University of Nairobi

School of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

Application of GIS in Selecting Areas Favourable for Coffee Farming

Case Study: Kericho County

WELDON, MARITIM

F56/75796/2014

A Project submitted in partial fulfillment for the Degree of Master of Science in Geographical Information System in the Department of Geospatial and Space Technology of the University of Nairobi

June 2016

DECLARATION

I, Maritim Weldon, hereby declare that this project proposal is my original work. To the best of my knowledge, the work presented here has not been presented for a proposal in any other university.

Maritim Weldon 3rd June, 2016

Name of student Date

This project has been submitted for examination with our approval as university supervisors.

Dr. S. M Musyoka ……………………. ………………………

Mr. D. K. Macoco …………………….

………………………

Name of supervisor Signature Date

ABSTRACT

Use of geospatial technology in agricultural production has brought a lot of revolution towards better achievements. Before this technique was directed towards agricultural fields, farmers at all levels leveraged on certain unpredictable gambling while trying to decide on suitable areas for their crops. Losses have been witnessed because of failure to do prior analysis before any farming activity is started. This has led to misuse of labour and farm inputs, not to mention waste of time, which could have been avoided through certain approaches.

Use of GIS (Geographic Information Systems) technology, together with other Multi-Criteria Evaluation (MCE) methods in carrying out suitability analysis has created an avenue of doing land planning. This has made it possible to assigned development activities to appropriate sites. Areas favourable for coffee growing in Kericho County have been identified using these technologies. The type of coffee being studied is the Arabica coffee. Kericho County is at an altitude which cannot favour the growing of Robusta coffee. It is because of this reason that the study was confined to Arabica Coffee. Therefore, whenever coffee is mentioned in any part of this research then it refers to the Arabica coffee. By use of such factors as climate, topography and soil as the main criteria in the study, sub-criteria were extracted from them.

Climate, rainfall and temperature were considered as separate entities which affect the process of determining areas favouring coffee growing in the County. Topography, on the other hand, carries two distinct elements, elevation and slope. Soil entails soil texture, which is related to soil type, soil pH, soil depth and soil drainage. Cation Exchange Capacity (CEC) was not considered since it is mainly dictated by the aforementioned attributes of soil. Present land use and land cover analysis was also done through the use of Landsat 8 satellite image for the area acquired in 2016. The image is within path 169 and row 60. Image enhancement, supervised image classification using Maximum Likelihood Classifier (MLC) and validation of classified results was done. Once the factors were put in a model on ArcGIS 10.2 software, their weighted overlay was further overlaid with unwanted land use classes to obtain potential areas for coffee farming. Economic analysis was done using the potential areas and areas with existing coffee farms so as to appreciate the expected per capita income from the crop.

DEDICATION

This project is dedicated to my late Father, Cheruiyot A. Rono, who although he did not live to celebrate this achievement with me, his great encouragement and effort still remain dominant in my success.

ACKNOWLEDGEMENTS

It is with all sincerity that I feel indebted to acknowledge the Almighty God for His powerful inspiration and power which made me healthy and strong throughout the entire period of my study.

I cannot also forget my Supervisors, Dr. S.M Musyoka and Mr. D. K. Macoco for being committed and available during the time when I required their guidance and advice. Their positive criticism on the project has made it a success. God bless you abundantly.

My further gratitude goes to Mr. Matolo, staff of Kenya Agricultural and Livestock Research Organization (KALRO), who enabled me to procure relevant datasets required for this study. I must also recognize the efforts of Ms. Regina Ng'ang'a from the Department of Geospatial and Space Technology for her willingness to guide during certain stages of data processing using ArcGIS as the main software that has been used in the study. God bless you.

The efforts of Mr. Rono Franklin, staff of Kenya Meteorological Department also contributed a lot to the accomplishment of this task. His assistance in procurement of datasets for climate was of great significant. God bless you brother. Special thanks goes to Mr. Sammy Too, Manager of Kipkelion Coffee Millers, who assisted me to access the data on coffee production from different cooperative societies in the County. It was also out of his effort that comparison in production of coffee and tea was possible. God bless you.

I cannot end without appreciating the efforts of my family: Wife Eunice, children Faith, Gideon, Timothy, Ezra and Jeremiah. With all their patience, encouragement support and prayers, I am able to complete this study.

Finally, I must thank all people wherever they may be for making coffee their main beverage. May they increase their appetite on the same so that farmers may eventually celebrate their good income.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

AHP	-	Analytic Hierarchy Process
CBK	-	Coffee Board of Kenya
CEC	-	Cation Exchange Capacity
CRF	-	Coffee Research Foundation
FAO	-	Food and Agricultural Organization
GIS	-	Geographical Information System
GPS	-	Global Positioning System
LULC	-	Land Use Land Cover
MCA	-	Multi-Criteria Analysis
MCDM	-	Multi-Criteria Decision Making
MCDMA	-	Multi-Criteria Decision Making Analysis
MCE	-	Multi-Criteria Evaluation
RICAD	-	Research and Information Center Against Discrimination
RCMRD	-	Regional Centre for Mapping Resource for Development
KTDA	-	Kenya Tea Development Agency

CHAPTER 1: INTRODUCTION

1.1 Background

Kenya has been a country whose greatest population depend on agriculture. While the major part of the population carry out subsistence farming so as to get food for their own consumption, a small percentage engage in cash crop farming while others grow food crops in a large scale. They do it mainly for selling. It has been appreciated that agriculture contributes a larger share of foreign exchange earnings. This is witnessed from the cash crops being produced in the country. The main cash crops being produced in Kenya are coffee, tea and pyrethrum. However, tea and coffee are the leading cash crops at the moment.

Coffee farming has brought a lot of benefits into the country. Through this crop foreign exchange earnings have been boosted, citizens have earn income from farming and many people have been employed in coffee sector at diverse levels.

1.1.1 Coffee Plant Overview

Coffee plant is a dicotyledon. It is also a perennial crop which always does not shade its leaves throughout the year. This makes it an evergreen plant. There are two most cultivated species of coffee in the world. These are the *Caffea arabica*, also commonly known as Arabica coffee, and Caffea canephora, which is the Robusta coffee. Both species have some similar characteristics owing to the fact that the main trunk is vertical and the primary, secondary and tertiary branches are mainly plagiotrophic in nature. They can also grow up to a height of 10 metres if not pruned but must always be controlled for easy harvesting. (Damatta and Ramalho, 2006).

In Kenya, the variety being cultivated is Arabica coffee. This is because it is favored by high altitudes and low temperatures as compared to Robusta coffee which do well in lowlands. Since Kericho County is in the highlands, with low temperatures to the tune of 18°C, this research concentrates on the arabica coffee. Some of the varieties of coffee that have been discovered and are currently being planted include SL (Scotland Laboratory) variety, Kent (K) variety, Blue Mountain, Bourbon, Ruiru 11, and Batian variety. SL variety is further broken into subsets which are the SL28 and SL 34. Although the two are SL variety of coffee, SL28 is low yielding but resistant to drought while SL34 does well in various altitudes and climatic conditions. SL variety is currently the most popular and contributes over 90 per cent of all coffee being produced in Kenya (CBK, 2015). Kent variety exists in two categories. These are the K7 and K20 varieties. K7 variety is resistant to leaf rust but gives low yield as compared to K20 variety. Although K20 is susceptible to leaf rust attack, its flavour makes it a variety to be admired.

The popular Ruiru 11 variety was released to farmers in 1985 by Coffee Research Foundation of Kenya. It has Robusta genes and is capable of resisting leaf rust as well as coffee berry diseases. This variety takes about 18 months to mature after planting as a seedling. Within this period the crop produces coffee beans. It is a high yielding variety of coffee when compared with the other varieties. Despites this good characteristic of giving high yield and being resistant to pests and diseases, taste of the processed beans is totally inferior to that of the SL varieties.

In the year 2010, Coffee Research Foundation of Kenya released another variety of coffee known as Batian. Farmers who planted it during that time when it was released have now experienced the good yield from the crop (CBK, 2015). It has a tall stature similar to that of SL28 variety. It is resistant to coffee berry disease and leaf rust. The crop matures within 18 months and gives high yields. Roasted and processed beans from the variety have been found to be having good taste or good cup quality.

Coffee originated from Kaffa region in Ethiopia. It is in this region where the plant grows naturally like any wild bush. According to Bennett Alan et al. (2001), the origin of coffee dates back to the 9th century. It was in this period when an Ethiopian goat-herder named Kaldi, out of curiosity, noted how energized his goats were after eating the bright red berries. He decided to also have a taste of the berries himself. On chewing the berries he felt amazing energies as well that he could not clearly explain. He decided to take some berries to the monks in the nearby monastery. The monk who received the berries from Kaldi disapproved the berries and immediately threw them in burning fire. As the berries get roasted a nice aroma bellowed from the fire. The aroma made other monks who were in other parts of the monastery to go and investigate the origin of the good aroma. That is when they decided to rake out of the fire the roasting berries. They decided to grind and dissolve them in hot water. It became the first hot cup of coffee in the world.

From Kaffa, coffee entered into the market as the first item of trade in Yemen in the fifteenth century. Through the sea ports of Yemen, that is Aden and Mocha, coffee seed were taken in other parts of the world. The seeds transported were that of Arabica coffee. It was transported to Bourbon, modern Reunion Island, by the French missionaries in 1708. The crop flourished and by the year 1817, approximately three thousand tons of coffee was being produced yearly.

From Reunion Island, the crop was later taken for planting into Tanganyika at places called Bagamoyo and Morogoro, in 1863. This was done by the Holy Ghost Fathers of the French Catholic Church. In the early 1890s the seeds were brought to Kenya and first planted in Bura near Taita hills. During that time seeds from Mocha in Yemen were already in Kenya and had been planted in several areas including Kikuyu and Kibwezi. This was done by the Protestant Scottish Missionaries in 1893.

By the year 1904 a tremendous increase in coffee planting was being witnessed in Muthangari. This was as a result of the planting of the seeds which came from Morogoro in Tanzania. A total of five thousand mature trees were already in existence. By the year 1914 the number increased to 52000 trees. It was from this area where seeds and seedlings were then supplied to other coffee growers in the country.

Although the crop that was first introduced into the country was mainly one, Arabica coffee, it currently exists as multiple varieties. The varieties have been derived from genetic manipulation by agricultural research organizations. This has been achieved through intensive research, selection and breeding processes. It is all aimed at getting a variety that can resist diseases, pests, withstand drought and give high yields. Diseases such as coffee berry disease and leaf rust are the common ones that attack coffee. Mealy bugs also form the main pests that invade coffee. Farmers struggle to fight them through many methods that have been proposed by coffee experts after extensive research.

1.2 Problem statement

There is a great decline in coffee production in Kenya. This is attributed to the loss of large plantations of coffee farms in areas near urban centres to real estate development. For example, in the suburbs of Nairobi such as Kiambu and Ruiru, real estate developments have taken the centre stage. The expectation is that the overall coffee production in the country will begin to drop. Kenya is known worldwide for its high grade coffee. The crop is the most sought-after in the world. This is attributed to its intense flavour and pleasant aroma (Wikipedia, 2016). The acidic soil in the highlands, adequate amount of rainfall and sunlight, have provided favourable conditions for coffee growing in Kenya.

Since the introduction of the crop by the French Holy Fathers in 1893, it has been greatly embraced by the local farmers as one of the best cash crop in many parts of the country. It is currently being grown in both large-scale and small-scale holdings. However, the challenges attributed to land becoming a scarce resource, leading to decrease in land sizes meant for farming, has negatively affected the production of the crop. This is largely due to increase in human population that has been witnessed a few decades ago.

Urbanization has also taken an unpredictable reforms in that, instead of people moving to the urban areas, in what used to be called Rural-Urban migration, urban setup is forming in the rural areas. This is expected to affect agriculture in a significant way. Coffee production is therefore not spared by this phenomenon. While areas that constitute the suburbs of our towns and cities are currently encountering real estate developments, efforts must be made to have other coffee producing areas in the Country doubling their production so as to compensate for the decline in production being felt currently.

In the process of trying to increase coffee farming in other areas such as North Rift and South Rift regions of the country, the best methods of ascertaining the most favourable areas for the crop are required. This will help in ridding off the trial and error approaches normally used by the farmers. At this age of technological advancement, Geographic Information Systems

(GIS) and various scientific methods of decision making have proved to be of great help in many sectors of economy. Farmers can therefore be relieved of the tough times that they go through as they struggle to carry out farming of their choice. Great losses having been caused by the haphazard decisions on the type of crops suitable for planting in their main scarce resource, land.

1.3 Objective of the Study

1.3.1 Main Objective

To use GIS and Multi-Criteria Analysis methods in developing a land suitability model to be used in selecting areas favourable for coffee farming.

1.3.2 Specific Objectives

- To evaluate the criteria which favour growing of coffee.
- To develop a land suitability model for coffee.
- To create coffee suitability map for Kericho County showing the potential areas.

1.4 Scope and limitations

The research study will cover the whole of Kericho County. Integration of GIS and Multi-Criteria analysis will be used to find out the areas which can favour coffee farming in the County. Environmental factors such as climate, topography and soil characteristics will be used in the study to carry out analysis with a view of designing a land suitability model which can be used to evaluate land suitability. Appropriate satellite image, Landsat 8 image in particular, will be procured to assist in assessing the present land use and land cover throughout the county.

Owing to the short period allocated for this research and financial constraints, a broad-based research becomes impossible. It will therefore mean that primary elements or factors which dictate growth of coffee shall be considered. It is worth noting also that the study will entail only one type of coffee plant, which is the Arabica coffee. This is because the main ecological factors such as rainfall, temperature and elevation do not qualify any research on

Robusta coffee, a type which is normally for the lowlands. This was arrived at from prior knowledge from literature about coffee growing.

1.5 Justification of the Study

The need to increase coffee production countrywide has forced the Central Government to find out ways and means of expanding the areas where the crop can be planted and empowerment of coffee farmers. Among the steps taken include subsidy on farm inputs and assisting farmers in paying debts owed to different loaning institution. These include STABEX (STABilisation des Recettles d' Exportation). It was introduced in 1975 through Lome Convention. Its aim was to assist in giving remedy to instability experienced in export of agricultural products (http://en.m.wikipedia.org/wiki/stabex, visited on 27th June, 2016).

There are other factors beyond farm inputs and payment of debts. This include the urban sprawl in areas that were producing coffee in the Country. The rise in estate development in areas around Nairobi city and suburbs of other towns have also contributed to the decline in coffee production. Farmers have embraced the practice and hence resorting to clearing coffee bushes to have space for estate development. Kericho County is one of the few counties where people still appreciate agriculture as one of their major source of income. Since coffee is being produced in some parts of the County, land suitability analysis is necessary to help in finding out other areas where coffee growing can be done. Use of GIS, Remote Sensing and Multi-Criteria Evaluation (MCE) methods is able to accurately locate areas where coffee can do well.

CHAPTER 2: LITERATURE REVIEW

2.0 Geographical Conditions Favouring Coffee Growing in Kenya

Coffee production is influenced a lot by rainfall, temperature, topography, soils, elevation or altitude, labour and transport (Pearson et al, 2005).

(a) Rainfall

Arabica coffee requires rainfall ranging between 1000 and 2000 mm per annum. Many coffee growing areas in Kenya receive high rainfall of about 1000 — 2000 mm. The rainfall pattern is well distributed hence favouring the growing of coffee.

(b) Temperature

Coffee does well under temperatures of 14 to 26°C. Arabica coffee can withstand temperatures of up to 30°C. In Kenya the coffee growing areas experience cool to hot climate which are suitable for coffee growing. The temperatures average 15°— 30°C.

(c) Topography

The coffee growing areas have undulating landscape with hill slopes and gentle slopes. This has ensured well drained and aerated soils with good Cation Exchange Capacity (CEC) which dictates the soil fertility.

(d) Soils

Soil is the main platform where other activities are carried out. In coffee, like any other agricultural activity, soil contributes a larger percentage of influence towards the crop. It is in the soil where we have soil texture. Soil texture refers to the soil porosity or impermeability contributed by the percentage components of silt, clay and sand. These are the three primary components of soil. Their ratio in soil makes the soil to be either sandy loam, loamy sand, clay or loam. Normally, particles of clay are less than 0.002mm in size that of silt ranges between 0.002 mm-0.06 mm, while that of sand is in the range 0.06 mm – 2 mm. This dictates the soil type and ultimately the crop which can flourish in such type of soils.

Soil pH also is an inevitable factor that influence soil productivity. This refers to the degree of acidity or alkalinity of the soil. It is dictated by the amount of hydrogen ions in the soil. Soil pH is affected by decomposition of organic matter, rainfall, soil depth, crops being grown, nitrogen fertilization and parent materials which made the soil.

Most of the growing areas in Kenya have fertile, deep, volcanic soils which are suitable for growing of coffee. The soils are well drained and are acidic with a pH level of between 5.3 and 6.0. Coffee do well in relatively acidic soils. This can always be controlled and manipulated through application of artificial fertilizers and liming. It all depends on the degree of acidity of the soil. Therefore farmers are always encouraged to have their soils tested for pH before applying any fertilizer.

(e) Elevation or Altitude

Most of the growing areas have a high altitude ranging between 610 m and 1,830 m. However in a few areas like Machakos, coffee is grown at slightly lower altitudes. Arabica coffee does well in altitudes between 1000 m – 1650 m above sea level.

(f) Transport

Most of the growing areas have good roads which has enabled the crop to be transported to the buying centres and factories. This has also helped in marketing of the processed berries. However, other areas have very poor road infrastructure despite that the ecological conditions favour growth coffee. It there implies that while the farmers play their crucial part in the cultivation of the crop, authorities responsible for road construction should ensure that this infrastructure should not become an impedance.

(g) Labour

Coffee growing is labour-intensive because of its short period of harvesting. A lot of manual labour is required for planting, pruning and harvesting the crop. The dense population in the growing areas has provided a source of labour.

2.1 Coffee Plant Propagation

Coffee is mainly propagated through seeds. There are two methods which are used to propagate coffee (Lempke, 2000). These are propagation by seeds and vegetative propagation. However, in Kenya, use of seeds is most popular. The seeds used are often called coffee beans. Farmers have always been encouraged to plant seeds which have been prepared by Coffee Research Foundation (CRF). The seedlings from such seeds have undergone thorough selection and scientific research. Some farmers have resorted to preparing seeds from their own farms. Although this is normally discouraged by CRF, it has been happening in many areas where the seeds supplied by CRF are not accessible.

(a) Propagation by Seed

In the propagation using seeds, two methods can be used. Each method can be applied separately. One of the methods involves sowing the parchment in nursery bed by putting the beans in such a way that the flat sides of the beans face downwards. The seeds are left to germinate and then transplanted in polythene bags when the first leaf pair appear. The polythene bags are filled with soil before the seedling are put therein.

The second method involves putting the seeds directly in to the polythene bags but ensuring that the flat sides of the seeds face downwards. In both methods of seed propagation the seed takes 1-2 weeks before the root penetrates the parchment. However, this may take a longer period of up to 3 weeks if the area is colder. After another period of 2 weeks, the plant will appear from the soil but with the parchment still covering the top. This is known as epigeal germination. When the parchment is eventually shed, first leaf pair appear. The leaves are oval in shape and are referred to as bracteoles. The terminal bud develops together with the bracteoles. The terminal bud is the one which will form the ultimate part of the plant above the soil (Kuit et al., 2004).

(b) Vegetative Propagation

Although this method of propagation exists in various literature, it is not commonly applied in propagation of coffee in Kenya. However, there are two ways of carrying out vegetative propagation. These are grafting and cutting. Grafting makes it possible for good traits of plants to be combined into one tree. For instance, if one tree has a potential of giving high yield but have poor root system, a tree with good root system facing poor yield can be cut and grafted with the former.

Research was done in Vietnam, at an institute called Tay Nguyen Research Institute, to find out the optimal age for grafting coffee plants. It emerged that the best age of the tree should be between 4 and 6 months old. The best grafting practice is one known as top grafting. Effective grafting is also dependent on the timing as far as weather condition is concerned. It is advisable to carry out this practice during short rains. This is a period when there is high humidity and the weather is cool (Kuit et al., 2004).

2.2 Coffee Harvesting and Processing

Coffee harvesting period is every farmer's period of happiness because the returns are just a few steps ahead. However, it is the most challenging stage in coffee production because it determines the expected income. Harvesting of coffee entails the manual hand picking of the ripe berries from the coffee plant. It always requires keenness to ensure that only ripe berries are picked while leaving the green, unripe berries intact on the tree.

The ripe berries picked are taken to the factory where they are weighed. They are then put through a pulping machine which normally operates together with flowing water. The water helps to separate the outer pulp of the ripe berries from the coffee beans. The beans are put in a fermentation tank for about 48 hours (Coffee Research Foundation, 2006). Thereafter, the fermented beans are then taken to the sun to dry for about one week when they are passed through a machine which removes the two outer layers of thinner husks.

The next step in processing is winnowing the beans to get rid of husks. Grading follows to separate the beans in terms of sizes and quality. Grading involves use of different types of sieves which are categorized in terms of hole sizes. The sieves are number as No. 21, No. 18, No. 16, No. 7 and No. 10. The beans are passed through a compartment consisting of these sieves and every bean will pass through a particular sieve depending on its size. Air is also blown through the sieves to ensure that each bean gets trapped only in a genuine sieve number. Each sieve is also given a certain grade such that the coffee beans, which will be found there at the end of the process, will be assigned that corresponding grade or class. In every session of grading, the beans fall in any of the classes. These classes or grades are E, AA, AB, C, TT, PB and T (Kuit et al., 2004). The grading process can be summarized in Figure 2-1.

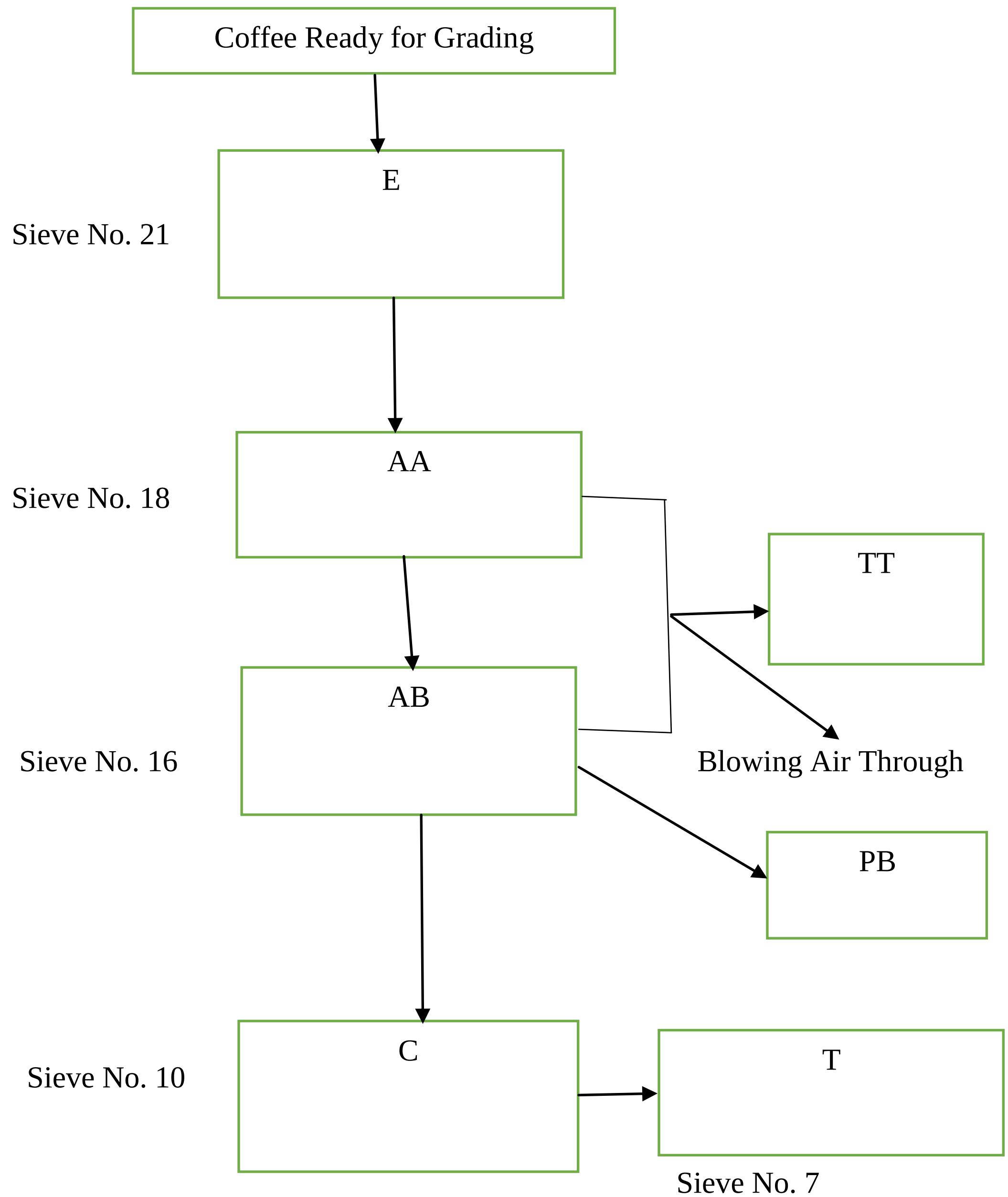

Figure 2-1: Coffee Grading before processing (http://www.crf.co.ke/)

2.3 Criteria of Decision Making

Decision making has always been taken by many people as a very simple occurrence in life. However, it later became clear that the process of any decision making is totally a complex phenomenon. It is also a hard task to comprehend what goes on until a final choice out of a multiple alternatives is arrived at. Koscienlniak and Puto (2015) defined the word "decision" to mean a resolution or settlement which enables people to solve problems.

Human life is governed by a multitude of actions which are always anchored in the ability to make choices or decisions. Decision making is therefore a daily operation which goes on in the minds of all rational human beings. Whenever a decision is to be made, a critical moment is reached where certain changes from the normal operation are expected. Although decision making had overtime became one of the tasks that are too obvious to be put under study, Saaty (2001) decided to carry out a research. His objective was to get a clear, systematic and comprehensive approach to decision making.

Since decision making is known to be a process of making choices by setting goals, gathering information, and assessing alternative occupations, it has also been discovered that an effective decision making process must undergo seven steps (Cabala, 2010). These are:

i. Identifying the decision to be made.
ii. Gathering relevant information.
iii. Identifying alternatives.
iv. Weighing evidence.
v. Choosing among alternatives.
vi. Taking action.
vii. Reviewing decision and consequences.

The ability to choose the best alternative from a set depends on the ability and expertise of the decision maker. It means that limitations of the decision maker affects the ultimate choice of the best alternative. The limitations are attributed to the power to precisely define the objectives, requirements and ability to determine the achievements generated by the alternative choice (Amine et al, 2014).

In the determination of land suitable for a particular use, rigorous processes of decision making are involved. Elements that entail biophysical, socio-economic, cultural and institutional factors are put into consideration. The factors being explored in the land suitability analysis are mostly independent in nature although they concurrently affect land suitability. However, each of the factors may affect land use potential in a certain way (Saaty, 1990). Hence to be able to precisely determine land suitability, decision making becomes the pivot or common denominator in the process.

According to Cook et al (2007), certain assumptions are taken during decision making. These include an assumption that a rational decision maker has adequate information which will assist in the decision making process. From this assumption it is taken that the person making decision has complete set of all the alternatives and a clear picture of anticipated results. Cook et al. (2007) continues to postulate that decision makers are very keen in all manner of steps towards decision making and are able to notice any slight difference amongst the given alternatives. In this case the alternatives are assumed to be totally different from one another.

Another author called Sharma (2009) indicated that decision making is based on both acquired knowledge and experience gained by decision makers over a long period of time. Decision making process become complex when sources of information to be used become many. This means that there will be a need to study the different types of information made available, the authenticity of their sources and the prior analysis of the information.

Saaty (1990) also pointed out that the processes involved in decision making are very complicated. A multiple number of criteria are used in making choices. This involves some systematic procedures and methods which are mainly scientific in nature. Any choice made during decision making process is influenced by the intuitive character of the decision makers as well as social forces that try to pull them towards a given unidirectional path. It is cumbersome to make choices from a large collection of criteria especially when priorities are no crystal clear. Other approaches may become a necessity when personal feelings of the decision makers is found to be exerting some unnecessary influence in the whole process of decision making.

Decision making processes are expected to yield best alternatives which are devoid of biases. It is fundamental therefore to use systematic and comprehensive procedures which may be revisited and applied in future when good results are realized. Some of the methods in common use currently are Multi-Criteria Decision Making Analysis (MCDMA) and Multi-Criteria Decision Making (MCDM).

2.2 Multi-Criteria Decision Making (MCDM)

Multi-Criteria Decision Making has become a popular approach used by decision makers in the daily business of making best choices in business or administrative levels of diverse organizations. It has proved to be a reliable technique which performs its functions by incorporating a multiple set of methods. All the methods that constitute this technique are geared towards assisting decision makers executing their roles of decision making (Greene, 2011).

As MCDM took the center stage in decision making problems, numerous methods have been formulated to augment the technique. Some of these very important methods include Multi-Attribute Utility Theory (MAUT) (Fishburn, 1967; Keeny, 1974, 1977), Analytical Hierarchy Process (Saaty, 1980), Fuzzy Set Theory (Zadeh, 1965), Case-based Reasoning (Daengdej et al., 1999), Data development Analysis, Simple Multi-Attribute Rating Technique, Goal Programming, ELECTRE, PROMETHEE, Simple Additive Weighting, and Technique of Order of Preference by Similarity to Ideal Solution.

2.2.1 Analytical Hierarchy Process (AHP)

This method is one of the popular techniques used in an environment where decision making involves searching for the best choice from numerous alternatives. It is employed by Multi-Criteria Decision Making (MCDM). In some literature, it is referred to as Saaty Method. This is because it was first designed by Thomas Saaty in 1970.

Development in modern world has gone to a complex level due to rapid improvement in technology. As a result, it has created an environment with a lot of challenges to decision makers. The most critical part of any decision making process is the involvement of stakeholders. Owing to the fact that not all stakeholders are well-informed in the modern approaches being used in making good choices, they have found themselves scrambling for resource allocation in many occasion. This has often led to some vital resources being allocated to areas where they should not have been put. In many instances it has given rise to scenarios where governments have been blamed for misuse of resources. The whole problem lies with the improper decision making. Thomas L. Saaty derived this method in 1970s by using both psychology and mathematics concepts. His aim was to come up with a method which could be used to aid decision makers in making best choices.

Complex problems always require rigorous decision making process which having a capacity to break the problems in to manageable levels. There are generally three main levels in any problem solving process. These are the goals, criteria and alternatives. A problem is deemed to have been completely solved if the best consideration and choice is used to realize the stated goal. By use of hierarchical approach or arrangement towards solving any problem, every element that may be involved in the process is considered and given a chance to contribute some impact (Figueira et al., 2005; Saaty, 2008; Promentilla & Tan, 2014).

In any AHP process, it is possible to disintegrate or simplify a decision involving numerous criteria through a six-step process (Russo & Camanho, 2015). The first step deals with the definition and choice of the problem as well as considering any assumptions taken during the process. This entails breaking the problem into parts which are then putt in a hierarchical arrangement beginning with the goal, then criteria, sub-criteria and any alternatives in the lowest level of the hierarchy. It is very important to arrange or structure decision problem as a hierarchy whenever AHP is intended to be used (Bushan and Rai, 2004).

The following is a generalized hierarchic structure in Figure 2-2:

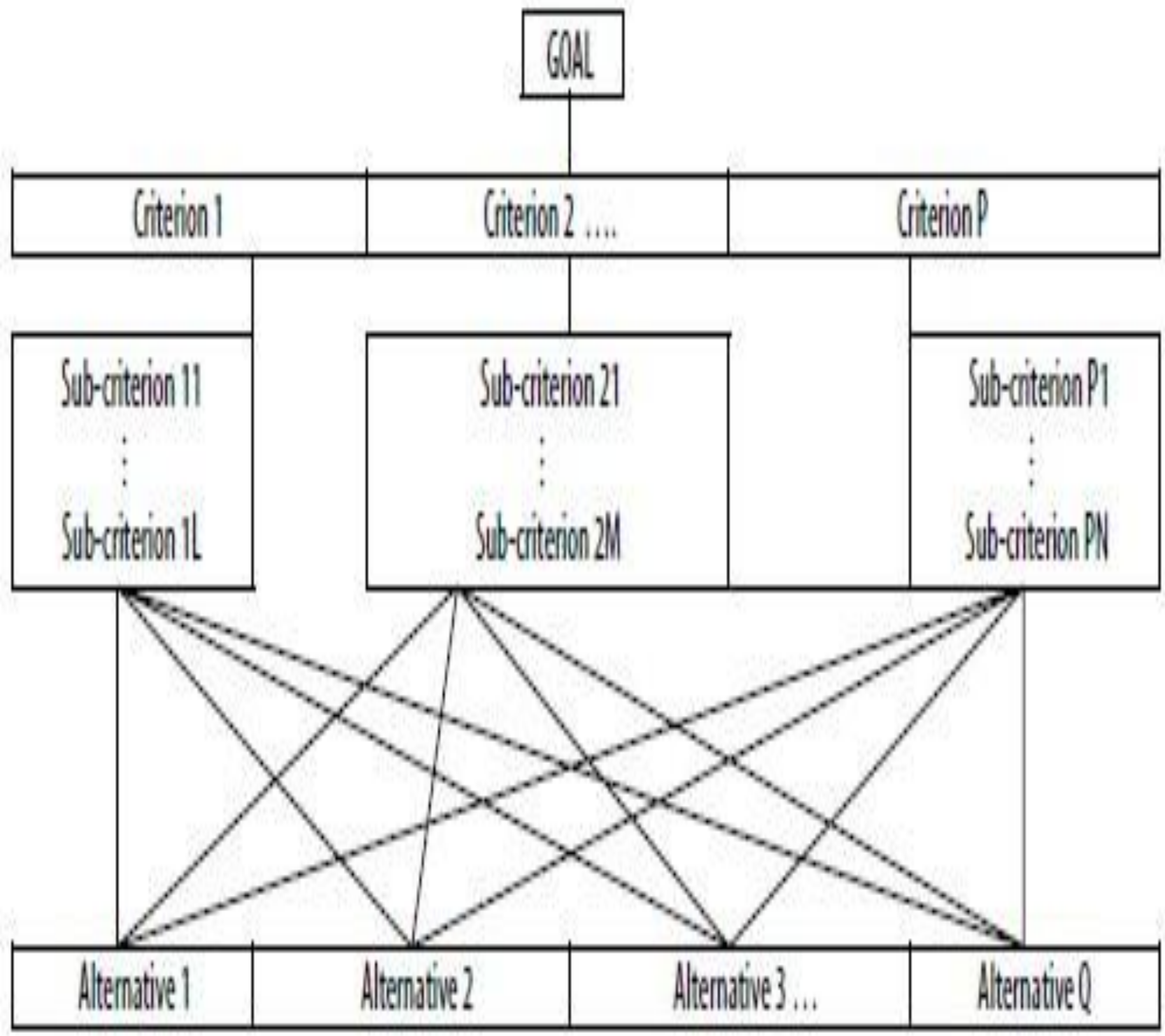

Figure 2-2: Generalized Hierarchic Structure (Saaty, 1980)

Elements of one level of the hierarchy are related to that of another level which are below them. These relationship goes down up to the lowest level in the hierarchy. It is suggested that the best way to structure the hierarchy is to start from the goal then move down to the lowest level of alternatives. While in the level of alternatives, it is also required that one moves up to the goals again until a clear connection among the elements in the hierarchy is achieved. This will be a good indication that comparisons that are to be made during the process will be possible.

Step two in the process of designing the hierarchical structure for AHP is that of collecting data from experts or decision-makers. It is done by putting all elements in a pairwise comparison of alternatives and assigning scores as per a qualitative scale which was first designed by Thomas Saaty during his time of discovering this analytical method. The scale has been named as Saaty scale just after its founder.

Thirdly, the pairwise comparisons, as per step two, are then arranged in a square matrix which has the following characteristics:-

i) The primary diagonal of the matrix is always unity or one.

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

ii) Also, the criterion in the *i*th row is more important than that in the *j*th column if the value of (i, j) element is greater than one. Otherwise the criterion in the *j*th column is better than that in the *i*th row. The (*j*, *i*) element of the matrix is the reciprocal of the (*i*, *j*) element.

During the analytical process, criteria are subjected in a gradation scale where from comparison each pair of the criteria, sub-criteria or alternatives, categorization is done as shown in the Table 2-1.

Table 2-1: Gradation scale for quantitative comparison of alternatives.

Option	Score
Equal	1
Marginally important	3
Important	5
Very important	7
Extremely important	9
Intermediate values for fuzzy inputs	2, 4, 6, 8

The fourth step in the application of AHP involves computation of Eigen vector whose values are referred to as principal Eigen values. It is out of the Eigen values where weights of the criteria or sub-criteria are obtained through normalization of the Eigen vector. Ratings of the alternatives is also done using the weights.

2.2 Land Suitability

Food and Agricultural Organization (FAO) of United Nations (UN) gave some recommendations on the best ways in which land suitability evaluation should be conducted. These included making choices of factors to be considered, carrying out an evaluation of every element which constitute the criteria of any land suitability analysis (FAO, 1976). There are four major types of land suitability classifications adopted from the organization. These are land suitability orders, land suitability classes, land suitability subclasses, and land suitability units.

CHAPTER 3: METHODOLOGY AND MATERIALS

3.1 Study Area

The area under study is the whole of Kericho County as shown in Figure 3-1.

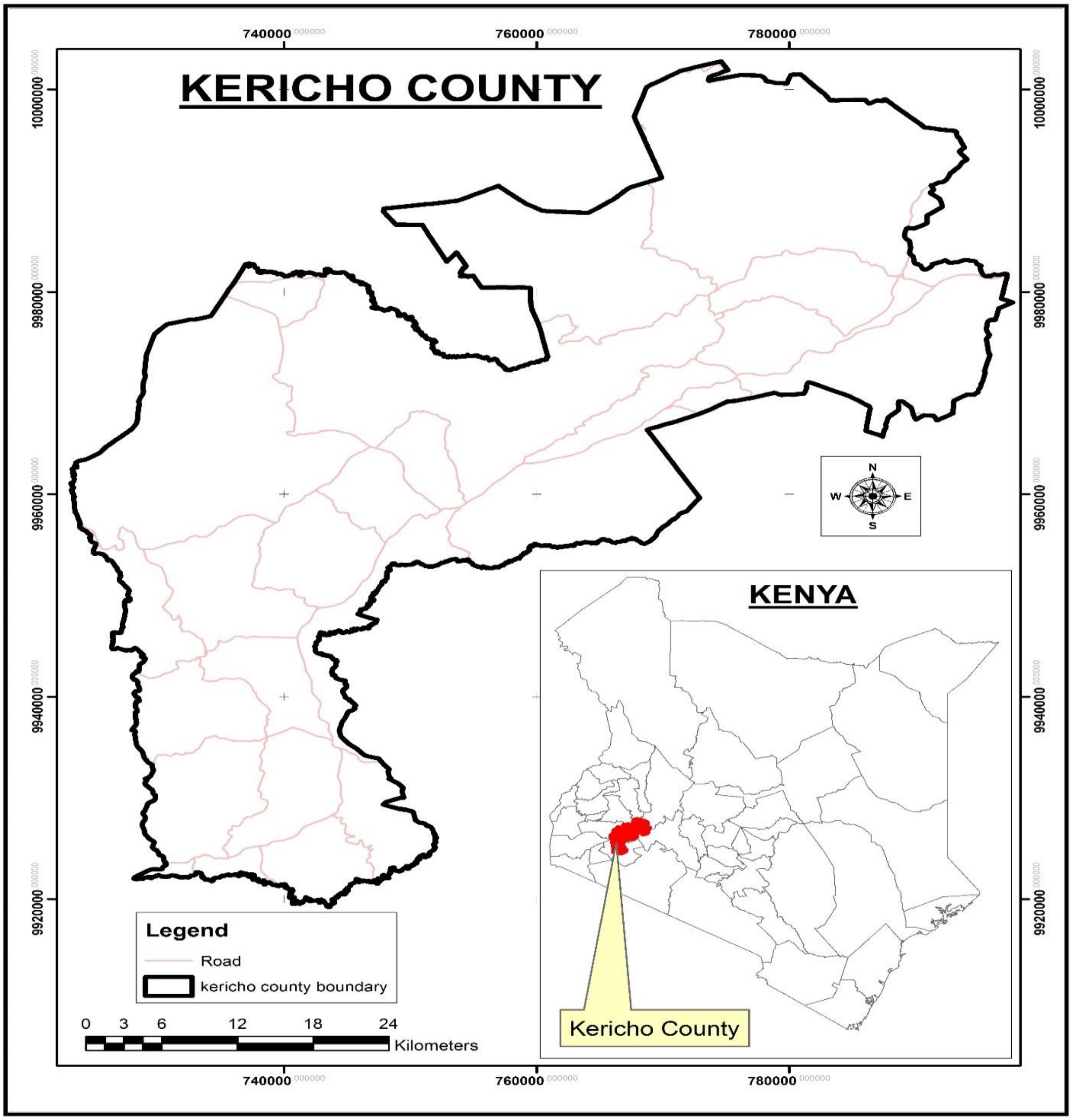

Figure 3-1: Location of Study Area

The County is situated in the larger Rift Valley, most specifically in the southern part. It is comprised of six constituencies with a total of thirty administrative wards. The distribution of the wards in the six constituencies is as follows:-

Table 3-1: County administrative divisions.

Constituency	Number of Wards	Wards
Kipkelion West	four	Kunyak, Kamasian, Kipkelion, Chilchila
Kipkelion East	four	Londiani, Kedowa/Kimugul, Chepseon, Tendeno/Sorget.
Ainamoi	six	Kapsoit, Ainamoi, Kipchebor, Kapkugerwet, Kipchimchim, Kapsaos.
Buret	seven	Kapkisiara, Tebesonik, Cheboin, Chemosot, Litein, Cheplanget, Kapkatet.
Belgut	five	Waldai, Kabianga, Cheptororiet/Seretut, Chaik, Kapsuser.
Sigowet/Soin	four	Sigowet, Kaplelartet, Soliat, Soin.

The County lies between the equator and 0°23' South and longitudes of 35°02' East and 35°40' East. The County falls at an average altitude of 1800 metres above sea level with temperatures ranging from 17°C to 20°C. It covers an area of approximately 2591 km^2.

According to the national population census of the year 2009, the population of the County was 752, 396. The number must have increased currently. The County is served by one major town, Kericho Town with all the County offices in the same town. The County receives an average annual rainfall of about 1350 mm. Long rains are experienced within a period of three months, starting from June.

The predominant type of soil in the County is the nitro-rhodic Feralsol (Uh6) which originates from igneous rocks Chisanya et al., 2007). It has characteristics of being well-drained, high depth, and is mainly dark reddish brown in colour. The soil ranges from sandy clay to loamy clay. It is mainly found in high lands. On the valleys is the cambisols (R9) which is also well-drained but with shallow depth. It ranges from loamy clay to clay and has acidic, humic, topsoil.

3.2 Methodology

The figures 3-2, 3-3, and 3-4 are flow charts showing the overall process of carrying out a land suitability analysis for coffee growing. A number of factors are considered in the process and their combined effect on the crop is represented in a suitability map.

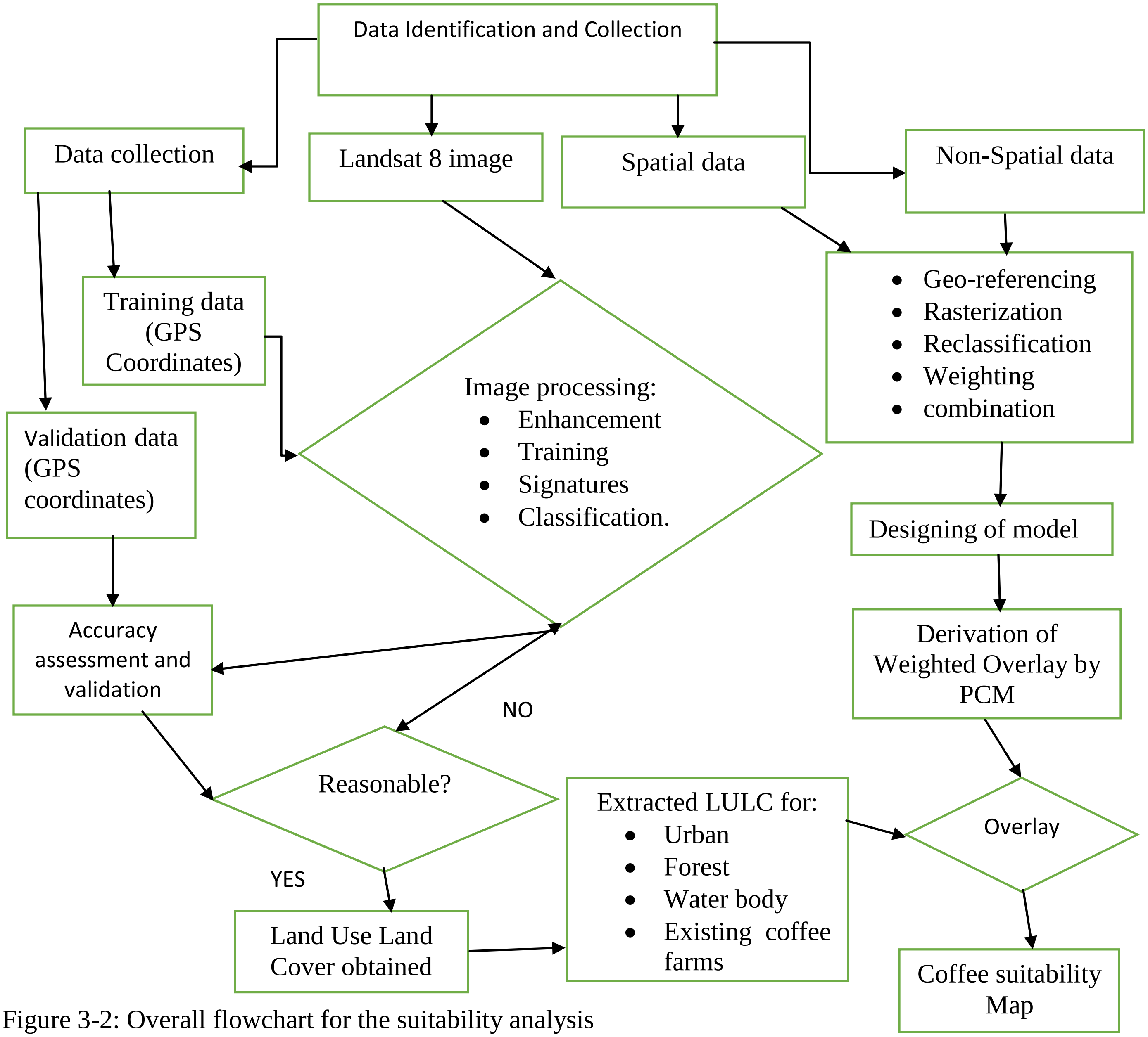

Figure 3-2: Overall flowchart for the suitability analysis

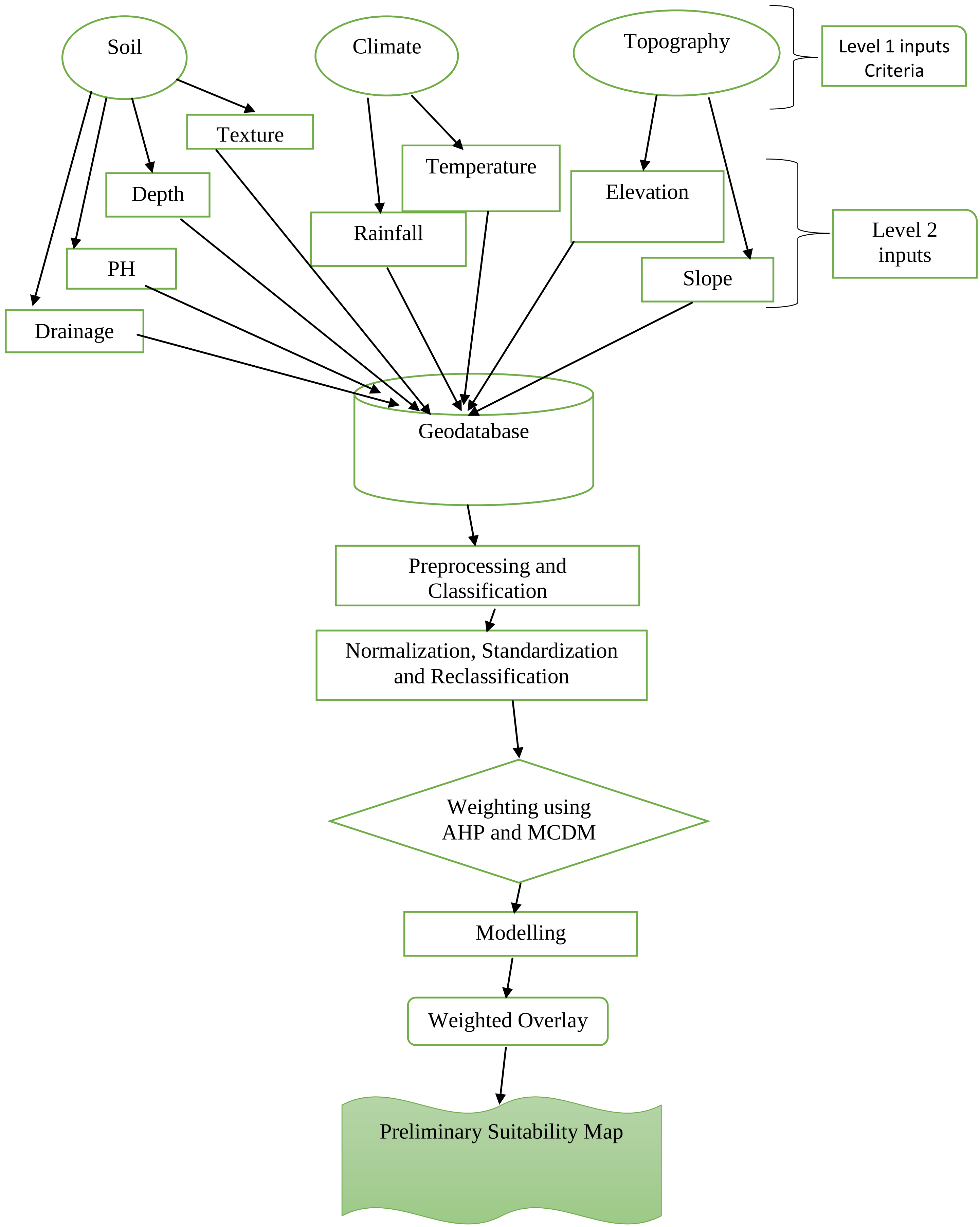

Figure 3-3: Suitability Map from weighted overlays

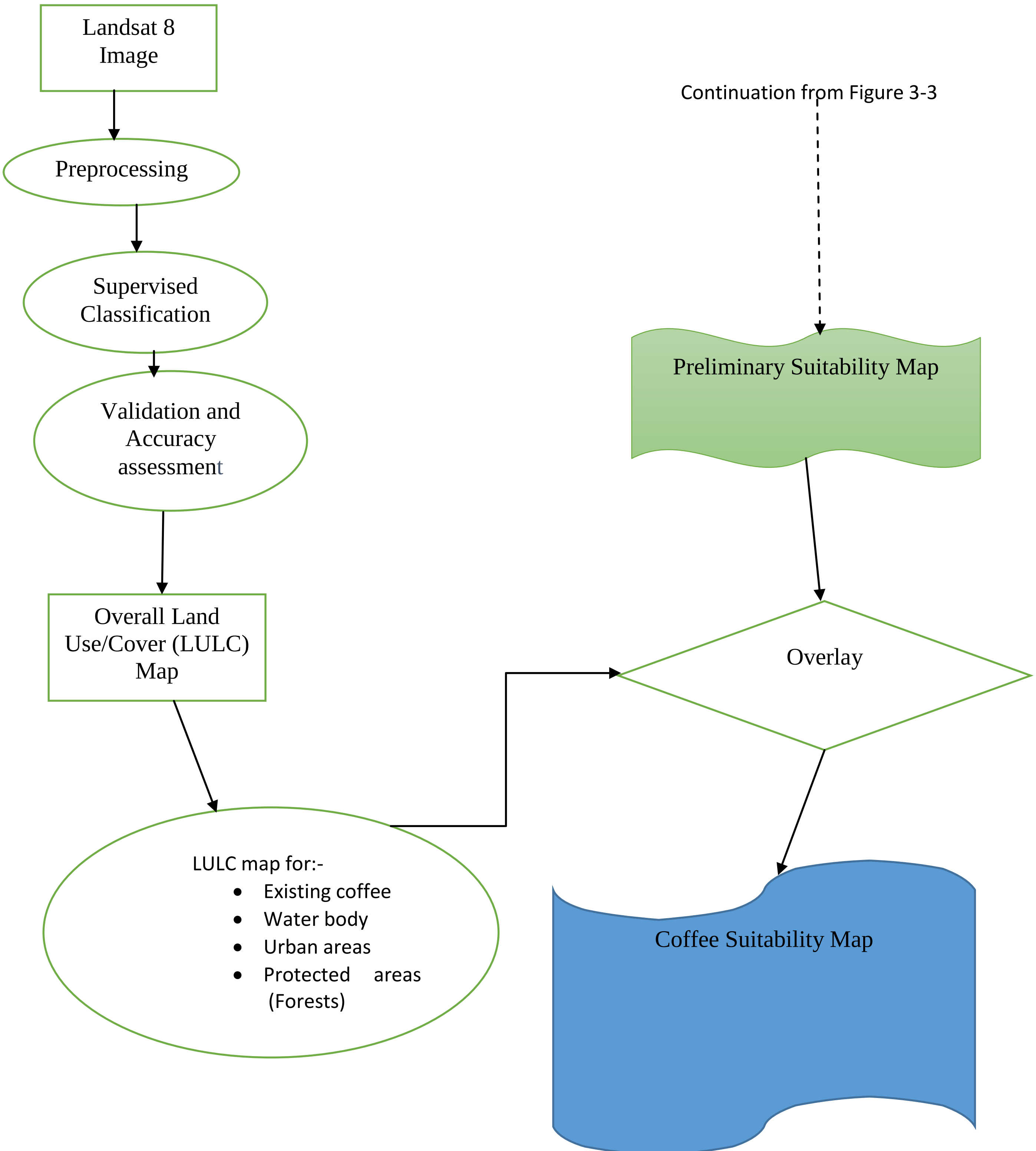

Figure 3-4: Coffee Suitability Map

The product from land use/cover is overlaid with the suitability map obtained from the weighted overlays.

3.3 Datasets in use

Data of different types have been used in the study. They were obtained in different formats and from different sources. The following is a tabular representation of the different datasets, their sources, data formats and resolutions (where necessary).

Table 3-2: Datasets used in the study

Dataset	Format of Data	Data Source	Resolution of Data
Climate (Temperature and Rainfall)	MS Excel	Kenya Metrological Department (KMD)	!980-2014
Topography (Elevation)	MS Excel	Kenya Agricultural and Livestock Research Organization (KALRO)	2016
Soil(Depth, PH, Drainage, Texture)	Shapefile	Kenya Soil Surveys	2015
Existing Coffee farm points and polygons	UTM Coordinates	Handheld GPS	March 2016
Training sites	UTM coordinates	Handheld GPS	March 216
Administrative Boundaries	Shapefile	Survey of Kenya	1992, 1:250,000
Satellite Image (Landsat 8 Image)	Tiff	Regional Centre for Mapping Resource For Development (RCMRD)	30 m accuracy
Weather stations locations	MS Word	KMD	2015

3.4 Data Acquisition

3.4.1 Climate Data

The data obtained from Kenya Metrological Department on climate were in Excel format file. They were scrutinized on excel spread sheet to ensure that all the values representing both temperature and rainfall were free from obvious errors and mistakes. In the MS Excel file containing the climate data, spatial data in terms of latitudes and longitudes of the locations of weather stations were entered into corresponding climate data. In the climate data, averaging was done starting from the year 1984 up to the year 2015 in the excel spreadsheet. The results were exported to the ArcGIS 10.2 software for further manipulation. There was a need to generate raster image from the data put in ArcGIS but a geostatistical method of interpolation called ordinary kriging was used to interpolate point data into a continuous surface. The resultant image was then clipped to the study area by use of the County boundary.

3.4.2 Topography Data

The data on topography, which were in MS excel format were exported to ArcGIS 10.2 software. They were then interpolated through ordinary Kriging so as to have representative values of elevation in every part of the area under study. The resultant surface was a continuous surface which formed a raster image. It was then clipped to the study area using the existing county administrative boundary.

From the elevation data, which was converted to a raster image, slope was derived by utilizing the arc Toolbox properties of ArcGIS 10.2 software.

3.4.3 Soil Data

Data on soil type, drainage, texture and pH was in shapefile form representing polygons of different soils. They were imported into ArcGIS 10.2 platform where they were explored and displayed in map format. It was ensured also that the data adequately covered the area of study.

3.4.3 Satellite Image

The Landsat 8 image covering the entire County was procured from Regional Centre for Mapping Resource for Development (RCMRD). The image had already been corrected for all errors such as those due to radiometric effects and atmospheric effects. Some image enhancement was done on the image to ease feature identification while selecting training sites. Supervised classification of the image was done using ArcGIS 10.2 platform. This resulted in to ten land cover classes, namely: Bare areas, Coffee (existing coffee farms), cropland, Forest (Protected areas for forest), Agro-forest, Grassland, Tea, Sugar plantations.

3.4 Standardization and Reclassification of Criteria

Since the criteria used in the study were of different types, yet they were supposed to be put together in a competitive weighting and comparison process, standardization was mandatory. Criteria factors such as temperature, drainage, texture, rainfall, soil pH and slope could only be compared upon subjecting them to certain common scale. They are quantified in different units and yet they are very important during suitability analysis. To be able to have a reasonable comparison, common standard is required so as to apply weighted overlay over each of the input criteria (Mishra , 2015).

CHAPTER 4: RESULTS AND ANALYSIS

4.1 PREPROCESSING OF DATA AND CLASSIFICATION RESULTS

The data used in the study were land use land cover (LULC) from satellite image, weather stations, climate (rainfall and temperature), topography (elevation and slope), and soil (soil drainage, soils depth, texture and soil pH).

4.1.1 RAINFALL AND TEMPERATURE

Rainfall data for over a period of thirty years, from 1984-2015, were used in the study. The data for rainfall were interpolated using ordinary Kriging from ArcGIS 10.2 software and the results were further converted to raster format. The raster was then clipped using the County boundary map and the results were as in Figure 4-1.

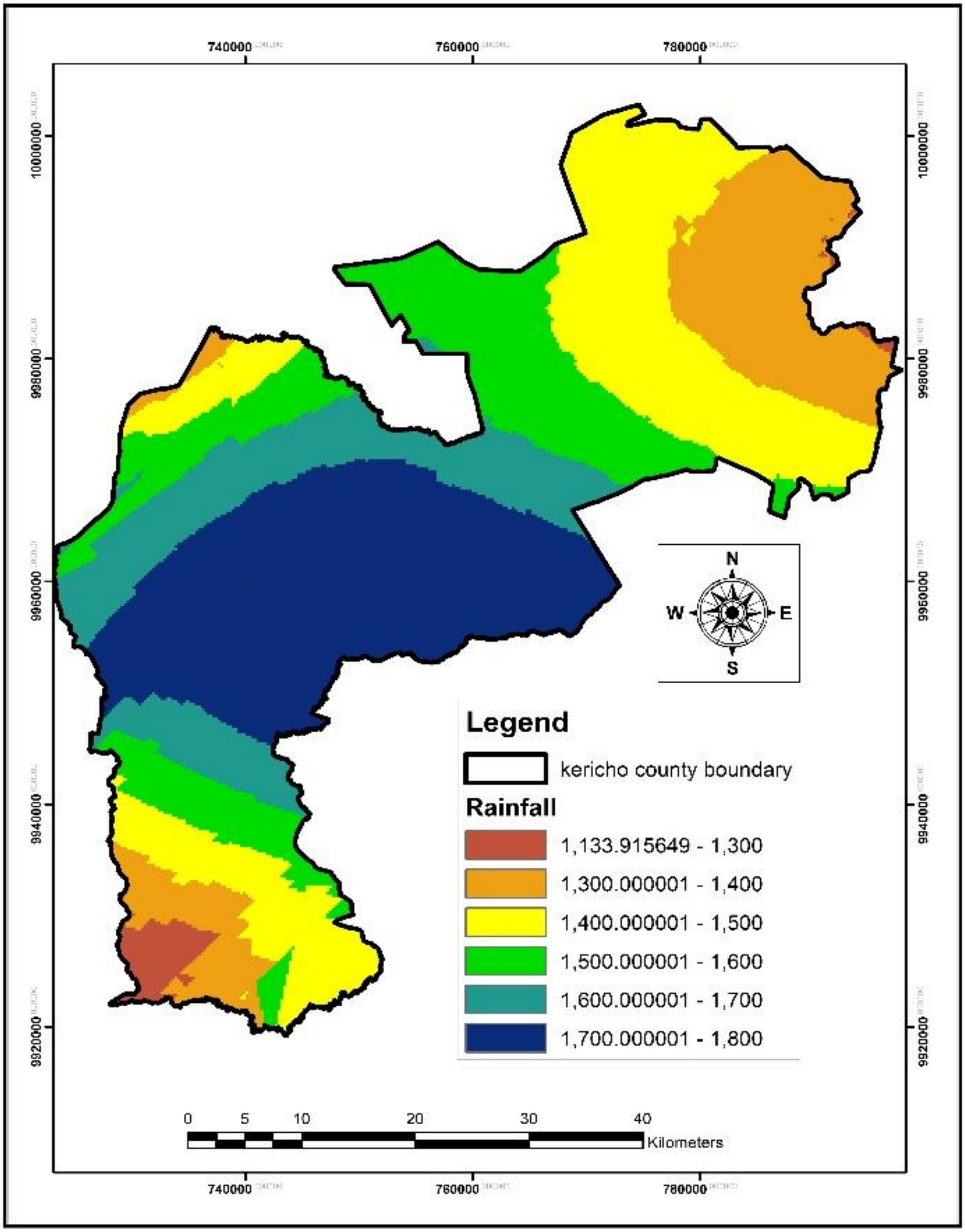

Figure 4-2. The annual mean rainfall (mm)

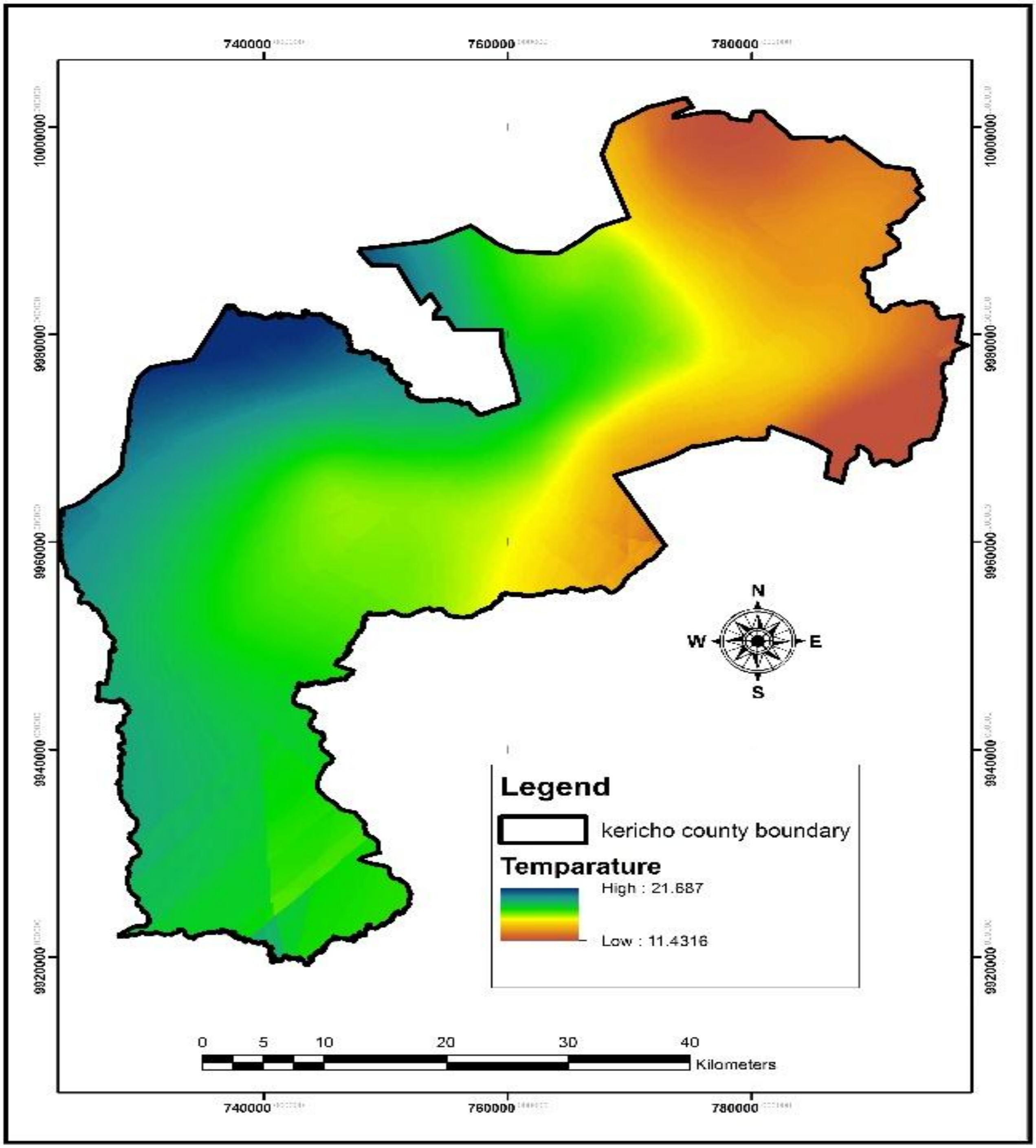

Figure 4-1. The annual mean temperature (°C)

The area has annual temperature of between 11.4 °C and 22°C. Similarly, rainfall ranges between 1300 mm and 1800 mm annually. This is as per average temperatures computed for over 30 years. From the Figure 4-1 above high temperatures are found as the distances from existing forests increase. It is also apparent that rainfall increase proportionately with decrease in temperatures. This is as per the Figure 4-2. The two factors were then reclassified into intervals with respect to their own individual units. This was done in readiness for the designing of the appropriate suitability model. The reclassified datasets for rainfall was into four classes.

4.1.2 SOIL TEXTURE AND DRAINAGE

Soil texture was created by rasterizing the soil data. The ratio of sand particles in the soil categorized the soil as loam, loamy-sand, clay and sandy soils. The rasterized data were then clipped using the County boundary map and results were as depicted in a map on the Figure 4-3. Soil drainage was also represented as moderately well-drained, poorly drained, somewhat excessively drained or well-drained. These soil attributes were finally displayed in a clipped map as shown in Figure 4-4.

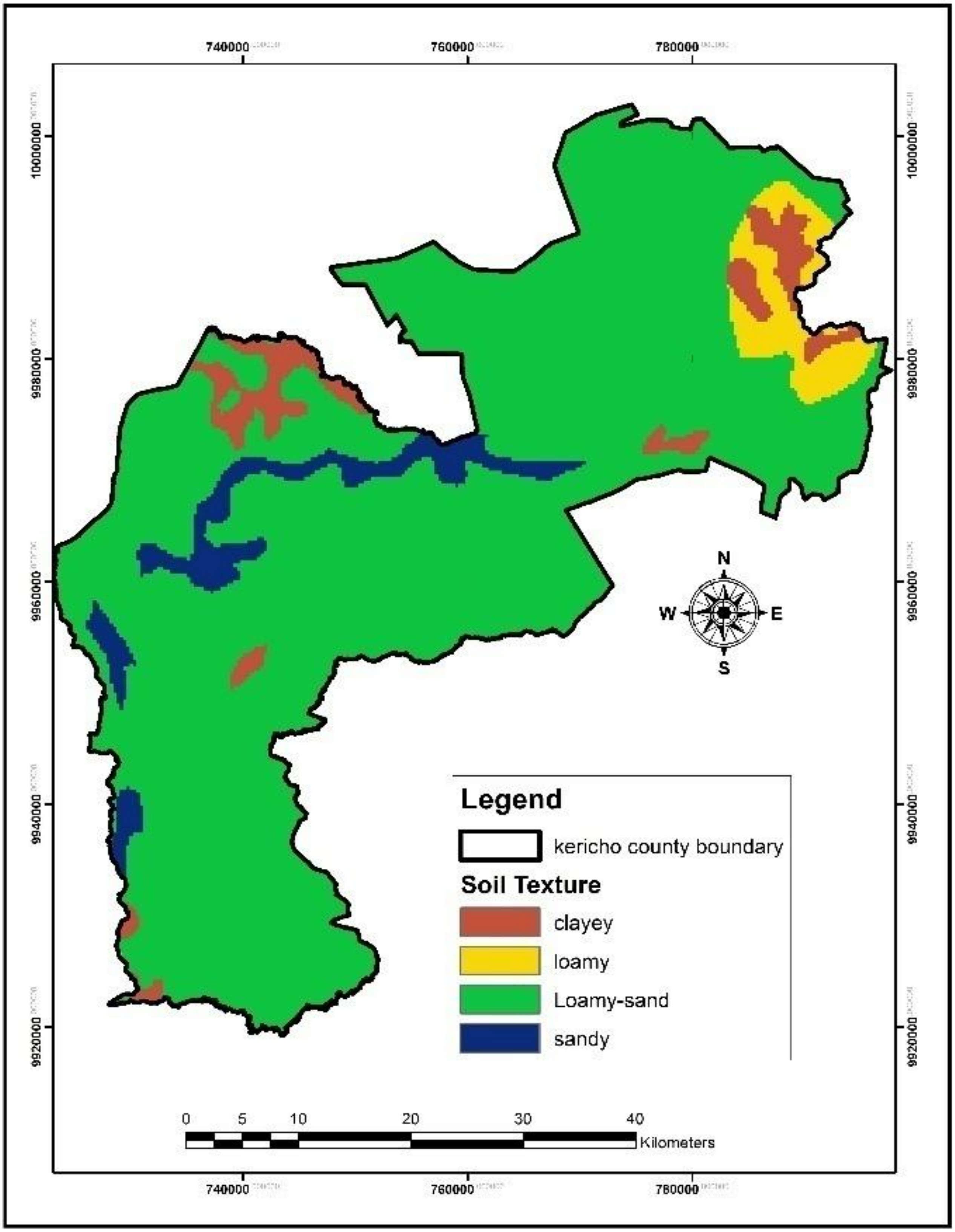

Figure 4-3: Soil texture raster output

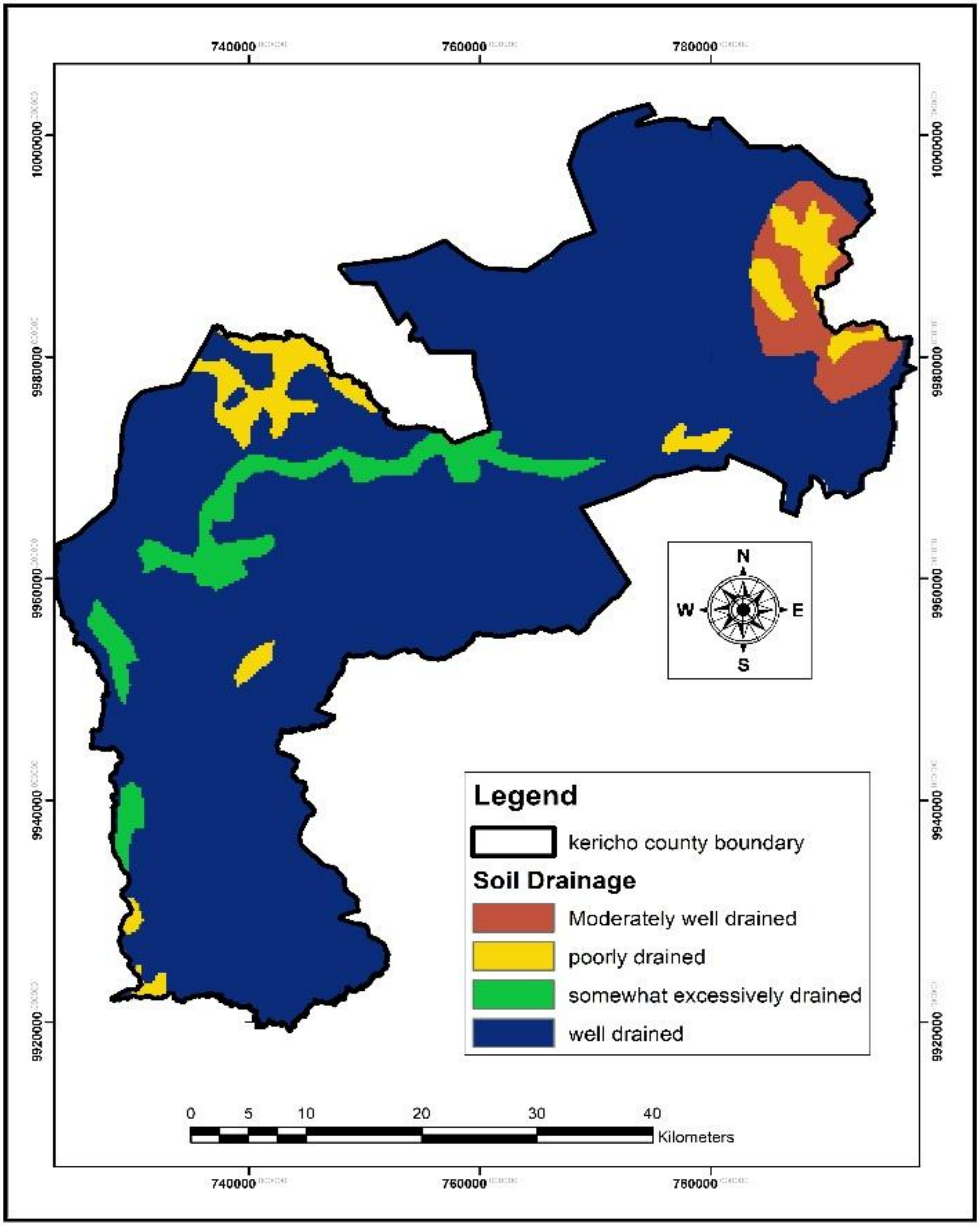

Figure 4-4: Soil drainage attributes

4.1.3 ELEVATION AND SLOPE

From the datasets, it was found out that elevation in the County ranges from 1369m to 2807m above sea level. The slope on the other hand changes from 0° to 22° but in a multidirectional pattern over the area. The results are as shown in Figures 4-5 and 4-6.

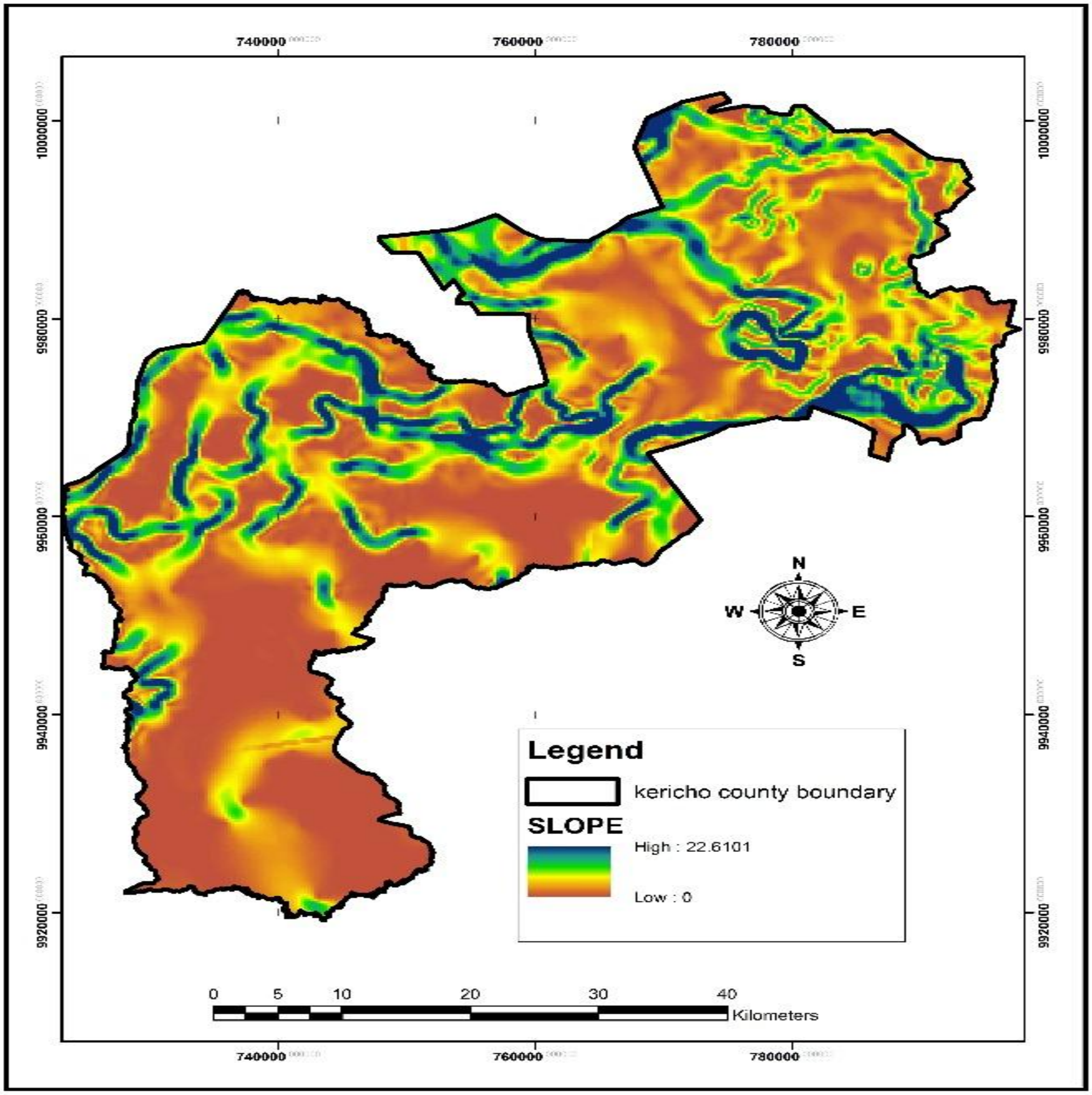

Figure 4-6: Slope

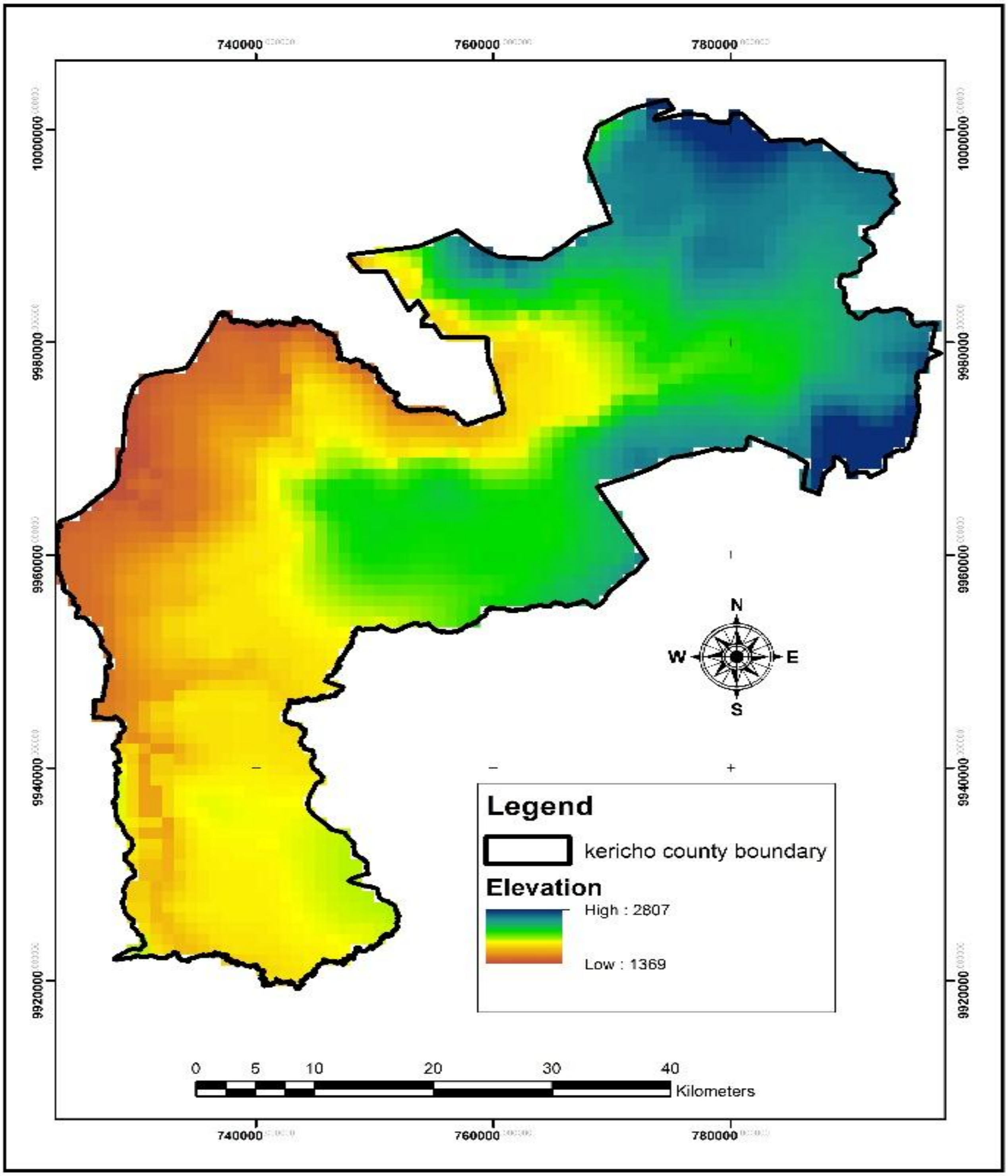

Figure 4-5: Elevation

4.1.4 SOIL PH AND DEPTH

From the preliminary results of the rasterized and clipped data for soil pH, it shows that soil in the county is relatively acidic and ranges from a minimum value of 5.3 to a maximum value of 6.5. The result was represented in a map as shown in figure 4-7. Soil depth was also mapped using such attributes as deep, moderately deep, shallow and very deep. The results are as shown in Figure 4-8.

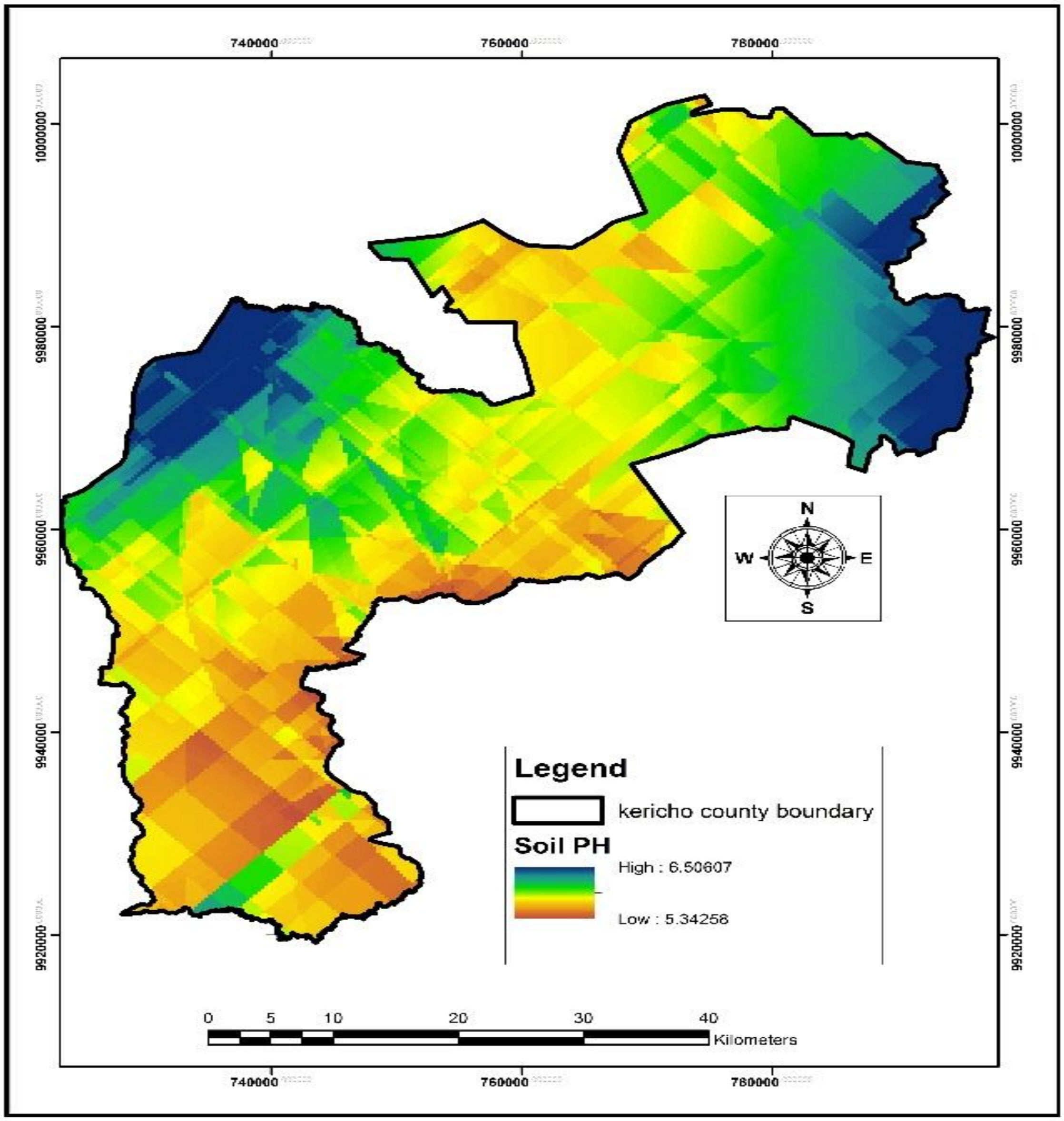

Figure 4-7: Soil pH

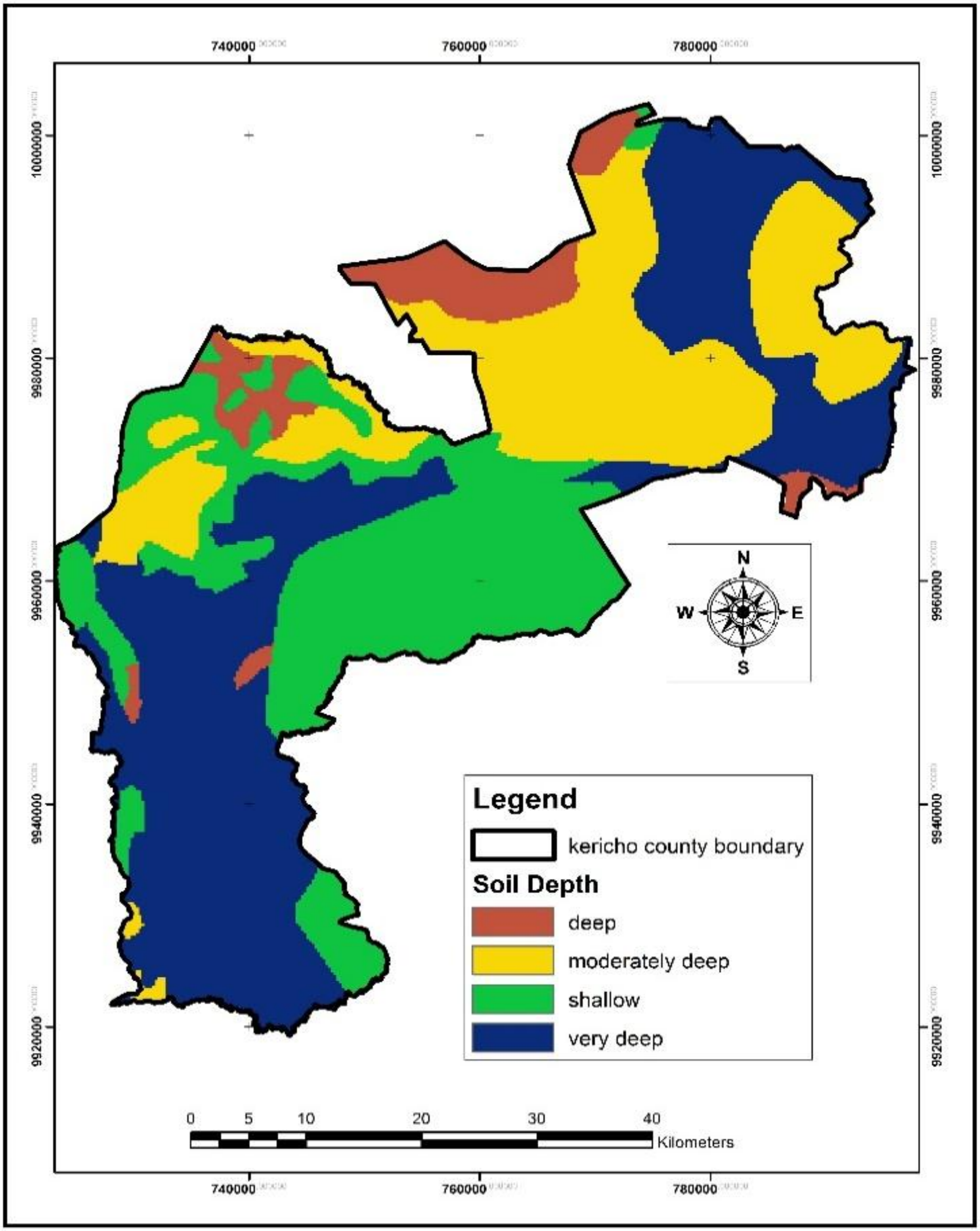

Figure 4-8: Soil depth

4.2 RESULTS FOR RECLASSIFIED DATA

The datasets already rasterized were later reclassified in accordance with what was adapted by FAO and also implemented by Saaty (1980) in his famous method of Analytic Hierarchy Process (AHP). FAO gave certain recommendations on how land suitability is supposed to be evaluated. In the process of reclassification of the datasets, use of such grading as S1, S2, S3 and NS which represented classes 1, 2, 3 and 4 respectively was done. S1, S2, S3 and NS were used to imply most suitable, moderately suitable, marginally suitable and not suitable respectively.

4.2.1 RAINFALL AND TEMPERATURE

During reclassification on rainfall data, the mean annual rainfall distribution was broken into four classes. These are S1 (1), S2 (2), S3 (3) and NS. However, no rainfall data fell on the NS class. Temperature was also reclassified and put into classes of S1, S2, S3 and NS as well. Like in the case of rainfall data, no NS class was found in temperature data. They were each processed using ArcGIS tool called ‘reclassify’ in ArcGIS 10.2 software. The results were displayed in map formats as shown in figures 4-9 and 4-10.

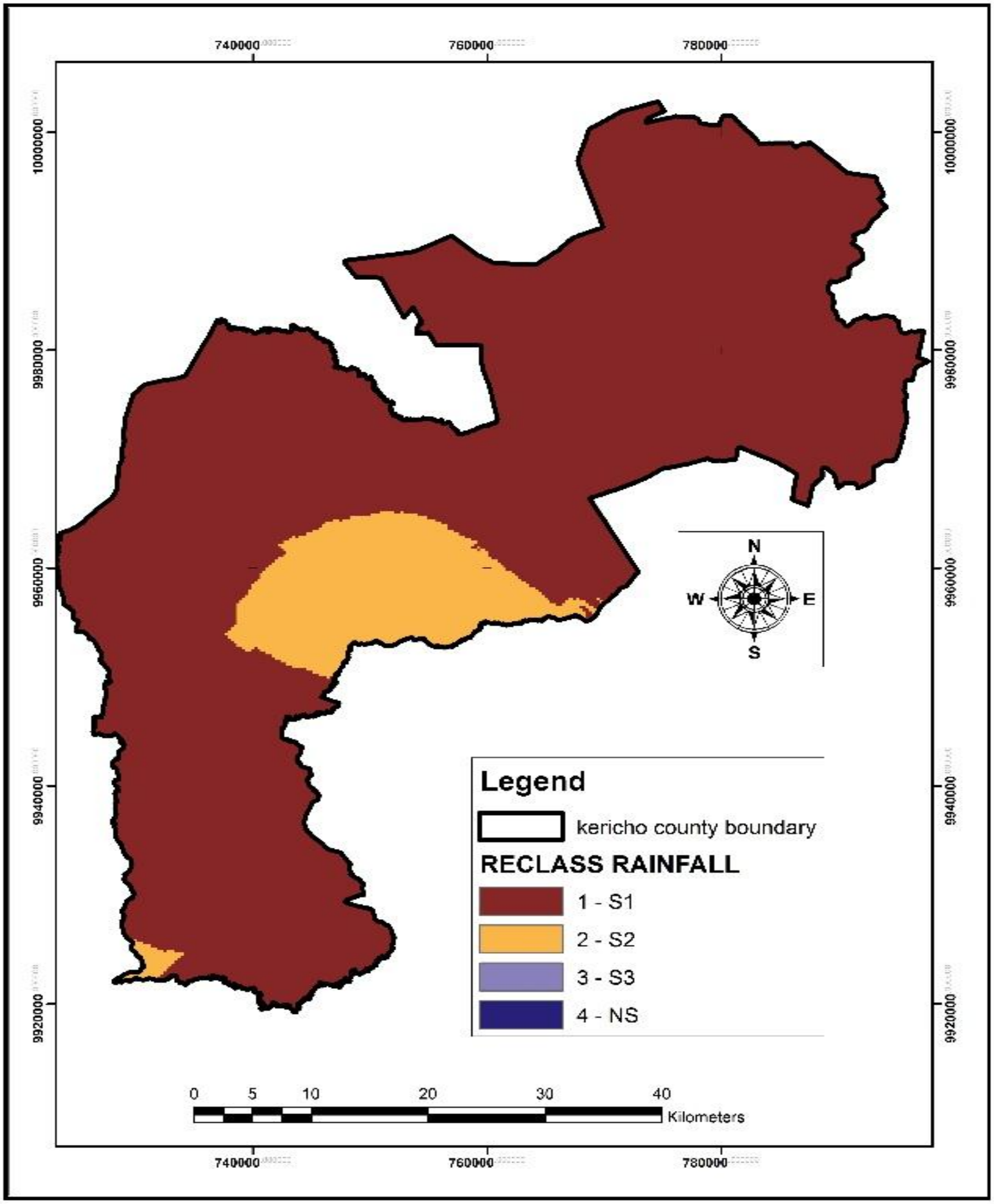

Figure 4-11: Reclassified rainfall

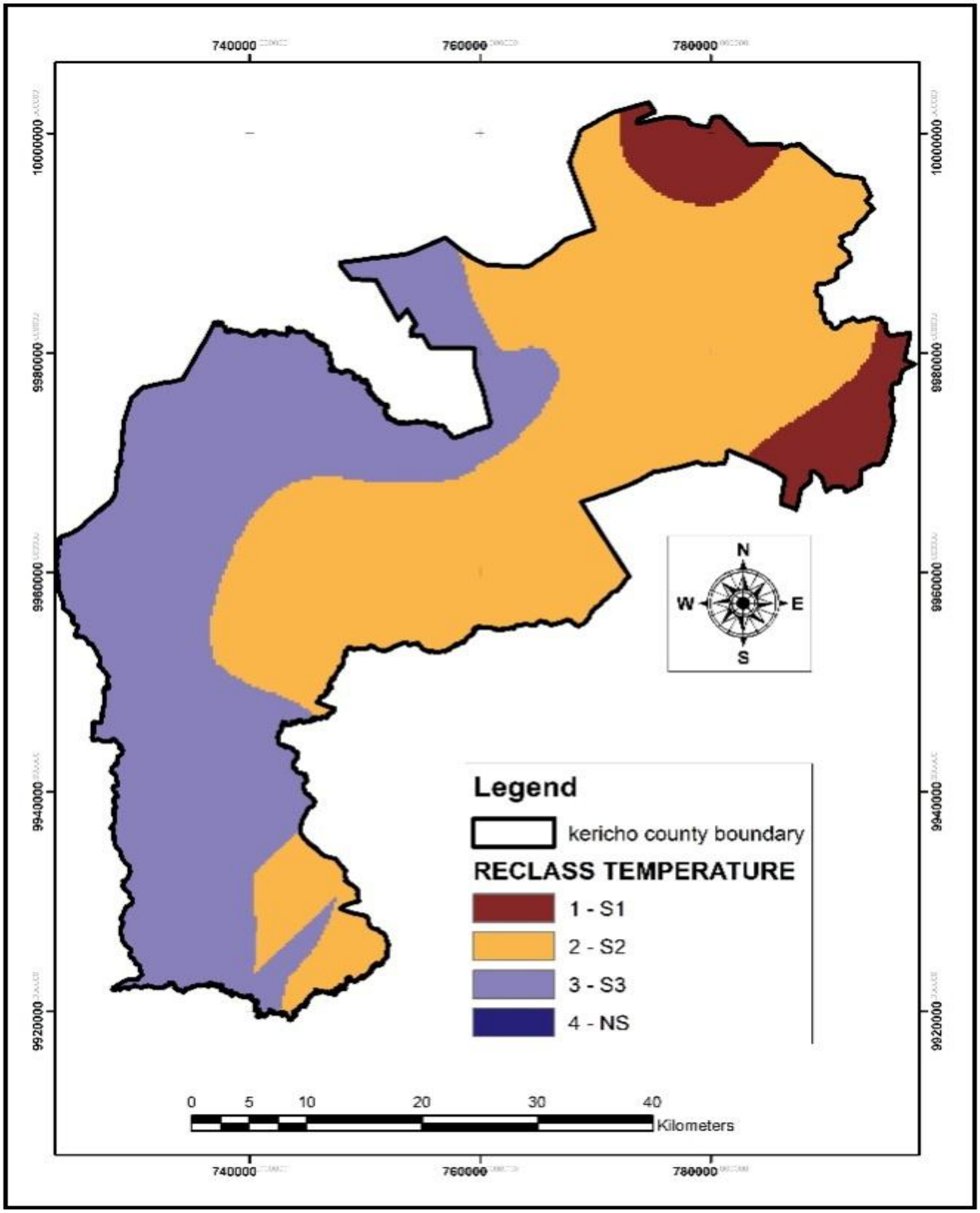

Figure 4-12: Reclassified temperature

4.2.2 SOIL TEXTURE AND DRAINAGE

The reclassified raster data for both soil texture and drainage were as shown in the maps below.

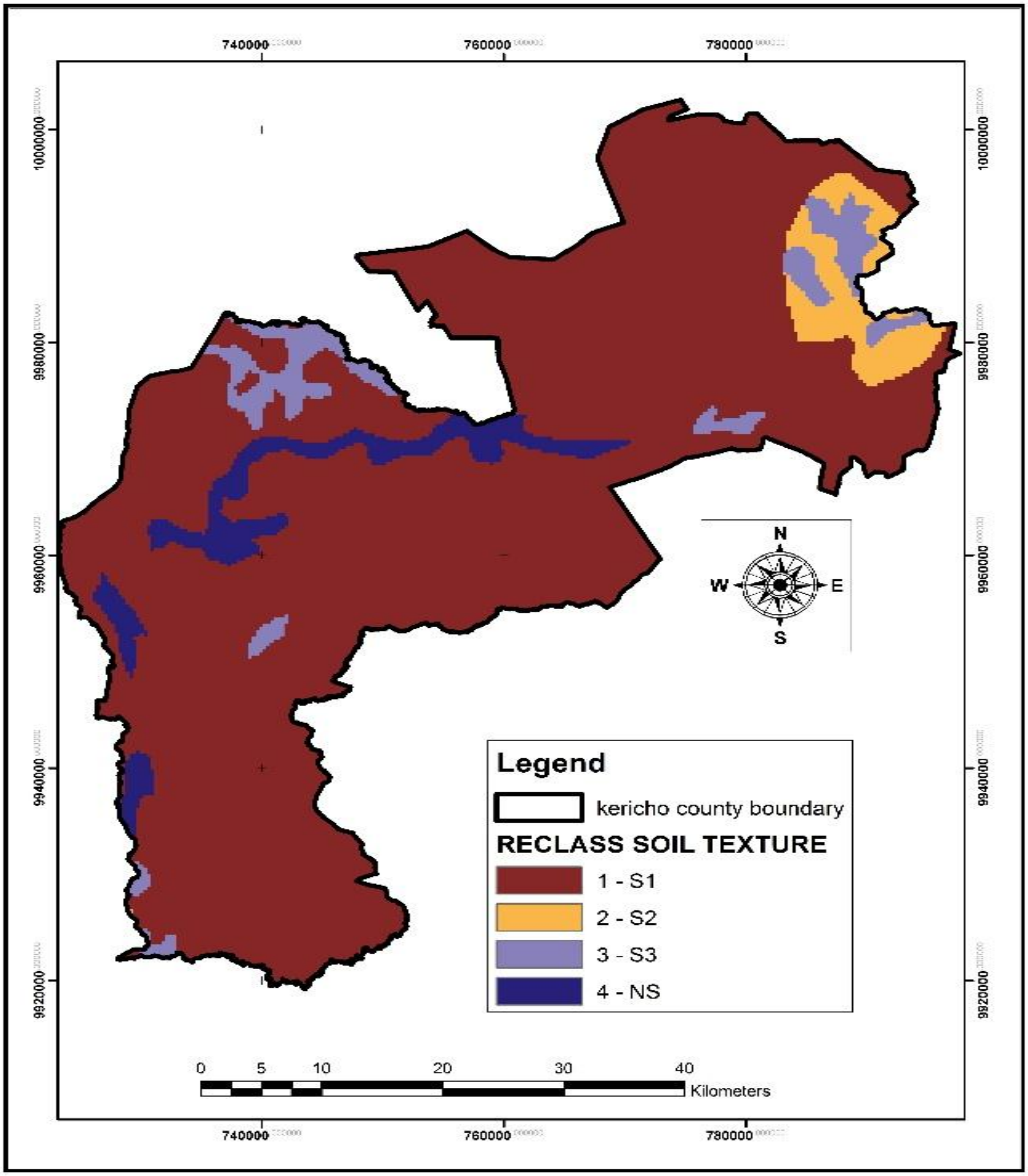

Figure 4-13: Reclassified soil texture

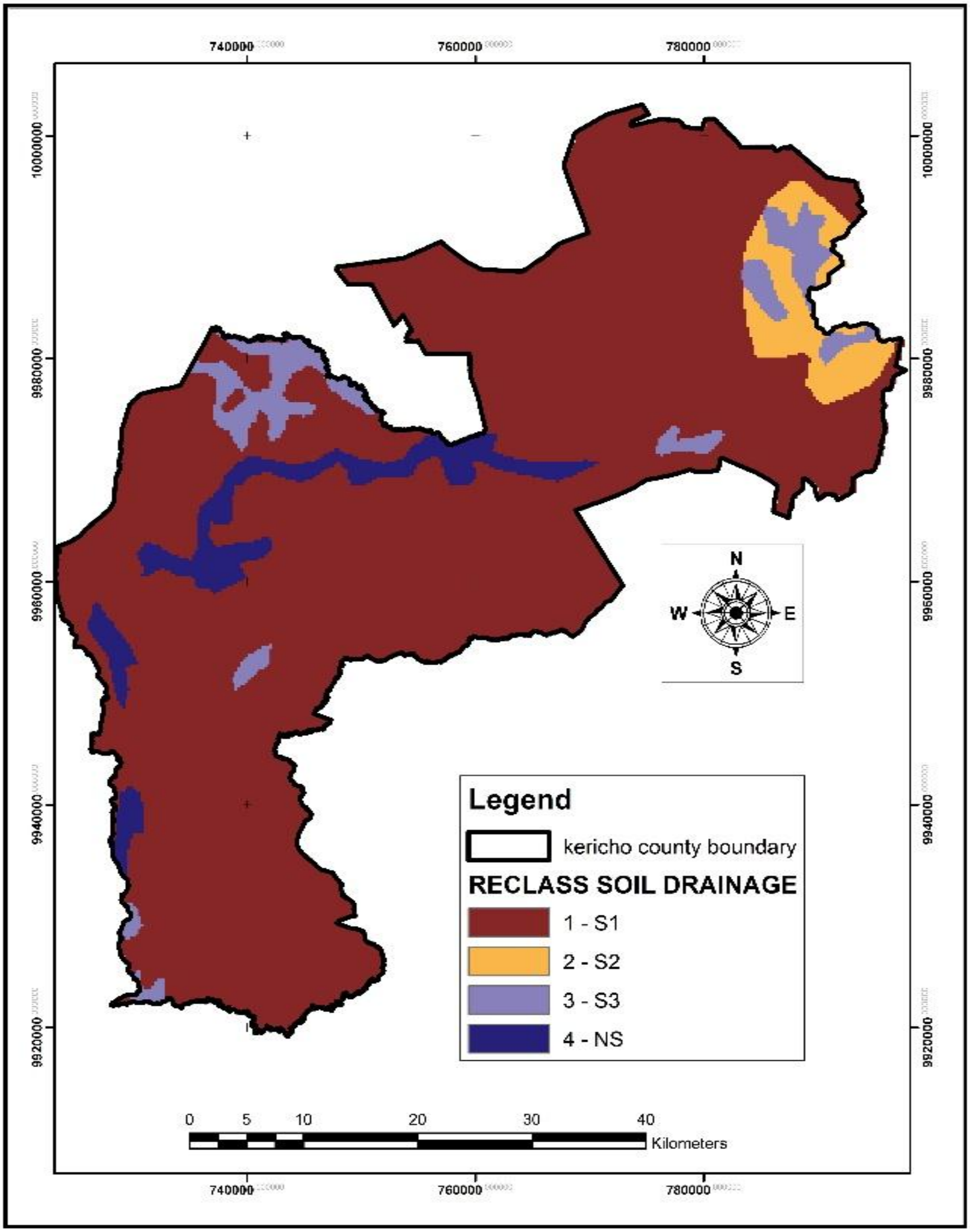
740000
760000
780000
10000000
9980000
9960000
9940000
9920000
N
W
E
S
Legend
kericho county boundary
RECLASS SOIL DRAINAGE
1 - S1
2 - S2
3 - S3
4 - NS
0
5
10
20
30
40
Kilometers

Figure 4-14: Reclassified soil drainage

4.2.3 ELEVATION AND SLOPE

The reclassified raster data for both elevation and slope were as shown in Figures 4-15and 4-16.

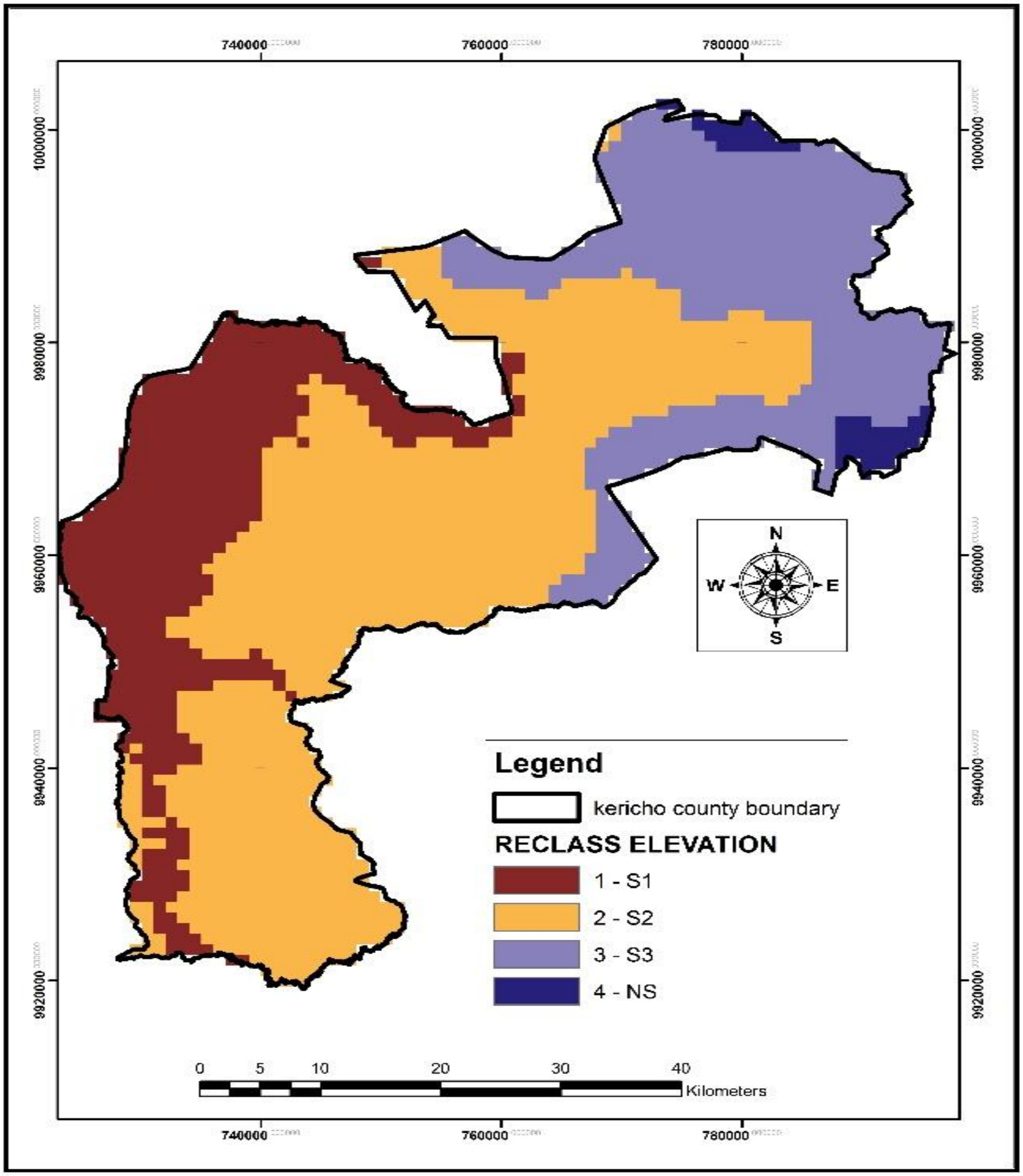

Figure 4-15: Reclassified elevation

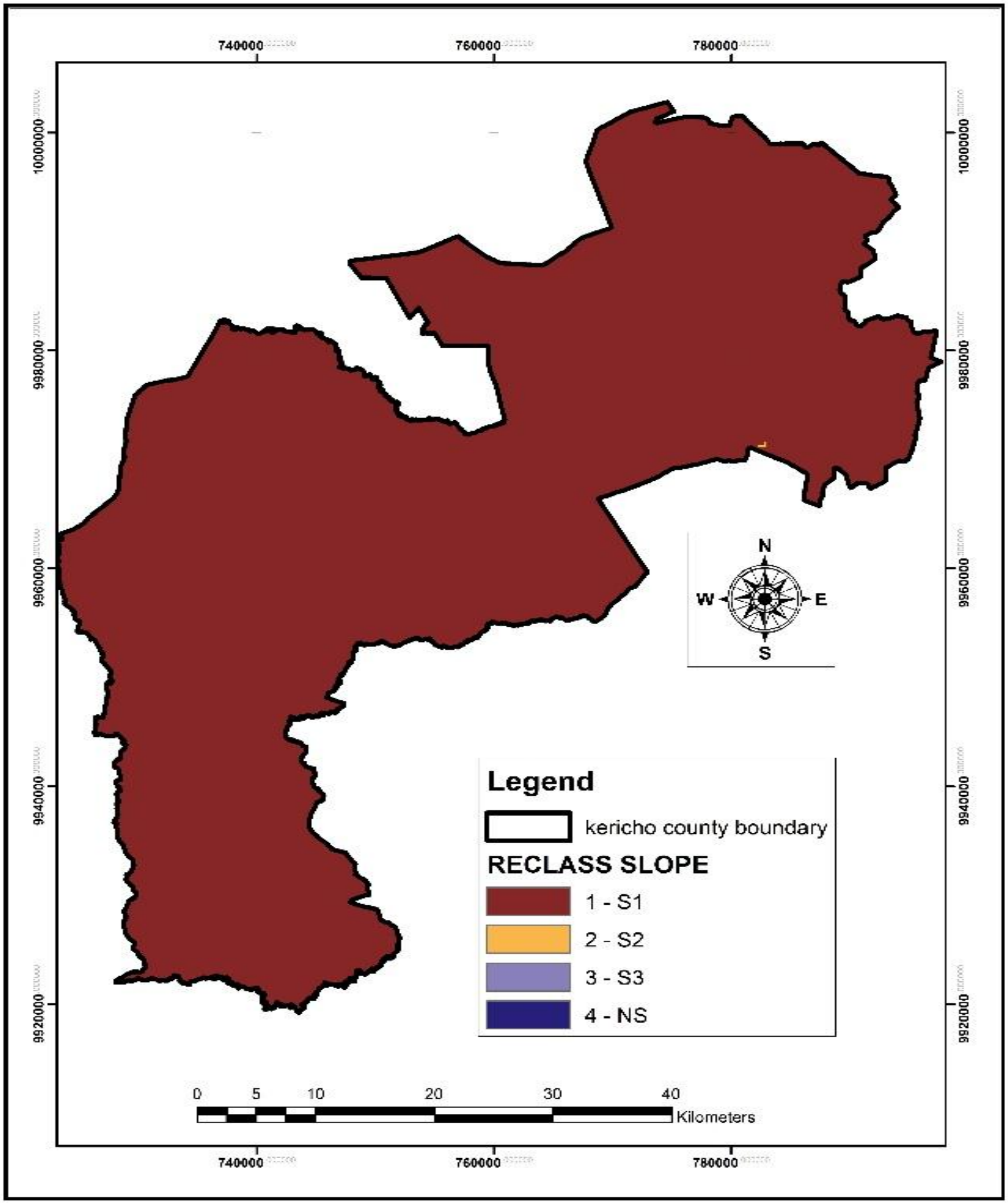

Figure 4-16: Reclassified slope

4.2.4 SOIL pH AND SOIL DEPTH

The reclassified raster data for both soil pH and depth were as shown in Figures 4-17 and 4-18.

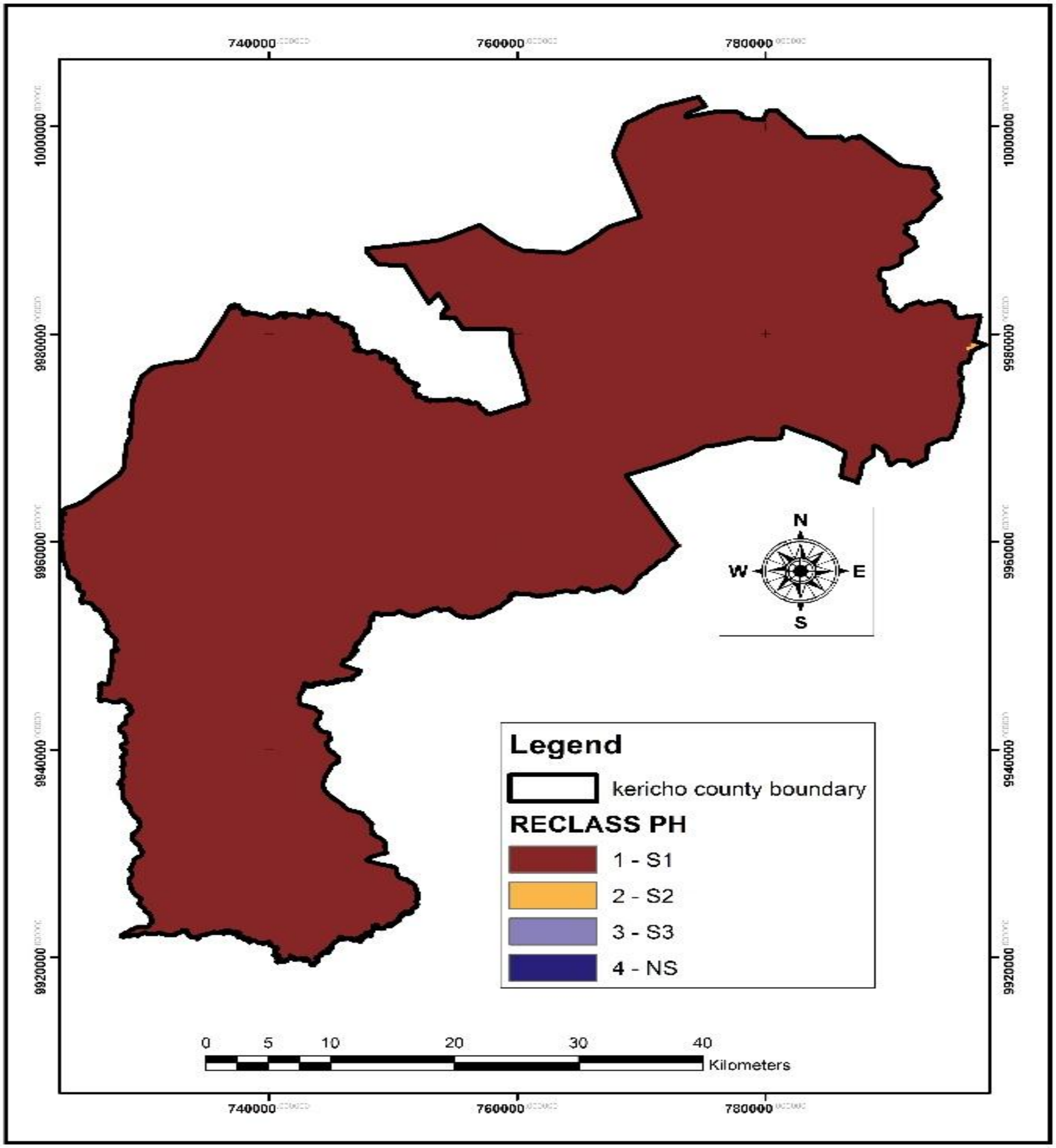

Figure 4-17: Reclassified Soil pH

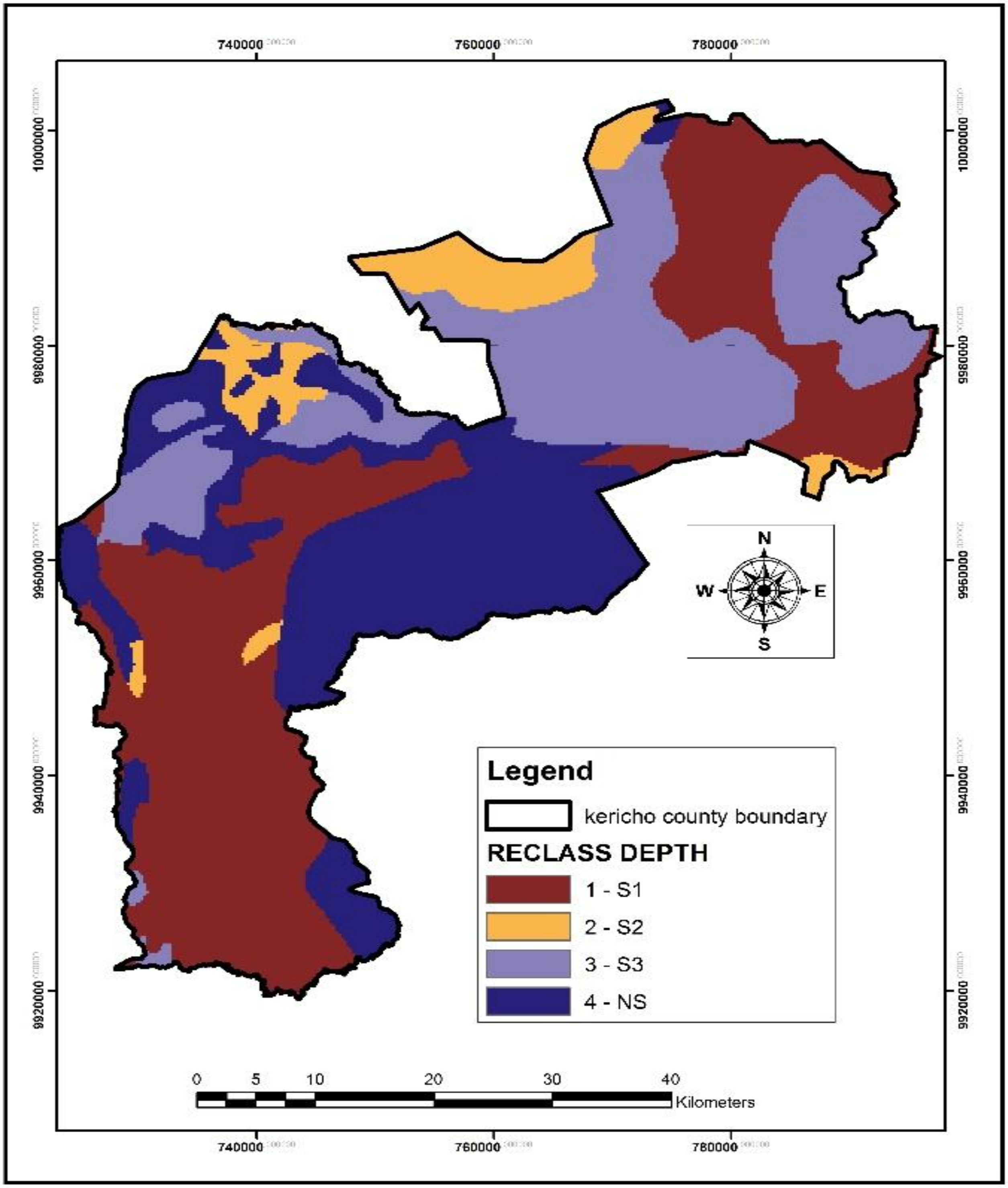

Figure 4-18: Reclassified soil depth

4.3 SUITABILITY MODEL USED

Using a model builder from ArcGIS toolbox, a suitability analysis model was designed and used in processing the first suitability map. It is referred to as the first suitability map because it was not integrated in the first instant with the LULC classes. The model operated solely with the seven sub-criteria elements while excluding the LULC. The model which generated the preliminary suitability map was as shown in Figure 4-19.

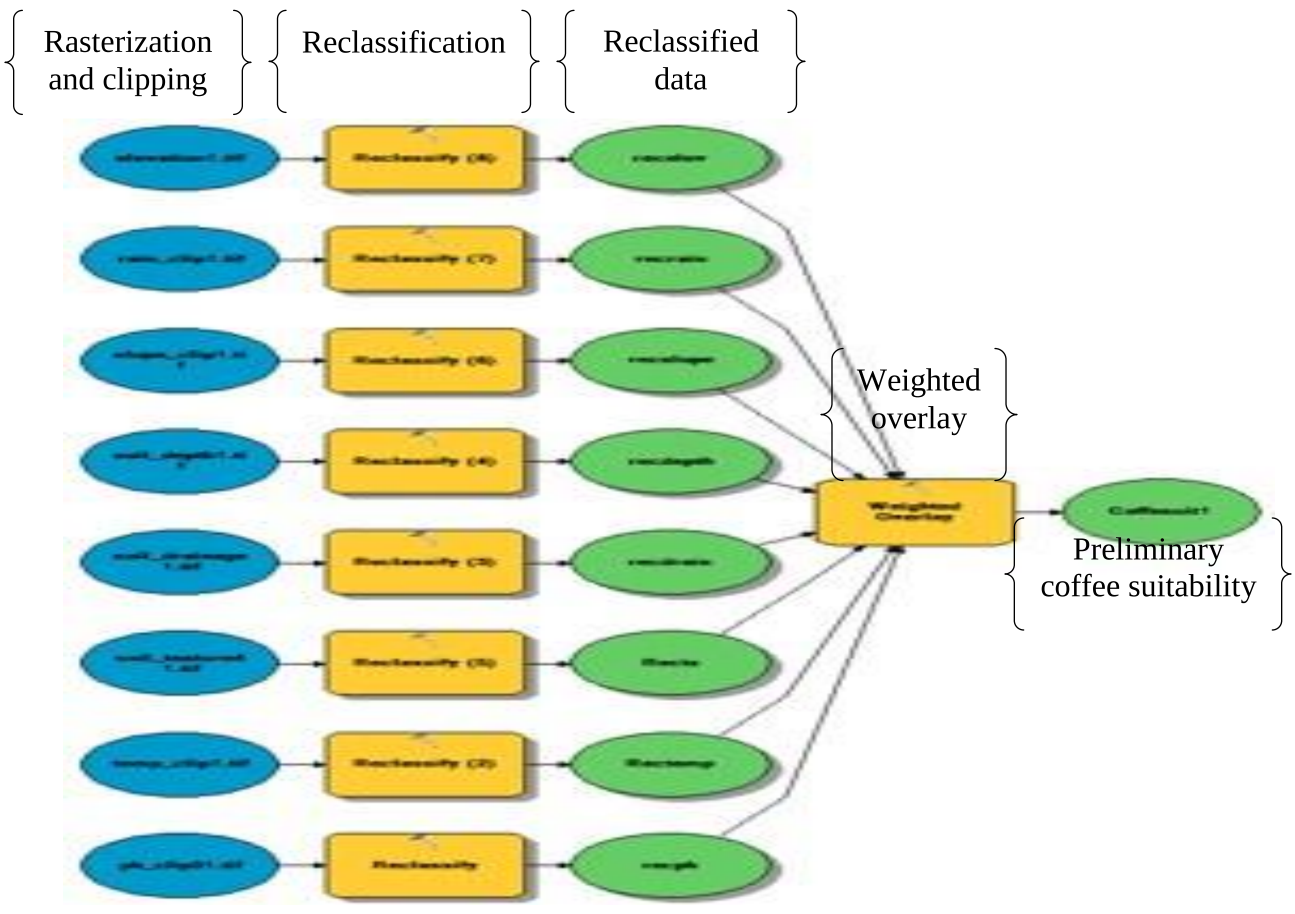

Figure 4-19: Suitability analysis model used

Below is also one of the incidences captured while the model was being run to give the preliminary suitability map.

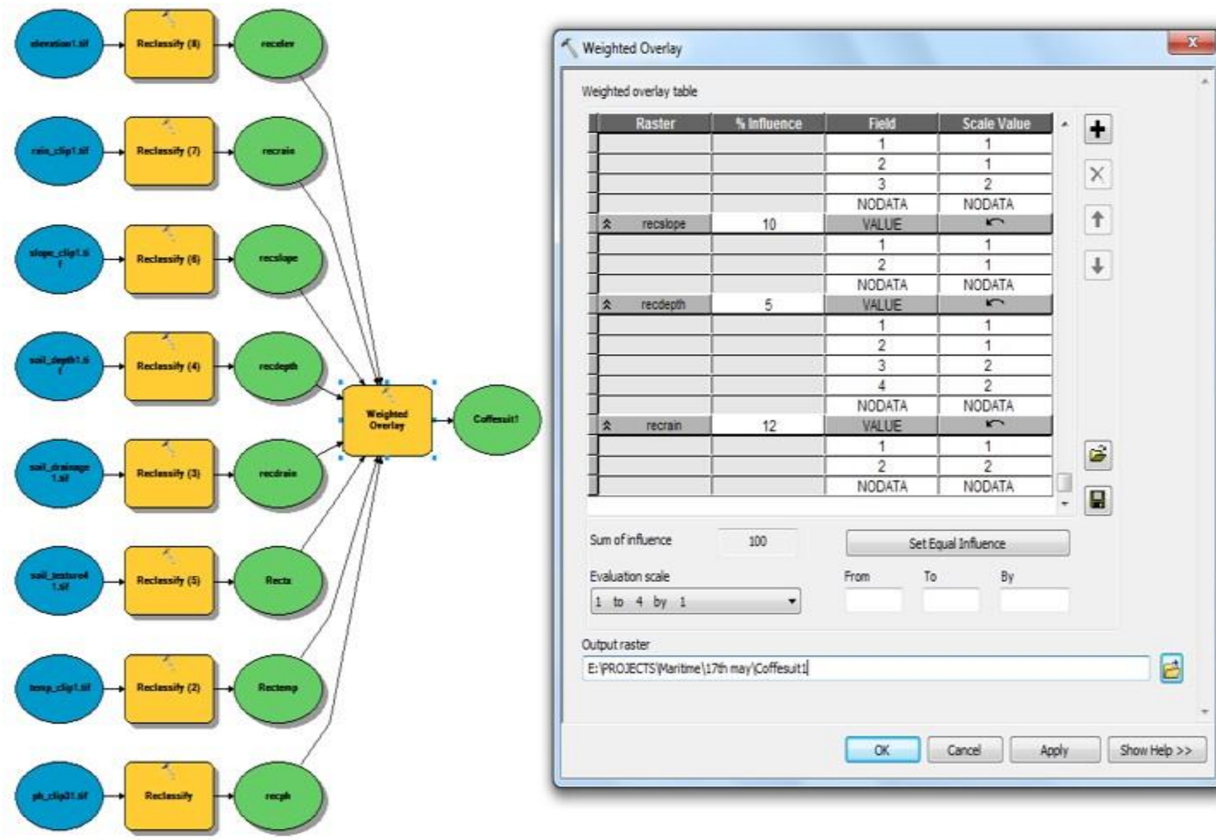

Figure 4-20: Model in action

4.3.1 PRELIMINARY SUITABILITY MAP

This is the suitability map generated from the weighted overlay of eight sub-criteria so far discussed. It is the first product realized before the actual coffee suitability map is generated. The final map product will be obtained from integrating the preliminary map with some LULC classes. Therefore, the preliminary suitability map generated by the model is as shown in the Figure 4-21.

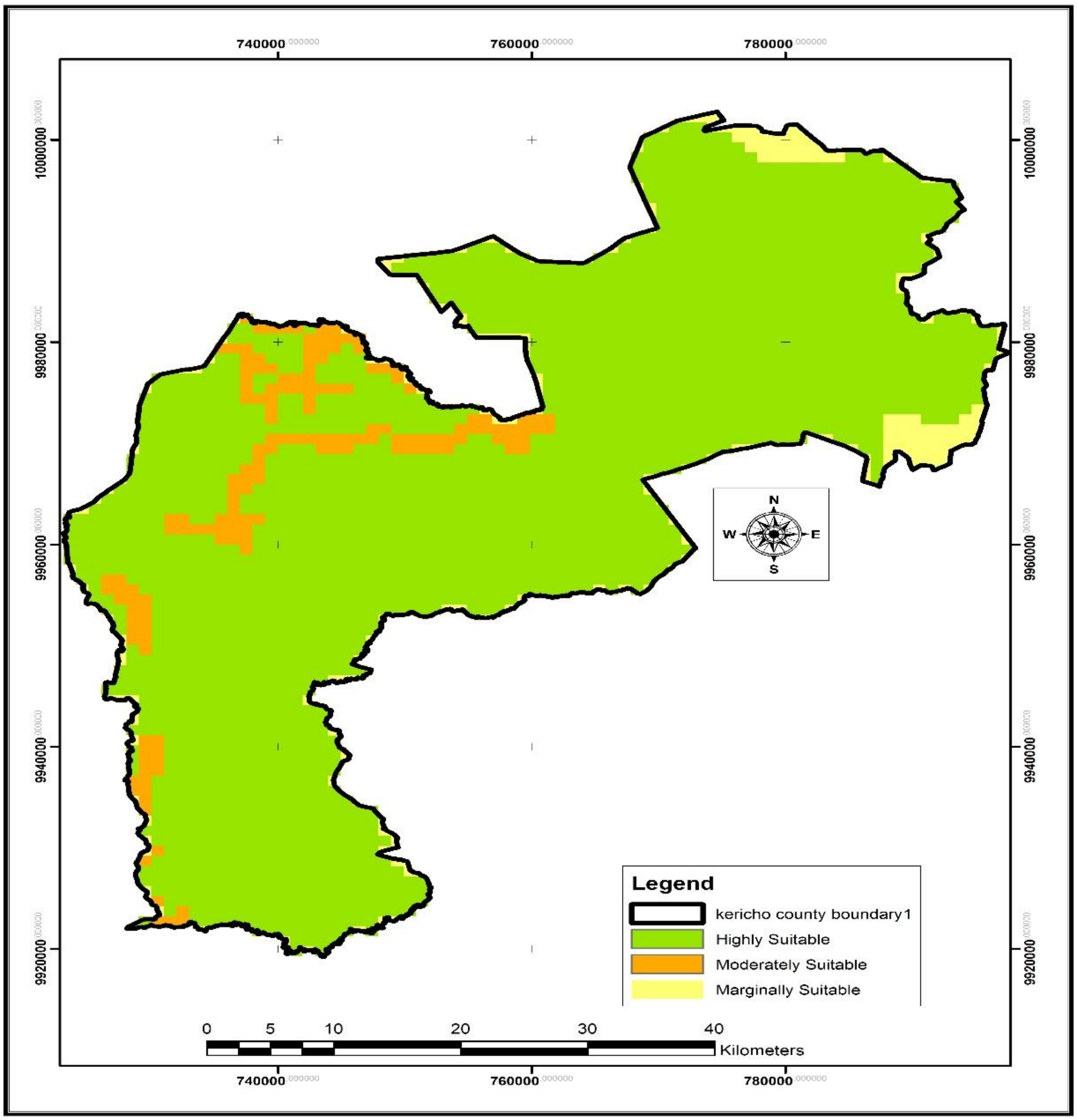

Figure 4-21: Preliminary Coffee suitability Map

4.4 LAND USE / LAND COVER (LULC)

The land use and land cover exploration was done using Landsat 8 satellite image covering the whole county. The image was already georeferenced and thus clipping was done in ArcGIS 10.2 software platform using the County boundary map. Image enhancement, where the different bands in the image were evaluated with a view of choosing the best combination which could be used to effectively distinguish different features. The infrared band, together with the red band were used. The LULC map generated was as shown in Figure 4-22.

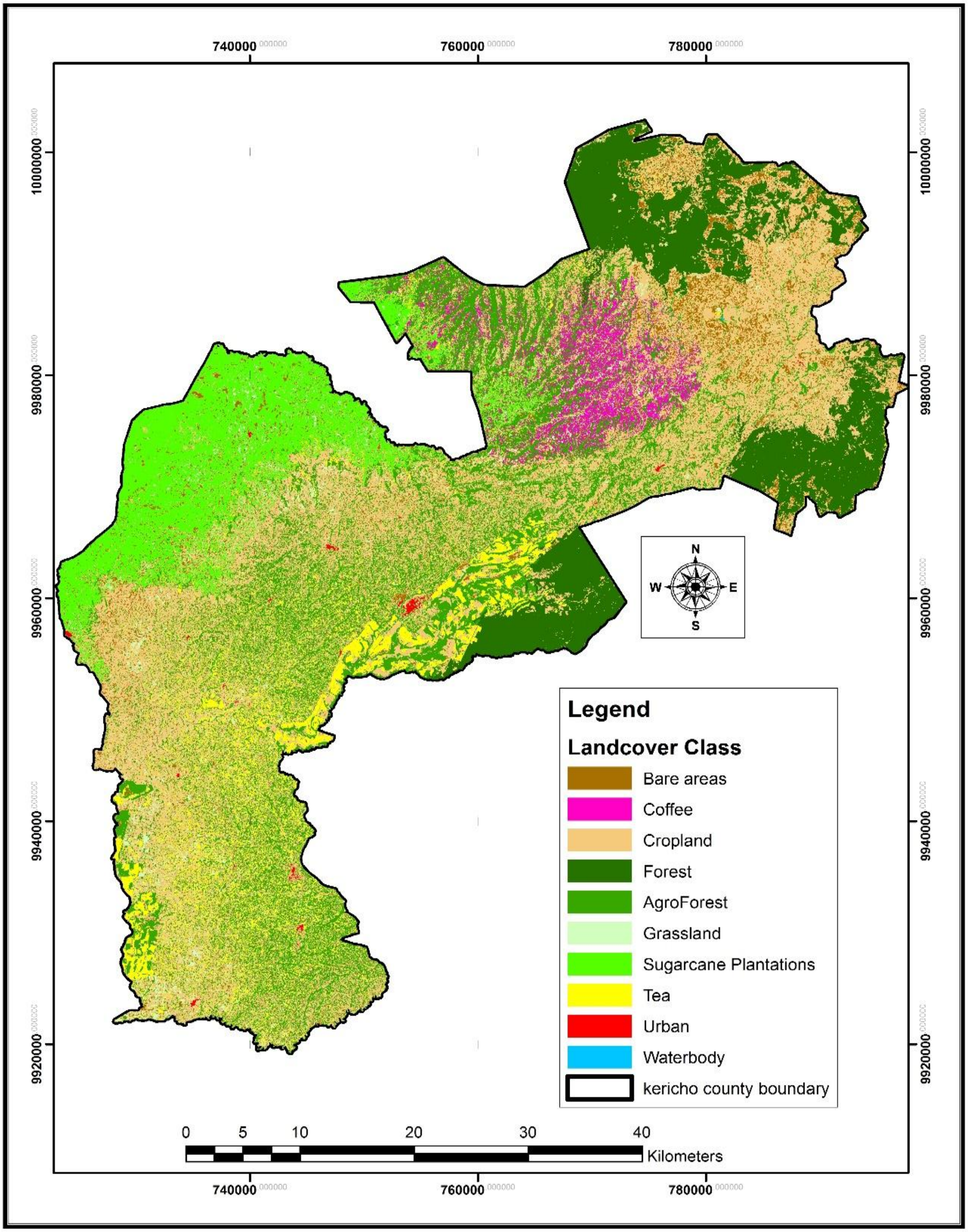

Figure 4-22: Land Use Land Cover map

4.4 COFFEE SUITABILITY MAP

Integration of preliminary coffee suitability map and LULC gave the final Coffee suitability map. A few land cover classes were selected and overlaid with the preliminary coffee suitability map. The land cover classes considered are: Urban class, Forest (protected area), water body and existing coffee farms. The end product was potential areas or areas where coffee farming can be extended. This resulted in a coffee suitability map as shown in the Figure 4-23.

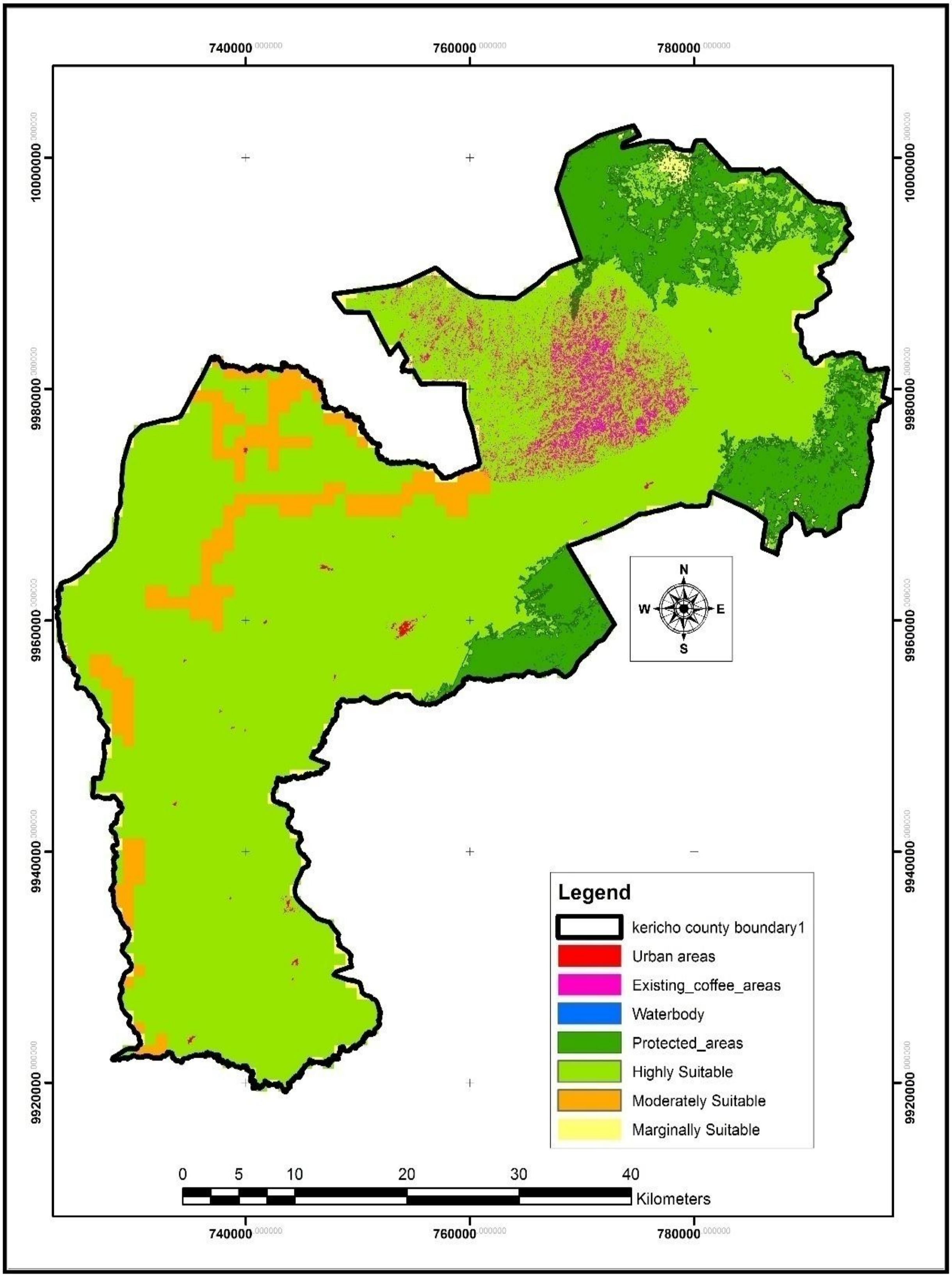

Figure 4-23: Coffee Suitability Map

4.5.1 ECONOMIC ANALYSIS

From the coffee suitability map, the potential area for coffee growing is as follows:

Table 4-1: Potential area for coffee from coffee suitability map

Land Cover Class	Area (In Hectares)
Bare areas	10, 946
Coffee	7, 591
Cropland	93, 101
Grassland	7, 719
Sugarcane plantations	28, 621
Tea	19, 143
Urban	346
Water body	4.75
Forest	33, 737
Agro-Forest	57, 026
Total area	258, 434
Others	651
Area of County	259, 086

From the above findings, it implies that the total area available for coffee farming is about 224, 998 hectares.

For the purposes of this study, if an acre of coffee is considered for its production and eventual income generation to a farmer, references from experts and information gathered from farmers through oral interviews, 980 plants of coffee can be planted. It is also obtained from the interviews that a mature coffee tree can produce cherries of about 15 kilograms per annum.

It means that a total of 14700 kilograms of ripe cherry is realized in one acre.

A farmer normally earns an average of Kenya shillings forty per kilogram of coffee. The farmer gets a gross income of Kenya shillings 588,000. Considering the expenditure, right from labour to farm inputs, the farmer normally spends Kenya shillings 70, 000. This means that the amount to be known as the net income for the farmer is Kenya shillings 518,000.

Assumptions: All roads in the county do not significantly affect the total area available for coffee growing. Also, all farmers cultivate coffee and their homesteads do not take

significant amount of land for the crop. Weather conditions favour the crop all through the year.
From the assumptions made expected per capita income for the population in Kericho County can be computed as about 224998 hectares divided by the total population of about 752396 people. This gives per capita income of Kenya shillings 364,400.

Although the study was about coffee, a very low return will be realized by planting tea. It will go to a level of Kenya shillings 231,000 per acre of tea. This means that the per capita income will be approximately Kenya shillings 170,200 (KTDA, 2013).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From results emanating from this study, it shows that all the intended objectives during the onset of the project have been met. Geographical Information System (GIS) and Multi-Criteria Analysis (MCA) methods have been used to interrogate and verify the conditions which favour growing of coffee in Kericho County. A relevant suitability model was designed and the results from model were obtained with a lot appreciation.

The final product initially anticipated from the study, which is coffee suitability map for Kericho County, has now become a reality by itself. It is therefore the right moment to state that all the set objectives of the study were met. Justification of the study was also strengthened by doing some economic analysis with an assumption that if all farmers embrace coffee growing, high per capita income is expected compared to the popular attitude of taking tea as the main cash crop.

From the comparison of per capita income for coffee and tea, it shows that farmers can get much income from coffee than tea.

5.2 RECOMMENDATIONS

From this research study, it is therefore recommended that:

- Geospatial techniques and Multi-Criteria Evaluation methods should be embraced by the County if at all a meaningful and economic utilization of land, as a resource, is to be realized.
- Land suitability analysis should be considered as a necessity in any agricultural venture. Hence, the County Government should encourage this scientific approach to avoid haphazard and loss-generating agricultural activities. This is because farmers will avoid unnecessary losses before they engage in any farming activity.
- Land suitability analysis must be entrenched into the county master plan so as to guide all activities anticipated in the future. It will also mean that human resource with the capability of doing the analysis becomes a significant consideration for the county government.

- The county needs to know that tea is not out rightly the best cash crop suitable for the area. Hence by embracing these technology it is possible to carry out research on which other crops suit where in the county.
- Land suitability analysis using the named approach is not by itself capable of bringing good income to the farmers. Instead, it should be supported by subsidizing farm input prices and financing intensive research in good quality seeds of crops such as coffee as well as modern farming methods.
- Agricultural extension activities should be given priority so that farmers in the grassroots can be enlightened on the rapid change in technology and introduction of GIS as a tool which assist in decision making.
- Coffee growing should be encouraged in the County so that farmers may get better income.

REFERENCES

1. Amine, M. E., Pailhes, J., & Perry, N. (2014). **Critical Review of Multi-criteria Decision Aid Methods in Conceptual Design Phases: Application to the Development of a Solar Collector Structure**. *Procedia CIRP*, *21*, 497–502. http://doi.org/10.1016/j.procir.2014.03.134.

2. Bushan, N. and Rai, K. (2004). ***Strategic Decision-making Applying the Analytic Hierarchy Process***.

3. Cabala, P. (2010). **Using the analytic hierarchy process in evaluating decision alternatives**.

4. Cook, Malcolm, Noyes, Jan, Masakowski, & Yvonne. (2007). ***Decision Making in Complex Environments*****.** Abingdon, Oxon, GBR: Ashgate Publishing Group. Retrieved from http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10211174

5. Daengdej, J., Lukpse, D., Tsui, E., Beinat, P., & Prophet, L. (1997). Combining case-based reasoning and statistical method for proposing solution in RICAD. Knowledge Based Systems: 10, 153-159.

6. Damatta , F. M., & Ramalho, J. D. C. (2006). ***Impacts of drought and temperature stress on coffee physiology and production***: a review, 18(1), 55-81.

7. FAO, (1976). LAND USE, LAND COVER AND SOIL SCIENCES - Vol. II -The FAO Guidelines for Land Evaluation

8. FAO. (1976). ***A framework for Land Evaluation*** **(**Vol. FAO Soils bulletin 32). Retrieved from http://www.fao.org/docrep/x5310e/x5310e00.htm

9. Fishburn, (1967). **Stochastic Models in Operations Research**: Stochastic optimization.

10. H. Lempke, 2000. **Extension Manual**

11. Kimemia, J.K., (2013). **Coffee Production In Kenya**. Coffee Research Foundation Kenya. Retrieved from http://www.crf.co.ke/.

12. Kościelniak, H., & Puto, A. (2015). **BIG DATA in Decision Making Processes of Enterprises**. *Procedia Computer Science*, *65*, 1052–1058.

13. Kuit, M., Jansen, D. M., & Van Thiet, N. (2004). ***Coffee handbook: Manual for Arabica cultivation***. Retrieved from https://bootcoffee.com/wp-content/uploads/2015/04/manual-for-arabica-cultivation-vs.pdf

14. KTDA (2013). Kenya Tea Development Agenda Ltd., http://www.ktdateas.com.

15. Michiel Kuit, Nguyen Van Thiet & Don Jansen Khe Sanh, (2004); **PPP Project "Improvement of Coffee Quality and sustainability of coffee Production in Vietnam". Manual for Arabica Cultivation.**

16. Mishra, (2015). Identification of suitable sites for organic farming using AHP & GIS. Retrieved from http://www.sciencedirect.com/science/article/pii/S1110982315000289. Procedia Computer Science.55:1123-1132.

17. Pearson et al., (2005). Kahawa. Kenya's Black Gold.

18. Promentilla et al., (2006). **Evaluation of remedial countermeasures using the analytic network process.** Waste manage 26: 1410-1421.

19. Randal Greene, (2011). **GIS-Based Multiple-Criteria Decision Analysis**

20. Russo F.S.M., Camanho R. (2015). Criteria in AHP: a systematic review of literature.

21. Saaty, T.L., (1980). **The Analytic Hierarchy Process**. McGraw-Hill, New York.

22. Saaty, T.L., (2008). **Decision making with the analytic hierarchy process**. Int. J. Services Sciences, Vol. 1, No. 1, 2008.

23. Saaty, T. L. (1990). **How to make a decision: The analytic hierarchy process**. *European Journal of Operational Research*, *48*(1), 9–26. http://doi.org/10.1016/0377-2217 (90) 90057-I.

24. Sharma, A. (2009). ***Quantitative Techniques for Decision Making***. Mumbai, IND: Himalaya Publishing House. Retrieved from http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10415943.

25. Shisanya et al., (2007). Farm Management Handbook of Kenya, Vol.II. Natural Conditions and Farm Management Information, 2nd Edition. Retrieved from http://www.kenya.soilhealthconsortia.org>handbooks.