricultural potential and limitations. The land potential classification for KZN conducted by Guy and Smith (1995) is a combination of soil and climatic land capability classifications that used the BRU framework.

This classification is broader in comparison to the BRU, and therefore does not provide a great deal of information on land resources as the BRU classification. It does however, use the BRU information to classify areas into potential capability rather than simple AEZ's. The potential capability classes can be used as a guide for field workers at a local scale and for policy makers at a regional scale.

2.5 Approaches and Methods of Land Evaluation

2.5.1 Approaches to Land Evaluation

Most land evaluation systems have interpretative classifications, which can originate an evaluation in different categories, by each category corresponding to a certain level of detail and at each level the interpretation differs in precision, objectives requirements and assumptions (Sys, 1985).

Beek (1978) identified three approaches to land evaluation based on whether the evaluation is for a general or specific purpose, physical or integral, and qualitative or quantitative. The FAO *Framework for Land Evaluation* also differentiates between current and potential land suitability evaluations (FAO, 1976).

General-purpose land evaluation is a standardized procedure used for land to evaluate the capability that supports a generally defined land use. The suitability classification depends on the links between broadly defined kinds of land use and qualities of the physical environment expressed in terms of limitations or hazards (Beek, 1978). This land evaluation system is easy to understand because it relates to physical land variables and land use requirements only. It is also relatively unaffected by social, economic and technological changes. The disadvantage of this approach is that it is only directed to the most common land uses which are of a specific importance in the socio-economic development of developing countries, without taking into consideration the technological variability between countries and the conflicting demand for land between different land uses (Beek, 1978).

The *specific purpose* of land evaluation, evaluates land suitability for specific purposes based on relevant physical and socio-economic land suitability for specific purposes based on relevant physical and socio-economic data, that are not identified (Beek, 1978).

Physical land evaluation deals with the physical ecological aspects of land, and is used within a general socio-economic context (Masahreh *et al*, 2000). This approach identifies and compares potential land use alternatives, and therefore is preceded by the recognition of the need for some change in the use of land (FAO, 1976).

Physical land evaluation commences with the basic survey of soil, water, climate and other biophysical resources characteristics, Often it has been applied to land use on particular land types and does not provide adequate information to establish land use policies and guidelines (Masahreh *et al*, 2000).

Integral land evaluation is a combination of *physical* land evaluation and socio-economic analysis (Beek, 1978). The *integral* land evaluation deals with the determining the critical importance of land for specific uses in order to meet basic social goals such as economically acceptable production levels and needs for goods and services (Masahreh *et al*., 2000).

Qualitative or *quantitative* are other approaches of land evaluation. *Qualitative* deals with the evaluation of land suitability for alternative purposes that are expressed as highly, moderately or marginally suitable or not suitable for a particular use (Dent and Young, 1981) without specific estimation of inputs and outputs such as production costs, yields and profits (FAO, 1983). *Quantitative* land evaluation distinguishes between suitability classes that are based on common numerical terms, which allow objective comparisons between classes that relate to different kinds of land use (Beek, 1978). It can also be categorised into physical and economic evaluations according to whether results are expressed in yields or in economic terms (FAO, 1983). The degree of quantification in which the suitability criteria are expressed depends on the purpose and detail of land evaluation (Beek, 1978). Furthermore, criteria such as yield can be more easily expressed in quantitative terms.

Current land evaluation deals with the present condition of land based on direct observations (Sys, 1985) and could refer to the evaluation of land as to its present suitability for the intended use, either with existing or improved management practices or for another different land use without any improvement to correct its restrictions (FAO, 1976). *Potential* land suitability reflects future situations, after the land has been changed by major land improvement practices (Sys, 1985).

2.5.2 Methods of Land Evaluation

Land can be classified in a number of different ways depending on the objective of classification (Ivy, 1981). The FAO *land suitability* and USDA *land capability* classification methods are the most widely used. The main objective of land evaluation is to systematically arrange and group different kinds of land to show their intensive safe use and to indicate their management requirements and permanent hazards attached to the use of land (Manson *et al*., 1995).

Suitability and *capability* are often regarded as being synonymous (McRae and Burham, 1981). Suitability deals with a single clearly defined, reasonably homogeneous purpose, while a capability classification is applied to a broader use like agriculture or urban development (McRae and Burham, 1981). Suitability assessment focuses on looking for sites that have positive features associated with successful production or use and capability is unclear, and is often defined in terms of negative limitations which prevent some or all of the individual activities being considered.

2.5.2.1 The USDA System of Land Capability Classification

The USDA system was developed in the USA during the 1930s and was adopted in other places after 1960 (Davidson, 1992), This classification involves an evaluation of the degree of limitation posed by permanent and semi-permanent attributes of land to one or more land uses (Davidson, 1992).

Essentially, it is a negative approach whereby as the degree of constraints increases, land is allocated to a lower class. A map is final product of land capability classification that shows which areas of land are classified into capability classes ranging from I (best) to VIII (worst) (Dent and Young, 1981). Each class of land has properties or capability for use in a prescribed number of ways or with special management techniques. Therefore, class I land can be used for arable purposes without soil conservation measures and class II to IV requires increasing costly conservation practices and classes VI-VIII should not be used for arable use at all (Dent and Young, 1981). This system of classification is based on the following principles:

a) The criteria used in assessing land units are the physical land properties made available after a soil survey.
b) The seriousness of a limitation is a function of the severity of which crop growth is inhibited.
c) The capability of a land unit for crop growth is better when a wide range of crops can be cultivated on it than on another land unit (Sys, 1985).

This classification structure provides three major categories (Sys, 1985):

a) Classes

b) Sub-classes

c) Units

The land *capability class* is the broader category that has the same degree of limitation with a total of eight classes defined I to VIII (Davidson, 1992). Land *capability sub-classes* are based on information on the type of limitations encountered within the classes (Davidson, 1992) like erosion hazard, rooting restrictions and low fertility. Lower case letters following the Roman numbers indicates the limitations. For example, land capability subclass IIe indicates an erosion hazard and IIw indicate a problem of excess water (Dent and Young, 1981).

A land *capability unit* is a subdivision of a land capability *sub-class* based on potential productivity (Sys, 1985). All soils within a subclass having a comparable potential productivity and similar conservation, treatment and management requirement belong to the same capability unit. The yield range of crops within a unit should not be greater than 25% (Davidson, 1992). Land *capability units* in Arabic numbers (Dent and Young, 1981).

Land evaluation is a limitation method. Comment needs to be made about the nature of limitations for the fact that some limitations can be easily corrected. On one hand while a farmer can apply fertilizer limitations on his land, land characteristics such as soil depth, soil texture and slope are relatively permanent and more difficult to improve. The USDA land capability classification structure uses permanent limitations for classifying the broader level of classification, that is, the land capability class by the use of land capability subclass. The third level of classification provides management practices required to correct the less permanent limitations.

The capability classification attempts to provide a single scale grading of land from capability classification attempts to provide a single scale grading of land from the best to the worst; it assumes arable use is the most desirable; and it is strongly biased towards considerations of soil conservation; it is also biased on negative land features and it only takes economics into consideration as a background (Dent and Young, 1981). These points are mentioned as limitations of the system. The system also has many advantages. The system is versatile, simple and easy to present and it can be adapted to any physical environment and to any level of farming technology (Dent and Young, 1981).

2.5.2.2 The FAO System of Land Evaluation

The FAO *Framework for Land Evaluation* (FAO, 1976) differentiates between two levels of detail of land use namely major land use types and land utilization types (Beek, 1978). This concept is one of the basic principles of the FAO *Framework for Land Evaluation* and will be discussed in section 2.6.5.

The FAO *Framework for Land Evaluation* (FAO, 1976) defines land suitability evaluation as "an evaluation of fitness of a given type of land for a defined land use". McRae and Burnham (1981) describe suitability evaluation as a practice of land evaluation for a single clearly defined, reasonably homogeneous purpose. In land suitability evaluation the physical and socio-economic aspects of a given area of land are compared with the requirements of specific land use and differences in degrees of suitability are determined by the relationships actual or anticipated between benefits and required inputs associated with the use of land in question (Sys, 1985). Sustainability, which is a process of progress that meets the needs and aspirations of present generation without comprising the ability of future generations to meet their needs, is the main focus of the FAO method of the land evaluation. As stated by the FAO *Framework Land Evaluation* (FAO, 1976), there might be a land use that may appear highly profitable in the short term, but may likely lead to some hazardous impacts such as soil erosion, pasture degradation, deforestation, environmental pollution and depletion of resources in the future. These impacts usually overweigh the short-term profitability and cause the land to be classified as unsuitable for land use. It is also advised not to misunderstand the meaning of sustainable use of land as preserving land as it is. The use of a given land is always concerned with some form of changing the status of land, which cannot be avoided. The probable consequences on the environment should be assessed and the results need to be taken into consideration when evaluating a land for any proposed form of land use. (FAO, 1976). This means that a given land is said to be suitable for specific use if it can support the land use on a sustained basis, and if it yields benefits that justify the inputs (FAO, 1976).

The FAO land suitability evaluation system is based on six principles (FAO, 1976) namely:

a) Land suitability is assessed and classified with respect to specified kinds of land use.
b) Evaluation requires comparison of inputs and outputs.
c) Requires a multidisciplinary approach.
d) The evaluation is made with careful reference to the physical, economic and social context of the study area.
e) Suitability refers to the use on a sustainable basis.
f) Different kinds of land use are compared.

Suitability is classified as four levels: suitability order, classes, subclasses and units.

1) *Suitability order* distinguishes between lands, which are suitable with an upper case "S", and "N" is used to denote not suitable.
2) *Suitability classes* indicate degrees of suitability and comprises of three classes: "highly suitable" (S1), "moderately suitable" (S2) and "marginally suitable" (S3). Within the "not suitable" order there are two classes, "N1" indicating currently not suitable and "N2" indicating Permanently not suitable areas.
3) *Suitability subclasses* indicate different kinds of limitations such as moisture limitations, erosion risks and drainage limitations. Subclasses are denoted by letter symbols like S2d, which indicate drainage limitations.

    3) Suitability units represent divisions of sub-classes on the basis of differences in detailed aspects of production characteristics or management requirements. Using tile drains or open ditches can rectify a land that has a drainage limitation. Depending on which management requirement needs to be practiced, the land suitability units can either be S2d-1 or S2d-2, where the letter "d" denotes a drainage limitation, and numbers 1 and 2 indicates the management method to be applied.

The FAO land suitability evaluation procedure involves a sequence of activities that can be summarized as follows:

- Initial consultations between planning authorities and the organization, which will carry out the evaluation.
- Planning the evaluation.
- Identification of land utilization types.
- Selection of relevant land qualities for evaluation.
- Description of land mapping units.
- Assessment of land use requirements.
- Comparisons of land qualities with land use requirements.
- Presentation of results.

Although several methods can be used within the FAO land suitability evaluation system, it is essential to compare land characteristics with crop requirements (Sys, 1985). Similarly, the types and number of criteria given for defining land suitability classes are not fixed and there is complete freedom of choice in the number and type of criteria (Sys, 1985). Also, a summary of the activities in the FAO land evaluation procedure into three phases has been done (Sys, 1985).

The FAO land suitability focus on looking for sites that have positive features associated with successful production and a suitability appraisal of a comprehensive list of crops with specific guidance on appropriate management practices. This has great advantages over a general capability classification, where a low rated land might conceal high suitability for a single crop with relatively unusual requirements (McRae and Burnham, 1981).

2.6 Basic Concepts of Land Evaluation

2.6.1 Land

Land as a basic source of the natural resources plays a vital role in the economic and social component of people and of any community. The struggle over the use land has been part of human life from the beginning of mankind (Rhind and Ray, 1980), which also increases as the population increases (McRae and Burnham, 1981). This requires rational planning and state involvement to ensure proper use and distribution of land. This can only be possible if land is appropriately defined. The concept of land is and has been a constant subject of discussion and can be defined in a number of ways (Davidson, 1992).

According to the FAO *Framework for Land Evaluation* (FAO, 1976), land is defined as "an area of the earth's surface, a characteristic which comprises of all reasonably stable, or predictability cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, hydrology, plant and animal populations and the results of past and present human activities, to the extent that these attributes exert a significant influence on the present and future uses of land by man". This gives a clear guidance on how land use can be read taking into consideration all environmental variables that influence land use. Land can also be analysed as a consumer commodity, location or as a form of capital (Davidson, 1992).

2.6.2 Land Use

Land use is defined as "any kind of permanent or recurring human involvement to satisfy human needs". It involves the application of human control of natural ecosystems in a relatively systematic manner to derive benefits from it and is a continuous field of tension created between available resources and human needs and acted upon by human efforts (Sys, 1985).

Land use is very significant, because while we all need land to live on, the use of any site of land does not only affect those who use the land but also affects those who live on or use the adjacent and surrounding areas (Rhind and Ray, 1980).

The use of the actual land cannot be seen, but the physical characteristics of the use can be seen. It is easy to identify an urban land use from an agricultural or industrial use, which can also be identified from other land use categories. In the case of forestland, there is little or no difference between forestland used timber production or recreational use. Therefore, it is generally common to distinguish between land use and land cover, as land cover designates the visible indication of land use (Campbell, 1983).

2.6.3 Land Mapping Unit

A land resource survey such as a soil survey attempts to define homogeneous units of land that behave differently or will respond differently to a specific management (Dent and Young, 1981). Defining a given area into homogeneous varies depending on the purpose of the survey. For agricultural land use these units can be (FAO, 1983), soils and land systems (Dent and Young, 1981).

The FAO Guidelines for Land Evaluation for Subsistence Agriculture (FAO, 1976) defines land evaluation as 'the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to objectives of the evaluation.

Conceptually, land evaluation requires corresponding of ecological and management requirements of relevant kinds of land use with land qualities, whilst taking local economic and social conditions into account. Land evaluation provides practical answers to such questions as "What other uses of land are physically possible and economically and socially relevant?" "What inputs are necessary to bring about a desired level of production?" and "What are the current land uses and what are the consequences if current management practices stay the same?"

Depending on the questions that need to be answered, land evaluation can be carried out at different scales (e.g. local, national, regional and even global) and with different levels of quantification (i.e. qualitative opposed to quantitative). Studies at the national scale may be useful in setting national priorities for development, whereas those targeted at the local level are useful for selecting specific projects for implementation. Land evaluation is applicable both in areas where there is strong competition between existing land uses in highly populated zones as well as in zones that are largely undeveloped.

Land evaluation is often carried out in response to recognition of a need for changes in the way in which land is currently being used. The information and recommendations from land evaluation represent only one of multiple inputs into the land use planning process, which often follows land evaluation. In turn, the land use planning process can serve to screen preliminary land use options that should be considered for land evaluation. The two processes are therefore interlinked.

Land evaluation should be distinguished from land valuation (i.e. estimation of the monetary or "market" value of land for the purpose for which it is currently used, e.g. farming). It should also be distinguished from 'land capability' as used, for example, within the context of the Canada Land Inventory or the USDA land classification system. For these systems, capability is based primarily on an assessment of soil conditions to support common cultivated crops and pasture plants. The FAO land-evaluation approach, on the other hand, additionally takes into account specific crops and aspects related to land-management and socio-economic setting. The approach has been applied extensively in projects backstopped by FAO in various countries in different parts of the world for over thirty years.

2.6.4 Land Evaluation Principles

The first FAO publication setting out the principles of land evaluation as well as the broad methodological approach for identifying a range of relevant agricultural land-use options for a given area appeared in 1976, "A framework for land evaluation" referred to hereafter as the “1976 Framework” (FAO, 1976). Subsequent FAO guidelines on land evaluation concerned detailed application of the 1976 Framework to several specific major land uses, namely, rain-fed agriculture, irrigated agriculture, livestock and forestry production (FAO, 1983; 1984; 1985; 1991 respectively).

The automated land evaluation tools and databases that are based on the original 1976 Framework principles were published in 1993 (FAO/UNEP, 1993). A technical guideline on such approaches appeared three years later (FAO, 1996).

Framework Principles

The principles of the 1976 Framework specify that land should be assessed with respect to its suitability for a range of alternate land uses based on several criteria, in particular:

- The requirements of specific land uses
- A comparative multi-disciplinary analysis of inputs vs. benefits
- The physical, economic and social context
- Potential environmental impacts and land-use sustainability

2.6.5 Land Characteristics and Land Qualities

Beek (1978) identified the physical and socio-economic attributes of land as the main criteria in the study of land evaluation. The FAO *Framework for Land Evaluation* (FAO, 1976) differentiates between land characteristics and land qualities.

The comparisons of land use requirements with land attributes of land mapping units are done by comparing *land qualities* and *land characteristics*.

a) Land Characteristics are land attributes that can be measured or estimated (FAO, 1976) and these include mean annual rainfall, slope angle, soil drainage class, soil effective depth and topsoil texture. These characteristics can be used to estimate land qualities and to also assess land suitability (FAO, 1983). The evaluation of land suitability characteristics is using a direct comparison between the characteristics observed and suitability rating (Dent and Young, 1981; FAO, 1983). Land characteristics are very large in number and do not take into account the interaction between different environmental factors and their effects on land use (Dent and Young, 1981; FAO, 1983).

b) Land Qualities are comprehensive attributes of land obtained by synthesizing the measurable land characteristics (Beek, 1978). This concept was originally used in 1953 to distinguish between observable and measurable soil characteristics and qualities interpreted from them (Beek, 1978).

The FAO *Guidelines for Land Evaluation* defines land quality as "an attribute of land, which acts in a distinct manner in its influence on the suitability of specific land for specified kinds of use". These include temperature management, moisture availability, drainage, nutrients supply and rooting conditions. The utilisation of land qualities for land suitability evaluation has several advantages as compared to the utilisation of land characteristics.

2.6.6 Major Types of Land Use and Land Utilization Types

Rural land classifications have been based on groupings of land characteristics according to their suitability for generalized land use types. A limitation of this classification system is that they assess land characteristics for generalized purposes, with little attention to specific land use types (Beek, 1978).

In response to this limitation, Beek (1972) introduced the concept of land utilization type (LUT). The FAO Framework for Land Evaluation adopted the LUT concept in 1976, to differentiate between two levels of land use; a major class of land use and a land utilization type.

A *major* class of land use is a generalized sub-division of rural land use (FAO, 1983) and includes rain fed agriculture, grazing agriculture, forestry and subsistence agriculture. Major types of land use are employed in evaluation studies of broad qualitative or survey nature (Dent and Young, 1981).

A set of technical specifications in a given physical, economic and social setting, defines a LUT in more detail (FAO, 1983). In terms of the FAO *Guidelines for Land Evaluation* (FAO, 1983), a single crop can be regarded as a LUT, provided that a reference is made to the socio-economic setting in which it is cultivated, and the productivity will vary according to the technology that is available to the farmer. It is generally appropriate to regard the farming system as a definition of LUT's at a more detailed level of land evaluation (FAO, 1983). The degree of detail at which the land utilization types are described varies according to the amount and purpose of the evaluation. While LUT's for land evaluation procedures at a survey scale is described in a generalized manner, for detailed and semi-detailed scale surveys, LUT's are described in detail, and another method of modifying LUT's is undertaken through the repeated process of comparing land qualities (Dent and Young, 1981).

2.6.7 Land Use Requirements

Each type of land use requires different environmental conditions to be practiced on a sustained and economically viable basis (FAO, 1976). The term *"Requirement"* in agriculture is normally used when speaking of land conditions required for proper function of a certain crop (Beek, 1978). These include water, nutrients, soil and topographic requirements. To define crop requirements for a specific crop is the most difficult and critical aspect of land evaluation (Beek, 1978; McRae and Burham, 1981), because land use requirements in developing countries is insufficient and difficult to obtain.

According to Beek (1978) and Sys (1985), land evaluators should not use land use requirement data in handbooks that refer to ideal conditions of specific agro-ecological zones (Sys, 1985), which may have little comparisons to local conditions of the study area. This information should only be considered and used as guidelines. Their relevance to local conditions should be reviewed if it is to be used (Sys, 1985).

According to the FAO (1983), there are three major groups of crop requirements

a) *Physiological crop requirements*: climatic and ecological requirements of a crop for its proper physiological functioning.
b) *Management requirements*: requirements related to technology of management systems.
c) *Conservation requirements*: are the requirements for avoidance of soil erosion and degradation.

2.7 The Need for Improved Subsistence Farming Production

It has been estimated that 83% of expected global population of 8.5 billion people will be living in developing countries by 2025. The capacity of available resources and technologies to satisfy the demands of this growing population for food and agricultural commodities is uncertain. This can be achieved by increasing production on land already in use and by avoiding further intrusion on marginally suitable land (FAO, 2004).

This requires major adjustments in agricultural, environmental and macro economic policy at local, national and international levels in developing countries in order to create conditions of sustainable agriculture development by promoting Sustainable Agriculture and Rural Development (SARD), United Nations (FAO, 2004.) The major objective of the SARD is to increase food production in a sustainable manner and improve food security. Although maintaining and improving the capacity of potential agricultural lands to cater for the increasing population is a priority, the conservation and rehabilitation of natural resources on lower potential lands in order to maintain and manage sustainable man/land ratios is also needed (FAO, 2004).

GIS as a technology and geography as a science can be seen as a framework for what many people call "sustainable development". Sustainability is a commonly defined concept that we use with our ability to set up systems that can maintain themselves. Usually this means economically, but it can include strategies that have minimum impact on the environment that do not deplete the natural resources. (Falconer, *et al.*, 2003).

Although we manage the streams, rivers as part of the vast and complicated hydro projects that conserves water, provides water and generates electricity, we do not consider the severe consequences degradation of a particular floodplain or riverine ecosystem (Falconer, *et al.*, 2003) .

The full impact of development can only be understood when cumulative impact of many decisions is recorded, mapped and monitored. These activities occur in a zone of interaction between remote sensing, GIS and GPS. This in turn enables us to understand the nature of our impact on the planet's natural system.

The concepts of sustainability in the full geographic context have been documented in The Earth Charter. The Commission in Paris in 2000 approved the Earth Charter comprises of four major principles:

- respect and care for the community of life;
- ecological integrity;
- social and economic justice; and
- democracy, non-violence and peace.

Earth has sustained human civilization for several thousands of years and can sustain human civilization. The mechanism of sustainability must be understood and the balance between various elements of our existence must be translated into operational requirements. This means that air is safe to breathe, water is safe to drink, food is safe to eat and shelter is free from internal and external threats. We take it for granted that water and air is safe to consume (Falconer, *et al.*, 2003) .

Even the air is not guaranteed safe to breath as in the case of the chemical factory in Bhopal, India from which poisonous gas escaped that killed thousands of people. This showed us that we are sometimes unable to sustain the quality of the air for humans to breathe. This also happens with livestock farming (chickens, cattle, goats and sheep) that is farmed to efficiently and profitably produce food. The effluent results in air pollution. The manufacturing of fertilizers, herbicides, pesticides and food packaging; petrol and diesel for mechanised agriculture can pollute air and water (Falconer, *et al.*, 2003).

It is clear that the impact of these activities need to be measured and documented to determine how they affect the sustainability of resources. By mapping the activities geographically, the measurements can be better understood and communicated to stakeholders. We will be in a position to see where and who are affected and this will assist us to make more reliable predictions. GIS is and can be used to generate and support cartographic queries. (Falconer, *et al.* ,2003).

2.8 The Role of GIS in Agriculture

The study of geographic features and relationships that exist between them, commonly known as spatial analysis in the GIS field, can be applied to many areas of agriculture. Understanding how features in the landscape interact will enable decision makers to improve efficiency and economic returns. The use of integrated GIS systems by government departments is increasing, as in the case of agricultural industry, GIS is used at the farm level or at provincial and regional levels to increase crop yields and implement better agricultural practices. (ESRI, 2002).

Geographic Information Systems (GIS) grew dramatically in the 1980's. It now holds a common place in many businesses, government offices and academic institutions, where it will perform many diverse applications.

The main function of a GIS is to perform geographic queries and analysis based on the available data. This is a search for a specific suitable area by prescribing certain attributes and parameters. This includes searches for spatial relationships among crops, soils and climatic conditions. Other examples are searches for suitable lands for development with minimal environmental impact and improve management of organization and resources.

GIS combines datasets together by geography, facilitating information sharing and communication. It improves the decision making process. "Better information leads to better decisions." GIS doesn't make decisions, it performs the functions that facilitate the decision making process. It assists in presenting information for planning, resolving territorial disputes, minimizing visual intrusion of pylons etc. It also helps to minimise possible environmental impacts before development even gets underway. GIS focuses on managing data while allowing decision makers to focus on the issues at hand (Goodchild et *al.*, 2000).

2.8.1 Data Collection

The advances in GIS and GPS technology have made the GPS an effective method to collect spatial data that is not available digitally or from hard copy maps. A typical example is farm plantations and fields. The GPS can collect point, line and polygon (area) data in a specified projection that can be downloaded to a computer, which can be converted to CAD drawings or GIS shapefiles and coverages. The Global Positioning System (GPS) developed by the United States Department of Defence as a navigation tool.

Remote sensing is the recording, observing, perceiving of objects or events in the distant future. It is defined as a science and technology that the characteristics of objects of interest can be identified, measured, or analysed without direct contact. It also deals with collecting information about earth from a distance. This is done a few metres from the earth's surface with an aircraft flying hundreds or thousands of metres above the surface or by a satellite orbiting hundreds of kilometres above the earth. To extract information, image processing techniques are applied to enhance the image to help visual interpretation, and also to correct the image if it has been distorted, blurred are degraded by other factors.

2.8.2 Integration of GPS Remote Sensing and GIS

GPS and GIS for field data collection can be integrated. GPS is also used for remote sensing in photogrammetry, aerial scanning and video technology. It is also an effective tool for GIS data capture. Locational data captured by a GPS is useful for various GIS applications. The GPS can be easily connected to a laptop computer in the field. A GPS can be used to with the design of accurate and timely GIS databases. (Falconer, *et al*, 2003 and Goodchild, et *al*, 2000)

Satellites for remote sensing are equipped with sensors that look down at the earth. They are referred to as the "eyes in the sky". The satellite images provide a synoptic view of any place on the earth's surface at local regional and global scales. Remote sensing is cost effective and gives a better spatial coverage compared to ground sampling.

Remote sensing data can be integrated with other geographic data. The trend of integrating remote sensing data into GIS for analytical purposes is increasing. Remote sensing data can be used in many ways. (Falconer, *et al.*, 2003)

2.8.3 Case Studies

The uses of GIS in a variety of local agricultural applications have significantly increased in the past five years.

In Dane County, Wisconsin in the US, PC ARC/INFO (ESRI, 2003) spatial analysis tools were used to perform automated conservation programme, determinations, compliance monitoring and farm planning. The field applications were used to direct the application of seed, fertiliser, pesticide and water in order to minimise chemical inputs, increase crop yields and to preserve the natural habitat.

The province of Loja in Ecuador was assessed for the suitability for cherimoya (a wild fruit-tree) growth was undertaken by mapping the attributes of the physical environment using a GIS (Bydekerke *et al*., 1998). Crop requirement tables were created from the growth requirements of the plant collected from literature, local researchers and farmers. Using ArcInfo a procedure was set up to attribute suitability classes to individual land units and to present the results of the classification on maps. The area was then classified into different suitability classes based on the comparison between land resources mapped for the purpose of evaluation and crop growth requirements.

The FAO developed an integrated software package to link databases, GIS and models for an agro-ecological study in Kenya (FAO, 1993a). The land resources database was achieved by combining various data layers (map and tabular data) on the physical aspects of land resources such as soil, landform and climate. The models were used to create land resources databases, calculate suitabilities, productivity and to determine optimum land resources allocations (FAO, 1993a).

Basically land suitability evaluation focuses on the evaluation of land resources in a specific area in relation to a specific crop (land use), In 1996 Wandahwa and Ranst, used an integration of GIS (IDRISI), Automated Land Evaluation Systems (Ales) and expert knowledge to assess the suitability for pyrethrum cultivation in an area west of Kenya. The expert knowledge was applied in ALES by defining Land Utilization Type (LUT) and crop requirements, selecting relevant land characteristics and constructing decision trees used by the program to rate land qualities and to rate the suitability classes.

A thesis on land suitability evaluation for rainfed agriculture for the Weenen Nature Reserve in KwaZulu-Natal, South Africa by Ghebremeskel in 2003 based on the climatic, soil topographic and drop requirement data from different sources was used to derive the spatial information of land resources. The spatial information was converted to a GIS database to create thematic layers (shapefiles) of land resources. The crop requirements for the selected crops were compared to land resources parameters. The thematic layers of land resources were then overlayed with land resources using a GIS to select areas that satisfied the crop requirements.

2.9 Summary

The FAO has been expressing its concern over the continually increasing world population and the likely need for increased food production in a sustainable manner (FAO, 1976). In the framework developed by the FAO in 1976, it was proposed that for sustainable agricultural production, land potential should be correctly evaluated as a solution to this problem. This approach may vary from place to place even within the FAO framework. Irrespective of the approach used in land evaluation, the land must be matched with land use requirements. Advances in computer technology and in particular the various GIS software packages, GIS have become an effective tool in the management and analysis of land resources for effective land evaluation.

CHAPTER THREE

THE STUDY AREA

3.1 Location

Nkwezela is a rural village, situated in the Hlanganani District that falls within the Ingwe Municipality (KZ5a1) in the Sisonke District Council (DC43) in KwaZulu-Natal, South Africa between 29º.71’ and 29º.79’ south and 29º.87’ and 29º.94’ east. The Ingwe Municipality is situated in the southern part of KwaZulu-Natal, South Africa, (Figure 3.1). Nkwezela is 211ha in extent and is approximately 40km south to south east from Bulwer and falls within the Impendle and Polela magisterial district. A study area of 12 kilometres by 12 kilometres, which is 1440ha in extent around Nkwezela, was designated as the study (Figure 2: Site Plan).

The study area is accessed from the R612, which connects to the Kokstad-Merrivale which passes through Bulwer to the west to Pietermaritzburg and Kokstad and to Park Rynie and Umzinto to the east (Figure 3.2).The study area is interlinked with a network of corrugated unpaved roads that connects onto the R612.

3.2 Historical Background

Nkwezela has been a rural village, inhabited by blacks for many centuries (De Villiers and Letti, 2001) where rural communities depend on subsistence agriculture to supplement their household incomes. All the farmers cultivate crops for their own consumption (Strategy and Tactics, 2003). Maize, dry beans, potatoes, sorghum and turnips are grown. The most common crops are maize and potatoes. Most of maize is used for home consumption. The maize yields are very poor, although the maize production is estimated at between 2.8 and 5.6 tons/per hectare according to the bioresource unit data (Camp, 1997).

Soil acidity is a problem and generally livestock destroy the crops because of inadequate control of livestock movement. The veld is in a poor condition that is characterised by an increase in unpalatable species. Subsistence agriculture is conducted to for their own

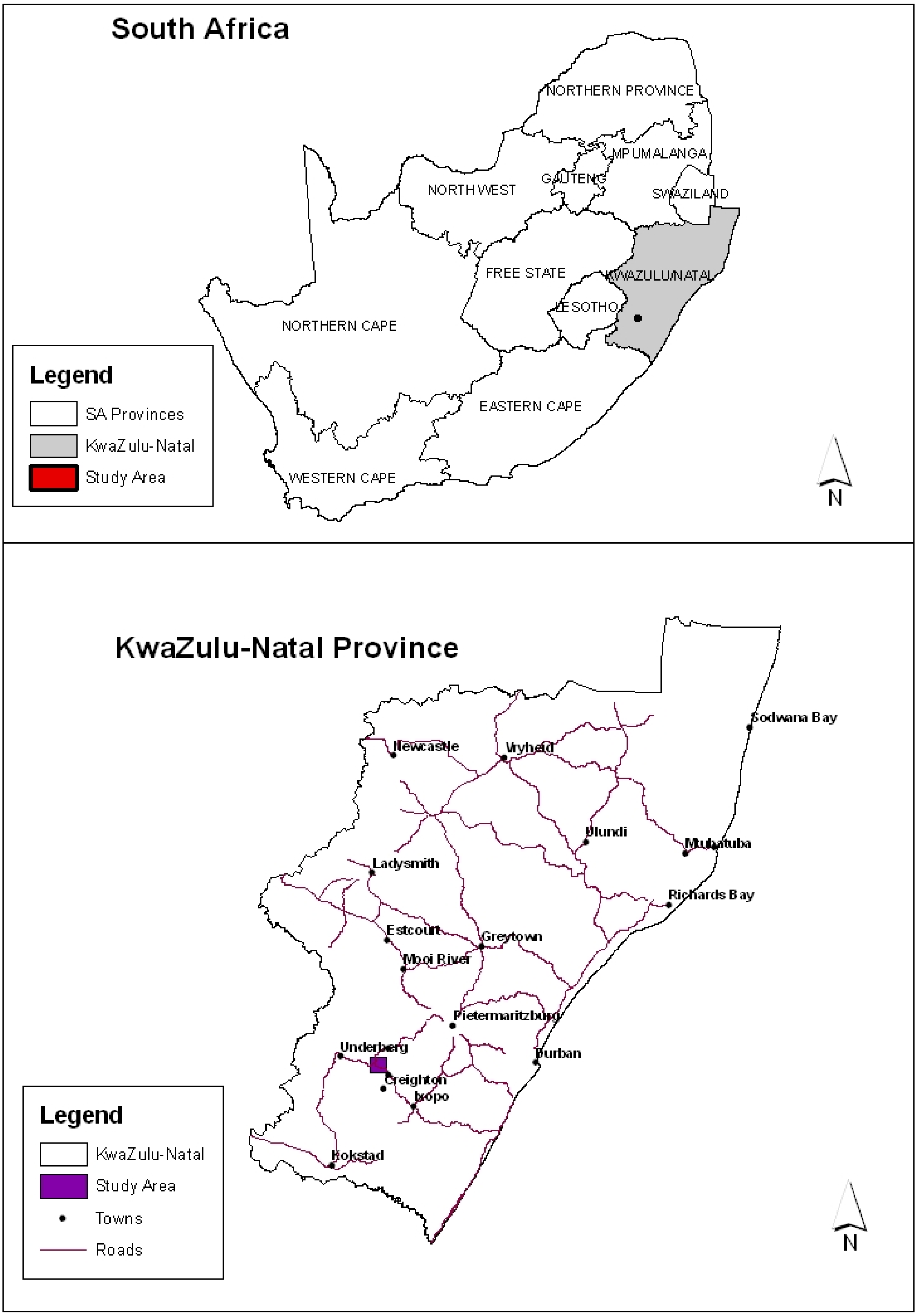


Figure 3.1: Location of the Study Area.

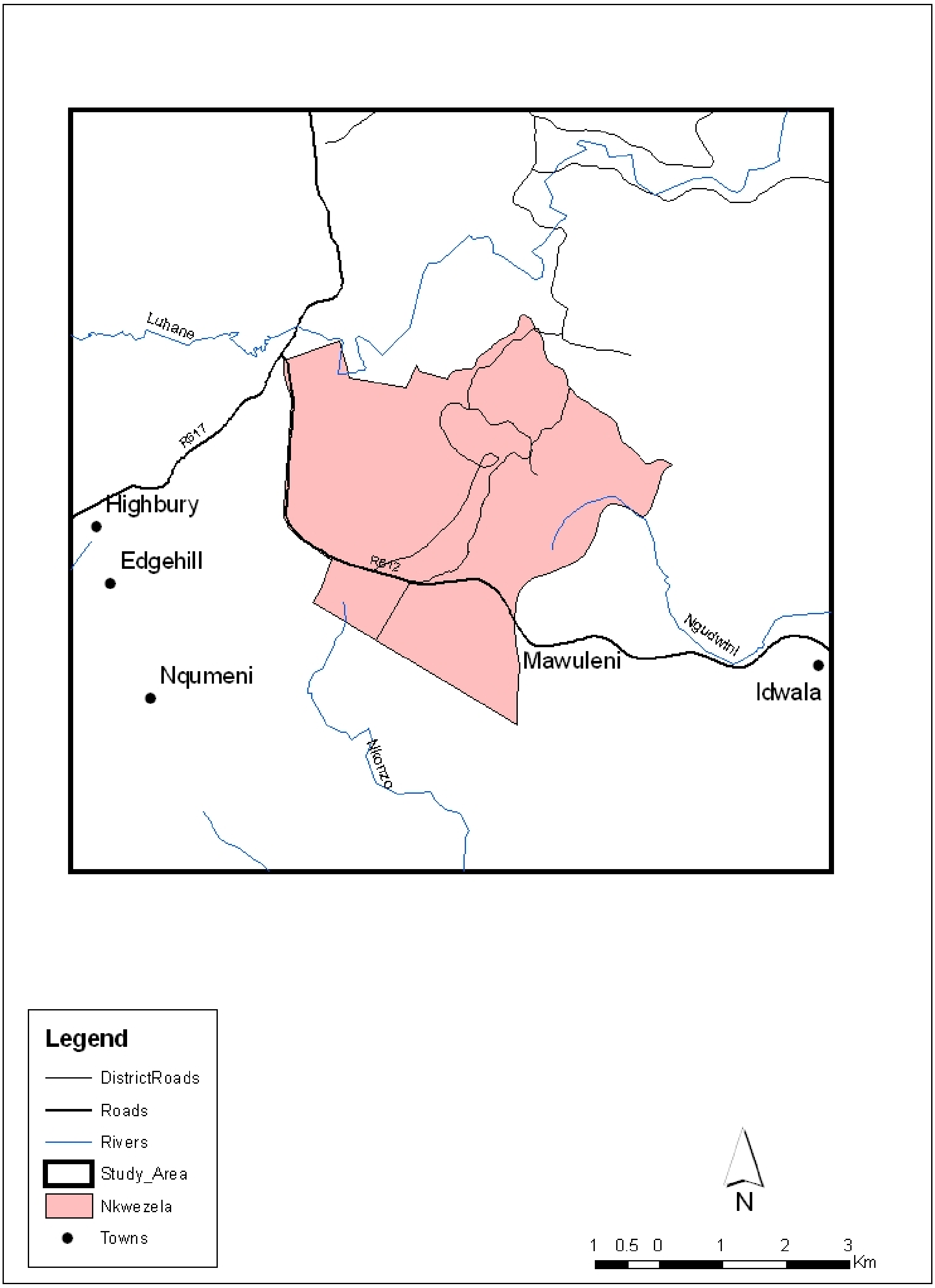


Figure 3.2: Site Plan of the Study Area in Nkwezela.

consumption. Majority of the people are involved in agriculture on a full time basis and they need agriculture training with crop production as the main training need. While some farmers use tractors, the majority of them use hand-hoes and one farmer uses animal traction. Soil erosion, easy depletion of soil nutrients and the presence of shale is a limiting factor of crop production.

3.3 Climate

Nkwezela is approximately 1433m above sea level and is characterised by a hot wet summer and a dry cold winter with a mean annual rainfall of 923mm. Nkwezela receives 80% of the rainfall between September and April summer and 20% of the rainfall in winter. The mean annual temperature is 14.7 degrees, with a mean maximum of 20.9 degrees (De Villiers & Letti, 2001).

In conjunction with the high altitude values in the study area, the spatial variables in the rainfall parameter are usually high. This could be attributed to the physiographic features of continentality and altitude, which were some of the factors that were used in the modelling of the rainfall information. The spatial variability in the temperature regime follows the topography of Nkwezela with relatively low temperatures in the high elevation areas and relatively high temperatures in the low elevation areas. The seasonal variations in the rainfall and temperature conditions are mainly due to the general circulation of the atmospheric conditions (Camp, 2002). The climate in Nkwezela is characterised by hot, wet summers and dry cold winters (De Villiers and Letti, 2001).

3.4 Topography and Geology

Topographically, Nkwezela is characterised by a high mixture of topographic features which comprises of bottomland plains, steep hillsides, deep valleys, undulating land forms and upland plateaus.

The northern part of the study area is also relatively flat dominated by slope values of 4 – 8% with gradual to steep slopes scattered in the north eastern, south eastern, and western and in the northern parts of the study area. Nkwezela has approximately 73% of the total area has topographic values that are within the limits of the arable slope classes according to the criteria prescribed for KZN from the Camp's BRG (1999). The rest of the study area is dominated by steep slopes that do not fall within the range of arable slope. These are situated on both sides of the Ngudwini River in the western parts of the study area and the Nontshibongo River in the south eastern part of the study area (Figure 3.2).

The geological formation of the study area comprises mainly of dolerite, mudstone and shale of the Beaufort series (Hughes, 1989) which falls within the Karoo system. The rocks of this series are relatively hard when fresh, and can break up into smaller irregular fragments when exposed to water (West, 1951). The nature of the parent material influences soil characteristics, as it significantly increases the rate of erosion. It is also assumed that to be basically responsible for the formation of deep dongas in the areas occupied by these rock types (Hughes, 1989; West, 1951), (Figure 3.3).

Soils derived from dolerite are structurally better suited to plant growth than soils derived from sedimentary rocks. The soils are relatively deep, highly leached with a high acid content, low fertility and favourable physical properties.

These rocks can be further classified as igneous and sedimentary rock types. Igneous rocks are classified on a chemical basis which is classified as being acidic, intermediate, basic and ultrbasic according to the amount of silica.

In comparison to mudstone which is very large and does not split along bedding planes, shale is well-bedded and splits easily along closely-spaced planes. Generally they consist of clay minerals and tiny fragments of quartz and other rock forming minerals. (Lurie, 2004).

3.5 Vegetation

The Bioresource Classification by Camp (1999) identifies two Bioresource Groups based on the vegetation types of Nkwezela are shown in Figure 3.4. The central part of the study area is classified as BRG 8 (Moist Sour Highveld) covers most of the study area and the northern and western parts of study area are classified as BRG 11 (Moist Transitional

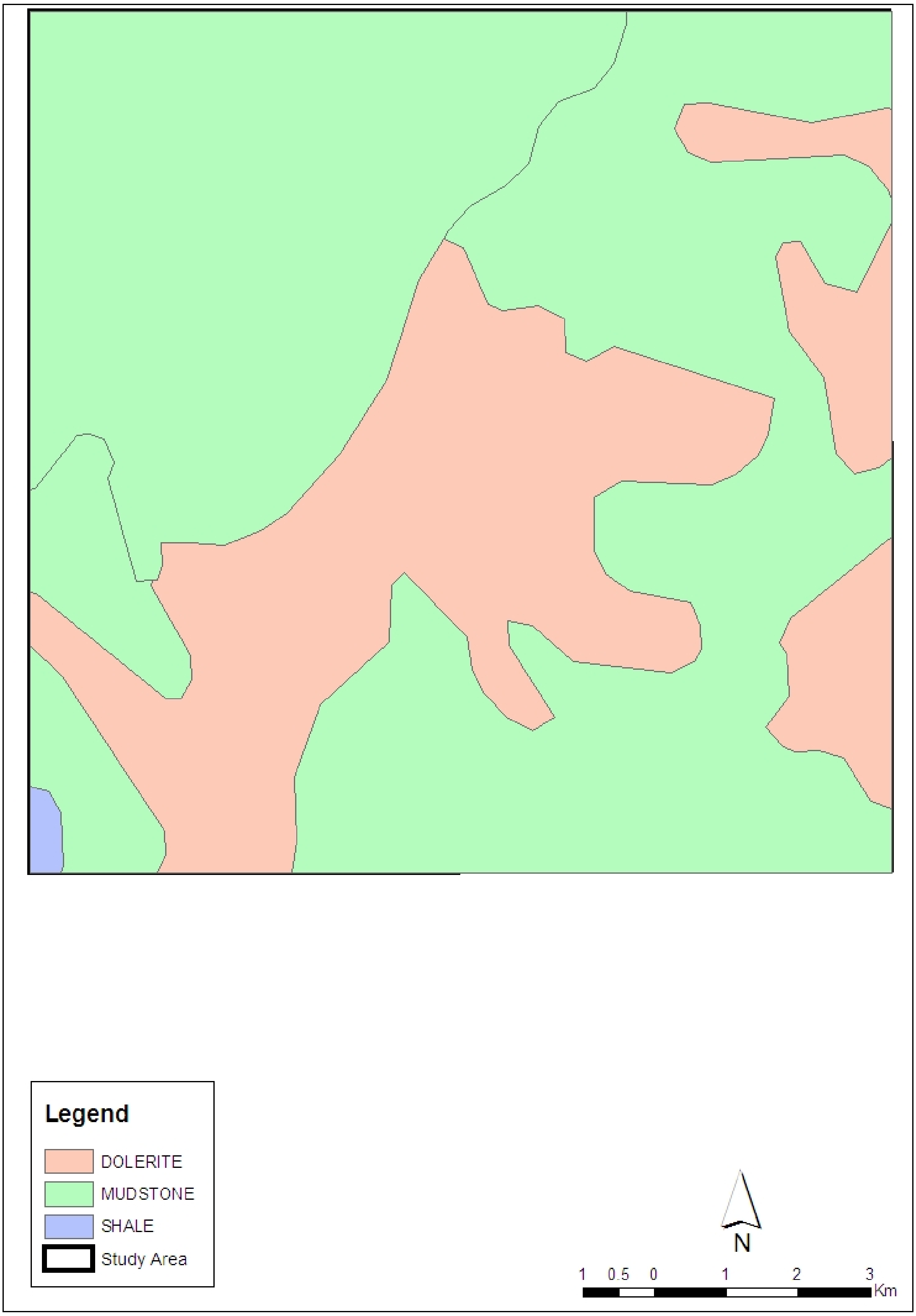
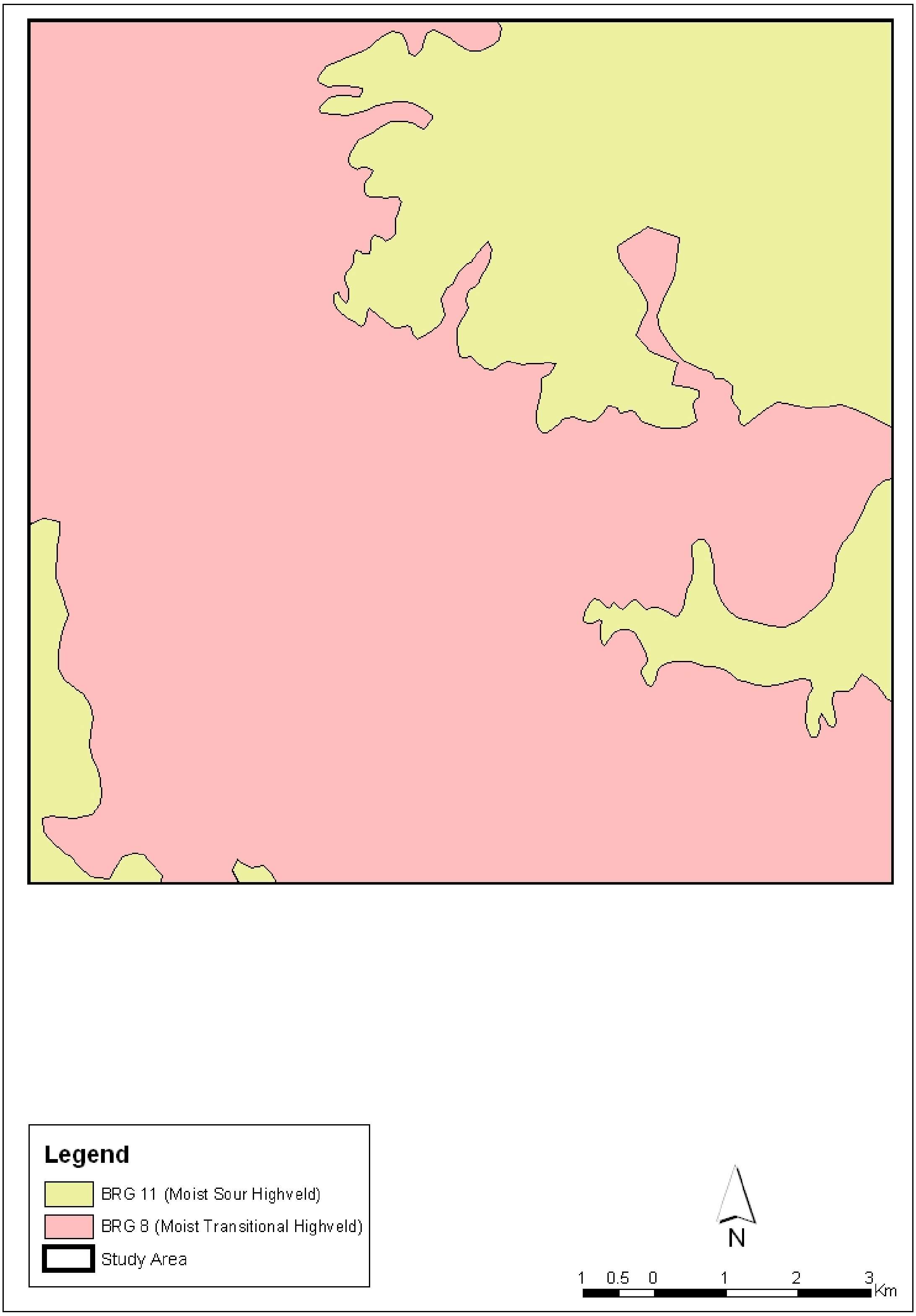


Figure 3.3: Geology of Nkwezela .

Figure 3.4: Bioresource Groups Map of Nkwezela (Camp, 1999).



Highveld). Figure 3.5 shows the Bioresource Units of the Bioresource Groups classified by Camp, 1999, which is discussed in section 4.1.5

The vegetation comprises of number of grass species such as *Alleropsis semialata, Andropogon appendiculatus, Themeda triandra and Tristachya leutcothrix, Brachiara serrata, Cymbopogon excavatus, Cymbopogon validus, Digitaria tricholaenoides, Diheteropgon amdplectens, D. filiolius, Eulalia villosa, Harpochloa flax, Elionurus muticus,Eragrostis, E. cuvula, E. plana, E. racemosa, Hereropogon contortus, Microchloa caffra, Monocymbium ceresiiforme, Setaria nigrirostris, Sporobolus africanus, Thermeda triandra, Trachypogon spicatus, Tristachya leutcothrix,*.and *Themeda Hyparrthenia Grassland* (Camp, 1997). *Hyparrhenia hirta* dominates much of the veld/ and the grass cover is generally good (Camp, 1997).

Veld based on doleritic soils generally have a good basal cover and can endure grazing pressure reasonably well which is usually dominated by *Themeda triandra* The cover is generally poorer on sedimentary soils (Camp, 1997).

Soils on the south facing aspects are generally deeper and grass productivity is relatively higher than the north facing slopes. The grass cover on the south facing aspects comprises of *Festuca costata* and *Cymbopogon* species. The leached soils on the south facing slopes are covered by taller, sour grasses such as *Cymbopogon excavatus. Eragrostis curvula, Eragrostis plana and Sporobolus* covers the long-term overgrazing areas.

3.6 Hydrology

The Ngudwini River, which flows through a valley in northern part of Nkwezela is the only river in the area, connects to the Mkomazi River. Approximately 87% of the households have direct access to piped water in their yards and 33% also collect water from the stream. Two dams are located at approximately seven kilometres from the centre of Nkwezela to east and west. Five of the nine springs are developed and can be accessed. Sixteen boreholes are in use, one borehole has been destroyed and five boreholes are not being used. There is no data available on the status of the remaining six boreholes. Seven of the boreholes are used for production. Fourteen of the boreholes are used for domestic purposes and five of the boreholes are used for public purposes (DWAF, 2004)

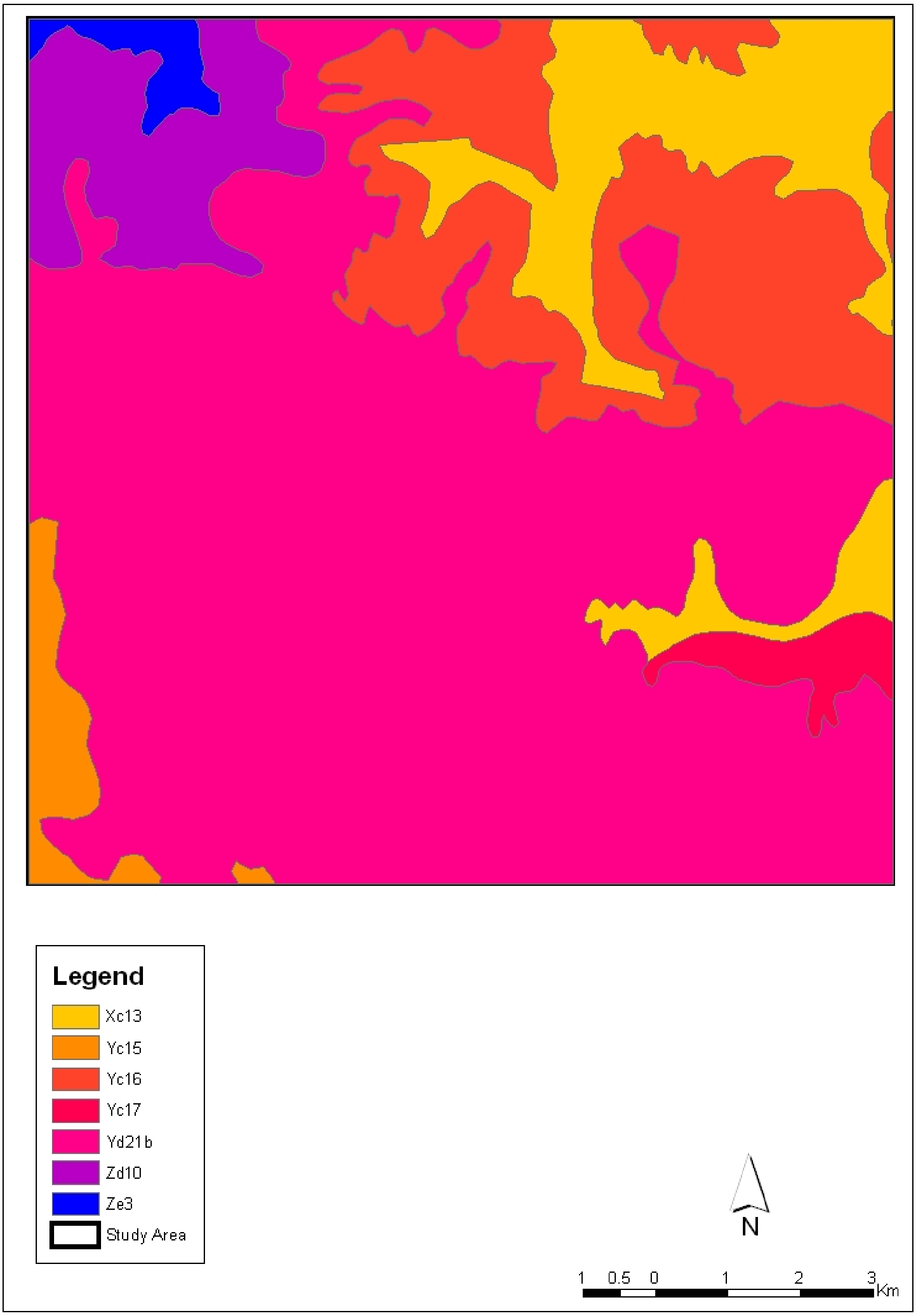


Figure 3.5 Bioresource Units Map of Nkwezela (Camp, 1999).

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3.7 Socio-Economic Status

It was noted from a socio-economic impact analysis conducted by Strategy and Tactics, 2003 that the quality of life is poor and they want better living conditions such as housing, electricity, better roads and employment opportunities. The farmers have lost interest in goat farming because of stock theft, which they believe is perpetrated by organised syndicates. This could contribute to their livelihood but they are concerned about their safety because these thieves are ruthless, which could lead to severe factions between the farmers and thieves. The farmers farmed for themselves and most of them learnt farming because their families had been farming for generations, a tradition which was passed on from one generation to the next. They want to farm for themselves and are not interested in commercial farming, as they feel that farming is something that they have learnt from their parents or it is something that they have to do. It was noted from the researcher's observations that the farmers recognized and were happy with the assistance that the FSR had given them. This could be seen as an opportunity for the FSR and the Department could work together with rural communities to improve their quality of their lives.

Maize and potatoes are the most commonly grown crops in rural areas for consumption and maize is the most important crop (De Villers, and Letti, 2001). The average price of maize is R95.00 for a 50kg bag and R129.00 for an 80kg bag (De Villers, and Letti, 2001). In the study area 18% of the households depend solely on pensions and 43% indicated that pension is the only source of income. Only 10% of the households indicated that agriculture as a source of income. Generally the incomes of rural people are below the breadline and the average family size is 10.33 people per family.

3.8 General Agricultural Problems

Shortage of labour, stock theft lack of fencing around fields, the cost and maintenance of tractors, dip tank not working and the lack of equipment are the problems facing the farmers (De Villers, and Letti, 2001). A limited knowledge and management of skills relating to crop production, weed infestation, hail and marauding livestock are problems experienced by the farmers.

Water is an important element in the agricultural sector. In the rural context it plays an even more significant role. Rural farmers do not have the resources or the expertise to implement irrigation schemes.

This is one of the reasons for the low crop yields discussed in section 4.2.1 and that also correct liming practises and farming methods need to be implemented in order to improve crop yields. While it must be acknowledged that the estimated crop yields as per the BRU information provides broad guidelines in terms of optimum crop yields and other valuable agricultural and climatic information. This could be used as a benchmark to determine the optimum crop yields.

3.9 Summary

Nkwezela is a rural and impoverished subsistence farming village a high rate of unemployment and has a high rate of illiteracy that depends on maize farming in order to support and sustain the community because most of the people depend on social grants and income from members of their families. Access to certain services is non-existent. There are no development initiatives in these communities. Livestock is used for their own consumption. Maize and potatoes are grown with maize being the most important crop grown. Although approximately 94% of them use a lot of fertilizer, they use the fertilizer incorrectly.

CHAPTER FOUR
MATERIALS AND METHODS

4.1 Data Collection

The four relevant datasets required for this study in order to a compile report that will to improve production of subsistence farmers, improve the quality of life and promote sustainable resource utilization were collected from different data sources. Most of the data collected was in Cape Datum, Geographic Projection and this data was projected to the Transverse Mercator Projection, by using ArcGIS 9.0 (ESRI, 2004b) project wizard tool in the Toolbox

These included a soil map of the area, a soil survey analysis on the chemical and physical properties, climatic data, and topographic data and crop requirement data for soil, climate and landform.

4.1.1 Soils Data

A soils dataset, land cover dataset, land potential dataset, arable lands dataset (1995) was obtained from the Natural Resources Section of the Department of Agriculture and Environmental Affairs at Cedara. The soils dataset shows that the soils in the study area red and yellow dystrophic and or mesotrophic, well drained, highly acidic and are in a high rainfall area. In terms of the geology the rock formation is Beaufort Group and comprises of mudstone and dolerite.

In addition a soil survey analysis was obtained from the Fertilizer Advisory Service section of the Department of Agriculture and Environmental Affairs at Cedara. A soil map was produced from the soil surveys (2003) was obtained from soil analysis conducted by the Soils Survey department (Table 5.1) in section 5.1.2. A total of 14 soil pits were used for soil profile description and sampling different sites in the study area captured by GPS. Soil samples from the diagnostic horizons for each profile were collected for laboratory analysis. Forty four special auger samples were collected from the soil units in the study area to determine nutrient status of the soil forms.

4.1.2 Climatic Data

Climatic data in grid format for the country was obtained from ICFR. Mark Horan of CCWR originally compiled this data. ICFR are now the custodians of climatic data. The data comprises of different climatic parameters at a grid of 1' x 1' latitude longitude horizontal interval. The Department of Agricultural Engineering University of KwaZulu-Natal, Pietermaritzburg, conducted the mean annual precipitation and other climatic variables at each grid point. This was based on data that was recorded approximately over twenty years ago at various stations by regression analysis against several locational, physiographic and climatic attributes (CCWR, 1989). These attributes include altitude, latitude, longitude, continentally, aspect, terrain roughness and topographic exposure.

This data was found to be broad and not detailed to be used at the level of study for this dissertation and would not provide a suitable evaluation of the climatic conditions of the study area and would be more suitable for large-scale analysis. However, the information extracted from this data and the climatic data from the BRU Inventory Programme is the only source of climatic data that can be used as a comparison to determine precipitation, evapotranspiration, temperature, and heat units discussed in section 4.2.1.

Additional climatic data in MS Excel format obtained from the ICFR, South African Atlas of Agrohydrology and Climatology (Schultze, 1997), captured as point feature dataset in X and Y coordinates. The points representing the different climatic variables were captured as points at approximately 1.6km x 1.75km grids. This dataset was more detailed and provides more accurate assessment of the climate in the study area.

The mean annual precipitation, median annual, median monthly and annual precipitation for 1989 and 2003; including the mean annual temperature, monthly means of minimum and maximum temperature, mean monthly A-pan Evaporation, Mean Monthly Solar Radiation, soil characteristics, geology (1:1 000 000 Geology Map), lithology (1:1 000 000 Geology Map), physiographic regions, forest economic zone, altitude derived from the 1:200/400m altitude grid and the slope derived from the 1:200/400 altitude grid was obtained for the study area from the ICFR.

a) Rainfall

The daily rainfall database developed by Lynch (2003) contains daily rainfall data for 11 269 stations located in the SADC (South African Development Community) region. This region comprises of South Africa, Lesotho, Swaziland, Namibia, Zimbabwe and Mozambique. This Data Rainfall Extraction Utility was developed in conjunction with the School of Bioresources Engineering and Environmental Hydrology (BEEH), University of KwaZulu-Natal; Pietermaritzburg campus was used to extract monthly rainfall data for the study area.

The utility can be used to extract observed and infilled daily rainfall values from a database, which was developed by Steven Lynch (20030 in the course of a Water Research Commission (WRC), funded research project (K5/1156), awarded to BEEH. The project, titled "The development of a raster database of annual, monthly and daily rainfall for southern Africa", was completed in March 2003. One of the main objectives of the WRC project was to revise the mean annual precipitation (MAP) values developed for the southern African region by Dent, *et al.* (1989) in another WRC funded project titled "Mapping of mean annual precipitation and other rainfall statistics designed to maximize use of daily rainfall stored in the database. This will be discussed in section 4.2.1.5

4.1.3 Topographic Data

Topography plays an important role in land use planning and in particular agriculture. For this dataset, two sources of topographic data were evaluated; firstly, a twenty-metre contour for KZN in ArcView shapefile format was obtained from the Natural Resources Section of the Department of Agriculture and Environmental Affairs at Cedara. The contours were originally produced for the DAEA by GIMS.

Secondly, an altitude dataset was obtained from the ICFR data, which showed altitude levels at a four metre interval. A contour map was then created from the altitude map which was initially generated from an ASCII file which contains X, Y and Z values at intervals of 4m horizontal distances into a shapefile format using the AD XY Data, which resulted in a finer and more accurate representation of the topography of the study area. This data was in the Geographic Projection Cape Datum and reprojected using the projection wizard in ArcToolbox to Clark 1880 Transverse Mercator with the central meridian of 31. From this dataset a Tin, Aspect, Slope and DEM maps were created. This dataset was be used to produce different kinds of topographic maps.

4.1.4 Crop Requirement Data

The combination of slope, climate and soil conditions is used to determine the agricultural potential of a site, an area or region. Successful crop production is dependent on climate and soil type with rainfall being a limiting factor to achieve feasible crop yields. Crop yields under Dryland and irrigation can be estimated using climatic data that include rainfall, temperature and evaporation.

According to the FAO (1976), land suitability evaluation is specific to specialized land utilization types. This means that crop requirements are crop specific and variety specific in some instances and there is no common crop requirement for rural areas.

The study area falls in Bioclimatic Group and in BRG 8 and 11 (Camp, 1999) Figures 3.3 and 3.4. The land potential is classified as L3 - Good Potential Land (Infrequent and/or moderate limitations due to soil, slope, temperatures or rainfall and appropriate contour protection must be implemented and inspected. The BRU provided information on what crops could be grown in the study area. Site visits, interviews with the farmers and discussions with Hannes the FSR who works in consultation with the farming community of Nkwezela identified three crops that are grown for their own consumption, and these are maize, cabbages and potatoes. Cattle and goats are kept for their own consumption and for cultural purposes.

Table 4.1 shows the crops that can be grown in the study area in terms of the BRU information.

Table 4.1 Crops that can be grown in terms of the BRU information.

Crop	**Growing Period**
Carrot (open Pollinated)-Sow	December
Kikuyu, Maize Irrigated	October
Oats, Irrigated and Potatoes	October to February
Ryegrass Annual	March
Soya bean Dry land, Tall Fescue Dry land, Tall Fescue Dryland, Carrot (open Pollinated)-Sow	December
Pinus e*lliotti,* Pinus *taeda*, Ryegrass	March
Tomato Transplant	October

Maize, potatoes and cabbages are the only crops grown in Nkwezela, with maize being most important as the community use the maize for their own consumption. Information on maize, cabbages and potatoes in the study area was obtained from different publications and reports of DAEA, and FAO publications and reports, in order to compare them with land qualities that were mapped to conduct a suitability evaluation. The literature include: Anon (1972), Anon (1974), Blanks and Horne (1993), Duxbury *et al*. (1990), Manson *et al* (1993), Manson (1997), Parsons and Liebenberg (1991), Rutherford (1982), Smith (1993), and Smith (1997) and FAO publications include: Doorenbos and Pruit (1977), Doorenbos and Kassam (1979), FAO (1978), and FAO (1980).

Table 4.2 shows the broad climatic conditions and land potential of Nkwezela that was obtained from the BRU information.

Table 4.1

BRU	MAP	Annual Temperature	Land Potential	Restrictions
Xc13	875mm	16.1°C.	Good potential land	Low temperature and frost
Yd21b	944mm	14.7°C.	Good potential land	Low temperature and frost
Ye17	979mm	15.0°C.	Good potential land	Low temperature and frost
Yc16	996mm	15.6°C.	Good potential land	Low temperature and frost
Zd10	1225mm	13.9°C	Good potential land	Low temperature and frost
Ze3	1101mm	13.0°C	Good potential land	Low temperature and frost
Yc15	994mm	15.2°C	Good potential land	Low temperature and frost

The crop requirements listed above shows that the study area has a good yield potential for a moderate range of crops.

4.2 Assessment of Land Resources

4.2.1 Assessment of Climatic Resources

Akin (1991) has identified climatic pattern, plant distribution and soil as the three most important natural variables that control the earth's environment with climate being perceived as one of the most important active component and more significantly an independent variable that determines soil and plant distribution on local and regional scales. Temperature, precipitation and solar radiation from the climatic variables are the major factors that direct the climatic adaptability and distribution of crops (FAO, 1978).

4.2.1.1 Precipitation

The average amount of precipitation may not necessarily restrict an agricultural operation (Schultze, 1997), because it does not show the natural variability of rainfall. It is the average of rainfall totals, which includes abnormally high or low extreme values that are particularly common to arid areas. It has relatively less importance to agricultural productivity, because the distribution and variability of rainfall are required (Schultze, 1997). Median rainfall values and their coefficient of variability (CV %) as recommended by Schultze (1997) were used in this study to describe the amount and the distribution of rainfall in the study area. The CV% is a measure of variability of rainfall and is expressed as a percentage. The approximate CV% for KZN can be calculated by using the equation shown below (Smith and Camp, 2002). The mean annual rainfall was used for the MAP.

$$CV\% = 640/\sqrt{MAP} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 4.1)}$$

Where: *CV%* is the coefficient of variability of the rainfall.

MAP is the mean annual precipitation in mm.

CV% is considered as an index of climatic risk which also indicates a probability of fluctuations in the mean precipitation because it deviates from the average (Schulze, 1997).

The probability of rainfall to exceed a certain value is another way to assess rainfall values. In this study the rainfall values are ranked in ascending order and the percentage of rainfall values that are greater than a certain rainfall value are used to assess the distribution of rainfall in an area (Schulze, 1997). This statistic is expressed in percentile values of the rainfall data and in this study the 80thth and 20 percentiles of the rainfall data were examined.

4.2.1.2 Evapotranspiration

Evapotranspiration is the process of water vapor transfer from vegetated land surfaces into the atmosphere, which is an essential part of the global hydrologic cycle. Evapotranspiration includes evaporation (the change of liquid water, from bodies of water and wet soil, into water vapor) and transpiration (in which water is drawn from the soil into plant roots, transported through the plant, and then evaporated from leaves and other plant surfaces into the air (FAO, 1978). www.globalchange.org/glossall/glossd-f.htm

The average moisture of the growing period over southern Africa can be determined by adapting a simple water budget approach by the FAO (1978). This was originally developed for agro-ecological zone mapping of Africa. It is assumed that during the period when the precipitation is at least equal to one third of the evapotranspiration, sustained plant growth occurs (Schultze, 1997). The equation shown below was used to determine the length the growing season based on evapotranspiration according to the FAO water budget approach (Schultze, 1997).

In the equation A-pan monthly evaporation is taken as a reference potential evaporation (Er). The A-pan evaporation is a US method of direct measurement of potential evaporation, and is usually used by South African agricultural hydrologists (Schultze, 1997).

$$P \geq 0.3\ Er \qquad \text{(Equation 4.2)}$$

Where: *P* is the median monthly precipitation (mm)

Er is the monthly reference evaporation

4.2.1.3 Temperature

Temperature is a basic climatic parameter frequently used as an index of the status of the environment (Schultze, 1997) and has three main effects on plant growth (FAO, 1983; Schultze, 1997). Plant growth varies with temperature; below critical temperatures, growth stops; and very high temperatures has adverse effects. It has been suggested by the FAO (1983) that land quality temperature system can be assessed based on the individual characteristics such as mean temperatures during the growing season, temperatures of the coldest and hottest months of the growing season and heat units (see section 4.2.1.4). According to

Schultze, (1997), that although many activities are defined or described by mean temperatures, the supposed essential temperatures are generally of more significance to both natural plant and agricultural crop distributions

Mean monthly maximum and minimum temperatures including mean monthly temperatures of the growing season were assessed as important factors for sustainable agriculture in this study.

4.2.1.4 Heat Units

The temperature requirements of plants are more conveniently expressed in terms of heat units (degree days), (Smith, 1997). Heat units are an accumulation of mean temperatures above a certain threshold value (below which the active development is considered not to take place, and below an upper limit (above which growth is considered to remain static or even decline), over a period of time (Schultze, 1997). This threshold temperature is referred to as base temperature and varies from plant to plant. Most crops such as maize, potatoes and cabbages stop growth when the temperature is below 10°C (Smith, 1997). Therefore, the base temperature is used to calculate the amount of heat required for different crops. An example of this can be used for maize, if the threshold temperature is 10°C and the mean temperature of a given day is 22°C, this means that 12 heat units are accumulated for that day and are added to the heat units of the previous days. A heat unit is expressed as the average of daily temperature minus the threshold temperature referred to as the base temperature (Smith, 1997) and the daily heat units are calculated for the growing season. The base temperatures for maize potatoes and cabbages (10°C and 5°C) were used for the crops that are presently grown in the study area (Smith, 1997). The heat units were obtained form Crop, Pasture and Timber Yield Estimates for KwaZulu-Natal (Smith, 1997) listed in section 4.6.1, in Table 2 (Criteria Used in Suitability Evaluation).

4.2.1.5 Water

With reference to Data Rainfall Extraction Utility discussed in section 4.1.5, the monthly mean rainfall from 1991 to 2001 for rainfall station 0182331 W, St Faiths Polela was extracted (Table 4.3). It shows the mean monthly and annual rainfall for the period 1991 to 2001. The estimated MAP is 860mm and the observed MAP is 886mm measured from weather station number 0182331W. 17% of the data is accurate with 0.7% missing and 81.9% data patched over a 110-year period. The figure -99.9 shows the missing data.

Table 4.3 Mean Monthly Rainfall for Nkwezela.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	-99.9	73.7
1992	78.1	56.5	50.5	9.9	0	1.3	4	35.3	86.1	68.4	69.9	94.5
1993	76.4	114	32.3	42.5	3.4	3.1	8.5	18.2	185.1	163.2	66.3	152.6
1994	110.5	97.1	120.5	13.7	2.5	9.4	22.1	36.1	16.5	74.5	69.8	111.6
1995	149.9	62.4	169.8	85.7	8	71.8	4	14.2	38.9	138.4	80.3	224.1
1996	189.2	148.7	95.7	32.8	8.1	0	66.4	0	44.2	141.7	110.4	77.1
1997	135.1	97.8	96	107.3	19.9	105.9	17.6	19.7	85.4	103.6	148.1	70.6
1998	101.8	160.4	112.5	69.4	32.5	0	4	57.4	54.1	41.4	111.8	117.5
1999	111.8	131.5	61.3	43.2	0	2.5	4.6	0	0	200.3	56.6	197.2
2000	283.6	86	195.5	68.4	44.2	0	0	-99.9	-99.9	-99.9	-99.9	-99.9

The seasonal distribution of rainfall is important as different crops grow at different times of the year. Table 4.4 illustrates the rainfall distribution for KwaZulu-Natal (Smith, 1997).

Table 4.4 Seasonal Rainfall Patterns in KZN.

Cropping Season	Percentage of MAP
October to March	80%
February to November	70%
May to September	20%

4.2.2 Assessment of the Natural Resources

4.2.2.1 Soil Resources

Blanks and Horne (1993) have identified soil as the most significant decisive factor to determine the agricultural potential of a particular area. The evaluation and examination of soil characteristics such effective depth, clay and mineral content, and slope are the main criteria utilised to determine land use potential (Camp, 1995) and Dent and Young (1981) have identified that an assessment of soils and how they respond to management is required for effective decision making in rural planning.

The assessment of the soils in the study area was based on a soil type's dataset, land cover dataset; land potential dataset, arable lands dataset (Guy and Smith, 1998). The soils dataset shows that the soils in the study area are red and yellow dystrophic and or mesotrophic, well drained, highly acidic and are in a high rainfall area. In terms of the geology the rock formation is Beaufort Group and comprises of mudstone and dolerite (Figure 5.10).

In addition a soil survey of forty four sample points based on a 1km x 1 km grid of the study area using the Trimble GPS to locate these points was undertaken to supplement the soil map of the study area. The results of the soil chemical and physical analysis were also used to enhance the soil map with additional soil information for the evaluation of agricultural potential of the soil units.

4.2.3 Assessment of Topographic Features

Topographic features such as elevation, slope, aspect and orientation are important factors of land evaluation (McRae and Burnham, 1981). These attributes may also have significant effects on soil properties, soil erosion hazard, and cultivation of or mechanised operations (Manson *et al*., 1995; McRae and Burnham, 1981). The assessment of topographic characteristics and attributes is fundamental in land evaluation.

The topographic assessment of the study area was based on the DEM that was created from the 4 metre contour dataset that was used to generate the DEM. Different topographic maps such as Slope and Aspect maps that are essential are required to evaluate the suitability of an area for sustainable agriculture were derived.

Agriculturally, slope is the most important factor because it helps to determine the area of land available for cropping and conservation practices that are required on the land (Blanks and Horne, 1993). The slope assessment was based on 24.15m grid cell because of the scale of the study area and spatial distribution of the fields in the study area.

Contour ploughing is an established practice of enabling sustainable agriculture on sloping land, and is the practice of ploughing along topographic lines.

Topography is important in determining weather patterns. Two areas in fairly close proximity geographically may differ radically in characteristics such as rainfall because of elevation differences or because of a "rain shadow" effect.

4.3 Assessment of Crop Requirements

The availability and access of reliable crop requirement data is generally the most fundamental aspect of land suitability evaluation. Generally, crop requirement data is only available in crop production guidelines and handbooks are based on local conditions and may not be appropriate in other areas or under different conditions. In addition, agronomic guidelines for crop production generally refer to crop requirements for optimal growth. In practice, most crop production activities are conducted under some pressure from climatic and biophysical conditions. It is for this reason, that the FAO Guidelines of *Land Evaluation for Agriculture* identifies five levels rating these conditions according to their suitability to crops (FAO, 1983). The suitability rating method is discussed in section 4.5. In this study, the availability and access of readily available crop requirement tables that rate land characteristics for some of the selected crops was a problem. Information on crop requirements from different literature was correlated to the FAO land suitability rating depending on the various assumptions such as critical values of land characteristics, hazardous effects to crops and yield estimates to solve this problem.

The soil factor table (Smith, 1997), was utilised to calculate the yields of the selected crops based on rainfall, soil depth, and soil texture as an index of soil suitability for crops. In this study, only one rainfall class (993mm) was used because almost the entire study area is within this class. The soil factors were correlated to the FAO assumptions of attainable yield for different qualitative suitability ratings by converting the soil factors into qualitative indices. In this study, it was assumed that with other factors being optimum, the achievable yield will vary according to the soil factor. Accordingly, the maximum yield (100% of the achievable yield) can be multiplied by the soil factor to provide the percentage achievable yield adjusted to soil conditions. For example, if the soil factor is 0.9, then the achievable yield will be 100%*0.9 = 90%. This is rated as highly suitable (S1) according to the FAO Guidelines for *Land Evaluation*. The correlations of the soil factors (Smith, 1997) to the qualitative suitability rating of the FAO guidelines evaluation (FAO, 1983), based on the above assumption are shown in Table 4.4

The topographic requirements of the selected crops were not readily accessible. The only source of topographic requirements was available from the arable slope classes (Table 4.6) in the BRG's, which was developed Kelson Camp (1999) for the KZN Department of Agriculture and Environmental Affairs. These slope classes were correlated to the FAO land suitability evaluation structure, which classifies land into three suitability classes, namely highly suitable (S1), moderately suitable (S2), and marginally suitable (S3), which is discussed in section 5.1.3.

Table 4.5 Correlation of the FAO suitability ratings (FAO, 1983) to soil factors of Smith (1997).

FAO suitability Rating	Achievable yield (FAO assumption)	Soil factor used to adjust yield (Smith, 1997)
S1	>80%	>0.8
S2	40 – 80%	0.5 – 0.8
S3	20 - 40 %	-
N	< 20%	-

Table 4.6 Slope classes for arable land determination in the BRG's in Nkwezela (Schrőder, 2002).

Class	Slope %	
	BRG 8	BRG 11
A	0 - 5	0 – 5
B	5 - 10	5 - 10
C	10 - 12	10 - 12
D	12 – 20	12 – 20

The tables that summarize the results of the assessments for the crop requirements for the relevant land resources are given in Appendix III.

4.4 Mapping of Land Resources

4.4.1 Mapping Climatic Variables

The climatic variables such precipitation and rainfall varies over space and topography (Bryan and Adams, 1999). Therefore, a good understanding of the spatial variability in climatic conditions is the solution to agricultural and natural resource management activities. The only source of climatic data presently available are the meteorological, that only provides data for single locations and for this reason, an accurate estimation of climatic parameters for areas in involving meteorological stations is always required.

The interpolation method was used in this study to map climatic variables from point data sources of meteorological stations to produce a continuous surface map of climatic variables. Burrough and McDonnell, (1998) defines interpolation as a process utilised to convert data from point observations to continuous surfaces so that the spatial pattern sampled from these measurements can be compared with the spatial entities.

The data comprises of different climatic parameters at a grid of 1' x 1' latitude longitude horizontal interval. These attributes include altitude, latitude, longitude, continentally, aspect, terrain roughness and topographic exposure. This was based on data that was recorded approximately over twenty years ago at various stations by regression analysis against several locational, physiographic and climatic attributes (CCWR, 1989). These attributes include altitude, latitude, longitude, continentally, aspect, terrain roughness and topographic exposure. This climatic data comprises of different climatic parameters at a grid of 1' x 1' latitude longitude horizontal interval grid format. This is a coarse spatial resolution for the Nkwezela area and where reference could only be made in areas of 1' x 1' latitude and longitude intervals. Therefore, in order to make a continuous surface of a better-quality continuous surface from the original data, ArcGIS 9.0 GIS's mapping and interpolation functions and capabilities were used.

Alternative quantitative climatic surface interpolation methods have become possible by using point-based climatic data within a GIS (Bryan and Adams, 1999). A number of interpolation methods are available from ArcGIS 9.0 (ESRI, 2004c). Although none of these methods can be considered as the most preferred method for all types of data and situations, the selection of a suitable technique is based and reliant on the actual data, the required level of accuracy, time and resources available at the time.

Surface interpolation uses a defined set of all the samples to estimate each of the output grid's cell values. The Spatial Analyst Extension of ArcView 3x and ArcGIS 9.0 provides four interpolation methods namely, IDW, Spline, Kriging and Trend with each of the four interpolation methods using a different approach to determine the output cell values for a selected set of sample points for the distribution of sample points and the phenomena being studied.

The Spline and Inverse Distance Weighting (IDW) interpolation methods were utilised to evaluate their relative efficiency quantitatively by comparing them with original datasets in order to sustain the actual measurement of climatic variables in the resulting surface.

The IDW interpolation determines cell values by using a linearly weighted combination of a set of sample points by a nearest neighbour or a fixed radius, where the input points influence diminishes with distance. The surface being calculated should be a locationally dependent variable. Constraints or barriers such as rivers and ridges can be selected from another layer, which the IDW interpolation technique considers during the interpolation process. An advantage of the IDW technique is its sensitivity and efficiency that gives the best results in evenly distributed points. In comparison to the Spline technique, IDW is sensitive to outliners and randomly distributed data clusters results in introduced errors (Anderson, 2000).

The Spline technique is like fitting a rubber sheet around sample points over a minimum curvature surface through input points and is mostly used for gently varying surfaces such as elevation by using a mathematical function (Anderson, 2000. Increasing the number of points creates smoother surfaces, and this increases the computation time (ESRI, 2004c). This technique can generate accurate surfaces from a small number of sampled points and can maintain small features, which is an advantage. A disadvantage is that it could have different minimum and maximum values than the dataset, which is sensitive to outliners due to the addition of original data values at the sample points (Anderson, 2000).

4.4.2 Comparison of Interpolation Techniques

The relative accuracy of the interpolation methods was evaluated by comparing the original data values using a GIS's surface interpolation techniques. The IDW and Spline methods of interpolation were used to calculate the differences between of the interpolated and original data values of the different climatic variables. The method that showed the lower differences was considered to be relatively more accurate.

The IDW method was used for all the climatic variables because it resulted in lower differences between the original data values and the interpolated values than the Spline method. The comparison of the maximum and minimum values of the interpolated surfaces with the original data indicates and confirms that the IDW method had relatively lower ranges. A comparison of the maximum ranges of the selected variables using both the methods is illustrated in Table 4.7.

The relatively low differences obtained between the original data and the interpolated data using the IDW method, can be attributed to the fact that the data sources used for the interpolation was equally spaced out using a grid system of 1.6 km x 1.2km point system in which the IDW is supposed to produce more accurate results. (Burrough, 1986, ESRI, 2004c). The IDW interpolation method was used to create a continuous surface of the climatic variables for the study area based on the comparison shown in Table 4.6.

Table 4.7 Comparison of differences in values between the original values and the interpolated values using Spline and IDW interpolation methods using for selected climatic variables

Interpolation Method	**Maximum Temperature**	**Minimum Temperature**	**Solar Radiation**	**Mean Annual Precipitation**
Spline	27.80	1.20	304.97	1088.899
IDW	26.89	1.05	281.69	1073.99
Original Values	26.90	1.20	281.70	1080.00

The IDW method also showed that as the weighting power increases, the smoothing increases and the differences between the original data and the interpolated data also increases. A weighting power of 2. 12 neighbouring points and a cell size of 30 pixels was used, which resulted in better results in smoothing and the retention of the original data. This was because the higher powers resulted in less influence of the data points and the lower powers over estimated the influence of the data points. (ESRI, 2004c).

4.4.3 Soils Map

The extent of the study area was based on Nkwezela, which falls within the Polela tribal ward. Soils data was extracted from the soil type's dataset, land cover dataset; land potential dataset, and arable lands dataset (Guy and Smith, 1998), was obtained from Natural Resources Section of the DAEA in ArcView shapefile format in geographic projection.

The shapefiles were reprojected to Transverse Mercator L031, Cape Datum and selecting the Polela tribal wards and exporting the study area shapefile using ArcGIS 9.0. The ArcGIS 9.0 Geoprocessing Wizard was then used to clip out the soils dataset, land cover dataset and the land potential dataset based on the study area shapefile.

In addition, a soil survey of forty four sample points was obtained to complement the soil type's map to determine chemical and physical properties of the study. This map was created by generating a 1km x 1km grid in AutoCAD 2000 (AutoDesk, 1982-2000) and then converted to ArcView Shapefile format using the Add XY Data function in ArcGIS 9.0 (ESRI, 2004a). These points were then used with the Trimble GPS to locate the points on the ground, from which soil samples were taken. The results of the soil chemical and physical characteristics are discussed in section 5.1.2. The results of the soil chemical and physical analysis were used to add more information to soil types dataset, as this table was added to fields dataset that shows the points that were captured by GPS and converted to an ArcGIS 9.0 shapefile. The fields' dataset was then combined with the soil type's map to produce three additional datasets: final soils map, land potential map and a land use map. This is discussed in detail in section 4.6.

All the relevant attributes for the soil characteristics for the description of soil forms and for the evaluation of agricultural potential of the soil units, that include chemical and physical properties Table 5.1 was converted from MSExcell format to Dbase IV and converted to ArcGIS shapefile format using Add XYData in the geographic projection which was then reprojected to transverse mercator using the projection wizard in ArcToolbox.

4.4.4 Topographic Mapping

A contour map with a four metre contour interval was created from the altitude map which was initially generated from an ASCII file which contains X, Y and Z values at intervals of 4m horizontal distances into a shapefile format using the AD XY Data, which resulted in a finer and more accurate representation of the topography of the study area. This data was in the Geographic Projection Cape Datum and reprojected using the projection wizard in ArcToolbox to Clark 1880 Transverse Mercator with the central meridian of LO 31. From this dataset a Tin, Aspect, Slope and DEM maps were created.

In terms of agricultural planning the slope is classified as 0-4%, 4-8%, 8-12%, 12-16%, 16-20% and greater than 20% in order to determine the best slopes for agriculture. This slope classification was obtained from Mr R. Bennett, Natural Resources Section, DAEA, Cedara in Pietermaritzburg. Table 4.8 shows slope classification as percentages into 6 equal intervals were derived from the Soil Conservation Act Recommendations.

Table 4.8 Slope Classification.

Slope %	Classification	Description	Land Use
0-4%	S1	Highly Suitable	Crops
4-8%	S2	Suitable	Crops
8-12%	S3	Moderately suitable	Crops
12%-16%	N1	Marginally suitable	Pastures and trees
16-20%	N2	Limited suitability	Pastures and trees
>20%	N3	Permanently not suitable	Grass and pastures

The suitability classes were derived from the methodology discussed in section 2.5.2, The FAO *Framework for Land Evaluation* (FAO, 1976) land suitability classes was used to correlate the slope classes in Table 4.5 to the land evaluation of the study area.

The slope percentage classes and their ratings, was obtained from the Soil Conservation Act Recommendations was correlated to the land potential requirements that are used by the Natural Resources Section of the DAEA , who also uses ratings shown in Table 4.7 to determine land potential for KZN by using ArcGIS 9.0. (ESRI, 2004c).

The IDW interpolation technique was used to estimate the values of points to create a continuous DEM. Section 4.4.2 discusses and shows a comparison of the IDW and the Spline methods of interpolation that were used to determine the accuracy of the original datasets. It was observed in the interpolation of climatic data, the IDW method is relatively more accurate than the Spline method and as a result, the IDW method was used in the interpolation of topographic data.

4.5 Suitability Evaluation Procedure

Generally, the FAO *Land Evaluation Framework* (FAO, 1976), discussed in section 2.5.2 is the most the extensive land evaluation system used. The evaluation practice was adapted in this assessment with some slight modifications according to the aims and objectives of this study and the local conditions.

The land qualities were compared with the crop requirements in order of their importance for the crops measured in the FAO Agro-Ecological Zoning evaluation method (FAO, 1996). The climatic conditions were compared with climatic requirements. The areas that did not suit the climatic requirements for each crop in the study area were classified as *"Not Suitable"* and were excluded from any further analysis and if the climatic conditions satisfied the crop requirements, then these areas were considered for further assessment
Next, the soil units in the area were then matched to the crop requirements of each crop to determine for the soil resources. The crop requirements for each of the selected crops were based on the climatic, topographic and soil parameters of the study area. The evaluation of the soil resources were based on soil form, effective depth, texture, surface rockiness, fertility status and other chemical and physical properties. The soil characteristics were rated according to their suitability for each crop considered. The suitability rating of the soil units was then modified according to other significant soil limitations imposed by slope, depth, texture, and fertility status.

The suitabilities of the individual land qualities were then combined to provide an overall suitability of the land resources for each crop.

There are different ways used to combine individual suitability ratings recommended by the FAO *Guidelines Land Evaluation for Dryland Agriculture* (FAO, 1983) and the FAO *Guidelines Land Evaluation for Irrigated Agriculture* (FAO, 1985) identifies four different ways to combine the individual suitability ratings:

1) *Subjective combination*: defines overall suitability based on the understanding of the interaction between land qualities.
2) *Limiting combination*: rates all land qualities measured to be of same importance and a limitation in one land quality limits the overall suitability.
3) *Arithmetic procedures*: a value is assigned to each suitability class whereby the overall suitability is obtained by multiplying or adding values.
4) *Modelling method*: uses models that relate crop requirements to land qualities to predict crop yields based on their interaction.

In this study the limiting combination method was used because it takes the least favourable resource as a restriction (FAO, 1983). This is the simplest method as it does not consider the complicated interactions between environmental factors and their effects on land potential. Nevertheless, it has a number of advantages in this study. Initially the suitability of the area for agriculture was evaluated and therefore any climatic risks or uncertainties were excluded. Therefore, any part of the study area with one or more unfavourable land qualities was evaluated as "*unsuitable".* Furthermore, land qualities evaluated in this study are major and most limiting where the absence of one land quality could not be comprised by the good condition of another land quality. This means that having satisfactory rainfall could not improve the suitability of the soils in the area and that all the soil, topography and climate were rated individually and that the overall suitability will be the suitability of the *least suitable* land quality.

In order to derive meaningful information, which can be used in the evaluation of land suitability, a powerful analysis technique is required to integrate information from the land resources mapping and crop requirement assessment. Therefore, a GIS (ArcGIS 9.0) was used in this study to identify areas that satisfy the lower limits of crop requirements for each of the mapped land resources.

The Spatial Analyst Raster Calculator in ArcGIS 9.0 (ESRI, 2004c) was used to overlay the climatic variables, soil variables in an overlay analysis process from the interpolated data to create a climatic suitability and a soil suitability raster datasets. These two datasets were then combined with the topographic dataset to create an overall suitability. The Reclassify command in Spatial Analyst was used to select the crop requirements that matched the requirements by using the Boolean method where the suitable criteria was given a value of 1 and 0 for the unsuitable criteria.

In ArcGIS, the "*limiting combination*" method of suitability was applied by using a Boolean overlay analysis, where the thematic layers of the selected crops were overlayed to select areas that satisfied the lower limits of the crop requirements. The *intersection* "*AND*" operation was used to select areas where the suitabilities of all land qualities were satisfied. Figure 4.5 shows a flow diagram of the operations utilised in the land suitability evaluation.

The land evaluation method developed by the FAO F*ramework for Land Evaluation* (FAO, 1976), expresses qualitative land suitability in descriptive terms as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently unsuitable (N1) and potentially unsuitable N2). In this study, this classification structure was adapted to classify Nkwezela into different suitability classes for subsistence agriculture. As most of the crop requirements data obtained from the literature do no provide information on the limits between crop requirement rating N1 and N2, suitability classes N1 and N2 were not differentiated in this study because of a lack of readily available crop requirement information.

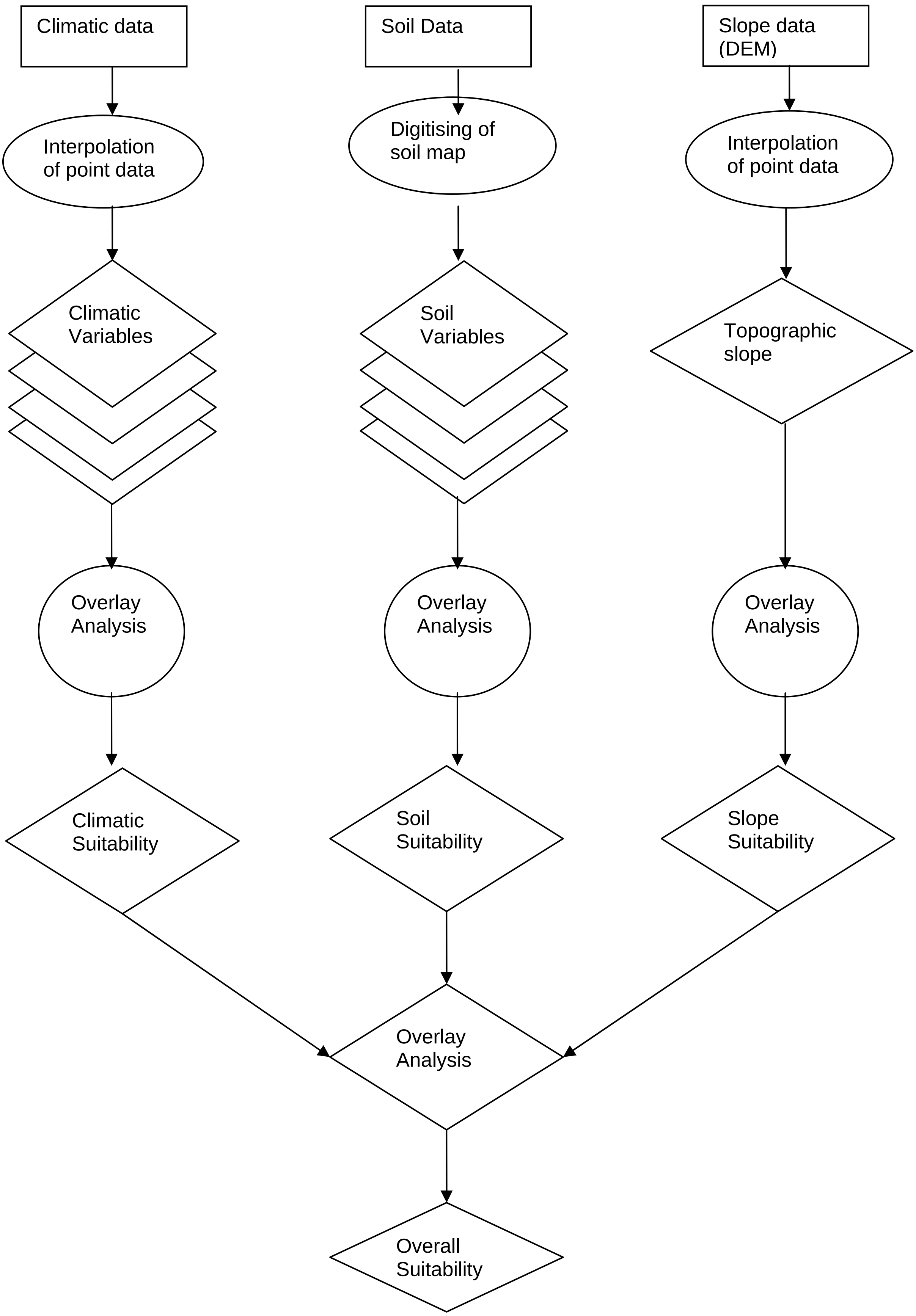

Figure 4.5 Flow Diagram showing the procedure to create the land suitability maps using the FAO land suitability evaluation procedure.

4.6 Summary

The climatic, soil, topographic and crop requirement datasets used as the basis of a land suitability evaluation in this study were obtained from different existing data sources and field surveys were undertaken as part of the study. The datasets were assessed using a GIS to facilitate and derive accurate mapping of the land resources for additional analysis in order to obtain a land suitability evaluation of the study area. The land resources dataset (climatic, soil and topographic) and the crop requirement datasets were integrated into a GIS for the analysis stage by the utilisation of the analysis functions of the GIS. The land resources were then correlated and matched to the suitability ratings on their capability to satisfy the relevant crop requirements.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Inventory of Land Resources

5.1.1 Climatic Resources

5.1.1.1 Precipitation

Precipitation is a broad meteorological term which refers to the moisture obtained from rain, hail, mist dew and frost, from which rainfall is the main source of water for plant growth and the only form for which comprehensive records are achievable (Camp, 2002). Therefore, the assessment of moisture availability in this study is based on the amount of rainfall, which has been discussed in section 4.1.1.1 and that mean rainfall may not necessarily be a constraint to plant growth. One should depend on and use median values to evaluate rainfall in an area for agricultural production. A comparison between the mean and median rainfall values of the year in the Nkwezela is shown in Figure 5.1.

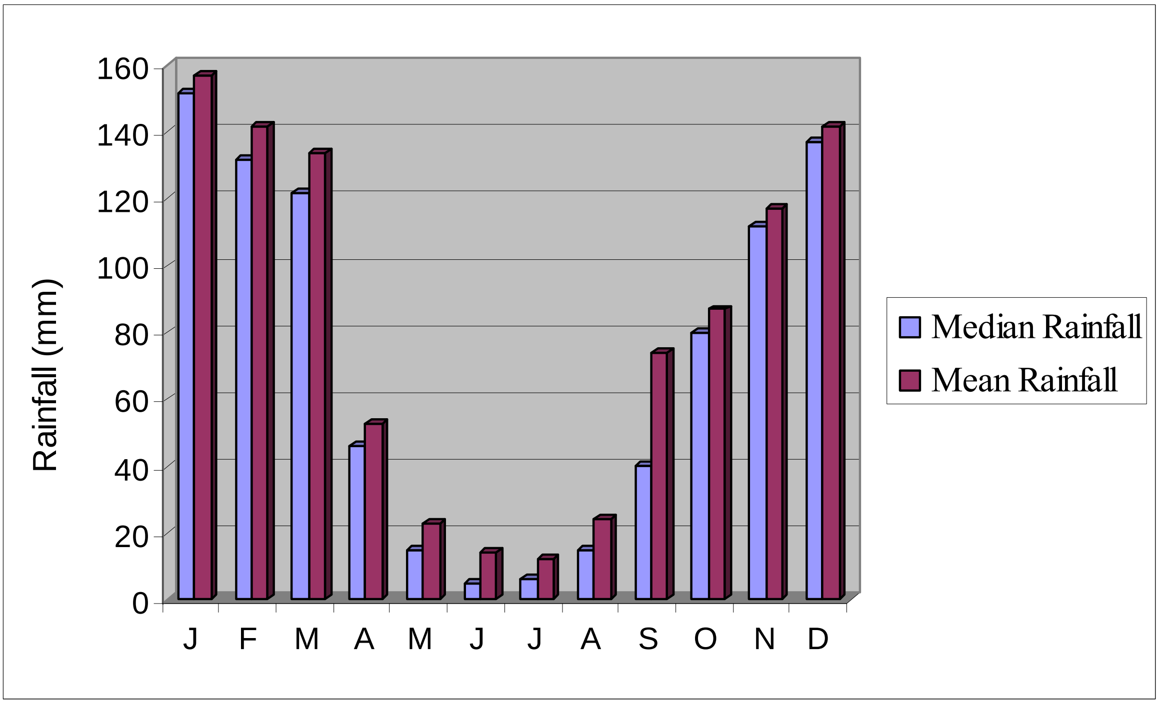

Figure 5.1 Comparison of monthly mean and monthly median rainfall statistics in Nkwezela.

The comparison in Figure 5.1 shows that mean annual rainfall values is higher than the median rainfall values throughout the year. This is generally true for the drier months, during which intermittent high rainfall occurrence increases the mean rainfall values while most days of the month are without any rainfall occurrence, whereas the median values are always the middle values and there are as many days in the month with rainfall records greater than the median as there are with less than the median values.

Figure 5.2 shows the spatial distribution of the mean annual rainfall at Nkwezela. The highest rainfall of 1039mm to 1082mm is received in the northern and southern parts of the study area, and along the Luhane River, where the highest rainfall of 1082mm is received. The lower rainfall of 870mm to 946mm is received towards the western side of Nkwezela, where the lowest rainfall value of 870mm is recorded (Figure 5.2).

The mean annual rainfall map shows circular patterns in some areas of Nkwezela, The reasons for these circular patterns are possibly due to the fact that the IDW interpolation method was used in Spatial Analyst (ArcGIS 9.0) to map the spatial distribution of the climatic and topographic parameters (see section 4.4) and is susceptible to the grouping of values in the original data points (Burrough, 1986; Mitas and Mitasova, 1999). The interpolation technique used to generate data has produced these circular patterns in the maps.

Annual rainfall values do not necessarily reflect moisture deficit in the soils. The distribution of the median rainfall, evapotranspiration and CV% for the months of the year is shown in Figure 5.3. Figure 5.3 shows the distribution of the three climatic parameters (median rainfall, evapotranspiration, and CV %) during the year and it also shows the evapotranspiration factor ($0.3E_{r}$) which is used to establish the months of the growing period according to equation 4.2. According to Figure 5.3, a month is considered part of the growing period if its median (red bar) is greater than or equal to one third of the potential evaporation (blue bar) which is illustrated by the yellow line ($0.3E_{r}$). This chart, which also shows the growing season in Nkwezela, starts in October and ends in March, a period of approximately 180 days

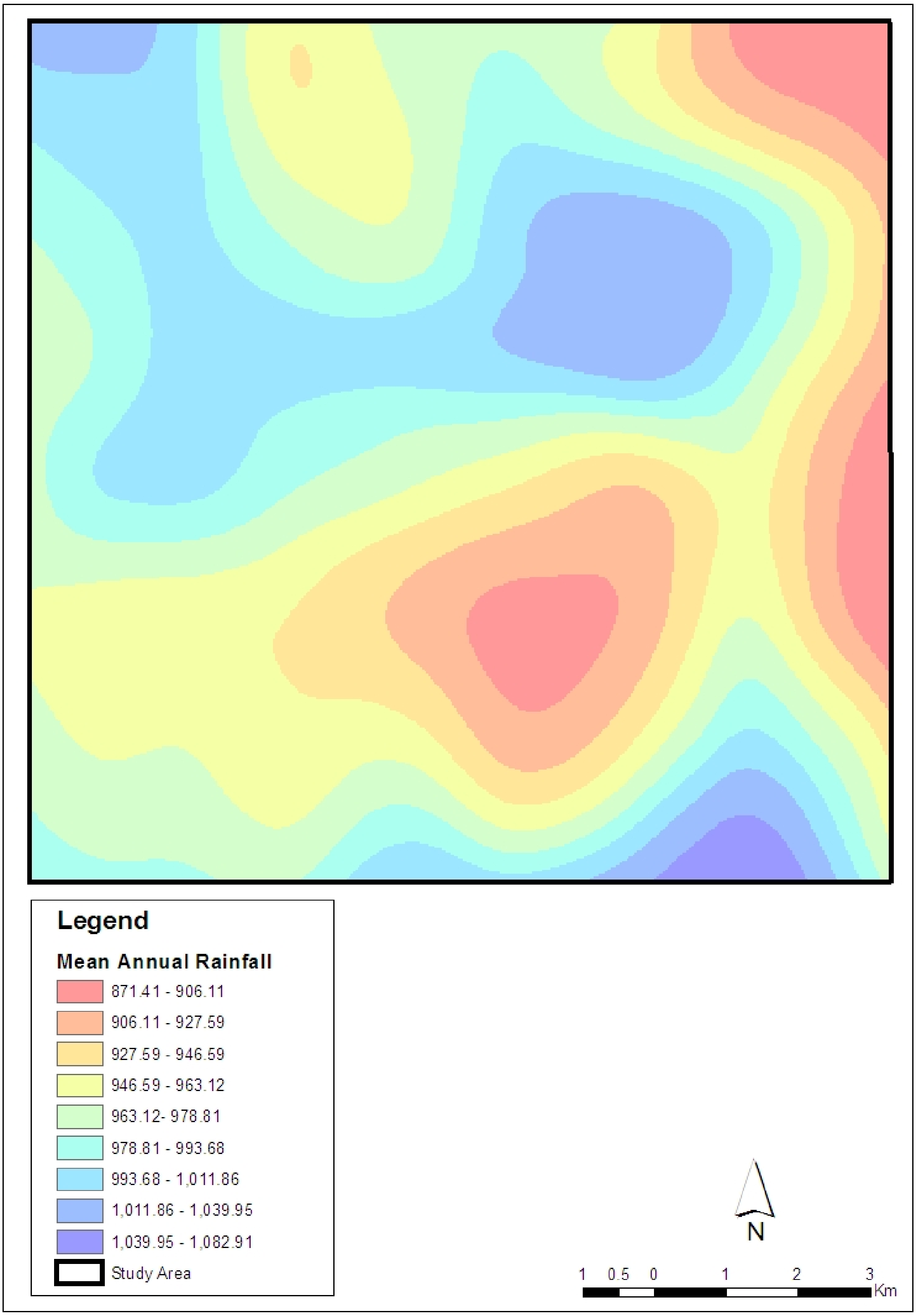

Figure 5.2 Spatial distribution of the mean annual rainfall in Nkwezela.

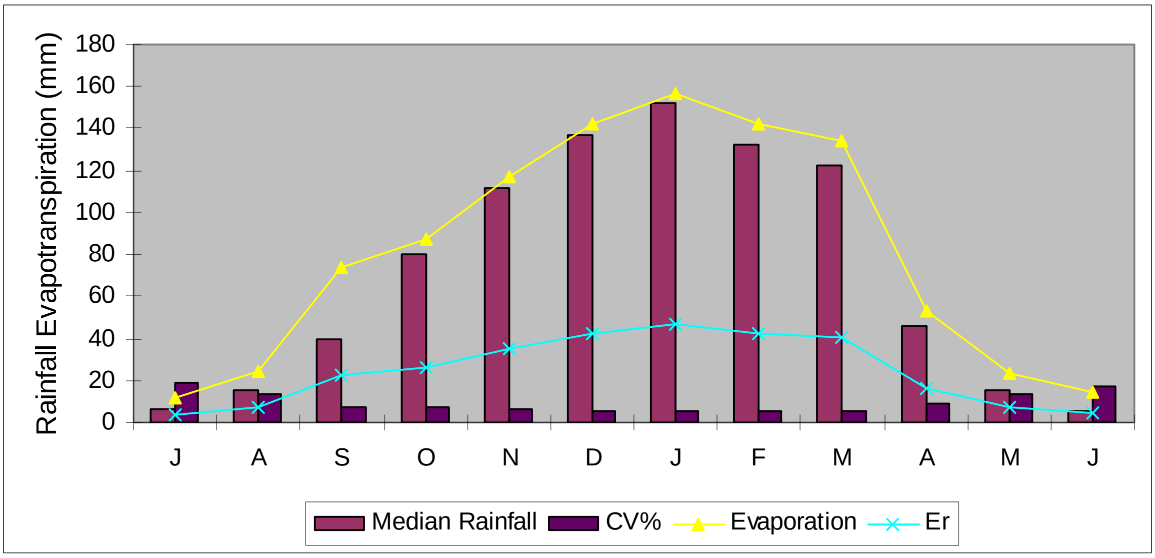

Figure 5.3 Distribution of the three climatic parameters (Median Rainfall, Evapotranspiration and CV% for the year and an evapotranspiration factor for the determination of the length of the growing period (0.3Er).

Figure 5.4 shows the spatial distribution of median rainfall of the growing period in Nkwezela. The spatial distribution of the median rainfall is similar to the spatial distribution of the mean annual rainfall, with minimum values of 775mm in the western parts and maximum values of 971mm in the southern parts of the study area respectively.

The rainfall in Nkwezela is characterised as highly seasonal, as 80% of the total mean annual rainfall occurs between October and March. The rainfall in the study area has an annual coefficient of variability (CV %) of 24% which is calculated according to Equation 4.1 from the mean annual rainfall of the study area, which is 970mm. This indicates that the rainfall in the study area is relatively high between October to March and relatively low in the drier months of April to August.

5.1.1.2 Evapotranspiration

In arid and semi-arid areas, a high proportion of the total amount of precipitation is lost to the atmosphere by evapotranspiration. In South Africa approximately 91% of the mean annual precipitation (MAP) is lost by evaporation. This is considerably higher than where worldwide 65% of the MAP (Schulze, 1997). Therefore, in order to achieve optimum plant growth, the precipitation in an area is necessary to exceed a certain threshold value,

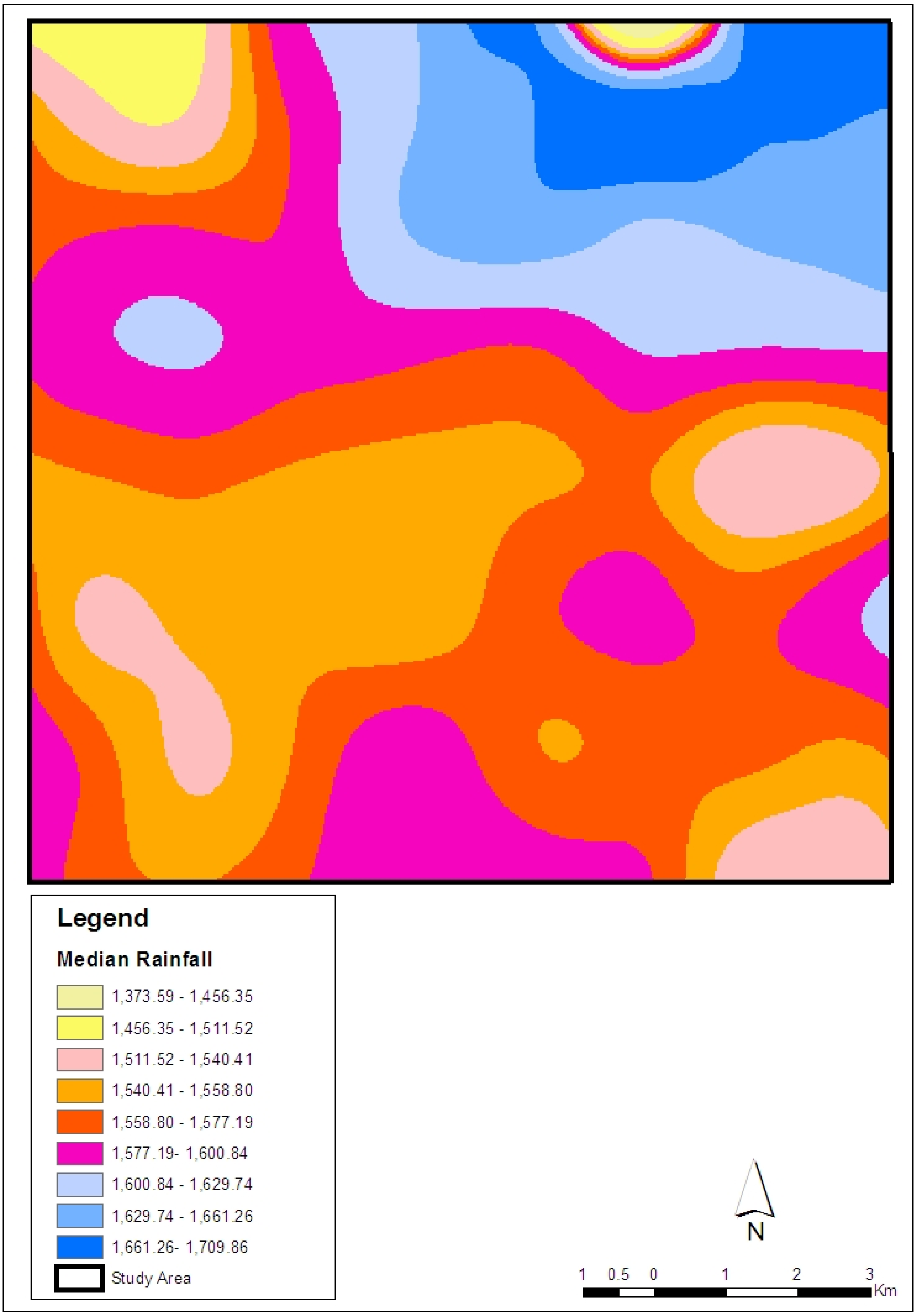

Figure 5.4 Spatial distribution of the median rainfall of the growing season in Nkwezela.

where moisture deficiency due to evapotranspiration can be retained by plants. The threshold in southern Africa is considered to be one-third of the evapotranspiration (Schulze, 1997).

According to the equation 4.2 in section 4.2.1.2, the threshold where the precipitation exceeds one-third of the evapotranspiration starts in October and ends in March as shown in Figure 5.3. This period is referred to as the growing period (FAO, 1978; FAO, 1983).
The precipitation during this period is high enough to guarantee that the soil moisture deficit due to evapotranspiration is low so that optimum plant growth can occur.

5.1.1.3 Temperature

Temperature is the most important climatic factor to be considered for vegetable production and it determines where a specific crop can be grown. The three temperature statistics of the months of the year (mean monthly minimum, mean monthly maximum, and the mean monthly temperature) for Nkwezela are illustrated in Figure 5.5. The summer temperatures are hot, with mean monthly temperatures ranging from 27ºC during October to 30ºC during February. The mean monthly minimum temperatures in the study area vary from 13ºC to 16ºC, with minimum monthly temperatures ranging from 0.4ºC during June to 11.2ºC during February.

The spatial distribution of the mean monthly maximum and the mean monthly minimum temperatures are illustrated in Figures 5.6, 5.7 and 5.8. The low elevation regions of the study area have higher temperature values for all three-temperature statistics, which is due to the extreme topography of the study area. The high elevation areas are generally associated with the low temperature values in Nkwezela. The summer months (October to March) are hot with the mean monthly maximum temperature values ranging from 22ºC in October to 24ºC in March. The mean monthly temperature values vary from 15.5ºC in October to 18ºC in March. The remaining months of the year are cooler with June, July and August being the coldest months.

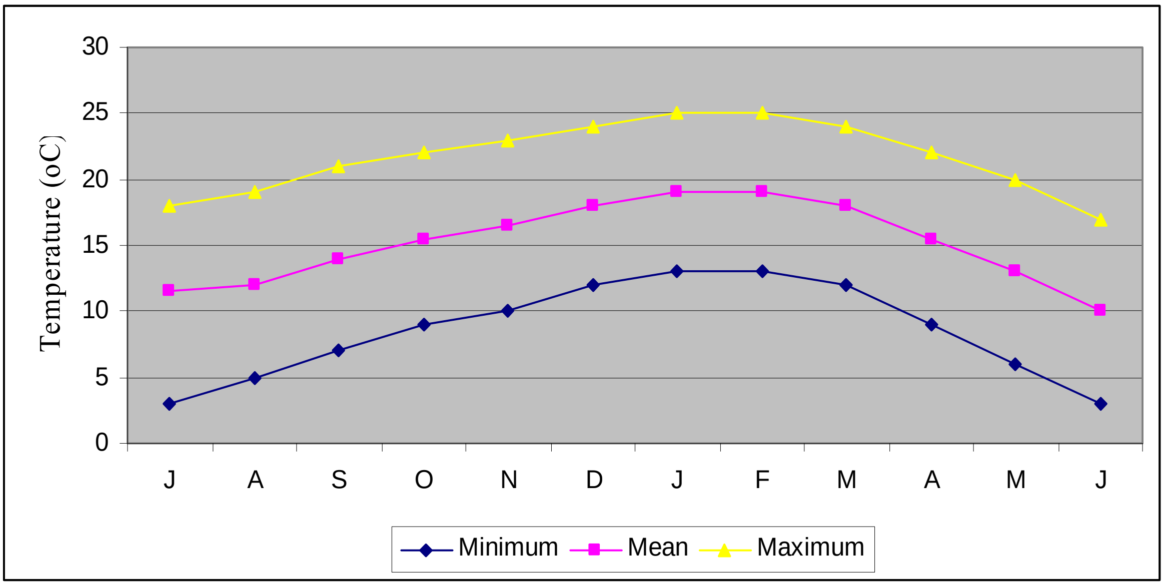

Figure 5.5 Mean monthly minimum, mean monthly and mean monthly maximum temperatures of months in the year in Nkwezela

The spatial distributions of the mean monthly, mean monthly maximum and mean monthly minimum temperatures of the months of the growing season are shown in Figures 5.6, 5.7 and 5.8 respectively.

5.1.1.4 Heat Units

Figure 5.9 displays the spatial distribution of the heat units (base of 10ºC) for the growing season in Nkwezela. The heat unit's values range from 1680 to 2280. High values of heat units are generally correlated to areas with high temperatures. Therefore, the low elevation areas result in higher heat units as compared with areas with higher topography.

The climate in Nkwezela is characterised by hot, wet summers and dry cold winters. The rainfall is seasonal with approximately 80% of the rainfall occurring between October and March. The spatial variables in the rainfall parameter are generally high in conjunction with the high altitude values in the study area (see Figures 5.2 & 5.4).

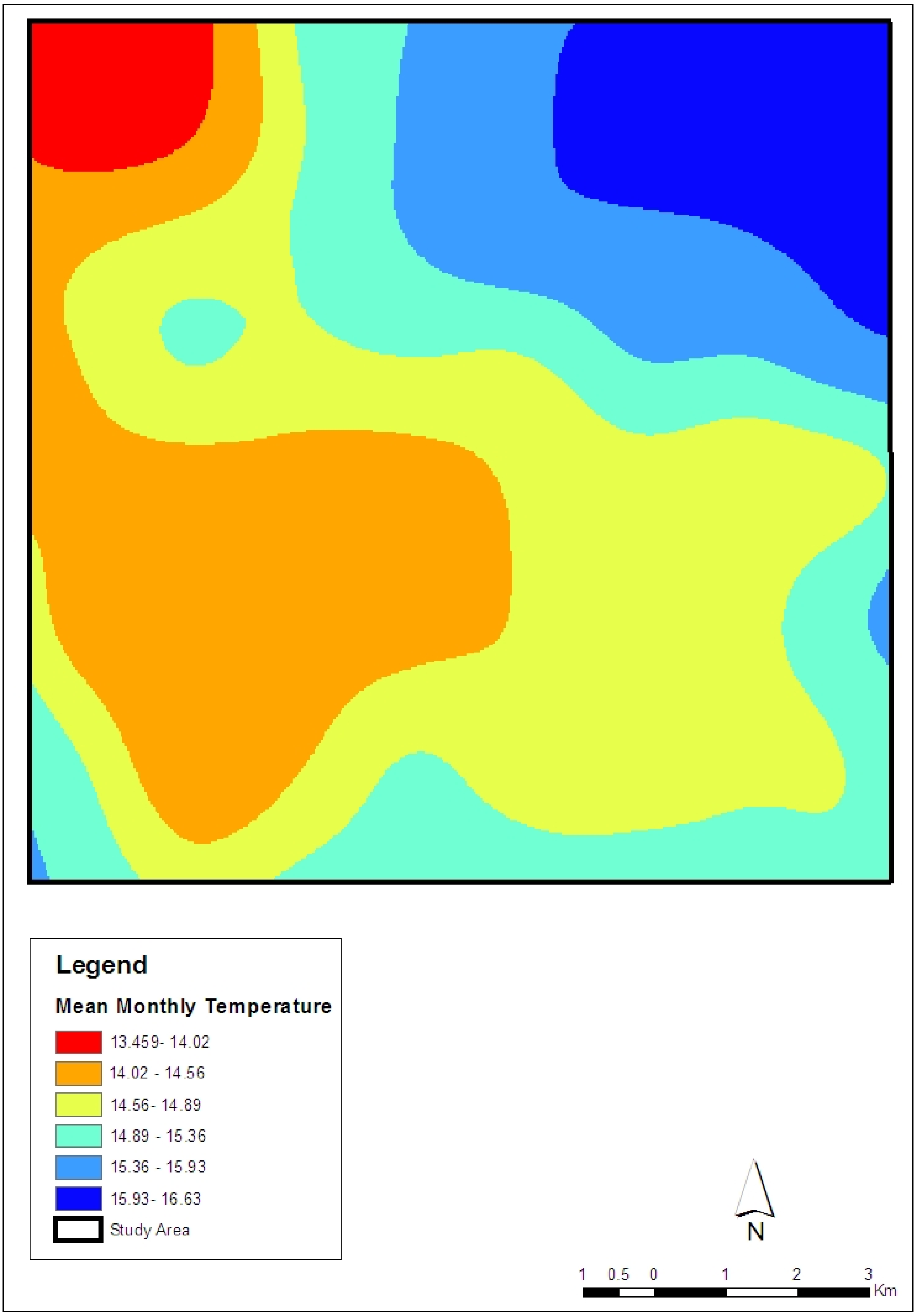

Figure 5.6 Spatial Distribution of the mean monthly temperature of the growing period in Nkwezela.

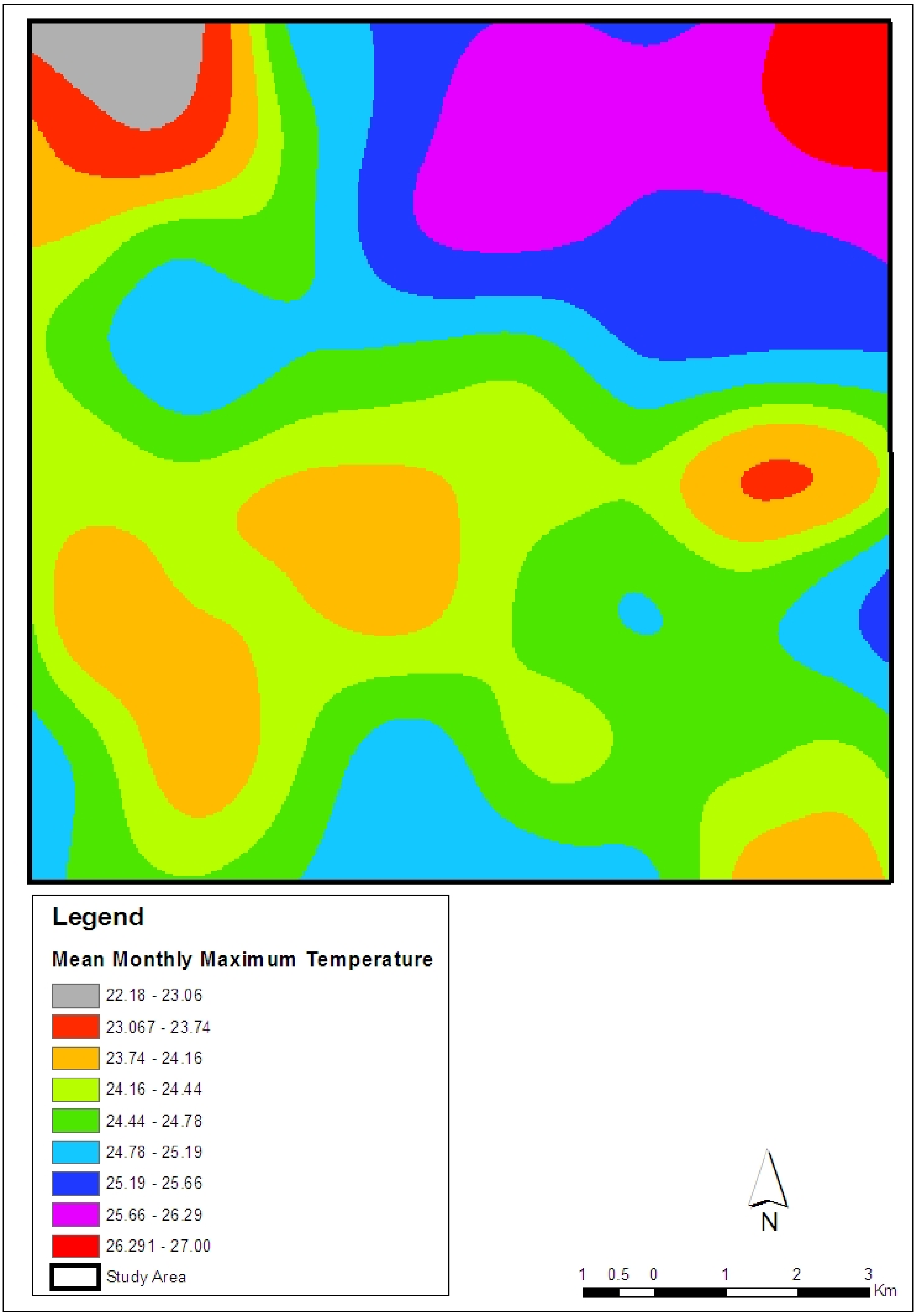

Figure 5.7 Spatial Distribution of the maximum monthly temperature of the growing period in Nkwezela.

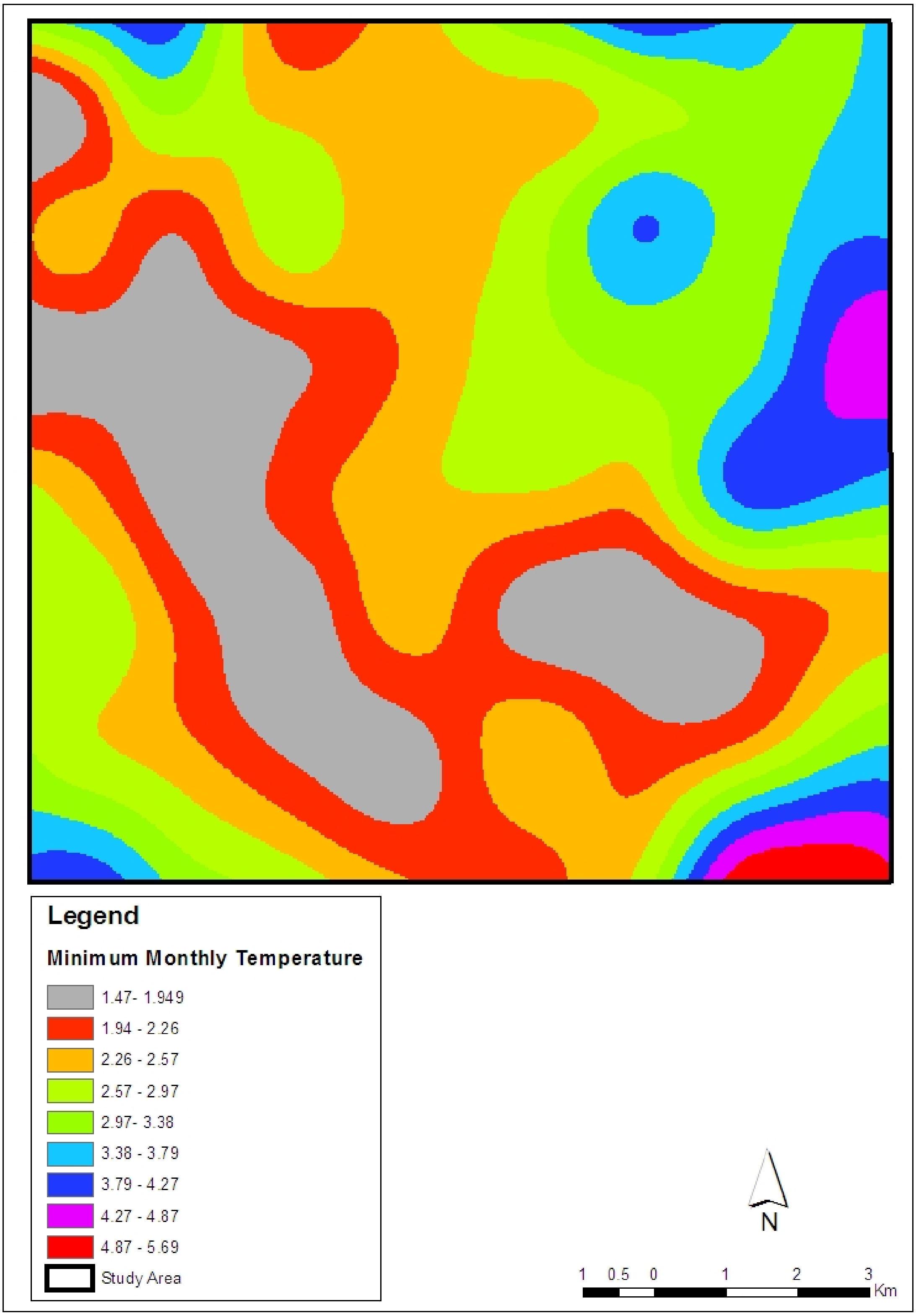

Figure 5.8 Spatial Distribution of the mean monthly minimum temperature of the growing period in Nkwezela.

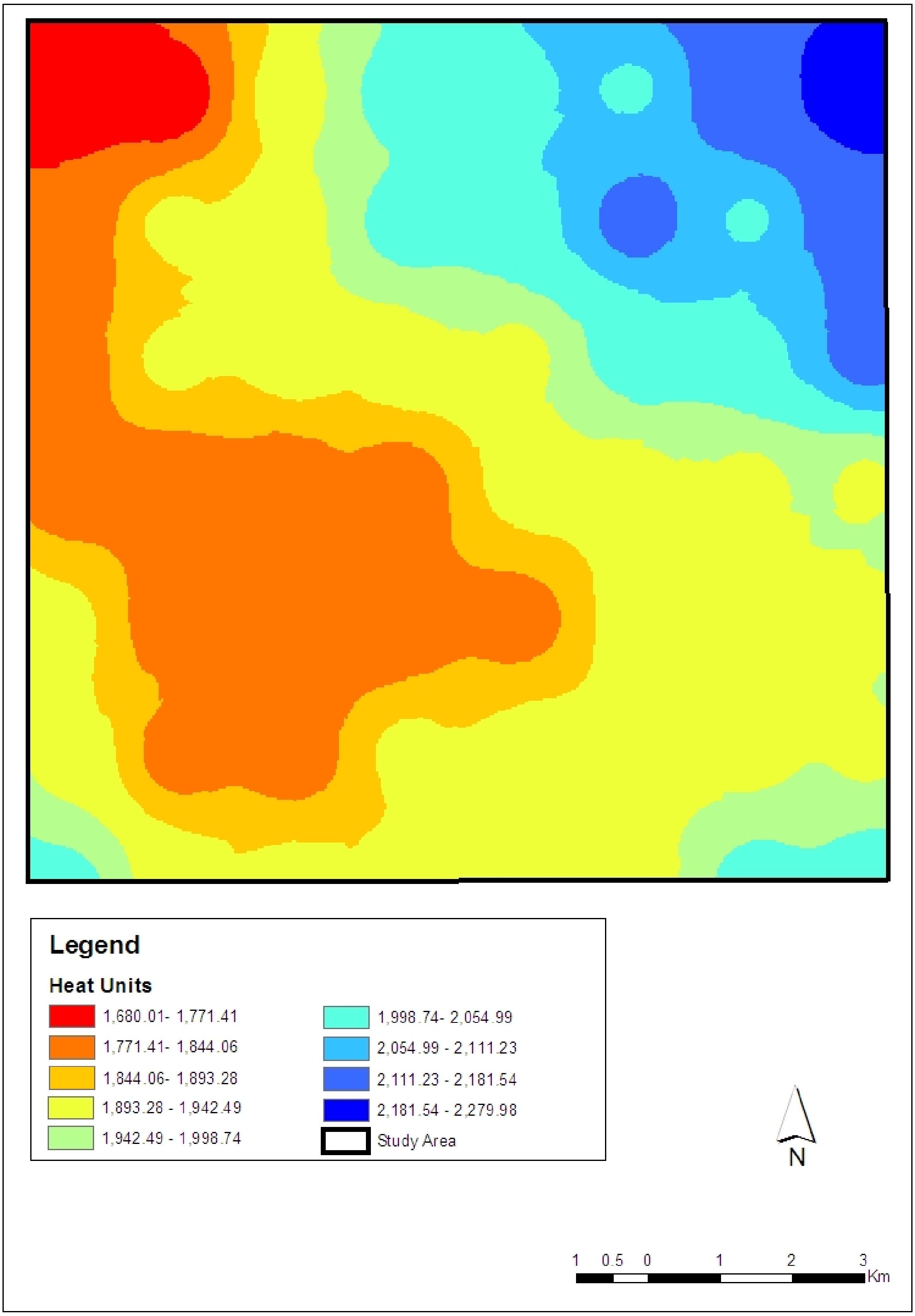

Figure 5.9 Spatial Distribution of the heat units of the growing period in Nkwezela

This could be attributed to the physiographic features of continentally and altitude, which were some of the factors that were used in the modelling of the rainfall information (CCWR, 1989; Dent *et al*., 1989). The spatial variability in the temperature regime follows the topography of Nkwezela with relatively low temperatures in the high elevation areas and relatively high temperatures in the low elevation areas. The seasonal variations in rainfall and temperature conditions are primarily due to the general circulation of atmospheric conditions (Camp, 2002).

5.1.2 Inventory of Soil Resources

Figure 5.10 illustrates the soil forms of the study area and classifies Nkwezela into soil form and depth classes, which is based on the *Binomial Soil Classification for South Africa* (MacVicar, 1977; MacVicar, 1991). Appendices Ia, Ib and Ic provides a brief description of the soil forms in the study area and their correlation to the FAO soil units illustrated in respectively. The soils types map is supplemented by an analysis of the soil chemical and physical properties of the study area to evaluate the potential of soil units for sustainable agriculture. The *soil forms* (units) have been defined in terms of measurable and identifiable properties of soil. In terms of the FAO, 1978, many of the soil properties are relevant to soil use and production potential and consequently have a practical application value. Accordingly, the distinguished soil units on the soil map of Nkwezela have values to predict the optimum use of soils. Table 5.1 shows the results of soil analysis undertaken in the study area and section 5.1.2.1 discusses the interpretation of the results.

The soils in Nkwezela comprises mainly of dystrophic soils, which occurs in a high rainfall area and red and yellow soils that are well leached (Figure 5.10). Therefore the soils are humic, well drained, strongly acidic and highly leached with a low fertility level (Guy *et al*, 1995). Generally they have a soil depth of $\geq$ 50mm and < 750mm with a clay content of $\geq$15% and <35%. In this study, the soil depth values range from 466mm to 911mm which can be rated as suitable as the crop requirements for the selected crops are within the range of 500mm to 1000mm.

Soil forms Ac is the most dominant soil forms in Nkwezela (see Figure 5.10 and Ib), which contains more than 2% organic carbon throughout a minimum depth of 450mm that accommodates very distinctive topsoils and are found in humid and cool misbelt area in

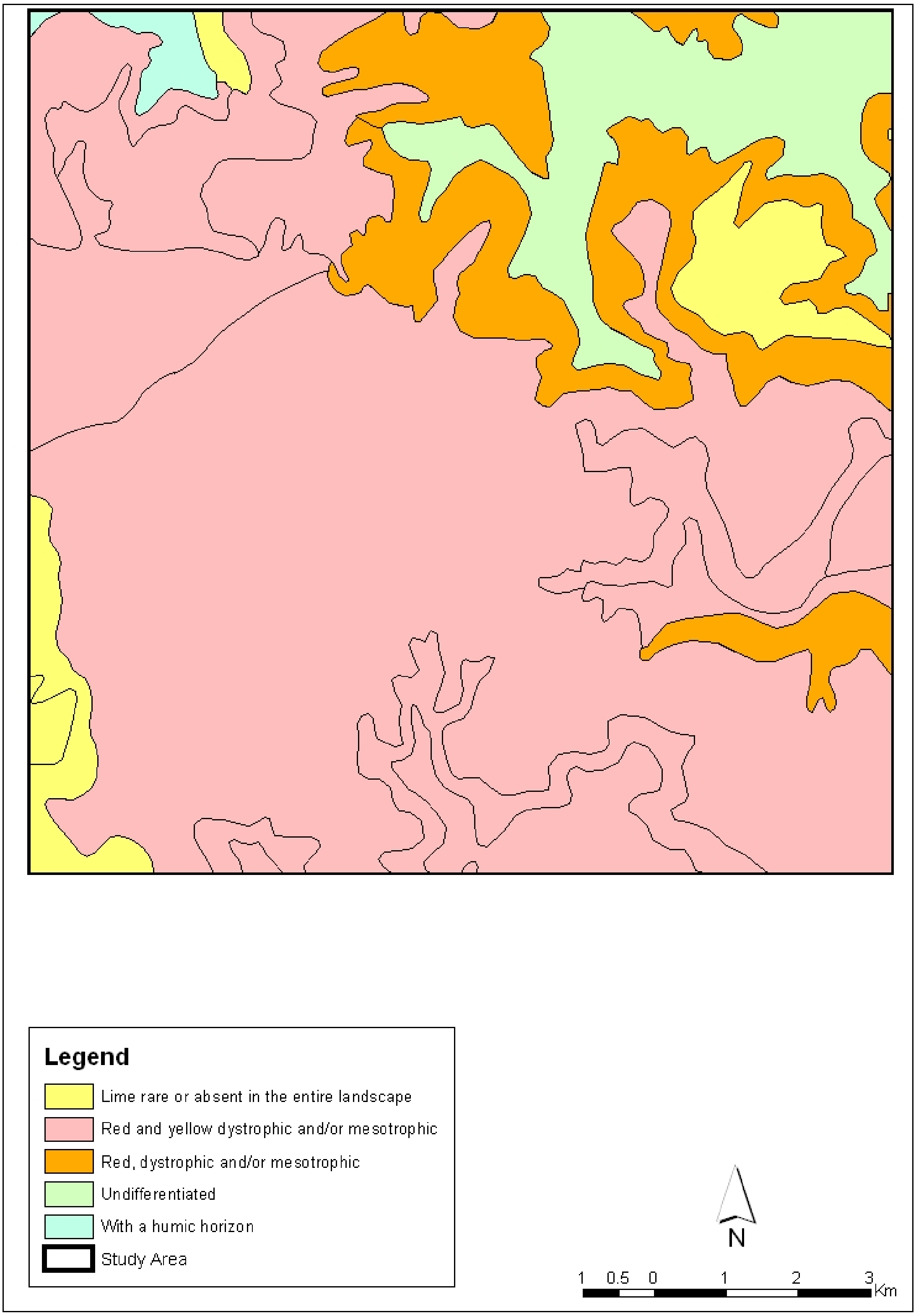

Figure 5.10 Soil Forms in the Study Area.

well drained upland area. Soil form Ac covers approximately 71% of the total area in Nkwezela (see Ib). Ea and Fa soil forms are found in the northern parts of the study area. The soils in the central part of Nkwezela are red-yellow well drained soils which are weak structured soils with a low to a medium base status, without lacks a strong texture contrast. The soil depth is ≥ 450mm and < 750mm with a clay content of ≥15% and < 35%.

The humic A horizon is defined to have low base status, freely drained topsoil horizons, which have accumulated comparatively large amounts of humidified organic matter in cool or cold moist climates. The external and internal drainage is good in the humic A horizon soils and contains in some part more than 1.8% organic carbon. It also contain less than 4 cmol(+) of exchangeable cations (Ca, , K, Na) per clay for every one percent of organic carbon present, with a high clay content

The E horizon is characterised by its greyish colour which is normally paler in colour than the overlying topsoil. This soil type may contain distinct streaking with a higher chroma matrix than that of periodic saturation with water It is also loose in the moist state, non-plastic and, when dry, can be very hard and brittle depending on texture. It has very weakly developed structures and usually does not have aeolian structures. The E horizon does not qualify as diagnostic regic sand.

5.1.2.1 Physical and Chemical Soil Properties

The capacity of soils to sustain plant growth depends on its physical and chemical properties as these properties verify the ability of soils to supply water and the necessary nutrients for plant growth. Table 5.1 illustrates the results of the soil analysis that was undertaken in the study area with the physical and chemical properties. Understanding of the crop requirements makes the interpretation of the physical and chemical soil properties meaningful, although some general interpretations and ratings can be derived.

Soil Texture

The particle size analysis shows that approximately 38% of the soils in the study area have clay percentages range from 40% to 49% and the rest of samples are in excess of 50% (see Table 5.1). Table 5.2 can be used as a guide to assess the analytical results of the soil particle size analysis.

Table 5.1 Chemical and physical soil properties

Sample No	Sample Density	P	K	Ca	Mg	Exchange Acidity	Total Cations	Zn	Mn	pH (KCI)	Acid Sat	Organic C	Clay	Cu
	Mg/L	Mg/kg	cmol(+)/kg								%			
1	0.84	3	94	621	67	0.59	4.93	4.6	9	4.34	12	3	60.2	2.7
2	0.76	3	185	417	174	2.22	6.21	1.1	9	4.08	36	5	>70	3
3	0.85	4	340	650	261	0.46	6.72	2.6	18	4.34	7	2.7	60.9	5.6
4	0.89	2	206	317	91	1.1	3.96	1.8	9	4.23	28	1.1	58.3	2.2
5	0.83	5	54	158	47	3.53	4.84	1.4	4	3.97	73	3.4	57.2	2.3
6	0.7	12	207	319	73	4.09	6.81	2.4	13	3.76	60	>6.0	55.1	1.6
7	0.85	8	186	236	60	3.32	5.47	1.4	13	3.73	61	4	59.7	1.6
8	0.85	8	219	288	105	2.48	5.34	4	7	3.97	46	2.3	55.7	2.3
9	0.74	6	48	159	21	2.74	3.83	1.9	8	4.13	72	4.5	52.8	2.9
10	0.81	5	108	78	28	4.18	5.08	1.1	7	3.82	82	4	61.3	2.7
11	0.87	6	260	145	72	3.83	5.81	0.9	10	3.79	66	3.3	58.6	1.7
12	0.89	3	104	283	98	2.22	4.7	2.2	6	4.08	47	2.9	55.6	1.9
13	0.73	5	42	58	21	2.67	3.24	1.4	7	4.17	82	1.65	48.9	2.2
14	0.85	6	251	813	123	0.92	6.63	1.4	24	4.2	14	3.1	47.5	2.3
15	0.79	4	268	239	196	2.37	5.24	0.7	5	4.02	45	4.9	69	1.9
16	0.83	6	93	89	32	1.97	2.92	0.9	11	4.17	68	4.1	56.8	3.5
17	0.85	4	111	149	53	3.16	4.62	1.2	9	3.94	68	3.3	67.6	2
18	0.89	6	157	286	91	2.17	4.75	8.5	11	3.97	46	2.7	61.4	2.9
19	0.8	6	87	127	38	1.88	3.05	1.8	6	4.15	62	4	55.3	2.9
20	0.85	3	75	220	67	1.27	3.11	1.2	3	4.17	41	3.2	64.8	3.3
21	0.86	2	210	532	323	0.18	6.03	6.5	28	4.51	3	<0.5	64.6	3.3
22	0.84	5	160	458	197	1.61	5.93	3	10	3.98	27	2.9	61	3.3
23	0.93	13	271	164	34	2.61	4.4	11	5	4.08	59	2.4	49	2.1
24	0.98	59	260	487	94	2.35	6.22	10.7	12	4.02	38	2.4	54	4.5
25	0.87	98	424	850	242	0.79	8.11	17	16	4	10	3.8	850	3.1
26	0.95	137	137	640	182	1.58	7.37	19.6	22	3.93	21	2.8	56	4.11

Table 5.1 continued

Sample No	Sample Density	P	K	Ca	Mg	Exchange Acidity	Total Cations	Zn	Mn	pH (KCI)	Acid Sat	Organic C	Clay	Cu
	Mg/L	Mg/kg	cmol(+)/kg							%				
32	0.91	14	223	261	56	2.67	5	2.7	3	4.08	53	2.7	55	1.5
33	0.96	10	332	321	68	1.44	4.45	3.9	2	4.21	32	2.1	52	2.1
34	0.89	32	332	420	76	2.77	6.31	9.4	6	4.11	44	3.4	45	1.4
35	0.89	32	332	420	76	2.77	6.31	9.4	6	4.11	44	3.4	45	1.4
36	0.91	6	194	313	86	3.03	5.8	4.3	10	3.94	52	2.6	54	1.4
37	0.86	11	280	279	183	0.6	7.85	2.9	0	4.58	8	4.4	53	2
38	1.02	20	237	369	77	1.78	5.2	12.9	4	4.15	94	3	51	1.4
39	1.06	35	571	665	171	3.08	9.27	33	3.91	21.1	16	2.1	39.1	2.2
40	1.02	64	205	924	422	0.86	9.47	9	4.77	2.0	3	1.5	43.3	1.2
41	1.05	4	469	765	180	3.38	9.88	34	4.05	3.3	15	0.5	37.7	4.1
42	1.05	17	189	691	261	0.23	6.31	4	4.79	4.6	3	0.9	32.7	2.6
43	1.11	25	280	575	98	1.33	5.72	23	4.19	10.5	6	1.8	32.8	3.4
44	1.07	10	192	522	196	0.6	5.31	11	4.49	3.4	3	2	37.3	1.5

These values show that the soils in Nkwezela are clayey in nature which can aggravate the vulnerability of the soils to erosion by water through the effect of reduced infiltration due to surface crusting. Nkwezela has a high clay content that ranges from 43% to 60%, which can be rated high to very high.

Table 5.2 Rating of analytical results of clay percentage (Adapted from Hazleton and Murphy, 1992).

Clay Content (%)	Rating
<10	Very Low
10-25	Low
26-40	Moderate
41-50	High
>50	Very High

Soil Nutrients

The guidelines used to assess the results of the soil analysis of the most common essential soil nutrients in Nkwezela are illustrated in Table 5.3. Although fertilizer requirements depend on individual crops, the analytical results show that the soils are rich in the base elements (K, Ca). The 50% of sample density values of the samples are <1.0 (0.8 -0.99) with a phosphorus content of >12 and a level of >100.

Table 5.3 Guidelines for rating the results of some soil nutrients (Adapted from Hazleton and Murphy, 1992).

Nutrient	Unit	Very Low	Low	Moderate	High	Very High
K	Cmol(+)/kg	0-02	0.2-0.3	0.3-0.7	0.7-2	>2
Ca	Cmol(+)/kg	0-2	2.5	5-10	10-20	>20
	Cmol(+)/kg	0-0.3	0.3-1	1-3	3-8	>8
CEC	Cmol(+)/kg	<6	6-12	12-25	25-40	>40
P	/kg	<5	5-10	11-17	18-25	>25

Cation Exchange Capacity (CEC) is an important measure of soil fertility status, it is the capacity of soils to retain and exchange cations and is a good indicator of soil fertility status, soil texture stability, and the main controlling agent of soil pH and soil reaction to fertilizers and other ameliorants (Hazelton and Murphy, 1992). Approximately 67 of the samples have low CEC values which are in the range of 6-12 cmol (+)/kg.

The phosphorous contents are extremely rich in almost all the samples. Approximately 72% of the samples in Table 5.1 have moderate to very high phosphorous contents (11 – 17 /kg) in most of the samples.

Soil pH

Table 5.4 can be used to interpret pH values measured in water using a ratio of 1:5. The pH measurements in this study were done in a chloride solution, where the pH values measured in chloride solutions were 0.5 to 1.0 units lower than the pH values measured in a water solution (Hazelton and Murphy, 1992). Adjustments were made to the pH values in Table 5.1 by adding a value of 1.0pH to each of the values when the results of the pH analysis were interpreted. The pH levels in the study area are low and ranges from 3.91 to 5.62 which can be classified moderately acidic to extremely acidic. Approximately 37 samples have a pH content of less than 4.5 (extremely acidic), 15 samples have a pH content of between 4.5 and 5.0 (very strongly acidic) and 13 samples with a pH content of between 5.0 to 5.5 (strongly acidic).

The analytical results of the study area shows that the soils in Nkwezela are generally highly acidic with approximately 97% of samples analyzed having an acid saturation of 43% to 66.2%. In terms of the pH values they range from 3.92 to 4.61 with only ten samples below 4.5 (extremely acidic) with the rest of the samples being very strongly acidic.

The acid saturation of a soil is expressed as a percentage of the ratio of extractable acidity (A1 + H3+ + H+) to the total cations. The acid saturation values in Nkwezela for most of the samples varies from 1 to 59% which are considered to high levels of acid saturation. In terms of maize production soils with an acid saturation of < 20% are suitable. Therefore, high levels of liming are necessary in Nkwezela. The Fertilizer Advisory Service at Cedara has recommended liming and nutrient applications for maize, which is illustrated in III. In terms of maize, production varies with sample density.

Table 5.4 General ratings of pH values measured in water (1:5 ratios) (Adapted from Hazleton and Murphy, 1992).

pH	**Ratings**
>9.0	Very strongly alkaline
9.0-8.5	Strongly alkaline
8.4-7.9	Moderately alkaline
7.8-7.4	Mildly alkaline
7.3-6.6	Neutral
6.5-6.1	Slightly acidic
6.0-5.6	Moderately acidic
5.5-5.1	Strongly acidic
5.0-4.5	Very strongly acidic
<4.5	Extremely acidic

Organic matter is the material in the soil that is directly derived from plants and animals is an important soil property. It is primarily responsible for physical and chemical properties through its breakdown and interaction with other soil constituents.

The organic matter is usually calculated from the levels of the organic carbon (%) in the soil by multiplying by 1.72 based on the assumption that the organic matter in the soil has a constant carbon composition of approximately 57% (Hazelton and Murphy, 1992). Therefore, when interpreting the results of organic carbon content in Table 5.1, according to the rating in Table 5.5, the multiplication of the organic carbon values in Table 5.1 by 1.72 is required.

The rating according to the organic content in the soils indicates that approximately 18% (8) of the samples is low, 48% (22) is moderate and 34% (15) are can be rated as being high. This rating shows that soils in Nkwezela are rich in organic matter as the majority of the samples have moderate to high organic matter content

Table 5.5 Guidelines for ratings of soil organic matter contents (Adapted from Hazleton and Murphy, 1992).

Organic Matter Content %	**Rating**
0.5	Extremely low
0.5-1.0	Very low
1.5-2.0	Low
2.0-3.0	Moderate
3.0-5.0	High
>5.0	Very High

The soils in Nkwezela have favourable nutrient status in terms of the essential nutrients namely; K, Ca, and have moderate to very high organic matter. On the other hand the soils have low CEC and Zn contents and P values are extremely low in almost all the soils.

5.1.3 Topography

Topographically, Nkwezela is characterised by a high mixture of topographic features, which include bottomland plains, steep hillsides, deep valleys and undulating landforms. The variability of the topographic features plays a major function that controls the other environmental factors such as climate, soil and vegetation. The Triangulated Irregular Network (TIN) of the DEM and Slope map of Nkwezela are illustrated in Figures 5.11 and 5.12. The TIN map was used for visual analysis of the topography of the study area and to show a presentation of DEM data. The Tin map shows that the elevation ranges from 1088 meters above mean sea level (a.m.s.l.) in the south eastern part of the Nkwezela to along the Luhane River to 1722 and 1813m a.m.s.l. with an elevation of 1450 to 1722 in the northern half of the study area. The TIN map has a lower maximum value of 1904 a.m.s.l. in comparison to the Slope map, which has a higher maximum value of 1960 a.m.s.l. due to two reasons:

Firstly; the DEM data originally had a maximum value of 1904 a.m.s.l; and secondly, the IDW interpolation method used and discussed in section 4.4.2 always results in the minimum and maximum values being different from the original minimum and maximum values. This can be considered as a disadvantage of the IDW interpolation technique.

Slope is the most important topographic used to evaluate the agricultural potential of an area as it helps to determine the land available for cropping and the conservation practices required on land (Blanks and Horne, 1993). The Slope map was used from the two maps produced from the DEM data (TIN and Slope map) in the evaluation of the agricultural suitability of the study area.

The Slope map at 30m x 30m grid cell size in Figure 5.14 shows that slope values range from 0% to 20% which is based on the classification discussed in section 4.4.4 Table 4.5 and Table 5.7. The central part of Nkwezela is relatively flat with slope values of ranging from 0% - 4%.

Table 5.6 Summary of slope in terms of area coverage.

Slope classes (%)	**Area covered (ha)**	**Area covered (%)**
0- 4	250.74	17.00
8 -1 2	636.10	44.17
12 – 16	163.49	11.35
16 – 20	197.97	13.74
> 20	191.31	13.28
Total	1440.00ha	100%

The northern part of the study area is also relatively flat dominated by slope values of 4 – 8% with gradual to steep slopes scattered in the north eastern, south eastern, and western and in the northern parts of the study area. Nkwezela has approximately 73% of the total area, has topographic values that are within the limits of the arable slope classes according to criteria prescribed for KZN from the Camp's BRG (1999). The rest of the study area is dominated by steep slopes that do not fall within the range of arable slope. These are situated on both sides of the Ngudwini river in the western parts of the study area and the Nontshibongo river in the south eastern part of the study area.

The topography of Nkwezela is characterised by a high mixture of topographic features that comprises of bottomland plains, steep hillsides, deep valleys, undulating land forms and upland plateaus. The variability of the topographic features plays a fundamental role in controlling the other environmental factors like climate, soil and vegetation.

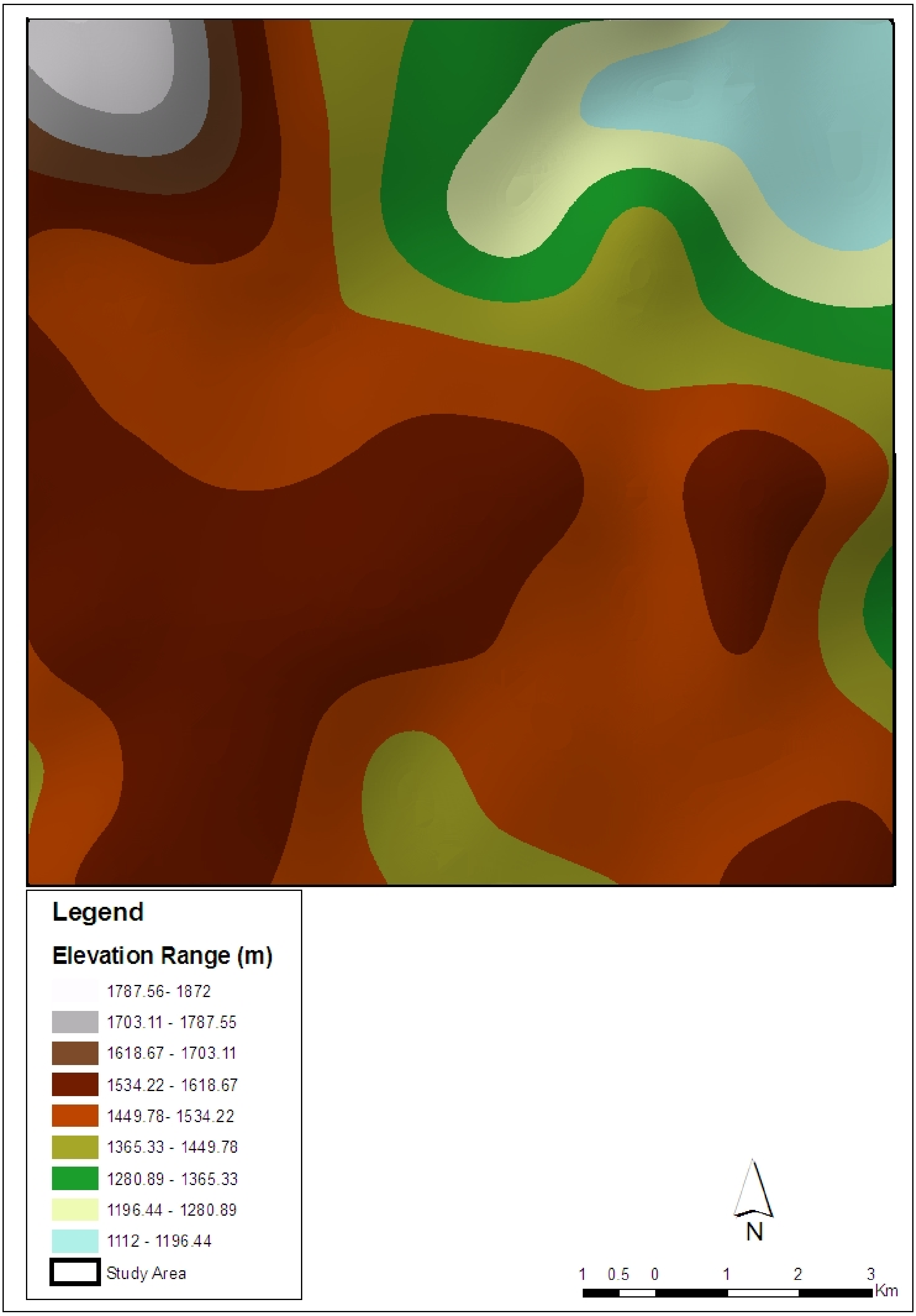

Figure 5.11 Elevation in the Study Area.

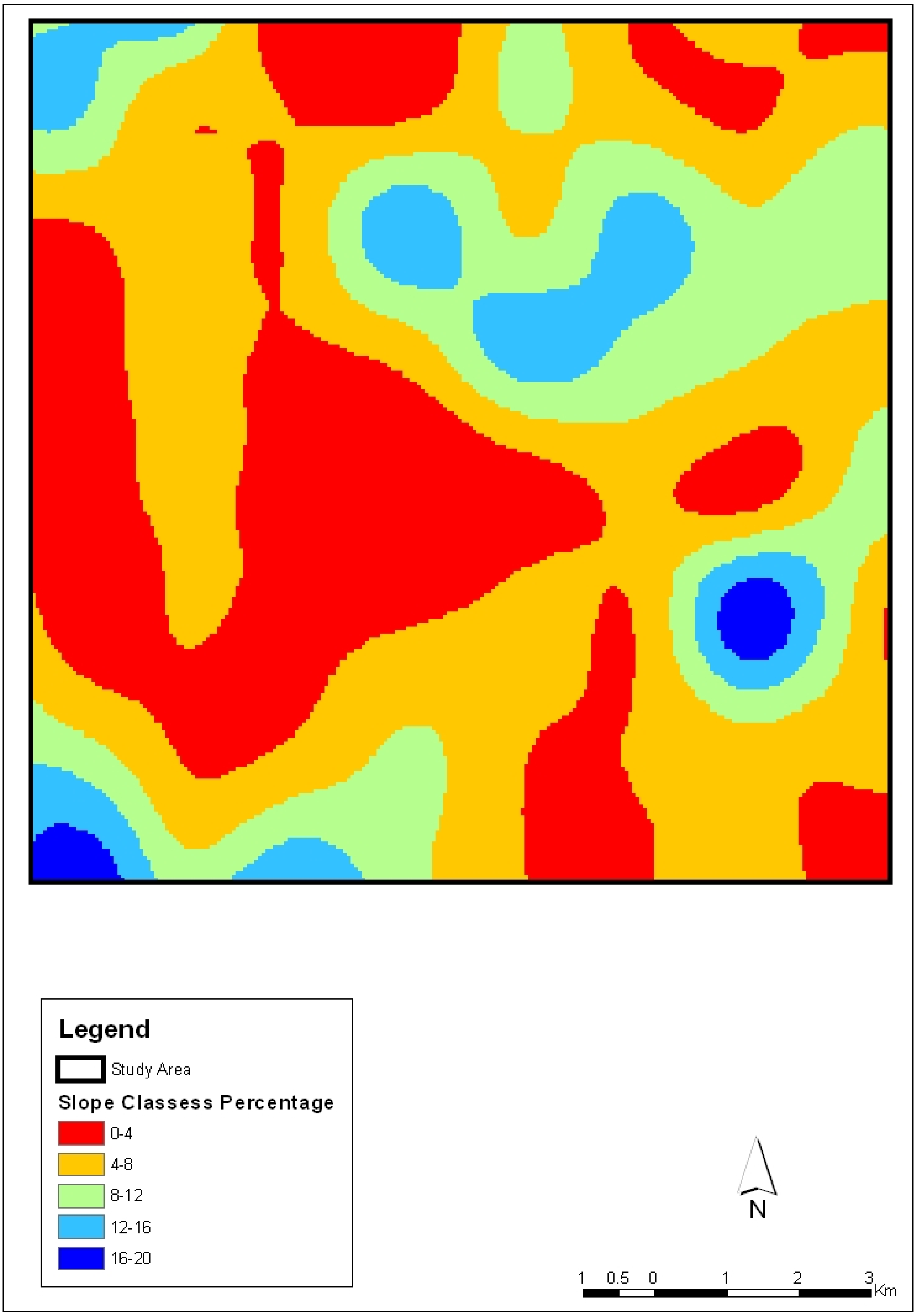

Figure 5.12 Percentage Slope Map of Nkwezela.

5.2 Crop Requirements

In addition to the FAO *Land Evaluation Framework* and discussions with Mr. Hannes De Villiers of the FSR, maize, potatoes, cabbages, spinach, turnips and dry beans are the most common crops grown in the study area, with maize being the most dominant crop grown. This information on the growth of the six selected crops was obtained from different types of literature, publications, research reports and crop production guidelines and the criteria used do determine the crop requirement data was obtained from the Crop, Pasture, Timber Yield Estimates for KwaZulu-Natal by J M B Smith, 1997, Vegetable Production in Kwa-Zulu Natal (Allemann and Young, 2001) and with Rob Moolenschot from Starke Ayers. This section summarizes the crop requirements of the tables in Appendix II and provides an overview of the climatic, soil and topographic requirements for each crop.

5.2.1 Climatic and Soil Requirements

Maize

Dryland maize can be grown in an area with a mean annual rainfall of 850mm and 1800 heat units during October to March on well drained soils with a depth of 750mm. Irrigated maize with an annual evaporation of 1900mm, evapotranspiration of 855mm and with 1800 heat units during October to March. For very hot areas, maize should be planted in April where the total annual evaporation is 1982mm, the expected evaporation during April to September is 808mm, with an evapotranspiration is 606mm and the heat units is 1735 (Smith, 1997).

Potatoes

Potatoes require a cool temperate climate. In KZN there are few climatically suitable areas for potato production and requires 500 to 700mm rain or supplementary irrigation during growing season 110 to 150 days and in areas with a daily temperature between 15 and 20°C. Optimum temperatures of 13 to 16°C and 1168 heat units are needed during the growing season (Smith, 1997). Areas with a temperature range of 12 to 23° C are also suitable and require well drained areas with a sandy loam texture and at least 500mm deep.

Evaporation of 817mm October to February with irrigation should compensate for evapotranspiration. Potatoes require 421mm of water required from January to April. A cold area requires1252 heat unit (BRG 8) and a cool area require 1067 heat units (Camp, 1997).

Cabbages

Cabbages require a cool and moist climate, cultivated in autumn, winter and spring and require irrigation and needs 300 to 450mm rain depending on the temperature, evaporation and length of growing period. It needs a daily optimum temperature between 15 and 18°C with a monthly mean of max of 24°C and a mean min of 5°C. Although cabbages can grow on a variety of soils, well drained loam soils with a root depth of 600mm to 750mm is preferred. Evaporation of 420mm in warm areas and 428mm in cold area is required. Irrigation should compensate for evapotranspiration. 310mm of water required for March to June. Requires 800 to 1200 heat units (degree days). Acid Saturation should be less than 1% (Smith, 1997).

Dry Beans

Dry beans grow well in areas with warm conditions with a medium rainfall. Requires between 400 to 500mm of rainfall (Blanks and Horne, 1993) and an annual rainfall of 700mm (Smith, 1997). Temperature range is 18°C and 24°C, with a minimum temperature of 10°C and a maximum temperature of 30°C and 1600 heat units. Also requires well drained deep soils 0.9m with clay content of 15% to 35% and the acid saturation should not exceed 5%. The growing season for dry beans is from October to March in KZN, which receives approximately 80% during this period.

Sorghum

Sorghum is a comparatively drought resistant crop in comparison to the other crop. It requires 300mm of water which is less than maize (400mm) and sunflower (720mm), to produce one unit of dry material (Smith, 1997). Dryland sorghum requires 450mm to 650mm of rain for high production and 500 to 1100 heat units. Suitably high temperatures and a reasonably long and frost –free growing season is necessary in order to obtain optimum yields (FAO, 1980).

Sorghum can successfully grow on a variety of soils than maize but light to medium textured soils are the most suitable (Smith, 1997). Sorghum requires a pH range of 5.5 to 8.5 with some deficit of alkalinity, salinity and poor drainage (Blanks and Horne, 1993).

Turnips

Turnips is a cool season crop and requires an a minimum temperature of 5°C and a maximum of 24°C with and optimum temperature range of 15°C to 18°C with an effective rooting depth of 600mm. Turnips grows on a variety of soils, but reasonably drained soils are most suitable with a 30 to 40% clay content and an acid saturation of 5 to 10 %. This crop requires a minimum of 450mm and a maximum of 700mm of rainfall, supplemented by irrigation and needs 1070 heat units (Allemann and Young, 2001).

5.3 Land Suitability Evaluation

5.3.1 Climatic Suitability

Figures 5.13 and 5.14 show a graphical representation of the climatic parameters that were used in the suitability evaluation and maps for a sample crop (sorghum). A comparison of the rainfall parameters for Nkwezela is discussed in section 5.1.1.1 with the crop requirements for rainfall in the study area (Appendix III) shows that rainfall is more than adequate for maize, dry beans, cabbages, potatoes, sorghum and turnips. Therefore the whole study area can be rated as highly suitable (S1) for these crops in terms of rainfall conditions.

A comparison of the temperatures variables (Figures 5.5 -5.9) with the crop requirements (Appendix II) showed that all the temperature parameters with the exception of the minimum temperatures for cabbages and sorghum (5ºC), the minimum temperatures for the other crops range between 7ºC and 16ºC are suitable for the selected crops. The temperature conditions in the growing season are not hot enough for enough for optimum

Sorghum production in the north to north-eastern parts of the study area and exceeds the maximum temperature requirement of 20ºC in the north western and northern parts of the study area. The amount of available heat units during the growing season is sufficient for all the selected crops.

The hot temperature conditions of the rainy season and the very cold winter temperatures cannot sustain potato and turnip growth and even though the rainfall is suitable for potatoes and turnips in the study area, therefore, potato and turnip cultivation is unsuitable in Nkwezela. Potatoes and turnips did not qualify any further suitability analysis according to FAO land suitability assessment methodology used in this study. This resulted in the entire study area being rated "*unsuitable*" for potato cultivation.

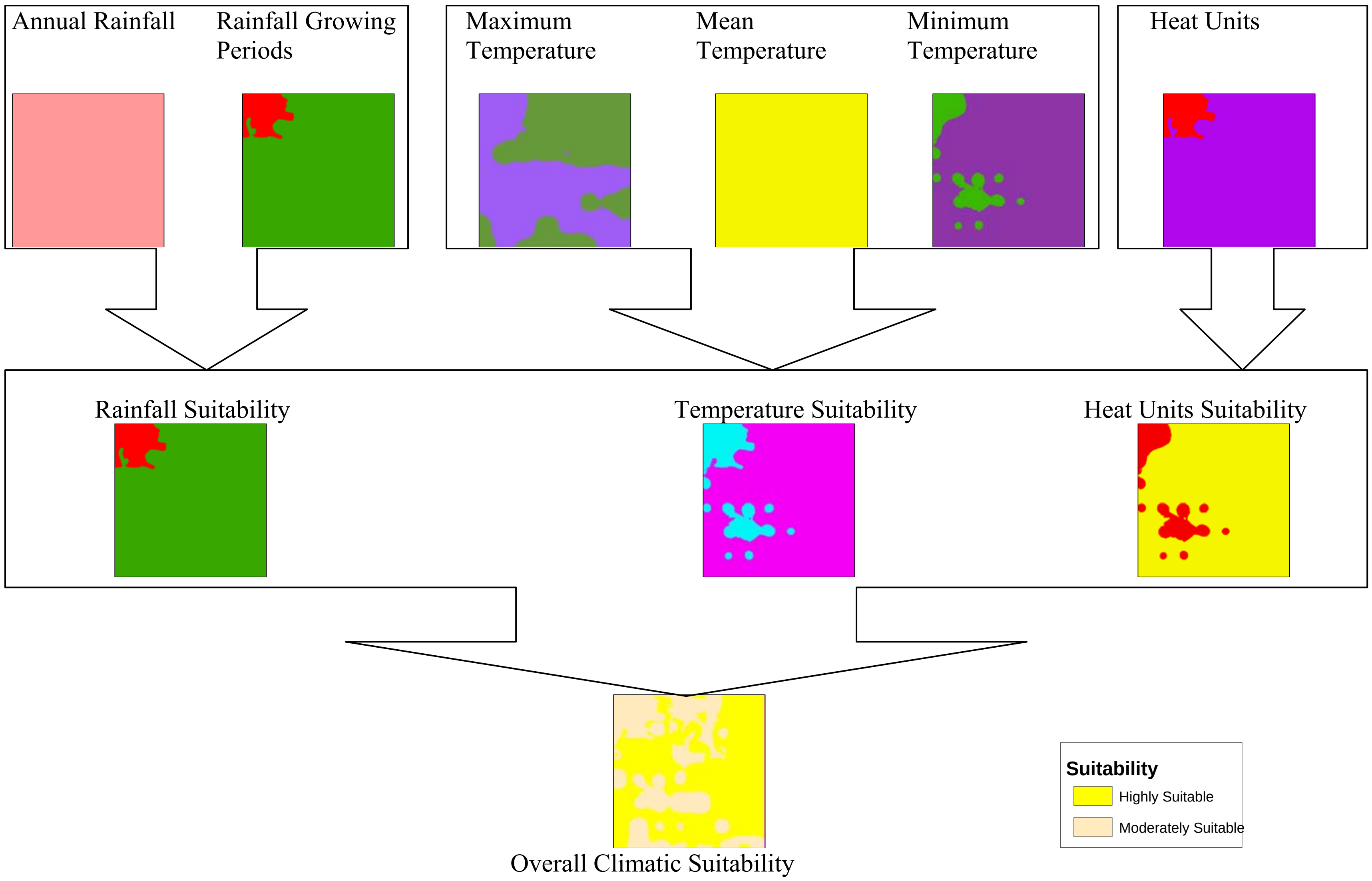

Figure 5.13 Pictorial representation of climatic parameters used for land suitability evaluation in a GIS's overlay analysis

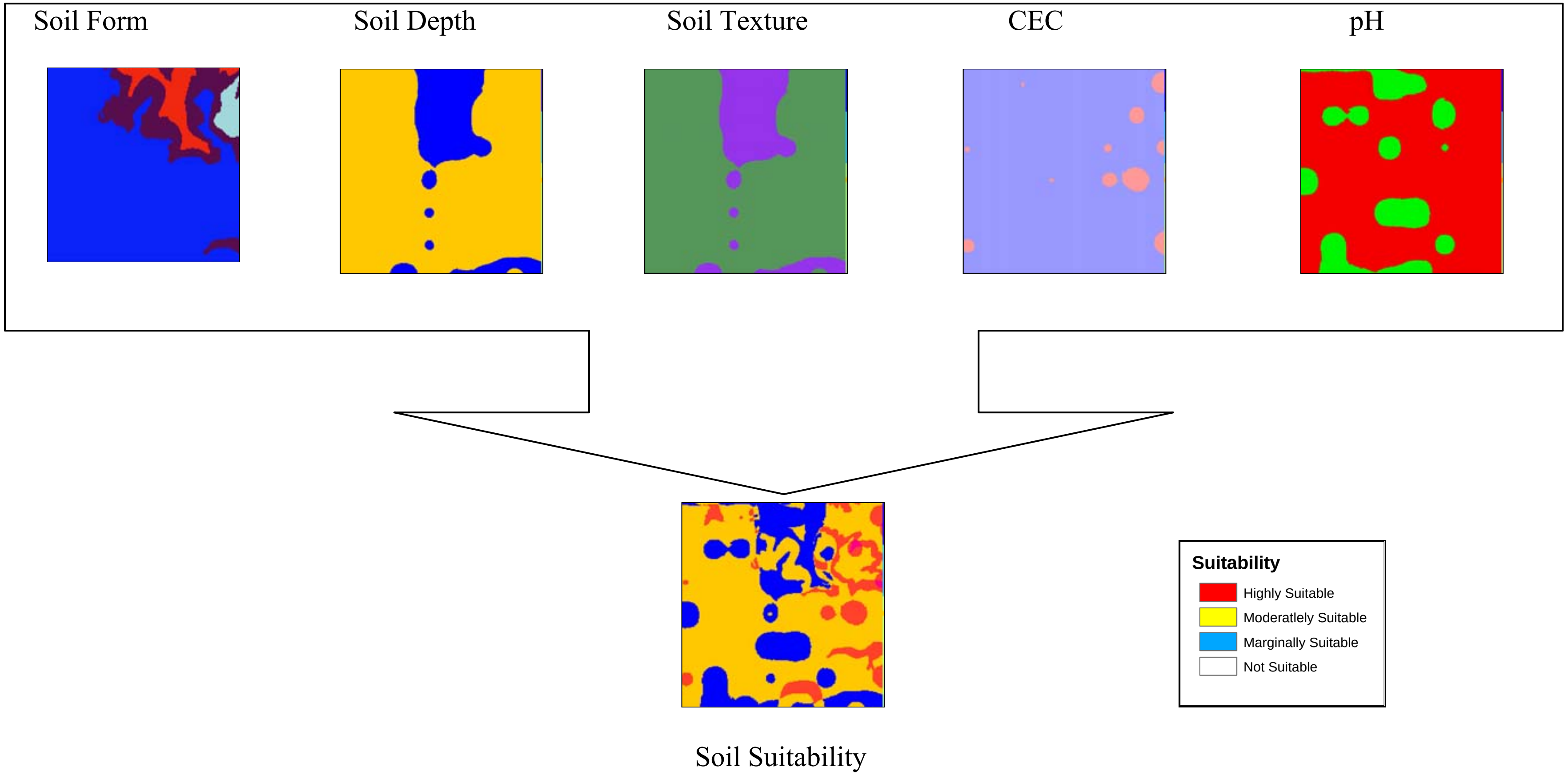

Figure 5.14 Pictorial representation of soil parameters used for land suitability evaluation in a GIS's overlay analysis

5.3.2 Soil Suitability

The soil parameters used in the soil suitability evaluation and the resulting map for sample crop sorghum is illustrated in Figure 5.1.4. These are well drained humic and highly leached soils found in a high rainfall area, Nkwezela, which comprises of soil forms Aa, Ab and Ac have the highest suitability for all the crops as discussed in Figure 5.10 & Appendix I). These soils cover approximately 1224ha (85.84%) of the study area and have a clay content of 15 to 35% and soil depth between 450mm to 750mm. Although these soils are highly acidic, correct liming applications with necessary fertilizer requirements can improve the crop yields. This has been achieved for the farmers who have been working with the FSR section of the DAEA (see the fertilizer recommendations in Appendix III). In addition the required liming and fertilizer requirements for the soil samples used in this study are also indicated in Appendix III.

The soil analysis in Appendix III conducted for maize which comprises of liming and fertilizer requirements for dry beans, sorghum and cabbages can also be performed by the Fertiliser Advisory Service Section of DAEA (2006) to improve crop yields.

The chemical and physical properties discussed in section 5.1 and soil requirements shown in IIa-IIc indicates that the soils in the study area are favourable in the essential soil nutrients of K, Ca, and organic matter content with low levels of Zn and CEC. The pH levels are favourable for all crops and the acid saturation levels are low which indicates that the study area is rated as being highly acidic. Therefore, high levels of liming applications have to be implemented in order to obtain relatively good crop yields.

Soil depth and soil texture are generally the most limiting soil characteristics in the study area. Therefore soil types Aa and Ac are freely drained soils with soil depths that range from 740mm to 911mm in depth. They also have a clay loamy texture and are rated as highly suitable (S1), and soil type Ab with soil depths of ≥ 627mm is rated suitable (S2). This is followed by soil form Ea that has soil depths of ≥500m and ≤627mm that are rated as marginally suitable (S3) and soil type Fa rated as not suitable (N), which accounts for 14.6% of the total area of Nkwezela

5.3.3 Slope Suitability

Slope is an important land feature that influences the use of a known land for agricultural purposes. This generally means that steeper areas are not selected for crop cultivation due to limitations that are related to soil erosion.

The slope map of the Nkwezela (Figure 5.13) with the slope classes discussed in section 4.4.4 shows that approximately 61% of the study area is covered by slope classes A and B, which are assumed to have no or slight limitations that do not significantly reduce productivity and do not require conservation and management inputs above an acceptable level. These areas are rated as highly suitable for agriculture according to the FAO suitability ratings. These highly suitable areas are found in the central, northern and southern parts of the study area. The areas of slope class C are rated as moderately suitable (S2), which covers northern part along the Luhane river, the eastern part along the Ngudwini and on the south to south western parts of study area along the Nkonzo and Nontshibongo rivers. This class covers about 11.35% of the study area. Slope class D is rated as marginally suitable (S3) and are found scattered in the eastern, western and northern parts of Nkwezela, which amounts to 13.74% of the total area. The remaining 13.28% is excessively steep and highly hazardous for crop production and is rated as "Non-arable". The slope limits for non-arable slopes are greater than 12% for BRG 8 and also greater than 12% for BRG 11. Approximately 27% of the study area is excessively steep and highly hazardous for crop production. The non-arable slopes are rated as not suitable (N) in terms of the FAO suitability rating. This class covers the steep areas on both sides of the Ngudwini River valley and the hillsides of the eastern, south western and north western corner of Nkwezela. The slope suitability for Nkwezela is illustrated in Figure 5.15, based on the comparison between the slope map of the study area and the arable slope classes in KwaZulu-Natal

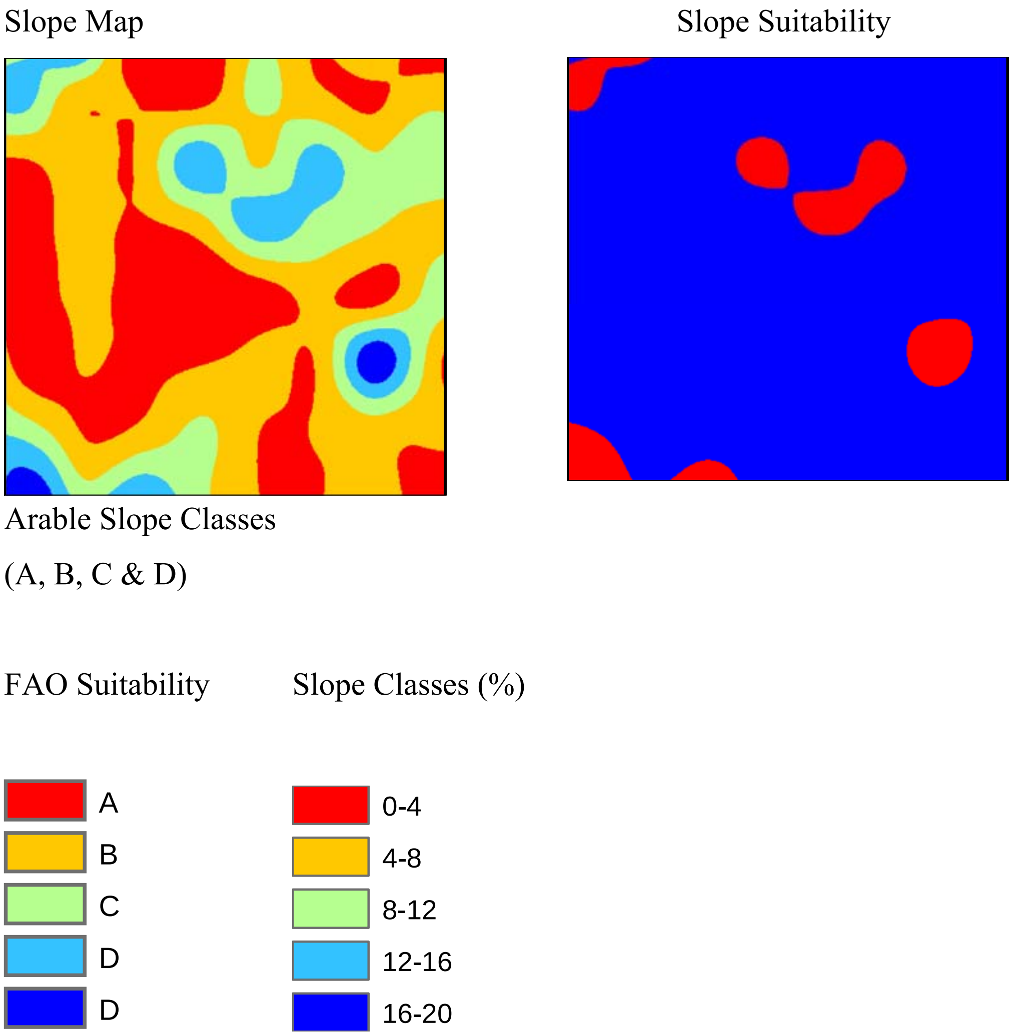

Figure 5.15 Slope suitability of Nkwezela based on the comparison of the slope map of the study area and the arable slope classes in KZN

5.3.4 Overall Suitability

Figure 5.16 shows the method used in the evaluation of the land suitability to derive land suitability for each of the selected crops (maize) was obtained by overlaying the climatic, soil and slope suit abilities. This was achieved by using the *limiting combination* method (FAO, 1983) shown in Figure 5.16, which is discussed in section 4.5 by using a GIS overlay analysis to produce a suitability map for each of the selected crops.

Table 5.7 summarizes the results of the land suitability evaluation. The overall suitability map for maize has all four suitability classes with the classes N1 and N2 being combined. The highly suitable class (S1) accounts for 11.1% of the total area, moderately suitable

(S2) constitutes 37.5%, marginally suitable (S3) is 24% and the remaining 24% is unsuitable (N). In terms of the climatic requirements the minimum temperature is the only limiting factor which ranges from 1.7 to 5ºC. With reference to the crops analysed, maize has the highest adaptability to the study area. Therefore the suitability map shows that the highest suitability for maize is the moderately suitable (S2). This suitability shows the suitability of the moderate and high potential soils.

Table 5.7 Summary table of the results of the land suitability evaluation.

	Area coverage of suitability classes					
Crop	S1	S2	S3	S1+S2+S3	N	Total Area (ha)
	Ha %	Ha %	ha %	ha %	ha %	
Maize	160 11.1	540 37.5	350 24	1050 73	340 24	1440
Dry beans	296 20	200 13.8	560 39	1056 73	384 27	1440
Sorghum	380 26.3	259 20	472 33	1112 77.2	328 22	1440
Potatoes	- -	- -	- -	- -	- -	1440
Cabbages	3 0.2	97 6.7	715 49.6	815 56.6	625 43.4	1440
Turnips	- -	- -	- -	- -	- -	1440

For dry beans, the highly suitable class (S1) accounts for 20% of the total area, the moderately suitable (S2) constitutes 13.8%, the marginally suitable (S3) is 39% and the remaining 27% is unsuitable (N). In terms of the climatic requirements, the minimum temperature which ranges from 1.7 to 5ºC is the only limiting factor which results in only the marginally suitable (S3) being the most adaptable for dry beans production.

For sorghum, the highly suitable class (S1) accounts for 26.3% of the total area, moderately suitable (S2) constitutes 20%, marginally suitable (S3) is 33% and the remaining 22 % are unsuitable (N). In terms of the climatic requirements the minimum temperature and annual rainfall are the two limiting factors which results in only the marginally suitable (S3) being the most adaptable for sorghum production which ranges from 1.7 to 5ºC.

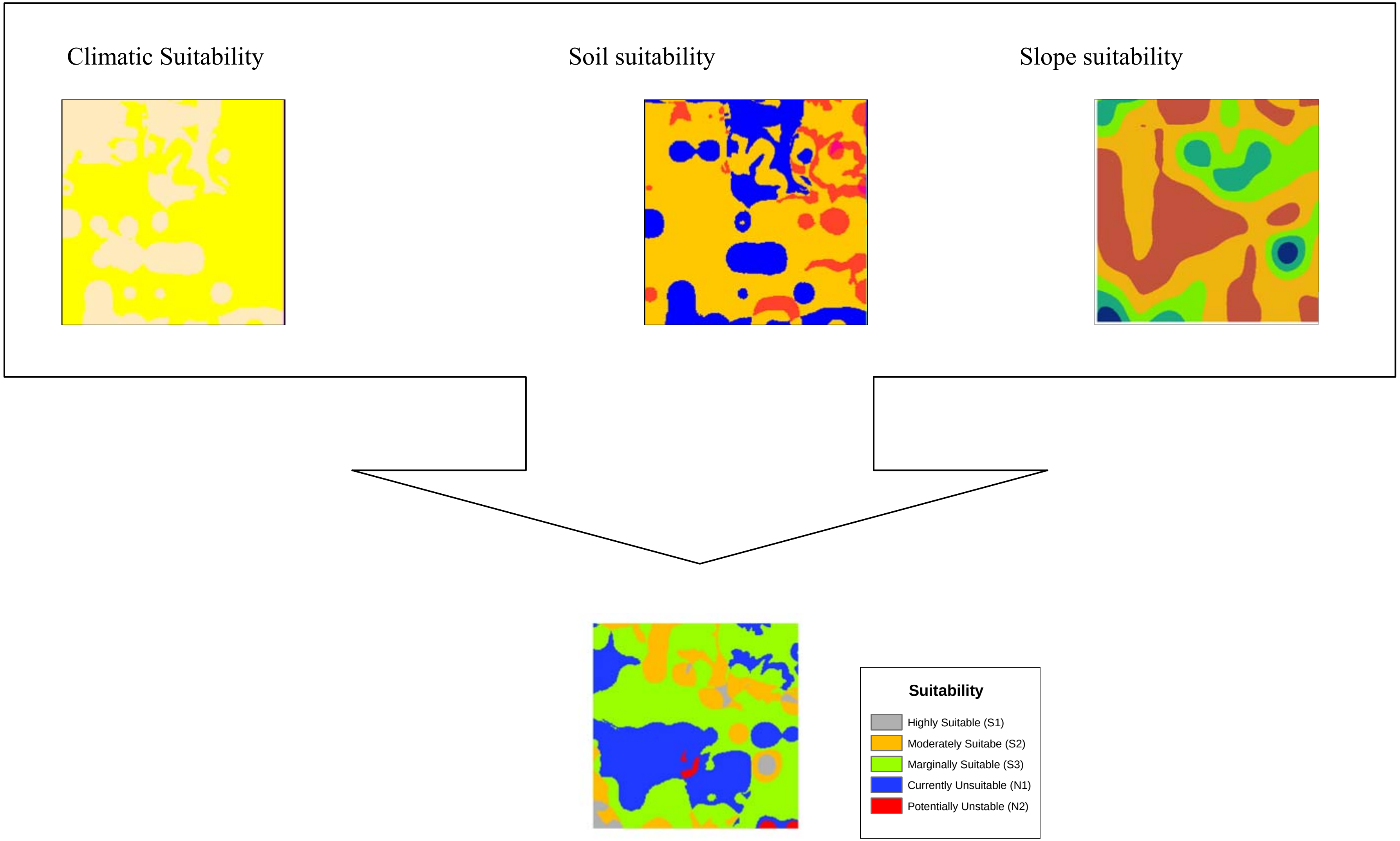

Figure 5.16 Pictorial representation combining climatic, soil and slope suitability maps into an overall suitable map.

Similar to dry beans, the minimum temperature is the only limiting climatic factor which may be also be the reason for the marginally suitability (S3) being the most suitable for sorghum production.

For cabbages, the highly suitable class (S1) accounts for 0.2 % of the total area, moderately suitable (S2) constitutes 6.7%, marginally suitable (S3) is 49.6% and the remaining43.4% is unsuitable (N). In terms of the climatic requirements the minimum temperature which ranges from 1.7 to 5ºC and required daily heat units which ranges form 1600 to 2300, are the two limiting factors which results in only the marginally suitable (S3) being the most adaptable for cabbage production. In comparison to dry beans, the minimum temperature is also a limiting climatic factor that could be recognized for the marginally suitability (S3) being the most suitable for cabbage and dry beans production.

The climatic conditions and soil characteristics do not meet the specified criteria in section 5.2.1 for productive potato and turnip cultivation in the study area and therefore, this crop is excluded from the analysis. The winters are too cold, minimum temperature ranging from 1.7 to 5.59ºC and the hot summer temperature 22.78 to 26.88ºC and the rainfall in the study exceeds the specified rainfall of between 450mm and 700mm. The specified soil depth for both the crops is located in the steep north and far north portions of the study area which is too cold for potato and turnip cultivation.

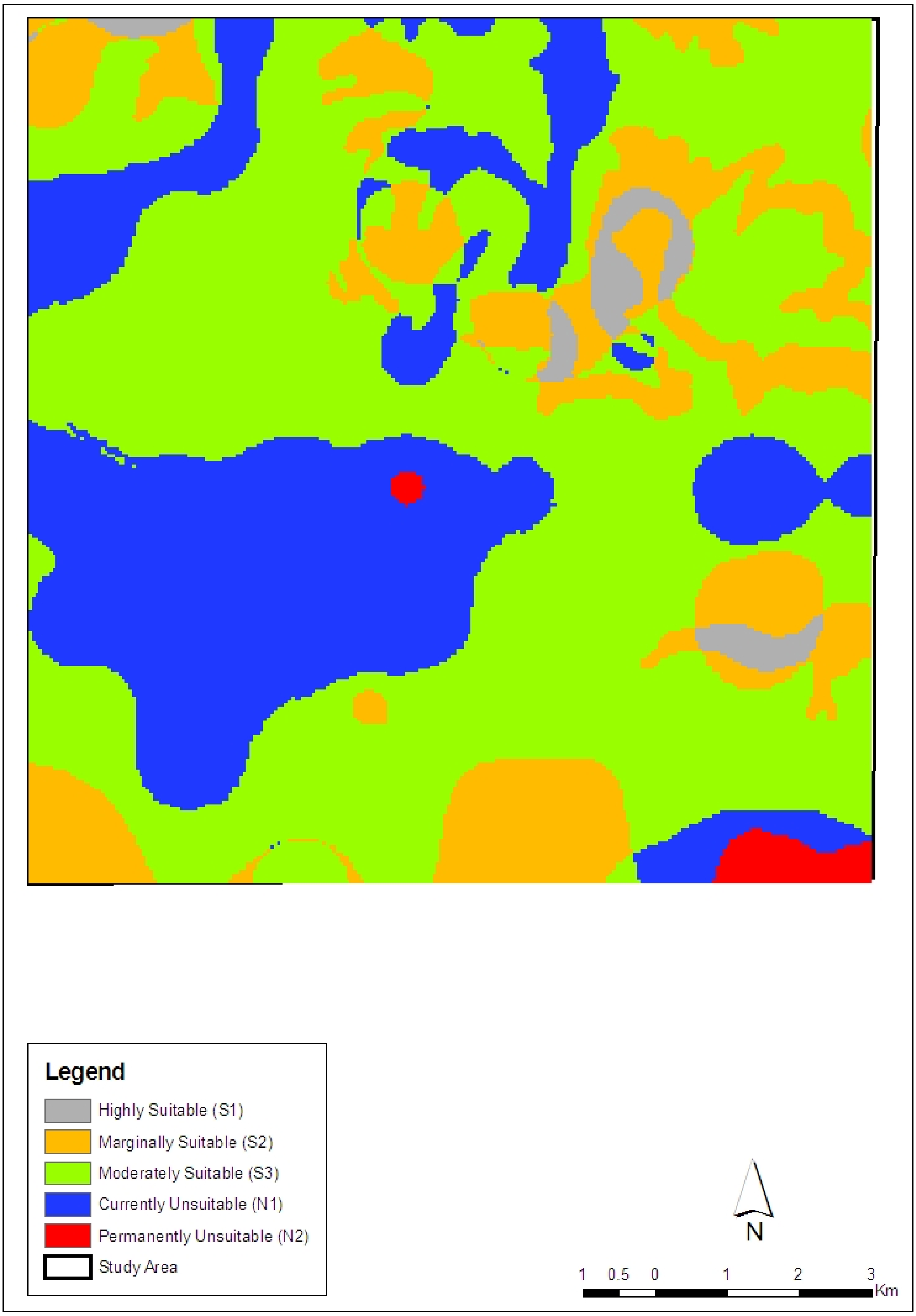

Figure 5.17 Overall suitability map for maize production in Nkwezela.

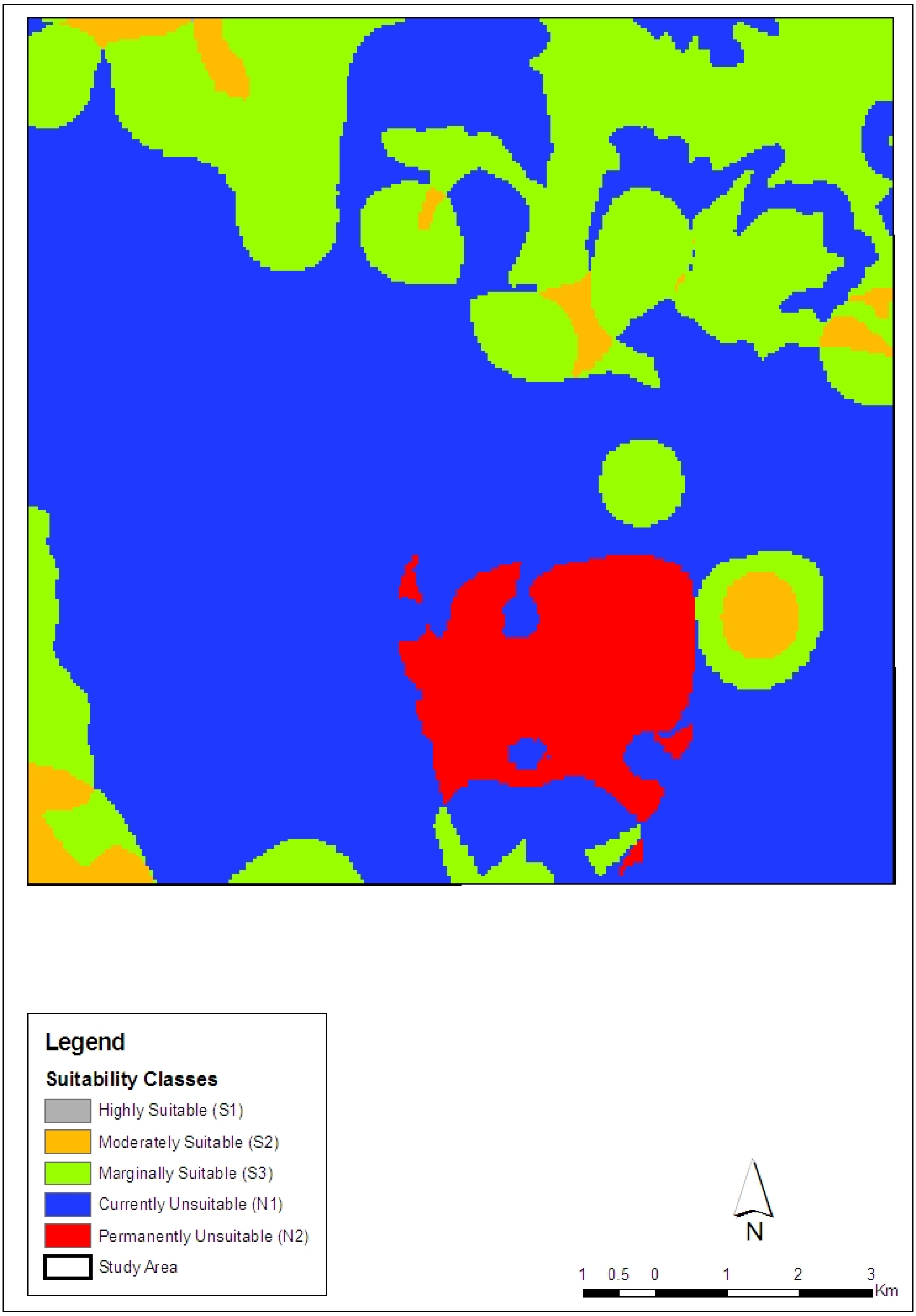

Figure 5.18 Overall suitability map for dry beans production in Nkwezela.

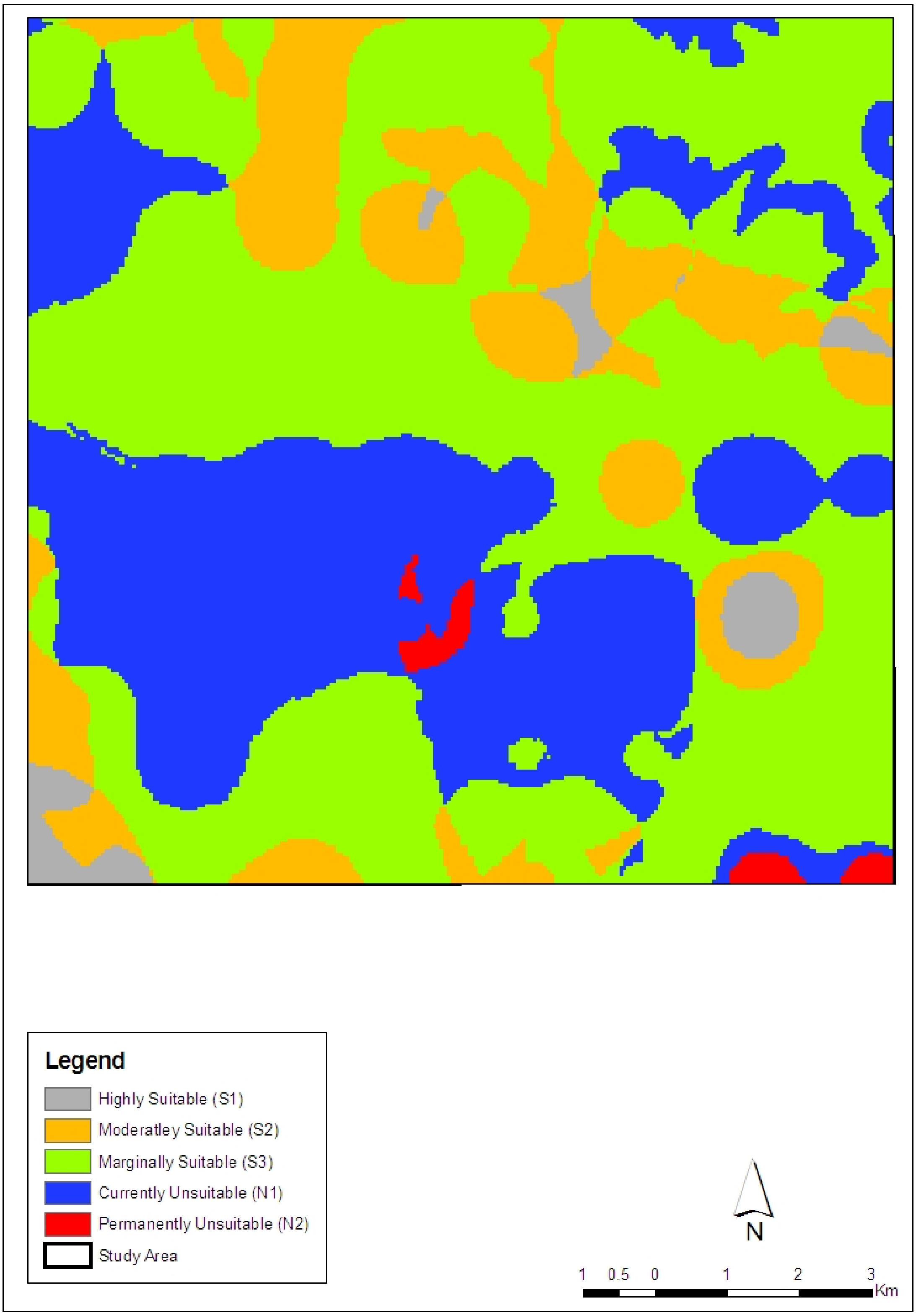

Figure 5.19 Overall suitability map for sorghum production in Nkwezela.

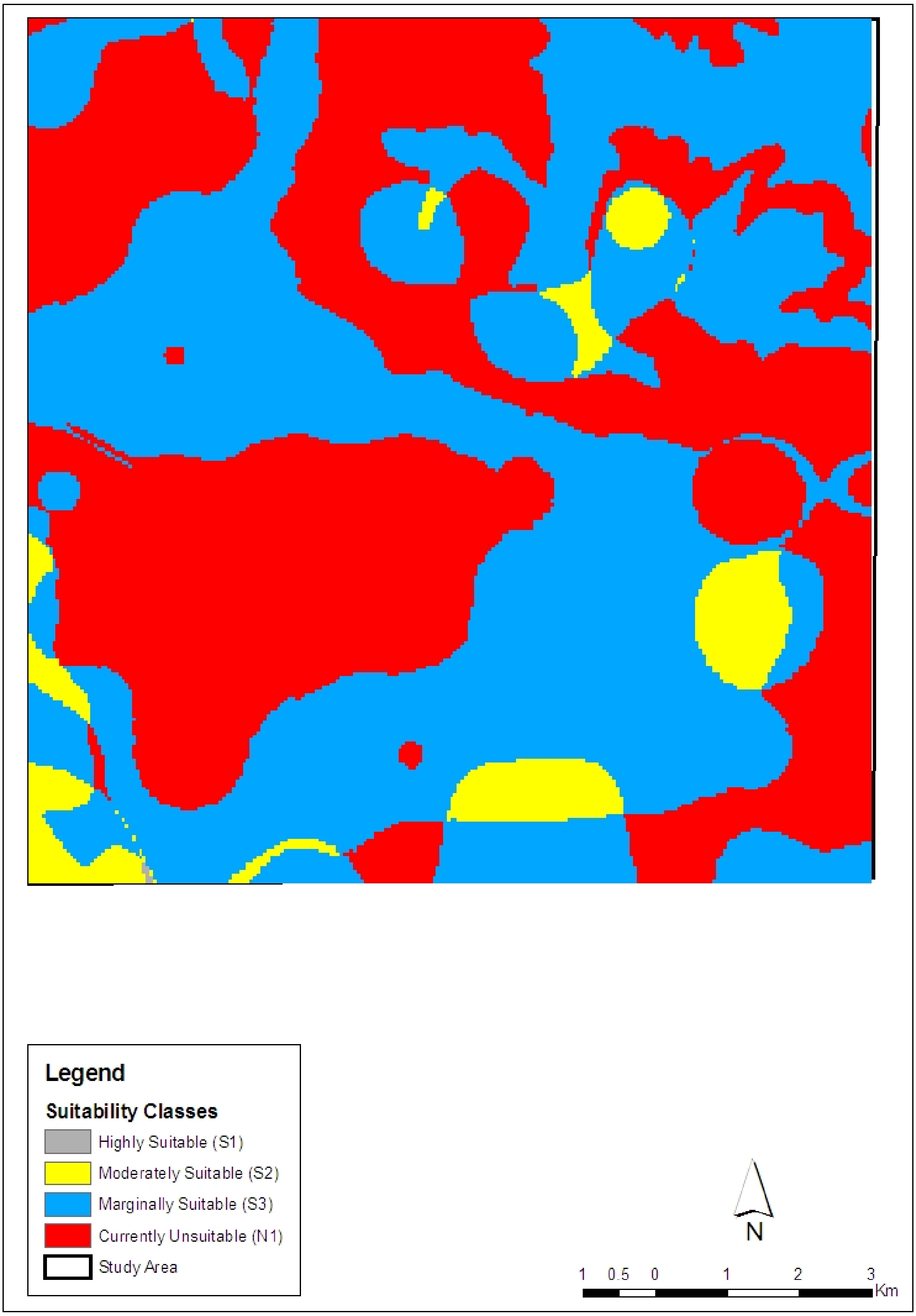

Figure 5.20 Overall suitability map for cabbage production in Nkwezela.

5.4 Summary

The evaluation of the natural resources in section 5.1 has shown that Nkwezela is characterised by very hot summers and very cold winters in a high rainfall area, with clayey well drained soils. The topography in the study area meets the requirements for productive subsistence agriculture. With the exception of the very low winter temperatures and the high acidity, the study area, apparent significant variations were usually associated with the variations of the topographic conditions. Therefore, in this study all the factors were used in the analysis procedure.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

For the purpose of land suitability, the assessment of land characteristics in relation to the land use requirements of the different crops show that Nkwezela has a high suitability for warm season crops such as sorghum and a low suitability for cool season crops such as cabbages in a high rainfall area. This is mainly due to the fact that the summers are extremely hot and the winters are extremely cold.

Although the soil depth in the study area ranges from approximately 485.7mm to 911mm. which is suitable for most crops, the, soil analysis in Appendix III shows that that the soils have a high clay content, are highly acidic and requires relatively high levels of liming and fertilizer applications in order to improve crop yields for maize. In addition, the Summary of the Analytical Results in Appendix III indicates the approximate levels of liming and fertiliser are required for the current maize, dry beans and potatoes in order to improve crop yields in the study area. This is an expensive exercise and can discourage the farmers and the community. The FSR of the DAEA currently provides liming and fertilisers to the farmers in Nkwezela and in other subsistence farming communities in KZN at no cost.

The hot wet summers and dry cold winters are only marginally suitable for maize, dry beans and sorghum in the study area and also most suitable for sorghum followed by dry beans and maize. The high rainfall and hot summer temperatures are most suitable for these crops.

Cabbages are the least suitable crop in the study area which requires a cool and moist climate with a minimum daily temperature of 15ºC to 18ºC . This is mainly due to very cold winters that range from 5.4ºC to 1.7ºC and the high acid saturation and is therefore not regarded as a viable crop for cultivation.

Similar to cabbages, potatoes and turnips require cool temperatures with specific climatic requirements. The winters are too cold and the summers are too hot with high rainfall levels, in the rainy seasons which could not be satisfied and due to this limitation, Nkwezela is evaluated as *"unsuitable"* for potato and turnip cultivation Therefore the cultivation of cabbages, potatoes and turnips is not a viable option.

Topographically, the study area is suitable for agriculture, as it falls within the requirements of the arable slope classes prescribed by Camps BRG criteria (1991).
The north western portion of the study area is dominated by steep slopes, which covers approximately 27.2% of the total study area.

6.2 Recommendations

The sustainable use of a certain land requires the consideration of the physical attributes of land and the socio-economic aspects like profitability, market availability, social acceptability, land tenure system, population dynamics, national and regional governmental policies. The socio-economic aspect was not considered in this study and recommendations are based on the physical aspects of the land that have been assessed in detail in this study in relation to the potential for subsistence agriculture.

In addition to the overall recommendations, this investigation has also identified the recommendations discussed below, which will add value to the improved sustainable use of the natural resources, improve agricultural practices and will ultimately improve the quality of life for subsistence communities.

The Summary of Analytical Results in Appendix IIIa shows the nutrient and lime requirements for maize, dry beans and potatoes derived from the soil analysis. This can be applied in the study area to improve crop yields.

6.3 Limitations of the Study

This study has attempted to evaluate the suitability of Nkwezela for subsistence agriculture and has successfully achieved its objectives. The results of the land resources and land suitability evaluation may be used in land use planning for agricultural land use and in particular subsistence agriculture. The methodology used in the evaluation of land suitability can be applied in other areas, provided that the appropriate soil, climatic and topographic information is available. Nevertheless, some limitations due to data quality and availability have resulted from this study.

The climatic one–minute by one-minute spatial resolution of the original climatic data is too coarse for small study areas. Although the interpolation of the original dataset improved the data resolution, effects of the coarse data resolution of the original dataset could not be avoided. The interpolation technique also has its own disadvantage in that it yields data values that are outside the range of the original dataset. Therefore, although the climatic dataset gives a good indication of the overall climatic conditions in the study area, there are some inaccuracies especially in areas where there is a high spatial variability in the climatic conditions.

The crop requirement data used as a basis for land suitability evaluation, as per the FAO methodology for land evaluation (FAO, 1983), recommended that crop requirement information should be based on local conditions. Although most of the crop requirement data was obtained from publications of KwaZulu-Natal Department of Agriculture, some of the crop requirement data was collected from FAO publications. The crop requirement information in the local publications does not rate the land characteristics according to their degree of suitability in a similar manner to the FAO land suitability rating. Therefore the degree of suitability was defined according to the FAO land suitability classification structure based on the assumption such as the critical values of land characteristics and their adverse effects on crops and yield estimates as discussed in section 4.3. These assumptions are subjective, and are not free of errors.

The north western portion of the study area is dominated steep slopes, which constitutes approximately 27.2% of the total study area, cannot be considered for cultivation because of the steep topography. The soils are relatively deep, highly leached with a high acid content, low fertility and favourable physical properties.

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Appendix I

Ia

Description of Soil Forms of the South African Soil Classification System Encountered in Nkwezela

Soil Form Aa

These are red-yellow apedal, freely drained soils with a humic horizon. They contain more than 1.8% organic carbon and also contain less than 4 cmol (+) of exchangeable cations (Ca, K, Na) per kg clay for every one percent of organic carbon present. It has a strongly developed that has a high clay content and a predominance of smectitic clay minerals which has the capacity to swell and shrink distinctly in response to moisture changes. This soil form is most dominant in the study area.

Soil Forms Ab and Ac

These are red and yellow dystrophic and/or mesotrophic, freely drained soils and soils with low, medium and high base status. The diagnostic eutrophic horizons are not calcareous. Dystrophic soils highly leached soils as the Ca, K and Na, expressed in cmol (+) per kg clay is less than 5. In mesotrophic soils, this figure ranges from 5 to 15 and in eutrophic soils this figure is greater than 15. (MacVicar, 1991)

Soil Form Ea

These are eutrophic soils that are usually shallow and found on hard or weathering rock. They are also undifferentiated soils that contain one or more of vertic, melanic, red structured diagnostic horizons which is essentially a greyish horizon that is generally paler in colour than the overlying topsoil or horizon. It occurs as the second in a sequence of diagnostic horizons when present, except where it has been exposed as a result of the topsoil or mixed with the A horizon by ploughing. There are orthic topsoil horizons with a colour of a diagnostic E horizon which are often thicker than 350mm.

Soil Form Fa

Lime in these soils is rare or non existent in the entire landscape. These soils are Glenrosa and/or Mispah soil forms although other soils may occur.

Ib. Summary of Soil Forms in terms of Area coverage

Soil *form*	**Area covered (Ha)**	**Area covered (%)**
Aa	12.20	0.84%
Ab	202.72	14.0%
Ac	1017.82	71.0%
Ea	129.76	9.01%
Fa	75.59	5.24%
Total Area	1440	100

Ic. Correlation of South Soil Units (*Soil Forms*) to FAO Soil Units (MacVicar, 1991).

South African Classification		**FAO Correlation**
Soil *form*	**Symbol**	**Soil Phases**
Champagne	Ch	Histic Gleysoils (Ox). Dytric (Od) & Eutric (Oe) Histisoils
Kranskop	Kp	Humic Acrisols (Ah), Ferralsols Fh) & Cambisols (Bh)
Magwa	Ma	Humic (strongly) cambisols (Ah); Humic Ferrasols (Fh); Helvic acrisols
Inanda	Ia	Humic Ferralsols (Fh); Humic cambisols (Bh)
Nomanci	No	Rankers (U) with thick A-horizon; Humic (strongly) cambisols (Ah); humic soils
Rensburg	Rg	Pelvic (Vp) & (dark) chromic (Vc) Vertisols; (with Gleyic horizon)
Arcadia	Ar	Pelvic (Vp) (some dark coloured) chromic (Vc) Vertisols; Vertic Cambisols
Willowbrook	Wo	Gleyic Phaeozems (hg); humic Gleysols (Gh) (with melanic A – horizon)
Bonheim	Bo	Luvic Phaeozems (HI), castanozems (KI) & possibly chernozems (CI)
Tambankulu	Tk	Plinthic castanozems, Phaeozems & Chernozems

Inhoek	Ik	Haplic Phaeozems (Hh), castanozems (Kh) possibly Chermozems (Ch) all on stratified alluvium
Mayo	My	Haplic Phaeozems (Hh), castanozems (Kh) possibly Chermozems (Ch); Rendzinas
Milkwood	Mw	Haplic Phaeozems (Hh), castanozems (Kh) possibly Chermozens (Ch) all on stratified alluvium
Katspruit	Ka	Gleysols (various)
Swartland	Sw	Brunic & chromic Luvisols (Lc); Luvic Xerosols (XI) &ermosols
Valsrivier	Va	Brunic & chromic Luvisols (Lc); Luvic Xerosols (XI) & ermosols (A-horizon usually hard and dry)
Sterkspruit	Ss	Ochric Solonetz
Estcourt	Es	Ochric Solonetz (with Albic horizon): Gley Solonetz; Solod; some Ochric Planasols
Kroonstad	Kd	Ochric Planosols
Constantia	Ct	Albisols, Ferric Podozols (Pf) & Rhodic, Helvic and Humic (Ah) Acrisols
Shepstone	Sp	Albisols, Albic luvoisols & Helvic and Humic (Ah) Acrisols
Vilafontes	Vf	Albic (La) & Glossic Luvisols
Houhoek	Hh	Humoferric Podozols (Lithic) (Ph,Pf)
Lamotte	Lt	Humoferric Podozols (Lithic) (Ph,Pf)
Cartref	Cf	Not accommodated specifically, but inter- alia Gleyic Luvisols (Lg)
Wasbank	Wa	Not accommodated specifically
Longlands	Lo	Plinthic Gleysols (Gp) (with Albic horizon)
Westleigh	We	Plinthic Acrisols (Ap) & Luvisols (Lp) (Plinthic and Argilluvic horizons coincide)
Avalon	Av	Plinthic Luvisols (Lp), Ferralsols (Fp) & Acrisols
Glencoe	Gc	Concretionary (hardened Plinthite) phases of Ochric & Eutric cambisols
Clovelly	Cv	Mainly Ochric, Eutric (Be) & Calcic (Bk) Cambisols; Helvi & Ochric Ferrasols, but also some arenosols,

		Rhegosols, Xerosols & ermosols
Bainsvlei	Bv	Plinthic Ferrasols (Fp), Acrisols (Ap) & Luvisols
Hutton	Hu	Mainly Rhodic (Fr) & Helvic Ferrasols & arenosols, but also some Cambisols, Xertosols and Ermosols
Shortlands	Sd	Chromic (Lc), Ferric (Lf) & Rhodic Luvisols
Oakleaf	Oa	Ochric, Eutric (Be) & Calcic (Bk) Cambisols; Haplic (Xh) & Calcic (Xk) Xerosols and Ermosols; Ochric Solonchaks
Frenwood	Fw	Dystric (Rd) Eutric (Re) Regosols; Ochric and Humic (Gh) Gleysols (Coarse textured in all cases); Arenosols
Dundee	Du	Eutric (Je), Carbonatic & possibly Dystric (Jd) & Gleyic Fluvisols
Glenrosa	Gs	Ochric, Eutric (Be) & Calcic (Bk) Cambisols; Haplic Xerosols (Xh) (Lithic phases)
Mispah	Ms	Lithosols, Linthic, concretionary (Ironstone), Petracalcic & Duripin phases of Calcic Ermosols, Calcic Xerosols (Xk), Rhegosols & Solenchaks
Immerpan	Im	

Appendix II

Crop Requirements

IIa. Soil properties for maize production in KZN (Milborrow, 1989)

Land Characteristics	Landscape Classes				
	S1	S2	S3	N1	N2
Soil Texture	C-60s-SCL	C+60V-LS	C+60V-fS	C+60V-fS	cS
Soil depth (mm)	900	500-900	250-500	-	<250
Acid Saturation	<20	-	-	-	-
Organic matter (%C 0-15cm)	>1.2	0.8-1.2	<0.8	-	-
Phosphorous (/kg)	>15	10-15	-	<5	-
Potassium (/kg)	>3.1	-	-	<3.1	-

IIb. Climatic requirements for maize production in KZN (Parsons, 1991; Smith, 1997)

Climatic Characteristics	Climatic Classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	750-500	600–50	500-600	<500	-
Length of growing season (days)	130-170	110–130	90-110	-	<90
Rainfall growing Season (mm)	700-1500	600-700	500-600	-	-
Mean temp. grow. Season (ºC)	18-24	16-18	14-16	-	-
Mean min temp. grow. Season (ºC)	12–24	9-12	7-9	-	-

IIc. Soil factor to be applied to calculate crop yields for Potatoes according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting Depth (mm)	Well Drained Soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
100	0.90	1.0	0.85
750	0.85	0.95	0.90
500	0.80	0.90	0.85

The soil factor was used as index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that:

Soil facto r≥ 0.8…………………………..S1 80 – 100% attainable yield
Soil factor 0.06 – 0.08………………….. S2 60 – 80% attainable yield
Soil factor 0.5 – 0.6………………………S3 40 – 60% attainable yield

IId. Climatic requirements for potatoes in KZN (Smith, 1997)

Climatic Characteristics	Climatic Classes				
	S1	S2	S3	N1	N2
Monthly rainfall (mm)					
1st month	>45	>30	>20	-	Any
2nd month	>80	>65	>50	-	Any
3rd month	>80	>65	>50	-	Any
4th month	>20	Any	-	-	-
Mean temp. grow. Season (ºC)	13-24	10-27	8-30	-	Any
Average absolute min temp. in the 1st month (ºC)	>0	>-1	>-2	-	Any
Average absolute min temp. for the other months (ºC)	>-1	>-2	>-3	-	Any

IIe. Soil factor to be applied to calculate crop yields for dry beans according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting Depth (mm)	Well Drained Soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
1000	0.8	1.0	0.8
750	0.7	0.8	0.7
500	0.85	0.7	0.6

The soil factor was used as index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that:

Soil factor ≥ 0.8…………………………..S1 80 – 100% attainable yield

Soil factor 0.06 – 0.08………………….. S2 60 – 80% attainable yield

Soil factor 0.5 – 0.6………………………S3 40 – 60% attainable yield

IIf. Climatic requirements for dry beans in KZN (Smith, 1997)

Climatic Characteristics	Climatic Classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	> 700	-	-	-	-
Length of growing season (days)	90-120	-	-	-	-
Mean temp. grow. reason (ºC)	<24	24-27	27-30	>30	Any
Mean min temp. grow. Season (ºC)	18-24	15-18	10-15	<10	Any
Mean min temp. of grow. Season (ºC)	>15	12-15	10-12	<10	Any

IIg. Soil factor to be applied to calculate crop yields for cabbages according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting Depth (mm)	Well Drained Soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
750	0.9	1.0	0.95
500	0.85	0.95	0.90
The soil factor was used as index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that: Soil factor ≥ 0.8…………………………..S1 80 – 100% attainable yield Soil factor 0.06 – 0.08………………….. S2 60 – 80% attainable yield Soil factor 0.5 – 0.6………………………S3 40 – 60% attainable yield			

IIj. Climatic requirements for cabbages in KZN (Smith, 1997; Doorenbos and Kassam, 1979)

Climatic Characteristics	Climatic Classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	300-450	-	-	-	-
Length of growing season (days)	90-120	-	-	-	-
Mean temp. grow. season (ºC)	15-18	11-15 18-22	10-11 22-24	<10 >24	-
Mean min temp. grow. Season (ºC)	> 5	-	-	< -3	-
Mean max temp. of grow. Season (ºC)	<24	-	-	> 25	-

IIi. Soil factor to be applied to calculate crop yields for sorghum according to soil depth and texture (soil factors adapted from Smith, 1997).

Rooting Depth (mm)	Well Drained Soils		
	Sand <15% clay	Loam 15-35% clay	Clay >35% clay
1000	0.90	1.1	0.9
750	0.8	1.0	0.8
500	0.6	0.90	0.70

The soil factor was used as index of land suitability and was correlated to the FAO land suitability rating according to the FAO assumption that:

Soil factor ≥ 0.8…………………………..S1 80 – 100% attainable yield

Soil factor 0.06 – 0.08………………….. S2 60 – 80% attainable yield

Soil factor 0.5 – 0.6………………………S3 40 – 60% attainable yield

IIj. Climatic requirements for sorghum production in KZN (Sys, 1985, Smith, 1997)

Climatic Characteristics	Climatic Classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	600-1200	400-400	350-1500	-	Any
Length of growing season (days)	120-240	90-200	75-300	-	Any
Mean temp grow. season (ºC)	24-34	>22	>20	-	Any
Mean temp grow. Season (ºC)	31-32	>18	>15	-	Any
Mean min temp. of grow. Season (ºC)	>15	>12	>8	-	Any

IIk. Climatic requirements for turnip production in KZN (Starke Ayers, 2004; Smith, 1997)

Climatic Characteristics	Climatic Classes				
	S1	S2	S3	N1	N2
Annual rainfall (mm)	700mm	-	-	-	Any
Length of growing season (days)	120-240	-	-	-	Any
Mean temp. grow. season (ºC)	15-18	-	-	-	Any
Mean min temp. grow. Season (ºC)	>5	-	-	-	Any

APPENDIX III

SUMMARY OF SOIL ANALYTICAL RESULTS

Appendix IIIa. Nutrient and lime recommendations for maize production

		Nitrogen	Phosphorous			Pottassium			Lime			Lime type	Zinc
Sample No	Yield target t/ha	Required kg N/ha	Sample soil test mg/L	Target soil test mg/L	Req.P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. lime t/ha		
1	4.0	50	3	12	95	94	100	15	12	20	.0		No
	5.0	75	3	12	95	94	100	15	12	20	.0		No
	7.0	140	3	12	95	94	100	15	12	20	.0		No
5	4.0	50	3	12	95	185	100	0	36	20	4.0	dol/calc	Yes
	5.0	75	3	12	95	185	100	0	36	20	4.0	dol/calc	Yes
	7.0	140	3	12	95	185	100	0	36	20	4.0	dol/calc	Yes
6	4.0	50	5	12	75	54	100	115	73	20	10.0	dol.	Yes
	5.0	75	5	12	75	54	100	115	73	20	10.0	dol.	Yes
	7.0	140	5	12	75	54	100	115	73	20	10.0	dol.	Yes
7	4.0	50	4	12	85	340	100	0	7	20	.0		No
	5.0	75	4	12	85	340	100	0	7	20	.0		No
	7.0	140	4	12	85	340	100	0	7	20	.0		No
13	4.0	50	2	12	110	206	100	0	28	20	1.0	dol/calc	No
	7.0	140	2	12	110	206	100	0	28	20	1.0	dol/calc	No
16	4.0	50	12	12	20	207	100	0	60	20	11.0	dol/calc	No
	5.0	75	12	12	20	207	100	0	60	20	11.0	dol/calc	No
	7.0	140	12	12	20	207	100	0	60	20	11.0	dol/calc	No

	5.0	75	2	12	110	206	100	0	28	20	1.0	dol/calc	No
18	4.0	50	8	12	45	186	100	0	61	20	9.0	dol/calc	Yes
	5.0	75	8	12	45	186	100	0	61	20	9.0	dol/calc	Yes
	7.0	140	8	12	45	186	100	0	61	20	9.0	dol/calc	Yes
19	4.0	50	8	12	45	219	100	0	46	20	5.5	dol/calc	No
	5.0	75	8	12	45	219	100	0	46	20	5.5	dol/calc	No
	7.0	140	8	12	45	219	100	0	46	20	5.5	dol/calc	No
20	4.0	50	6	12	65	48	100	130	72	20	8.0	dol.	No
	5.0	75	6	12	65	48	100	130	72	20	8.0	dol.	No
	7.0	140	6	12	65	48	100	130	72	20	8.0	dol.	No
23	4.0	50	5	12	75	108	100	0	82	20	12.5	dol.	Yes
	5.0	75	5	12	75	108	100	0	82	20	12.5	dol.	Yes
	7.0	140	5	12	75	108	100	0	82	20	12.5	dol.	Yes
25	4.0	50	6	12	65	260	100	0	66	20	10.5	dol/calc	Yes
	5.0	75	6	12	65	260	100	0	66	20	10.5	dol/calc	Yes
	7.0	140	6	12	65	260	100	0	66	20	10.5	dol/calc	Yes
26	4.0	50	3	12	95	104	100	0	47	20	5.0	dol/calc	No
	5.0	75	3	12	95	104	100	0	47	20	5.0	dol/calc	No
	7.0	140	3	12	95	104	100	0	47	20	5.0	dol/calc	No
27	4.0	50	5	12	75	42	100	145	82	20	8.0	dol.	Yes
	5.0	75	5	12	75	42	100	145	82	20	8.0	dol.	Yes
	7.0	140	5	12	75	42	100	145	82	20	8.0	dol.	Yes
30	4.0	50	6	12	65	251	100	0	14	20	.0		Yes
	5.0	75	6	12	65	251	100	0	14	20	.0		Yes
	7.0	140	6	12	65	251	100	0	14	20	.0		Yes
32	4.0	50	4	12	85	268	100	0	45	20	5.5	dol/calc	Yes
	5.0	75	4	12	85	268	100	0	45	20	5.5	dol/calc	Yes
	7.0	140	4	12	85	268	100	0	45	20	5.5	dol/calc	Yes
33	4.0	50	6	12	65	93	100	20	68	20	5.5	dol.	Yes
	5.0	75	6	12	65	93	100	20	68	20	5.5	dol.	Yes

	7.0	140	6	12	65	93	100	20	68	20	5.5	dol.	Yes
34	4.0	50	4	12	85	111	100	0	68	20	9.0	dol.	Yes
	5.0	75	4	12	85	111	100	0	68	20	9.0	dol.	Yes
	7.0	140	4	12	85	111	100	0	68	20	9.0	dol.	Yes
38	4.0	50	6	12	65	157	100	0	46	20	5.0	dol/calc	No
	5.0	75	6	12	65	157	100	0	46	20	5.0	dol/calc	No
	7.0	140	6	12	65	157	100	0	46	20	5.0	dol/calc	No
39	4.0	50	6	12	65	87	100	35	62	20	5.0	dol.	No
	5.0	75	6	12	65	87	100	35	62	20	5.0	dol.	No
	7.0	140	6	12	65	87	100	35	62	20	5.0	dol.	No
40	4.0	50	3	12	95	75	100	65	41	20	2.5	dol/calc	Yes
	5.0	75	3	12	95	75	100	65	41	20	2.5	dol/calc	Yes
	7.0	140	3	12	95	75	100	65	41	20	2.5	dol/calc	Yes
46	4.0	50	2	12	110	210	100	0	3	20	.0		No
	5.0	75	2	12	110	210	100	0	3	20	.0		No
	7.0	140	2	12	110	210	100	0	3	20	.0		No
57	4.0	50	5	12	75	160	100	0	27	20	1.5	dol/calc	No
	5.0	75	5	12	75	160	100	0	27	20	1.5	dol/calc	No
	7.0	140	5	12	75	160	100	0	27	20	1.5	dol/calc	No

Appendix IIIb. Nutrient and lime recommendations for dry beans production

		Nitrogen	Phosphorous			Pottassium			Lime			Lime Type	Zinc
Sample No.	Yield target t/ha	Required kg N/ha	Sample soil test mg/L	Target soil test mg/L	Req.P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. lime t/ha		
1	1.0	40	3	10	75	94	100	15	12	5	1.5	dol/calc	No
	2.0	80	3	10	75	94	100	15	12	5	1.5	dol/calc	No
	3.0	120	3	10	75	94	100	15	12	5	1.5	dol/calc	No
5	1.0	40	3	10	75	185	100	0	36	5	9.0	dol/calc	Yes
	2.0	80	3	10	75	185	100	0	36	5	9.0	dol/calc	Yes
	3.0	120	3	10	75	185	100	0	36	5	9.0	dol/calc	Yes
6	1.0	40	5	10	55	54	100	115	73	5	16.0	dol.	Yes
	2.0	80	5	10	55	54	100	115	73	5	16.0	dol.	Yes
	3.0	120	5	10	55	54	100	115	73	5	16.0	dol.	Yes
7	1.0	40	4	10	65	340	100	0	7	5	1.0	dol/calc	No
	2.0	80	4	10	65	340	100	0	7	5	1.0	dol/calc	No
	3.0	120	4	10	65	340	100	0	7	5	1.0	dol/calc	No
13	1.0	40	2	10	85	206	100	0	28	5	4.5	dol/calc	No
	2.0	80	2	10	85	206	100	0	28	5	4.5	dol/calc	No
	3.0	120	2	10	85	206	100	0	28	5	4.5	dol/calc	No
16	1.0	40	12	10	20	207	100	0	60	5	18.0	dol/calc	No
	2.0	80	12	10	20	207	100	0	60	5	18.0	dol/calc	No
	3.0	120	12	10	20	207	100	0	60	5	18.0	dol/calc	No
18	1.0	40	8	10	20	186	100	0	61	5	14.5	dol/calc	Yes
	2.0	80	8	10	20	186	100	0	61	5	14.5	dol/calc	Yes
	3.0	120	8	10	20	186	100	0	61	5	14.5	dol/calc	Yes
19	1.0	40	8	10	20	219	100	0	46	5	10.5	dol/calc	No

	2.0	80	8	10	20	219	100	0	46	5	10.5	dol/calc	No
	3.0	120	8	10	20	219	100	0	46	5	10.5	dol/calc	No
20	1.0	40	6	10	45	48	100	130	72	5	12.0	dol.	No
	2.0	80	6	10	45	48	100	130	72	5	12.0	dol.	No
	3.0	120	6	10	45	48	100	130	72	5	12.0	dol.	No
23	1.0	40	5	10	55	108	100	0	82	5	19.0	dol.	Yes
	2.0	80	5	10	55	108	100	0	82	5	19.0	dol.	Yes
	3.0	120	5	10	55	108	100	0	82	5	19.0	dol.	Yes
25	1.0	40	6	10	45	260	100	0	66	5	17.0	dol/calc	Yes
	2.0	80	6	10	45	260	100	0	66	5	17.0	dol/calc	Yes
	3.0	120	6	10	45	260	100	0	66	5	17.0	dol/calc	Yes
26	1.0	40	3	10	75	104	100	0	47	5	9.5	dol/calc	No
	2.0	80	3	10	75	104	100	0	47	5	9.5	dol/calc	No
	3.0	120	3	10	75	104	100	0	47	5	9.5	dol/calc	No
27	1.0	40	5	10	55	42	100	145	82	5	12.0	dol.	Yes
	2.0	80	5	10	55	42	100	145	82	5	12.0	dol.	Yes
	3.0	120	5	10	55	42	100	145	82	5	12.0	dol.	Yes
30	1.0	40	6	10	45	251	100	0	14	5	3.0	dol/calc	Yes
	2.0	80	6	10	45	251	100	0	14	5	3.0	dol/calc	Yes
	3.0	120	6	10	45	251	100	0	14	5	3.0	dol/calc	Yes
32	1.0	40	4	10	65	268	100	0	45	5	10.0	dol/calc	Yes
	2.0	80	4	10	65	268	100	0	45	5	10.0	dol/calc	Yes
	3.0	120	4	10	65	268	100	0	45	5	10.0	dol/calc	Yes
33	1.0	40	6	10	45	93	100	20	68	5	9.0	dol.	Yes
	2.0	80	6	10	45	93	100	20	68	5	9.0	dol.	Yes
	3.0	120	6	10	45	93	100	20	68	5	9.0	dol.	Yes
34	1.0	40	4	10	65	111	100	0	68	5	14.0	dol.	Yes
	2.0	80	4	10	65	111	100	0	68	5	14.0	dol.	Yes
	3.0	120	4	10	65	111	100	0	68	5	14.0	dol.	Yes
38	1.0	40	6	10	45	157	100	0	46	5	9.5	dol/calc	No

	2.0	80	6	10	45	157	100	0	46	5	9.5	dol/calc	No
	3.0	120	6	10	45	157	100	0	46	5	9.5	dol/calc	No
39	1.0	40	6	10	45	87	100	35	62	5	8.5	dol.	No
	2.0	80	6	10	45	87	100	35	62	5	8.5	dol.	No
	3.0	120	6	10	45	87	100	35	62	5	8.5	dol.	No
40	1.0	40	3	10	75	75	100	65	41	5	5.5	dol/calc	Yes
	2.0	80	3	10	75	75	100	65	41	5	5.5	dol/calc	Yes
	3.0	120	3	10	75	75	100	65	41	5	5.5	dol/calc	Yes
46	1.0	40	2	10	85	210	100	0	3	5	.0		No
	2.0	80	2	10	85	210	100	0	3	5	.0		No
	3.0	120	2	10	85	210	100	0	3	5	.0		No
57	1.0	40	5	10	55	160	100	0	27	5	6.5	dol/calc	No
	2.0	80	5	10	55	160	100	0	27	5	6.5	dol/calc	No
	3.0	120	5	10	55	160	100	0	27	5	6.5	dol/calc	No

Appendix IIIc. Nutrient and lime recommendations for potato production

			Phosphorus			Potassium			Lime				
Sample ID	Yield target	Required kg N/ha	Sample soil test mg/L	Target soil test mg/L	Req.P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. lime t/ha	Lime type	Zinc
1	20.0	90	3	16	140	94	160	165	12	30	.0		No
	40.0	160	3	16	140	94	200	265	12	30	.0		No
	60.0	200	3	16	140	94	240	365	12	30	.0		No
5	20.0	90	3	16	140	185	160	90	36	30	1.5	dol/cal	Yes
	40.0	160	3	16	140	185	200	110	36	30	1.5	dol/cal	Yes
	60.0	200	3	16	140	185	240	140	36	30	1.5	dol/cal	Yes
6	20.0	90	5	16	120	54	160	265	73	30	8.5	dol.	Yes
	40.0	160	5	16	120	54	200	365	73	30	8.5	dol.	Yes
	60.0	200	5	16	120	54	240	465	73	30	8.5	dol.	Yes
7	20.0	90	4	16	130	340	160	10	7	30	.0		No
	40.0	160	4	16	130	340	200	30	7	30	.0		No
	60.0	200	4	16	130	340	240	50	7	30	.0		No
13	20.0	90	2	16	150	206	160	75	28	30	.0	low	No
	40.0	160	2	16	150	206	200	95	28	30	.0	low	No
	60.0	200	2	16	150	206	240	115	28	30	.0	low	No
16	20.0	90	12	16	45	207	160	75	60	30	8.0	dol.	No
	40.0	160	12	16	80	207	200	95	60	30	8.0	dol.	No
	60.0	200	12	16	80	207	240	115	60	30	8.0	dol.	No
18	20.0	90	8	16	85	186	160	85	61	30	6.5	dol.	Yes
	40.0	160	8	16	85	186	200	105	61	30	6.5	dol.	Yes
	60.0	200	8	16	85	186	240	135	61	30	6.5	dol.	Yes
19	20.0	90	8	16	85	219	160	70	46	30	3.5	dol/cal	No

	40.0	160	8	16	85	219	200	90	46	30	3.5	dol/cal	No
	60.0	200	8	16	85	219	240	110	46	30	3.5	dol/cal	No
20	20.0	90	6	16	110	48	160	280	72	30	6.5	dol.	No
	40.0	160	6	16	110	48	200	380	72	30	6.5	dol.	No
	60.0	200	6	16	110	48	240	480	72	30	6.5	dol.	No
23	20.0	90	5	16	120	108	160	130	82	30	10.5	dol.	Yes
	40.0	160	5	16	120	108	200	230	82	30	10.5	dol.	Yes
	60.0	200	5	16	120	108	240	330	82	30	10.5	dol.	Yes
25	20.0	90	6	16	110	260	160	50	66	30	8.5	dol.	Yes
	40.0	160	6	16	110	260	200	70	66	30	8.5	dol.	Yes
	60.0	200	6	16	110	260	240	90	66	30	8.5	dol.	Yes
26	20.0	90	3	16	140	104	160	140	47	30	3.0	dol.	No
	40.0	160	3	16	140	104	200	240	47	30	3.0	dol.	No
	60.0	200	3	16	140	104	240	340	47	30	3.0	dol.	No
27	20.0	90	5	16	120	42	160	295	82	30	7.0	dol.	Yes
	40.0	160	5	16	120	42	200	395	82	30	7.0	dol.	Yes
	60.0	200	5	16	120	42	240	495	82	30	7.0	dol.	Yes
30	20.0	90	6	16	110	251	160	55	14	30	.0		Yes
	40.0	160	6	16	110	251	200	75	14	30	.0		Yes
	60.0	200	6	16	110	251	240	95	14	30	.0		Yes
32	20.0	90	4	16	130	268	160	45	45	30	3.0	dol/cal	Yes
	40.0	160	4	16	130	268	200	65	45	30	3.0	dol/cal	Yes
	60.0	200	4	16	130	268	240	85	45	30	3.0	dol/cal	Yes
33	20.0	90	6	16	110	93	160	170	68	30	4.5	dol.	Yes
	40.0	160	6	16	110	93	200	270	68	30	4.5	dol.	Yes
	60.0	200	6	16	110	93	240	370	68	30	4.5	dol.	Yes
34	20.0	90	4	16	130	111	160	125	68	30	7.0	dol.	Yes
	40.0	160	4	16	130	111	200	225	68	30	7.0	dol.	Yes
	60.0	200	4	16	130	111	240	325	68	30	7.0	dol.	Yes

38	20.0	90	6	16	110	157	160	100	46	30	3.0	dol.	No
	40.0	160	6	16	110	157	200	120	46	30	3.0	dol.	No
	60.0	200	6	16	110	157	240	210	46	30	3.0	dol.	No
39	20.0	90	6	16	110	87	160	185	62	30	4.0	dol.	No
	40.0	160	6	16	110	87	200	285	62	30	4.0	dol.	No
	60.0	200	6	16	110	87	240	385	62	30	4.0	dol.	No
40	20.0	90	3	16	140	75	160	215	41	30	1.5	dol.	Yes
	40.0	160	3	16	140	75	200	315	41	30	1.5	dol.	Yes
	60.0	200	3	16	140	75	240	415	41	30	1.5	dol.	Yes
46	20.0	90	2	16	150	210	160	75	3	30	.0		No
	40.0	160	2	16	150	210	200	95	3	30	.0		No
	60.0	200	2	16	150	210	240	115	3	30	.0		No
57	20.0	90	5	16	120	160	160	100	27	30	.0		No
	40.0	160	5	16	120	160	200	120	27	30	.0		No
	60.0	200	5	16	120	160	240	200	27	30	.0		No