UNIVERSITY OF NAIROBI

DEVELOPING A SUITABILITY MODEL FOR OPTIMIZED CROPS PRODUCTION

A case study of Groundnuts in Meru County.

By

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F19/2467/2009

A project study submitted to the Department of Geospatial And Space Technology in partial fulfillment of the requirements for the award of the degree of:

Bachelor of Science in Geospatial Engineering

April 2014

Abstract

Agriculture, and specifically crop production is the main source of livelihood for the greatest populace in Africa. With the outbursts in population growth, land-to-population ratio has drastically reduced over years. Crop-land suitability modeling and analysis is a prerequisite to achieve optimum utilization of the remaining land resources for sustainable agricultural production. One of the most important and urgent needs in Kenya agricultural sector today is to improve agricultural land management and cropping patterns to increase crop production. This can only be achieved by efficient utilization of land resource as well as optimized factors-of-production combination.

The purpose of this study is to develop a crop-land suitability model for Meru County and using the production requirements for groundnuts, run the model to demonstrate the various suitability classes for the production of this crop. This is done using the analysis tools in ArcGIS 10.1. The study was done in Meru County, Kenya. Relevant biophysical variables of soil, climate and topography were considered for the suitability analysis and modeling. Suitability modeling for the crop is based on rating and weighting of all these factors of production.

The rated variables were then analyzed by overlaying them in ArcGis 10.1 environment. The output was a suitability map for all the combined factors of production weighted according to their influence to crop yields. In this study it is evident that the entire county of Meru is suitable for the cultivation of groundnuts, however, the levels of yields and returns to such investments varies as can be seen from the suitability map.

This research provides important information to farmers and investors at the county level. This could be used by the farmers to select their cropping patterns and suitability. As well as the county government in setting up factories, silos, store and collection centers. Investors in agriculture could use this model to

investigate the suitability of specific areas; not limited to Meru County, to specific crop variety.

Dedication

I dedicate this project to my dear parents Mr. and Mrs. Kalawa and my siblings; for their continued support morally, spiritually and materially throughout my studies.

May the Good Lord bless and reward them.

Acknowledgement

Am very grateful to my supervisor Mr. S.N. Nthuni, Department of Geospatial and Space Technology, University of Nairobi. He was very available for me throughout the whole period. His advice, encouragement and support for me towards this project are unparalleled.

I am also greatly indebted to all the members of staff, Department of Geospatial and Space Technology, University of Nairobi, under the leadership of chairman, Dr-Ing. S.M. Musyoka, for their continuous assistance and guidance regarding this project and the learning as a whole.

I am greatly indebted to the Kenya Agricultural Research Institute and the Kenya Soil Survey staff, especially Mr. Tanui Kiphirchir who assisted me to acquire the datasets, and gave me insights that challenged me to give all my best to this research.

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Acronyms and Abbreviations

ACZ	Agro-climatic Zone
AHP	Analytical Hierarchical Process
DEM	Digital Elevation Model
FAO	Food and Agricultural Organisation
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	Gesellschaft für Technische Zusammenarbeit
ILRI	International Livestock Research Institute
KARI	Kenya Agricultural Research Institute
KBS	Kenya Bureau of Statistics
KSS	Kenya Soil Survey
MCDA	Multi Criteria Decision Analysis
SRTM	Shuttle Radar Topography Mission
UTM	Universal Transverse Mercator
WGS84	World Geodetic System of 1984 (a reference frame)

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Agriculture is the backbone of the Kenyan economy. Most Kenyans depend on agriculture for subsistence production while a few do farming for commercial purposes. With the steady growth of demand for agricultural products in the world economies, agribusiness has in the recent past been ranked as one of the most profitable and sustainable forms of investments in the world. This has culminated in many people adopting specialized and technical approaches to farming. This has been enhanced greatly by the advent of many inventions and innovations; not to mention the various genetic and biochemical researches that are being done day by day.

Food is one of the few basic needs for every human being. Healthy and balanced diets are very important with regard to the health of the world population. Countries have invested greatly in research institutions and agencies that develop varieties of crops that are modified to meet the needs of peoples' health, as well as cope with the climatic and biophysical characteristics available for their production. Over a long period of time, there have been continual multi-disciplinary engagements in finding the best and optimal approaches to carry out farming. This is a great idea especially, when population has drastically increased, exerting a lot of pressure on the available land for farming. Suitability analysis is the result of these multi-disciplinary approaches to agriculture and crop farming in particular. It seeks to optimize production of specific type of crop in specific parcels of land, using the best factor combination, or optimizing the choice of the best crop variety for the particular piece of land.

In Kenya, particularly, according to nations' encyclopedia, 8% of the land is used for crop and food production. Less than 20% of the land is suitable for cultivation, of which only 12% is classified as high potential (adequate rainfall) agricultural land and about 8% is medium potential land. The rest of the land is arid or semiarid. About 80% of the work force engages in agriculture or food processing. Farming in Kenya is typically carried out by small producers who usually cultivate no more than two hectares (about five acres) using limited technology. These small farms, operated by about three million farming families, account for 75% of total production. Although there are still important European-owned coffee, tea, and sisal plantations, an increasing number of peasant farmers grow cash crops.

With such a scenario, it is of great importance to optimize the utilization of the available and productive agricultural land. This can only be done by identifying the most suitable areas to plant a specific crop. GIS provides the most user friendly and accurate approaches for analyzing data using different softwares and producing qualitative and/or quantitative maps about spatial distribution, availability, density and relationships of phenomena. This is basically determined by the parameters used, data inputs, analysis tools used and the technical manipulation of data employed in the analysis.

In this research project, the use of GIS analysis functionality was explored to identify suitable areas for growing groundnuts in Meru County. This was done by overlaying digital map layers of the various parameters affecting the growth of groundnuts; temperature, rainfall, altitude, slope soil PH, soil drainage and soil depth.

Model builder gives the best integration of programming workflows and visualization of the data analysis processes in ArcGis. It is the most simplified approach that enhances visual impression, understandability of the workflows and actual data analysis. This is the approach used for this project.

1.2 Problem statement

Traditional farming methods are no longer capable of meeting all the demands made on the farming community; widespread application of scientific methods is required, but knowledge of these methods is obtained, compiled and stored elsewhere, out of reach of the farmer (Farm Management Handbook Vol VII). Traditional methods of farming have proved unsustainable in providing for the dietary needs of the populations in the world today. The reason behind this is two-fold; one, due to the drastically increasing population there is a proportionate decrease in sizes of agricultural land, and two, due to the continued deterioration of the quality and fertility of the soil as well as negative changes in climatic conditions in the world; there is reduced productivity of the available land. Moreover, historical knowledge of the suitability of certain crops in specific areas has been unreliable over time due to the latter reason above. In order to overcome the above reasons and cater for the dietary needs of the people, best farming practices need to be employed. Such methods need to be adaptive to the changes in the factors of crop production as well as optimally utilizing the available land parcels to meet the increasing dietary needs.

GIS-suitability analysis is a multi-disciplinary approach that analyses the best-factor-combination, and produces respective suitability classes based on the variables, parameters and geo-processing tools used in the analysis. In farming, for instance, this would, if properly carried out, produce the most accurate suitability classes that would guild the farmer to plant the best crop at its best spatial location and to a great extent reduce artificial inputs for the farmer as well as improve yields per acre. Developing countries have relatively bigger availability of productive land that has not been utilized or are considerably underutilized. These countries could potentially play a very significant role in supplying the crop products to the rest of the world, provided they paid more attention to scientific approaches like precision farming.

In Kenya, for instance, agricultural counties like Meru could produce food sufficient for its residents and feed other counties whose biophysical conditions do not support crop production, especially, the northern part of the country. This can only be achieved if farmers could apply knowledge-based approaches to farming which would help them optimally utilize the available land.

A gradual transition from the classical farming methods towards the technology based farming approaches; like GIS-suitability analysis could thus have many advantages to counties, countries and regions. This is the approach being spearheaded in this research project.

1.3 Justification

In general, the Kenyan farmer is well informed as to the potential of his own land, the labour force of his family and the production techniques to be used when planting crops cultivated for generations. In the past, this was a perfectly satisfactory situation, but today, the farmer is called upon to feed a rapidly increasing population and earn a major share of vital foreign currency through exports, i.e. he / she has to shoulder the cost of economic development in Kenya, in particular in the urban areas (JTZ-Farming Management Manual, 2007). In particular, food is the most basic need for every human existence. There is drastic increase in the population of the country and the world, which has continually increased the demand for food. The paradox to this development is that, the land for agricultural investments has decreased over years, due to human settlements and desertification. Besides, the larger population have developed biases toward industrialization, technology or business, but most likely anything else other than agriculture.

The little land for farming, the fewer investors in the farming sector and the overstretched factors of farming have seen tremendous decrease in crop production, hence, prices for food increase in a skyrocketing rate every year. Meeting the dietary needs for the 7.139 billion people in the universe today has proved a great challenge. Every healthy and economically productive human being requires three meals per day which becomes an incredible statistics of how much food is consumed per day in the world! Despite all this need, it is a shocking fact that most of the agricultural areas are found in the third world or developing countries where farming methods used are poorly considered, with most farmers using the traditional methods of crop production! Food production for the greater population is left in the hands of approximately 7% of the farmers who practise the commercialized farming, with the remaining, more than 90%, being small scale farmers who do farming for subsistence only.

Therefore the approach to farming needs to be highly innovative, dynamic, very specialized and adaptive to the changes in both the climatic conditions and the decreasing sizes of the productive land. When this is done well, agriculture becomes one of the best investments; giving 100% or more returns on investment to the farmers.

For instance, in Kenya, Meru County has for a long time been known as one of the best agricultural regions in the country. Most parts of the county have sufficient rainfall, fertile volcanic soils and favorable altitude. This is justified, especially, by the spatial location of the county, on the windward side, and on the foot of the second tallest mountain in Africa: Mt. Kenya, as well as the Nyambene hills. The county enjoys average annual rainfall between 370mm and 2800mm, and temperatures between 8^0C and 28^0C. This climatic bracket is favorable for most agricultural practices. Hitherto, agriculture in this county remains the most popular economic activity. However, production by the farmers remain far below the optimum. This is mainly due to the reliability by the farmers on the historical suitability of certain crops to certain areas. This kind of approach no longer works. Precision farming is a foreign idea to the farmers. If adopted, precision farming would help the least of the farmers achieve the best utility for his/her parcel of land. If such an idea is taken up by the county government, best farming practices would be realized and the county would greatly diversify its crop production, in different parts of the region, just to mention a few. In this project, I seek to classify the spatial coverage of the county according to its suitability to the production of groundnuts. Unquestionably, this has resulted into identification of new areas for planting the crop as well as helped those who are cultivating the crop know how suitable their land is (at their parcels), relative to other areas.

Different approaches have previously been used in doing suitability analysis. Some of them are mult-criteria analysis, Analytic Hierarchy Process (AHP), querying the Gis geo-database etc. However, these approaches have proved to be tasking, complicated and are not very interactive to analysts and the users. They do show neither the process nor the suitability classes as would be expected. To seal these gaps, model building in GIS is best suited for designing workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. Model-Builder can also be thought of as a visual programming language for building workflows. This makes the sequence easy to follow by the user and the analyst, as well as making it easy to program the analysis process graphically. Different from other approaches, it is easy to change variables, edit the parameters and change the tools used at different stages of the model, in addition to achieving best results.

Suitability analysis therefore is very needful in the current farming practices. It would give agricultural counties a competitive advantage over their competitors. Model building in ArcGis makes this analysis simple and best user-friendly approach. This is the approach used in this research project.

1.4 Objectives

The main objective of this study is to develop a suitability model for the optimization of crop production in Meru County using groundnuts for the case study; consequently, producing a suitability map showing the various suitability classes for the crop in the county.

The specific objectives are:

1. To identify the biophysical requirements for groundnuts production.
2. To develop the suitability model for optimization of crop production.
3. To use the above stated model to classify Meru County into suitability classes for the groundnuts production.

1.5 Scope of the study

This study is limited to Meru County in Kenya. The main bio-physical factors that determine the growth of groundnuts, considered for this research are:

a) Rainfall
b) Altitude
c) Slope
d) Temperature
e) Soil PH
f) Soil depth
g) Soil drainage

1.6 Organization of the Report

This report is organized into five chapters. Chapter one tackles the introduction to the concepts of GIS analysis and modeling, as well as agriculture in Kenya and the world, the objectives and the scope and limitations of the study. Chapter two addresses literature review with reference to the cultivation groundnuts and GIS analysis functions and modeling. Chapter three gives an overview of the study area, materials and methodology used to come up with the results. Chapter four presents the results and analysis from the study. Then lastly, chapter five presents the conclusions and recommendations from the research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Agriculture and Land Suitability

2.1.1 Overview

Making effective decisions in agricultural-land suitability problems is vital to achieve optimum land productivity and to ensure environmental sustainability. According to FAO 1976, the term "land suitability evaluation" could be interpreted as the process of assessment of land performance when the land is used for specified purpose. It is the measure of how well the qualities of a land unit match the requirements of a particular form of land use.

In generally terms, there are two kinds of land suitability evaluation approaches: qualitative and quantitative. By qualitative approach, it is possible to assess land potential in qualitative terms, such as highly suitable, moderately suitable, or not suitable. In the second approach, quantitative, assessment of land suitability is given by numeric indicators.

Many parameters of soil and plant growth, measurable at various scales of assessment, are used as numeric indicators of agricultural land suitability. For example, weighting factors related to soil characteristics (soil PH, Soil Depth, Soil Drainage), climatic factors (temperature and Rainfall), nature of Terrain (Slope and Elevation) could be used. This can be used in classifying land into various suitability classes for certain crops.

The classification procedure used in this project is qualitative and is primarily based on the physical and chemical limitations of the soil, terrain as well as climate. Four suitability classes have been distinguished:

Class S4 - Highly suitable

The land suitable for sustained high yields of ground nuts and generally for most crops, with minimum costs of development associated with the land.

Class S3 – Moderately suitable

This is the Land of moderate productivity and/or requiring moderate costs of of development and management. This is because of the prevailing slight to moderate limitations in the land characteristics.

Class S2 – marginally suitable

The land under this class is characterized with of restricted productivity for most crops or land requiring relatively high costs for development and management because of moderate to severe limitations of land characteristics.

Class S1 – not suitable

Land that is considered unsuitable due to excessively severe limitations in soils, topography and climatic conditions.

2.2 Need for Land Suitability Modeling and Analysis

2.2.1 Land Suitability analysis

The increasing world population, coupled with the growing pressure on the land resources, necessitates the application of technologies such as GIS to help in identifying the most suitable areas for a sustainable agricultural production for food supply according to the environmental potential. Selecting the best location for agricultural production is a complex process involving not only technical requirement, but also physical, economic, social, and environmental requirements that may result in conflicting objectives. Such complexities necessitate the simultaneous use of several decision support tools such as Geographic Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA) using analytical hierarchy process (AHP). In this project a model was developed to determine the suitability of the area for agricultural production using soil PH, Soil Drainage, Soil Root-Depth, Temperature, Rainfall, Slope and Elevation of the area to support decisions making for sustainable agricultural production. This integration could benefit farmers and decision makers in agriculture planning. GIS was used based on a set of criteria derived from the spatial and environment aspect.

Land suitability is a component of sustainability evaluation of a land use. Suitability together with vulnerability defines the sustainability of the land use. The sustainable land use should have maximum suitability and minimum vulnerability. (Rosa, 2000)

2.2.1 Suitability Modeling

In ArcGIS platform, a Model-Builder is an application you use to create, edit, and manage models. Models are workflows that string together sequences of geo-processing tools, feeding the output of one tool into another tool as input. Model-Builder can also be thought of as a visual programming language for building workflows.

While Model-Builder is very useful for constructing and executing simple workflows, it also provides advanced methods for extending ArcGIS functionality by allowing you to create and share your models as a tool. Such a tool was developed in this model. This makes it very user friendly, both visually and as a programming interface. When properly designed and executed, A suitability model has many advantages. Two of these are:

- User friendliness during programming stage
- Possibility of tracing the process, editing the parameters and setting environments with ease and convenience.
- Graphical user interface for the users who do not have the technical knowledge of the programming scripts.

In consideration to the preceding advantages, suitability modeling is the approach used in this research project.

2.3 Groundnuts

Domain: Eukarya
Kingdom: Plantae
Phylum: Magnoliophyta
Class: Magnoliopsida
Order: Fabales
Family: Leguminosae
Sub-family: Papilionaceae
Genus:*Arachis*
Species: *hypogaea*

Local names: Njugu (Swahili)
Common names: Peanut, earth nuts, monkey nuts.

2.3.1 Pests and Diseases:

Aphids, Aspergillus, crown rot,Bacteria, wilt, Broomrape, damping off diseases, Groundnut blight, Groundnut hopper, Groundnut rosette disease, Leaf spots,Leaf-mining caterpillars, Milipedes, Root-knot nematodes, Rust, Sedges, Snails (Giant-EastAfrican nail) Spider, mites, Storage pests, Termites, Thrips, White grubs. E.t.c

2.3.2 Crop Description

Groundnuts originated in South America from southern Bolivia to north-western Argentina. The Portuguese apparently took them from Brazil to West Africa and then to south-western India in the 16th century. Africa is now regarded as a secondary centre of diversity. Groundnuts are now grown in most tropical, subtropical and temperate countries between 40°N and 40°S latitude, especially in Africa, Asia, North and South America.

Groundnuts are a small erect or trailing herbaceous legume, about 15 to 60 cm high. The fruit is a pod with one to five seeds that develops underground within a needle-like structure called a peg. The seeds are rich in oil (38-50%), protein, calcium, potassium, phosphorus, magnesium and vitamins. Groundnuts have also considerable medicinal value. They are reported to be useful in the treatment of disease such as haemophilia, stomatitis, and diarrhoea.

2.3.3 Climatic, soil and Relief Requirements

Groundnuts are grown in fat to gently sloping-warm tropics and subtropics below 1500 m above sea level, and in temperate humid regions with sufficiently long warm summers. Optimum mean daily temperature to grow is between 20^{O}c to 30°C and growth ceases at 15°C. Cool temperatures delay flowering. Groundnuts cannot stand frost. Rainfall should be between 500 and 600 mm reasonably well distributed through the growing season. Because pods develop underground and must be recovered at harvest, crumbly, well-drained soils are preferred, but plants grow and develop adequately on heavier clay soils. Since this is a root-crop, it requires deep soils that allow a root depth of up to 100 cm. For optimum growth, soil pH should be in the range 5.5 to 6.5, though Spanish types tolerate more acid conditions (pH 4.5) yields drop considerably for the PH above 7.5 to pH 8.5.

2.3.4 Propagation and planting

Ideally the seedbed should be deep and friable with an even particle size. Take care that the seedbed is weed-free. Cloddy and uneven seed beds can result in uneven emergence and heavy losses of plants. Recommended plant densities are near 200,000 to 250,000 plants/ha for the typically short-season Spanish cultivars. In most countries, cultivation is in rows with plant spacing ranging from 40x20cm to 30x20cm.

After ploughing and harrowing to a fairly good tilth, ridges, which are 80 cm apart with flattish tops, should be made so that two rows of nuts can be planted on each ridge. Seeds for planting should be well selected: they should be clean, well filled and without any blemishes. Seeds for planting should be kept in their pods and shelled a few days before planting. Planting depth is like maize about 5 to 8 cm. Seed rate is 40 to 50 kg/ha depending on the size of the seeds.

Figure 2.1 Groundnuts plant. (www.shutterstock.com)

2.3.5 Varieties

There are 2 types of groundnuts:

- Bunch type
- Runner type

Bunch varieties such as Red Valencia mature within 90 to 100 days, while runner types such as "Homa Bay" mature in 120 to 150 days (require a longer growing season).

Yields

Variety	Mean yield Kg/ha
"Red Valencia"	1500
"Severe 116" (white)	1250
"Texas Peanut"	1360
"Bukene"	1530

"Manipintar"	2450
"Makulu Red"	2720
"Altika"	900
"Homa Bay"	770
"Asirya Mwitunde"	1300

With good husbandry current farmers' yields of between 450-700 kg/ha could be doubled.

2.3.6 Uses of groundnuts

Most of the world production of groundnuts is crushed for oil that is used mainly for cooking. The press cake from oil extraction is a feed rich in protein but is also used to produce groundnut flour, which is used in many human foods. The seeds or kernels are eaten raw, boiled or roasted, made into confectionery and snack foods, and are used in soups or made into sauces to use on meat and rice dishes. The vegetative residues from the crop are excellent forage.

In sub-Saharan Africa, groundnuts are a basic staple crop, cultivated mainly by small-scale farmers both as subsistence and as a cash crop. It is an important source of protein and other nutrients for poor rural communities. In Africa, groundnut yields are traditionally low, due to unreliable rains, little technology available to small-scale farmers, pest and disease occurrence, poor seed variety, and increased cultivation on marginal land (ICRISAT).

1. Food

Peanut plants produce a nut-like seed that is the peanut itself. The nut can be boiled or roasted and eaten out-of-hand. The roasted peanut also is used in a variety of food products including peanut butter, baked goods, sauces, and candies. The nut also is the source of peanut oil, which often is used for cooking and baking

1. Livestock feed

   Being rich is protein, the peanut plant itself, including the vines and leaves, is harvested for cattle and horse feed. The seed pods and shells also work as high fiber roughage in animal feeds.

2. Non-food Products

Peanuts are used in making personal care items including soaps, cosmetics, shaving cream, face creams, and shampoos. The shells can be manufactured into fireplace logs, mulch, kitty litter and particle board. Peanut plants also contribute to the production of inks, dyes and paints, lubricants, medicines, and explosives.

3. Soil Improvement

As part of a crop rotation program, peanuts can help to enrich the soil. Peanuts are legumes and are able to fix nitrogen in their roots. When peanut plants are tilled back into the soil, that nitrogen improves the soil for other crops, such as cotton or wheat, which require nitrogen to grow well.

Figure 2.2 Groundnuts seeds (www.shutterstock.com)

2.4 GIS

A geographic Information System (GIS) is a computer based information system that enables the input, management, manipulation, analysis, output and dissemination of all kinds of spatially referenced, land related data and information at all times and all scales (Mulaku, 2013)

A GIS is made up of five components: people, Data, Hardware, software and procedure.

GIS functionality plays a major role in spatial decision making. One of the most engaging aspects of geo-analysis is data identification and preparation.

Datasets required for analysis exists in different projections and formats, hence the need to have uniformity for all the layers required for every analysis. GIS, when necessary data is provided, has the analytical capabilities to integrate complex and multi-spectral functionalities and produce most accurate results. This requires an in-depth knowledge of the tools available in the software platform being used. Most GIS softwares like ArcGIS 10.1 (used in this project) have diverse capabilities that integrate variety of geospatial techniques like GPS (GNSS), Remote sensing and scripting languages. It also supports various data formats as well as produce outputs in formats that are compatible across many image processing and engineering softwares like CAD.

2.4.1 Integrated Analytical Functions in a GIS

Most GIS's provide the capability to build complex models by combining primitive analytical functions. Systems vary as to the complexity provided for spatial modeling, and the specific functions that are available. However, most systems provide a standard set of primitive analytical functions that are accessible to the user in some logical manner. Buckey (2009) identifies four categories of GIS analysis functions. These are:

- Retrieval, Reclassification, and Generalization;
- Topological Overlay Techniques;
- Neighborhood Operations; and
- Connectivity Functions.

The range of analysis techniques in these categories is very large. Accordingly, this project focuses on the first two functions. These are mainly discussed in the proceeding chapter.

CHAPTER THREE: METHODOLOGY

3.1 Area of Study

This research is based on Meru county of Kenya. According to UTM projection this area falls within zone 37North and approximately between longitudes 37^0 0' 00"east and 38^0 30' 00"east and latitude 0^0 20' 00"North and 0^0 40' 0"North the spatial extent of the area is approximately 6,933 km^2 and the elevation ranges between 330 and 4975 metres above mean sea level. It also has a population of 1,356,301 people (KNBS, 2009).

Meru County is located along the eastern side of the Mt Kenya. It borders Isiolo County to the North and North East, Tharaka County to the South West, Nyeri County to the South West and Laikipia County to the West.

The county has the following constituencies.

1. Igembe South,
2. Igembe Central,
3. Igembe North,
4. Tigania West,
5. Tigania East,
6. North Imenti,
7. Buuri,
8. Central Imenti,
9. South Imenti

The county can further be classified into the following sub-regions.

1. Imenti
2. Tigania
3. Igembe

3.1.1 Imenti

This is the region occupied mostly by the imenti-dialect speaking Ameru people. It covers four constituencies: Imenti south, Imenti central, Imenti north and Buuri. It has an approximate population of 581400 people (KBS - 2009 census) the area of the four constituencies combined is approximately 2971.4 km^2. This sub-region stretches from the foot of Mount Kenya in the south western part, and borders Tharaka-Nithi County to the south eastern. The people are mainly farmers; a fact that is encouraged by the favorable rainfall, altitude and the volcanic soils. On the cooler parts, there are large tea plantations, and wheat farms in the areas of Timau, Ngusishi and the regions around the Mount Kenya. Dairy farming is another agricultural activity in these regions. The lower slopes, that are also warmer, are extensive farming of bananas and fruits. These are highly commercialized and famous throughout the country. In areas like Igoji and Ntima farmers grow ground nuts, maize and beans. The other parts like Kiirua and larger parts of Buuri constituency are known for Irish potato farming.

3.1.2 Tigania

This sub-region borders Imenti North constituency to the south, Buuri constituency to the south western, Isiolo County to the north and Igembe south constituency to the north eastern. It consists of two constituencies: Tigania west and Tigania East constituencies. This region has an approximate population of approximately 348,500 people (KNBS - 2009 census). This sub-region is regarded as the hottest part of the county. Only the area around the Nyambene hills has cool temperatures and rainfall for tea farming. The rest of the sub-region depend on rainfall for subsistence agriculture. Some of the crops in Tigania region are maize, Irish potatoes, beans, peas, cow peas, bananas and sorghum.

Due to the unfavorable climatic conditions for farming in this region, suitability study would be very helpful to the farmers in selecting the best crop to plant, and their respective bio-physical requirements.

3.1.3 Igembe

This is the northern part of the county. The main economic activity is miraa farming as well as maize and beans. It borders Meru National park, Tharaka-Nithi, Isiolo County and Tigania east constituency. It is composed of three constituencies: Igembe South, Igembe North and Igembe Central and an approximate population of 387,600 people.

The Figure 3.1 below shows the three sub-regions of the area of study. The smaller polygons within each region represent divisional boundaries in the region.

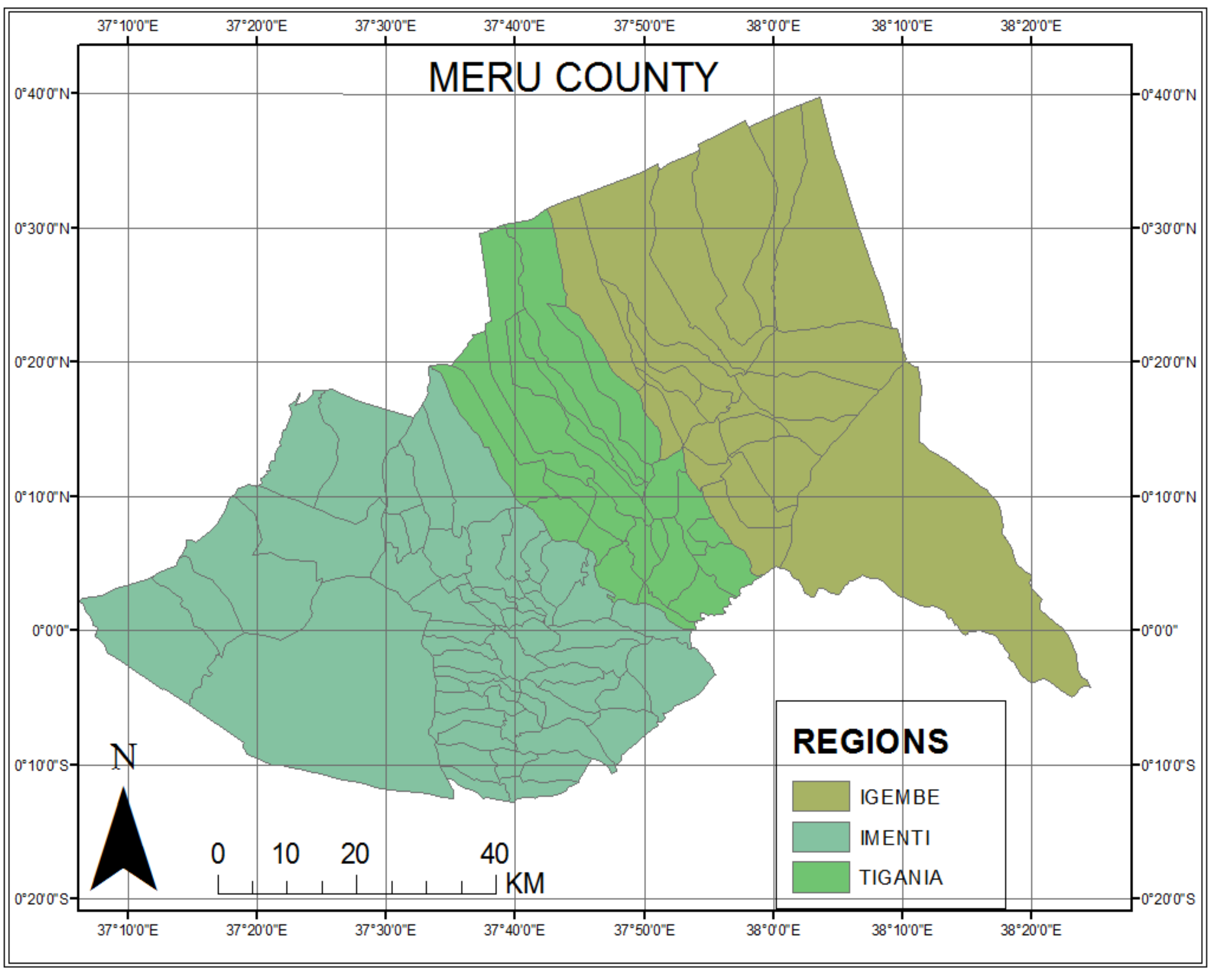


Figure 3.1 Area of Study

3.2 Overview of the Methodology

The figure 3.2 illustrates the model for this research, the Overview of the methodology beginning from the identification of the relevant datasets for the research. The datasets are majorly the main factors of crop production. This includes et al; temperature, rainfall, soil characteristics and altitude.

Some of the non spatial datasets were the crop datasets and the other non spatial characteristics of the county like place name. All these datasets were acquired from various organizations as outlined in table 3.1

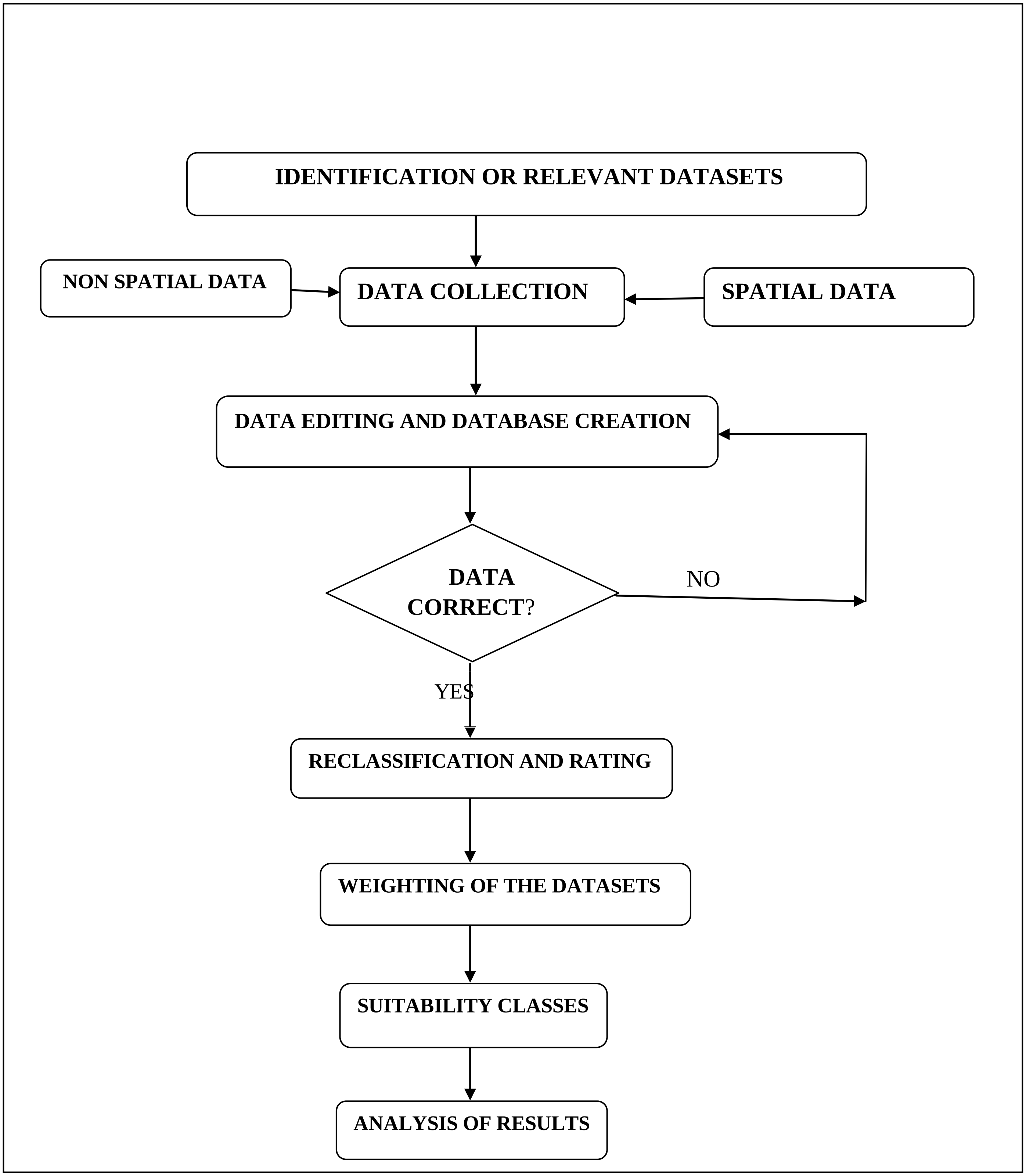
This was followed with data editing and creation of the databases. This included clipping of the data, data conversion and creation of the databases in the respective software platforms. All the datasets were therefore converted into raster data to enhance further analysis. Also at this stage, projection and datum harmonization of the data was done. This was by ensuring that all the datasets were in one projection system as well as the Datum. Mapping scale was also unified at this stage.

Data reclassification was one of the most significant steps in the whole process. At this step all datasets were given values that could be comparatively analyzed against each other and overlaid. Moreover, the data-values for each dataset were classified into *four classes,* according to the factor's suitability for the groundnuts production. This is called rating; values of the data are classified according to their importance in production and given comparative values according to their influence. It should be noted that, for accuracy and reliability, rating should be done by agricultural experts.

Weighting of the datasets is then undertaken. At this step, each dataset is given a comparative weight to other datasets. For this project, all soil datasets are weighted and overlaid against each other first. Similarly, the climatic datasets are weighted and overlaid. These two categories are the overlaid together with the elevation dataset.

This is finally followed by the realization of the *four suitability classes*. Upon these findings, the analysis of the results is undertaken.

Figure 3.2: research methodology



3.3 The Conceptual Model

In this section, a more detailed and rigorous work-flow of the whole project work was designed. The project is broken down into several processes as shown in the model. Datasets from the same composite map data are extracted and processes first before overlaying with other data. Firstly, the first level weighted overlay was done for the three categories of data separately, and finally, the final level weighted overlay follows. This has two advantages:

- It makes it easier to carry out the comparative weighting of relatively similar type of data, for example, it is easier to compare soil PH with Soil depth, than to compare soil PH with Temperature.
- It makes the analysis more rigorous. Differences of little significance are considered within each category of data before combining all the categories together. For example, analysis is done within the soil sub-dataset (soil PH, soil drainage, soil depth) as well as the climatic data (Temperature and Rainfall).

The final output of the whole analysis is a suitability map, showing the four suitability classes. This conceptual model can be applied for different spatial areas as well as for different crops. It would only require the analyst to use the appropriate datasets as inputs as well as the necessary analysis tools. However, minimum deviations are expected regardless of the crop or the area of study.

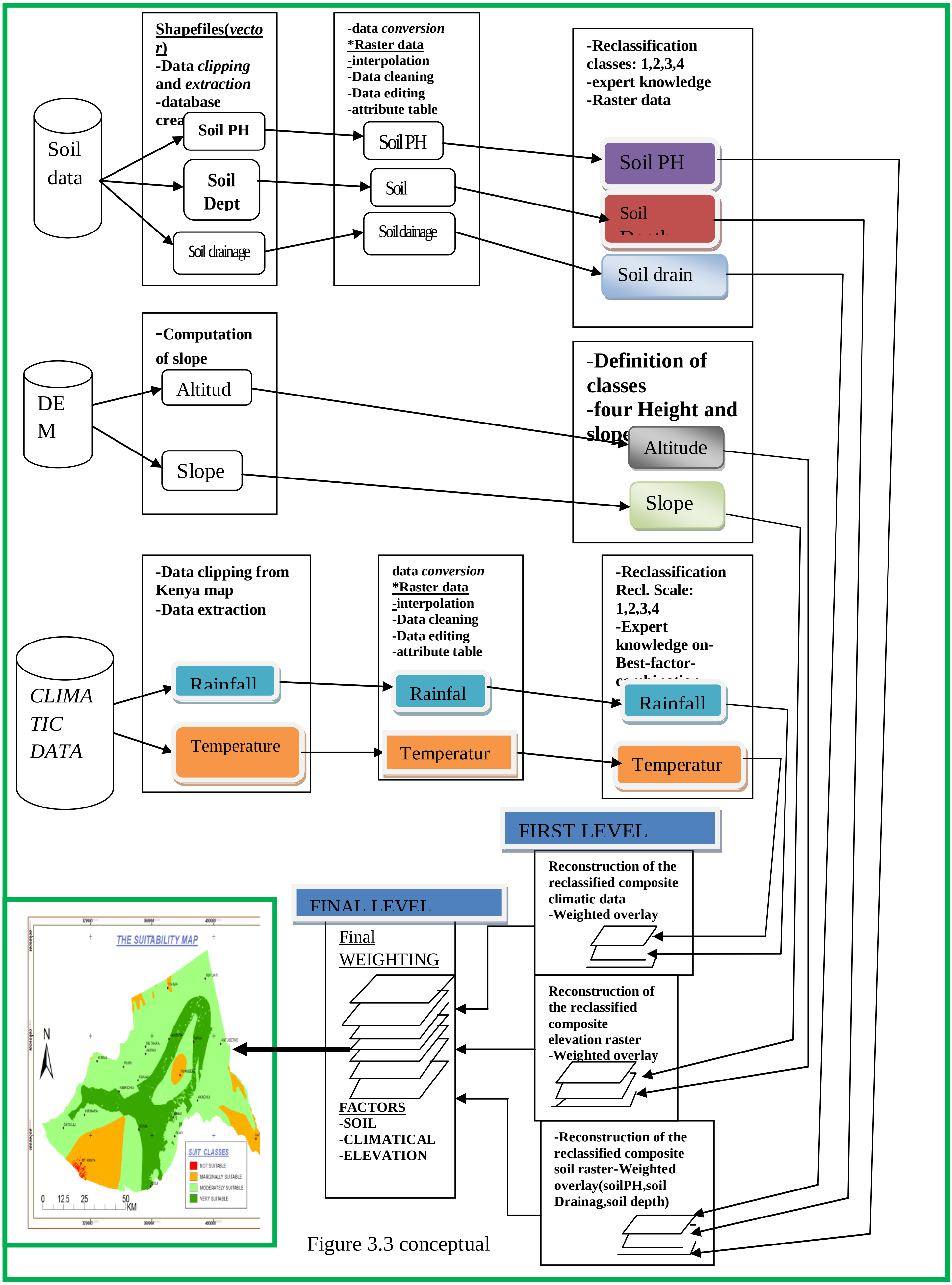


Figure 3.3 conceptual

3.4 Materials and Equipment

Hardware

The hardware used for this research study includes:

- A personal computer with the following specifications
    - 2.50 GHZ core i5
    - 4.00 GB RAM
    - 500 GB Hard Disk
- External storage
    - 8 GB Flash disk
    - 700 MB Compact Disk
- Hp laser Printer

3.5 Software

The software used includes:

- ArcGIS 10.1 (trial version)
- Global Mapper 10
- Microsoft office 2007

3.6 Data

3.6.1 Data Acquisition

The datasets used for this research project were obtained from various sources (organizations) and with varying characteristics (formats, scale, projections). This is summarized as below.

DATA	CHARACTERISTICS	SOURCE
Administrative boundaries, Roads and rivers.	Shape files (digitized topographical map of scale 1:50000)	Surveys OF Kenya (SOK)
Soil map (soil type, soil PH, soil Drainage, soil depth)	Shape files (created in 1995 at a scale of 1:1000000)	Kenya Agricultural Research Institute (KARI). The GIS section of the Soil Survey (KSS) department.
Climatic maps (temperature and rainfall)	Shape files Created in 1995 at a scale of 1:1000000)	Kenya Agricultural Research Institute (KARI). The GIS section of the Soil Survey (KSS) department.
Elevation data	Dem Spatial resolution of 90M.	Downloaded from the SRTM website

Table 3.1 Datasets

3.6.2 Data clipping and extraction

Most of the data was obtained as composite map data; either, covering large spatial area, or/and containing different datasets in their databases. For instance, the soil map data obtained from KARI was a composite map with all soil types, soil PH, soil depth, soil drainage and area of coverage for each soil type. The specific map for the county containing the necessary data was obtained by clipping it from the Kenya soil. This resulted into shapefiles for Meru County, each with a specific type of input data. The figure 3.4 below shows the soil composite soil map for the county while figure 3.5, figure 3.6 and figure 3.7 shows the extracted soil PH, soil depth and soil drainage respectively. Similarly, rainfall and temperature datasets were extracted from the Agro-Climatic Zones (ACZ) map, as shown in the following section. The elevation data was obtained by clipping the county DEM from the Kenyan DEM map. The datasets so obtained were the ones used as inputs for the research. Various geo-processing procedures were undertaken for the analysis, mainly using the ArcGIS 10.1 software.

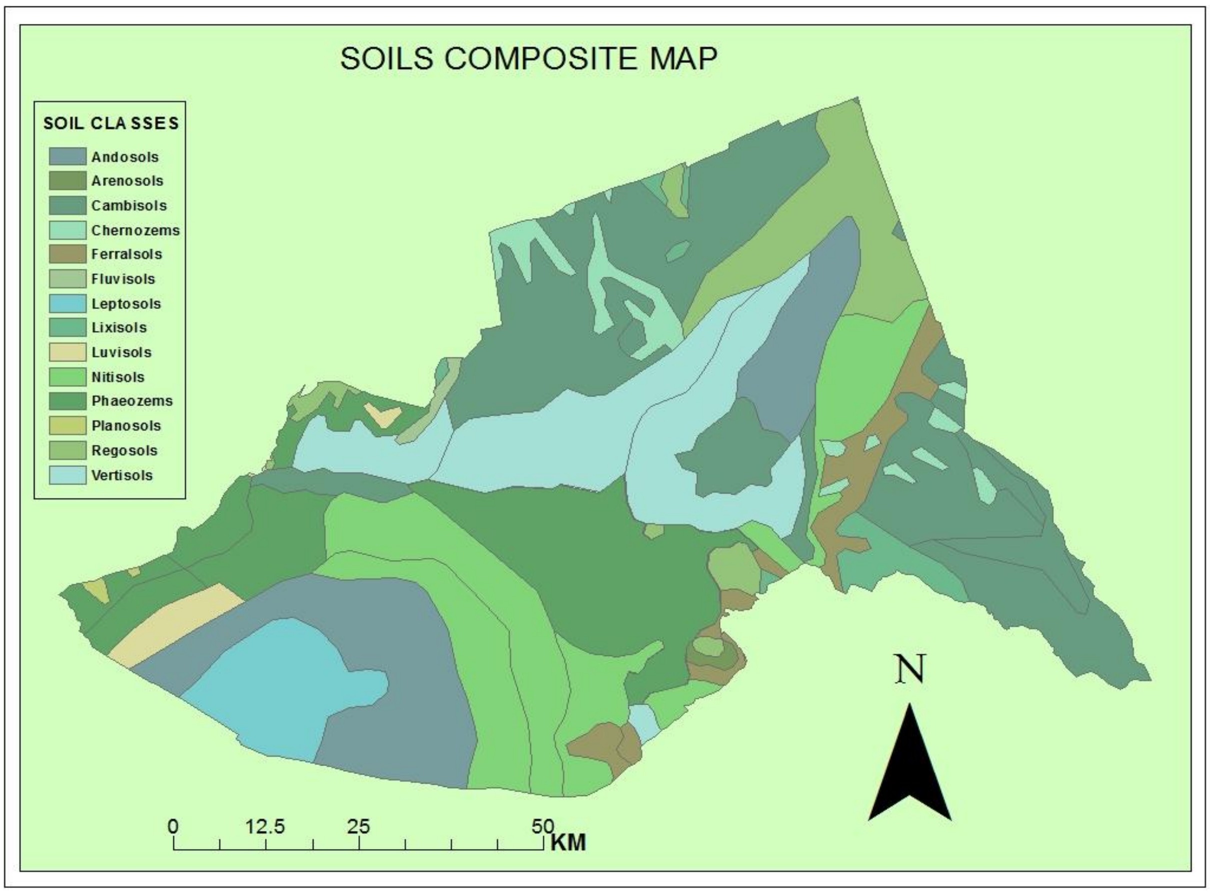


Figure 3.4 Soil Map

3.6.2a Soil Data

A composite map data for soil PH, soil Depth and soil Drainage was obtained from the Kenya Soil Survey (KSS) department at Kenya Agricultural research institute at a scale of 1:1,000,000. This data was first collected in 1995, by carrying out soil survey by soil scientists (ISRIC, KenSoTer, 1998). The map was already in digital format, and saved as shape file.

Soil PH

The soil pH is a measure of the acidity or basicity in soils. PH is defined as the negative logarithm (base 10) of the activity of hydronium ions (H^+ or, more precisely, H_3O^+aq) in a solution. In water, it normally ranges from 1 to 14, with 7 being neutral. A pH below 7 is acidic and above 7 is basic. Soil pH is considered a master variable in soils as it controls many chemical processes that take place. It specifically affects plant nutrient availability by controlling the chemical forms of the nutrient. The optimum pH range for most plants is between 5.5 and 7.0, however many plants have adapted to thrive at pH values outside this range. The PH-Water (PH_{aq}) is used as an index of soil suitability for crops or plants in general (KARI 2009). The soil PH map is shown below.

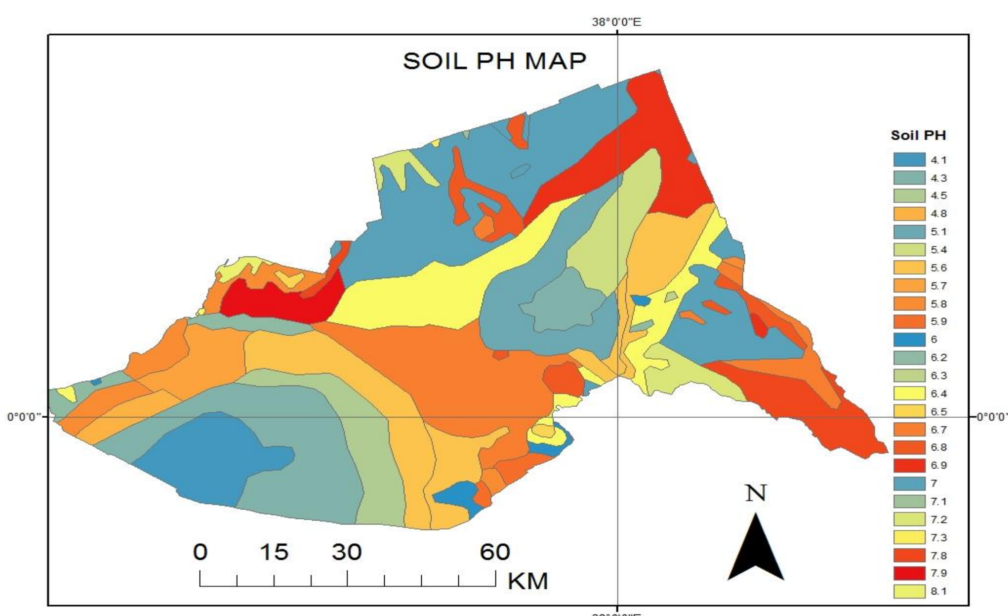


Figure 3.5 Soil PH

Soil Depth

The effective soil-depth for plant growth is the vertical distance into the soil from the surface to a layer that essentially stops the downward growth of plant roots. The barrier layer may be rock, sand, gravel, heavy clay, or a cemented layer (e.g. caliche). It is hard to establish soil depth at a good accuracy. However, the best way to estimate soil depth is by means of topography, bedrock outcrops and observations made in pits dug during soil classification and sampling the map showing the soil depths for various parts of Meru County are shown in figure 3.6 below.

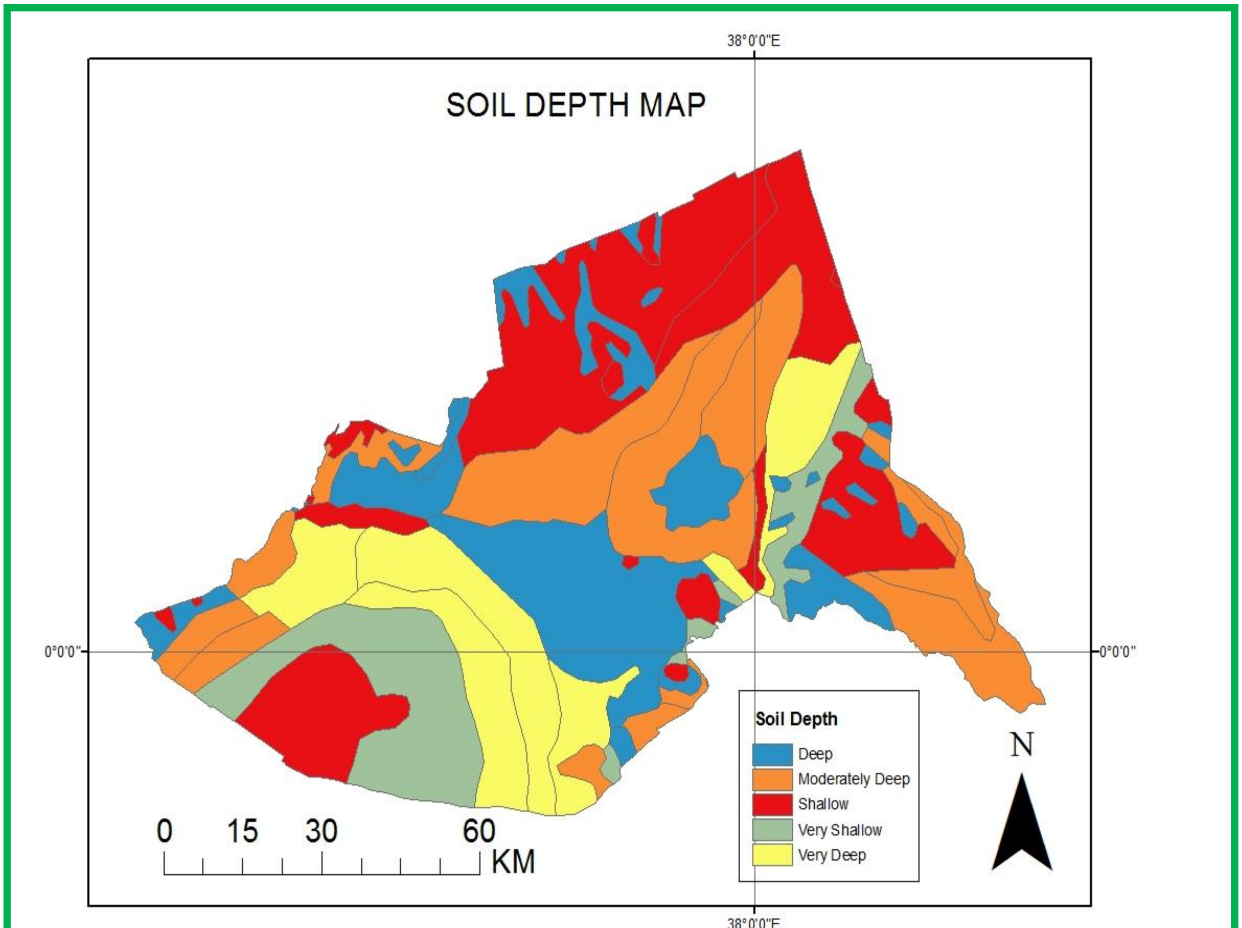


Figure 3.6: soil Depth

Soil drainage

Soil drainage is very important especially for the root (tuber) crops. The internal soil drainage characteristics determine which type of crops will grow on a particular landscape site. When soils retain too much water, the result is root suffocation, root disease, and eventually root death. The soil drainage map for the area of study is shown in figure 3.7 below.

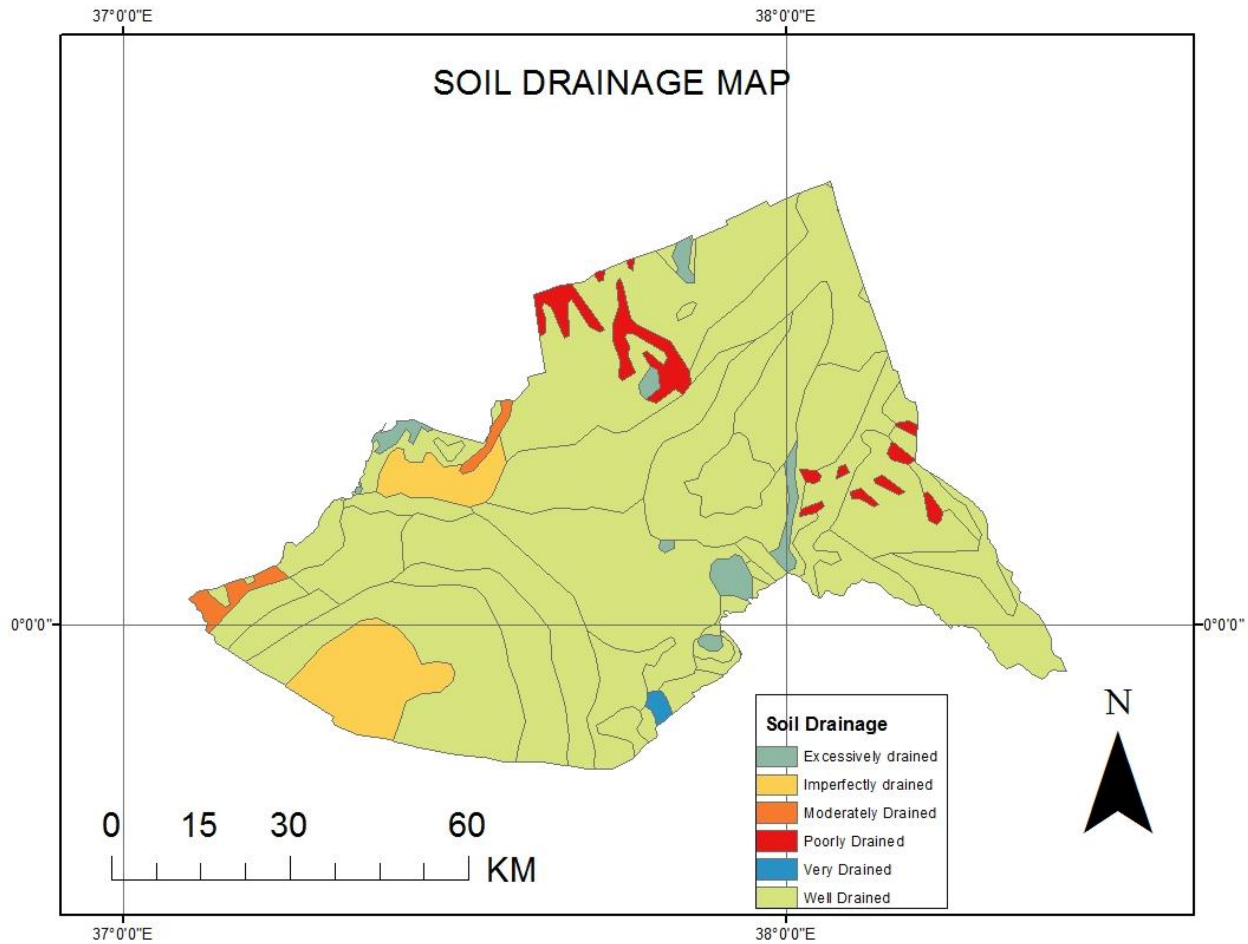


Figure 3.7: soil Drainage

3.6.2b Climatic Data

i. Temperature Data

The temperature data was clipped from the national Agro-Climatic Zones (ACZ) map, obtained from KARI**.** The composite map was at a scale of 1:1000000. The temperature is measure in degrees centigrade (^{o}C), and the values represents the average temperature. The map is shown in figure 3.8 below.

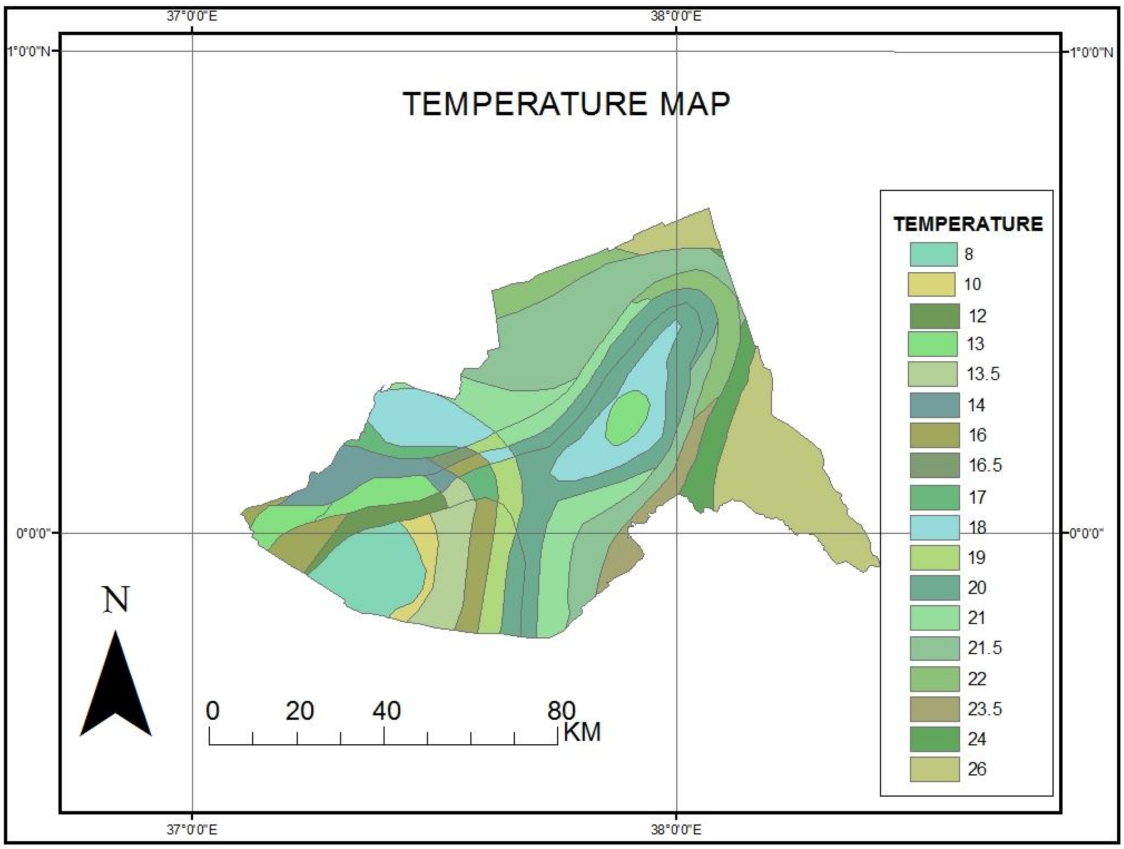


Figure 3.8: Temperature map

Figure 3.8 Average Annual Temperature

ii. **Rainfall Data**

The national database obtained from KARI also contained the Rainfall data. The rainfall data was then clipped from this map, which was, initially at a scale of 1:1,000,000. This data was originally collected by the Kenya Meteorological Department Staff in 1995. The rainfall units are millimeters, and the map is shown below in figure 3.9

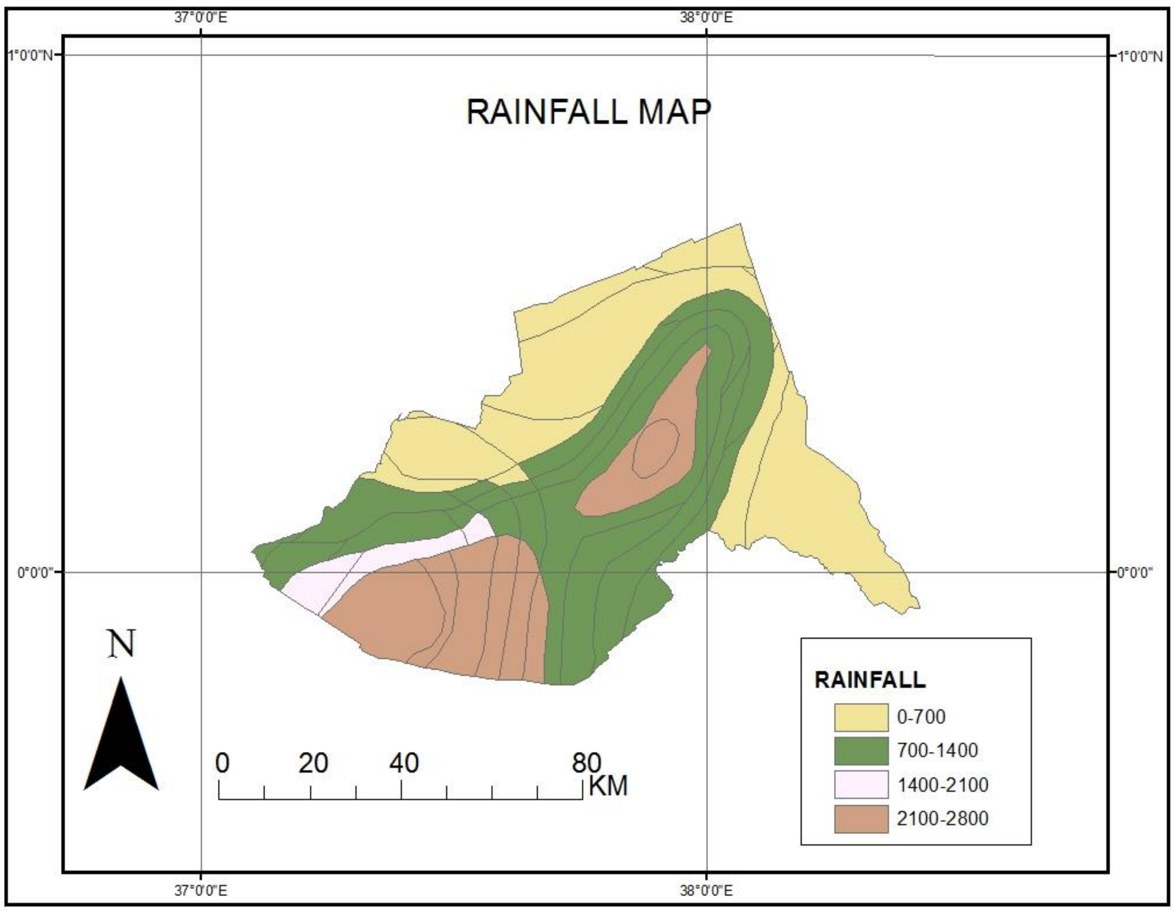


Figure 3.9 Average Total Annual Rainfall

3.6.2c Terrain Data
Altitude

Altitude is simply defined as the height of a point above the mean sea level. The altitude data was obtained from the SRTM website. This height is usually measured in metres and is as shown in figure 3.9a below. The surface has a pixel size of 30 metres.

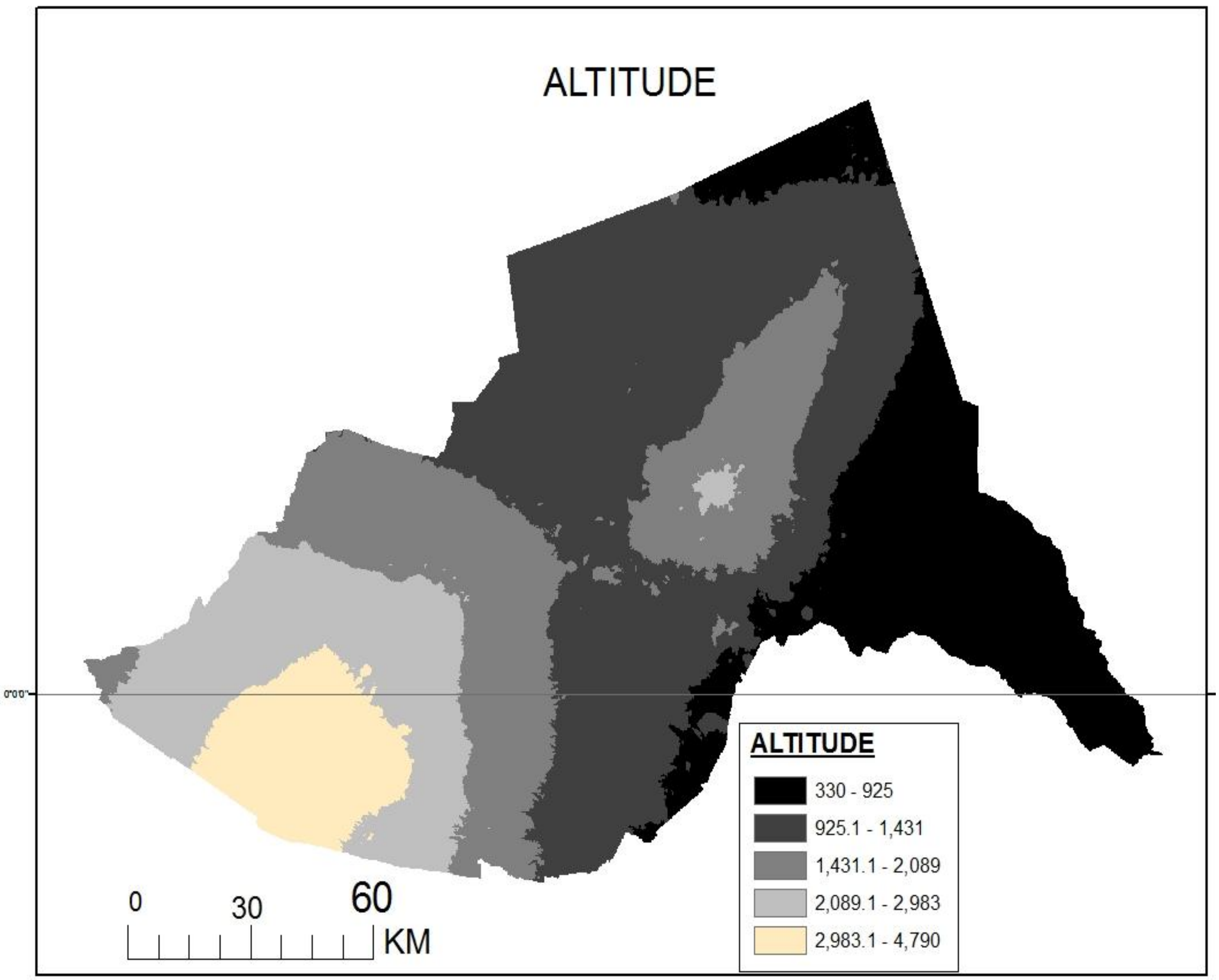


Figure 3.9a Elevation Data

SLOPE

The slope is the percentage rise of the terrain to the horizontal increase of the respective spatial extent. This is obtained by the use of the spatial analyst tool in the arctool box of the ArcGIS 10.1 software. The tool computes the rate of change of the terrain and obtains a map as below, in fig 3.9b below.

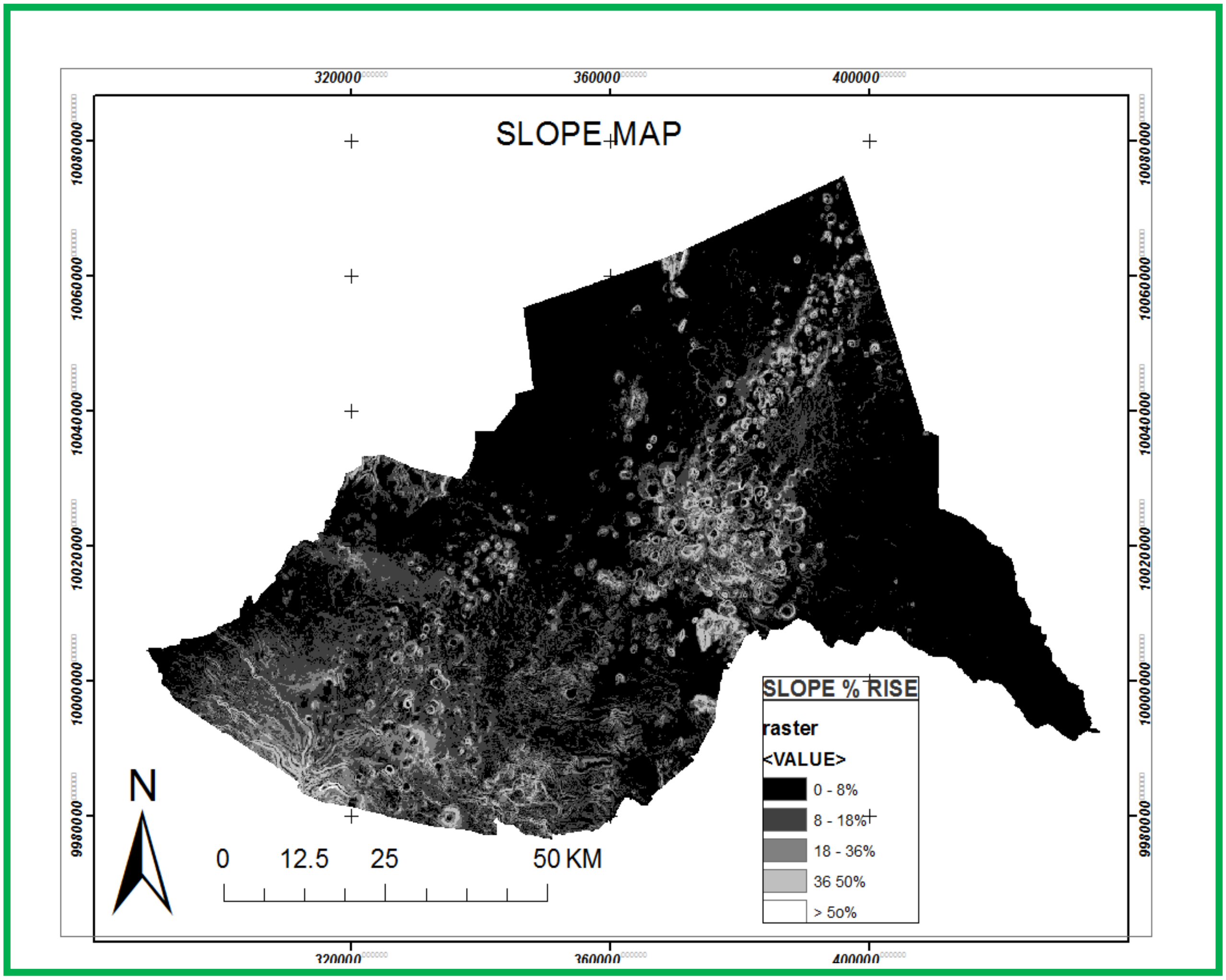


Figure 3.9b Slope Map

3.7 Data Preparation

3.7.1 Data pre-processing Techniques

Data conversion

Most of the data acquired was mainly in vector formats, whereas for the analysis, raster data formats were required. *Conversion* was very necessary. This was done using the conversion tools in the Arc toolbox in ArcGis 10.1. The command; *convert from polygon to Raster* was used to convert the vector data to the required raster data that could be analyzed. Raster data is used, because unlike vector data, the former enables the assignment of values for each cell in the dataset, thereby enabling a cell-by-cell analysis. Moreover it helps in reclassification and other types of analyses like map algebra and interpolation.

Reclassification was another data preprocessing that was done. This was a very important part of the analysis. Databases whose fields in the attribute table were in alphanumeric and string could not be weighted together with others, for example the ones in float field-type. This required that all the databases have attribute tables whose filed types were compatible or similar, to enable overlaying and weighting. For all the datasets, data values were classified into four classes: 1, 2, 3 and 4. This was in accordance to the relative suitability of each factor-value or ranges of values. The value or range of values best suitable for the production of groundnuts was given the highest reclassed value, while the least suitable value or range of values, was given the least reclassed value respectively. This is shown in the rating table 3.1 to table 3.7.

Interpolation was done for the zero and Nodata locations. This was especially for the case of Soil PH where there were areas with zero values. IDW method of interpolation was used obtain the soil PH map with continuous values, and in which every pixel had some value.

The data obtained was in different projection systems. It was, therefore important for the harmonization of the projection and the datum. The datasets from KARI were in UTM projection but were under the WGS84 Datum. These datasets were projected to Arc 1960 in UTM zone 37 north.

The models used for conversion and reclassification of the soil and climatic data are shown below.

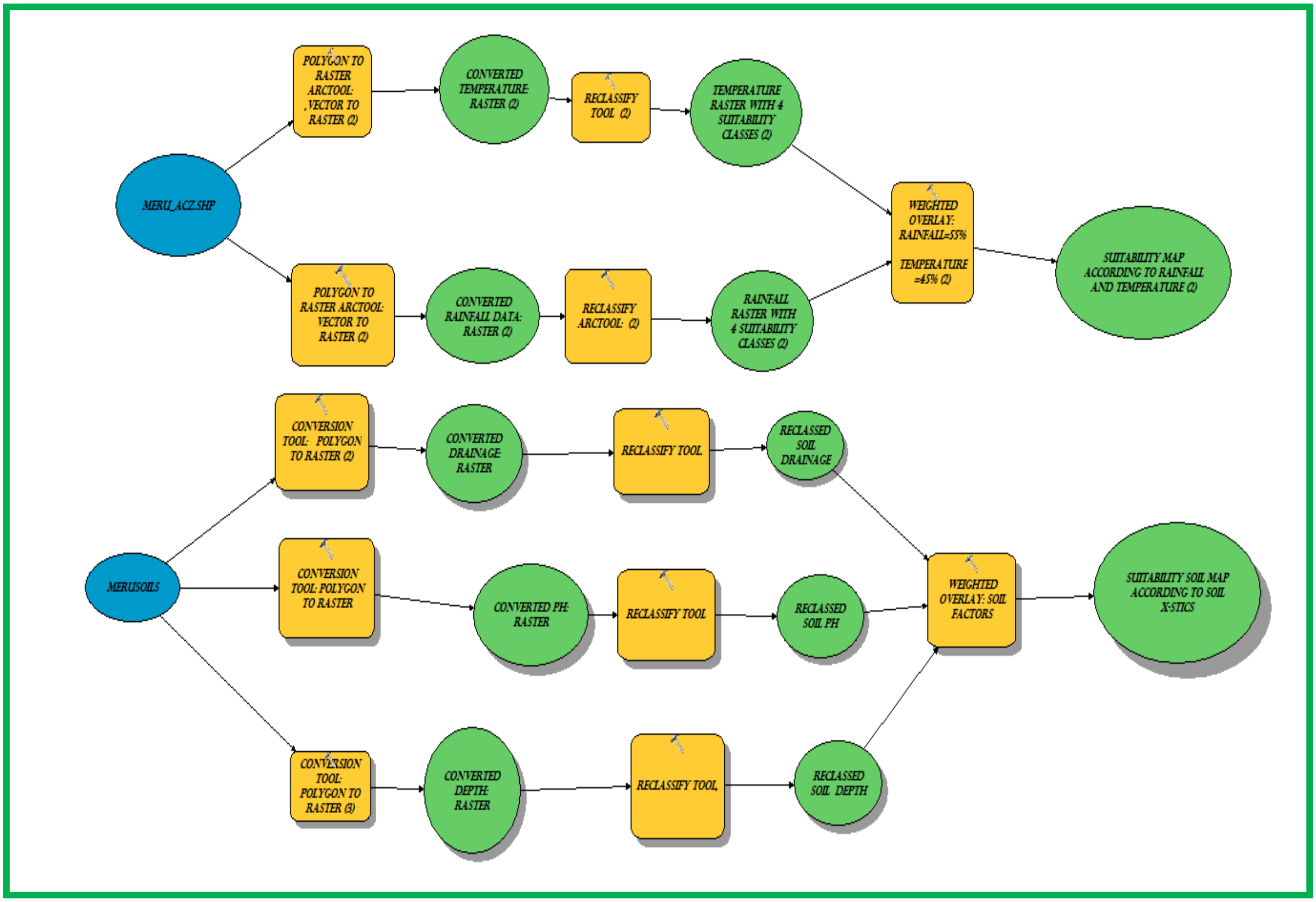


Figure 3.9c Data Preparation Model

The rating tables were also constructed. All the data values were categorized into four classes, according to the level of suitability for ground nuts. The rating tables for the factors of production used for the purpose of this research are shown in tables 3.2 to table 3.8.

It should be noted that ranking of the factors for the crop production should be done by a panel of experts in the specific field of study.

a) **Soil PH**

Class Name	PH Ranges	Rating	Suitability Class
High	6.0 – 6.5	4	Highly suitable
Moderate	5.0 – 6.0 and 6.5 - 7.6	3	Moderately suitable
low	4.0 – 4.9 and 7.6 – 8.5	2	Marginally suitable
Very low	0 - 4	1	Not suitable

Table 3.2 Soil PH Rating table

b) **Soil Drainage**

Class Name	Description	Rating	Suitability Class
High	Well drained (W)	**4**	Highly suitable
Moderate	Moderately drained (M)	**3**	Moderately suitable
Low	Imperfectly(I) & poorly(P) drained	**2**	Marginally suitable
Very low	Excessively(E) & Very poorly(V) drained	**1**	Not suitable

Table 3.3. Soil Drainage Rating table

c) **Soil depth**

Depth to limiting layer	Description	Rating	Suitability class
High	Moderately deep-M (50 -100Cm)	4	Highly suitable
Moderate	Deep-D (100-150cm)	3	Moderately suitable
Low	Shallow-S (30-50 Cm)	2	Marginally suitable
Very low	Very deep(V) & Very shallow(X)	1	Not suitable

Table 3.4 Soil Depth Rating table

d) **Temperature**

Class Name	Mean Annual Temperature (degrees) ^{o}C	Rating	Suitability Class
High	21.5 – 28.5	**4**	Highly suitable
Moderate	18– 21.5 and 28.5 – 30.0	**3**	Moderately suitable
Low	14.5 – 18 and ≤30.1	**2**	Marginally suitable
Very low	0 – 14.5	**1**	Not suitable

Table 3.5 Temperature rating table

e) Rainfall

Class Name	Mean annual rainfall (mm)	Rating	Suitability Class
High	1000 – 1800	**4**	Highly suitable
Moderate	600 – 1000 and 1800 - 2200	**3**	Moderately suitable
Low	450 – 600 and 2200 – 2500	**2**	Marginally suitable
Very low	<450 and >2500	**1**	Not suitable

Table 3.6 Rainfall rating table

f) Altitude

Class Name	Elevation in Metres above Datum	Rating	Suitability Class
High	1000 - 2500	**4**	Highly suitable
Moderate	0 – 1000 and 2500 - 3000	**3**	Moderately suitable
Low	3000 - 4000	**2**	Marginally suitable
Very low	>4000	**1**	Not suitable

Table 3.7 Altitude rating table rating table

g) Slope

Class Name	Slope in % rise	Rating	Suitability Class
Flat-to-Gentle	< 8	**4**	Highly suitable
Gentle	8 – 20	**3**	Moderately suitable
Slopy	20 – 40	**2**	Marginally suitable
Very slopy	>40	**1**	Not suitable

Table 3.8. Slope rating table

CHAPTER FOUR: RESULTS AND ANALYSIS

4.1 Results

The results from this research project are analyzed in this chapter. This helps us exhibit how effective, efficient and user friendly, GIS is and how it can be applied in suitability analysis. More so, we get to qualify the fact that model building is the most simplified and user friendly approach in using ArcGIS for analysis. In the view of the objectives for this project, the following were attained:

- Agro-ecological and Bio-physical requirements for groundnuts production
- A suitability model for the optimization of crop production.
- A suitability map showing the various suitable areas for the production of ground nuts in Meru County.

The agro-ecological and bio-physical growth requirements for groundnuts were found to be the following:

- Well drained soils
- Soil PH values ranging from 6.0 to 7.5
- Altitude between 500 to 2000 metres above mean sea level.
- Mean annual temperature between 23.5^{0}C to 28.5^{0}C
- Mean annual rainfall ranging from 1250mm to 2250mm.
- And a flat-to-gentle sloping terrain of gradient between 0% to 20%.

(source; KARI and World Bank- e-library website)

4.1.1 Suitability classes

a) Highly suitable

The land is sustainably suitable for a long term production of groundnuts in the area of study. This is due to the availability of the combination the best factors: the climatic, soil and elevation factors of production. Areas falling under this class can produce the highest yields with minimum artificial farming applications, e.g. fertilizers, irrigation or even erosion control methods. This means that in these areas, the maximum production can be achieved with minimum cost. This class falls in areas where optimum values of almost all the factors considered for the analysis converge.

b) Moderately suitable

The land is moderately productive. This is the second-best class obtained from the analysis. In this class, there is a moderate limitation in land characteristics as well as the climatic factors (see section 2.3.3). This means that the land would require moderate costs for management, maintenance and development for groundnuts farming.

c) Marginally suitable class

There are moderately severe limitations in land and climatic factors of production in these areas. These areas are less suitable for most legumes, especially if artificial additives are not used, e.g fertilizers and irrigation. Specifically, groundnuts would do poorly in these areas and farmers are advised to plant their next best alternative crop. Moreover, it is advisable also to avoid the crops of the same family with groundnuts since most of the factors are scarcely available. A farmer intending to do groundnuts production in these areas should anticipate high cost of farming and relatively low yields, and consequently low marginal returns to investment.

d) Not suitable

This is the land that is considered unsuitable due to the excessively severe limitations in soil, climatic and elevation factors. Even with the application of artificial factors, these areas are most likely to produce very little or nothing at all.

4.2 Overlaying

4.2.1 First level weighting

The datasets were weighted as shown below according to the data preferences in the production of groundnuts.

Soil data

Dataset	details	Percentages influence
Soil PH	The acidity or bacisity of the soil	27%
Soil Depth	How deep for the root-feed	35%
Soil Drainage	Capacity to hold water	38%
Totals		100%

Table 4.1 soil data weighting table

Terrain data

Dataset	Details	Percentage influence
Slope	The percentage change in elevation with horizontal distance.	45%
Elevation	The height of a point above the mean sea level. Measured in metres	55%
TOTAL		100 %

Table 4.2 Terrain Data weighting table

Climatic data

Dataset	**Details**	**Percentage influence**
Rainfall	the mean total annual rainfall measured in mm	55%
Temperature	the total mean temperature measured in ^0C	45%
Total		100%

Table 4.3 Climatic Data weighting table

The first level weighting was done to ensure that the analysis was rigorous. This is made possible by the fact that it is easier and reasonable to weight datasets of similar type than those which are very different. Also, it helps narrow down the analysis to the individual components of the factors of production, for example, soil factors were; soil PH, soil depth and soil drainage. The resultant weighted suitability maps were then overlaid again in the second and final level weighting.

4.2.2 Results from the first level weighting

At this level, there were three suitability maps obtained. This was in accordance to the data being analyzed: the terrain data (slope & elevation), the soil data (soil PH, soil depth, soil drainage) and the climatic data (rainfall and temperature). This map, as can be visualized, demonstrates that a single data cannot provide a rigorous analysis for suitability of the land. The more the factors of production that are considered for analysis, the better and more rigorous the results will be. This is because; every factor of production has its particular influence to production no matter its relative influence in comparison to others. Therefore more factors as may be required by a particular crop should be used and in the required proportions during weighting.

The first level weighting is very important as stated in the previous sections of this chapter and in the methodology of this report.

The following were suitability maps as per the individual categories of data:

4.2.3 Climate suitability

The factors weighted were rainfall and temperature data for the county. The data was obtained from KARI. The suitability map in consideration to the climatic data was as shown below.

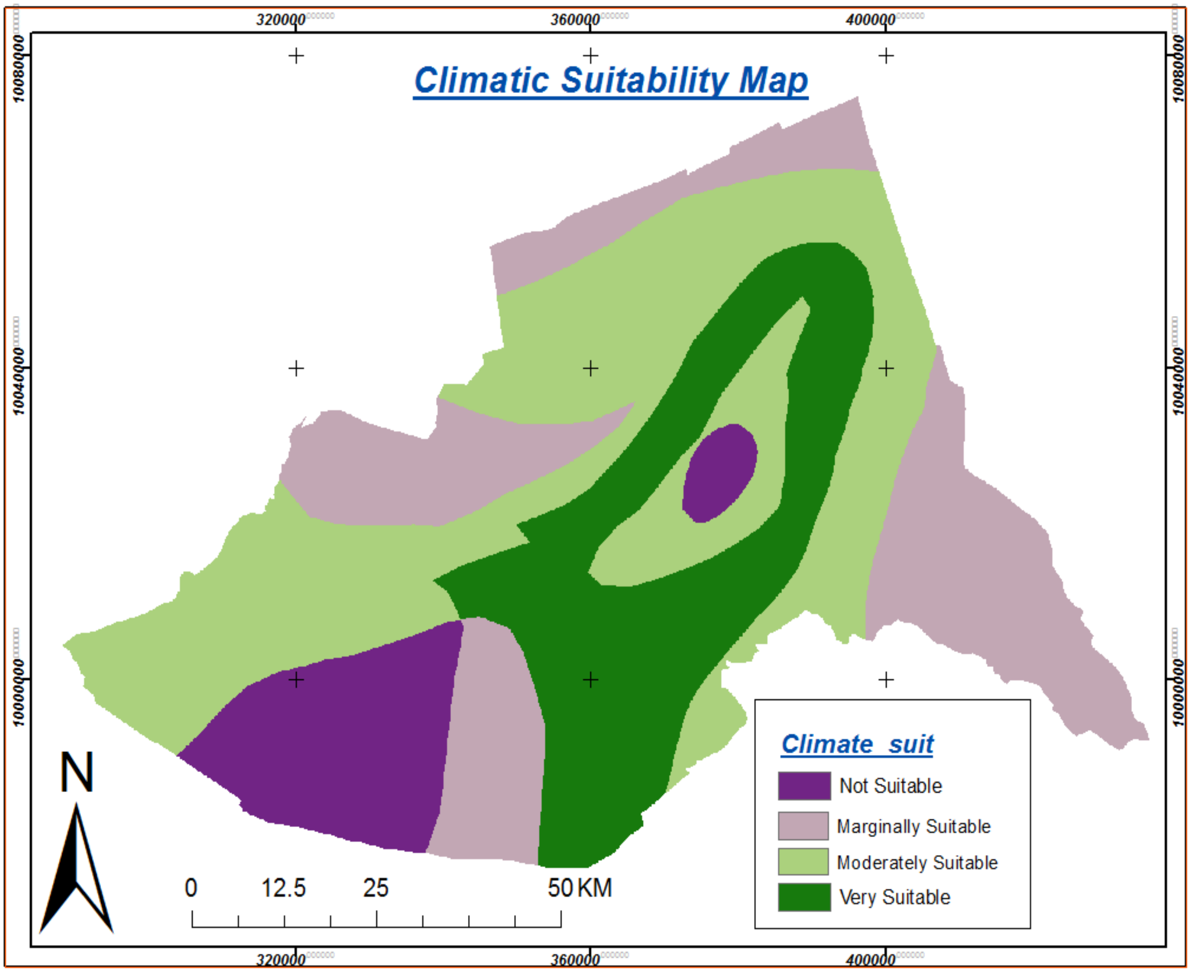


Figure 4.1 Climatic-Factors Suitability Map

4.2.4 The soil suitability

The factors considered in this category were the Soil PH, Soil drainage and soil depth. They were weighted as described in the previous sections of this chapter. The suitability map obtained is as shown below.

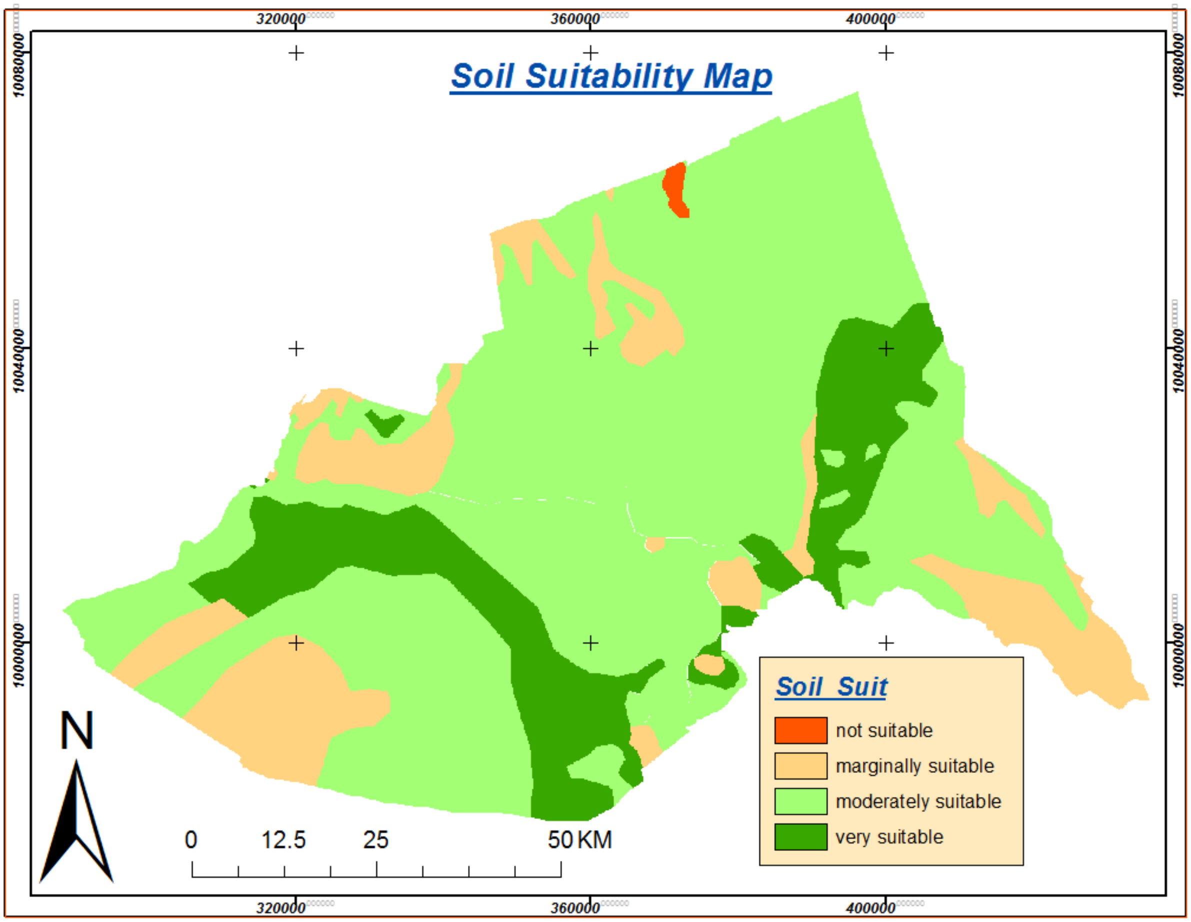


Figure 4.2 Soil-Factors Suitability Map

4.2.5 The Terrain suitability

The factors considered in this category of data were the Slope and the Elevation . they were weighted relative to each other in accordance to their influence to production as shown in the previous sections of this chapter. The resultant suitability map was as shown below;

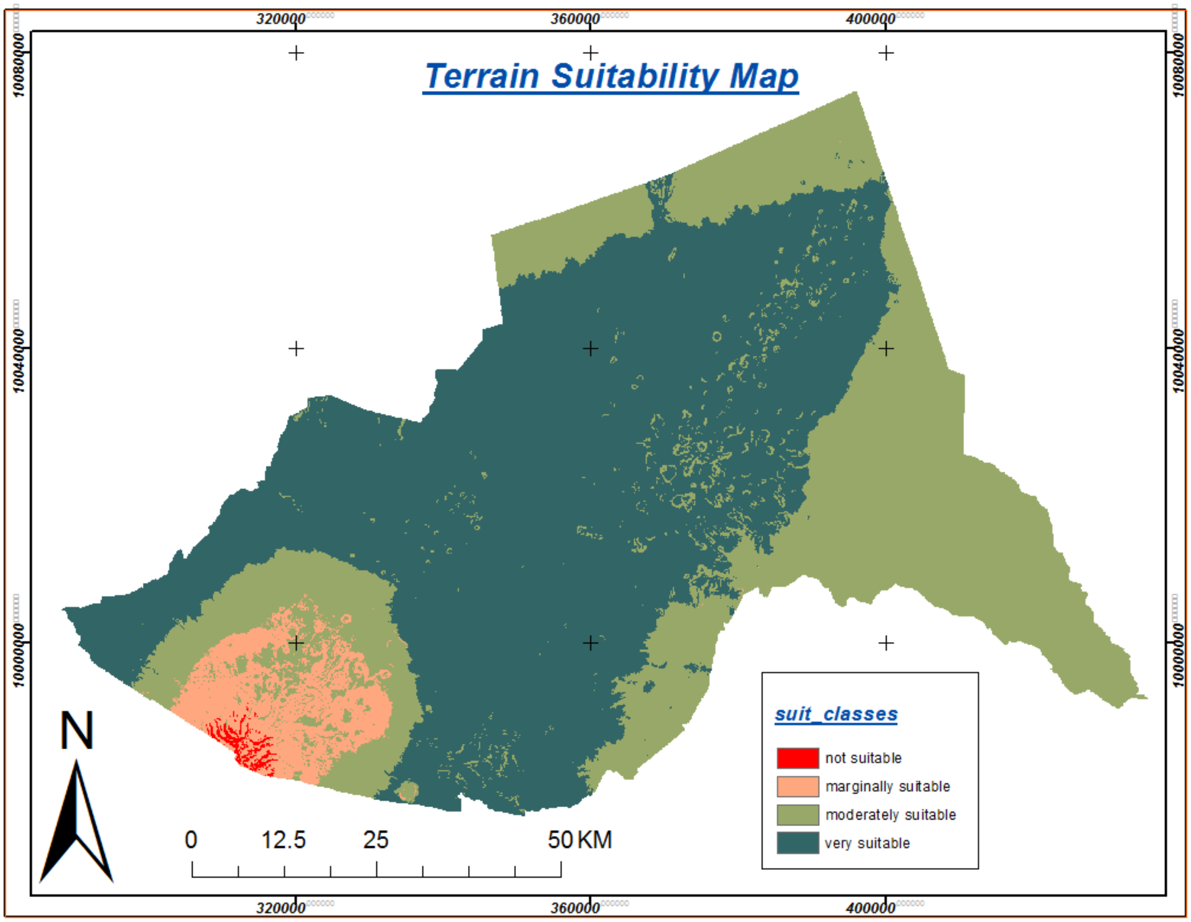


Figure 4.3 Terrain-Factors Suitability Map

The following were the areas per suitability class, considering each production factor. These are the results of the first level of the analysis.

Factor	Sub_factor and %ge influence (first Level)	Suitability classes	Area in Hactares
Soil Factors	Soil ph 27% Soil depth 35% Soil Drainage 38%	S1 S2 S3 S4	173.709 11161.57 47885.85 11224.33
Terrain Factors	Slope 45% Elevation 55%	S1 S2 S3 S4	759.017 11349.605 32557.719 26125.564
Climatic factors	Temperature 45% Rainfall 55%	S1 S2 S3 S4	8021.745 18665.59 27650.83 16159.81
Total			70,182.81

Table 4.4 Areas of suitability classes: first level

4. 3 Comparison of the results from the first level weighting

Graphs and pie charts were plotted to illustrate the areas and size of the various suitability classes at this level of the analysis. The objective of this level of analysis is to demonstrate the importance of considering as many factors as possible for the suitability analysis. Comparison also with the final suitability results was carried out to bring this into perspective.

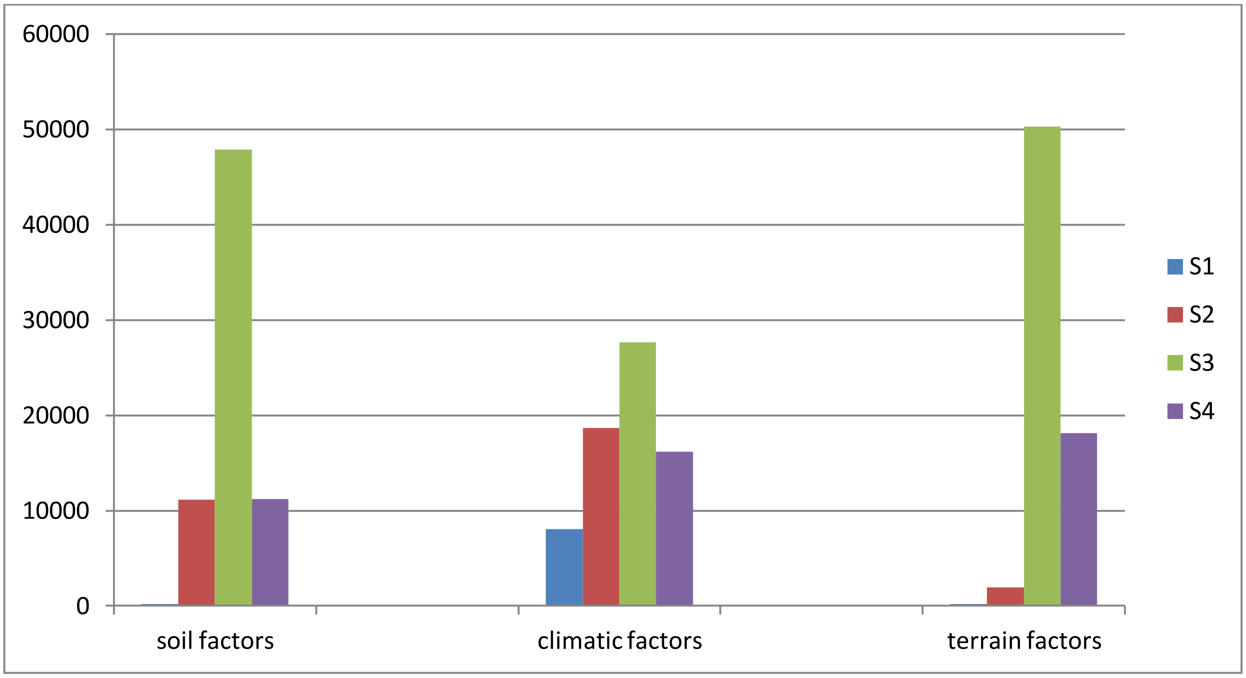


Figure 4.4 Relative suitability per factor

Not-suitable areas (S1)

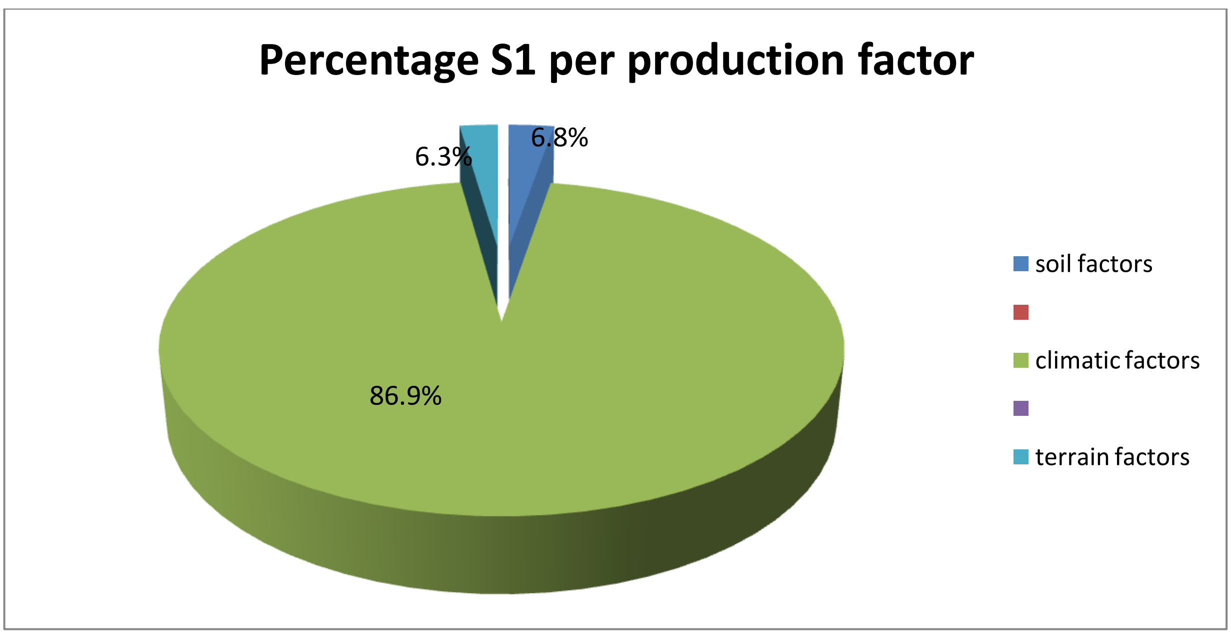


Figure 4.5 Not Suitable class (S1)

Marginally Suitable areas (S2)

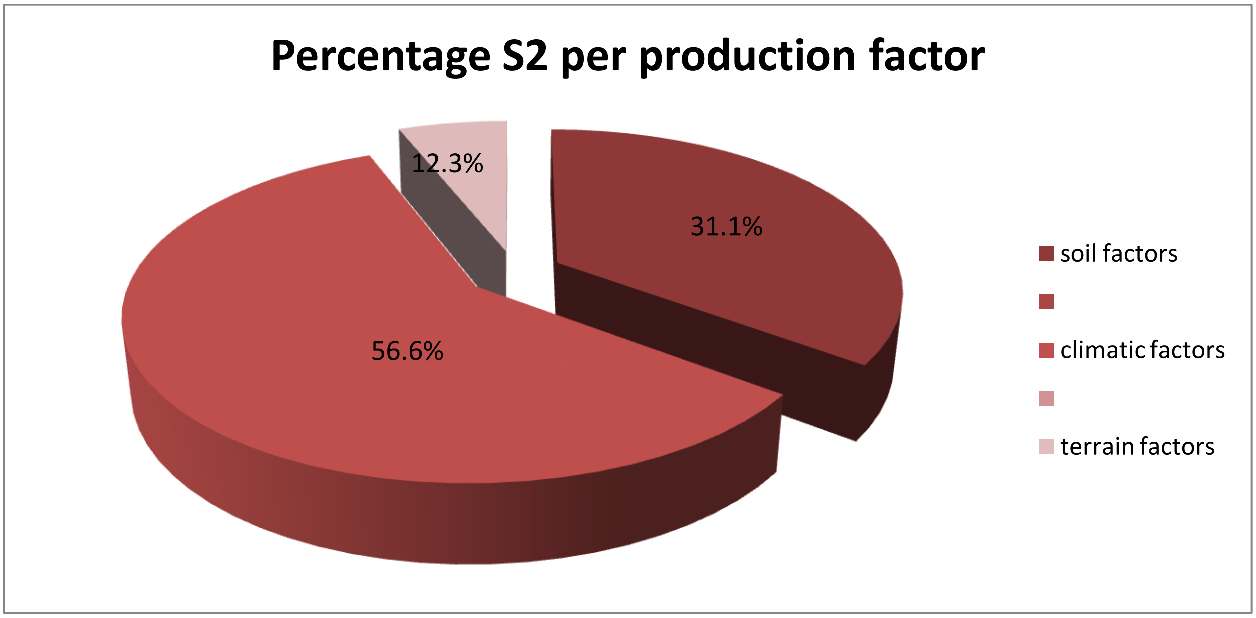


Figure 4.6 Marginally Suitable Areas

Moderately Suitable areas (S3)

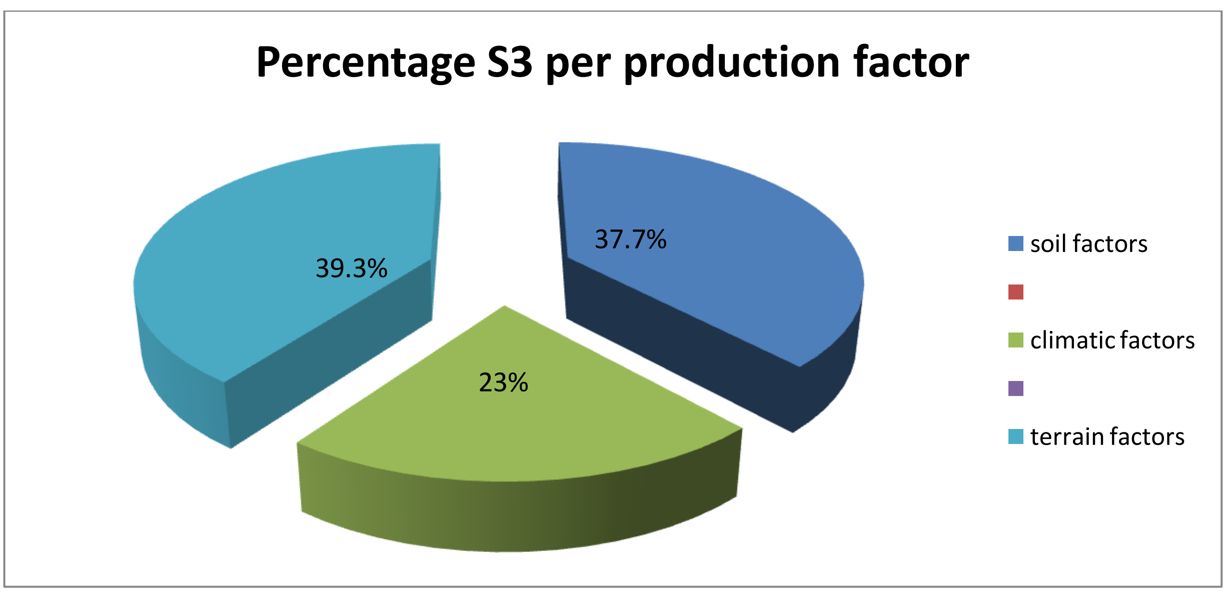


Figure 4.7 Moderately Suitable Areas (S3)

Very suitable areas (S4)

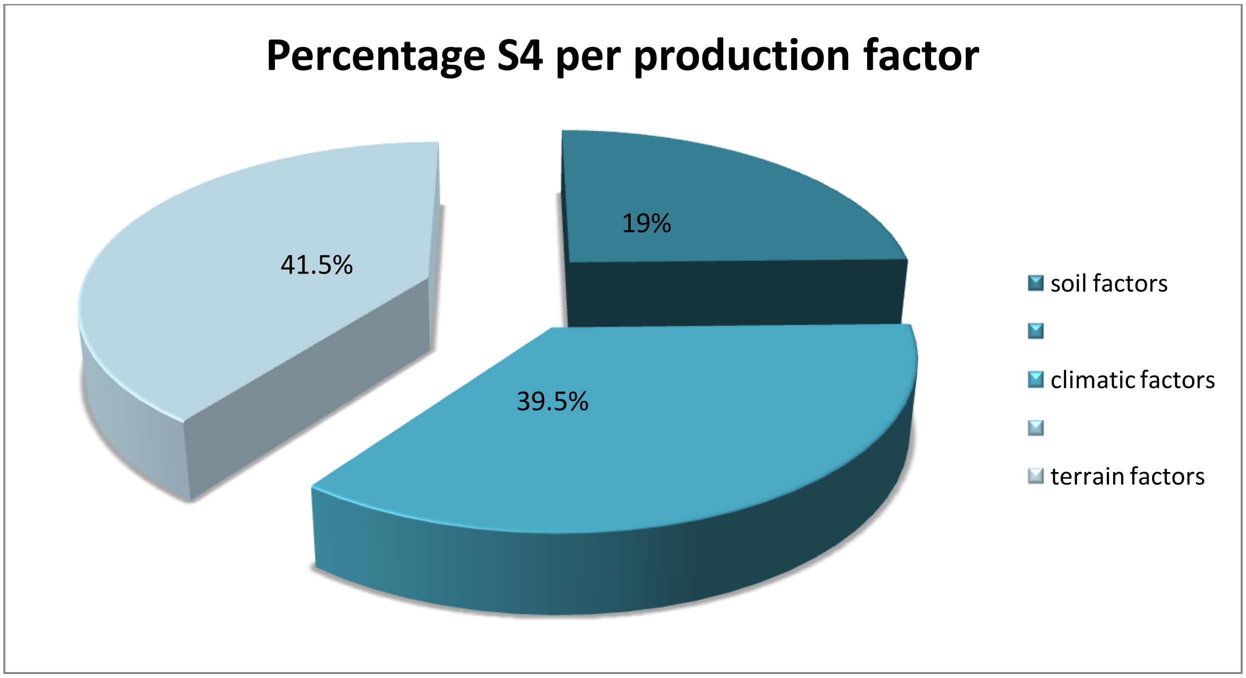


Figure 4.8 Very Suitable Areas (S4)

4.4 Final Level Weighting

This is the second level of weighting. The three composite datasets were analysed using the weighted overlay tool in Arcmap 10.1. The three composite datasets are the elevation data, soil data and the climatic data. These were the resultant suitability datasets obtained from the first level weighting as explained above. The resultant map was the final suitability map for the growth of groundnuts in Meru County. It should be noted that the relative weights for each dataset can only be obtained through research and consultations with agricultural experts. The weights were as shown in the following table:

Dataset	Details	Percentage influence
Climatic data	This includes the rainfall and temperature composite data at the ratio of 55:45 respectively	40%
Soil data	This includes the soil PH, soil Depth and soil Drainage in the ratio of 27:35:38 respectively	34%
Terrain data	This includes the elevation and slope data in the ratio of 55:45 respectively.	26%
Total		100%

Table 4.5 final level weighting table

4.5 The Suitability Analysis Outputs

Using the above GIS analysis functions, it was possible to achieve the objectives of the project satisfactorily. The three main outputs of the analysis are:

a. The suitability model
b. The suitability map
c. Suitability tool

These were displayed in the proceeding:

4.5.1 Suitability model

ArcGIS provides very sophisticated applications for both vector and raster analysis. One of the most useful approaches that provides friendly user interface is the model builder. Model builder is an application that helps to create, edit, and manage models. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. Model Builder can also be thought of as a visual programming language for building workflows. While Model Builder is very useful for constructing and executing simple workflows, it also provides advanced methods for extending ArcGIS functionality by allowing you to create and share your models as tool (ESRI). This is the approach used in this project. The model that was constructed and run in the analysis is shown below.

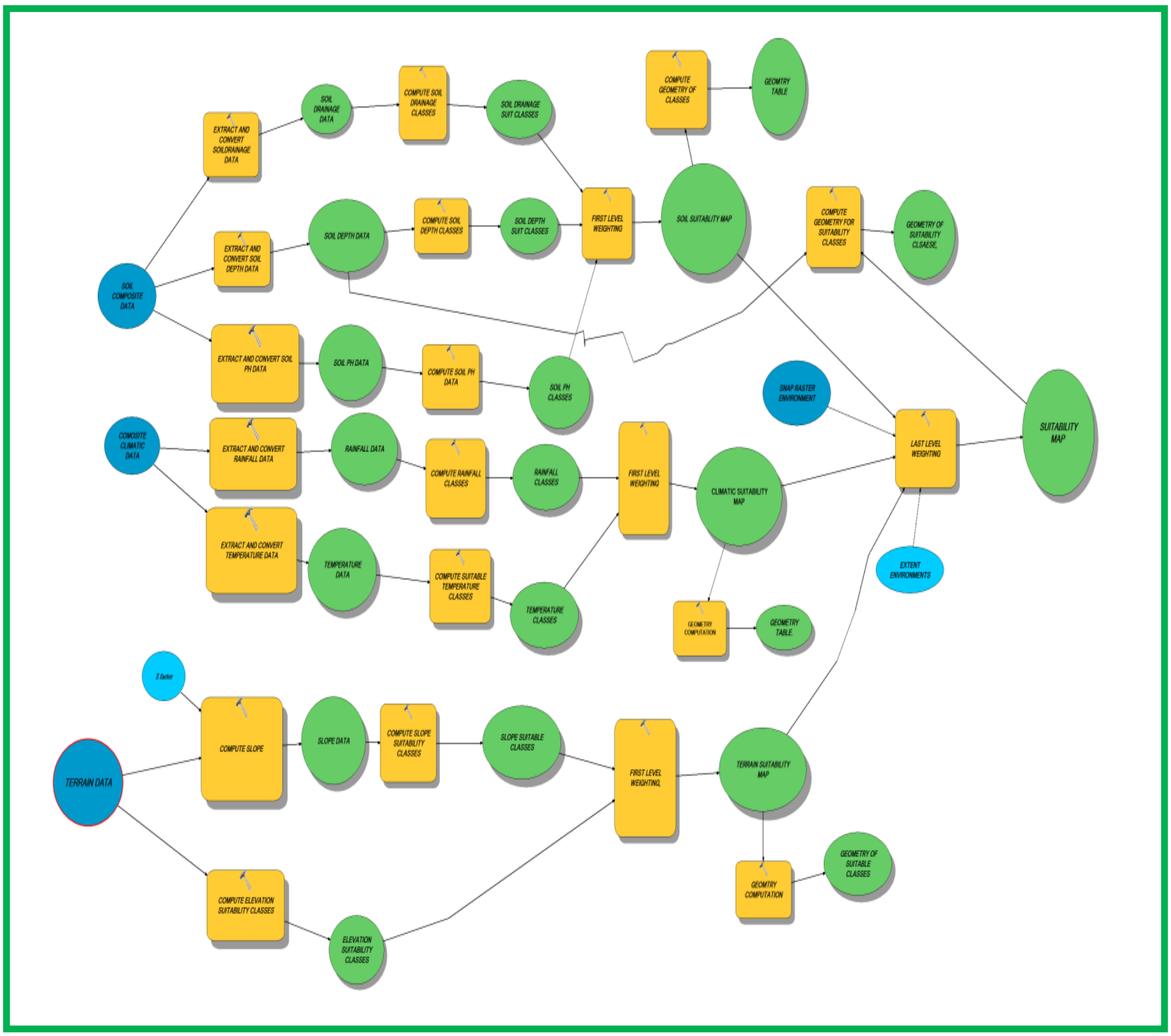


Figure 4.9a: Suitability Model

4.5.2 Crop Farming Suitability Tool

From the suitability model, a 'Crop Farming Suitability Tool' was developed. The tool provides the interface that the user would find easier to use. It gives the user the option to call for the required parameters and inputs just like any other Tool in ArcGIS. This tool is the summarized and simplified interface of the suitability model, such that whenever the user defines all the required data-paths, environments and the specific drop requirements (in the model), he/she only clicks at 'ok', and the tool runs the model in the background to produce all the intermediate outputs (maps and geometric tables), as well as the final suitability map for the crop being studied.

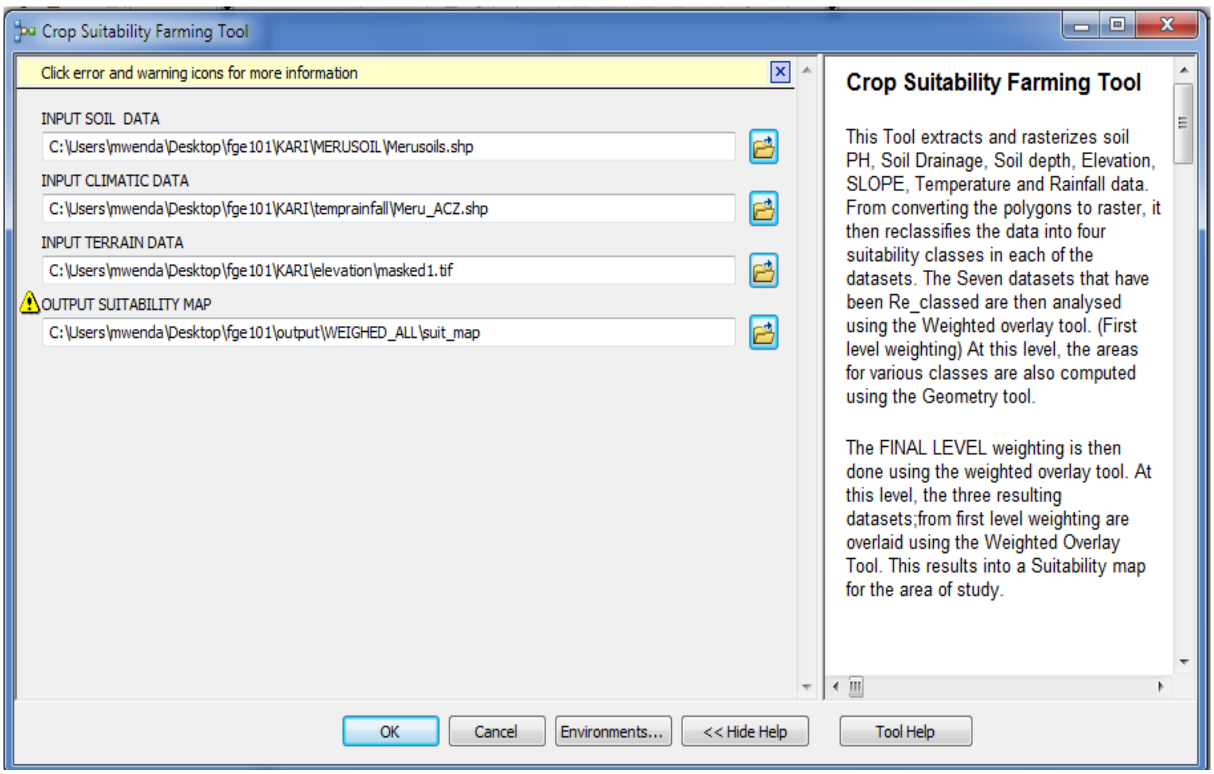


Figure 4.9b: Crop Farming Suitability Tool

4.5.3 Groundnuts Suitability Map for Meru County

The map displays all the four suitability classes as described sections 2.1.1 and 4.1.1 of this report. These classes are:

- S1 – Not suitable
- S2 – Marginally Suitable
- S3- moderately suitable
- S4 – very suitable

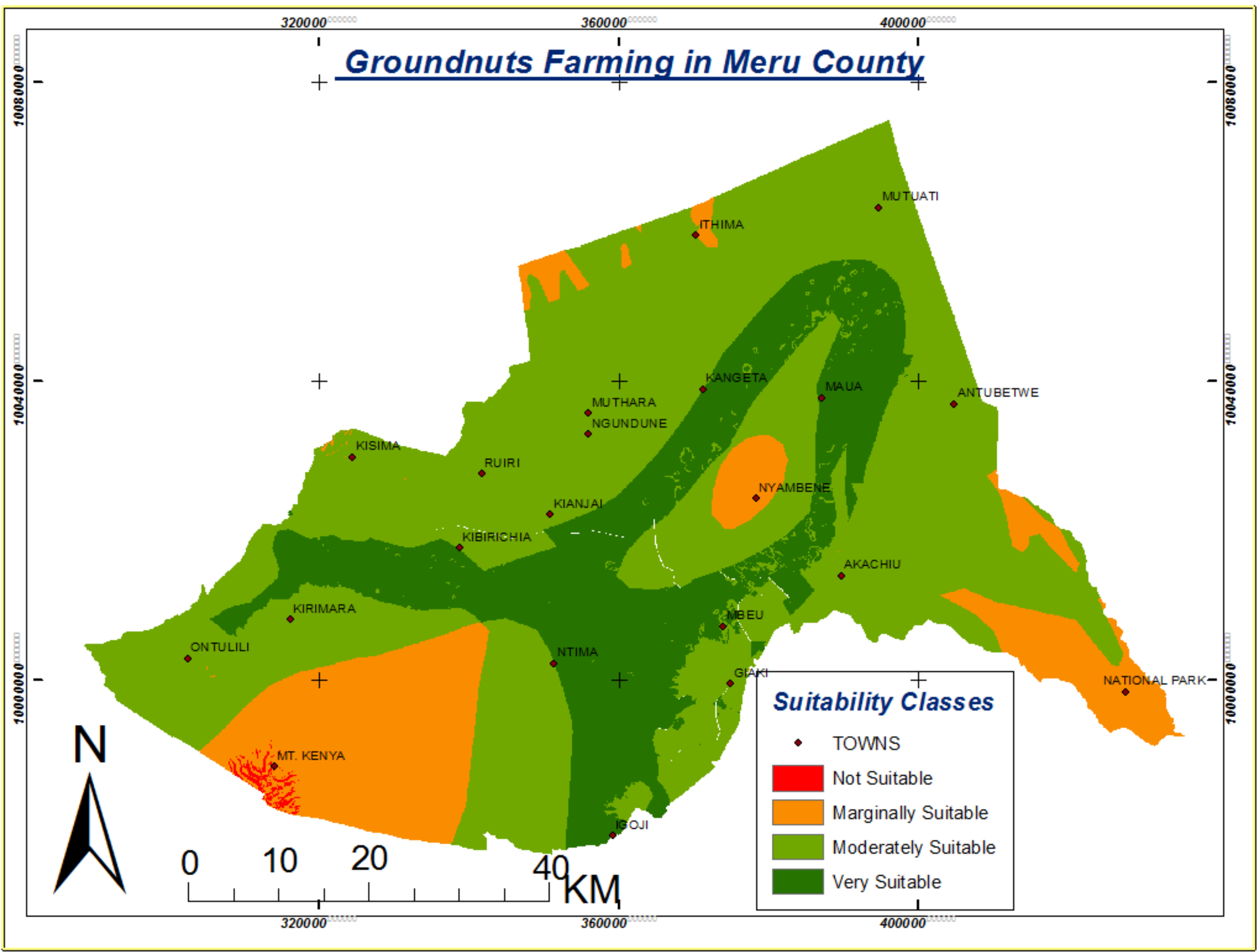


Fig 4.9c Groundnuts Farming Suitability Map in Meru County

4.6 Area for each Suitability class

The sizes for each of the suitability classes were computed and the sizes tabulated as below. Using these areas for the suitability classes the percentages of each class to the total area was also computed.

Suitability class	**Details**	**Area (Ha)**
S1	Not suitable	184.05
S2	Marginally suitable	11,287.44
S3	Moderately suitable	42,792.48
S4	Very suitable	15,918.84
Total	Area	70,182.81

Table 4.6 Area of Suitability Classes

Percentage per suitability classes were computed as shown below;

$$\mathrm{S1} = \frac{184.05}{70182.81}\, x\, 100 = 0.2622\%$$

$$\mathrm{S2} = \frac{11{,}287.44}{70182.81}\, x\, 100 = 16.0829$$

$$\mathrm{S3} = \frac{42{,}792.48}{70182.81}\, x\, 100 = 60.9729$$

$$\mathrm{S4} = \frac{15{,}918.84}{70182.81}\, x\, 100 = 22.6820$$

The area of study is covered by the four suitability classes only, after computing the percentage per suitability class, a pie chart and a bar graph were plotted to represent these results. This is shown below in figure 4.9d and figure 4.9e

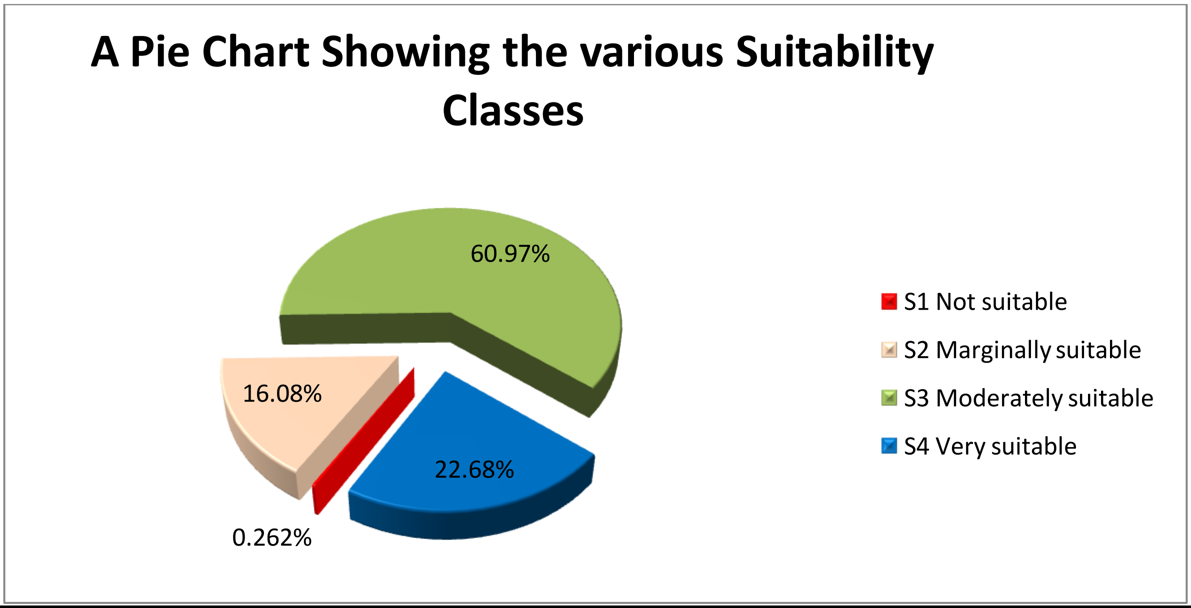


Figure 4.9d: Percentage Area Per Suitability Classes

A bar graph of area in M^2 against the various suitability classes was plotted as shown below.

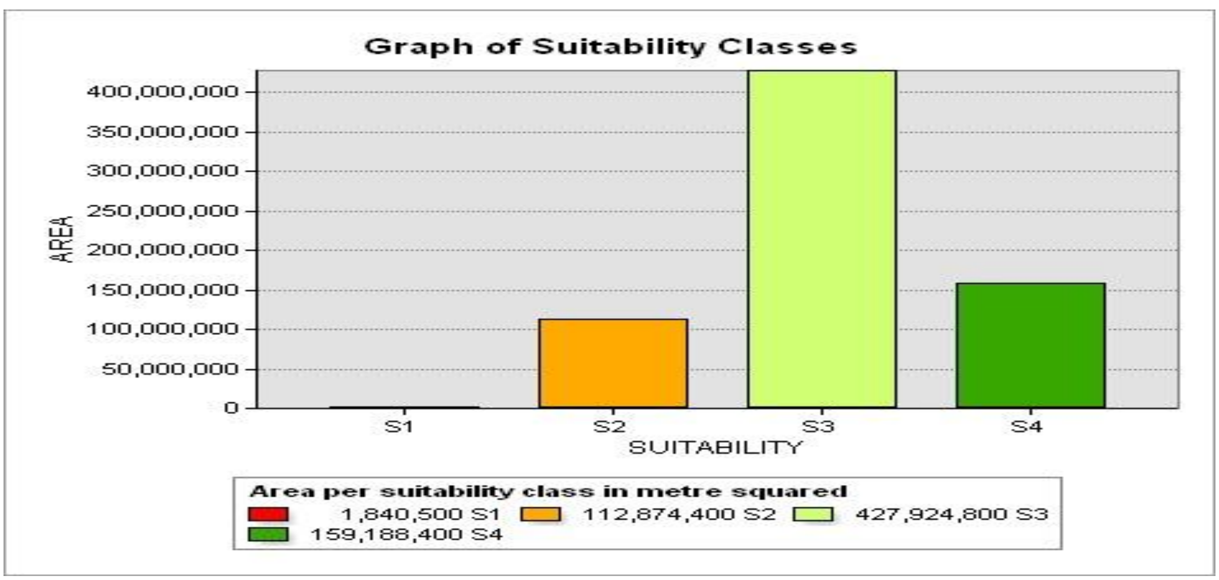


Figure 4.9e: Graphs showing suitability classes for groundnuts farming

4.7 Comparison table

The purpose for this section was to compare the sizes (in hectares) of various suitability classes in the suitability maps resulting from the first level and the last level of weighting. This is achieved through the table below. This table is a summarized combination of table 4.2 and table 4.3 in the preceding sections of this report.

SUITABILITY CLASS	FIRST LEVEL WEIGHTING	AREA(HA)	LAST LEVEL WEIGHTING(*Ha)*
S1	Climatic factors 40% Soil factors 34% Terrain Factors 26%	=8021.745 =173.709 =759.017	S1 =184.05
S2	Climatic factors 40% Soil factors 34% Terrain Factors 26%	=18665.59 =11161.57 =11349.605	S2=11,287.44
S3	Climatic factors 40% Soil factors 34% Terrain Factors 26%	=27650.83 =47885.85 =32557.719	S3=42,792.48
S4	Climatic factors 40% Soil factors 34% Terrain Factors 26%	=16159.81 =11224.33 =26125.564	S4=15,918.84
Total			**70182.81**

Table 4.7 Comparison of First and Last Level Weighting Results

4.8 Discussion of Results

Rating and reclassification of different suitability classes is was based on the 'worst case scenario' as recommended by FAO (1976). The rationale for this method is that each parameter considered assigns each mapping unit area a suitability class according to the rating of that particular parameter. Then the worst suitability class assigned to an area by any parameter is adopted as the general suitability class for that area.

It was evident that, in a general sense, the entire area of study is suitable for the cultivation of ground nuts. However, after classifying the study area into four suitability levels, it was found that approximately 22.6% of the study area lies under very suitable class(S4), 61% is moderately suitable, 16.1% is marginally suitable while 0.3% is as shown in table 4.1.

Considering the first level weighting (table 4.2), it was evident that climatic factors (rainfall, temperature), had the highest influence in the not-suitable class (S1). This is because the areas around and in Mount Kenya have very high average annual rainfall (above 2200mm) and very low temperatures (less than 8 ^{0}C). Conversely, soil factors had least contribution to the influence in this class. This is because most of the county soil has favorable PH, is well drained and favorable root depth. These conditions are best for groundnuts production. Similar scenario was observed in the marginally suitable class (S2) as well as class S3, where climatic and soil factors contributed the highest and the least influence respectively. The general justification for this would probably be the geographical location of the county, at the Equator and around the second tallest mountain in Africa as well as the Nyambene ranges. These contribute in two ways: one, the fertile volcanic soils that are deep, well drained and of favourable PH. These soils are good for agriculture especially for root crops like groundnuts. This justifies the fact that the 'not-suitable' areas in relation to soil factiors are relatively small. Two, due to high altitude (above 4500m), temperature and rainfall are considerably low and high, respectively. This is the case of the highlands. From the suitability map shown in figure 4.8, it is clear that the areas around the Mount Kenya lie in class S1. The main contribution to this is the very high rainfall (above2500mm), very low temperature (below 8^0C) and very high altitude (above 4000m). Conversely, the area around the national park lies in class S2, because of its adverse climatic conditions (very high temperature: above 25^0C, rainfall below 600mm) and the low altitude (below 1000M).

Similarly, it was observed that terrain and soil factors contributed most in class S3, (moderately suitable), while Terrain and climatic factors contributed most in to class S4 (most suitable). The elevation of Meru County ranges between 330M and 4790M above sea level (ref. figure 3.9a). Most of the county is between 1250M and 2500M above sea level. This range of elevation is favourable for ground nuts. Therefore, most of the county, considering the elevation data, was found to be very suitable. The above notwithstanding, all the three factors were weighted together in the last level weighting. The relative weights for each factor helped to harmonize all the data and consolidate it into one composite suitability map.

The model builder application in ArcGIS 10.1, was found to be very user friendly. All the analysis processes were joined in a workflow and the model run successfully. (see figure 4.9a). The model gives the analyst the ability to modify and/or change as well as add and/or remove any parameter and factors used in the analysis. The main products for this project were the suitability model, crop farming tool and the suitability map. These were successfully generated as shown in figure 4.9a, figure 4.9b and figure 4.9c respectively.

Finally, the Tool developed provides the simplest interface for the user who has minimum understanding of the model builder. The other importance of this tool is that it can be shared easily between different platforms and still be useful. The tool can also be used as an input in other models and tools.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objectives of this research project as outlined in section 1.4 were successfully achieved. The results illustrating how these objectives were achieved are outlined mainly in chapter four. The suitability map obtained match well with the agro-ecological zones known to support ground nuts as mapped by GTZ (2007) as well as the ground truthing visits and knowledge by the analyst. During ground truthing, it was observed the existence of the production of the groundnuts in areas like Mbeu, Igoji, Ntima and Maua of Meru County.

The results from this project indicate the powerful capability of GIS in raster cell-by-cell- analysis and its application in suitability modeling. This can be applied in agricultural production especially precision farming.

This study clearly brings out the spatial distribution of suitable areas for the cultivation of groundnuts in Meru County. This is achieved from the evaluation of biophysical factors of soil and topographic data (section 2.3.3) in the GIS context; this is useful in crop management options for intensification and/or diversification.

5.2 Recommendations

These approaches to precision farming provide information at a local level that could be used by farmers to select their cropping patterns. This study was limited to seven factors of production, and spatially to the Meru County. More factors can be, likewise, integrated into the model to obtain more rigorous results. Similarly, a larger or smaller spatial area can be analyzed and still achieve optimized results. Moreover, this approach can be used for the suitability analysis for cultivation of any other crop.

When appropriately applied, this approach will give very accurate results that would aid in land use-planning and faster decision making in farming. Suitability analysis in GIS can also be used in other applications other than agriculture like site selection, zoning, and encroachment on natural resources amongst others.

In whichever case it might be, the analyst should take very careful consideration to some factors;

- The appropriate datasets required for the problem at hand.
- The suitability and sufficiency of the datasets obtained.
- The resolution (spatial and temporal) of the datasets
- The analysis tools to use. (the ArcTools)
- The weights given each datasets during weighting.

Over 60%of the land in Kenya is either arid or semi-arid. In these areas, there are minimum agricultural activities that take place. It is important for the government to invest in research programs in order to realize any possible utility that can be applied in these areas. Subjective suitability analysis, for example, would yield incredible results. Such analysis can be used to assess which crop could be grown where and the level of suitability. This can be done at a very small scale hence realizing very accurate results, even for the dry parts of the country.

Model builder provides very user friendly approach to the analyst and to the user of the analysis information. It makes it possible to edit the variables and the input as well as the intermediate data; to achieve the desired results. The 'Crop Farming Tool' developed in this project can be very useful , with little editing of the parameters, in doing such suitability analysis for any crop as well as any geographical location and achieve optimum results.

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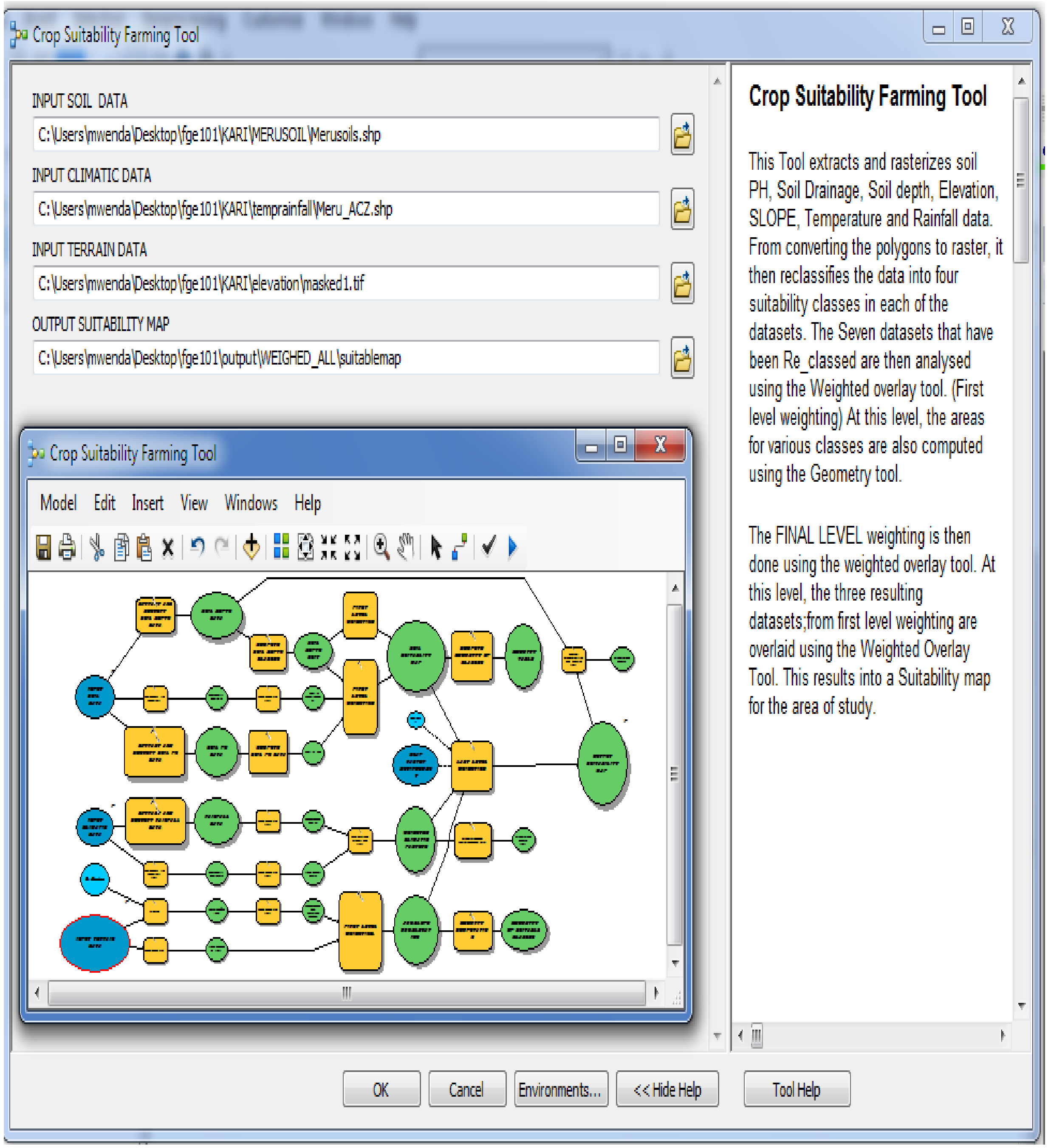
APPENDIX A: CROP SUITABILITY FARMING ARCTOOL



APPENDIX B: PHOTOGARAPHS

Photo 1: groundnuts seedling. (source; http//www.shutterstocks.com)

Photo 2: groundnuts plantation (source;http//www.shutterstocks.com)

Photo 3: groundnuts seeds and peanut oil. (source; http//www.shutterstocks.com)

Photo 4: peanut Butter and sandwich. (source; http//www.shutterstocks.com)