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ORIGINAL RESEARCH ARTICLE

LAND SUITABILITY ANALYSIS FOR PINEAPPLE CULTIVATION IN KIAMBU COUNTY, KENYA

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ABSTRACT
Driven by dwindling incomes from coffee and tea and the need to diversify their sources of income, farmers in Kiambu County are increasingly shifting to pineapple cultivation in areas formerly dominated by coffee and tea cultivation. However, not all areas in the County are suitable for pineapple production due to spatial variability of factors affecting growth (climate, soils, topography). There is therefore a need to identify and delineate suitable areas for growing pineapples in the County. Land suitability assessment for pineapple production in Kiambu County was carried out by a combination of GIS and the Analytical Hierarchical Process (AHP) model. Using GIS, thematic maps of all factors affecting pineapple growth (soil, climate and topography) were developed showing their spatial variability within the county. The maps (of factors affecting growth) were assessed against the published optimum parameter value ranges for pineapple cultivation. AHP was used to assign ratings/weights (of importance) of the thematic layers in regard to pineapple production. The land suitability map was developed from a weighted overlay of the thematic layers in ArcGIS. The map was categorized into four classes based on pineapple cultivation's suitability; highly suitable, moderately suitable, marginally suitable, and not suitable. From the results, 38% of the (Kiambu) County is highly suitable for pineapple cultivation while 5% is not suitable. The rest of the County is moderately suitable (41%) and marginally suitable (16%). We recommend the use of these findings by agricultural extension officers for the planning and guiding farmers on where to invest in pineapple production.

Key words: Land suitability; Analytical hierarchical process; pineapple; GIS

1.0 INTRODUCTION
Pineapple (Ananas comosus) is ranked the second most important tropical fruit globally, after mango (Altendorf, 2019). The global pineapple production in 2017 was approximately 25.8 million tonnes, accounting for 27% of the total global production of major tropical fruits (Altendorf, 2019). It is also one of the most traded tropical fruit globally. It accounted about 44% of the total volume of tropical fruits traded in 2017 (Altendorf, 2019). The world major producers of pineapples are Costa Rica, the Philippines, Brazil, and India. Others include Thailand, Nigeria, Mexico, China, Indonesia, Kenya, Colombia, Ivory Coast, Venezuela, Vietnam, Malaysia, United States, and South Africa (Chaudhary et al., 2019; Rohrbach et al., 2003).

Pineapple is a tropical and subtropical fruit plant that thrives in a humid climate (Pandit et al., 2020; Chaudhary et al., 2019). It grows within a temperature range of 18-320C and can produce fruit under an annual rainfall of the range 650- 3800mm. In addition, it grows well in both plains and higher elevations up to 2300m from sea level (Morton, 1987). A well-drained, sandy loam having a high content of organic matter is the best for cultivating pineapple, and a PH range of 4.5-6.5 (Hossain, 2016). The range of these factors are quite wide and the fruit quality and rate of growth vary with how far the values are from the optimal (ideal) conditions. The optimal growth temperature is between 20 to 30^{0}C and, more specifically, at 23-24^{0}C (Hossain, 2016; Zhang et al., 2016). Pineapple grows slowly when temperatures drop below 140C and stops growing when the temperature drops below 100C. Temperature below 5^{0}C causes chilling injury to pineapples (Zhang et al., 2016). Exposure to temperatures over 30^{0}C heat damage may occur due to increased respiration rate and metabolism and impaired nutrient absorption (Neild and Boshell, 1976). During periods of intense sunlight and high temperatures above about 350C, the plant is susceptible to sunburn damage. The good quality of pineapple is attributed to growing sites having a combination of relatively cool night temperatures, sunny days, and day temperatures ranging from 20-30^{0}C, however not exceeding 32^{0}C (Neild and Boshell, 1976). Severe cold decreases the sweetness of the fruit (Hossain, 2016). Climatic conditions influence the nutritional content of the fruit particularly the acid content that fluctuates with weather conditions (prior to harvest). For example, pineapples produced in winter in sub-tropical regions have been found to be of low quality due to high acidity in the fruit (Hassan et al., 2011). With this change in fruit quality and productivity when the pineapple is grown outside the optimal conditions, there is a need to establish and map suitable areas for pineapple production. With a zoning of land for suitability of pineapple production, farmers would make informed decisions on the expected quality of pineapples. It would also give business people and consumers zones with good quality pineapple fruits.

Land suitability analysis is an important practice that is used as a decision-making tool by decision-makers and land use planners (Aburas et al., 2015). It is an assessment of an area to determine how proper or appropriate it is for a particular use of the land in a particular location (Chiranjit and Chandra 2016). In agriculture, it helps to determine the best crop (and variety) for a particular location based on biophysical and climatic factors. Land suitability analysis uses basic principles of GIS-based processes and tools to determine the appropriate areas for a particular use (Dedeoğlu and Dengiz 2019). Based on particular characteristics, the land is classified as suitable or unsuitable for a given activity (El Baroudy 2016; Kuria, et al., 2011). Land suitability analysis plays an important role in land use planning which leads to better agricultural production, saves resources and reduces unsustainable agricultural developments (Akpoti et al., 2019; Babakan et al., 2021; Karimi et al., 2018). For agricultural planning, it ensures that the right crops are grown in the right agro-climatic areas with a favourable climate for maximum yields and returns to investment (Caldana et al., 2020).

Land suitability mapping for pineapple production in Kenya is necessary as there has been a shift by farmers to pineapple production particularly in Kiambu County (Kimani et al., 2020). The shift is mainly informed by economic reasons and the returns expected from pineapple production as compared to traditionally grown crops like coffee and tea. In Kiambu County, for example, the climatic conditions of the area favour the cultivation of various types of crops. Land use within the area has changed in the past years. Coffee and tea have been the main type of crops grown within this area. Currently, some farmers are shifting to pineapple production (Kimani et al., 2020). This trend has been observed from the medium altitudes of coffee production to high altitudes dominated by tea production. Land suitability mapping in the county for pineapples growth can be used as a decision-making tool for farmers who would like to venture into their production. The objective of this study was therefore to delineate and map land suitability for pineapple production in Kiambu County.

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2.0 MATERIALS AND METHODS

2.1 Study area

This study was done in Kiambu County which is one of the 47 counties in the Republic of Kenya created under the constitution change of 2010 and covers a total area of 2,543.5 Km² (Kiambu County, 2018) and a population of 2,417,735 according to 2019 population and housing census (KNBS, 2019). The County is located in the central region of the country and borders Nairobi and Kajiado Counties to the South, Machakos to the East, Murang'a to the North and North East, Nyandarua to the North West, and Nakuru to the West (Figure 1). The County is further subdivided into 12 electoral constituencies as shown in Figure 2. The altitude of the study area lies between 1200 meters above sea level at Thika area to 2550 in the Aberdare ranges (Kiambu County, 2018). Coffee and tea are the main cash crops grown in the County. Horticultural crops such as pineapples and vegetables e.g. French beans, snow peas, kales, cabbage, garden peas, tomatoes, spinach and carrots are also widely grown in the county. Similarly, the cultivation of food crops (e.g. maize and beans) and dairy farming are also widely practised (Kiambu County, 2018). The annual rainfall varies with altitude, with higher areas receiving as high as 2,000 mm and lower areas of Thika Town constituency receiving as low as 600 mm (Macharia and Raude, 2017).

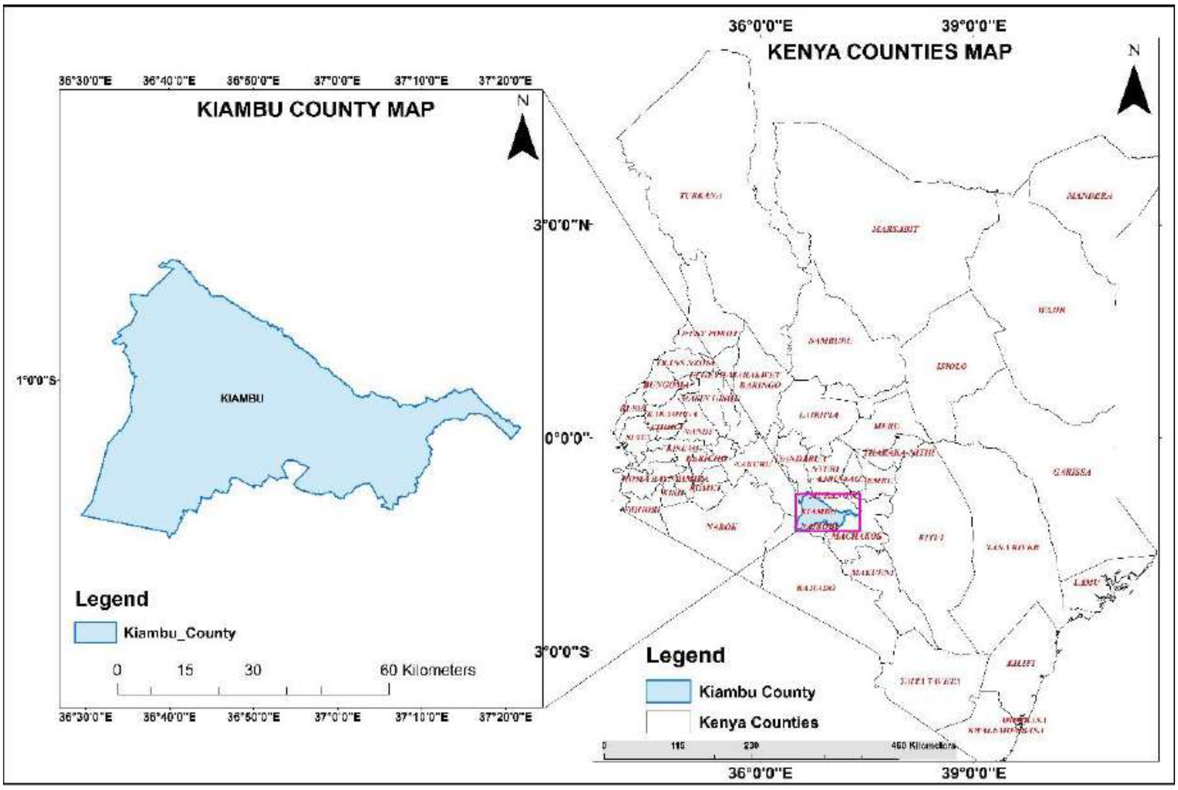

Figure 1: Location of Kiambu County

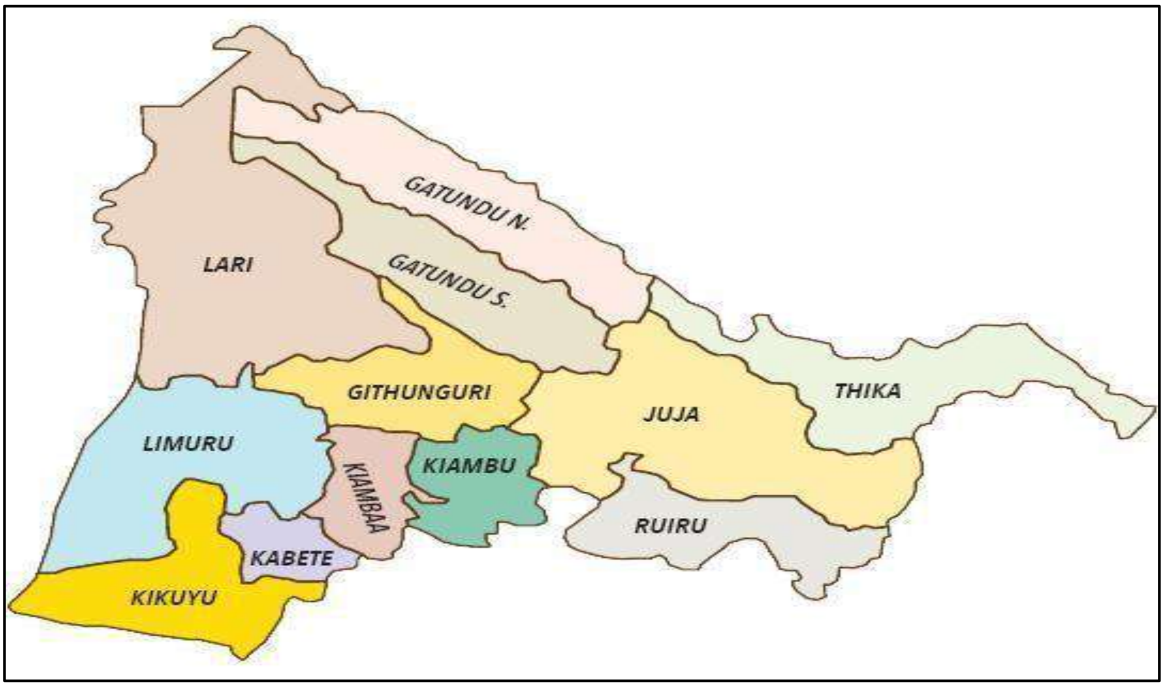

Figure 2: Sub-division of Kiambu County into electoral constituencies

2.2 Development of thematic maps of factors that affect pineapple production

Figure 3 shows a summary of the methodology used to generate a land suitability map while Table 1 gives a description of the data used in the study. As shown in Figure 3, maps for each factor affecting pineapple growth (soil, climate and topography (Digital Elevation Model (DEM)) were developed in ArcGIS 10.3 software. Soil type and soil PH maps were developed from the soil data obtained from the Kenya Soil Survey and the Soil and Terrain Database (SOTER) of the International Soil Reference and Information Centre (ISRIC) (Batjes, 2002). Rainfall and temperature maps were developed using spatial interpolation analysis in ArcGIS based on point measurements of data (rainfall and temperature respectively) from the Kenya Meteorological Department (KMD). Elevation and slope maps were derived from the 90-m Digital Elevation Model (DEM) obtained from the SOTER database.

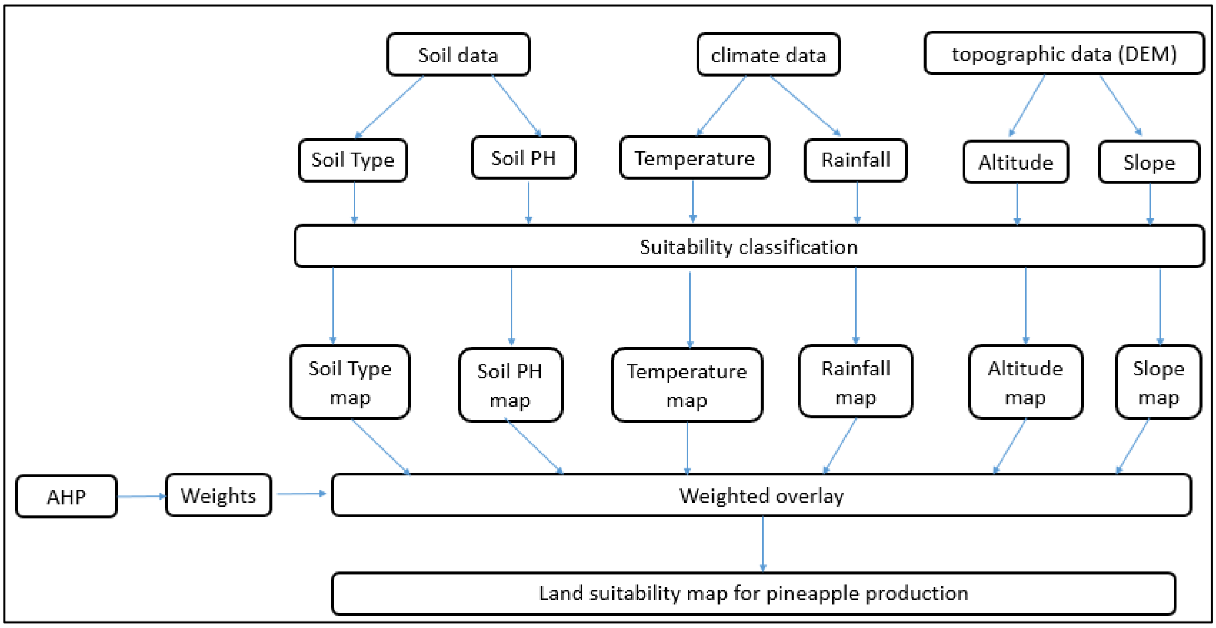

Figure 3: Summary of data and methods used

Table 1: Datasets for the study and their sources

Dataset	Description	Source
Temperature	Mean annual temperature (°C)	Kenya Meteorological Department KENSOTER
Precipitation	Annual rainfall (mm).	World Resource Institute
Soils Type	Soil properties	KENSOTER
Altitude	Raster strm 90 m Digital Elevation Model	United States Geological Survey **(**USGS)
Soil pH	Soil pH values with GPS location	KENSORTER
Slope	Degree of slope map created from DEM	United States Geological Survey (USGS)

All the maps (each representing one-factor affecting pineapple growth) were reclassified to generate thematic maps showing the suitability for pineapple growth based on each factor, separately. The classification of suitability classes were based on land suitability classes (Table 2) by the Food and Agriculture Organization of the United Nations (FAO, 1976).

Table 2: Land suitability classification framework (FAO, 1976)

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

For each factor (rainfall, soil pH, soil types, slope altitude and temperature), the values in the optimal range for pineapple growth was classified as *'highly suitable'* (S1) class in the thematic map. Values above and below the optimal range were distributed in other classes (moderately suitable, marginally suitable and not suitable) depending on their influence on the rate of growth or quality of the pineapple fruit according to Table 3 for the soil type and Table 4 for the rest of the factors. For each factor, the corresponding thematic maps were developed as follows:

2.2.1 Soil pH

Pineapples need a neutral to mildly acidic soil ranging pH from 4.5 to 6.5 (Hossain 2016; Morton 1987; Queensland State 2013) and the optimal range for pH is 5.5 to 6.0 (Hotegni et al., 2012). The optimal range was classified as the '*highly suitable'* (S1). Outside the optimal range, pineapple still grows in the wider range of pH but productivity is limited. These value ranges were classified as '*moderately suitable*' (S2) and '*marginally suitable*' (S3) depending on how close (above or below) they are with the optimal range of values. Where the values were outside this broader range, they were classified as '*not suitable'* (N) as shown in Table 4.

2.2.2 Altitude

Altitude influence the quality of the pineapple. It affects the flavour of the fruit. Pineapples can be cultivated from low altitudes (sea level) to high altitudes (over 2000 m) in the highlands (Morton 1987; Malézieux et al., 2003). At higher elevations, the fruit becomes too acidic. In Kenya fruits grown at an altitude range of 1350 -1750 m is sweet and suitable for canning and export. Above that elevation, the flavour of the fruit becomes undesirably acidic (Morton, 1987). The optimal range was classified as '*highly suitable'*, elevation above 2000 m that was classified as '*not suitable*'. Elevations between 1750 and 2000 m was classified as '*marginally suitable'* while elevation below 1350m was classified as moderately suitable.

2.2.3 Rainfall

Pineapples grow in a wide range of moisture conditions above 600mm but do favourably in regions where the annual rainfall is above 1000 mm (Neild and Boshell 1976; Neri et al., 2021). Pineapple can produce fruit under yearly precipitation rates ranging from 600 to 3,800 mm (Morton 1987). Therefore areas receiving annual rainfall above 1600 mm was classified as '*highly suitable'*, those receiving between 1200 and 1600 mm as moderately suitable, those receiving between 600 and 1200 as marginally suitable while those receiving less than 600 were classified and '*not suitable*'.

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2.2.4 Slope

A slope between 2-6% is best for pineapple growth (Hossain, 2016). A slope below this range may not provide the required drainage. For mechanized agriculture, operations become difficult for slopes above that range (Queensland State, 2013). A slope of 2-6% was classified as highly suitable (S1). Slopes below 2% and those in the range of 6-10% were classified as moderately suitable. Slopes between 10% and 20% were classified as marginally suitable while slopes above 20% were classified as unsuitable for pineapple cultivation.

2.2.5 Temperature

Pineapples generally grow in a temperature range of between 20^{0}C and 30^{0} C and, but more specifically, the optimal range of mean temperature is between 230C and 240C (Neild and Boshell 1976). Plant growth decreases rapidly at temperatures below 15° or above 32°C. When the ambient temperature drops below 15^{0}C, the fruit will be constrained. Temperatures above 32°C may affect the quality of the fruit due to tissue damage (Neild and Boshell 1976). Based on this information, a temperature range of between 23^{0}C and 24^{0}C was classified as '*highly suitable*' (S1). A temperature range of 20^{0}C to 23^{0}C and 24^{0}C to 30^{0}C was classified as moderately suitable. A temperature range between 15^{0}C and 20^{0}C was classified as marginally suitable and that below 15^{0}C and above 30^{0}C was classified as '*not suitable*'.

2.2.6 Soil type

Pineapples require well-drained and well-aerated soils with relatively good water retention (Hossain, 2016). Loams, sandy loams and clay loams with no heavy clay or rock within one metre of the surface are the best soils for pineapple production (Queensland State, 2013). Therefore, clayey soils are not recommended for growing pineapples. Table 3 shows the suitability classes adopted for soil types (based on texture) in the study area.

Table 3: The soil types classes for growing pineapple

Suitability class	Soil Type
S1	(L) Loamy---loam, sandy clay loam, clay loam, silt, silt loam, and silty clay loam
S2	(C) Clayey ---sandy clay, silty clay, and clay texture classes
S3	(S) Sandy---loamy sand and sandy loam texture classes
N	(Y) Very clayey ---more than 60% clay

Table 4: Suitability classes for growing pineapple

	S1	S2	S3	N
Soil pH	5.5-6.0	5.0-5.5, 6.0-6.5	4.5-5.0, 6.5-7.5	<4.5, >7.5
Annual rainfall (mm)	≥ 1,600	1200-1600	600-1200	<600
Mean temperature (^{0}C)	23-24	20-22.9, 24.1-30	15-19.9,	<15, >30
Altitude	1350-1750	<1350	1750-2000	>2000
Slope (%)	2-6	< 2, 6-10	10-20	>20

2.3 Assigning weight of factors through Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) (Saaty, 2008) was used to determine the relative importance of the various factors affecting pineapple growth. Pairwise comparison was used to assign weights for the developed criteria. Based on experts' knowledge and existing literature, a pairwise comparison matrix was developed where each factor was compared with other factors. The comparison was based on the relative importance of the factor relative to the others and was based on the scale developed by Saaty (2008) (Table 5). In the pairwise matrix developed (Table 6), soil type is 3 times more important in pineapple production than soil PH. The vice-versa is also true i.e. that soil pH is a third as important as soil type. Soil type is also seven times more important than the slope regarding pineapple cultivation and vice versa is also true. The diagonals compare a factor by itself and hence has a value of 1 i.e. equal importance. To determine the weights, eigenvectors were calculated from the pairwise comparison matrix. To do this, the nth root of the product of all the elements in each row of the matrix (Table 6) was computed (where n is the number of elements in the row, six in this study). The nth roots were then normalized by dividing them by their sum to get the eigenvectors (Table 6) which represents the weights of respective factors regarding pineapple cultivation (Kamau et al., 2015).

Human judgements are prone to some inconsistencies and it is therefore important to evaluate the consistency in the analysis. AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision-maker. This is done by calculating the Consistent Ratio (CR). The pairwise comparisons in a judgment matrix are considered to be adequately consistent if the CR is less than 10% (Kamau et al., 2015). If the CR is more than 10%, judgments are considered too inconsistent to be reliable. To calculate CR, the judgement matrix (right side of Table 6) was first multiplied by eigenvector (last column of Table 6) to obtain a new matrix (of 6 elements). Each element of the resulting matrix was then divided by the corresponding eigenvector to get estimates for maximum eigenvalue (λmax). The Consistency Index (CI) was calculated from the formula (λmax-n)/(n-1). CR was finally calculated by dividing the CI value by the Random Consistency Index (RCI). RCI was obtained from Table 7 by Saaty (2008).

Table 5: Scale for the pairwise AHP comparison (Saaty, 2008)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly one over the other.
5	Much more important	Experience and judgment strongly one over the other.
7	Very much more important	Experience and judgment very strongly one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Table 6: Pairwise comparison matrix foe assigning weights

	Soil Type	Soil pH	Annual Rainfall	Tempe rature	Altitude	Slope	nth root of product of values	Weight (Eigenvector)
Soil Type	1	3	3	3	5	7	3.133	0.404
Soil pH	1/3	1	1/3	1/3	3	3	0.833	0.107
Annual Rainfall	1/3	3	1	3	3	3	1.732	0.223
Temper ature	1/3	3	1/3	1	3	3	1.201	0.155
Altitude	1/5	1/3	1/3	1/3	1	3	0.530	0.068
Slope	1/7	1/3	1/5	1/3	1/3	1	0.319	0.041
Sum							7.748	1.000
λ_{max} = 6.387			CI = 0.08			***CR = 0.06***		

Table 7: Random Consistency Index (RCI) for AHP

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

2.4 Development of Land Suitability Map

The reclassified thematic maps of all the factors (rainfall, soil pH, soil types, slope altitude and temperature) were combined using the weights obtained from the AHP process through weighted overlay using the weighted sum tool and spatial Analyst tools in ArcGIS to develop a land suitability map (Hassan et al., 2020; Mishra et al., 2015).

3.0 RESULTS AND DISCUSSIONS

3.1 Thematic maps of factors affecting pineapple production

3.1.1 Altitude

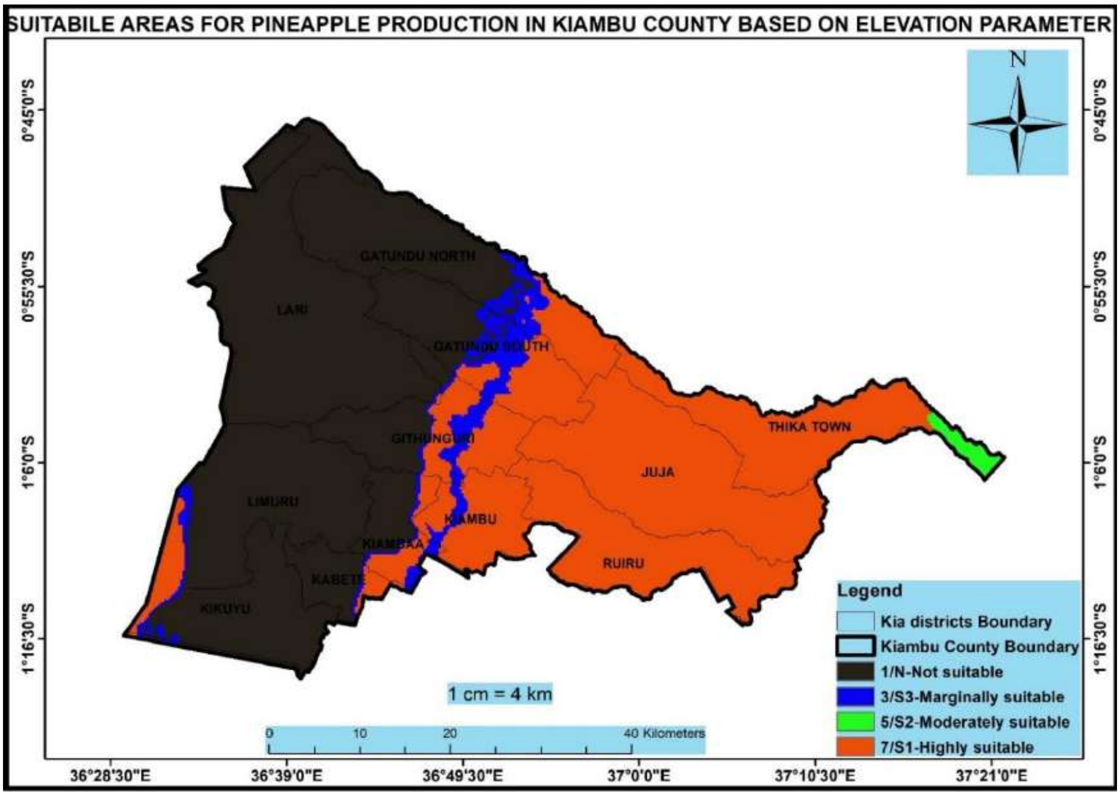

Figure 4 Pineapple production suitability map based on altitude

Figure 4 shows the reclassified map (thematic map) of pineapple production suitability based on elevation (alone). As indicated in Table 4, areas with an altitude of above 2000 which is near the Aberdare ranges are not suitable for pineapple cultivation. The study area becomes favourable for pineapple production as you drop down in altitude. Based on altitude, areas like Juja, Ruiru, Thika town and Kiambu town are classified as suitable areas for pineapple production. Lari, Limuru and Kikuyu areas are at a high elevation and hence classified as not suitable. Altitude has the biggest influence on the flavour of the fruit grown. At very high elevations, the flavour gets affected and the fruit becomes acidic (Neri et al., 2021; Morton, 1987). Pineapple grown in high altitudes (with cold night temperatures) has short and fewer leaves compared to those grown in low altitudes (with humid climates) which have many and wide leaves (Neri et al., 2021). Pineapples grown in higher altitudes take longer to mature as compared to those planted in lower altitudes (Rosmaina et al., 2019; Malézieux et al., 2003). The effect of change in altitude on pineapple growth and fruit quality is also related to other factors that change with altitude e.g. temperature and humidity.

Worldwide, pineapples are grown at a wide range of altitudes ranging from sea level to as high as 2000 m above sea level (Malézieux et al., 2003). In Kenya, pineapples grown at 1371 m are too sweet for canning; between 1371 and1738 m the flavour is most suitable for canning. The Del Monte farm is one of the biggest plantations of pineapple production and export in Kenya and is located in Thika in Kiambu County (Figure 4) at an elevation of about 1500 m. The plantation also crosses to the neighbouring Murang'a County.

3.1.2 Rainfall

The suitability map for pineapple production based solely on rainfall (Figure 5) shows that almost the entire Kiambu County is suitable for pineapple production. This is because the annual rainfall in Kiambu is high (ranging from 400 to 2400 (Musa and Odera, 2015)). The area around Aberdare (parts of Gatundu North and South, Githunguri and Lari) have favourable rainfall for pineapple cultivation. Some of the lower areas classified as marginally suitable (e.g. Thika) still have rainfall above 1000 mm and therefore in combination with other favourable factors, they still do produce good yields and quality of pineapples. For rainfed pineapple production, rainfall distribution throughout the year is more important than the total accumulation (Neri et al., 2021). Therefore, scarce and erratic rainfall may limit pineapple growth and production. Irrigation may thus help improve production in dry areas. However, pineapple is a drought-tolerant crop that can handle some level of moisture stress. It has therefore been grown in some dry areas with an annual rainfall of less than 600 mm such as some parts of Hawaii, U.S.A. In wet areas receiving high rainfall, the soils need to be well-drained because waterlogging reduces yield. Waterlogging impedes gas exchange, resulting in elevated CO_2 and depleted O_2 levels in the soil, which lead to decreased growth by inducing root anoxia. (Malézieux et al., 2003).

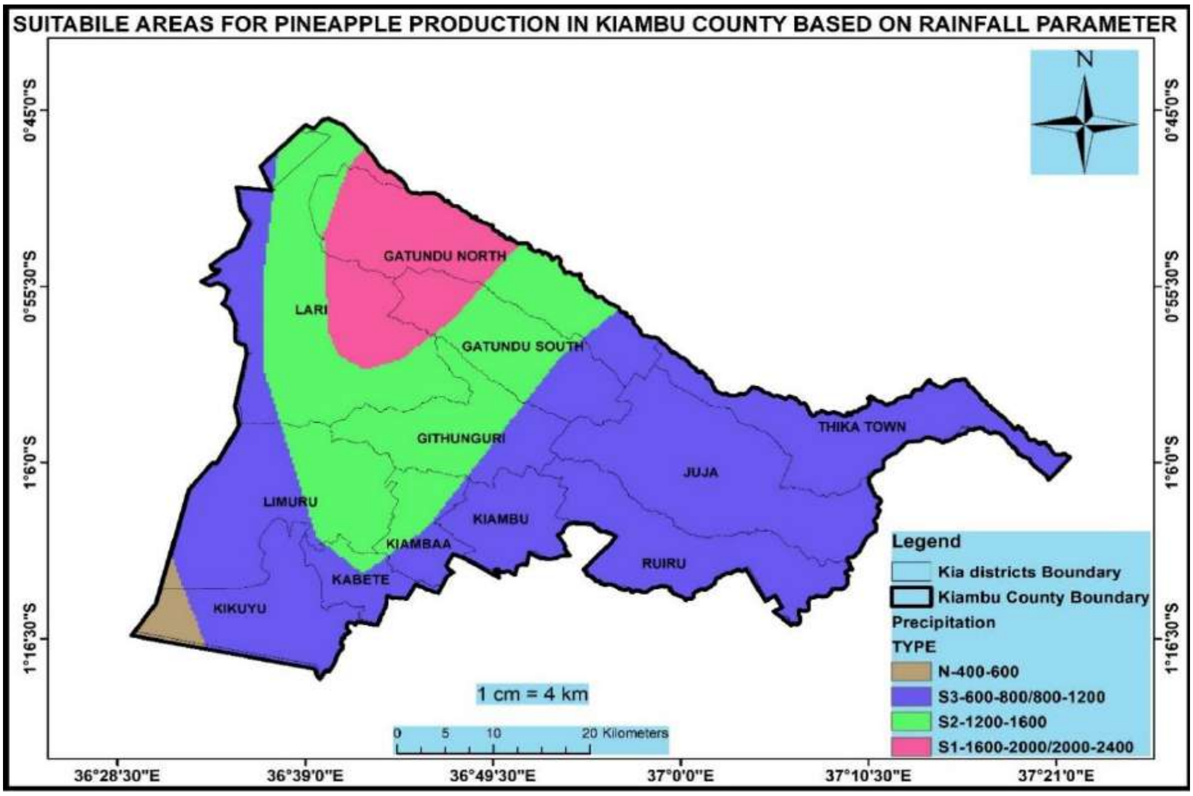

Figure 5 Pineapple production suitability map based on Rainfall

3.1.3 Slope

Results of land suitability for pineapple cultivation based on the slope are shown in Figure 6. Low land areas of the County (Ruiru, Juja and Thika) are categorized mainly as 'highly suitable' because they have low slopes. As elevation increases towards Aberdares, the slope increase and the land become less suitable for pineapple cultivation. Slopes less than 2% is not very favourable for pineapple cultivation due to risks of flooding. Flooding negatively affects the production of pineapples (Malézieux et al., 2003). High slopes mainly limit farm operations particularly mechanized farming. Therefore, large-scale farming of pineapples in the high elevations of the county is limited by the high slopes present. However, pineapple cultivation is still possible through small-scale un-mechanized farming, which is commonly practiced in the area.

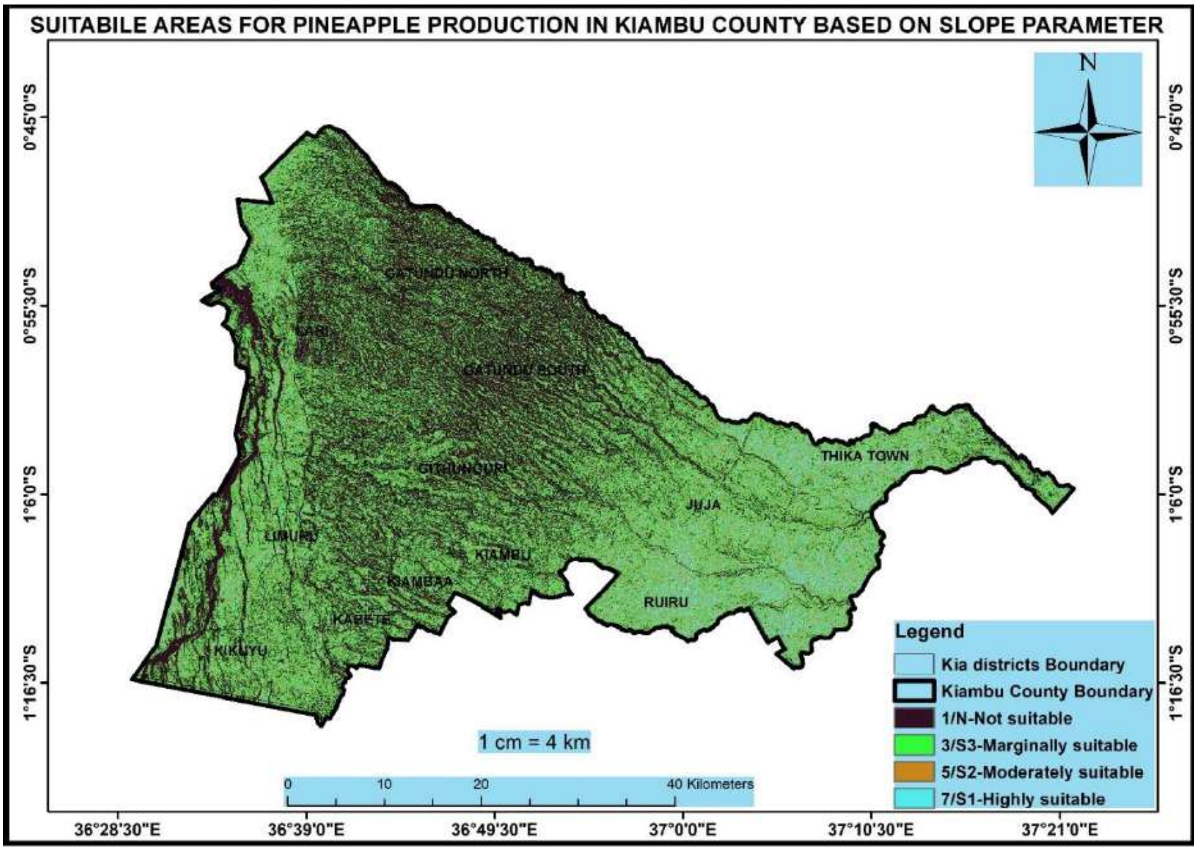

Figure 6 Pineapple production suitability map based on Slope

3.1.4 Temperature

Pineapple production land suitability based on temperature is shown in Figure 7. Based on the classification adopted, no area was highly suitable as mean annual temperatures were below the optimal range of 23^0C to 24^0C. The lower eastern end of the study areas (around Thika town) is relatively warmer than the rest of the county and has been classified as 'moderately suitable' (Figure 7). As the mean annual temperature continue to drop towards the western direction, the area was classified as marginally suitable'. These are the areas (e.g. Gatundu North) where farmers have of late started adopting pineapple cultivation. The area around the Aberdare ranges in the western end of the county is classified as 'not suitable' because of the low mean temperatures. Temperature is an important factor affecting crop growth and majorly determines the suitable area for cultivation worldwide. Pineapples generally grow in a temperature range of between 20^0 C and 30^0 C. A daytime temperature of between 25°C and 32°C and a nighttime temperature of between 15°C and 20°C at night is ideal for pineapple growth. High temperatures may cause tissue damage due to increased respiration rate and metabolism and impaired nutrient absorption (Hossain, 2016; Neild and Boshell 1976). Prolonged low temperature slows growth (by reducing the rate of increase of Leaf Area Index (LAI)) and delays maturity (Morton, 1987; Malézieux et al., 2003). Therefore, pineapple in cold areas takes longer to mature compared with pineapple grown in warmer climates. Long cold temperatures also cause the fruit to be more acidic (Morton, 1987). Therefore, the low temperatures that characterize the areas around Aberdare ranges may not be very ideal for pineapple production and hence are classified as not suitable (Figure 7). The area around Aberdare also suffers from frost (Kotikot and Onywere, 2014) which poses a greater risk to pineapple production in the region (Caldana et al. 2020). Pineapple does not tolerate frost as it causes the leaves to develop a red/white-flecked, scorched appearance which may eventually cause them to die (Malézieux et al., 2003). The average (annual) minimum temperature in the forest zone drop to as low as 8^{0}C making it unsuitable for pineapple cultivation. The area surrounding the Aberdare forest e.g. Gatundu North and Gatundu South, where farmers have ventured into pineapple production recently also suffers from low (minimum) temperatures and therefore the pineapple take longer to grow and the fruit is slightly acidic. The area has been classified as marginally suitable (Figure 7).

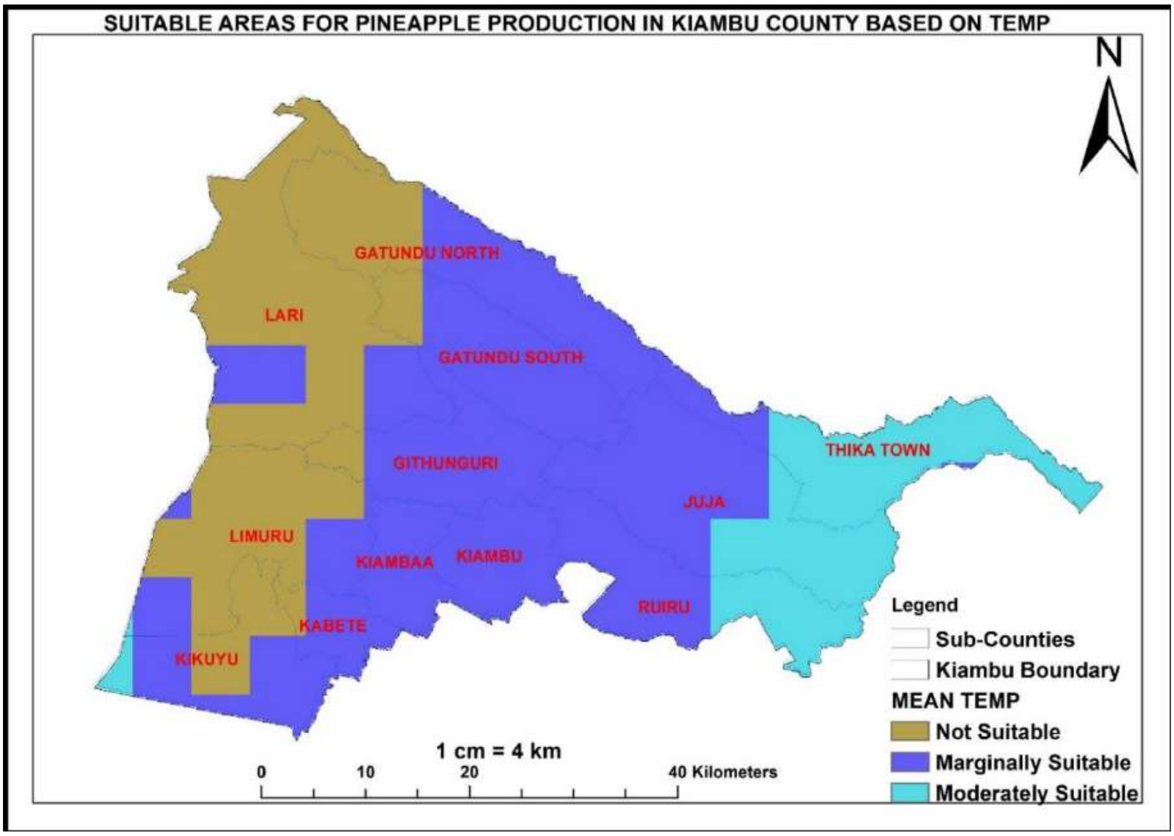

Figure 7: Pineapple production suitability map based on Temperature

3.1.5 Soil Type

Figure 8 shows a land suitability map based on soil type (texture). Most of the area is classified as moderately suitable and there are few pockets that are classified as highly suitable. The western areas of Ruiru, Juja and Thika are classified as not suitable for pineapple cultivation. Pineapple production requires well-drained soils e.g. sandy loam (Morton, 1987). There are only a few pockets of sandy loams in the County which has been classified as highly suitable (Figure 8). Other than the sandy loams, pineapples also do well in clay loam soil (Hossain 2016). Based on the classification criteria defined in Table 3, most of the study area was classified as 'moderately suitable' for pineapple cultivation (Figure 8). The more the clay content in the soil, the less suitable it is for pineapple cultivation. The area around Ruiru and Juja, which is classified as 'not suitable' is mainly dominated by vertisols which has high clay content and hence are not ideal for pineapple cultivation. The soils are also shallow and have poor drainage further making them unsuitable for pineapple production.

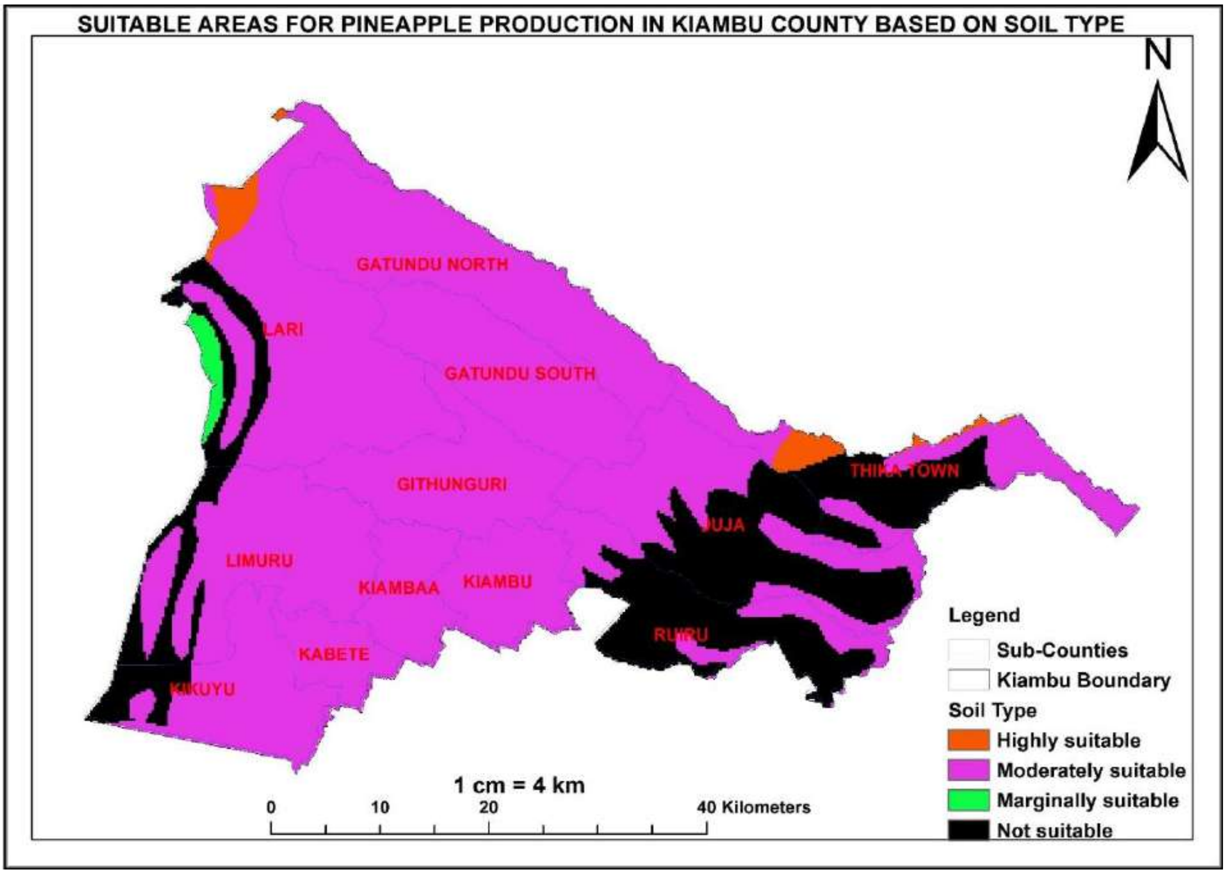

Figure 8: Pineapple production suitability map based on Soil Type

3.1.6 Soil pH

Pineapple cultivation suitability based on soil pH is presented in Figure 9. A soil pH of the range of 4.5-5.5 is optimal for pineapple production (Neild & Boshell, 1997). Ruiru, Juja and Thika mainly have the ideal soil pH for pineapple production with the exception of a few pockets where the pH is higher than ideal and hence classified as 'marginally suitable'. Kabete, Kiambaa and parts of Limuru, Kiambu, Githunguri, Gatundu South and North are classified as moderately suitable for pineapple cultivation based on pH. The pH in these areas is slightly above the optimal range. The remaining parts of Githunguri, Gatundu South and North have high acidic soil that makes them not suitable for pineapple production. Soil pH has an effect on plant nutrient availability and absorption particularly the micronutrients (Maia et al., 2020). Soil pH, therefore, determines pineapple fruit growth, yield, and quality. Pineapple can tolerate acidic soils the low pH may lead to nutrient imbalances and poor nutrient absorption by plants that could result in poor yields in the long term (Silva et al., 2005; Maia et al., 2020). For example, acidic soils have low calcium concentrations and the plant fruit suffer from calcium deficiency which causes fruit abnormalities such as severe fasciations, joined multiple fruits and rounded (cannonballs) fruits. Inadequate magnesium can cause sun-bleached coloured leaves in pineapple crops (Guinto and Inciong 2012; Silva et al., 2005). High acidity in soils also provides a thriving environment for nematode Pratylenchus brachyurus which affects pineapples roots affecting their growth and productivity (Osseni et al., 1997). On the other hand, pH above 5.5 causes deficiencies in micronutrient utilization by the plant (Maia et al., 2020).

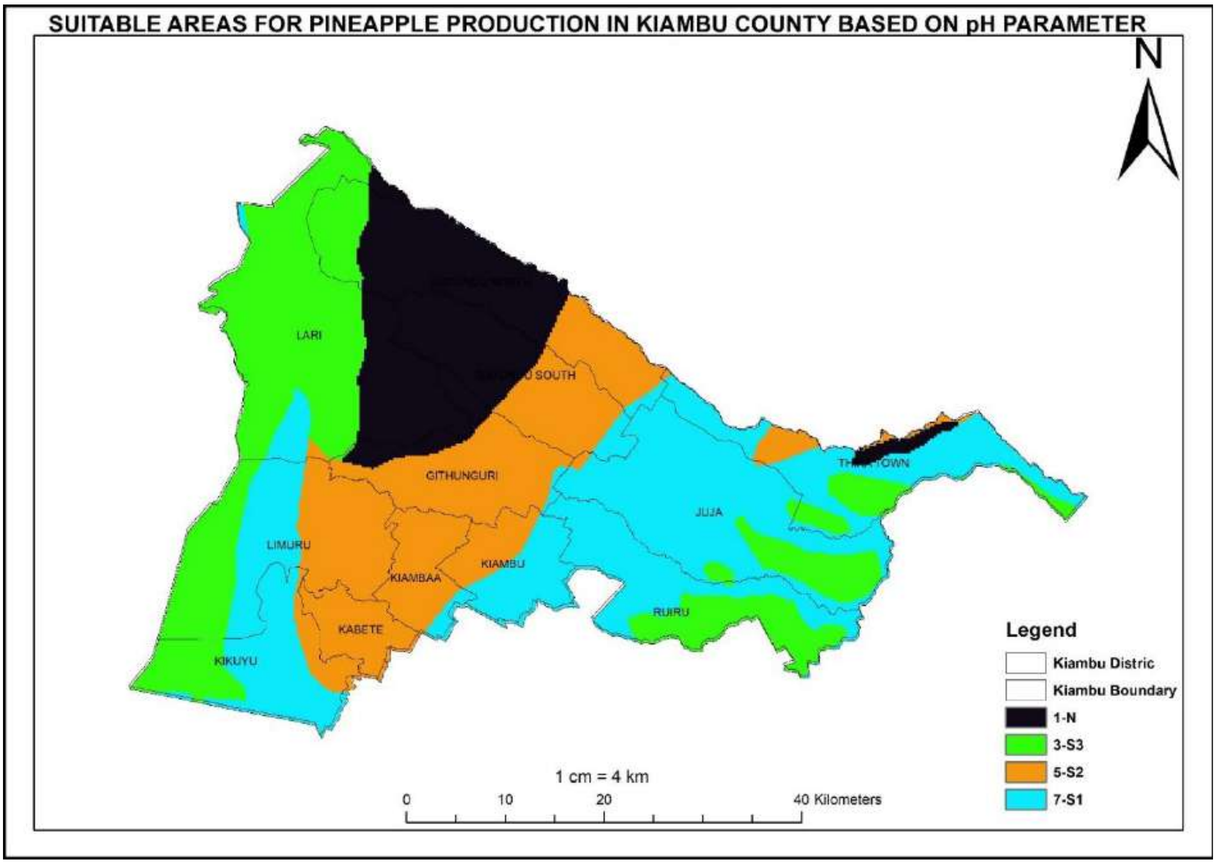

Figure 9: Pineapple production suitability map based on Soil pH

3.2 Land suitability for pineapple cultivation

The results of the weighted overlay of the thematic maps of factors affecting pineapple production was a land suitability map for pineapple cultivation in Kiambu County (Figure 10). The results show that 38% of the county is highly suitable, 41% is moderately suitable, 16% is marginally suitable and 5% is not suitable for pineapple cultivation.

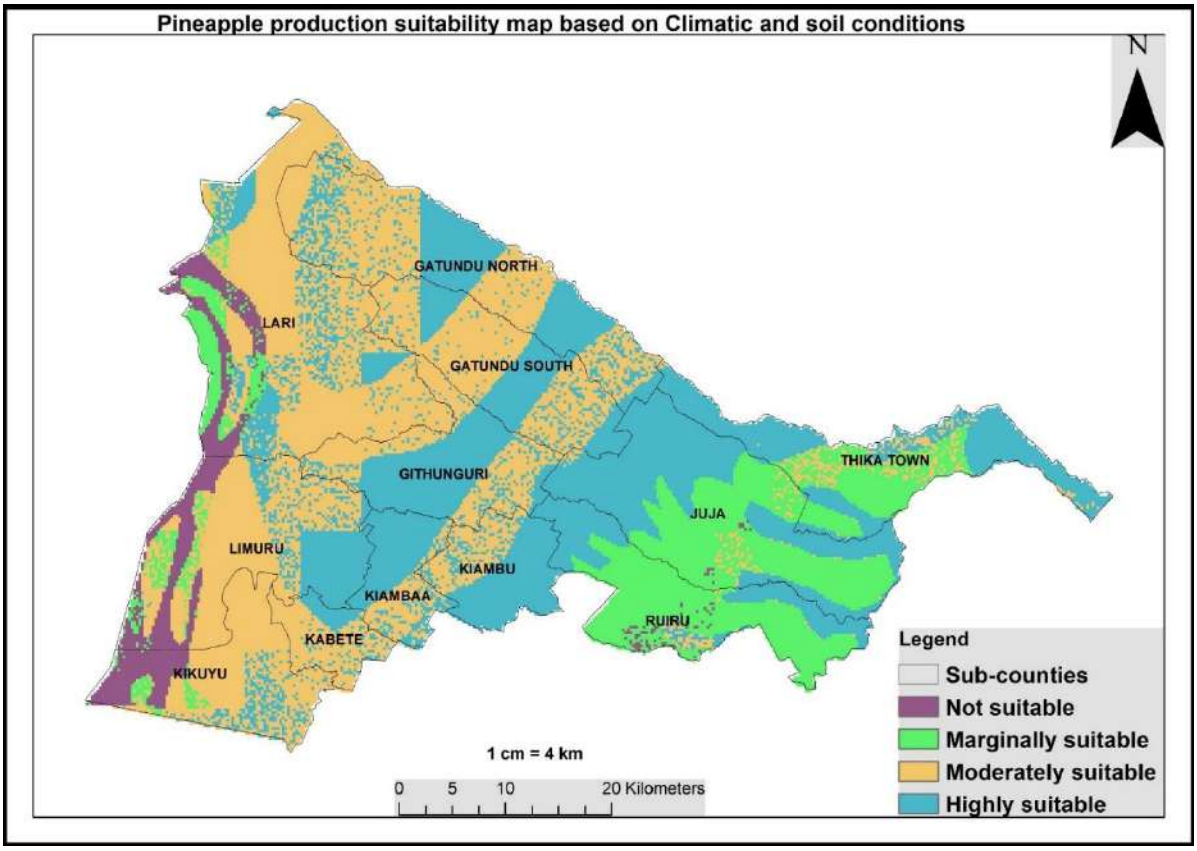

Figure 10: Pineapple production suitability map based on Climatic and soil conditions

From the map, parts of Juja, Ruiru and Thika in the lowland of the county is highly suitable for pineapple cultivation (Figure 10). At higher altitudes, i.e. Gatundu North, Gatundu South, Githunguri, Kiambaa and Kabete, the study area is classified either as highly suitable or moderately suitable. The western side of the County (Lari, Limuru and Kikuyu) is mainly classified as moderately suitable with the extreme western edge of the county being either marginally suitable or unsuitable for pineapple cultivation.

Also classified as marginally suitable are parts of the lower side of Ruiru, Juja and Thika on the eastern side of the county (Figure 10). These are areas despite having a good climate for pineapple production, have poorly drained soil as shown in Figure 8. In regard to pineapple cultivation, soil type (texture) is considered more important than any other factor in the judgmental matrix developed using the Saaty (2008) weighting scale (Table 6). For example, soil type was considered 3 times more important than both temperature and annual rainfall (Table 6). This implies that soil type has a higher weight than all the other factors (Table 6). Soil type had a weight of 0.40, more than double the weight of temperature (0.16) and far ahead of that of annual rainfall (0.22) (Table 6). With the controlling weight of the soil type, the final land suitability map (Figure 10) was largely (40%) influenced by the soil type. For example, most of the areas classified as 'not suitable' in the western edge of the soil type thematic map (Figure 8) remained 'not suitable' in the final land suitability map (Figure 10). On the eastern side, areas classified as 'not suitable in soil thematic map (Figure 8) improved only slightly and moved to 'marginally suitable' in the final land

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suitability map (Figure 10) despite the area having favourable elevation, slopes and temperature. Vertisols found in the area has a high clay content and are therefore poorly drained. The soils are also relatively shallow, further making them less favourable for pineapple production. Some of these areas also have slopes of less than 2% which cause water-logging during the wet season making them less favourable for pineapple production. The area to the East of Thika town (at around Gatuanyaga and Kilimambogo) is classified as 'highly suitable' and is currently under large-scale production of pineapples by Del Monte company, which validates the land suitability map developed in this study. Del Monte farm also extends to the North of Thika town in Murang'a County. The edge of Kiambu County to the North of Thika town (Figure 10) is also classified as 'highly suitable' and that implies that part of the Del Monte farm that extends to Murang'a county at that part is also 'highly suitable' for pineapple cultivation. That area (between Thika and Kabati towns) is currently under large-scale production of pineapples by Del Monte. Generally, the results show that most parts of Kiambu can produce pineapples, however, the quality of the fruits and the length of the growing season may vary spatially depending on the category of suitability shown in Figure 10.

The information in the thematic maps is also helpful for pineapple production. It can be used for the management of pineapple production in various parts of the county. For example, a farmer growing pineapples in areas where rainfall is not sufficient (Figure 5) can use irrigation to supplement soil moisture. In Thika, for example, the annual rainfall is about 1000mm which is not sufficient for pineapple production (Figure 5). Del Monte farm in Thika uses irrigation to supplement water requirements for pineapple production. In very acidic soils, farmers can add soil amendments such as lime, dolomite to raise (or to lower) the soil pH to the optimal range (Silva et al., 2005).

4.0 CONCLUSION

Land suitability for pineapple cultivation in Kiambu County was successfully studied using GIS and Analytical Hierarchical Process (AHP). Six land suitability thematic maps were first developed for each factor that affects pineapple growth i.e. temperature, rainfall, soil type, soil pH, altitude and slope. The thematic maps show (spatially) how suitability for pineapple cultivation vary spatially within the county based on that particular factor. A land suitability map was then developed from the weighted overlay of the thematic maps. From the AHP analysis, soil type was found to be the most important factor (highest weight) followed by rainfall, temperature, soil pH altitude and slope in that order. From the land suitability map developed 38% of the county was found to be highly suitable, 41% was moderately suitable, 16% was marginally suitable and 5% was not suitable for pineapple cultivation.

5.0 RECOMMENDATIONS

The study recommends that the Kiambu County government agricultural extension officers use the information for planning and advising farmers on where to (and not to) plant pineapples. For farmers in areas classified as moderately, marginal and not suitable for pineapple cultivation, information on thematic maps about suitability for pineapple production based on individual factors can be used to improve production. For example, farmers in areas where rainfall is not sufficient for pineapple production (based on rainfall thematic map) can supplement water availability using irrigation. The methodology applied in this study is also recommended for use for land resource planning and management by the County governments. The method can be applied to other crops as well.

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