

ORIGINAL RESEARCH ARTICLE**Land suitability assessment for mango production in Kitui County, Kenya**

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ABSTRACT

Mango remains an important tropical and sub-tropical crop, ranking as the sixth most cultivated and popular across the globe. Despite thriving in many tropical and sub-tropical areas, regions previously dedicated to mango cultivation are undergoing a shift to different agricultural pursuits due to a lack of sustainable mango output. Due to the spatial variability of factors affecting production, not all areas are suitable for mango production in Kenya. This study aims to develop a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) technique-based approaches for land suitability assessment for mango growing in Kitui County, Kenya. Thematic maps of all variables (Rainfall, temperature, soils, slope, rivers, land use/land cover, and roads) affecting mango growing were developed using GIS. The maps were evaluated in accordance with the published ideal parameter value ranges for mango production and these evaluations served as a basis for allocating weights to the thematic layers with respect to mango production. Thereafter, the weighted overlay maps of the thematic layers (ArcGIS) were used to develop the land suitability map. The map was categorized into four classes based on mango production suitability namely: highly suitable, moderately suitable, marginally suitable, and not suitable. Results show that 79.8 % of the study area is highly suitable for mango production, 1.1 % moderately suitable, 13.9 % marginally suitable, and 5.2 % is not suitable for mango production. This suggests that a significant portion of the study region is favorable for mango cultivation, with limited sections in the study area that are only moderately or completely unsuited for mango cultivation. The socio-economic factors highly ranked by farmers to be useful for mango production are roads. These results provide useful insights to policy makers, enabling them

make informed decisions on how to decrease land degradation and to assess sustainable land use, especially for mango production.

Key Words: Land, suitability, assessment, mango, GIS, Analytical Hierarchy Process (AHP), Kenya

1.0 Introduction

Agriculture is the mainstay of Kenya's economy, contributing 51 percent of Kenya's GDP (26 percent directly and 25 percent indirectly) while accounting for 60 and 65 percent of employment and exports, respectively (World Bank, 2018). Generally producing on farms averaging between 0.2 and 3 hectares, Kenya's agricultural sector is dominated by smallholder farmers, who account for 78 percent of total agricultural production and 70 percent of commercial production (World Bank & CIAT, 2015). In Kenya's 80% of land is classified as arid/semi-arid, This is attributed by the poor soils which again results to low yield (Yageta et al., 2022). Thus, selecting the appropriate agricultural areas for farming is a prerequisite for good ergonomics and economic viability.

Land is a very important natural resource that brings health and provides a good base for life by giving forth food, shelter, and fuel (Food and Agriculture Organization of the United Nations, 2017). The economic growth of every country relies mainly on land (Feizizadeh & Blaschke, 2013). Depletion of the land's resources caused by, among other things, soil erosion, water logging, and heavy runoff, greatly affects food security; something experienced around the world (Gupta, 2019). This brings about land degradation and a significant decline in soil productivity (AbdelRahman, 2023). When land allocation is required, the evaluation of land quality with respect to its potential and constraints is of great value (Mugiyo et al., 2021). Crop land suitability analysis is important for achieving optimum utilization of available land resources for agricultural production in a sustainable manner (Halder & Abu Hasan, 2020). This is due not just to the fact that the demand for land resources is increasing globally, as the population grows and prospers, but also because soil health and agricultural production continue to decline (Montanarella et al., 2016).

Land suitability assessment is defined as the appropriateness of specific kinds of land use based on social, economic, and environmental attributes (AbdelRahman et al., 2022). Identifying and assessing suitable areas should be conducted in such a way that local needs and conditions are reflected in the final decision (Everest et al., 2021). Activities like infrastructure development, land reclamation, and sand mining may damage areas suitable for agriculture, hence the need for assessment (Rizal Ichsan Syah & Hartuti, 2018). Land users will be able to know if the land has potential and constraints through suitability assessment (Everest et al., 2021). Land resources are not equally distributed across communities, people are struggling to gain access to the most suitable areas (Alden Wily, 2018). Therefore, having knowledge about land and the pattern of existing resources is important since it will help policymakers, land users, and planners to project and plan for future development. Information on land should also be collected to help identify areas suitable for agricultural production (Ordu & Demir, 2009).

Mango remains an important tropical and sub-tropical crop, ranking as the sixth most cultivated and popular fruit across the globe (Tharanathan et al., 2006). Despite the crop thriving in many tropical and sub-tropical areas, regions previously dedicated to mango cultivation are undergoing a shift to different agricultural pursuits due to a lack of sustainable mango output (Mugo et al., 2021). Due to the spatial variability of factors affecting production, in Kenya, not all areas are suitable for mango production (Salunkhe et al., 2023). This study assesses the suitability of land for mango production in Kenya using Kitui County as a case study. The focus on mango is because it is widely produced globally due to its nutritive value and economic value (Normand et al., 2015). Mango farming contributes about 5% of the agricultural GDP and 2% of the national GDP, employing a sizable portion of the seasonal labor force (Kihoro et al., 2013); Kitui County remains one of Kenya's top regions for producing mangoes, where it is the main livelihood for the majority of the households (Uckert et al., 2023). Cultivation of mango needs a well-planned suitable land (Salunkhe et al., 2023). In order to increase production and reduce food insecurity, mangoes should be grown in the most suitable areas; hence it is important to identify those land attributes that significantly influence mango production (Kihoro et al., 2013).

Although various studies on land suitability analysis have been carried out by different researchers, mainly targeting crop production (Kalogirou, 2002); (Bandyopadhyay et al., 2009); Mustafa et al., 2011); Mendas & Delali, 2012; Feizizadeh & Blaschke, 2013; Mugo et al., 2021 and Salunkhe et al., 2023 among others), there remains a dearth of information relating to suitable areas for mango production. In the Sapa district of northern Vietnam, Dang et al. (2019) use a hybrid neural-fuzzy model to map different land suitability classes and forecast rice yields. Harms et al. (2015) assessed the land suitability for irrigated crops, using digital mapping techniques and machine learning algorithms, across 155,000 km² of northern Australia. Except for Salunkhe et al., (2023), who assess the land suitability in the Ratnagiri district, India, for mango crop using a combination of multi-criteria decision making (MCDM) with GIS-based analytic hierarchy process (AHP), and sensitivity analysis, few studies capture mango as the crop of interest.

Further, majority of the existing studies on land suitability concentrated more on environmental and GIS approaches while giving less attention to the economic and social status that may have a significant influence on production and, in particular, on mango production. The studies also ignore other methods, including AHP techniques. This study fills these gaps by assessing suitable land for mango production in Kitui County using GIS and AHP techniques, incorporating both economic and social economic aspects. The study provides useful insights to mango producers and other stakeholders that will help boost mango production in the study areas.

2.0 Materials and methods

2.1. Study area

2.2.1. Location

The study was carried out in Kitui County, Kenya (Figure.1). It is a semi-arid region located in eastern part of Kenya. It is bounded by latitudes 0° 10'S and 3°10'S and longitude 37°40'E and 39°10'E. The

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county has 8 sub-counties (Kitui East, Kitui Rural, Kitui North, Kitui West, Kitui Central, Mwingi East, Mwingi Central, and Mwingi North) that cover an area of approximately 30,497 km², of which 690km² is in Tsavo national park. Kitui County has a population of 1,136,187 (KNBS, 2019). The county shares its borders with seven counties: Tharaka Nithi and Meru to the north, Embu to the northwest, Machakos and Makueni to the west, Tana River to the east/southeast and Taita Taveta to the south. It is located 160 km east of the capital Nairobi.

Kitui County is rated as the most drought-vulnerable area in Kenya during the period between January-February, and June – September each year. The rainfall pattern is bimodal with an average annual precipitation of 750 mm and 40% reliability. The annual mean minimum temperature ranges from 22 to 28°C while the annual mean maximum temperature ranges between 28° and 32°C (Musyimi et al., 2023). The predominant soil types in the County are Acrisols, Luvisols, and Ferralsols. The soils are well-drained, moderately deep to deep, and dark reddish brown to dark yellowish brown in color (Mugo et al., 2016). Since the 17th century, the economic activities of this area include livestock and farming activities. Somework as casual labor, moving from town to town for a living. The main crops are maize, green grams, cowpea, and pigeon pea.

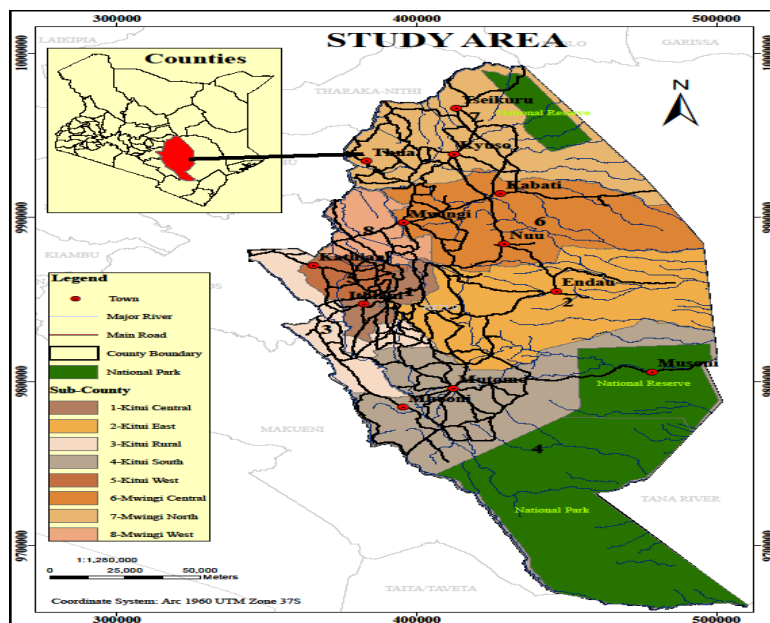


Figure 1: Location of the study area

2.2 Thematic Maps development

GIS technology is used in this study to generate a land suitability map. GIS is currently gaining popularity in research since it tries to consolidate a large amount of heterogeneous data and weighting for analysis (Lupia, 2012). A summary of the methodology used to generate a land suitability map from different datasets (Table.1) is shown in Figure 2. Maps generated in Arc GIS 12.0



were developed from the different criteria influencing mango production (rainfall, temperature, soil pH, soil texture, soil cation exchange capacity (CEC), rivers, land use, land cover, slope, and roads). Reclassification was done to generate thematic maps showing the suitability of mango growth based on individual criteria (suitability levels and assigning scores was done). Weight was assigned through Analytical Hierarchy Process (AHP) and overlaying GIS was done to get land suitability map for mango production.

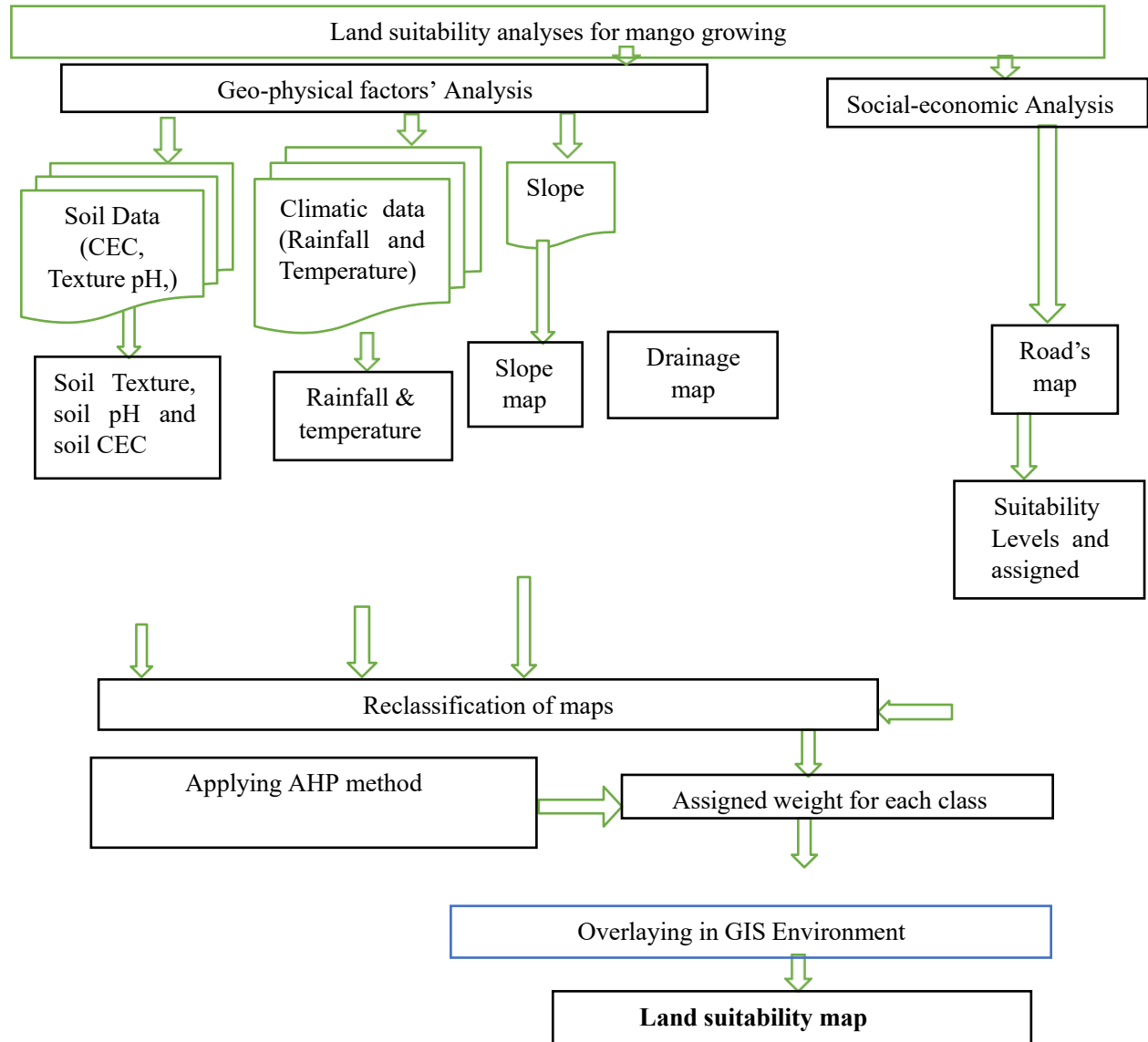


Figure 2. Summary of the data and methods used

2.3 Datasets and their sources

Datasets obtained from different sources were used for this study (Table 1). The datasets were grouped into climatic, soil, landscape attributes, and social-economic. Nine parameters (Table 1) were used, comprising two climatic parameters (rainfall and temperature), three soil parameter (Texture, Cation Exchange Capacity (CEC), pH,), three landscape parameters (Rivers, Digital elevation Model (DEM), and land use/land cover), and one social attribute (roads). Climatic data with high resolution was derived from (Climate Hazards Groups Infrared Precipitation with station data (CHIRPS) for three years (2020, 2021, and 2022) and Climate Hazards Group Infrared

Temperature with station data(CHIRTS-daily). Soil data files (vector form) with associated attributes-soil texture, CEC and pH were sourced from Kenya Soils Survey. Data onland use /land cover was sourced from ESRI Site and Slope data (raster form), with a resolution of 30m was derived from United States Geological Survey (USGS). Data on existing mango farms was sourced from handheld GPS receivers and questionnaires from experts’ opinion. All thematic variables used in thisstudy were converted to raster layers; before the analysis the thematic layers were geo referenced and resampled into the World Geodetic 1984 (WGS84) Geo-referencing system. All GIS layers transformationswere done in Arc GIS 10.4.1.

Table 1. Datasets for the study and their sources

Dataset	Source	Description	Remarks
Soil: pH, CEC, and texture	Kenya Soils Survey	Kitui layers	Vector format
DEM: Slope	United States Geological Survey (USGS)	30 m	Raster format
Temperature	CHIRTS	Mean annual temperature	Raster format
Rainfall	CHIRPS	Mean annual rainfall	Raster format
Land use/ land cover	ESRI site	Sentinel 2 ,10m resolution 9 (Yr 2021)	
Rivers	Survey of Kenya	21m from river riparian	Vector
Roads	Survey of Kenya	12m buffer	Vector
Satellite Images	30m resolution	Landsat Images	
Existing mango farms	Handheld GPS, Questionnaires		Date, August 2020
AHP ratings		MS word, Questionnaires	Date, August2022
Administrative boundaries	Survey of Kenya	10M	1:250,000 Shape file

Source: Compiled by Authors from various sources

2.4 Parameters required for mango growing

Table 2. Parameters required for mango growing

Parameter	Units	Ideal conditions	Suitability classes and Degree of limitation			
			SI	S2	S3	S4
Rainfall	Mm	650mm - 1294mm	634 -761	762-862	873-1002	1003-1294
Temperature	°	14-34	29.3-31.95	31.96-33.65	33.66-35.1	35.11-37.52
Slope	%	2%-6%	< 6	0-7	8-18	19-35
Soil pH	Reaction	5.5-7.5	6.5-7.3	7.4 – 8.3	0.1-6.4	<0
Soil texture	Class	Loamy or clay Sandy loamy	loamy	Sandy	clayey	Very clayey
Soil CEC	Meq/100g	15-25%	9.5 -19.0	19.1-51.6	0.1-1.8	1.9 - 9.4

These are the suitability classes for growing mangoes. The Ideal conditions for mango growing, Rainfall, Temperature, Slope, Soil pH, Soil Texture, Soil CEC, their measurement in Units, Ideal conditions, Suitability classes and degree of limitation are shown in Table 2.

The Food and Agriculture Organization (FAO) suitability classification ranks the suitability levels as Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N) as shown in Table 3. The suitability levels for each of the criteria (rainfall, temperatures, soil pH, soil texture, soil CEC, slope, rivers, land use land cover, roads) were defined according to existing literature review and an agronomist expert's opinion.

Table 3: Classification framework of land suitability analysis for mangoes

Code	Class	Description
S1	Highly suitable	Land having no significant limitation for agricultural productivity
S2	Moderately suitable	The land has some limitation that are severe for sustained productivity
S3	Marginally Suitable	Land with major limitation for sustained agricultural productivity
S4	Not suitable	Land with extreme limitation for sustained agricultural productivity

Source: FAO, 1976

2.4.1 Assigning weight to the parameters

In this study, several parameters are used to assess suitable land for growing mangoes as suggested by Bandyopadhyay et al. (2009): rainfall, temperature, slope, soil CEC, soil pH, soil texture, land use land cover, rivers and roads. There have been good attempts to undertake land suitability analysis using several parameters. For example, (Everest et al., 2021) analyze a large variety and amount of physio-graphic data (climatic characteristics; rainfall and temperature, internal soil characteristics; temperature, moisture, aeration, natural fertility, and depth) in northwestern Turkey. Determining the weight of the various parameters helps to assess land suitability (Elsheikh et al., 2013)

In order to come up with concrete informed decisions on mango growing areas in Kitui county, Kuria et al(2011) show that various parameters, like physical, climatic, and soil characteristics (Table 2), must be taken into consideration. Mango experts, literature reviews from various reviewed journal papers, and books helped to identify the parameters. In this study, structured questionnaires were administered to researchers, scientists, and GIS and remote sensing specialists via a Survey of Kenya and Jomo Kenyatta University of Agriculture and Technology. The analysis was then carried out using a pairwise comparison matrix to determine parameter weights. The comparison determines the importance of the parameters relative to each other (Saaty, 2008; Mugiyu et al. 2021). AHP technology helped in this assessment (Darko et al., 2019) as a support tool to solve the complex decision problems.

2.4.2 Analytical Hierarchy Process (AHP)

The analytical hierarchy process is widely accepted method in multi-criteria decision analysis (MCDA) (Mugiyu et al., 2021). It reduces complex decisions to a series of pairwise comparisons and then integrates the results (Nguyen et al., 2015). In this study, the AHP assesses different factors

and alternative options for which the best decision was to be made. Table 4 shows the nine-point scale measurement used in this study to calculate the weights of the different parameters used (Lange et al., 2020). An assignment of the weights was then based on literature, local knowledge, and expert consultation (researcher, scientist and GIS and remote sensing specialists from Survey of Kenya and Jomo Kenyatta University of Agriculture and Technology).

Table 4. Nine-point scale measurement

Intensity of Importance	Definition	Description
1	Equal Importance	Two activities contributing equally to the objective
3	Moderate importance of one over another one	Experience and judgment slightly favor one activity over another
5	The strong or essential Importance	Experience and judgment strongly favor one activity over another
7	Very Strong Importance	Activity is strongly favored, and its dominance shows in practice.
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6 and 8	Even numbers represent intermediate values between the two adjacent judgments	When compromise is needed

Source: Lange et al. (2020)

Pairwise comparison in the AHP (Table 5) was determined as per (Saaty, 2008), with values from 9 to 1/9. A rating of 9 shows that concerning the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative of the column factor, the row factor is less important. In cases where the column and the row factor are equally important, they have a value of 1. In this study, Table 5 shows that temperature is 7 times important in mango production than soils and vice versa i.e., the soils are 1/7 times important than the temperature. Temperature is also three times more important than the land use land cover in mango production and vice versa. The diagonals compare the parameter/factor by itself and, hence, a value of 1 implies that factor is equally important.

In the pairwise comparison matrix, the AHP calculates the weighting for each criterion by taking the eigenvector corresponding to the largest eigenvalue of the matrix and then normalizing the sum of the components to unity (Chandio et al., 2013). The ratio scale was derived from the principal eigenvectors and the consistency index was derived from the principal eigenvalue. An eigenvalue is a number that explains how much variance is spread out (Shrestha, 2021). Sangiorgio et al., 2018 showed that AHP has limitations in determining the weights; hence, to improve consistency, the study first derived the pairwise matrix based on scientific objective in non-scale situation.

Consistency ratio (CR) assesses the consistency of the decisions and is able to identify potential errors. It also measures the amount of variation allowed in acceptable outcomes, which is usually 10% or less, to be able to go on with the AHP. In contrast, if the CR value was 10% or more, then it is advisable that the pairwise comparison is modified to improve decisions. Values of unity (when comparison factors are compared with themselves), are assigned to the diagonal elements of pairwise comparison method (PWCM). It is only the lower triangular half that needs to actually be filled in, since the matrix is symmetrical.

Table 5: Pairwise comparison matrix for Assigned weight

	Soils	Temp	Rivers	Slope	Rainfall	Roads	LULC	Weight Eigenvector
Soils	1	0.14	0.2	0.2	1	0.33	0.11	3
Temperature	7	1	3	3	7	5	3	35
Rivers	5	0.33	1	1	5	3	0.33	14
Slope	7	0.33	1	1	3	1	0.33	12
Rainfall	1	0.14	0.2	0.33	1	0.33	0.11	3
Road	3	0.2	0.33	1	3	1	0.33	8
LULC	9	0.33	3	3	9	3	1	25
Sum	33	2.47	8.73	9.47	29	13.66	5.21	

2.4 Development of land suitability map

Weighted overlay from the weighted sum tool and spatial Analyst tools (Arc GIS) were used in developing the suitability map. This was done by combining the reclassified thematic map of all parameters (soil, temperature, rainfall, slope, LULC, rivers, roads) with the weights that were obtained from AHP (Luan et al., 2021).

3.0 Results

This section provides the findings on land suitability assessment for mango production in Kitui County. The findings outline the climatic, physical and soil characteristics that are important for mango production.

Basing on suitability classes for growing mangoes in Table 2, these results were derived at;

3.1 Climatic factors

The climatic factors (Table 1) that were evaluated in relation to mango production were mainly rainfall and temperature (Table 6).

3.1.1 Rainfall

Examining the rainfall factor, mango normally requires enough rainfall for its growth (Ochieng et al., 2016), hence mapping the available rainfall became crucial. Rainfall reclassified map (Figure 3) shows that the area that received 1003 mm – 1294mm (14.1%) was highly suitable, moderately suitable was 873 mm – 1002 mm (18.4%), marginally suitable 762mm- 872mm (24.6%), and not

suitable was (42.9%) 634mm- 761mm (Table 6). In this study area, rainfall ranges from 634mm to 1294mm. Considering that mango grows well in areas with annual rainfall of 650 mm, with the ideal rainfall amount being 634mm- 1294mm, the results indicate that the whole of Kitui County is suitable for mango production. Mango also grows best at low rainfall levels, especially during flowering and the fruit setting stage (Rangare et al., 2022). Thus, if all areas would receive quality and well distributed rainfall, and ensure other parameters are ideal mango would grow well across Kitui county (Carella et al., 2021), although unpredictable rains cause poor fruit formation during flowering and may affect the quality and appearance of ripe mango fruits (Normand et al., 2015). High and prolonged rainfall, on the other hand, leads to diseases that hinder fruit setting, fruit development, yields, and can also lead to flower dropping (Carella et al., 2021). Some areas in Kitui east (Endau, Zombe and Mwitika), Kitui south (Ikutha, Mutomo) Kitui west (Kabati, Katutu), and Mwingi North (Saikuru, Kyuso) receive as little as 634mm (annually) of rainfall, which is still adequate for mango production since mango is a drought-tolerant crop. With adequate rain water conservation and distribution, especially in the presence of erratic rainfall, all of Kitui County is suitable for mango production in respect to rainfall. The conservation dams used during rainy season would be useful for storing water for use especially during the dry seasons.

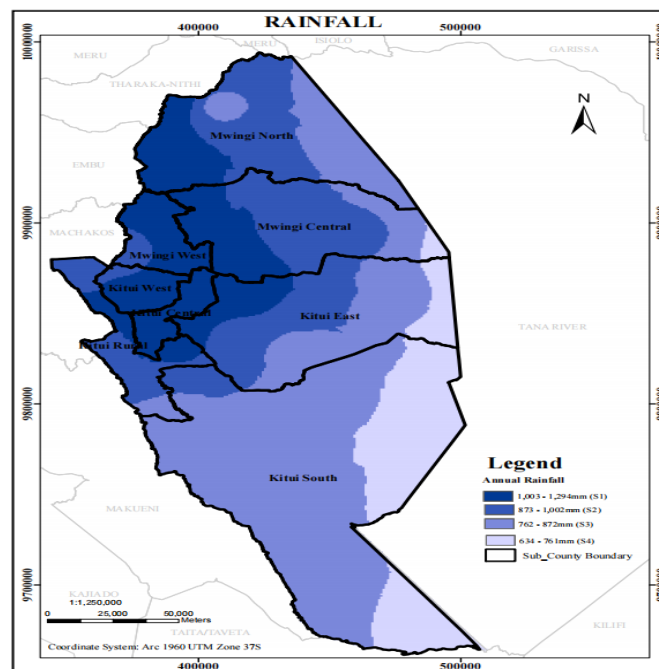


Figure 3. Mango production suitability map based on rainfall.

3.1.2 Temperature

In this study, the mean annual temperature ranges between 29.3°C and 37.52°C. Temperature reclassified map (Figure 4) shows that temperatures of 29.3 - 31.95°C (14.7%) are highly suitable (S1), moderately suitable (S2) is 31.96 - 33.65°C (22.3%), marginally suitable (S3) 36.66 – 35°C (30.9%), and not suitable (S4) is 35.11-37.52°C (32.1%) (Table 6). Based on the mean temperature required for mango production, 68% (S1, S2, and S3) of Kitui County has favorable temperatures for

mango production. The eastern (Zombe, Endau), western (Kitui west), southern (Kitui south and Kitui rural), and northern (Mwingi north) parts of Kitui have very high temperatures (35.11-37.53°C), about 41.9% of Kitui; in comparison of the central part of Kitui – Mwingi west, Mwingi central and part of Kitui East (59%) – has ideal temperatures for mango production.

Temperatures remain crucial for the development of mango, especially during the germination, development of fruit and flower production stages (Liu et al., 2023). The ideal temperature of mango production is 14 °C to 34 °C. High temperatures during mango production affect photosynthesis, vegetation growth, and fruit quality (Boudon et al., 2020). Further, (Halder & Abu Hasan, 2020) explains how high temperatures lead to drought and evaporation demand, resulting in low production. Low temperatures, on the other hand, kill the young active mango tree and causes fruit abortion (Liu et al., 2023). Ideal temperature influences the growth cycle, frequency of flowering, fruit growth, taste, and appearance of the mango fruit in all areas where production takes place (Halder & Abu Hasan, 2020).

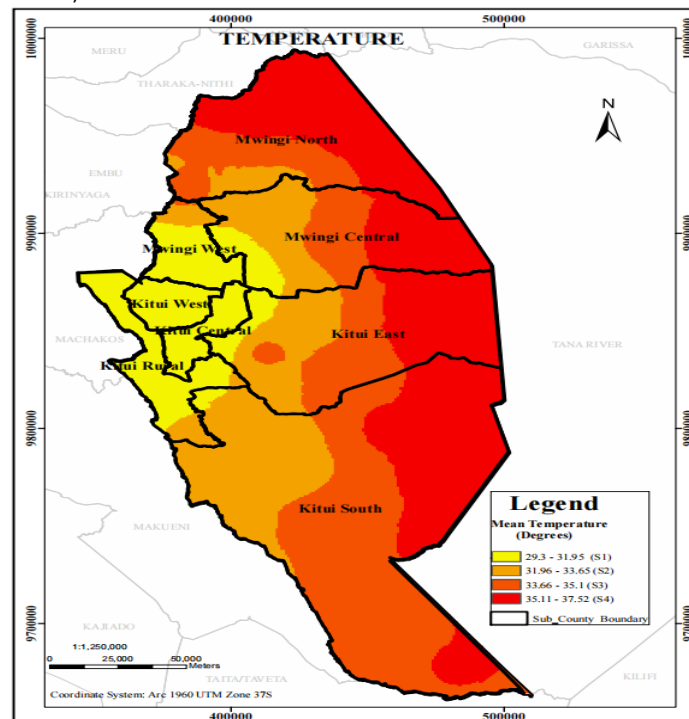


Figure 4. Mango production suitability map based on Temperature

Table 6: Spatial variation of Rainfall and Temperature

Suitability class	Rainfall		Temperature			
	Rainfall(mm)	Area(Ha)	Area(%)	Temperature (°C)	Area(Ha)	Area (%)
S1	1003-1294	443554	14.1	29.3 - 31.95	444666	14.7
S2	873-1002	746297	24.6	31.96 - 33.65	676646	22.3
S3	762-872	571113	18.4	33.66 – 35.00	939625	30.9
S4	634-761	1271077	42.9	35.11-37.52	71105	32.1

3.2 Soils

Soil characteristics (Table 1) guided in coming up with the soils' mapping results. i.e. soil CEC, texture, pH, and slope (Table 7).

3.2.1 Soil Cation Exchange Capacity (CEC)

The Soil CEC suitability map gives the cation exchange capacity (Figure 5). The CEC measurement for this study ranges from 0 to 51.6%. Table 7 provides a comprehensive overview of the CEC distribution and classification of the areas. The first category, with a CEC ranging 19.1 to 51.6, is classified as highly suitable, covering 79.6% (2422940 Ha) of the study area. The second category, with a CEC of 9.5 to 19.0 covering an area of 214370 Ha (7%), is classified as moderately suitable. The third category, with a CEC of 1.9-9.4%, is classified as marginally suitable and covers 13.1% (396110Ha) of the study area. Covering 0.3% (9768Ha) of the study area is the last category with a CEC ranging between 0.0 and 1.8, and is classified as not suitable. The highly suitable soil CEC is distributed along the central region, parts of Kitui East and Kitui West. The soil CEC is often influenced by fine soil texture, which may cause useful soil nutrients to disappear (Meimaroglou & Mouzakis, 2019). In addition, physical, chemical, and biological properties of soils also affect the soil CEC (Meimaroglou & Mouzakis, 2019). CEC contributes to the growth and development of the mango tree (Yunan et al., 2018). The ideal soil CEC ranges from 15-25%.

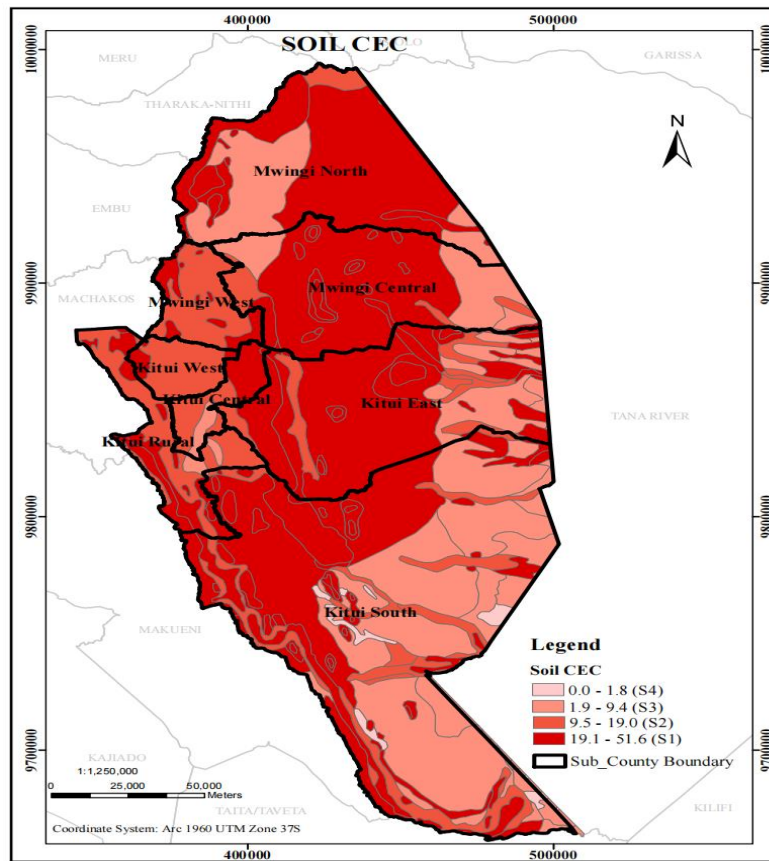


Figure 5. Mango production suitability map based on CEC

3.2.2 Soil Texture

The distribution of different soil texture classes is in the reclassified soil texture map (Table 7) and in Figure 6. Loamy soil is found to be the most suitable soil, covering an area of 13% (396110Ha), followed by sandy soil with 0.3 % (9768Ha), then clayey soil that covers an area of 2422940 Ha (79.6%), and finally very clayey soil, which covered an area of 214370 Ha (7.1%). The loamy soil (highly suitable) is found along the boundary lines of Kitui County and its neighboring counties, including parts of Kitui West and Kitui Central.

Soil texture is important for supporting crop growth, since different crops tend to do best with different soil textures. Sometime crops may experience stunted growth due to lack of good texture. Soil texture not only manages nutrients and water retention but also influences crop productivity (Roncucci et al., 2015).

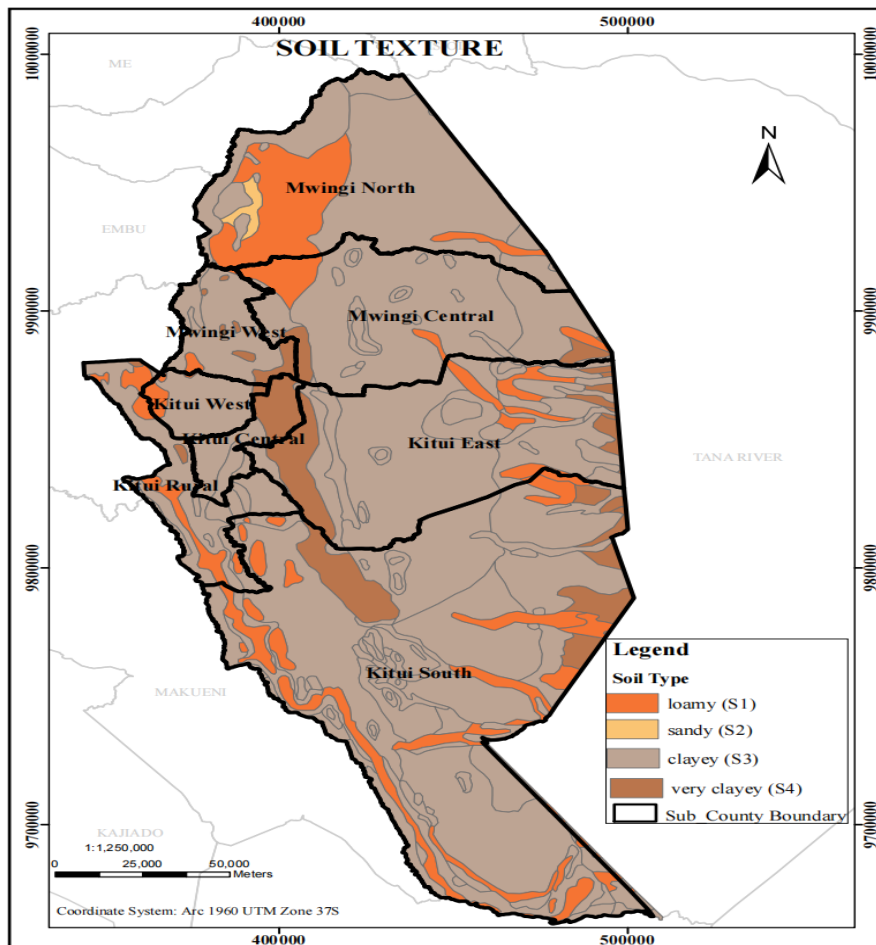


Figure 6. Mango production suitability map based on Soil Texture

3.2.3 Soil pH

The distribution of the different pH values are as shown in the reclassified pH map (Figure 7; Table 7). The areas with a pH range of 6.5- 7.3, which is found in some parts of the northern side, eastern side and a bit of southern side of Kitui County, are classified as highly suitable; these covered an area of 22.6% (685952 Ha). Moderately suitable, covered an area of 23.8% (721917 Ha), with a range of pH 0.1 to 6.4, and cover (721917 Ha). The marginally suitable areas have a pH range of 7.4 to 8.3 and cover an area of 4.8% (146147 Ha). The not suitable areas have a pH value of <0.0 and covered 48.8% (1482321Ha) of the area. The soil pH represents the alkalinity and acidity of soil. This can cause stress to the mango tree. The pH range of 5.5-7.5 is the optimal range for mango growth since it makes nutrients available to the plants (Msimbira & Smith, 2020). The pH also have a role in soil biogeochemical processes (Neina, 2019), which affects plant growth and biomass yield. Soil pH, therefore, helps in fruit growth, quality, and yield. Low pH leads to poor nutrients absorption and imbalance of the nutrients, this leads to poor yields (Maai, 2020). High acidity in soils also provides a

thriving environment for nematodes, which affects mango roots, thus affecting growth and productivity.

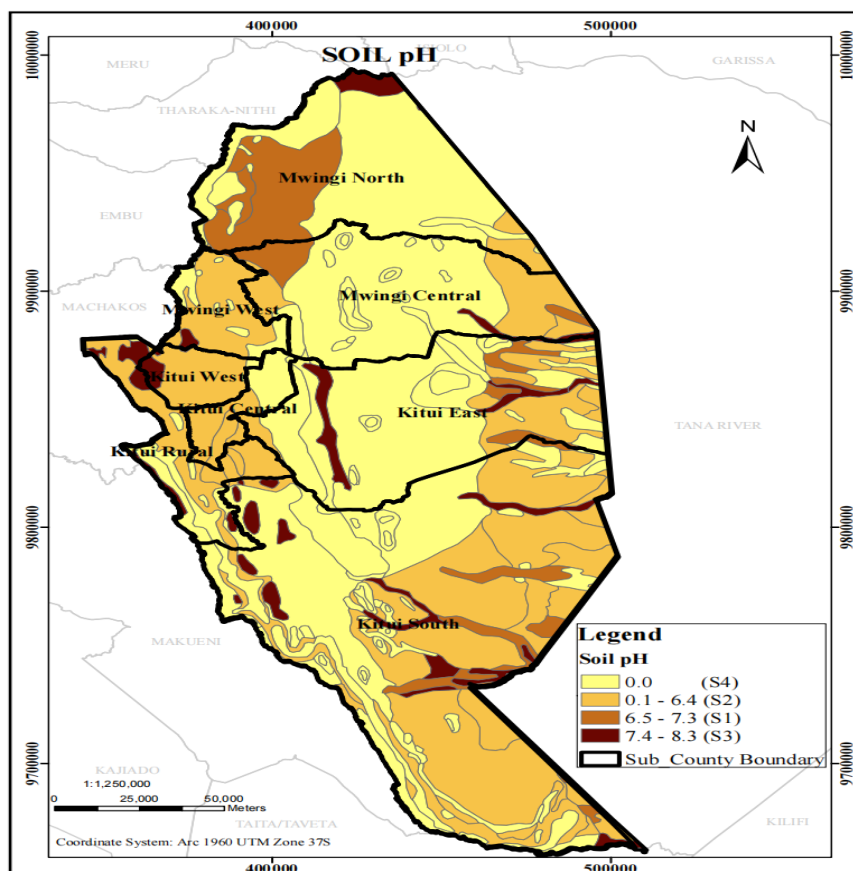


Figure 7. Mango production suitability map based on Soil pH

3.2.4 Slope

In this study the reclassified production suitability map (Figure 8) and Table 7 shows the distribution of slopes across the different areas. Primary data used (Table 1) gave the basis of the data used during reclassification. The areas that have a slope ranging between 0 and 7 are classified as highly suitable, these cover 1732068Ha (56.9%). The areas that have a slope of 8-18 are classified as moderately suitable; these cover 1061121Ha (34.9%). The areas that have a slope of 19-35 are classified as marginally suitable; these represent 204304Ha (6.7%). The areas with a slope of 36-301 are classified as not suitable, approximately 1.5% (46025Ha) of the area. The steepest areas in Kitui Central (Miambani area), Mwingi West and Mwingi North are challenging for growing mangoes since very steep areas are hard to manage. Again, very low areas with less than 6% slope often experience adverse effects of soil erosion, especially in Kitui East, which causes massive damage to the mango production. Slope largely contributes to mango growing and it is a determinant of soil erosion (Boardman et al., 2022). Slope is

also seen to have an effect on soil formation in that when there is no climate change and slope is different, soils are formed on the parent material (Brosens et al., 2020).

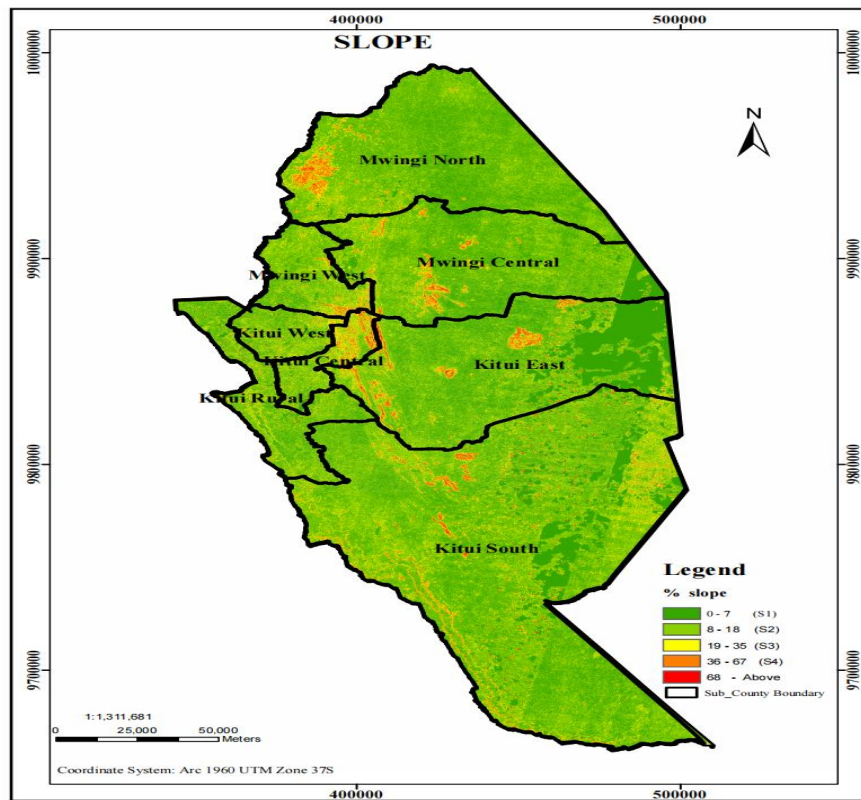


Figure 8. Mango production suitability map based on Slope

Table 7. Spatial variation of CEC, Texture, PH, and Slope

Suitability class	Soil CEC		Soil Texture				Soil PH				Slope		
	CEC (°c)	Area (Ha)	Area (%)	Texture (°c)	Area (Ha)	Area (%)	pH (Reaction)	Area (Ha)	Area (%)	Slope (°c)	Area (Ha)	Area (%)	
S1	19.1-51.61	2422940	79.6	Loamy	396110	13.0	6.5-7.3	685952	22.6	0-7	1732068	56.9	
S2	9.5-19.0	214370	7	Sandy	9768	0.3	0.1-6.4	721917	23.8	8-18	1061121	34.9	
S3	1.9-9.4	396110	13	Clayey	2422940	79.6	7.4-8.3	146147	4.8	19-35	204304	6.7	
S4	0.0 -1.8	9768	0.3	Very clayey	214370	7.1	<00	1482321	48.8	36-301	46025	1.5	

3.3 Land use and land cover

3.3.1 Area under different land cover

Land use and land cover remains an important aspect for mango production. This parameter impacts a wide variety of ecological processes (Salunkhe et al., 2023). Land cover in Kitui county can be classified under six major classes (Figure 9 and Table 8) as follows: water, trees, crops, built-up, bare-land, and shrubs. The results in Table 9 show that 55.3% of the land area is under shrubs, 41.1% under trees, 3% under cropland, 0.4% under built-up, 0.1% under water, and 0.1% under bare-land.

Table 8: The area under different land cover

Land cover	Area (Ha)	Area (%)
Water	4017.550049	0.1
Trees	1259181.375	41.1
Crop-land	91055.11719	3
Built-up	11797.2002	0.4
Bare-land	3088.840088	0.1
Shrubs	1676668.125	55.3

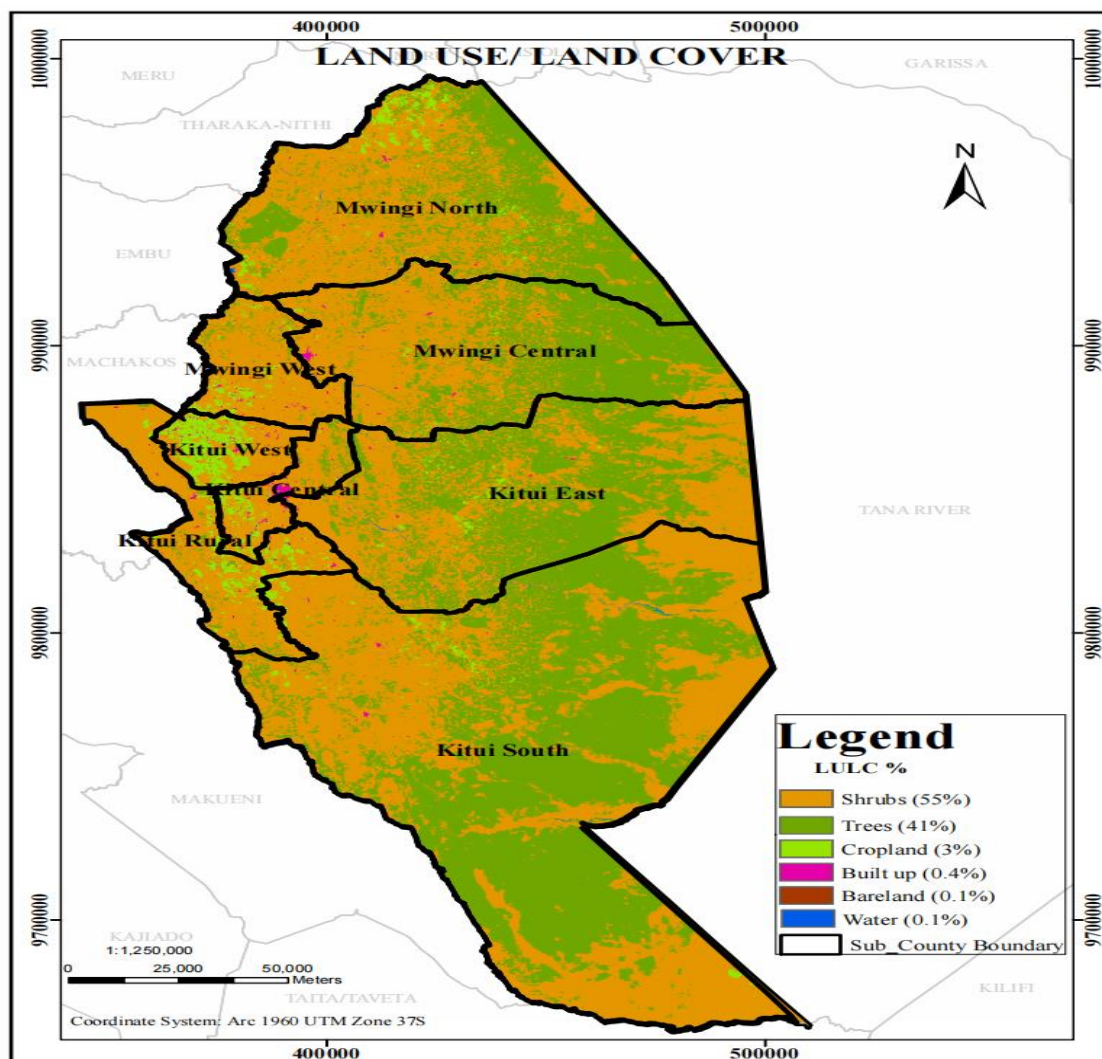


Figure 9. Mango production suitability map based on land use/land cover

3.3.2 Rivers

On the other hand, drainage contributes highly to mango production since water is required for irrigation. In Kitui County, especially in Kitui East, mango growing is predominant along the river beds, which provide a reliable source of water for growth and development of the plant (Wei et al., 2017). In this study, the rivers were mapped out, as shown on the reclassified map (Figure 10). The area covered by rivers present in the County (Table 9); where only 1.8% 550023 of the entire Kitui County is covered by rivers, while 98.2% lacks rivers.

Table 9: Spatial variation of Rivers

Rivers	Area (Ha)	Area (%)
With Rivers	550023	1.8
With No Rivers	2988924	98.2.

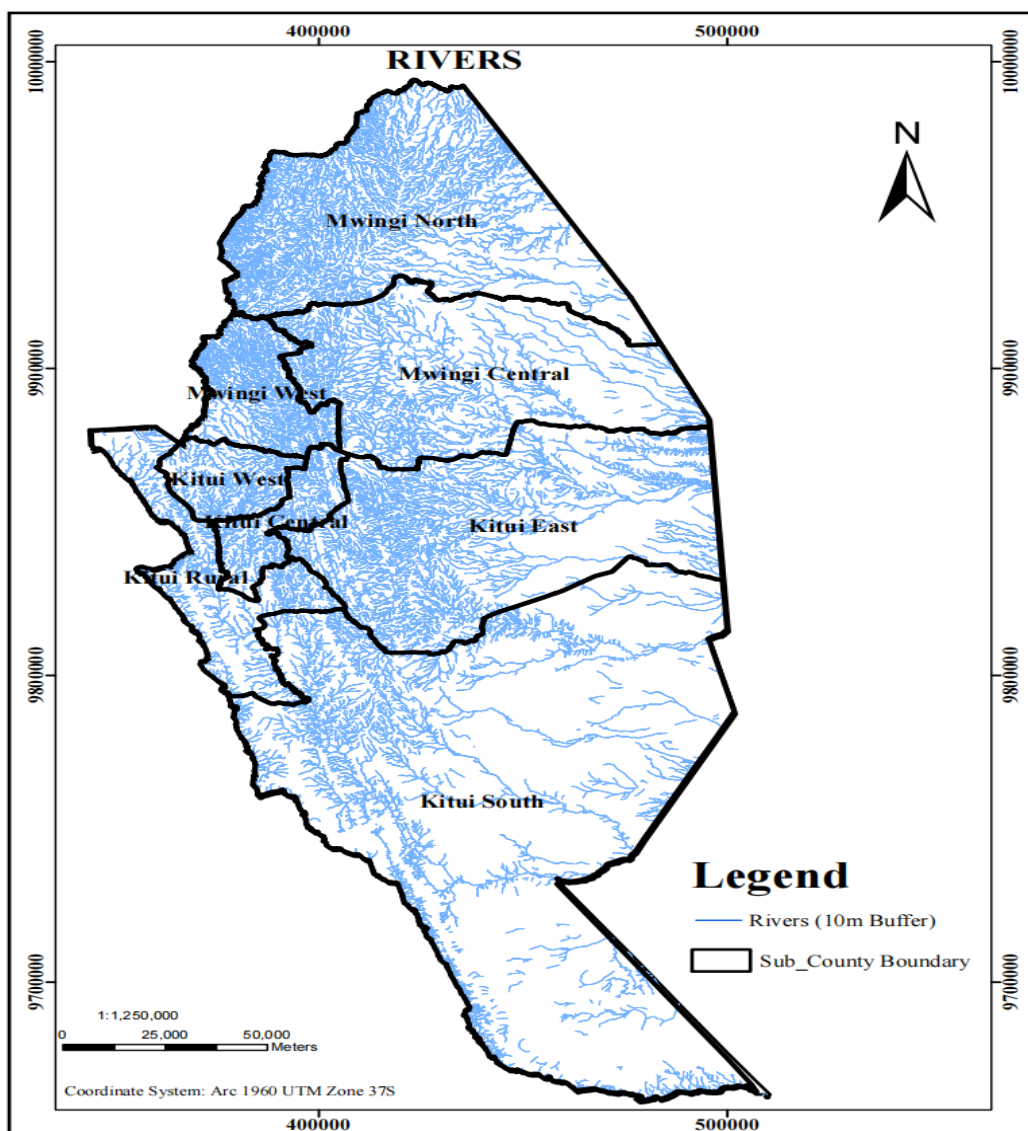


Figure 10. Mango production suitability map based on drainage

3.4 Roads

In this study the road network was mapped out, (Figure 11), elaborating mango production suitability based on roads. The area covered by roads is presented in Table 10; with only 0.9%(27575 Ha) of Kitui County covered by roads. Road is a social economic parameter that directly affects the mango production. Where roads are improved, accessibility and transportation of mango fruits is facilitated. Where the road networks and quality is rough and not passable, there is a lot of post-harvest losses (Costa et al., 2021).

Table 10: Spatial variation of Roads

Roads	Area (Ha)	Area (%)
With Roads	27575	0.9
With No Roads	3016371	99.1

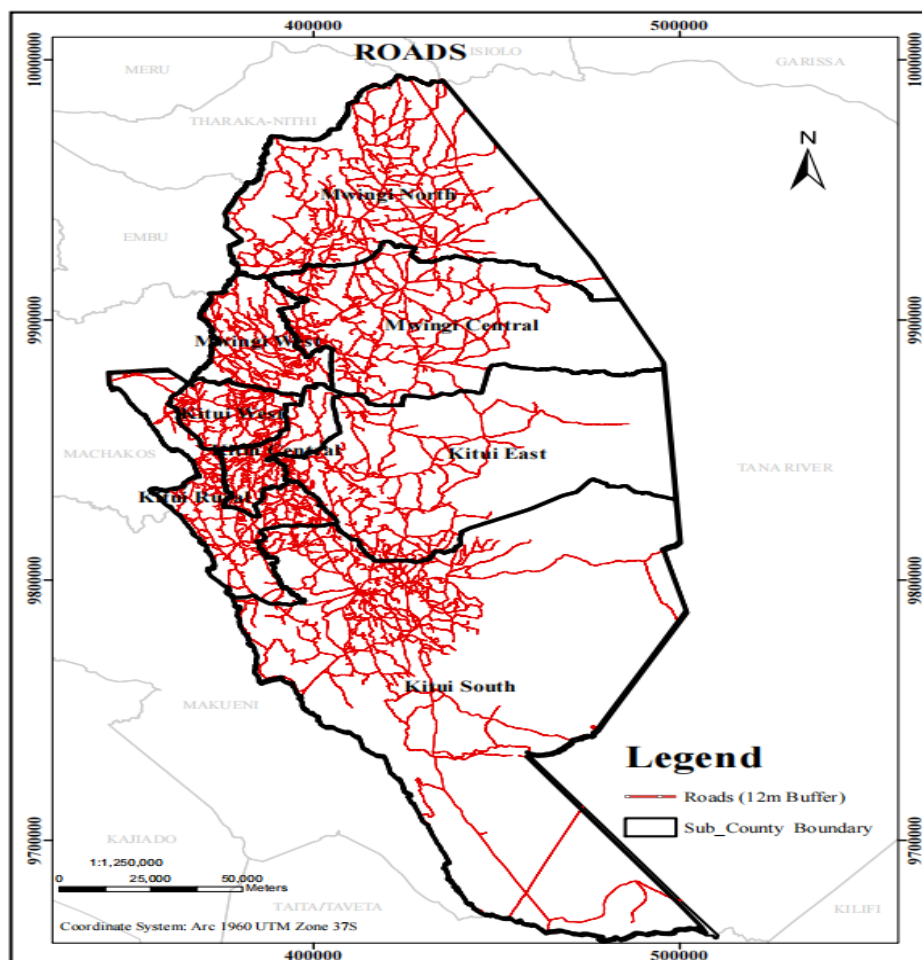


Figure 11. Mango production suitability map based on roads

3.5 Overall Land suitability map for mango production in Kitui

This section provides the results of the thematic maps (weighted overlay) of the parameters that affect mango production in Kitui County. The results showed that 79.8% of the area is highly suitable, 1.1% is moderately suitable, 13.9% marginally suitable, and 5.2% is not suitable for mango production. Kitui County have different suitability classes (Figure 12). Kitui central, Mwingi west, Kitui East, and Mwingi central are classified as highly or moderately suitable areas, while northern parts of Kitui (Mwingi North, Ngomeni, Tseikuru, Nuu, Nguni), some parts of Kitui East (Endau, Mutito, Kyamatu), Kitui Central (Kyangwithia west), and Kitui South (Kisasi, Kyatune, Kanziko) are classified as marginally suitable. There are also other areas (Kitui west (Mutongoni) that are classified as not suitable for mango growing.

The areas classified as marginally suitable have good climatic conditions, though soil pH is not suitable and soil texture is marginally suitable. When proper intensification systems are applied to these marginally suitable areas, they may shift to moderately suitable or even highly suitable status. The majority of rivers that may supply water to mango farms during the dry season are seasonal (Figure 10). The rivers occupy an area of 1.8%, with the eastern side having the fewest rivers; this contributes to its classification as 'not suitable' since farmers cannot farm when it is dry, due to lack of water, even for irrigation. Where the river network is sparse, the water table tends to be deeper, which also leads to minimal water availability for irrigation. Roads are social economic parameters that not just influence the movement of mango seedlings, agricultural incentives, farm equipments, agrochemical, and other inputs to the farms, but also the transport of mango fruits and their products from farms to market. In this study the mapped road network occupies 0.9% (Table 12) of Kitui. The lack of a good road network, especially during the rainy season, leads to poor linkages between farms and markets, thus affecting mango production.

The AHP (Table 5) shows the weights of the different parameters, revealing that LULC has the most weight, followed by temperature and then rainfall. This shows the three (respectively) are more important than the others for mango production. Having considered LULC, temperature, and rainfall, this shows that the final suitability map (Figure 11) is largely influenced by these three parameters. Kitui County is dominated by clayey soil (Figure 6) texture class, which is reflected by the poor drainage in the area. Some areas (Figure 8) experience slopes of less than 2%, which leads to water logging during wet season; hence not good for mango production.

The authors observe that many large-scale farmers are found in areas with good roads and near rivers. An example is Kitui East, which has mangoes planted along the river bank, Mwingi west and north have slopy grounds, while Kitui Central has a very good road network and rivers that ensure water availability. The slope of Kitui Central is also favorable and highly suitable for mango production.

Table 11: Spatial variation for overall suitable land for mango production

Suitability class	Area (Ha)	Area (%)
S1	2293043	79.8
S2	30945.8	1.1
S3	400174	13.9
S4	145501.2	5.2

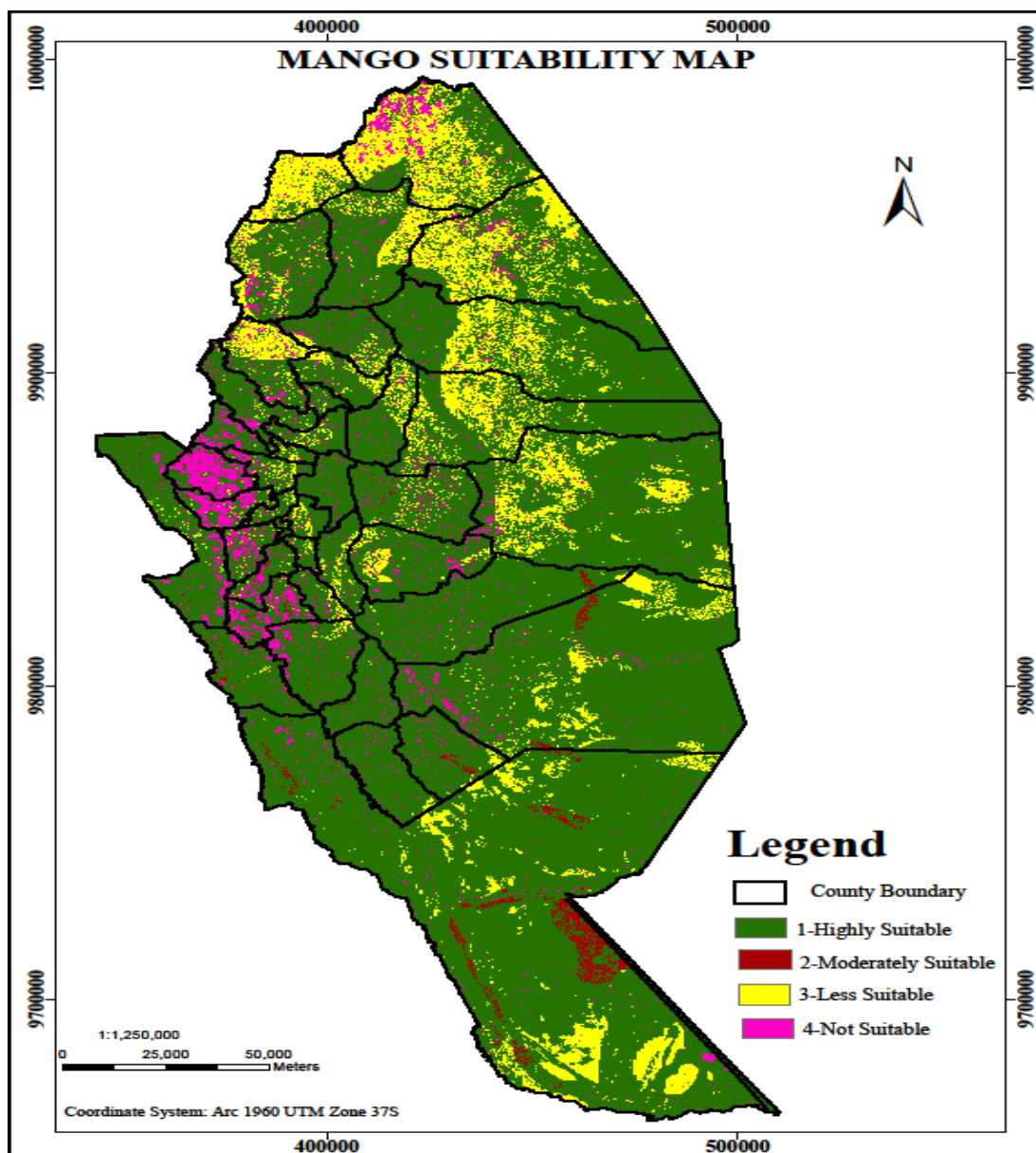


Figure 12: Map of the land suitability map for production;

4.0 Conclusion

A large proportion of land in Kitui County is suitable for mango production. Rainfall, temperature, slope, LULC, soil CEC, soil pH, soil texture, rivers, and roads are climatic and socio-economic factors captured by the thematic maps. In AHP, land use is seen as having the most weight and, hence, is the most important factor for mango production. The resulting land suitability map indicates that 79.8% of Kitui County is highly suitable, 1.1% moderately suitable, 13.9% marginally suitable, and 5.2% not suitable for mango production. Assessment of suitability land is very crucial for mango production to enable the necessary stakeholders to know the amount of land-location and parameters associated with it in Kitui County. Thus, policy measures that would help improve climatic and soil characteristics of Kitui County are recommended, Such as advising the county government conserve the soils, Increase water for irrigation, develop the roads by tarmacking, Provision of irrigation equipment and Trainings on smart agricultural practices.

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5.3 Ethical consideration

None

5.4 Conflict of interest

None.

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