GIS BASED MULTI-CRITERIA ANALYSIS FOR IDENTIFICATION OF SUITABLE AREAS FOR GREEN GRAM PRODUCTION: A CASE STUDY OF KITUI COUNTY, KENYA

MUGO JANE WANGUI (BSc. Hons)

(I01/MAI/20479/2014)

A ThesisSubmitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science (Agrometeorology) in the Institute of Mining and Mineral Processing, South Eastern Kenya University

2017

DECLARATION

Iunderstand that plagiarism is an offence and therefore declare that this thesis is my original work and has not been presented to any other insititution for any other award.

Signature …………………….. Date…………………….

Mugo Jane Wangui

I101/MAI/20479/2014

This research thesis has been submitted for examination with our approval as University Supervisors

Signature …………………….. Date…………………….

Dr. David K. Musembi

Department of Meteorology, South Eastern Kenya University.

Signature …………………….. Date…………………….

Dr. Patrick C. Kariuki

Department of Geological Sciences, South Eastern Kenya University.

DEDICATION

This thesis is dedicated to my dear mother Susan Wangui, my siblings Nahashon Thuo, Judy Muthoni and Gibson Ireri and to all my friends for their support in my studies.

ACKNOWLEDGEMENT

I would like to acknowledge the support given by South Eastern Kenya University during the research for this work and for giving me an opportunity to further my education. To both my supervisors Dr. D.K Musembi and Dr. P. Kariuki who worked with me tirelessly to ensure the completion of this study, your support, guidance and inspiration is highly appreciated. To all members of the Institute of Mining and Mineral processing who read my work and helped in improving its quality.

Special thanks go toresearchers in KALRO, SASOL and ASDSP who provided expert opinion that helped improve the quality of the work andto all SCALDOs who provided information for the validation of this work.

Most importantly, I would like to acknowledge the Almighty God. “Trust in God with all your heart and lean not your own understanding; in all your ways submit to Him, and He will make your paths straight” (Proverbs 3:5-6)

Table of contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

AHP	Analytic Hierarchy Process
ASDSP	Agricultural Sector Development Programme
BC	Before Christ
^{0}C	Degree Celsius
CEC	Cation Exchange Capacity
DPP	Directorate of Plant Production
DRASTIC	Depth to water, net Recharge, Aquifer media, Soil media, Topography,vadose Zone, Conductivity
FAHP	Fuzzy Analytical Hierarchy Process
FAO	Food and Agriculture Organization
GIS	Geographic Information System
Ha	Hectares
ILRI	International Livestock Research Institute
KDFP	Kenya Dryland Farming Project
KES	Kenya shilling
Kg	Kilogram
Km^2	Kilometer squared
LE	Land Evaluation
LM	Lower Midland
LM 3	Cotton Zone
LM 4	Marginal Cotton Zone
LM5	Livestock-Millet Zone
LM6	Lower MidlandRanching Zone
L5	Lowland. Livestock-Millet Zone
L6	LowlandRanching Zone
LSA	Land Suitability Analysis
M	Meters
MAM	March, April, May (Long rains)
MCE	Multi-Criteria Evaluation

MCDM	Multi-Criteria Decision Making
MCDA	Multi-Criteria Decision Analysis
Mm	Millimeters
MT	Mega Tones
NGO	Non-Governmental Organization
OM	Organic Matter
pH	Power Hydrogen
RoK	Republic of Kenya
SASOL	Sahelian Solution Foundation
SCALDOs	Sub County Agriculture and Livestock Development Officers
SMCA	Spatial Multi-Criteria Analysis
SMCDM	Spatial Multi-Criteria Decision Making
OND	October, November, December (Short rains)
UM	Upper Midland
UM 3-4	Transit Marginal Coffee Zone
UM 4	Sunflower-Maize zone
USGS	United States Geological Survey

DEFINITION OF TERMS

Geographic Information System (GIS): is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data

Land Suitability Analysis (LSA): a GIS-based process is applied to determine the Suitability of a specific area for contemplated use, that is, it discloses the suitability of an area regarding its inherent characteristics (suitable or unsuitable) (Jafari and Zaredar, 2010).

Multi-Criteria Decision Making (MCDM):Is a process that generally aims at assisting the decision maker in choosing the best alternative from a number of reasonable choice options under the presence of multiple choice criteria and diverse criteria priorities (Jankowski, 1995).

Biophysical factors: is the biotic and abiotic surrounding of Green gram, that is the factors that have an influence in its survival, development and evolution.

ABSTRACT

Green gram(*Vigna radiataL.*) has recently become an important crop in Kitui County because of its high economic returns and short growing season.The main objective of this study was therefore to develop a GIS-based Multi-criteria analysis for Green gram production in Kitui County using Geographic Information Sytem (GIS) based multi-criteria evaluation. Three main criteria were selected for analysis (soil, climate and topography) and 8 sub criteria (soil texture, soil depth, soil pH, soil cation exchange capacity, soil drainage, rainfall, temperature and slope). The criteria and subcriteria were selected based on discussions with crop experts and the information available about Green gram requirements from literature. The sub criteria maps were reclassified into 4 suitability levels:Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3) and Not Suitable(N) based on Food and Agriculture Organisation(FAO) guidelines. The Analytic Hierarchy Process (AHP) decision making tool was used to determine the perceived weights or influence that each criteria and subcriteria carries. The weights were then used as inputs in the weighted overlay and final maps generated. Based on the findings, all the land in Kitui County is suitable for Green gram production in March, April, May (MAM) season with varying degrees of suitability where 4.6% as highly, 54.7% as moderately and 40.7% as marginally suitable. All land is also suitable in October, November and December (OND) with 66.2% being highly suitable and 33.8% moderately suitable. Major limitations that prevent all land from being highly suitable include low rainfall during MAM season, highly acidic and alkaline soils, very poor drainage and steep slopes. Due to the higher potential in OND the County Government should adequately prepare to ensure they maximize on the good environmental conditions for Green gram production.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

The agricultural sector is the largest consumer of weather and climate information. Solar radiation, precipitation and temperature are the main factors affecting crop growth; therefore productive agriculture is highly dependent on the climatic patterns of a region (Hossain, 2010). Most regions in Kenya, including Kitui County, rely heavily on rain-fed agriculture.

The CountyGovernment of Kitui has shown a lot of interest in Green gram(*Vigna radiate L*.) and has been promoting it to farmers as one of the most suitable and profitable legumes for the County. Sahelian Solution Foundation (SASOL Foundation), a local Non-Governmental Organization (NGO), has been encouraging Green gram farming within the framework of enhancing food security with the Kenya Dryland Farming Project (KDFP). This project targeted to reach 1500 farmers in Kitui Rural and Kitui South sub counties in the year 2014 (SASOL, 2015). Farm Africa is also working with 7,000 farming households in the Mwingi and Kitui districts to better their incomes by cultivating drought-tolerant, commercially-attractive sorghum and Green gram crops (Farm Africa, 2016). The prioritized value chains in the County include indigenous chicken, Gadam sorghum (*Sorghum bicolor*) and Green gram with the CountyGovernment aiming to increase production of these commodities (ASDSP, 2016).

Land Suitability Analysis (LSA), a GIS-based process is applied to determine the Suitability of a specific area for contemplated use, that is, it discloses the suitability of an area regarding its inherent characteristics (suitable or unsuitable) (Jafari and Zaredar, 2010). The Spatial Analytical Hierarchy (SAH) method which was introduced by Saaty in the mid-1970s and developed in 1980s is among the best methods which are suitable for carrying out land suitability analysis (Jafari and Zaredar 2010). Among the various

Mulit-Criteria Evaluation (MCE) techniques, the Analytical Hierarchy Process (AHP) is a well-known multi-criteria technique that has been integrated into GIS-based land suitability procedures to obtain the required weightings for different criteria. GIS-based AHP has become popular in research because of its capacity to integrate a large quantity of heterogeneous data, and obtaining the required weights for analysis can be relatively straightforward, even for a large number of criteria (Feizizadeh *et al*.,2014).

There have been a lot of researches carried out by scientists around the world using GIS-based MCE approach. However in Kenya, the method of Green gram suitability analysis has not been done yet. Mustafa *et al*., (2011) in their research of land suitability inspection for different crops using MCE approach, remote sensing, and GIS, came to the conclusion that AHP is a useful system to determine the weights. Kihoro *et al*., (2013) using a MCE and GIS approach developed a suitability map for rice in the great Mwea region in Kenya. Other studies using this approach include; Boitt *et al*., (2015) who generated a crop suitability map showing areas suitable for agriculture in the Taita Hills in Kenya and land suitability analysis for potatoes in Nyandarua County (Kamau*et al*., 2015).

1.2 Statement of the problem

Agriculture plays an important role in Kitui County in terms of food provision, employment creation and also as a source of income for domestic needs. The County's population stood at 1,012,709 in the 2009 census and was expected to grow to 1,077,860 in 2012 (RoK, 2009; ASDSP, 2016). As the population continues to grow so will the demand for food in the County (ASDSP, 2016). Absolute poverty in the County holds at 63.8% (n=648,108) or 0.55% of the national absolute poverty. Further, Kitui is food insecure with food poverty rate (the inability to afford or have satisfactory access to food which can provide a healthy diet) reported at 55.5% (n=598,212) (ASDSP, 2016).

Green gram is one of the potential food/cash crops that have been observed to perform well in the arid regions of Kenya and most parts of Kitui County are favorable for growing them (SASOL, 2015).The CountyGovernment has prioritized three value chains for expansion which are indigenous chicken, Gadam sorghum and Green gram(ASDSP, 2016). However, there has been no spatial analysis combining the various biophysical factors that affect Green gram production. Spatial analysis is the most recent form of crop suitability analysis and can help in identifying the most suitable areas for growing Green gram.

Most suitable areas should be indentified so as to allow the Government adequately plan before planting green gram since they will know before hand some of the challenges they are likey to come across and plan to mitigate them. Table 1.1 shows that the amount of Green gram produced in the area, despite being lower than maize, still has the greatest value in Kenya shillings of all the crops in the County. Could it be that the area under Green gram in Kitui is low and can it be increased?

Table 1.1: Crop production in Kitui County

Crop	**Unit(Kg bag)**	**Total crop production in Kgs**	**%Total crop production**	**Value(Kshs Million)**	**%Value**
Maize	90	629,493	33	1473.64	19.8
Beans	90	156,993	8	736.77	9.9
Sorghum	90	227,005	12	521.66	7.0
Millet	90	23,144	1	64.8	0.9
Cow peas	90	339,744	18	1545.84	20.8
Green gram	90	296,267	15	1796.27	24.2
Pigeon peas	90	205,660	11	556.52	7.5
Sweet potatoes	140	5,099	0	11.22	0.2
Cassava	140	19,890	1	41.77	0.6
Horticulture	MT	33,115.10	2	680.39	9.2
Total		1,936,410	100	7,428.87	100.0

Source: Economic Review of Agriculture (ERA) 2013

1.3 Justification

Table 1.1 shows that Green gram accounted for 15% of the total crop production in the County compared to maize which took up 33% of the totalcrop production. However Green gram accounted for 24.2% of the revenue generated through crop farming as compared to maize which accounted for 19.8%. Green gram is therefore a potential food cash crop which if well managed can be a major source of income for many in Kitui County. This is in line with Sustainable Development Goals number 1 which aims at ending poverty in all its forms globally (UN, 2015).

For Green gramto be profitable for everyone in the value chain, the Government should focus its resources on the agricultural lands that are most productive for the legume. Kihoro *et al*., (2013) indicated that, in order to increase the production of food and enhance food security, crops have to be grown in areas where they are best suited. When crops are grown in the areas best suited they help in realization of Sustainable Development Goals number 2 which aims at ending hunger, achieving food security and improving nutrition and promoting sustainable agriculture (UN, 2015).

Halder (2013), stated that land suitability analysis is a method of land evaluation, which determines the level of appropriateness of land for a certain use. Crop-land suitability analysis is a necessary step to ensuring the maximum use of available land resources so that sustainable agricultural production is practiced (Lupia, 2014; Halder, 2013). GIS in one of the most essential tools for land use suitability mapping and analysis. AHP is one of the fastest developing decision-analysis techniques (Bello *et al.*, 2009; Jafari and Zaredar, 2010).

The use of GIS and spatial analysis in this kind of study is important because it can cover the whole County and different ecological zones at once. It will also make use of varied data (multi-criteria analysis) which will make it possible to compute some statistics (qualitative and quantitative analysis) for evaluation.

The Sustainable Development Goals number 4 is to ensure inclusive and equitable quality education and foster lifelong learning opportunities for all (UN, 2015). The findings of the study will act as guidelines to farmers in selecting suitable conditions for growing Green gram and the CountyGovernment could use the results to advise more farmers in adopting GIS- crop land analysis in agri-business so as to increase food production.

1.4 Main objective

The main objective of this study was to develop a GIS-based Multi-criteria analysis for Green gram production in Kitui County.

1.4.1 The Specific Objectives

The specific objectives of the study are to:

I. Undertake Multi-criteria analysis to weight the key biophysical factors affecting Green gramproduction in Kitui.
II. Assess the spatial variation of the key biophysical factors affecting Green gram.
III. Generate a Green gram suitability map for Kitui County
IV. Validate the Green gram suitability mapto confirm whether or not it reflects what is happening on the ground in Kitui County

1.5 Research questions

The research questions are the following:

I. Which are the key biophysicalfactors affecting Green gram and how will their weights be assigned?
II. Which is the spatial variation of the key biophysical factors affectingGreen gram?
III. Which is the Green gram suitability map for Kitui County?
IV. Does the Green gram suitability map reflect what is actually happening on the ground in Kitui County?

1.6 Limitations

The main aim of the study was to develop a GIS-based Multi-criteria analysis for Green gram production in Kitui County. At a later stage in the analysis it was important to validate whether the Green gram suitability map that was developed reflected what was happening on the ground in Kitui County. Due to lack of sufficient funds the validation exercise was conducted via telephone calls since it was not possible to visit all sub-counties in the County.Many factors affect the success of green grams such as availability of storage facilities, access to markets, price, availability of seeds, fertilizer and population density logistics did not make it possible for these factors to be mapped and added to the Green gram suitability model database.

1.7 Delimitations of the study

This study focused on developing a GIS-based Multi-criteria analysis for Green gram production in Kitui County so as to indentify the most suitable environment and land.The study was confined to one County that is Kitui out of the forty seven Counties in Kenya to serve as a case study. The whole County was involved in the study.

Only researchers in KALRO, SASOL and ASDSP were involved in the study, they provided expert opinion on the key biophysical factors that affect Green gram; SCALDOs provided information for the validation of this work. Other players in the value chain of Green gram such as farmers were not involved although their input also affects the productivity of Green gram in the County. Researchers in KALRO, SASOL and ASDSP were involved in the study because their decisionsaffect Green gram production in the whole County. Farmers were not involved because their influence is more on a small scale as compared to the key decision makers who make choices that affect the whole County.

CHAPTERTWO

2.0 LITERATURE REVIEW

2.1 Land suitability evaluation

Land suitability evaluation is the assessment or prediction of land quality for a specific use in terms of its productivity, degradation hazards and management requirements (Bunruamkaew and Murayam, 2011).Land suitability can also be described as the ability of a portion of land to tolerate the production of crops in a sustainable manner. The analysis allows identification of the main factors that limit production in a cropping system and equips decision makers with the information needed to develop a crop management system that will increase the productivity of their land (Halder, 2013). Land suitability evaluation is a necessity for sustainable agricultural production. Land suitability is a process of evaluating different criteria ranging from terrain, soil to socio-economic, market and infrastructure for the suitability of a certain land use (Prakash, 2003).FAO (1976) describes land suitability as the fitness or competence of a given type of land for a defined use. The land can either be considered in its present condition or after being improved on. The process of land suitability classification entails appraisal and grouping of different sections of land in terms of how suitable they are for a defined use.

The concept of sustainable agriculture involves growing quality products in an environmentally friendly, socially welcomed and economically efficient way that can last a long period of time(Addeo *et al*., 2001). In order to conform to these concepts of sustainable agriculture, crops need to be grown where they are best suited and land suitability assessment is the first step towards achieving this (Ahamed *et al*., 2000). Social economic, abiotic and biotic factors decide the success of a crop;so evaluation regarding crop value should take into consideration these factors that determine its profitability (Prakash, 2003).Ahamed *et al.,* (2000) recommended the use of suitability ratings i.e. from highly suitable to not suitable for crops based on the climatic, soil and terrain data of the area.

Land suitability Orders show whether the land being assessed is suitable or not suitable for the purposeunder thought. There are two orders displayed in maps or tables using the symbols S (Suitable) and N (Not suitable) (FAO, 1976).Land suitability Classes reflect degrees of suitability. The classes are numbered in Arabic numbers attached to the Order in decreasing levels of suitability. Within the Order Suitable (S), the number of classes is not specified. However, the number of classes placed is kept to the minimum needed to meet the aims of the analysis; ideallyfive classesshould be the most used (FAO, 1976). Table 2.1 shows a description of the suitability classes.

Table 2.1: Land Suitability classification structure

Order	Class	Description
S	S1	Land that has no significant limitations to the continued application of a given use, or only minor limitations that will not remarkably reduce productivity and benefits and will not raise inputs above a level that's acceptable.
	S2	Land having limitations which in total are moderately severe for continued application of a given use; the limitations will thus lower the productivity or benefits and increase the inputs required to the level that the final advantage to be obtained from the use, although still attractive, will be considerably lower to that expected on Class S1 land.
	S3	Land having limitations which in total are severe for continued application of a given use and will so lower productivity and benefits, or increase required inputs, such that this expenditure will be only marginally justifiable.
N	N1	Land having limitations which may be overcome in time but which cannot be rectified with existing knowledge at a currently acceptable cost, the limitations are so acute as to prevent the successful sustained use of the land in the given manner.
	N2	Land that has limitations which seem to be so severe as to surpass any chance of successful sustained use of the land in the given manner

Source: FAO(1976)

There are two types of classifications depending on the scale of suitability measurement, namely qualitative and quantitative (Prakash, 2003). In the qualitative classification, the classes are based mainly on the physical productive capacity of the land, with economics only there as a background. This classification is commonly used in reconnaissance work, aimed at a general appraisal of large areas.

In the quantitative classification, common numerical terms are used to define the classes and comparison between the objectives is possible. Here a considerable amount of economic criteria is used.

2.2 Green gram growing conditions (Botanical Information)

Green gram (*Vigna radiataL.*) or mung bean (Mogotsi, 2006; Swaminathan *et al.*, 2012) is commonly called “ndengu” in Kenya. Green gram is grown for its edible dry seeds and fresh sprouts but can also be used as forage for livestock or as green manure (Oplinger, 1990). It has 3 subgroups: one is cultivated (*Vigna radiata* subsp. *radiata*), and two which are wild (*Vigna radiata* subsp. *glabra* and *Vigna radiata* subsp.*sublobata*) (Mogotsi, 2006).

The Green gram plant reaches a height of 0.15-1.25 m (FAO, 2012; Mogotsi, 2006) and has somewhat hairy leaves, stems, root and pods (FAO, 2012; Mogosti, 2006). Its stems have many branches, sometimes twining at the tips (Mogotsi, 2006) while the leaves are alternate with ovate to elliptical leaflets. It has self-pollinated flowers which first appear near the top of the plant seven to eight weeks after planting and are papillonaceous, greenish or pale yellow in color. The pods which are borne at the top of the plant are long and cylindrical containing seven to twenty small, ellipsoid or globular seeds (FAO, 2012; Mogotsi, 2006; Oplinger, 1990). Depending on the color of the seeds two cultivars can be identified: the yellow Golden gram which has a low seed yield and pods that shatter at maturity and the bright colored Green gram which is more prolific and has pods that are less likely to shatter (Swaminathan *et al.*, 2012).

The Green gram origins can be traced to the Indian subcontinent where it was naturalized as early as 1500 BC. Later on, cultivated Green gram was established in Africa, southern and eastern Asia, America and West Indies. It is currently widespread across the Tropics (Oplinger, 1990; Mogotsi, 2006; Swaminathan *et al.*, 2012).

Green gram are a nutritious source of food with a protein content of 25% (SASOL, 2015), and thus can be consumed as a source of protein in the absence of meat (DPP, 2010). Aside from being consumed by man, it can also be grown for green manure, hay and as a cover crop (SASOL, 2015). In Kitui County, Green gram are grown for sale to the local and export market with good returns in terms of prices ranging from 40 to 100 Ksh per kg. Through value addition the seeds are processed into flour, bread and noodles (Mogosti, 2006).

2.2.1 Climatic requirements

2.2.1.1 Rainfall

Green gram is a drought tolerant plant with rainfall requirement range of between 350-1000mm/annum (SASOL, 2015; Mogosti, 2006; Morton *et a.l*, 1982; DPP, 2010) with 650mm of rainfall as the optimum (Mutua *et al.*, 1990). Heavy rainfall and cool temperatures result in increased vegetative growth with reduced pod setting and development (SASOL, 2015; Mutua *et al.*, 1990). Its water consumptive use ranges from 380 to 510mm per season (Krishna, 2010). Table 2.2 shows an example of the optimal climatic conditions for Green gram used to determine the best areas for Green gram production in the Sumbawa region in Indonesia (Takeshi and Ruth, 2015).

Table 2.2:Land suitability classes for Green gram (based on climatic factors)

Factors	**S1**	**S2**	**S3**	**N**
Average temperature(^{o}C)	12-24	24-27	27-30	>30
		10-12	8-10	<8
Rainfall (mm)	350-600	600-1000	>1000	
		300-350	230-300	<230
Humidity	42-75	36-42	30-36	
		75-90	>90	<30

Source:Takeshi and Ruth (2015)

2.2.1.2Humidity

High humidity and excess rainfall late in the season can cause disease problems and harvest losses caused by delayed pod setting (Mogosti, 2006; Oplinger *et al.*, 1990; DPP, 2010).

2.2.1.3 Temperature

Green gram is a warm season crop and grows in a temperature range of about 20 to 40^{o}C (Morton *et al.*, 1982). It is a short season crop adapted to multiple cropping systems in the drier and warmer climates of the lowland tropics and subtropics. A temperature of 28 to 30^{0}C is optimum for seed germination and plant growth (Mogosti, 2006; Morton *et al.*, 1982; DPP, 2010) and the temperatures should always be above 15^{0}C (Mogosti, 2006; DPP, 2010) during crop growth. Mean temperatures of 20 to 22°C are the minimum for productive growth(Morton *et al.*, 1982)

2.2.1.4 Day length

Green gram isresponsive to daylight length. Short days result in early flowering, while long days result in late flowering (DPP, 2010; Morton *et al.*, 1982). The photoperiod response restricts the latitude at which Green grammay be grown as it is moved north, or south, from the equator, flower initiation is delayed depending on the position of the sun which affects the length of the day. At latitudes above 40 to 45 degrees, flowering occurs late in the season, with fruiting further delayed by low night temperatures. Green gram genotypes will usually flower in photoperiods of 12 to 13 hours but flowering is progressively delayed as the photoperiod is extended. As the photoperiod is lengthened from 12 to 16 hours, flowering in some short-season, early strains may be delayed only a few days, but photoperiod sensitive strains may be delayed as much as 30 to 40 days (Morton *et al.*, 1982).

2.2.2 Soil Requirements

2.2.2.1 Soil texture

Green gram are suitable for most soil textures but prefer fertile, deep, well-drained loams or sandy loams (Mutua *et al.*, 1990; Mogotsi, 2006; Oplinger *et al.*, 1990; Morton *et al.*, 1982). They are well adapted to clayey soils (SASOL, 2015) but do poorly on heavy clay soils with poor drainage (Grealish *et al.*, 2008, Oplinger *et al.*, 1990) and are somewhat tolerant of saline soils (Mogotsi, 2006). Sandy soils require good fertilizer and water supply and organic soils need drainage and raised beds since their water tables occur at or near the soil surface (Grealish *et al.*, 2008).

2.2.2.2 Soil depth

Green gram produces moderately deep roots reaching 1.5m depth. This is required so that it can explore a sizeable soil volume for moisture and nutrients (Krishna, 2010).

2.2.2.3 Soil pH

Green gramis well adapted to a pH range of 5 to 8 (Grealish *et al.*, 2008; Mogotsi, 2006; SASOL, 2015). The performance is best on soils with a pH between 6.2 and 7.2 and plants can show serious iron chlorosis symptoms and micronutrient deficiencies on alkaline soils (Oplinger *et al.*, 1990; Morton *et al.*, 1982). They require slightly acid soil for best growth (Morton *et al.*, 1982).

2.2.2.4 Soil CEC

Soil CEC has an effect on the acidity and nutrient availability of the soil. Generally, soils with a High CEC do not require much liming as compared to those soils with low CEC. However, when high CEC soils become acidic higher lime rates are required to achieve the optimum pH (Moore and Blackwell, 1998).

Soils with CEC greater than 10meq/100g in general experience little Cation leaching making application of N and K fertilizer more realistic during the rainy season. Soils with a low CEC less that 5meq/100g are more likely to develop deficiencies of

Potassium, magnesium and other Cations (CUCE, 2007).A summary of the information on Green gram soil requirements based on texture, depth, pH and CEC is presented in Table 2.3.

Table 2.3: Soil requirements for Green gram

Factor	**S1**	**S2**	**S3**	**N**
Soil pH	6.2-7.2	5-6.2	7.2-8	>8 <5
Drainage	Well drained	Imperfect	Poorly	Very poor
Texture	Loam Sandy Loam	Clayey-Sandy Silt Clay	Very clayey Extremely sandy	-
Depth	>50cm	50-30cm	<30cm	-
CEC	>10	10-5	<5	-

2.2.3 Altitude and topography requirements

Green gram performs best at an altitude of 0-1600m above sea level (SASOL, 2015) and not exceeding 2,000 m elevation (SASOL, 2015; Krishna, 2010).

Grealish *et al.*, (2008) in a study conducted in Australia on the soils and land suitability of the agricultural development areas report that Green gram ishighly suitable at a slope of 0-10%, moderately suitable at 11-20%, marginally suitable at 21 to 35% and not suitable at slope above that percentage. This information is summarized in Table 2.4.

Table 2.4: Altitude and topography requirements for Green gram

Factor	**S1**	**S2**	**S3**	**N**
Altitude	0-1600m	1600-2000m	-	>2000m
Slope	0-10%	11-20%	21-35	>35%

2.3 Spatial multi-criteria decision making concept

Multi-Criteria Decision Making (MCDM)generally aims at assisting the decision maker in choosing the best alternative from a number of reasonable choice options under the presence of multiple choice criteria and diverse criteria priorities (Jankowski, 1995). Spatial multi-criteria decision making (SMCDM) adds the spatial aspect to the decision making process so that the entire analysis requires: (1) A GIS component (e.g. data capture, storage, manipulation, management and analysis capability); and (2) the MCDM analysis component (e.g. grouping of spatial data and decision makers' preferences into discrete decision choices) (Jankowski, 1995).

The aim of integrating Geographical Information Systems (GIS) with Multi criteria decision making analysis (MCDA) is to provide more open and accurate decisions to the decision makers so as to assess the effective factors. Furthermore, many decision scenarios or strategies can be produced by changing the criteria in this type of analysis, for some procedures (Mokarram and Aminzadeh, 2010).There are many MCDM techniques that have been developed to dateand the most popular are the compensatory and out ranking methods (Majumder, 2015)

2.3.1 Compensatory method

Compensatory methods are models that allow for systematic evaluation of criteria (Majumder, 2015). They allow "trade-offs" between attributes such that good or attractive attributes can compensate bad or less attractive ones (Majumder, 2015; Xu and Yang, 2001). For example, a vehicle may have a low price and good fuel consumption but slow acceleration. If the price of the vehicle is sufficiently low andit's also fuel efficient, the buyer may prefer it over a one with better acceleration that costs more and uses more fuel (Majumder, 2015). Non-compensatory methods do not allow tradeoffs between attributes. An unfavorable property in one attribute cannot be balanced by a favorable value in other attributes (Xu and Yang, 2001).There are many MCDM tools under the compensatory method but popular methods include the AHP, TOPSIS, and FLDM (Majumder, 2015).

2.3.1.2 Analytic Hierarchy Process (AHP)

The method was introduced by Saaty (1977)and is constructed of different hierarchy levels. It places the goal on the top, the criteria in the middle and alternatives at the bottom. The input of experts is a pair-wise comparison of the criteria values, which multiplied by the performances of the alternatives will result in the choice of the best scoring solution (Tisza, 2014).It has been used around the world in many fields such as Government, business, industry, healthcare, and education (Majumder, 2015). This method was chosen for the MCDA part of this study, therefore it is described more in details in the methodology.

2.3.1.3 The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) decision-making tool was developed by Yoon and Hwang in 1981 (Dadfar, 2014). According to this method, the best alternative is the one having the closest proximity to the ideal or positive solution as well as furthest from the worst alternative or negative ideal solution. The best alternative is rated as 1 while the worst has a rank approaching 0 (Xu and Yang, 2001; Dadfar, 2014; Tisza, 2014).The method can quickly identify the best alternative and requires limited input from the decision maker thus reducing the subjective part to defining the weights by which performances will be multiplied (Tisza, 2014).

2.3.1.4 Fuzzy Logic Decision Making (FLDM)

FLDM is a form of many-valued logic that is designed to deal with uncertainties.Methods derived from the theory are very useful to deal with non-statistical, qualitative or unquantifiable information (Tisza, 2014). It is based on approximate (Inexact) thinking rather than fixed and exact opinions (Prakash, 2003; Majumder, 2015). Boolean logic involves visualizing the results as either “0s and 1s”, “Yes or No”, “True and False” and “On and off”. Fuzzy logic parameters can have a truth value that varied between 0 and 1 (Majumder, 2015). Examples of FLDMs include the Fuzzy weighted-product model, Fuzzy weighted sum Model, Fuzzy AHP, Revised Fuzzy and Fuzzy TOPSIS although none of the methods are perfect the revised fuzzy AHP is considered the best among them (Prakash, 2003).

2.3.2 Outranking Methods

Outranking Methods (OMs) were first developed in France in the late sixties. As such a large part of the literature available is written in French which has limited their discussion internationally (Bouyssou, 2008). Two popular OMS include the ELECTRE III and PROMETHEE II, they represent ‘the European school’ of MCDM, rather than ‘the American school’, represented by methods such as the AHP method (Kangas *et al*., 2001).

Outranking shows the level of superiority of one alternative over another (Kangas *et al*., 2001). One choice is said to outrank another if it outperforms the other on adequate criteria of sufficient significance and is not outperformed by the other option in the sense of showing a significantly inferior performance on any one criterion (Majumder, 2015). The advantage of OMS is its ability to deal with ordinal and roughly descriptive information on the different strategies to be evaluated. The difficult interpretation of the results, on the other hand, is the main pitfall of the outranking methods. Outranking methods can be a good method for tackling complicated choice issues with multiple criteria and participants (Kangas *et al*., 2001).

2.4 Past studies and methods used

Several studies have been conducted using multi-criteria evaluation methods in different places.

Maddahi *et al*., (2014) evaluated land suitability for the cultivation of rice, in Amol District, Iran. Multi-criteria decision making (MCDM) was integrated with GIS and used to assess the suitable areas for growing this crop. Several biophysical, environmental and economic parameters were selected for the study based on the FAO framework and expert opinions. AHP was used to rate the various criteria and the weights obtained used to build the various suitability map layers. The result was a map showing the most suitable areasfor growing rice. They observed that the spatial analytical hierarchy process was a powerful support system in their analysis.

Chatterjee and Mukherjee (2013) studied and quantified the difference in the applications of AHP and fuzzy analytical hierarchy process(FAHP) on the assessment of self-financed private technical institutions in India. They noted some differences in weights obtained through non-fuzzy and fuzzy processes corresponding to some individual sub factors, but in the case of the weights corresponding to the factors and sub factors in aggregate, there was hardly any difference. Furthermore, the study provided empirical evidence on the convergence of the results of AHP and FAHP methods in factor weight generations as well as alternative score generations. This was seen from the SPSS outputs corresponding to the comparative studies. They noted that if pairwise comparisons are made carefully and consistently it can result in equally good outcomes irrespective of whether fuzzy mathematics is embedded with AHP or not.

Halder (2013) Carried out a qualitative evaluation as per the FAO land guidelines to determine land suitability in the Ghatal block of Paschim Medinipur district in West Bengal India, for rice and wheat cultivation based on four pedological variables:soil texture, Nitrogen-Phosphorus-Potassium (NPK) status, soil reaction (pH) and Organic Carbon (OC). The variables were weighted based on expert opinion and overlaid in a GIS environment, a map representing the most suitable areas for rice and wheat was produced.

Mustafa *et al*., (2011) using the land evaluation guidelines by FAO for land suitability analysis assessed the suitability of land in Kheragarah tehsil of Agra northern state of Uttar Pradesh, India to support different crops during summer and winter seasons. Different soil chemical and physical parameters wereevaluated. AHP was the multi criteria decision making process integrated with GIS to generate the land suitability maps for the crops. Results showed the suitability of the land for cultivation of sugarcane, pearl millet, mustard, rice and maize in varying degrees. They concluded that better land use options could be realized in various land units as the normal land analysis systems in the area are affected by limitations of spatial analysis for the suitability of crops.

Chandio *et al*., (2011) identified the optimal locations for public parks in Larkana city of Pakistan. AHP multi-criteria evaluation approach and GIS were integrated and used to calculate composite weights. Three suitability map scenarios were generated using GIS spatial analyst functions. It was concluded that land suitability assessment was an important tool for planning of public facilities and future land use initiatives in Larkana city.

Mokarram and Aminzadeh (2010) carried out a research in Shavur area, Khuzestan province to produce land suitability evaluation maps for Wheat using Fuzzy classification, the model used did not include physical factors. The results from the analysis were then compared to the classification using the standard FAO framework (parametric) for land evaluation which also includes non-physical parameters. Eight soil parameters (soil texture, wetness, Exchangeable Sodium Percentage (ESP), Cation Exchange capacity (CEC), soil depth, pH and Topography) were chosen and maps developed for each with the Inverse Distance Weighting (IDW) model. Using information from literature, AHP was used to weight each of the factors using the pairwise comparison matrix. The coefficient of Kappa was used to compare and choose between the fuzzy theory and the parametric method. They concluded based on the results that the Fuzzy methods presented results that seemed to best correspond with the present environment in the study area.

Jafari and Zaredar (2010) using GIS and analytical hierarchy process as a multi criteria evaluation decision system, determined the most favorable regions for rangeland growth in Taleghan basin. The results showed that the spatial analytical hierarchy process was an important support system for settling different uses of land suitability issues in the basin.

Khoi and Murayama (2010) delineated the suitable cropland areas in the Tam Dao National Park Region, Vietnam by applying a GIS-based multi-criteria evaluation approach. AHP integrated into GIS was applied to evaluate the suitability of agricultural land in the study area for some winter crops: mustard, wheat, sugarcane and barley and summer crops: cotton, rice, cotton, pearl millet maize and sorghum using the relevant soil physical and chemical variables. The results were crop suitability maps for winter and summer crops which were produced using the weighted overlay technique.

Tienwong*et al*. (2009) assessed the land in Kanchanaburi province, Thailand suitability for sugarcane and cassava cultivation. To achieve this objective, MCDM integrated with the FAO framework of 1976 for soil site suitability was used to evaluate the areas suitability for growing the crops. A map showing best sites for sugarcane and cassava crops was generated.

Baniya (2008) carried out a study using the methodology prepared by FAO in 1976 to classify the agricultural land of Kathmandu valley into different suitability classes for vegetable crop cultivation in the area. Spatial and non-spatial data for the analysis were obtained through literature review, fieldwork, and interviews with farmers in the area, specialist's opinions, professional agencies, and the local authorities. Pairwise comparison using AHP was used to rank and weight the sub-criteria and a map generated. They commented that MCE, AHP were an appropriate tool for suitability analysis.

Perveen *et al*., (2007) assessed the suitability of Haripur Upazila, Thakurgaon district of the north-west part in Bangladesh for suitability of rice crop cultivation using a Multi-Criteria Evaluation (MCE) and GIS approach and also compared present land use vs. potential land use. Relevant biophysical variables of soil and topography were considered for suitability analysis and stored in ArcGIS environment where relevant criteria maps were generated. Pairwise Comparison Matrix or the Analytical Hierarchy Process (AHP) was the Multi-Criteria Evaluation (MCE) approach applied for weighting and the suitable areas for cultivation determined. To generate present land use/cover map, ERDAS Imagine 8.7 was used to classify Terra/ASTER satellite image using supervised classification. Finally, they overlaid the land use with the suitability map for rice production to determine similarities and differences between the present and prospective land use. The results showed that most of the rice cultivated in the area is under the marginally suitable class, thus crop yield was substantially affected.

Prakash (2003) research focused on addressing the uncertainty involved in the procedure of land suitability evaluation for agricultural crops. Three approaches were considered: AHP, Ideal Vector Approach (IVA) and Fuzzy AHP. He noted that the process of decision making involves a range of criteria and a good amount of expert knowledge and judgments which influence the outcome greatly. The ability of the three MCDM techniques to model the sensitivity of the decision making process is examined. The MCDMs were applied to determine the suitability for rice cultivation in the Doiwala Block of Dehradun District, Uttaranchal, India. Results showed that the IVA had a tendency to exaggerate the positive ideal values and suppress the negative ideals. AHP produced satisfactory results that were comparable with those of the fuzzy AHP. Fuzzy AHP gave considerable good results and was able to incorporate the uncertainty of the expert's knowledge, opinions, and judgments.

Boitt *et al*., (2015) generated a crop suitability map showing areas suitable for agricultural cultivation in Taita Hills in Kenya. The methods used included the development of elevation models, watershed mapping, climate variability mapping, and soil erosion mapping that incorporated the revised universal soil loss empirical model (RUSSLE) and multi-criteria evaluation analysis. The sum weighted overlay was used to combine slopes, soil erodibility, vegetation index and rainfall in the model. Four classes were generated and mapped out: most suitable, more suitable, less suitable and least suitable. The research showed the most suitable areas for crop production in Taita Hills.

Kamau*et al*., (2015) carried out a study in Nyandarua County, Kenya to identify and delineate the land that can best support potatoes, using GIS-based MCE approach and Remote Sensing. Three suitability criteria i.e. climate (rainfall, temperature), soil (PH, texture, depth, drainage) and topography were evaluated based on the opinions of agronomist experts and FAO guideline for rain fed agriculture. AHP was the MCE technique used to determine the level of importance of each criterion and the resulting weights were used to develop the suitability map/layers using GIS software. Finally, a land suitability map was developed by overlaying these suitability maps with the current land cover map produced from LANDSAT images through supervised classification.

Results show that the area currently under potato farming in Nyandarua is currently low and can be expanded into the highly suitable lands.

Kihoro *et al*., (2013) generated a suitability map for rice crop based on physical and climatic factors affecting its production using a MCE and GIS approach in Kirinyaga, Embu and Mbeere counties in Kenya. For MCE, Pairwise Comparison Matrix or AHP was applied and the suitable areas for the crop were generated and calibrated. Biophysical variables of climate, soil and topography were considered for suitability analysis. The data was stored in a GIS environment and the relevant criteria maps generated. The results showed that the area under rice cultivation in the Counties is currently low and can be expanded.

Chebet (2012) in her study performed an analysis to determine the suitability of the watersheds in Keiyo District. The watersheds were delineated from the 3D data obtained by Shuttle Radar Topography Mission in 2001. It further integrated the slope data to determine areas suitable for certain land uses. A Landsat TM data of 2006 was then assessed for land use within every delineated watershed. Lastly, the slopes map was overlaid with the land use map to determine areas that were being used wrongly. The result was a suitability map that was overlaid with the watershed map to develop a map that indicated how each watershed was being environmentally managed.

Kuria *et al*., (2011) evaluated the Tana delta in Kenya for rice growing suitability using guidelines by FAO for rain-fed agriculture. They selected various criteria of soil texture, salinity and sodicity which were obtained from the Kenya soil survey maps and Landsat TM data used to generate landforms of the area. Weighted overlay based on the importance of each of the parameters and a land suitability rating model developed using the model builder in ArcGIS. A rice suitability map showing four classes: most suitable, suitable, less suitable and unsuitable was generated.

Gachari *et al*., (2011) used geospatial technologies to identify and map groundwater potential zones in Kitui County Kenya using climate, geological and geophysical data. These datasets were weighted accordingly in a modified DRASTIC model overlay scheme. Land-cover data was obtained from LANDSAT satellite imagery classification, with lineament density derived from the same satellite products. A groundwater potential zones map was produced which showed that the central and eastern regions of Kitui district were the most suitable for groundwater exploitation.

2.5 Why analytic hierarchy process

Multi-criteria decision processes inherently have subjective factors and the choice of method strongly depends on of the nature of the problem - all sets of criteria can be accepted or criticized depending on the stakeholder and the situation. Therefore, there is no perfect method (Tisza, 2014). A fuzzy logic can be able to replace almost any control system. This may not be necessary in many places however it makes the design of complicated cases simpler. Fuzzy logic is not the answer to everything and must be used when it is necessary to provide better control. If a simple closed loop is sufficient then there is no need to use a fuzzy controller (Majumder, 2015).

Many of the GIS-based land suitability evaluation methods that are recently developed, such as Boolean overlay and modelling for land suitability evaluation do not have a well-defined mechanism for factoring the decision-maker's preferences into the GIS analysis (Malczewski, 2006). The combination of Spatial AHP method with GIS is a new trend in land suitability analysis (Jafari and Zaredar, 2010). Mendoza (2000) identified five benefits of the Analytic Hierarchy Process (AHP) over other land suitability analysis techniques: it breaks down the suitability analysis problem into hierarchical units and levels for better understanding; AHP depends less on the completeness of the data set, but more on the opinion or suggestions of experts about the different factors and their deemed effects on land suitability; the approach is more transparent and hence more likely to be accepted especially when the analysis is a basis for land allocation; AHP allows for both stakeholders and experts to per take in providing the suitability measure of a site relative to a proposed land use. Such structure allows parameters of both quantitative and qualitative nature to be integrated in assessing site suitability.

2.6 Summary and research gaps

In conclusion, therefore, the review of literature has provided evidence that land suitability analysis is an important step in ensuring maximum use of availale land resources. It also showed that in order for crops to perform best they must be planted where most suitable and suitability analysis is the first step towards achievement of this. However, gaps exist in that there is no spatial analysis study that has been conducted to determine the most suitable lands for Green gram production in Kitui County. Previous studies have focused on other crops and were not done in Kitui County. Previous studies in Kenya also did not compare the productivity of their chosen crops during the two rainy seasons experienced in the County which are MAM (long rains) and OND (short) season.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

Kitui County(Figure 3.1) is located in Lower Eastern Kenya 150 km east of Nairobi. It has an estimated population of 1,012,709 people, and over 205, 491 households (RoK, 2009). The County comprises eight electoral constituencies, and covers an area of approximately 30,497Km² of which 690Km² is in the Tsavo East National Park (RoK, 2009). It lies between 0° 10' S and3° 10' S and 37° 40' E and 39° 10' E.

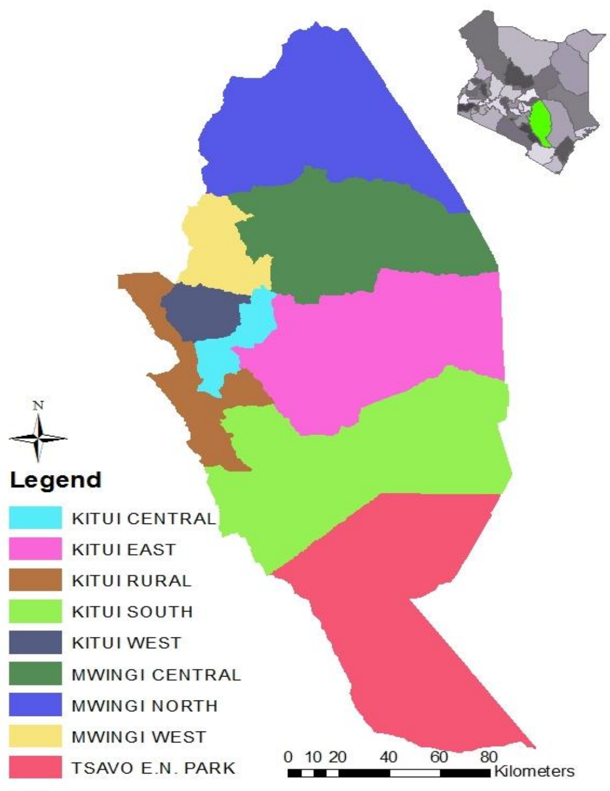

Figure 3.1:Kitui County and Sub Counties

As a semi-arid region, Kitui County is among the most drought-vulnerable regions in Kenya; the periods between June to September and January to February are usually dry. The rainfall pattern is bimodal with average annual rainfall of 750 mm but with an annual range of 500 – 1050 mm and 40% reliability (RoK, 2010).The annual mean minimum temperatures range from 22 – 28ºC, while the annual mean maximum temperatures rangesbetween28 and 32 °C. (RoK, 2010).Table 3.1 shows the eight Agro ecological zones of Kitui, the altitude in which each zone lies and the mean annual temperature and rainfall of each agro ecological zone.

Table 3.1: The Agro ecological zones of Kitui

Agro-Ecological zone	**Subzone**	**Altitude (m)**	**Annual mean temperature(°C)**	**Annual average rainfall(mm)**
UM 3-4 Trans. Mag. Coffee Zone	s/m + s	1340-1 620	20.2-18.6	900-1 050
UM 4 Sunflower-Maize zone	s + s	1180-1 550	21.0-19.0	850-1 000
LM 3 Cotton Zone	s + s	Very small and many steep hills		
LM 4 Marginal Cotton Zone	s/vs + s vs/s + s/vs vs + s/vs i + s/vs	760-1 280	24.0-20.9	800-1 000 750- 880 700- 820 720- 820
LM5 Livestock-Millet Zone	vs + vs/s vs + vs i + vs/s vs+i or i+vs i + vs	760- 910	24.0-23.2	650- 790 600- 780 600- 750 600- 650 550- 630
LM6 Lower Midland Ranching Zone	Br	No rain fed agriculture possible except with run-off techniques		
L5 Lowland. Livestock-Millet Zone	vs+i or i+vs i + vs	550- 760	25.3-24.0	450- 550 500- 700
L6 Lowland Ranching Zone	Br	No rain fed agriculture possible except with run-off techniques		

Source: Jaetzold *et al*., (1983)

The length of the growing period is the key to selecting the right annual crops within an agro-ecological zone. “Growing periods" are definded as seasons with enough moisture in the soil to grow most crops, starting with a supply for plants to transpirate more than 0.4 Eo (i.e. > 40 % of the open water evaporation), coming up to > Eo (in the ideal case) during the time of peak demand, and then falling down in the maturity phase again. The symbols used for the lengths of the growing periods are straight-forward:

vl=very long= 285 - 364 days

l=long= 195-214 days

m=medium= 135-154 days

s=short= 85 – 104 days

vs=very short= 40-54 days

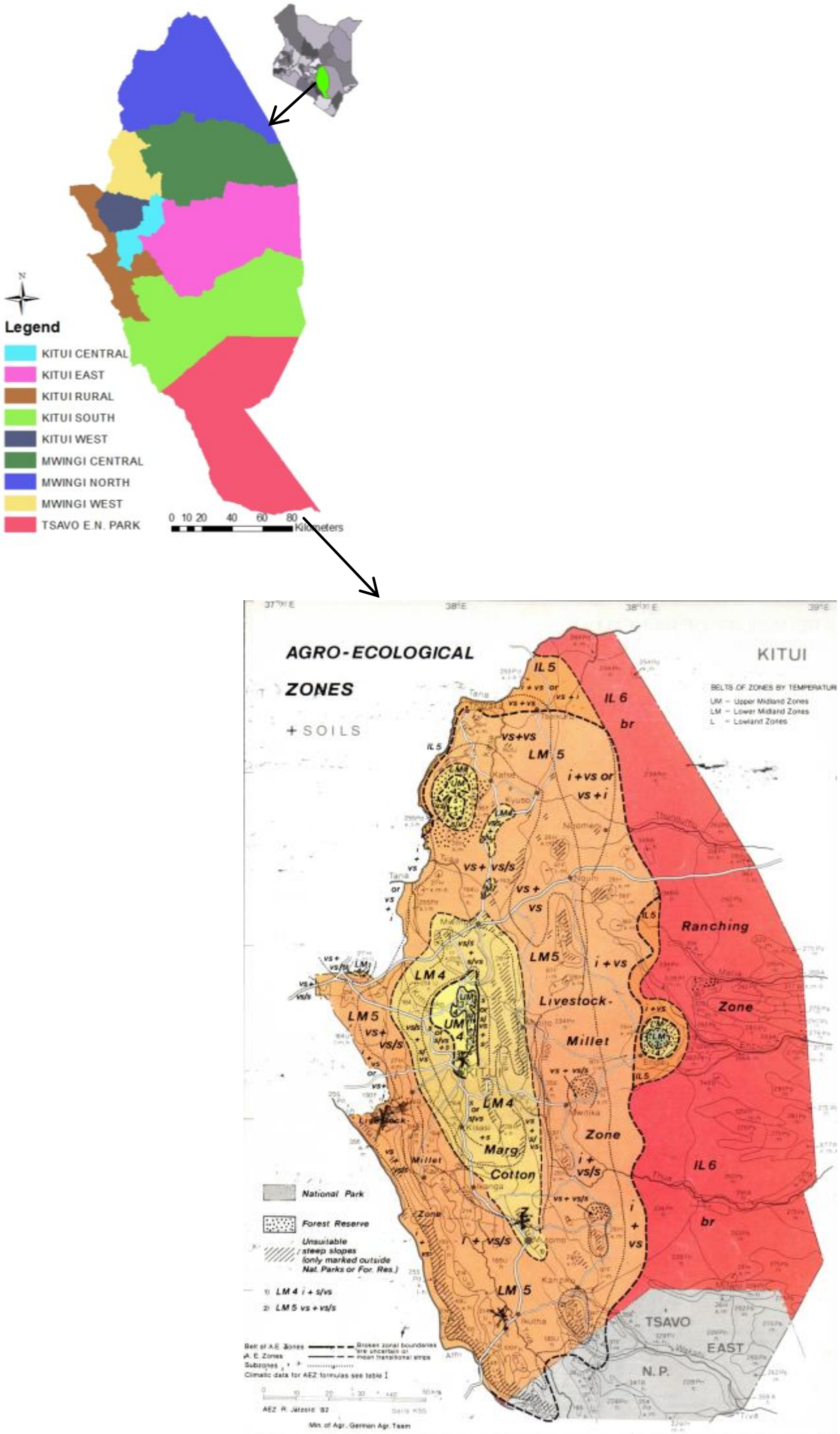

Figure 3.2: Agro ecological zones and soils of Kitui County (Jaetzold et al., 1983)

The predominant soil types in the Countyare acrisols, luvisols and ferralsols. The soils are well drained, moderately deep to deep, dark reddish brown to dark yellowish brown in color.The main agro ecological zones are associated with potential leading crops (Jaetzold *et al.*, 1983)and this is shown in Table 3.2.

Table 3.2: Leading crops and the agro ecological zones where they are likely to grow

Leading crops	**Agro-ecological Zones**
Maize	UM 3-4; LM 3
Hybrid maize	UM 3; LM 3
Irrigated rice	L 6, (7)*; LM 3-6
Sorghum	UM (3), 4; LM 4-5; L5
Finger millet	UM (3), 4; LM 4, (5); L (5)
Groundnuts	LM 3-4
Cotton	LM 3-4

*Bracket mean that in these zones the crop is normally not competitive to related crops (f.i. sorghum to maize)

Source: Jaetzold*et al*., (1983)

3.2 Methodology

3.3 Analytic Hierarchy Process

Analytic Hierarchy Process(AHP) is a widely used method in decision-making. AHP was introduced by Saaty (1977), with the basic assumption that comparison of two elements is derived from their real-time importance (Baniya, 2008). All criteria/factors which are considered relevant for a decision are compared against each other in a pair-wise comparison matrix which is a measure to express the relative preference among the factors (Lupia, 2014). The Analytic Hierarchy Processinvolves three main steps: selection of biophysical factors, pairwise comparison of key biophysical factors and generation of weights (Dadfar, 2014). In this study all the key biophysical factors affecting Green gram production were compared against each other.

3.3.1 Development of a pairwise comparison matrix

Saaty (2000) suggested a scale for comparison consisting of values ranging from 1 to 9 which describe the intensity of importance(Table 3.3). This is the scale that was used to rate the biophysical factors affecting Green gram.

Table 3.3: Scale of relative importance between two elements

Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly or essentially favour one activity over another
7	Demonstrated importance over the other	An activity is strongly favoured over another and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest degree possible of affirmation
2,4,6,8	Intermediates values	Used to represent compromise between the preferences listed above

Adapted from:Atthirawong and MacCarthy (2002) and Saaty (2000)

3.3.2 Criteria weights assignment

Lupia (2014) stated that weighting in land suitability analysis for agricultural crops is meant to express the importance of each factor relative to effects of other factors effects on crop yield and growth rate. In this study the relative weights of each of the biophysical parameters were determined from literature review and from discussions with crop specialists.

The AHP calculates the Consistency Ratio (CR) which helps to know whether the pair-wise comparison was consistent in order to accept the results of the weighting. The Consistency Ratio (CR) measures how much variation is allowed for reasonable results and is expected to be less than 10 percent for AHP to continue (Dadfar, 2014).

Consistency Ratio (CR) got from the Consistency Index (CI) is as follows:

$CI = (\lambda max - n) / (n – 1)$

$CR = CI / RI$

Where: λmax is the maximum Eigen value; CI is the Consistency Index; CR is the Consistency Ratio;RI is the Random inconsistency index and n is the numbers of criteria or sub-criteria in each pairwise comparison matrix (Baniya, 2008; Dadfar, 2014).

RI depends on the number of elements being compared as shown in Table 3.4.

Table 3.4: Random Inconsistency Indices (RI) for n=1, 2..., 15

N	**RI**	**N**	**RI**	**N**	**RI**
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

Source: Saaty (1980)

The overall weight of the main criteria and its sub criteria was calculated as

$W=W1*W2$ (Baniya, 2008)

Where: W- Overall weight, W1- Weight of main criteria, W2- Weight of sub criteria

An example:

STEP 1, let’s make pairwise comparisons of Peter’s preferences between an apple, banana and mango on a scale of 1-9 using (Table 3.3). Table 3.5 shows the pairwise comparison results between the 3 fruits.

Table 3.5: Pairwise comparison among three fruits.

	Apple	Banana	Mango
Apple	1	4	8
Banana	¼	1	4
Mango	1/8	¼	1
SUM	1.38	5.25	13.00

When you compare a fruit with itself e.g. apple vs apple or banana vs banana the score is 1. Numbers in red show that Peter prefers Apple to Banana by factor 4, Apple to Mango by factor 8 and Banana to Mango by 4. Numbers in blue are the reciprocal of those in red i.e. if his preference of Apple over Banana is 4 then his preference of Banana to apple will be 1/4.

STEP 2: Using the columns obtained in step one above divide each row element in Table 3.5 with its column total which is called normalisation. The sum of the columns should be 1.

Table 3.6: Normalized table

	Apple	Banana	Mango	Weights/Eigen Vectors
Apple	0.73	0.76	0.62	0.70
Banana	0.18	0.19	0.31	0.23
Mango	0.09	0.05	0.08	0.07
SUM	1.00	1.00	1.00	1.00

The weights or Eigen vectors are obtained by finding the average of the sum of the rows e.g. (0.73+0.76+0.62)/3=0.70.Therefore Peter prefers Apple with a weight of 70%.

STEP 3: We need to test how consistent Peter was in making his decision. λmaxis calculated by multiplying each weight in Table 3.6 with its corresponding column total in Table 3.5.

$CI = (\lambda max - n) / (n – 1)$

$CR = CI / RI$

$\lambda max = (1.38*0.7) + (0.23*5.25) + (13*0.07) =3.09$

CI = (3.09-3)/2=0.045

RI=0.58 (For N=3, Table 3.4)

CR=0.045/0.58=0.08 or 8% this is below 10% so we accept his decision.

3.3.3 Selection of evaluation criteria

Three main criteria were selected for analysis (soil, climate and topography) and 8sub criteria (soil texture, soil depth, soil pH, soil Cation exchange capacity (CEC), soil drainage, rainfall, temperature and slope). The criteria were selected based on discussions with crop experts and the information available about Green gram requirements from literature review.

3.4 Suitability table for Green gram from available literature

The data on suitability of Green gramwas summarized into four classes;Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3) and not suitable (N). Table 3.7 shows a summary of Green gram growing conditions based on reviewed literature and discussions with crop experts.

Table 3.7: Green gram Suitability Table

	S1	S2	S3	N
Rainfall	350-600mm	600-1000mm 300-350mm	>1000mm 230-300mm	 <230mm
Temperature	30-24 ^{0}C	24-20^{0}C	20-15^{0}C	<15 ^{0}C >30^{0}C
Soil pH	6.2-7.2	5-6.2	7.2-8	>8 <5
Drainage	Well-drained	Imperfectly drained	Poorly drained	Very poorly drained
Texture	Loam Sandy Loam	Clayey	Very clayey Extremely sandy	-
CEC	>10meq/100g	10-5 meq/100g	0-5 meq/100g	
Depth	>50cm	30-50cm	<30cm	
Slope	0-10%	11-20%	21-35%	>35%

3.5 Development of the model inputs

ArcGIS was the tool used in this study and several secondary digital databases were obtained from various sources (Table 3.8). The secondarydatabases were: maps of soil texture, cation exchange capacity, soil depth, soil pH and soil drainage extracted from Kenya Soil Survey map; rainfall and temperature (http://www.worldclim.org) and slope percentage extracted from digital elevation model (DEM) of the United States Geological Survey. The secondary layers were used as inputs to the model and the data was resampled to a cell size of 10m.

The study incorporated4 suitability levels S1, S2, S3 and N which were assigned the scores 4, 3, 2 and1, respectivelytoreflect the significance of each parameter. The highest value indicates the parameter that influencesGreen gram production the most.

Table 3.8: Description of Secondary Data Sources

Data layer	Source	Scale/ Resolution	Remarks
Climate: Temperature and rainfall	WorldClim (http://www.worldclim.org/) - Current conditions (interpolations of observed data, representative of 1950-2000)	30 arc-seconds resolution downloadable as tile of 30 x 30 degrees with 1km Resolution	Raster format
Soil: soil pH, Altitude, drainage and texture	Kenya Soils Survey	Kitui layers	Vector format
Topography/ DEM: Slope	United States Geological Survey (USGS)	30m	Raster format

3.5.1 Soil data

The soils data used in this research has been used by other researchers in Kenya for similar studies on different crops (Kamau *et al.*, 2015; Boitt *et al.*, 2015; Kihoro *et al.*, 2013; Kuria *et al.*, 2011). TheKitui soil map was clipped from the Kenya Soils map and 5 data layers of interest for this analysis (soil texture, soil pH, soil depth, soil drainage and soil CEC) were extracted. The layers were then converted into raster format and a cell size of 10 m used. The 5 raster layerswere then reclassified according to the 4 classes of suitability defined in the crop requirement for Green gram Table 3.7. The process is summarized in Figure 3.3.

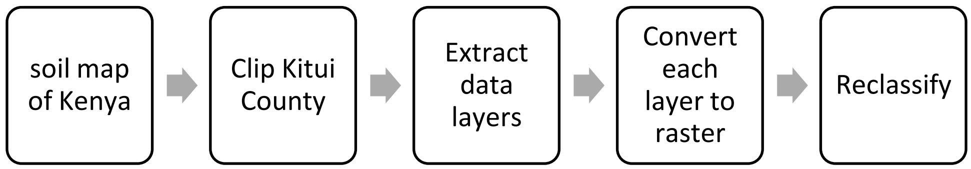

Figure 3.3: Flow chart for processing soil map

3.5.2 Topography

Topography of the area was obtained in raster format from the Digital Elevation Model (DEM) of the area and mosaicked to form a continuous layer. The percentage slope of Kitui was then calculated. The slope was then reclassified into 4 classes of suitability as defined in the crop requirements Table3.7 for Green gram. Figure 3.4 shows a summary of the process.

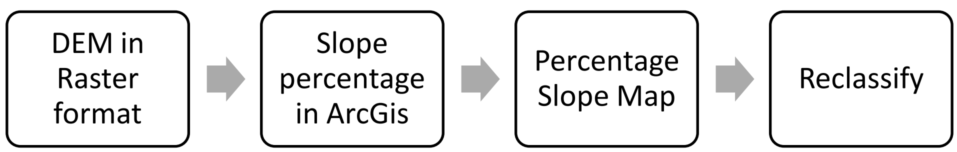

Figure 3.4: Flow chart for processing Topography map

3.5.3 Climate

Rainfall and temperature were obtained from WorldClim (http://www.worldclim.org/) and the 12 tiles (monthly) of precipitation and mean temperature downloaded. The data layers in the website were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (Hijmans *et al.*, 2005).

The seasonal MAM and OND precipitation total and seasonal mean temperaturewere thencalculated and Kitui County data extracted. The temperature and rainfall were then reclassified into 4 classes of suitability. The process is summarized in Figure 3.5.

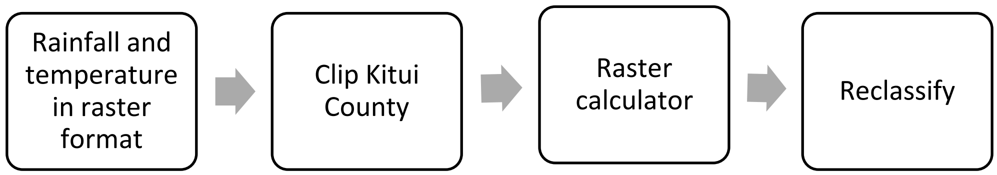

Figure 3.5: Flow chart for processing Climate information

3.6 Green gram suitability map

After rating and reclassifying thecriteria maps, theywereeach assigneda certain percentage stake (weighting)which was determined by experts on their influence in the production of Green gram. These are weights obtained through Analytic hierarchy process. The maps were then overlaid to generate the final output which is a Green gram suitability map.

In land suitability analysis, a map represents each evaluationcriterion with alternatives (like S1, S2 and S3) indicating the degree of suitability with respect to a criterion. These classes have to be rated, how important is the class S1 with respect to a particular criteria to contribute tothe final goal (suitability) (Baniya, 2008).

3.7 Validation

After obtaining the results from the weighted overlay, a validation exercise was conducted to determine whether the model reflects what is actually happening on the ground in Kitui County. The exercise was conducted by holding interviews with the Sub County Agriculture and Livestock Development Officers (SCALDOs) who deal with farmers on a day to day basis and are thus in a position to report on the productivity of Green gram in their respective sub counties.

CHAPTER FOUR

4.0 RESULTS

This section shows the spatial variation of each sub criteria as per the Green gram suitability classes and the results of land suitability through the AHP, MCE approach.

4.1 Climate

The spatial variation of rainfall and temperature of each season are described below.

4.1.1 Spatial variation of MAM Rainfall

The unclassified MAM rainfallvaried between 155 mm and 663 mm (Figure 4.1a). The reclassified rainfall mapshows that during this season, 50.4% of the County has varying degrees of suitability for growing Green gram; with 4.9% having high suitability while 11.1% and 34.4% have moderate and marginal suitability, respectively. The rest of the County (49.6%) is not suitable for Green gramproduction (Table 4.1 and Figure 4.1b).

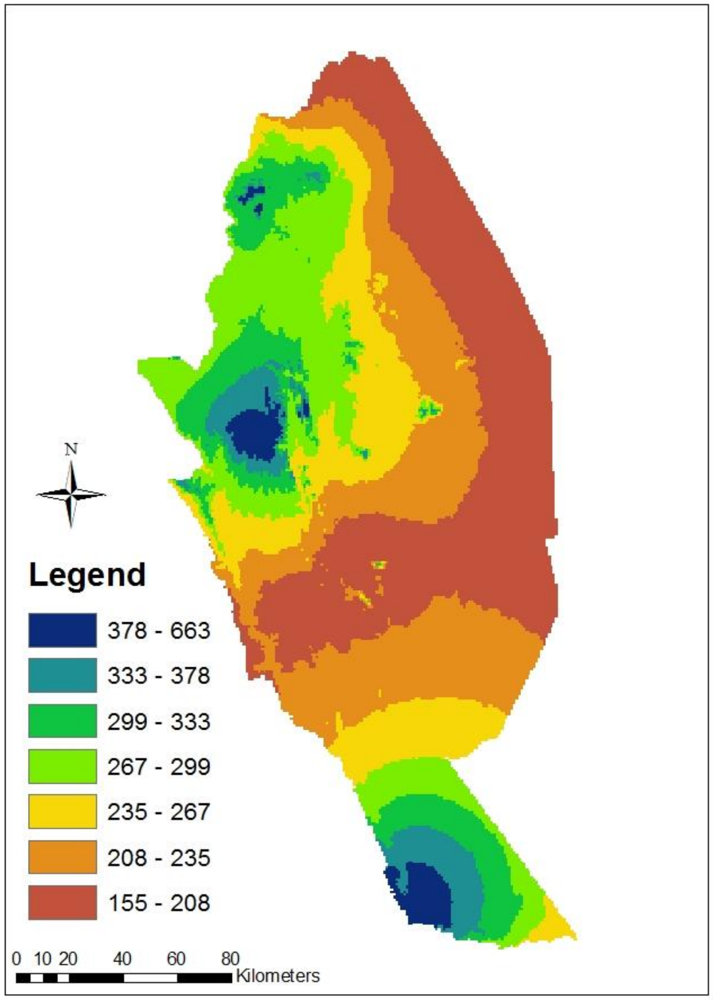

Figure 4.1a:Unclassified spatial variation of MAM Rainfall

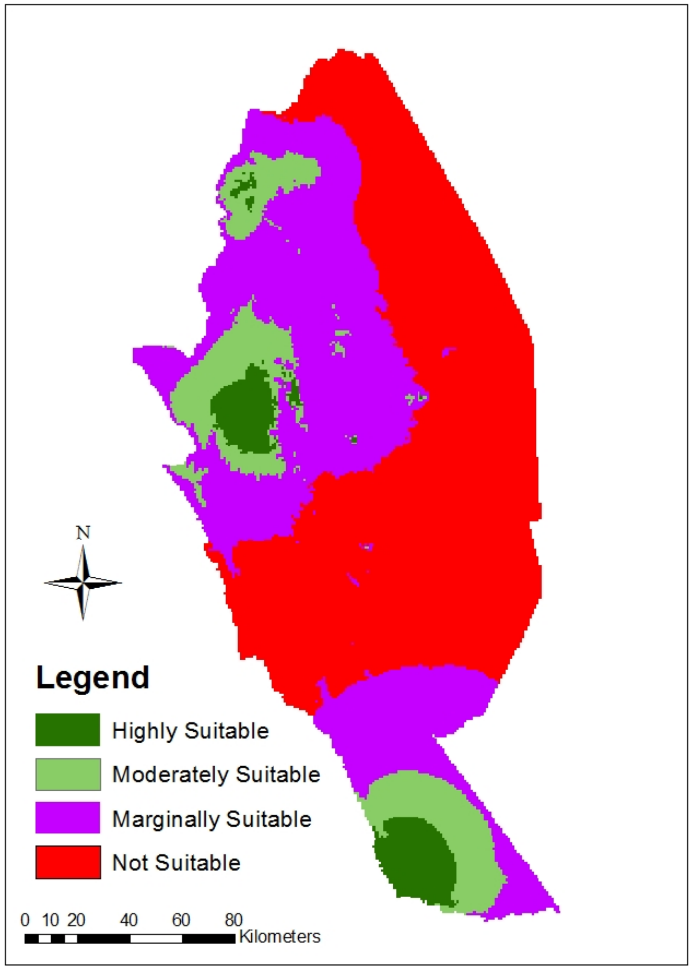

Figure 4.1b: Classified spatial variation of MAM Rainfall

Table 4.1: Spatial variation of reclassified MAM Rainfall

Suitability class	**Rainfall(mm)**	**Area (Ha)**	**Area (%)**
S1	350-600	149034	4.9
S2	600-663 300-350	339924	11.1
S3	230-300	1049925	34.4
N	<230	1515985	49.6

4.1.2 Spatial variation of OND Rainfall

The unclassified OND rainfallvaried between 240 mm and 729 mm (Figure 4.2a). The reclassified rainfall map shows that during this season, the entire County is suitable for Green gram production where 75.7% is highly suitable while 22.5% and 1.9% is moderately and marginally suitable for Green gram production, respectively(Table 4.2 and Figure 4.2b)

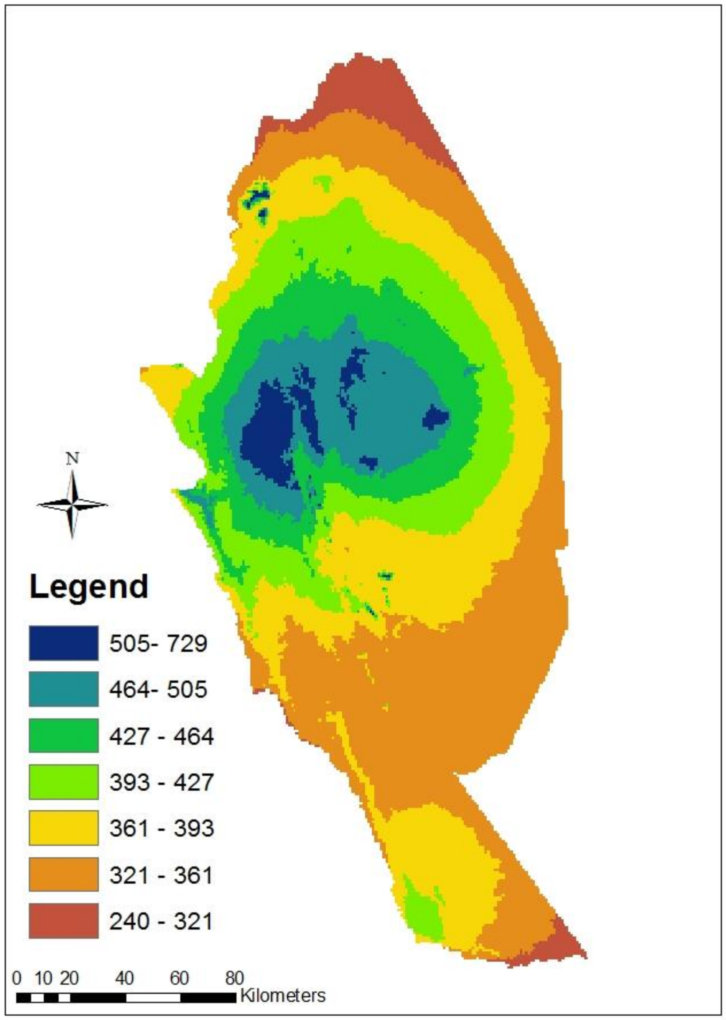

Figure4.2a:Unclassified spatial variation of OND Rainfall

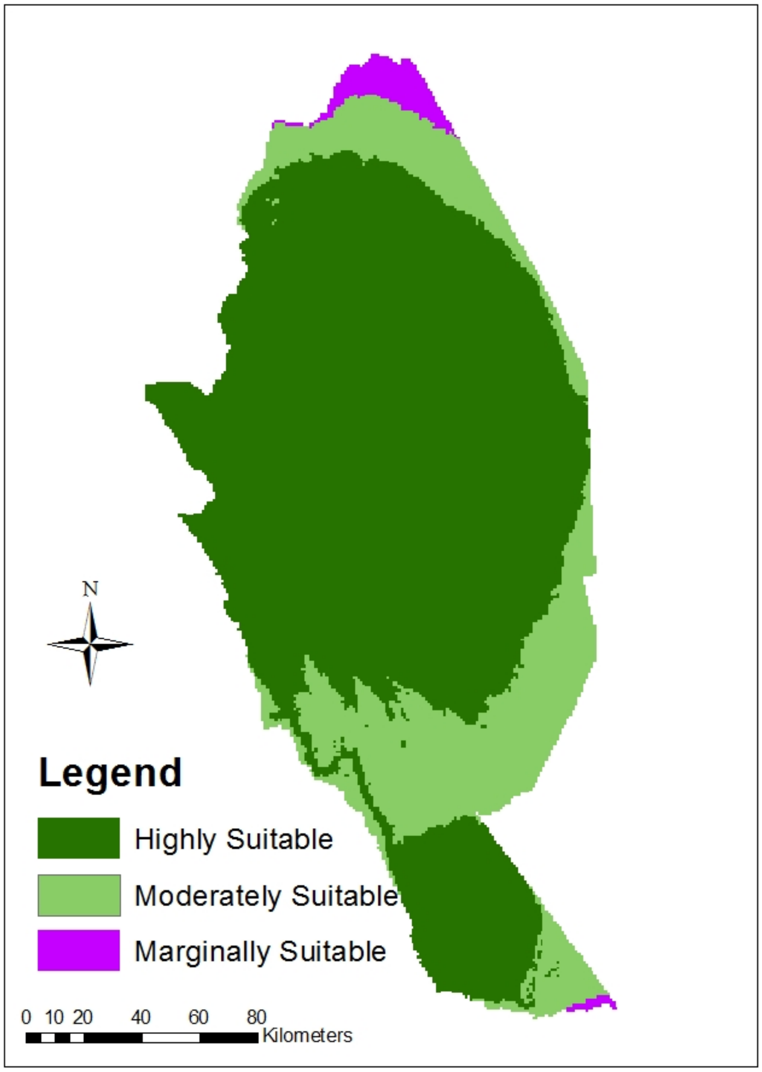

Figure 4.2b: Classified spatial variation of OND Rainfall

Table 4.2: Spatial variation ofreclassified OND Rainfall

Suitability class	**Rainfall(mm)**	**Area (Ha)**	**Area (%)**
S1	350-600	2,311,141	75.7
S2	600-729 300-350	686,332	22.5
S3	230-300	57,395	1.9

4.1.3 Spatial variation of MAM Temperature

The unclassified MAM temperature variedbetween 19.1^{0}C to 27.4^{0}C (Figure 4.3a). The reclassified temperature map shows that during this season 78.7% of Kitui has highly suitable temperature for growth of Green gram (Table 4.3 and Figure 4.3b).

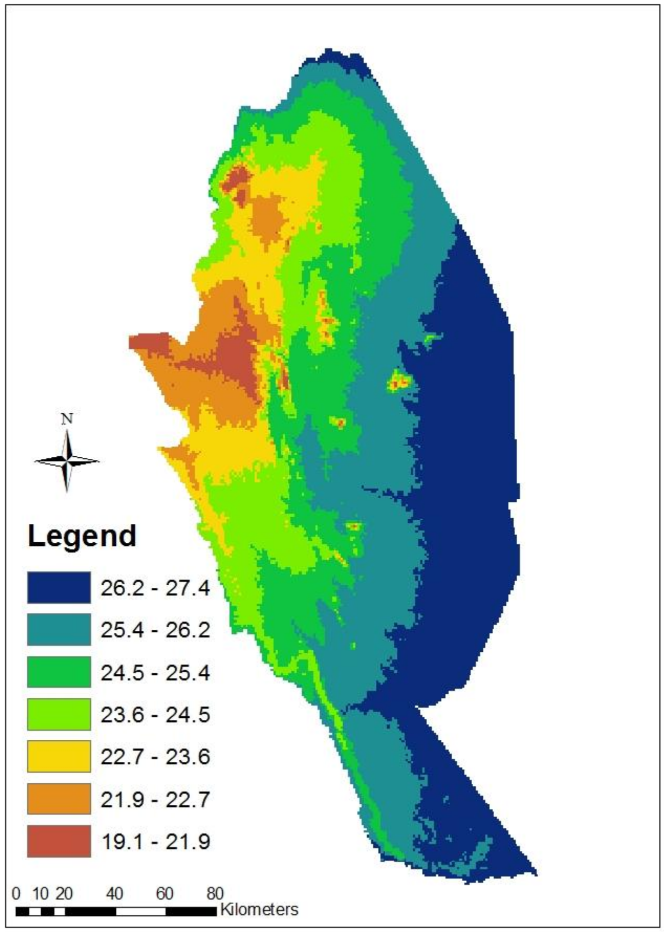

Figure 4.3a: Unclassified spatial variation of MAM Temperature

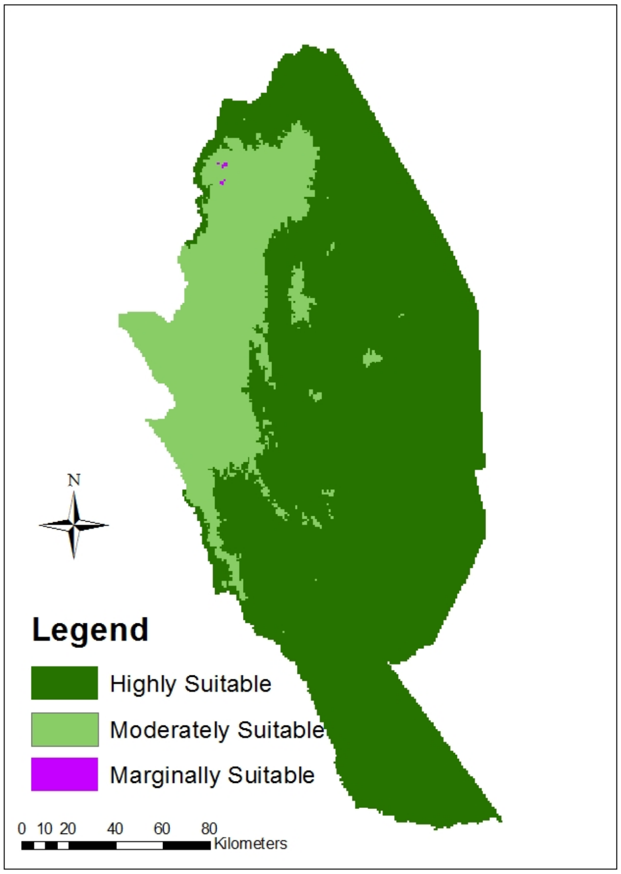

Figure 4.3b: Classified spatial variation of MAM Temperature

Table 4.3: Spatial variation of reclassified MAM Temperature

Suitability Class	**Temperature (^0C)**	**Area (Ha)**	**Area (%)**
S1	27.4-24	2,403,452	78.7
S2	24-20	650,477	21.3
S3	20-15	939	0*

*These values are much smaller than 0.05

4.1.4 Spatial variation of OND Temperature

The unclassified OND temperaturevaried between 18.6^{0}C to 26.9^{0}C (Figure 4.4a). The reclassified map shows that 70% of the area has highly suitable temperature for growth of Green gram (Table 4.4 and Figure 4.4b).

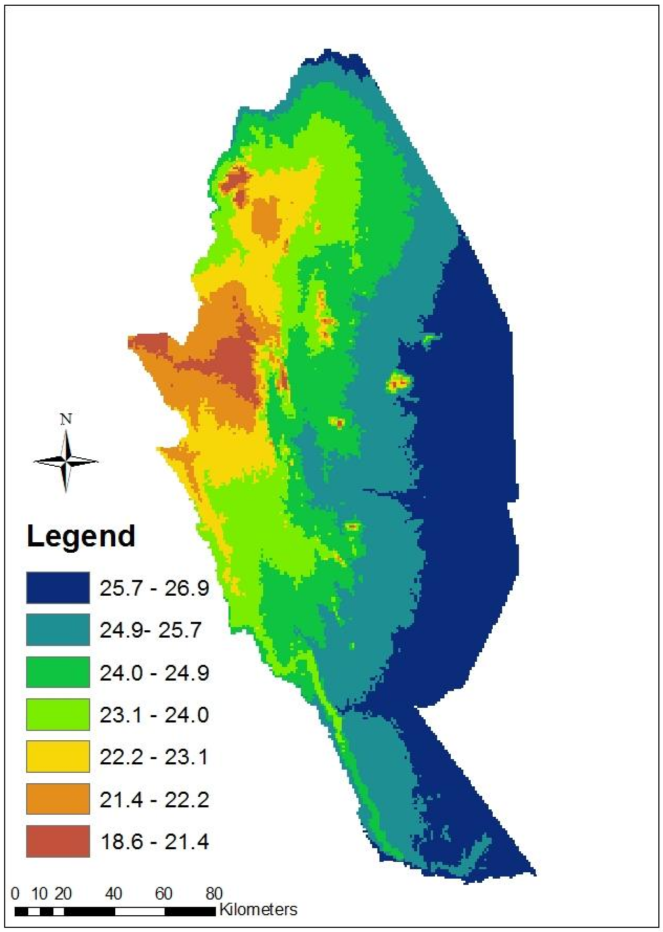

Figure 4.4a: Unclassified spatial variation of OND Temperature

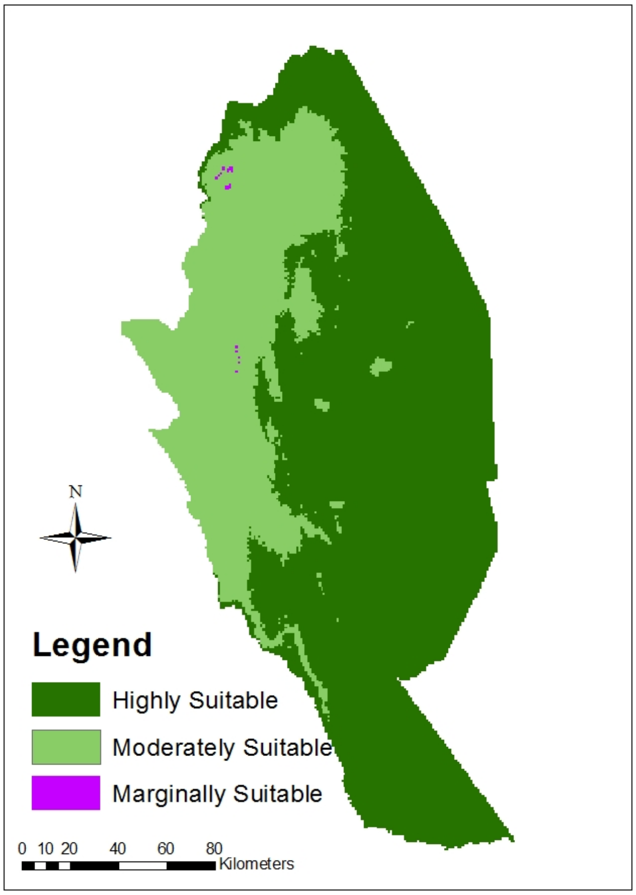

Figure 4b: Classified spatial variation of OND Temperature

Table 4.4: Spatial Variation of reclassified OND Temperature

Suitability class	**Temperature (^{0}C)**	**Area (Ha)**	**Area (%)**
S1	26.9-24	2137857	70.0
S2	24-20	915045	30.0
S3	20-15	1966	0.1

4.1.5 Green gram Climate suitability map

Using AHP approach, rainfall and temperature were rated using pairwise comparison method which resulted in weights between 0 and 100. The results show that experts consider rainfall more important with an influence of 67% (Table 4.5).

Table 4.5: Pairwise comparison results for climate sub criteria.

	Rainfall	**Temperature**	**Weight**	**Rank**
Rainfall	1	2	67	1
Temperature	0.5	1	33	2
CR=0%				

Since the CR< 10 the weights in Table 18 were assigned to the weighted overlayof rainfall and temperature which revealed that, there are 3 classes in the MAM season where 4.9% is highly suitable, 33.9% is moderately suitable and 61.3% is marginally suitable for production (Table 4.6 and Figure 4.5).

Table 4.6: Climate composite potentials for Green gram production during MAM and OND seasons

Suitability(MAM)	**Area (Ha)**	**Area (%)**	**Suitability (OND)**	**Area(Ha)**	**Area (%)**
S1	148266	4.9	S1	2309944	75.6
S2	1035109	33.9	S2	744924	24.4
S3	1871493	61.3			

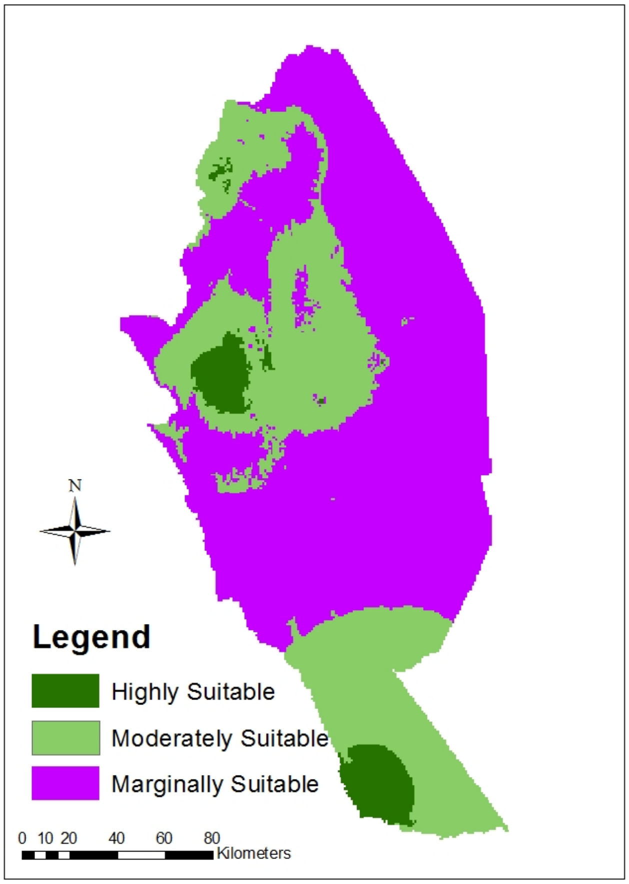

Figure 4.5: Climate composite potentials for Green gram production during MAM season

There are only two classes during OND season where75.6%of the study area is highly suitable and 24.4% is moderately suitable (Table 4.6 and Figure 4.6).

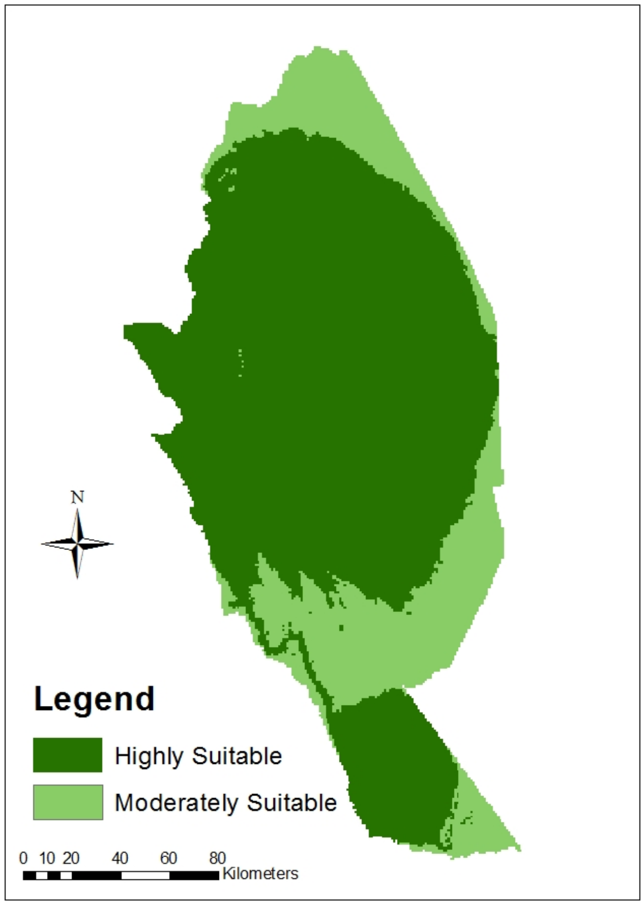

Figure 4.6: Climate composite potentials for Green gram production during OND season

4.2Soil

The spatial variation of soil texture, soil depth, soil pH, soil drainage and the Cation Exchange Capacity (CEC) are described below

4.2.1 Spatial variation of soil texture

The study area had the following texture classes.

I. Loamy---loam, sandy clay loam, clay loam, silt, silt loam and silty clay loam

II. Sandy---loamy sand and sandy loam texture classes

III. Very clayey ---more than 60% clay

IV. Clayey ---sandy clay, silty clay and clay texture classes

The reclassified texture map shows that on the basis of texture, the highest percentage (79.5%) is moderately suitable for Green gram production (Table 4.7and Figure 4.7) with high and marginal suitability taking 13.4% and 7.1%, respectively.

Table 4.7: Spatial variation of reclassified soil texture

Suitability class	**Soil texture**	**Area (Ha)**	**Area (%)**
S1	Loamy Sandy	408188	13.4
S2	Clayey	2428744	79.5
S3	Very clayey	217936	7.1

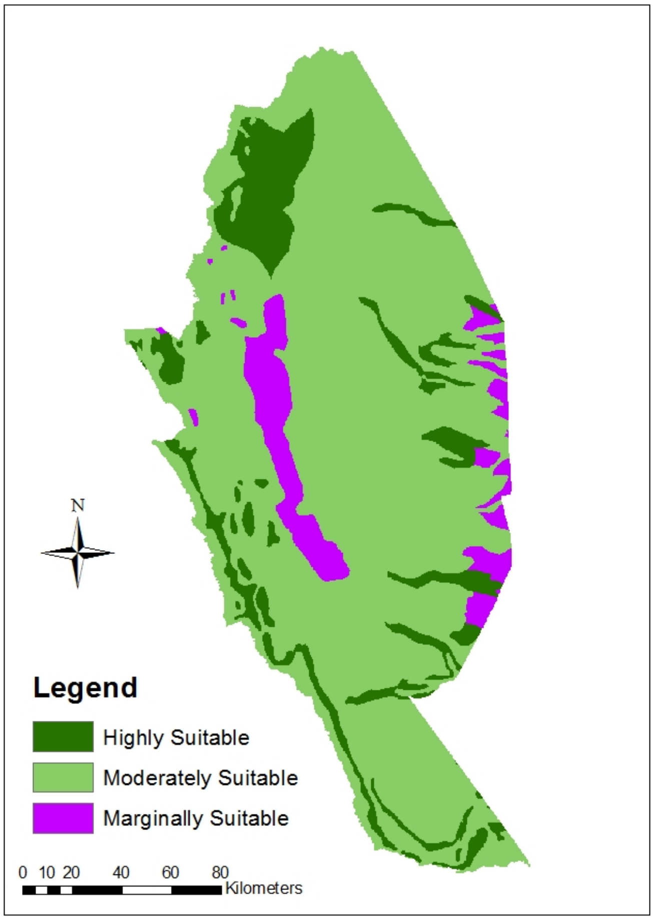

Figure 4.7: Spatial variation of reclassified soil texture

4.2.2 Spatial variation of soil depth

Soil depth refers to the estimated depth in cm to which root growth is unrestricted by any physical or chemical impediment such as impenetrable or toxic layer. The reclassified depth map shows that 50.9% and 49.0% are highly and marginally suitable for production, respectively (Table 4.8 and Figure 4.8).

Table 4.8: Spatial variation of reclassified soil depth

Suitability class	Soil depth	Area (Ha)	Area (%)
S1	>50cm	1554879	50.9
S2	50-30cm	3079	0.1
S3	<30cm	1496910	49.0

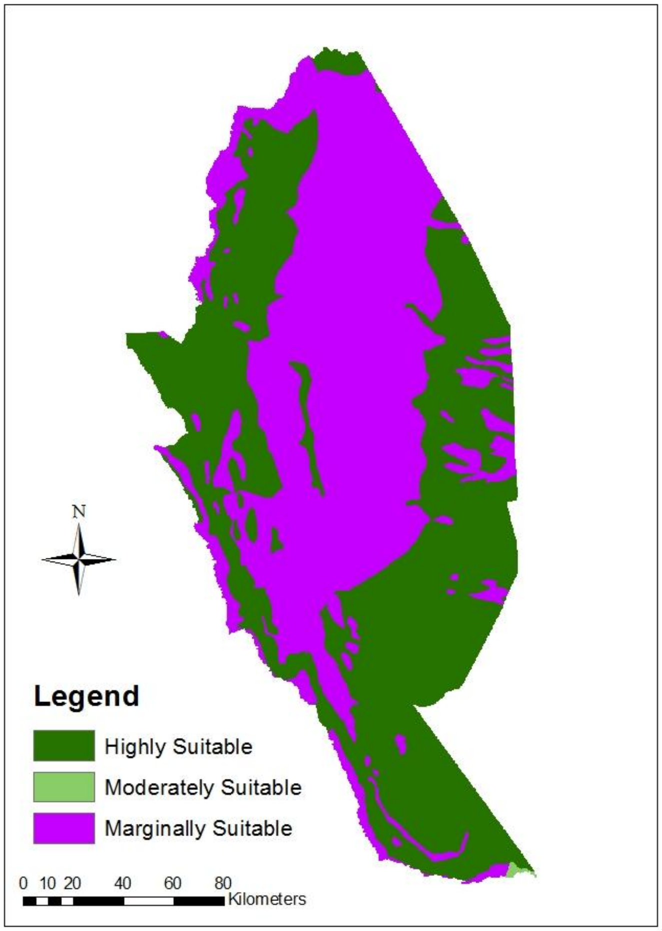

Figure 4.8: Spatial variation of reclassified soil Depth

4.2.3 Spatial variation of soil pH

The pH-water (Phaq) is used as an index of soil suitability for crops or plants. The reclassified pH map shows that the highest percentage of land (50.8%) is not suitable for Green gram growth(Table 4.9 and Figure 4.9) with high, moderate and marginal suitability taking 22.2%, 23.7% and 3.3%, respectively.

Table 4.9: Spatial Variation of reclassified soil pH

Suitability class	**Soil pH**	**Area (Ha)**	**Area (%)**
S1	6.2-7.2	678531	22.2
S2	5-6.2	723200	23.7
S3	7.2-8	102146	3.3
N	>8 <5	1550992	50.8

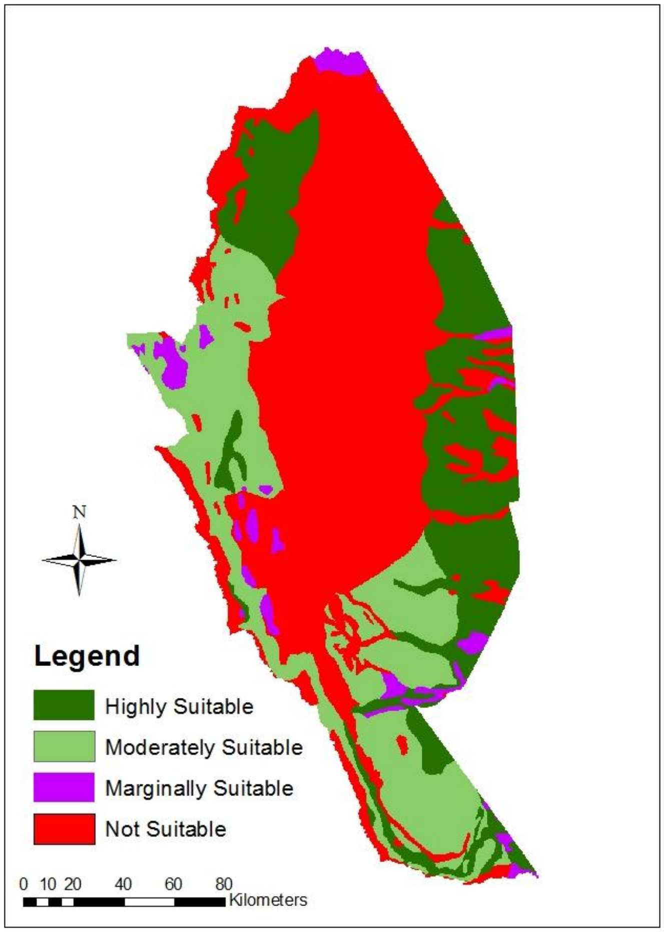

Figure 4.9: Spatial Variation of reclassified soil pH

4.2.4 Spatial variation of soil drainage

The soil drainage classes of KituiCounty are described below.

I. Well drainedsoil-water is removed from the soil readily but not rapidly
II. Imperfectly drained-water is removed slowly so that the soils are wet at shallow depth for a considerable period.

III. Poorly drained-water is removed so slowly that the soils are commonly wet for considerable periods. The soils commonly have a shallow water table

IV. Very poorly drained-water is removed so slowly that the soils are wet at shallow depth for long periods. The soils have a very shallow water table.

The reclassified soil drainage map shows that the highest percentage (47.1%) is not suitable for production (Table 4.10 and Figure 4.10) with high, moderate and marginal suitability taking 43.6%, 2.5% and 6.8%, respectively.

Table 4.10: Spatial Variation of reclassified soil drainage

Suitability class	**Soil drainage**	**Area (Ha)**	**Area (%)**
S1	Well drained	1331390	43.6
S2	Imperfect	76938	2.5
S3	Poor	206788	6.8
N	Very poor	1439752	47.1

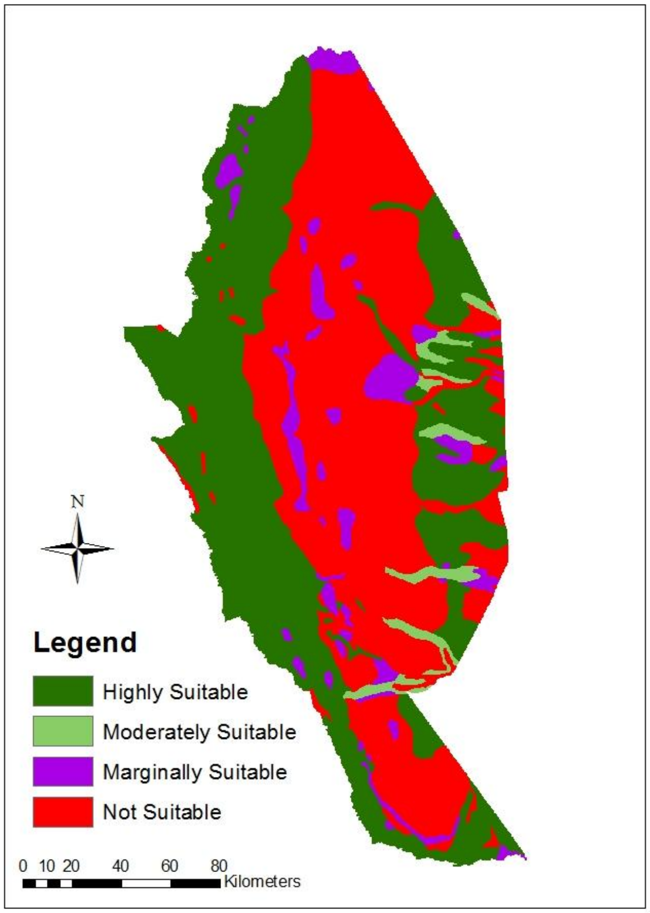

Figure 4.10:Spatial Variation of reclassified soil drainage

4.2.5 Spatial variation of soil CEC

The Cation exchange capacity of the soil in the study area ranges from 0 to 51.6 meq/100g. The reclassified CEC map shows that the highest percentage (69.8%) is highly suitable for Green gram production (Table 4.11 and Figure 4.11) with moderate and marginal suitability taking 18.1% and 12.1%, respectively.

Table 4.11: Spatial variation of reclassified soil CEC

Suitability class	Soil CEC	Area (Ha)	Area (%)
S1	>10	2131775	69.8
S2	10-5	552804	18.1
S3	<5	370289	12.1

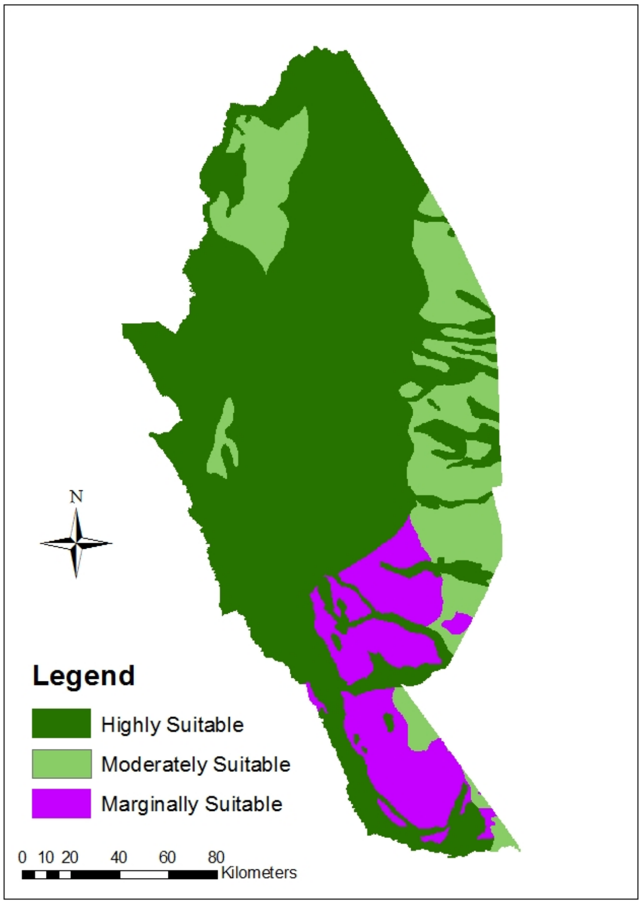

Figure 4.11: Spatial Variation of reclassified soil CEC

4.2.6 Green gram soil suitability map

Using AHP approach, soil texture, pH, depth, CEC and drainage were rated using pairwise comparison method which resulted in weights between 0 and 100. The results show that expertsconsider soil drainage most important with an influence of 39% (Table 4.12).

Table 4.12: Pairwise comparison results for soil sub criteria

	CEC	**Texture**	**Drainage**	**Depth**	**pH**	**Weight**	**Rank**
CEC	1	2	½	2	2	23	2
Texture	½	1	¼	2	½	12	4
Drainage	2	4	1	4	2	39	1
Depth	½	½	¼	1	½	9	5
pH	½	2	½	2	1	17	3
CR=2.6%							

Since the CR<10% the weights in Table 4.12 were assigned to the weighted overlay which revealed that all the land in Kitui Countyis suitable for Green gram production but in varying degrees when all the different aspects of the soil are considered. The results show that only 33.1% is highly suitable, 14.8% is moderately suitable and 52.1% is marginally suitablefor Green gram production (Table 4.13 and Figure 4.12).

Table 4.13: Soil Potential for Green gram

Suitability class	Area(Ha)	Area (%)
S1	1012205	33.1
S2	450758	14.8
S3	1591905	52.1

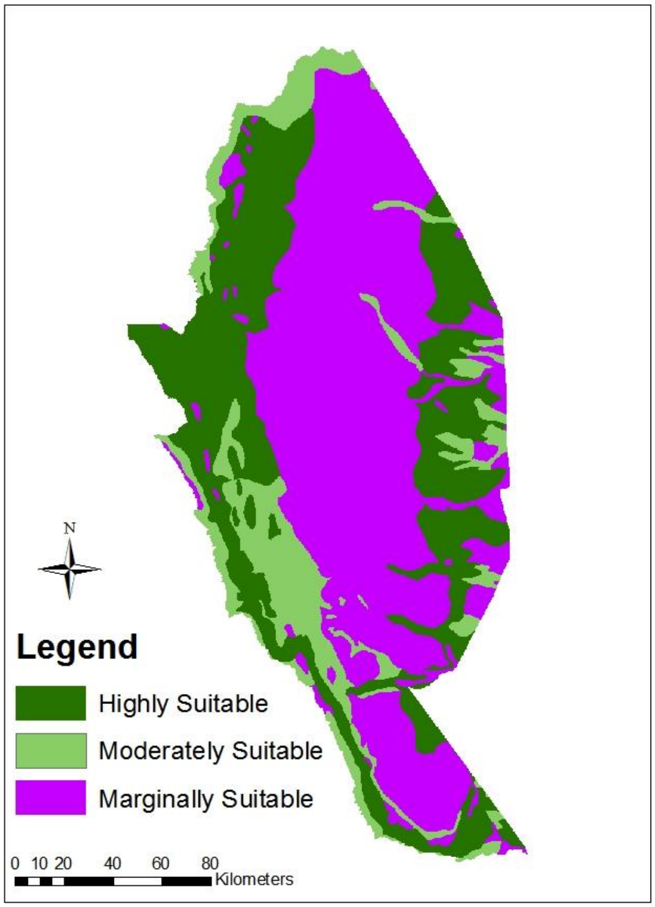

Figure 4.12: Soil Potential for Green gram

4.3 Topography

The slope of the study area varied from 0 to 297%,the reclassified map shows that the highest percentage of the area (89%) is highly suitable for production (Table 4.14 and Figure 4.13) with moderate, marginal and not suitable taking 6.6%, 2.2% and 2.1%, respectively.

Table 4.14: Spatial Variation of Slope

Suitability class	**Slope (%)**	**Area (Ha)**	**Area (%)**
S1	0-10	2719445	89.0
S2	11-20	202922	6.6
S3	21-35	67279	2.2
N	>35	65223	2.1

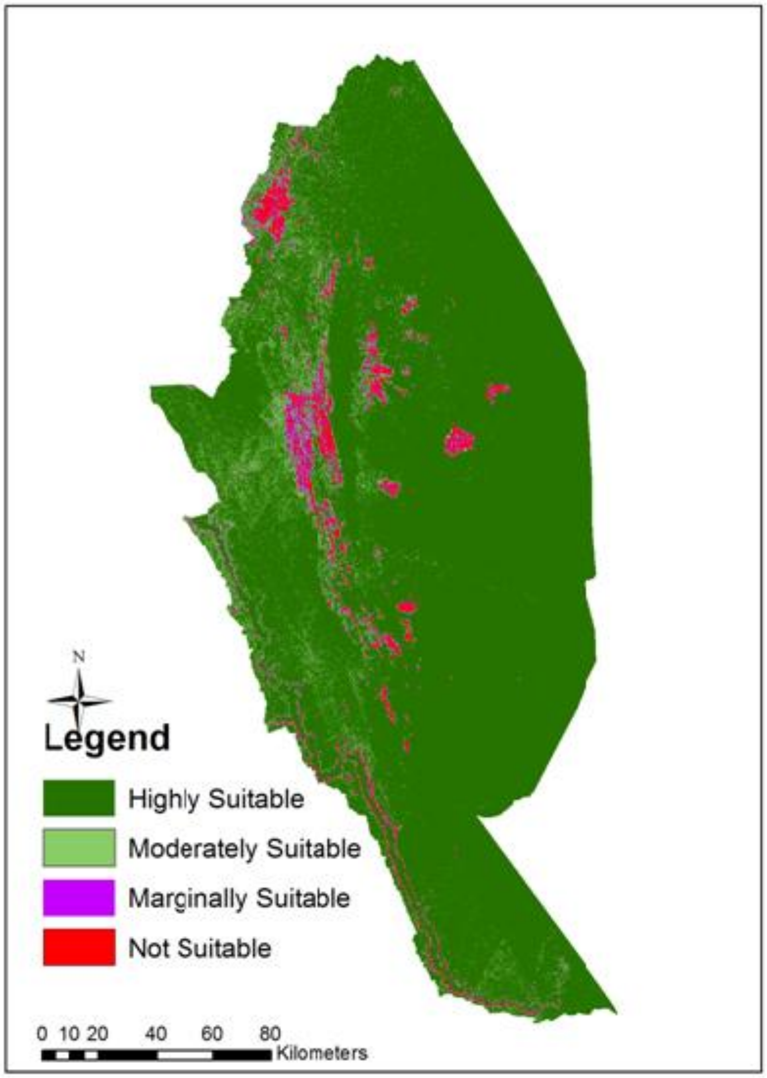

Figure 4.13: Spatial Variation of slope

4.5 Green gram suitability map

This section presents the final Green gram suitability map produced by overlaying sub criteria maps for the MAM and OND season on soil and slope maps using weighted overlay technique. AHP was used todetermine the weights of each main criterion which showed that experts consider climate most important with an influence of 70% (Table 4.15).

Table 4.15: Pairwise comparison results for main criteria

	Climate	**Soil**	**Topography**	**Weight**	**Rank**
Climate	1	4	8	70	1
Soil	¼	1	4	23	2
Topography	1/8	¼	1	7	3
CR=8.0%					

All the sub criteria were weighted and the results for these weights are in Appendix 3 which shows rainfall is themost important with an influence of 47%. The weights were assigned and revealed three classes of suitability during the MAM season where 4.6%, 54.7% and 40.7% of Kitui County is highly, moderately and marginally suitable, respectively (Table 4.16 and Figure 4.14).

There are two classes of suitability during the OND season where 66.2% and 33.8% are highly moderately suitable for Green gram production, respectively (Table 4.16 and Figure 4.15).

Table 4.16: Overall suitability for Green gram during MAM and OND season

Suitability(MAM)	**Area(Ha)**	**Area (%)**	**Suitability(OND)**	**Area(Ha)**	**Area (%)**
S1	139302	4.6	**S1**	2022940	66.2
S2	1672016	54.7	**S2**	1031208	33.8
S3	1243550	40.7	**S3**	720	0

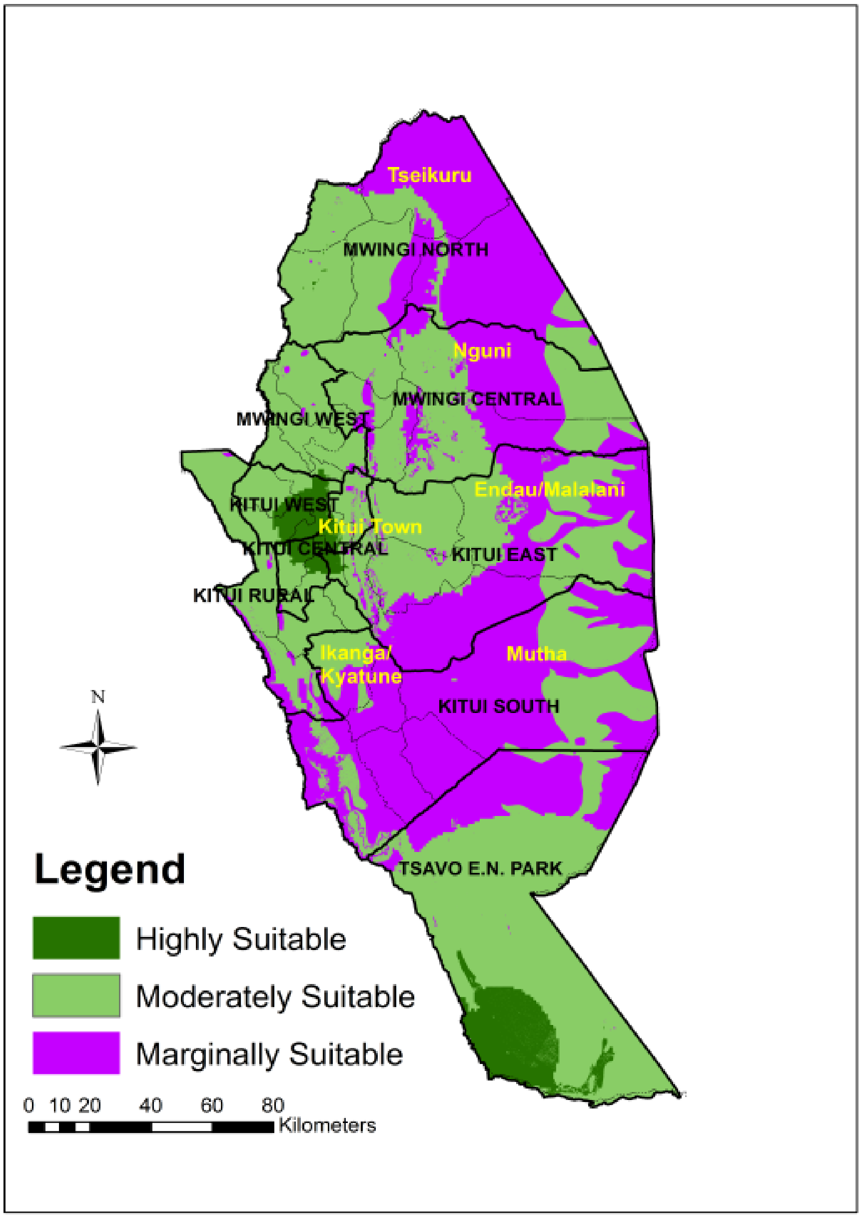

Figure 4.14: Overall suitability for Green gram during MAM season

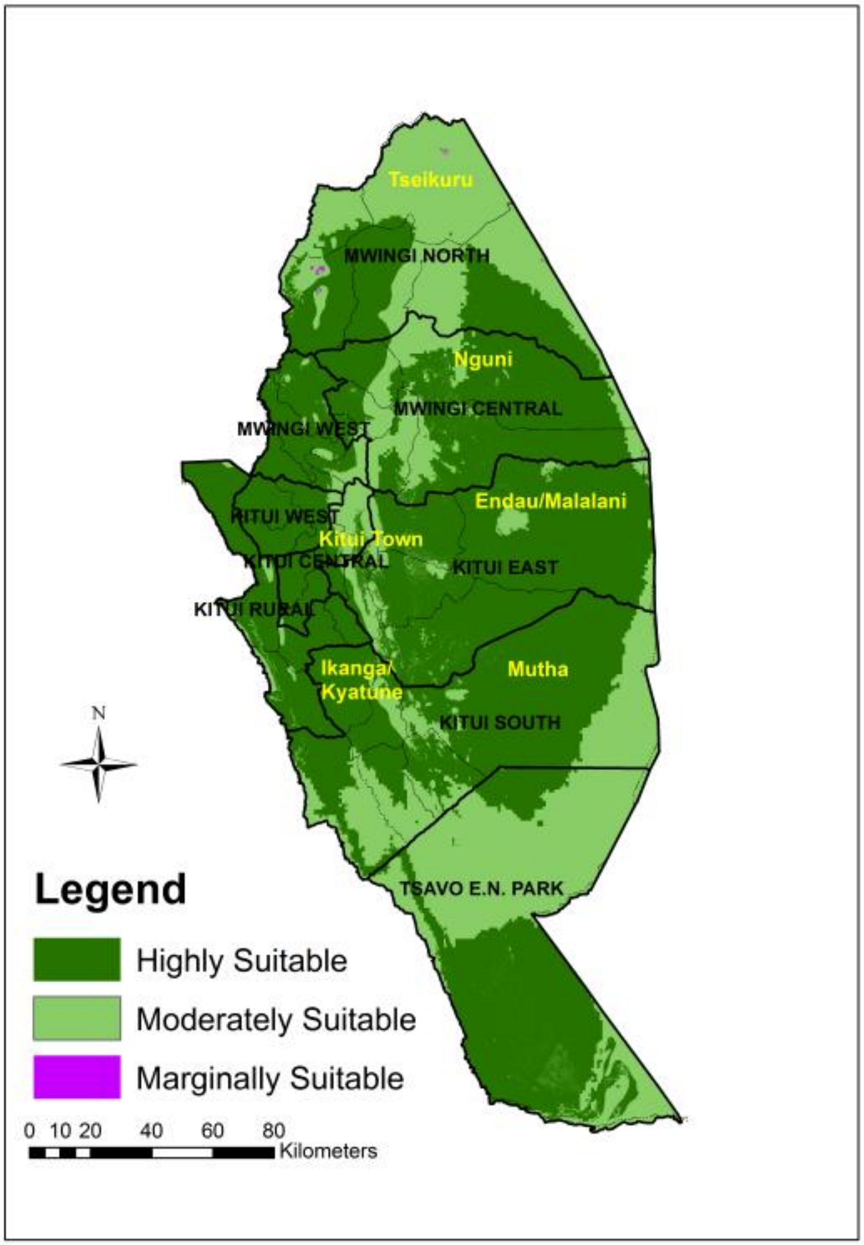

Figure 4.15: Overall suitability for Green gram during OND season

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion of findings

The discussion has been divided into four sections. Sections 5.1.1 to 5.1.3 are based on the main criteria Climate, Soil and Topography and show the potential for production ofGreen gram in KituiCountybased on each criteria. Section 5.1.4 discussesthe weighted overlay.

5.1.1 Different potentials for Green gram in MAM and OND seasons

During the MAM season, 50.4% of the County is suitable for Green gram production and 49.6% is not suitable. The suitable areas in MAM are in the Central and Western regions of the County (Figure 4.1b). During OND rainfall season the County receives increased rainfall such that the whole County is now suitable for Green gram production at varying levels with 75.7%, 22.5% and 1.9% being highly, moderately and marginally suitable, respectively. The areas of marginal suitability are located in the extreme Northern and Southern part of the County (Figure 4.2b). Takeshi and Ruth (2015) have described Green gram to perform best when rainfall is between 350 - 600 mm, moderately when it is 300 - 350 mm and 600 - 1000 mm and marginally at rainfall between 230 - 300 mm conditions which could explain the change in suitability levels for this season.

Unclassified maps of MAM and OND shows that temperature increases from West to East. Areas of high suitability in both seasons with respect to temperature are located in the central and eastern part of the County (Figure 4.3b and 4.4b). The suitability analysis shows that there are two suitability classifications for Green gram in Kitui. In MAM season 78.7% and 21.3% are highly and moderately suitable, respectively (Figure 4.3b and Table 4.3) but during OND seasonthe highly suitable area in MAM reduces such that 70.0% and 30.0% consists of highly and moderately suitable areas, respectively (Figure 4.4b and Table 4.4). The difference in potential could be explained by the factthat Green gram perform best at a temperature of 30-24 °C and moderately well at 24-20 °C (Mogosti, 2006; Morton *et al*., 1982; DPP, 2010) and MAM has higher temperature than OND.

The AHP showed rainfall to be more important in terms of climate with an influence of 67% relative to temperature with 33% influence (Table 4.5). This gives an indication of the importance of water in the dry lands in limiting crop growth (Kisaka *et al*., 2015) and agrees with Ongoma *et al*., (2015) that rainfall is the most important weather parameter in East Africa as the economies of the region are dependent on rain fed agriculture.

When rainfall and temperature are overlaid in MAM (Figure 4.5 and Table 4.6), 4.9% of Kitui County is highly suitable, 33.9% is moderately suitable and 61.3% is marginally suitable for Green gram production. The pockets of high suitability for Green gram production in MAM are found around Kitui west and Kitui Central Sub Counties and the extreme southern region of Kitui South which is part of the Tsavo National Park reserve thus not recommended for production (Figure 4.5). In OND two classes emerge where 75.6% is highly and 24.4% is marginally suitable for Green gram production (Figure 4.6). The higher area in OND is caused by increased rainfall and one can draw the conclusion that it is the better season to plant Green gram in Kitui County. This agrees with Ranawake *et al*., (2012) conclusions that yield of Green gram is more dependent on adequate water supply than any other single environmental factor.

5.1.2 Soil suitability for Green gram

Soils have different physical and chemical properties that affect the productivity of Green gram. There is no past study showing the spatial variation of soil texture, depth, pH, drainage, CEC in relation to Green gram productivity in Kitui County.

The maps of the soil pH (Figure 4.9) and drainage (Figure 4.10) reveal that the Central area of the County is not suitable but only marginally suitable in terms of soil depth (Figure 4.8). Marginally suitable areas of soil CEC are found in the extreme South Easternregion.

All the land was found suitable for Green gram production with respect to the texture criteria (Figure 4.7 and Table 4.7) with 13.4% highly suitable (Loamy, Sandy), 79.5% moderately suitable (Clayey) and 7.1% marginally suitable (Very Clayey). Texture is a very important factor that affects most of the physical characteristics of the soil (Halder, 2013; Mustafa, 2011). The relative proportion of clay, silt and sand gives the textural class of the soil (Baniya, 2008). Texture determines the suitability of a site for Green gram production in that Green gram perform best in fertile loams or sandy loams (Mutua *et al.*, 1990; Mogotsi, 2006; Oplinger *et al.*, 1990; Morton *et al.*, 1982) and are well adapted to clayey soils but perform poorly on heavy clays soils (Grealish *et al.*, 2008, Oplinger *et al.*, 1990).

In terms of depth (Figure 4.8 and Table 4.8), 50.9% (>50cm) of the County is highly suitable, 0.01% (50-30cm) moderate and 49.0% (<30cm) marginally suitable for Green gram production. Shallow soils limit root growth and thus the ability of the plant to absorb water and nutrients (DPP, 2010). In addition, shallow soils do not have adequate room for water storage thus during periods of prolonged dryness the plant suffers water stress. This could explain the importance of depth for green gram production.

The suitability analysis for Green gram in terms of soil pH (Figure 4.9 and Table 4.9) showed that 49.2% of the area has suitable pH of which 22.2% is highly suitable (6.2-7.2), 23.7% is moderate (5-6.2) and 3.3% (7.2-8) marginally suitable. 50.8% of the area has land that is not suitable (<5 or >8) for Green gram production. pH provides information on solubility and thus potential availability or phyto-toxicity of elements for any crop and thus determines the soil that is most suitable for a specific crop (Kamau *et al.*, 2015) in this case green gram.

Soil drainage is important in that good drainage shows the speed at which free moisture drains from the soil. Soils that are poorly drained are likely to result in root rot, pathogens and fungal growth. Green grams prefer well drained soils for best performance (Mutua *et al.*, 1990; Mogotsi, 2006; Oplinger *et al.*, 1990; Morton *et al.*, 1982). The study shows that 52.9% of the area is suitable for cultivation and 47.1% of the area is not suitable in this respect (Figure 4.10 and Table 4.10).

Green gram has Potassium, Phosphorus, Magnesium, Calcium and Sulfur requirements that must be met (DPP, 2010). Soil CEC affects the acidity and nutrient availability of the soil. High CEC soils require less liming compared to those soils with low CEC (Moore and Blackwell, 1998). Lower CEC soils are more likely to be deficient and also have high leaching capacity making fertilizer application not economical (CUCE, 2007). In the study area, all land is suitable in terms of CEC with 69.8% being high (>10), 18.1% moderate (10-5) and 12.1% marginally suitable (<5) (Figure 4.11 and Table 4.11).

When all the sub criteria of soil are composited (texture, depth, pH, drainage and CEC),only 33.1% of the Countyis highly suitable with 14.8% moderate and 52.1% marginally suitable. The marginal area is a zone running north to south through the center of the County (Figure 4.12 and Table 4.13).

Green gram perform well in all soils in KituiCounty with only limitationsin pH and drainage which can be managed through liming and adopting farming techniques that improve drainage. With sufficient knowledge about the different characteristics of soils, farmers and decision makers can manage their farms better to improve Green gram farming.

5.1.3Slope potential for Green gram

The results showed that 97.9% of Kitui Countyis suitable with only 2.1% of the total area being unsuitable for Green gram cultivation based on topography (Figure 4.13 and Table 4.14). This shows the County to generally have suitable topography for green gram production. The slope plays a significant role in crop production with steep slopes resulting in soil erosion during intense rainfall, acting as a hindrance to land preparation and to water and crop management especially for mechanized farming. In addition to this, steep slopes do not favor rain water infiltration thus water is not stored in the soil for usage during growth. Research has generally proposed slopes steeper than 35% not to be developed for green gram farming (Grealish *et al.*, 2008). The fact that 98% is suitable for production gives the County an advantage on crop production on the basis of topography.

5.1.4Overall suitability map

Based on the abovefindings, Kitui County has varying degrees of suitability for Green gram production during the MAM season where 4.6% is highly, 54.7% moderately and 40.7% marginally suitable. Pockets of high suitability for Green gram production in MAM are found in Kitui west and Kitui Central sub counties and the extreme southern region which is in the Tsavo East National Park reserve (Figure 4.14 and Table 4.16).

During OND (Figure 4.15 and Table 4.16)66.2% of the County is highly suitable and 33.8% moderately suitable for Green gram production. Areas of Moderate suitability are found in the Northern most part of Mwingi North and Kitui South Sub Counties and along a strip in the central region of the County, thisagrees with SASOL (2015) report that most areas in Kitui are suitable for growing Green gram.Farm Africa (2016) reported that farmers in Mwingi and Kitui are improving their livelihood significantly through Green gram farming which performs well.

5.2 Validation

The results of the validation are presented in Table 5.1.

Table 5.1: Validation results for Green gram suitability in Kitui County

Sub County	Approximate percentage of farmers who grow Green gram	Suitability of sub County for Green gram	Potential for Green gram production compared to rest of the County	Wards with the highest yields in each sub County	Seasons when Green gram is grown	Best performing season	Why season performs better	Why performance in other season is not as good
Kitui Central	60%	Highly suitable (do well)	Among the best in the County	Whole sub County produces but most comes from Miambani ward	MAM OND	OND	Receives more rains	Rainfall is poorly distributed and mostly below average.
Kitui East	>70% (mostly lower part)	Highly suitable(perform very well)	Best in the County	Endau/Malalani and Mutito/Kaliku	MAM OND	OND	Receive more rains	Rainfall is not enough
Kitui Rural	85%	Highly suitable (performance is okay)	Very high	Yatta/Kwa Vonza	MAM OND	OND	More reliable rains	Rains are unreliable
Kitui West	35-40%	Highly suitable (Quite well)	Potential less than Kitui South and Mwingi North	-Kauwi -Mutonguni -KwaMutonga	MAM OND	OND	More reliable rains	Rains are not as good as in OND season
Kitui South	70% (major cash crop)	Highly suitable (very well)	Lead the County with Mwingi North	-Mutha -Ikutha -Mutomo -Ikanga	MAM OND	OND	More reliable rains	MAM is a very short season

Sub County	Approximate percentage of farmers who grow Green gram	Suitability of sub County for Green gram	Potential for Green gram production compared to rest of the County	Wards with the highest yields in each sub County	Seasons when Green gram is grown	Best performing season	Why season performs better	Why performance in other season is not as good
Mwingi Central	100%	Highly Suitable (sometimes fairly well)	Best potential in the County	-Mui	MAM OND	OND	More reliable rains	- unreliable rains - higher incidences of Powderly mildew
Mwingi North	100%	Some parts highly and others Moderately suitable	High potential	-Tseikuri and Ngomeni are the most productive -Kyuso -Mumoni -Tharaka,	MAM OND	OND	Rains are sufficient	- Poor rains - Very low production
Mwingi West	80%	Moderately suitable (sometimes very well)	High potential	-Ngutani -Kiomo/ Kyethani -Kyome/Thaana -Migwani	MAM OND	OND	Almost always promising in terms of rainfall	- Crops are attacked by Wasps - Rainfall is not reliable

There are 8 sub counties in Kitui County, namely, Kitui Central, Kitui East, Kitui Rural, Kitui West, Kitui South, Mwingi North and Mwingi West and most farmers grow Green gram in all of them. The validation results show that when rainfall is adequate especially in the OND season productivity ranges from highly to moderately suitable in all the sub counties which agree with the model.

In Kitui Central Sub County, all wards are productive but the highest yields come from Miambani while in Kitui East Sub County the highest yields come from Endau/Malalani and Mutito/Kaliku wards.In Kitui Rural Sub County most yields come from Yatta/ Kwa Vonza ward. In Kitui West Sub County the highest producing wards are Kauwi, Mutonguni and Kwa Mutonga where farms areas differ in size. Mutha, Ikutha, Mutomo and Ikanga wards have the highest yields in Kitui South. Muui produces the highest yields in Kitui Central.

In Mwingi North Sub County highest yields come from Tseikuru and Ngomeni ward. Most farmers in Tseikuru ward have embraced Green gram farming since it's the only crop that does well in that environment. Kyuso and Mumoni ward in Mwingi North also grow Green gram; but farmers in Mumoni prefer to grow maize therefore the total volumes are not as high. Tharaka in Mwingi North is moderately suitable because in some areas the soils are very rocky and the area is hilly. Lastly in Mwingi West sub County Nguutani, Kiomo/Kyethani and Kyome Thaana wards have the highest yields; Green gram in Migwani ward in Mwingi west does not perform well since its hilly.

Although farmers grow Green gram in both seasons, the performance is better in the short rains (OND) season for all the Sub Counties. The OND season have the highest suitability because the rains are more reliable and sufficient for production. The MAM season is not suitable because rainfall is unreliable and poorly distributed. Incidences of Powderly mildew and Wasps infestations are also reportedly high during the MAM season.

The results of the validation agree with the study that rainfall is the most important factor affecting Green gram production as all the responses equate high performance to adequate rainfall. The validation results also agree with the study that OND is the most productive season to grow Green gram in the County. The model analysis shows that during the MAM season the highly suitable areas are found in Kitui Central and Kitui West Sub Counties (Figure 18), while the rest of the County has moderate to marginal suitablity which agrees with the results of the validation study.

5.3 Conclusions of the study

All land in Kitui County is suitable for Green gram production in varying degrees of suitability and has been ranked in accordance with FAO guidelines as highly, moderately and marginally suitable. The main factors limiting suitability in both MAM and OND season include highly acidic and alkaline soils, very poor drainage and steep slopes. In addition to this, during the MAM season most areas in the County receive rainfall amounts that are not enough to sustain Green gram production.

The model performed well in Kitui County because the validation results generally agreed with it. It can also be concluded that Kitui County has a vast potential for Green gram production

5.4Recommendations from the study

Most land in Kitui County falls into the highly, moderately and marginally suitable classes and the following recommendations can be made from the study which can help improve Green gram production.

1. In areas that are highly suitable in both seasons all players in the Green gram value chain should take opportunity of the good environmental conditions and adequately prepare for cultivation as a good harvest is highly likely. Preparation for farmers includes using the appropriate inputs in terms of seeds, fertilizers and pesticides which will ensure positive results as the environment is already suitable for cultivation.

2. In areas that are moderately or marginally suitable players in the value chain are also encouraged to grow and invest for example banks can give loans to farmers. The only issue is that more attention is required for a good harvest to be obtained as opposed to areas in the highly suitable class.
3. Since the main factor limiting suitability during MAM is poor rainfall, the Government could consider, where possible, supplementing the rainfall with irrigation to improve production.
4. Areas whose soilpH is not suitable for production should be improved uponthrough liming to raise the pH to suitable levels.
5. Areas with slope above 35% can be developed for activitieslike tree planting other than Green gram cultivation.
6. Area with poor drainage should be improved upon by building fallows to improve drainage during the rainy season

5.5 Suggested areas for further research

The following areas are suggested for further research

1. Many factors affect the success of green grams such as availability of storage facilities, access to markets, price, availability of seeds, fertilizer and population density these can also be mapped and added to the green gram suitability model database.
2. A further validation exercise should be done with real production figures in future, this would further strenghthen the results presented in the study.

REFERENCES

Addeo, G., Guastadisegni, G., and Pisante, M. (2001). Land and water quality for sustainable and precision farming. In *World Congress on Conservation Agriculture, Madrid*.

Agricultural Sector Development Programme(ASDSP). (2016). *Kitui County Profile*. Retrieved 15th February, 2016 from Agricultural Sector Development Programme: http://www.asdsp.co.ke/index.php/kitui-County/

Ahamed, T. N., Rao, K. G., and Murthy, J. S. R. (2000). GIS-based fuzzy membership model for crop-land suitability analysis. *Agricultural systems*, *63* (2), 75-95.

Atthirawong, W., and MacCarthy, B. (2002). An application of the analytical hierarchy process to international location decision-making. In *Gregory, Mike, Proceedings of The 7th Annual Cambridge International Manufacturing Symposium: Restructuring Global Manufacturing, Cambridge, England: University of Cambridge* (pp. 1-18).

Baniya, M. S. N. (2008). *Land suitability evaluation using GIS for vegetable crops in Kathmandu valley/Nepal* (Doctoral dissertation, Humboldt-Universität zu Berlin).

Bello, D. A., Farmani, R., Javadi, A.A., and Evans, B.M. (2009). The Analytical Hierarchy Process for contaminated land management. *Advanced Engineering Informatics*, *23(*4): 433-441.

Boitt, M. K., Mundia, C. N., Pellikka, P. K., and Kapoi, J. K. (2015). Land Suitability Assessment for Effective Crop Production, a Case Study of Taita Hills, Kenya. *Agrárinformatika/Journal of Agricultural Informatics*, *6*(2), 23-31.

Bouyssou, D. (2008). Outranking methods Outranking Methods. In*Encyclopedia of optimization* (pp. 2887-2893). Springer US.

Bunruamkaew, K., and Murayam, Y. (2011). Site suitability evaluation for ecotourism using GIS and AHP: A case study of Surat Thani province, Thailand. *Procedia-Social and Behavioral Sciences*, *21*, 269-278.

Chandio, I. A., Matori, A. N., Lawal, D. U., and Sabri, S. (2011). GIS-based land suitability analysis using AHP for public parks planning in Larkana City. *Modern applied science*, *5*(4), 177-189.

Chatterjee, D., and Mukherjee, B. (2013). A study on the comparison of ahp and fuzzy ahpevaluations of private technical institutions in india. *International Journal Of Innovative Technology And Research*, *1*(4), 283-291.

Chebet, C. (2012). Suitability Analysis of Watersheds in Keiyo District, Kenya. *Journal of Emerging Trends in Educational Research and Policy Studies*, *3*(5), 762-767.

Cornell University Cooperative Extension (CUCE). (2007). *Cation Exchange Capacity (CEC)*. [Agronomy Fact Sheet Series # 22]. Department of Crop and Soil Sciences, College of Agriculture and Life Sciences, Cornell University.Retrieved 10th June, 2016, from nmsp.cals.**cornell**.edu/publi**cations**/factsheets/factsheet22.pdf

Dadfar, N. A. (2014). *Suitability analysis of a new high school in the city of Calabasas* (Doctoral dissertation, California State University, Northridge).

Directorate Plant Production (DPP). (2010) Mung bean production guideline. PRETORIA: Retrieved 15th February, 2016 from Department of Agriculture, Forestry and Fisheries:www.nda.agric.za/docs/Brochures/MbeanpGUDELINS.pdf

Economic Review of Agriculture (ERA). (2013). Central Planning and project Monitoring unit Ministry of Agriculture, Livestock and Fisheries. Retrieved 12th February, 2016, from http://www.asdsp.co.ke/index.php/kitui-County/

FAO. (1976). A framework for land evaluation: *Soils Bulletin **32***, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. (2012). Grassland Index. A searchable catalogue of grass and forage legumes. FAO, Rome, Italy

Farm Africa. (2016). Sorghum and Green grams [Fact sheet]. Retrieved 10th February, 2016, from http://www.farmafrica.org/kenya/sorghum-and-green-grams/

Feizizadeh, B., Roodposhti, M. S., Jankowski, P., and Blaschke, T. (2014). A GIS-based extended fuzzy multi-criteria evaluation for landslide susceptibility mapping. *Computers & geosciences*, *73*, 208-221.

Gachari, D. K., Mary, W., and Mungai, E. (2011). Mapping groundwater potential in Kitui District, Kenya using geospatial technologies. *International Journal of Water Resources and Environmental Engineering*,*4*(1), 15-22.

Grealish, G. J., Ringrose-Voase, A. J., Fitzpatrick, R. W., Wong, M. T. F., and Winston, E. C. (2008). Soil Fertility Evaluation/Advisory Service in Negara Brunei Darussalam Volume 1-Soils and Land Suitability of the Agricultural Development Areas. *Science Report*, *57*(08).

Halder, J. C. (2013). Land suitability assessment for crop cultivation by using remote sensing and GIS, *Journal of Geography and Geology*, *5*(30), 65-74.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International journal of climatology*, *25*(15), 1965-1978.

Hossain, M. A. (2010, August). Global warming induced sea level rise on soil, land and crop production loss in Bangladesh. In *19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane. http://www. ars. usda. Gov/Services/docs. htm*.

Jaetzold, R., Schmidt, H., Hornet, B., and Shisanya, C. (1983). Farm Management Handbook of Kenya, Vol. II/C1. Ministry of Agriculture, *Kenya and German Agency Technical Cooperation team (CTZ).*

Jafari, S., and Zaredar, N. (2010). Land suitability analysis using multi attribute decision making approach. *International journal of environmental science and development*, *1*(5), 441-445

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International journal of geographical information systems*, *9*(3), 251-273.

Kamau, S. W., Kuria, D., and Gachari, M. K. (2015). Crop-land Suitability Analysis Using GIS and Remote Sensing in Nyandarua.*Journal of Environment and Earth Science,5*(6), 121-131.

Kangas, A., Kangas, J., and Pykäläinen, J. (2001). Outranking methods as tools in strategic natural resources planning. *Silva Fennica*, *35*(2), 215-227.

Khoi, D. D., and Murayama, Y. (2010). Delineation of suitable cropland areas using a GIS based multi-criteria evaluation approach in the Tam Dao National Park region, Vietnam. *Sustainability*, *2*(7), 2024-2043.

Kihoro, J., Njoroge, J. B., and Murage, H. (2013). Suitability analysis for rice growing sites using a multi-criteria evaluation and GIS approach in great Mwea region, Kenya, *SpringerPlus*, vol. 2, 265-274.

Kisaka, M.O., Mucheru-Muna, M., Ngetich, F.K., Mugwe, J.N., Mugendi, D., and Mairura, F. (2015). Rainfall variability, drought characterization, and efficacy of rainfall data reconstruction: case of eastern Kenya. *Advances in Meteorology*, http://doi.org/10.1155/2015/380404

Kuria, D., Ngari, D., and Waithaka, E. (2011). Using geographic information systems (GIS) to determine land suitability for rice crop growing in the Tana delta. *Journal of Geography and Regional Planning*, *4*(9), 525.

Krishna, K. R. (2010). *Agroecosystems of South India: nutrient dynamics, ecology and productivity*. Universal-Publishers.

Lupia, D. F.(2014). Crop/land suitability analysis by ArcGIS tools. Technical report, http://doi.org\10.13140/2.1.2379.2329

Maddahi, Z., Jalalian, A., Zarkesh, M. M. K., and Honarjo, N. (2014). Land suitability analysis for rice cultivation using multi criteria evaluation approach and GIS. *European Journal of Experimental Biology*, *4*(3), 639-648.

Majumder, M. (2015). Impact of Urbanization on Water Shortage in Face of Climatic Aberrations. Springer Verlag, Singapore, pp. 35-47. http://doi.org\10.1007/978-981-4560-73-3_2

Malczewski, J. (2006). GIS-based multicriteria analysis: a survey of the literature. *International Journal of Geographic Information Science*, **20**: 703–726.http://dx.doi.org/10.1080/13658810600661508

Mendoza, G. A. (2000). GIS-based multicriteria approaches to land use suitability assessment and allocation. *United States Department of Agriculture Forest Service General Technical Report NC*, 89-94.

Mogotsi, K.K., 2006. *Vigna radiata* (L.) R.Wilczek. [Internet] Record from Protabase. Brink, M. & Belay, G. (Editors). PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.http://database.prota.org/search.htm

Mokarram, M., and Aminzadeh, F. (2010). GIS-based multicriteria land suitability evaluation using ordered weight averaging with fuzzy quantifier: a case study in Shavur Plain, Iran. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *38*(2), 508-512.

Moore, G., and Blackwell, P. (1998). Water repellence. *Soil guide: a handbook for understanding and managing agricultural soils. Agriculture Western Australia Bulletin*, (4343), 53-63.

Morton, F., Smith, R. E., and Poehlman, J. M. (1982). The Mungbean. PUERTO RICO: the College of Agricultural Sciences.

Mustafa, A. A., Singh, M., Sahoo, R. N., Ahmed, N., Khanna, M., Sarangi, A., and Mishra, A. K. (2011). Land suitability analysis for different crops: a multi criteria decision making approach using remote sensing and GIS.*Researcher*, *3*(12), 61-84.

Mutua, P., Mutisya, M., and Kimotho, N. (1990)Green gram. Retrieved 12th February, 2016, from drylandseed.com/download/filedownload.php?file=green_gram.pdf/

Ongoma, V., Guirong, T., Ogwang, B.A., and Ngarukiyimana, J.P. (2015). Diagnosis of seasonal rainfall variability over East Africa: A Case study of 2010-2011 drought over Kenya. . *Pakistan Journal of Meteorology, 11*(22), 13-21.

Oplinger, E., Hardman, L., Kaminski, A., Combs, S., and Doll1, J. (1990). Alternative fields crop manual. Retrieved 12thFebruary, 2016, from Center for New Crops and Plant Products: https://hort.purdue.edu/newcrop/afcm/mungbean.html/

Perveen, F., Nagasawa, R., Uddin, I., and Delowar, H. K. (2007). Crop land suitability analysis using a multicriteria evaluation and GIS approach. In *5th International Symposium on Digital Earth. Berkeley, USA: The University of California* (pp. 1-8).

Prakash, T. N. (2003). Land suitability analysis for agricultural crops: a fuzzy multicriteria decision making approach. *MS Theses international institute for geo-information science and earth observation enschede, the Netherlands*.

Ranawake, A. L., Dahanayaka, N., Amarasingha, U. G. S., Rodrigo, W. D. R. J., and Rodrigo, U. T. D. (2012). Effect of water stress on growth and yield of mung bean (Vigna radiata L). *Tropical agricultural research and extension, 14*(4),http://doi.org/10.4038/tare.v14i4.4851

Republic of Kenya (2009). Agricultural Sector Development Strategy. Ministry of Agriculture. *Government Press*;Nairobi

Republic of Kenya (RoK) (2010). National Climate Change Response Strategy.*Government Press*;Nairobi

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of mathematical psychology*, *15*(3), 234-281.

Saaty, T. L. (1980). The Analytic Hierarchy Process: New York, NY, McGraw Hill, reprinted by RWS Publication, Pittsburgh.

Saaty, T. L (2000). *Fundamentals of decision making and priority theory with the analytic hierarchy process*. RWS Publications, Pittsburgh, 6: 21-28pp.

Sahelian Solution Foundation (SASOL). (2015)Green grams Hand Book, *A guide to farmers within project enhancing food security with Diversified Dry land Farming Techniques in Kitui County*. Retrieved 8th March, 2016, from www.sasolfoundation.co.ke/2013/wp.../02/Green-Grams-Manual.pdf

Swaminathan, R., Singh, K., and Nepalia, V. (2012). *Insect Pests of Green gram Vigna radiata (L.) Wilczek and Their Management*. INTECH Open Access Publisher.

Takeshi, T., and Ruth, B. (2015). Using climate information for supporting mung bean plantation over Sumbawa region. *OnWeAdapt, the Collaborative Platform on Climate Adaptation.* Retrieved 8th March, 2016, fromhttps://www.weadapt.org/knowledge-base/climate-adaptation-training/using-climate-information-for-supporting-mung-bean-plantation-over-sumbawa-region

Tienwong, K., Dasananda, S., and Navanugraha, C. (2009). Integration of land evaluation and the analytical hierarchical process method for energy crops in Kanchanaburi, Thailand. *ScienceAsia*, *35*, 170-177.

Tisza, K. (2014). GIS-based suitability modeling and multi-criteria decision analysis for utility scale solar plants in four states in the Southeast US. (MSc. Thesis, Clemson University, South Carolina)

United Nations (UN). (2015). Sustainable Development Goals. Retrieved 20th April, 2016, from http://www.un.org/sustainabledevelopment/sustainable-development-goals/

Xu, L., and Yang, J. B. (2001). *Introduction to multi-criteria decision making and the evidential reasoning approach*. Manchester School of Management.

APPENDICES

Appendix 1: Questionnaire for Crop Experts

NAME:

ORGANISATION:

AREA OF SPECIALISATION:

QUESTION	CRITERIA	PERCENTAGE INFLUENCE ON GROWTH	REMARKS
1. These are the **main criteria** affecting Green gram from your own experience please rate them out of a 100%.	Climate		
	Soil		
	Topography		
	TOTAL	**100%**	
2. These are the sub criteria under **climate** from your own experience please rate their influence of Green gram growth out of 100%.	Rainfall		
	Temperature		
	TOTAL	**100%**	
3. These are the main sub criteria under **soil** from your own experience please rate them out of 100%.	Cation exchange capacity(CEC)		
	Texture		
	Drainage		
	Depth		
	pH		
	TOTAL	**100%**	
4. This is the main sub criteria under topography.	Slope	No need to rate	

Appendix 2: Validation Questionnaire for Green Gram Suitability In Kitui County Using SCALDOs

NAME OF OFFICER:

SUBCOUNTY:

TELEPHONE:

1. Do farmers grow green gram in your sub County?

   …………………………………………………………………

2. What percent of farmers grow green gram in your sub County?

   ………………………………………………………………………..

3. How do green grams perform in this sub County?

   …………………………………………………………………………………
   ……..

4. How suitable is the environment in this sub County for green gram? (Would you say the sub County is highly suitable, moderately suitable, marginally suitable or not suitable for Green gram?)

   …………………………………………………………………………………
   ……………

5. How is the potential of green gram in this sub County compared to the rest of the County?

   …………………………………………………………………………………..

6. Which wards produce high yields within the sub County?

   …………………………………………………………………………………
   ……….

7. In which seasons do farmers grow Green gram in this sub County?

   ……………………………………………………………………………….

8. Is the performance the same in the seasons mentioned?

   ……………………………………………………..

9. In Which season does Green gram perform better in this sub County?
    a) ‘Long rains’ March-April-May (MAM) season

    b) ‘Short rains’ October-November-December season

10. Why in your opinion is more Green gram grown in the chosen season?

    …………………………………………………………………

11. Why isn’t the other season as preferred?

    ……………………………………………………………………..

Appendix 3:Weights of all Criteria and Sub Criteria

Main Criteria	W1	Sub criteria	W2/100	W=W1*W2
Climate	70	Rainfall	0.67	47
		Temperature	0.33	23
Soil	23	Soil CEC	0.23	5
		Soil Texture	0.12	3
		Soil drainage	0.39	9
		Soil depth	0.09	2
		Soil pH	0.17	4
Topography	7	Slope	1	7