# A GIS-based multicriteria analysis of land suitability for groundnut and maize crops in Niger East, Niger State, Nigeria

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**Abstract:** This study assesses the suitability of land for groundnut and maize cultivation in East Niger, Nigeria. By utilizing the Analytical Hierarchy Process (AHP) in conjunction with Geographic Information Systems (GIS), it evaluates critical factors influencing agricultural feasibility, including climate, soil properties, and topography. Climate data spanning 32 years (1985-2016) were sourced from the Climate Research Unit (CRU), and soil data from the Food and Agriculture Organisation (FAO) were used. The results indicate that rainfall is the most critical factor (weight: 0.324) for both crops, followed by temperature (0.227), soil pH (0.136), organic content (0.123), cation exchange capacity (0.08), soil texture (0.051), slope (0.029), and elevation (0.027). The suitability maps reveal that for groundnut farming, 51% (8,363.80 km²) of the area is highly suitable, 29% (4,695.46 km²) moderately suitable, 3% (458.54 km²) marginally suitable, and 17% (2,714.56 km²) not suitable. For maize, 52% (8,382.14 km²) is highly suitable, 30% (4,878.88 km²) moderately suitable, 10% (1,705.77 km²) marginally suitable, and 8% (1,265.57 km²) not suitable. The findings underscore the importance of understanding land suitability to optimize resource use and enhance food security. Further localized assessments and the promotion of sustainable agricultural practices will help improve soil health and productivity, serving as a valuable resource for policymakers and stakeholders in the region.

**Keywords:** analytic hierarchy process, food security, GIS, site selection, Nigeria

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## 1 Introduction

The rapid growth of the global population presents a significant challenge to food availability, highlighting food security as a critical issue. Food security is achieved when individuals have reliable access to sufficient nutritious and culturally appropriate food (Liu et al., 2008). The state of the nation's food, the citizens' well-being and its economic development are intrinsically linked (Özkan et al., 2020). The amount of food produced is influenced by land selection, making it essential to

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Land and soil properties vary due to slope, soil management practices, and the processes of soil formation (Malgwi and Abu, 2011). High-quality land is crucial for crop production, yet it is increasingly degraded due to growing population pressures and poor land-use practices (Mustard et al., 2012; Abdullahi et al., 2023). Climate change further exacerbates these issues, particularly in developing countries, necessitating the integration of risk management into food security strategies (Fan et al., 2013). Consequently, understanding land suitability is essential for enhancing agricultural resilience, optimizing resource use, and minimizing environmental impacts.

Land suitability analysis (LSA) is an effective method for evaluating the appropriateness of land for agricultural uses (Akıncı et al., 2013). This method considers various factors related to intended uses, guiding users toward informed decisions about land use. Advanced models, utilizing multi-criteria decision-making (MCDM) techniques such as the Analytical Hierarchy Process (AHP), enhance LSA by incorporating relevant geographic and agricultural data (Pramanik, 2016). The AHP-GIS technique is particularly effective for selecting agricultural sites (Abed et al., 2011).

Recent studies have employed the AHP-GIS approach globally, assessing parameters related to climate and soil quality (Pramanik, 2016; Tashayo et al., 2020; Amini et al., 2020). Sathiyamurthi et al. (2024) conducted an assessment of the agricultural suitability of the Krishnagiri district using AHP-TOPSIS along with GIS techniques. Their research produced crop suitability maps that were classified into five categories: "highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N)." The findings indicated that maize, field bean, cluster bean, groundnut, pomegranate, lemon, and lemongrass were highly suitable for cultivation in the Krishnagiri district. In contrast, rice, cotton, sugarcane, sunflower, and cashew nut were deemed moderately suitable, while vanilla was found to be unsuitable. Nguyen et al. (2021) assessed the potential lands for growing groundnut in Dien Chau district of Nghe An-province (Vietnam). They found that soil texture, average temperature, soil type, and soil depth are the most significant factors, carrying the highest weights for groundnut farming. In contrast, slope and average total rainfall were the factors with the lowest weights. Contrary to the finding of Nguyen et al. (2021), Sathiyamurthi et al. (2024) found slope to be an important factor after the soil texture. This suggests the role each factor plays varies with the environmental conditions. Although some research has focused exclusively on soil parameters or neglected climate factors, the careful selection of indicators is critical for reliable outcomes. Classifying indicators into inherent and dynamic factors helps capture essential metrics for suitability assessments. Furthermore, localized environmental variables significantly enhance the precision of LSA results.

Niger State in Nigeria is the largest state by land area, with about 80% of its territory suitable for agriculture (Merem et al., 2017). Major crops produced include maize, groundnuts, millet, yams, sugarcane, and rice, with annual production estimated at over 200,000 metric tons. Groundnuts and maize are crucial crops in Northern Nigeria, particularly Niger State, serving as significant sources of nutrition and income for local farmers (Jaji et al., 2023). The cultivation of these crops significantly improves farmers' livelihoods by enhancing their revenue through local sales and market access, thereby contributing to food security and economic viability within the community (Ojo et al., 2023). Although there has been a significant increase in recent years due to improved fertilizer application, challenges such as cultivating unsuitable land can raise production costs and affect food prices. Soil degradation is also a concern, as runoff from these lands poses a threat to freshwater resources (Niger State Bureau of Statistics, 2012).

Research indicates that intercropping groundnut and maize enhances soil quality and yield, as demonstrated by Nwite et al. (2017). This practice improves sustainable soil productivity and increases nitrogen content in the soil and maize leaves, even with reduced fertilizer use (Li et al., 2022). Despite existing studies on crop suitability in Nigeria, there is a lack of research specific to our study area. This highlights the need for regional studies that evaluate land suitability for these crops, taking into account climate, soil characteristics, and topography. Therefore, this study aims to assess land suitability in Niger East for the cultivation of groundnut and maize.

## 2 Materials and methods

### 2.1 Study area

The study was conducted in Niger East, Nigeria (NEN), a notable district situated between the latitudes of 9°7’47’’N to 10°41’28’’N and longitudes of 6°05'00"E to 7°12'00"E (see Figure 1). Known as Zone B, NEN is one of three Geo-political Zones in Niger State, which is strategically located in Nigeria’s North Central region. The climate of this area features two distinct seasons: the wet season, which runs from April to October, and the dry season, from November to March. Average annual rainfall fluctuates between 1000 mm and 1400 mm, with maximum temperatures reaching approximately 39°C and minimums around 22°C (Animashaun et al., 2020). Furthermore, Niger East encompasses virtually all soil types found in the savannah regions of West Africa, particularly the alluvial soil that is renowned for its exceptional potential for both rain-fed and irrigated agriculture (Merem et al., 2017).

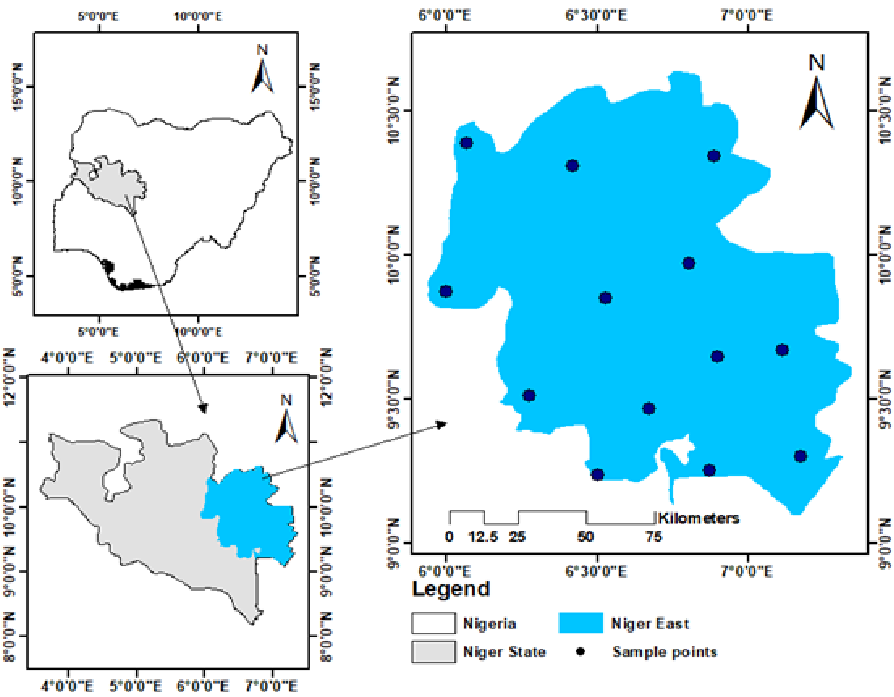


Figure 1 Area of study

### 2.2 Dataset and method

2.2.1 Climate data

The observed climate datasets used in this study were obtained from the Climate Research Unit, East Anglia (CRU_TS 4.06). CRU datasets are gridded monthly data with 0.5 by 0.5 latitude and longitude resolution. Data for thirteen grid points were extracted over 32 years (1985 –2016). The choice of the CRU dataset for the study was due to the non-availability of station data for the area and the high correlation between the CRU data and the available station data within the state (Animashaun et al., 2023a). CRU monthly data for both the rainfall and temperature were aggregated to obtain the annual data needed for the suitability analysis

2.2.2 Soil and GIS data

Soil properties used for the analysis were extracted from FAO-UN (The Food and Agriculture Organization of the United Nations) soil data. FAO-UN World Soil Classification provides the soil classification adopted in the study. To determine spatial variability in the soil characteristics (soil type, soil pH, cation exchange capacity, and organic content) within the study area, thirteen grid/sample points were considered. For topography data, the digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM) of the United States National Aeronautics and Space Administration (NASA) was downloaded from ttps://earthexplorer.usgs.gov/. The data was projected to WGS_1984_UTM, Zone_32 N and used to produce a slope map for the study area. The DEM data used is of 30-m resolution. The land use/land cover data was created as mentioned in Animashaun et al. (2023b). Landsat 8 satellite images downloaded from USGS Earth Explorer were layer stacked, mosaicked, and processed for land use/land cover classification. The accuracy of the data used was checked through ground truthing.

**2.3 Method**

The data used for the LSA analysis are classified as criteria and sub-criteria. A total of three criteria and eight sub-criteria were selected for the study. The criteria are climate, soil properties, and topography, while the sub-criteria are rainfall, temperature, soil organic content (OC), soil pH, cation exchange capacity (CEC), soil texture, elevation, and slope.

2.3.1 Analytical hierarchy process

The AHP theory is an approach that uses the MCDM method for classifying data that is structured hierarchically. The method allows for the numerical evaluation of qualitative and quantitative data and uses a hierarchy structure to analyze complex problems. The AHP, as adopted in this study, involves three stages. The first stage is the hierarchy structure of the framework as shown in Figure 2. The other stages are making pair-wise comparisons, and the determination of priorities and consistency ratio (CR) (Akhtar et al., 2021).

The pair-wise comparison was performed according to the relative importance of each sub-criterion over the others. Within each stage of the hierarchy, the relative importance of each pair of sub-criteria was assessed in relation to the overall goal. A nine-point numerical scale was used for the ranking (Table 1). To determine the priority, the values assigned to sub-criteria in the ranking process were used to obtain the resulting priorities (weights of the criteria) and the consistency ratio (CR).

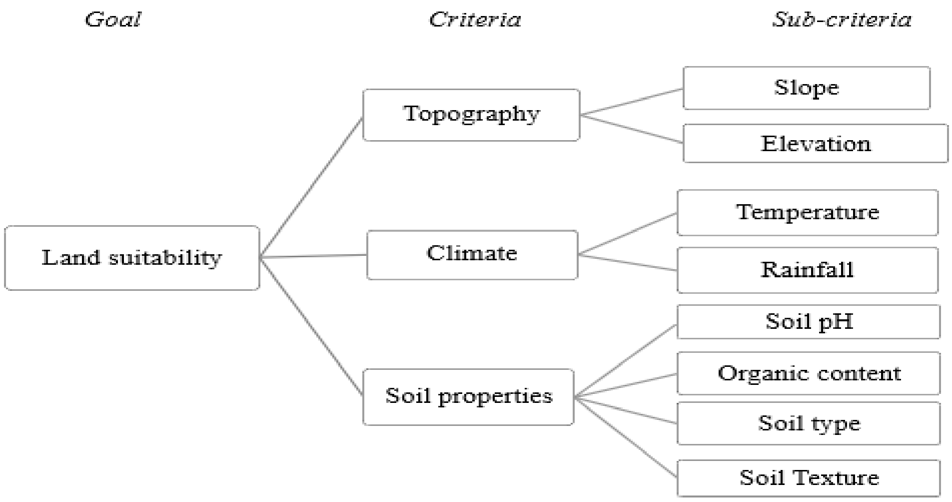


Figure 2 Hierarchy structure of LSA factors for groundnut and maze farming.

Measurement theory was used to evaluate pair-wise comparison matrices. The sum of the values of each sub-criterion in the pairwise comparison matrix (Table 2) was obtained down the column, and all the elements in each column were divided by their sum to get a normalized pair-wise matrix (Table 3). The average of each row was obtained to get the criteria weight. Thereafter, the consistency of the matrix was checked (i.e., confirming the correctness or otherwise of the calculated values), the pair-wise comparison matrix that was not normalized (first pair-wise comparison matrix) was picked and each value in the column was multiplied by their corresponding criteria weight. The sum of each row of the resulting matrix (third matrix) was obtained to get the weighted sum value. Then, the ratio of the weighted sum value and the criteria weight for each row was obtained. The average of the resulting ratios was obtained to get the eigenvalue (λmax).

Consistency Index (C.I.) and Consistency Ratio (C.R.) were computed using Equations 1 and 2, respectively. The consistency ratio was used to determine how much variation is allowed in the AHP result, and this must be less than 10% (CR ≤ 0.1) for the relative weights to be suitable for use in land suitability analysis (Saaty, 1980).

$$\text{Consistency Index (C.I.)}=\frac{\lambda max-n}{n-1} \quad (1)$$

$$\text{Consistency Ratio (C.R.)}=\frac{C.I.}{R.I.} \quad (2)$$

Where，

$n$ is the number of compared elements (sub-criteria)；

R.I. (i.e., random index), as provided by Saaty (1987), is the consistency index of the randomly generated pair-wise matrix n (Table 4).

**Table 1 The fundamental scale for pair-wise comparison (Saaty, 2008)**

| Importance | Definition | Explanation of preference score |
|---|---|---|
| 1 | Equal importance | Two attributes having equal importance |
| 2 | Weak/slight | Intermediate between 1 and 3 |
| 3 | Moderate importance | Judgement slightly favours one attribute over another |
| 4 | Moderate plus | Intermediate between 3 and 5 |
| 5 | Strong importance | Judgement strongly favours one attribute over another |
| 6 | Strong plus | Intermediate between 5 and 7 |
| 7 | Very strong | Judgement very strongly favours one attribute over another |
| 8 | Very very strong | Intermediate between 7 and 9 |
| 9 | Extreme importance | Judgement extremely favours one attribute over another |
| Inverse | 1/2=0.500, 1/3=0.333, 1/4=0.250, 1/5=0.200, 1/6=0.166, 1/7=0.143 1/8=0.125, 1/9=0.111 | If judgement favours activity j against i with any of the above non-zero values, i score inverse of the value of j |

**Table 2 Pair-wise comparison matrix for sub-criteria (matrix 1)**

| Sub-criteria | Rainfall | Temp | Soil pH | Soil OC | Soil CEC | Soil text | Elevation | Slope |
|---|---|---|---|---|---|---|---|---|
| Rainfall | 1 | 3 | 3 | 3 | 5 | 5 | 9 | 7 |
| Temp | 1/3 | 1 | 3 | 3 | 3 | 7 | 5 | 7 |
| Soil pH | 1/3 | 1/3 | 1 | 1 | 3 | 3 | 7 | 5 |
| Soil OC | 1/3 | 1/3 | 1 | 1 | 3 | 5 | 3 | 3 |
| Soil CEC | 1/5 | 1/3 | 1/3 | 1/3 | 1 | 3 | 5 | 3 |
| Soil texture | 1/5 | 1/7 | 1/3 | 1/5 | 1/3 | 1 | 3 | 3 |
| Elevation | 1/9 | 1/5 | 1/7 | 1/3 | 1/5 | 1/3 | 1 | 1 |
| Slope | 1/7 | 1/7 | 1/5 | 1/3 | 1/3 | 1/3 | 1 | 1 |
| **Total** | 2.65 | 5.49 | 9.01 | 9.20 | 15.87 | 24.67 | 34.00 | 30.00 |

2.3.2 Analysis based on FAO crop requirement and sub-criteria attribute scoring

FAO requirements for groundnut and maize crops were considered in the suitability analysis. FAO suitability requirements classified attributes of each sub-criterion into four categories: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (NS), as shown in Tables 5 and 6 for the groundnut and maize, respectively. Scoring of the sub-criteria attribute was done according to their importance or suitability score class after matching with FAO requirement using a scale from three (3) to nine (9) to score the increment from not suitable to highly suitable class for a particular land-use type (Table 7).

**Table 3 Normalized matrix for sub-criteria (matrix 2)**

| Matrix | Rainfall | Temp | Soil pH | Soil OC | Soil CEC | Soil Texture | Elevation | Slope | Eigen Value |
|---|---|---|---|---|---|---|---|---|---|
| Rainfall | 0.377 | 0.547 | 0.333 | 0.326 | 0.315 | 0.203 | 0.265 | 0.233 | 0.324 |
| Temp | 0.126 | 0.182 | 0.333 | 0.326 | 0.189 | 0.284 | 0.147 | 0.233 | 0.227 |
| Soil pH | 0.126 | 0.061 | 0.111 | 0.109 | 0.189 | 0.122 | 0.206 | 0.167 | 0.136 |
| Soil OC | 0.126 | 0.061 | 0.111 | 0.109 | 0.189 | 0.203 | 0.088 | 0.100 | 0.123 |
| Soil CEC | 0.075 | 0.061 | 0.037 | 0.036 | 0.063 | 0.122 | 0.147 | 0.100 | 0.080 |
| Soil Text | 0.075 | 0.026 | 0.037 | 0.022 | 0.021 | 0.041 | 0.088 | 0.100 | 0.051 |
| Elevation | 0.042 | 0.036 | 0.016 | 0.036 | 0.013 | 0.014 | 0.029 | 0.033 | 0.027 |
| Slope | 0.054 | 0.026 | 0.022 | 0.036 | 0.021 | 0.014 | 0.029 | 0.033 | 0.029 |

**Table 4 Random index (source: Saaty, 2008; Everest et al., 2021)**

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8[a] | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Note: The RI value for eight criteria is 1.41.

**Table 5 Requirements for land suitability for groundnut farming (Source*:* FAO, 1983)**

| Land characteristics | S1 | S2 | S3 | NS |
|---|---|---|---|---|
| Climatic factors | | | | |
| Mean rainfall (mm) | >700 | 600-700 | 500-600 | <500 |
| Aver. Temperature (˚C) | 22-28 | 18-22 | 15-18 | <15 |
| Soil factors | | | | |
| CEC (cmol$_{(+)}$ kg$^{-1}$) | >12 | 6-12 | 4-6 | <4 |
| Soil pH | 5.8-6.2 | 5.5-5.7,6.3-6.5 | 5.0-5.4,6.6-7.0 | <5, >7 |
| OC.(g kg$^{-1}$) | >12 | 8-12 | 5-8 | <5 |
| Soil texture | SL, SiL, LS | CL, SiCL | S, SC, SiC | C |
| Topography factors | | | | |
| Elevation (m) | 200-500 | 500-1000 | 1000-1400 | >1400 |
| Slope(%) | 0-2 | 2-5 | 5-8 | >8 |

**Table 6 Requirements for land suitability for maize farming (Source: FAO, 1976)**

| Land characteristics | S1 | S2 | S3 | NS |
|---|---|---|---|---|
| Climatic factors | | | | |
| Mean rainfall (mm) | >800 | 700-800 | 600-700 | <600 |
| Aver. Temperature (˚C) | 24-30 | 20-24 | 15-20 | <15 |
| Soil factors | | | | |
| CEC (cmol$_{(+)}$ kg$^{-1}$) | >25 | 13-25 | 6-13 | < 6 |
| Soil pH | 6.0-6.5 | 5.5 - 6.0 | 5.0-5.5 | < 5.0 |
| OC (g kg$^{-1}$) | > 20 | 10-20 | 5-10 | <5 |
| Soil texture | L,CL,SC,C | SL, SCL | LS, SiL, SCL | SiC,S,Si |
| Topography factors | | | | |
| Elevation (m) | <1700 | 1700-2000 | 2000-2300 | >2300 |
| Slope(%) | 0 – 2 | 4 – 8 | 8-16 | >16 |

Note: CEC = Cation Exchange Capacity, C=Clay, CL=Clayey loam, L= loamy, LS=Loamy sand, S=Sandy, SC=Sandy clay, SCL=Sandy-clay-loam, Si= Silt, SiC=Silt clay, SiCL=Silty-clay-loam, SiL=Silt loam, SL=Sandy loam.

**Table 7 Scale for scoring sub-criterion attribute class for Land-use type (LUT)**

| Score (Xi) | Definition |
|---|---|
| **3** | Sub-criterion is unsuitable for evaluating LUT. |
| **5** | A sub-criterion may be suitable for evaluating LUT with many concerns |
| **7** | The sub-criterion is suitable for evaluating LUT with a few concerns |
| **9** | The sub-criterion is suitable for evaluating LUT without any concerns |

2.3.3 Classification of suitability level

The suitability level of land for groundnut and maize farming was determined using the suitability index (Si) (Equation 3).

$$Si = \sum_{i=1}^{n} wi * xi \qquad (3)$$

Where,

$S_i$ is the land suitability index for a particular land mapping unit (LMU);

$w_i$ is the weight of criterion $i^{th}$ obtained from the AHP exercise and $x_i$ is the score assigned for each sub-criterion attribute of a particular land-use type $i^{th}$;

$n$ is the total number of sub-criteria (Cengiz and Akbulak, 2009; Huynh, 2008).

2.3.4 Suitability mapping and processing in ArcGIS

Based on the selected sub-criteria, and the land-use land cover map, nine thematic maps (rainfall, temperature, soil pH, soil CEC, soil OC, soil texture, elevation, slope and land use land cover) produced were reclassified according to their attribute scores (xi) and calculation for *Si* was done in the attribute table of their vector layers using Equation 3 (Huynh 2008). Thereafter, a land suitability map for each crop (groundnut and maize) was produced using the weighted sum method to process thematic maps created for sub-criteria with their corresponding AHP weight (wi). To obtain the final suitability map, the LULC map was multiplied with the weighted overlay map of each crop using the map algebra method (Cengiz and Akbulak, 2009; Bunruamkaew and Murayam 2011). The result of the suitability analysis was then classified into 4 classes according to FAO guidelines for land suitability analysis classification (FAO, 2007). The flow diagram of land suitability analysis is shown in Figure 3.

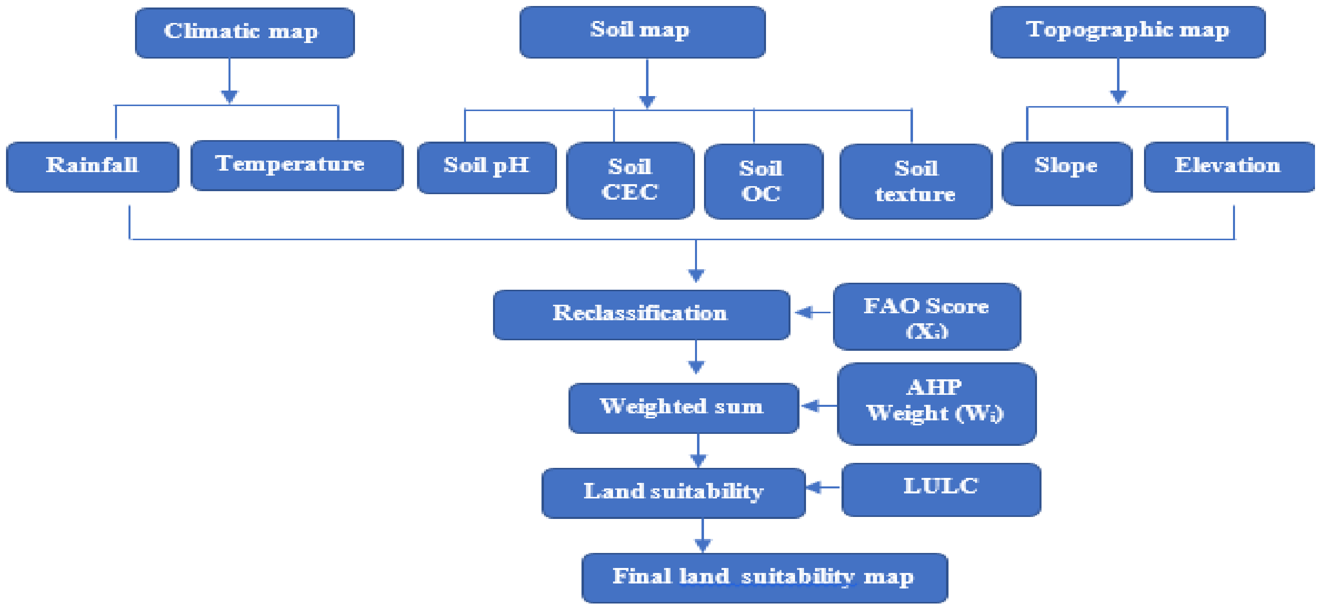

Figure 3 Flow diagram of land suitability analysis

## 3 Results and discussion

### 3.1 Descriptive statistics of soil attributes

Descriptive statistics of the soil's inherent properties influencing land suitability for groundnut and maize farming are summarized in Table 8. Wilding (1985) classifies soil attributes into three categories based on the coefficient of variation: low (<15%), moderate (15%-35%), and high variability (>35%). The findings showed that sand content varied between 13% and 75.1%, with a mean of 53.19% and a coefficient of variation (CV) of 37%, indicating high variability. Clay also showed high variability with a CV of 51%, while silt exhibited moderate variability at 34%. The pH values ranged from 5.4 to 8.9, with a CV of 18%, indicating moderate variability. This range means that the soil is slightly acidic to moderately alkaline. Consequently, parts of the area, particularly where pH is below 5.5, could negatively impact microbial activities, while other areas exhibit favourable pH levels.

**Table 8 Descriptive statistics of soil attributes in the study area**

| Attributes | Minimum | Maximum | Mean | Median | Std. Dev. | CV (%) | Skewness |
|---|---|---|---|---|---|---|---|
| **Sand (%)** | 13.00 | 75.10 | 53.19 | 56.00 | 19.77 | 37.17 | -1.31 |
| **Silt (%)** | 6.70 | 19.85 | 12.58 | 12.90 | 4.26 | 33.86 | 0.13 |
| **Clay (%)** | 18.30 | 71.30 | 34.26 | 31.25 | 17.46 | 50.96 | 1.67 |
| **pH** | 5.40 | 8.90 | 6.68 | 6.50 | 1.19 | 17.81 | 0.90 |
| **OC (g/kg)** | 2.20 | 7.45 | 3.70 | 3.50 | 1.53 | 40.82 | 1.10 |
| **CEC Cmol kg$^{-1}$)** | 5.50 | 13.45 | 8.66 | 8.00 | 2.71 | 31.29 | 0.56 |

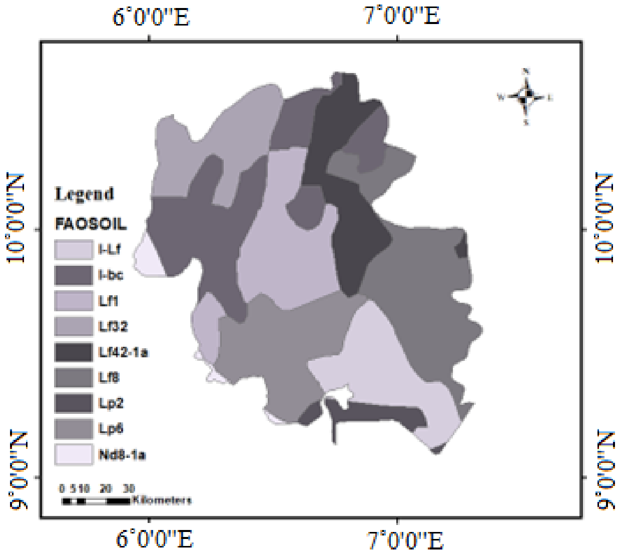


Figure 4 Map for soils in the area of study

Animashaun et al. (2015) reported similar observations in the region. Given that the study area is characterized as semi-arid, the occurrence of alkaline soil in certain regions is to be expected. Jafari et al. (2018) noted that alkaline soils are typical in arid and semi-arid regions. The moderately acidic nature of some parts may be linked to moderate rainfall that leaches essential basic cations (Afolabi et al., 2014). Approximately 58% of organic matter comprises carbon, making its presence in the soil a critical factor for determining soil viability for crop production. Organic carbon is especially significant in tropical soils, as it enhances various soil properties, including aggregate stability and nutrient retention. Low levels of organic carbon can diminish the soil's biophysical and chemical functionality and exacerbate the leaching of basic cations into subsoils (Adiaha et al., 2022; Nwaloka et al., 2019).

In this study, organic carbon levels ranged from 2.2 to 7.5 g kg$^{-1}$, with a mean of 3.7 g kg$^{-1}$. These relatively low values may be linked to bush burning and livestock grazing practices. Previous studies have indicated that for optimal crop production, the critical carbon level should be between 10 and 15 g kg$^{-1}$ (Esu, 1991). Similarly, Nwaloka et al. (2019) reported low values in the same region. Additionally, the organic carbon content exhibited high variability, with a coefficient of variation of 40.8%. This aligns with research indicating that different land uses can lead to significant fluctuations in organic carbon levels (Jeloudar et al., 2014).

The cation exchange capacity (CEC) ranged from 5.5 to 13.46 Cmol kg$^{-1}$, presenting a coefficient of variation (CV) of 31%, which indicates moderate variability. The CEC values reported in this study are higher than those noted by Afolabi et al. (2014), which fell between 4.4 and 8.1 Cmo kg$^{-1}$; this difference may be due to the smaller area encompassed in their research. Aside from pH, CEC exhibited the least percentage variation among the soil attributes. Baquy et al. (2017) observed a close relationship between soil CEC and pH. Furthermore, various anthropogenic and natural factors—including soil type, climate, overgrazing, and agricultural management practices—

can significantly impact the variability of soil attributes (Selmy et al., 2022; Soropa et al., 2021).

Notably, while the sand component showed negative skewness (-1.31), all other soil attributes exhibited positive skewness. The spatial distribution of soil is depicted in Figure 4 and detailed along with other parameters (climate data and land use/land cover) in Table 9. The predominant soil types within the study area include Ferric Luvisol (Lf), Plinthic Luvisol (Lp), Lithosol Chromic Cambisol (I-bc), Lithosol Ferric Luvisol (I-Lf), and Distric Nitosol (Nd), along with their respective attributes as shown in Table 9.

**Table 9 Distribution of soil and climate attributes across the sampling points**

| Sample points | Long. | Lat. | Mean rainfall (mm) | Mean temp (°C) | Soil class | Soil Texture | Sand % | Silt % | Clay % | Soil pH | OC (g kg$^{-1}$) | CEC (Cmol kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 6.23 | 10.95 | 1047.8 | 27.90 | I-bc | SCLSi | 48.9 | 19.85 | 31.3 | 6.5 | 7.45 | 13.5 |
| **2** | 6.07 | 10.39 | 1017.8 | 26.50 | Lf32 | SCLSi | 67.7 | 8.9 | 23.4 | 7 | 2.50 | 6.2 |
| **3** | 6.00 | 9.87 | 1100.4 | 28.16 | Nd-8 | CLSiS | 13 | 15.8 | 71.3 | 5.4 | 5.20 | 11.4 |
| **4** | 6.80 | 9.97 | 1155.0 | 27.42 | Lf-42-1a | SCLSi | 55.8 | 12.9 | 31.3 | 8.9 | 2.80 | 7.6 |
| **5** | 6.53 | 9.85 | 1116.2 | 27.97 | Lf1 | SCLSi | 75.1 | 6.7 | 18.3 | 6 | 2.20 | 5.5 |
| **6** | 6.67 | 9.47 | 1155.0 | 27.49 | Lp6 | SCLSi | 57.5 | 10.9 | 31.6 | 5.6 | 3.50 | 9.2 |
| **7** | 6.90 | 9.65 | 1203.9 | 26.72 | I-Lf | SCLSi | 56 | 17 | 27,0 | 7.2 | 4.00 | 8.0 |
| **8** | 7.17 | 9.30 | 1203.9 | 26.72 | I-Lf | SCLSi | 56 | 17 | 27.0 | 7.2 | 4.00 | 8.0 |
| **9** | 6.87 | 9.25 | 1203.9 | 26.72 | Lp2 | SCLSi | 49.9 | 10.2 | 39.9 | 5.7 | 4.21 | 12.5 |
| **10** | 7.11 | 9.67 | 1192.4 | 26.66 | Lf8 | SCLSi | 55.8 | 12.9 | 31.3 | 8.9 | 2.80 | 7.6 |
| **11** | 6.50 | 9.24 | 1100.4 | 28.16 | Nd-8 | CLSiS | 13 | 15.8 | 71.3 | 5.4 | 5.20 | 11.4 |
| **12** | 6.42 | 10.31 | 1017.8 | 26.50 | Lf32 | SCLSi | 67.7 | 8.9 | 23.4 | 7 | 2.51 | 6.2 |
| **13** | 6.27 | 9.51 | 1116.2 | 27.97 | Lf1 | SCLSi | 75.1 | 6.7 | 18.3 | 6 | 2.22 | 5.5 |

### 3.2 Analytical hierarchy process and priorities of the criteria

The weight values of each sub-criteria based on experts' opinions and subsequent computation using the AHP method are presented in Table 10. The results indicated the main limiting factor for maize and groundnut is rainfall (32.4%) followed by temperature (22.7%). Other limiting factors of high impact are soil pH (13.6%) and organic content (12.3%). Cation exchange capacity, soil texture, slope, and elevation have limiting weights of 8.0%, 5.1%, 2.9%, and 2.7%, respectively. From the result, slope and elevation were the least important factors. The consistency ratio (0.065) of the computed AHP indicates that the result is within the threshold (<0.1) (Saaty, 1980).

However, our results partially conflict with the findings of Ayenew et al. (2020), which ranked the parameters in the following order: soil depth, soil texture, rainfall, mean temperature, slope, and elevation. While our study diverges regarding the most significant factors, it agrees on the least important ones. In contrast, our findings are in line with those of Mugiyo et al. (2021), who identified rainfall and temperature as the primary limiting factors for sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), amaranth, and taro (*Colocasia esculenta*) in South Africa. Moreover, Chivasa et al. (2019) ranked climate parameters as the most critical limiting factors for maize in Zimbabwe. The designation of slope as a low-priority factor is consistent with Merem et al. (2017), who considered it a minor limiting factor due to the area's gently undulating to flat terrain.

### 3.3 Sub-criteria attribute score based on FAO Requirement

The attribute scores for the sub-criteria, determined per FAO requirements for optimal conditions for cultivating both groundnut and maize, are presented in Table 11. An analysis of the 32-year average annual rainfall data indicates that values ranged from 1017 mm to 1203 mm across the thirteen grid points. Compared to FAO requirements, greater than 700 mm for groundnut and more than 800 mm for maize, the rainfall in the study area is classified as highly suitable, resulting in an attribute score of 9. While water requirements differ among crops, this study noted high suitability for maize and groundnut, contrasting with Rhebergen et al. (2016), who identified insufficient water as the main limiting factor for palm oil plantations in West Africa.

The average annual values for temperature, ranging from 26.49℃ to 28.15℃, organic content between 22 and 74 g kg$^{-1}$, and elevation spanning 89 m to 744 m all received attribute scores of 9, indicating high suitability. This is consistent with the findings of Atiah et al. (2022), who attributed 26.7% and 62.3% of annual maize yield variation to water (including rainfall and soil moisture) and temperature, respectively. Regarding soil texture, the percentages of sand, silt, and clay constituents categorize the available soil texture into two classes (SCLSi and CLSSi), though both classes received the same score of 5.

**Table 10 Sub-criteria weights and priorities result from pair-wise comparison**

| Sub-criteria | Normalized average of rows (Criteria weights, %) | Priorities |
|---|---|---|
| Rainfall | 32.4 | 1 |
| Temp | 22.7 | 2 |
| Soil pH | 13.6 | 3 |
| Soil OC | 12.3 | 4 |
| Soil CEC | 8.0 | 5 |
| Soil Texture | 5.1 | 6 |
| Slope | 2.9 | 7 |
| Elevation | 2.7 | 8 |

Note: Number of sub-criteria, n= 8, $\lambda max$ = 8.647, CI = 0.092, RI = 1.41, CR = 0.065

**Table 11 Attribute score for groundnut and maize**

| Sub-criteria | Attribute (Area of Study) | Based on FAO Requirement (Groundnut) | Groundnut Score ($x_i$) | Based on FAO Requirement (Maize) | Maize Score ($x_i$) |
|---|---|---|---|---|---|
| **Rainfall (mm)** | 1017-1203 | 1017-1203 | 9 | 1017-1203 | 9 |
| **Temperature (℃)** | 26.50-28.15 | 26.50-28.15 | 9 | 26.50-28.15 | 9 |
| **Soil pH** | 5.8-8.9 | 5.8-6.2<br>6.3-6.5<br>6.6 - 7.0 7.1-8.9 | 9<br>7<br>5<br>3 | 5.8-6.0<br>6.0-6.5<br>6.6-8.9<br>- | 9<br>7<br>3<br>- |
| **Organic content (g kg$^{-1}$)** | 22-74 | >12 | 9 | >20 | 9 |
| **CEC (cmol$_{(+)}$kg$^{-1}$)** | 5.5-13.43 | 12-13.43<br>6-12<br>5.5-6.5 | 9<br>7<br>5 | 13-13.43<br>6-13<br>5.5-6.3 | 7<br>5<br>3 |
| **Soil texture** | S,CL,Si<br>CL,S,Si | S,CL,Si<br>CL,S,Si | 5<br>5 | S,CL,Si; CL,S,Si | 5<br>5 |
| **Slope (%)** | 0-100 | 0-2<br>2-5<br>5-8<br>8-100 | 9<br>7<br>5<br>3 | 0-2 4-8<br>8-16<br>16-100 | 9<br>7<br>5<br>3 |
| **Elevation (m)** | 89-744 | 200-500 500-744 | 9<br>7 | 84-744 | 9 |

The soil texture in the area is predominantly composed of sand and clay. Clay soils restrict air and water circulation due to excessive swelling after rainfall. In contrast, sandier soils facilitate faster infiltration rates, limiting water availability for shallow-rooted crops like groundnut and maize. This relationship highlights the importance of the ratio of soil textural classes in determining the scores assigned to the soil, as crop yield is closely tied to these ratios. The soil pH, cation exchange capacity (CEC), and slope of the area yielded attribute scores ranging from 9 to 3, indicating spatial variation in the quality and suitability of the land based on these parameters. Differences in slope suggest that some areas are better suited for crop cultivation, reflected in the points assigned. Land with a slope of 0-2% received 9 points, while areas with slopes exceeding 8% (for groundnut) and 16% (for maize) were assigned only 3 points due to their steepness, rendering them less suitable for cultivation. Elevation also played a role in land suitability; regions below 500 m scored 9 points for high suitability, whereas those above 500 m received 7 points, indicating that no areas are entirely unsuitable for crop production. The spatial distribution of climate, topographic, soil, and land use/land cover parameters is illustrated in Figures 5-8 and detailed in Table 12.

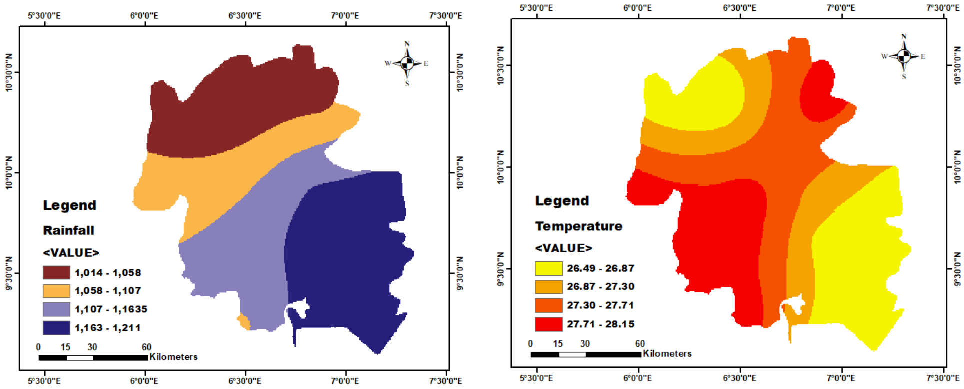


Figure 5 Thematic map for climate data (rainfall and temperature)

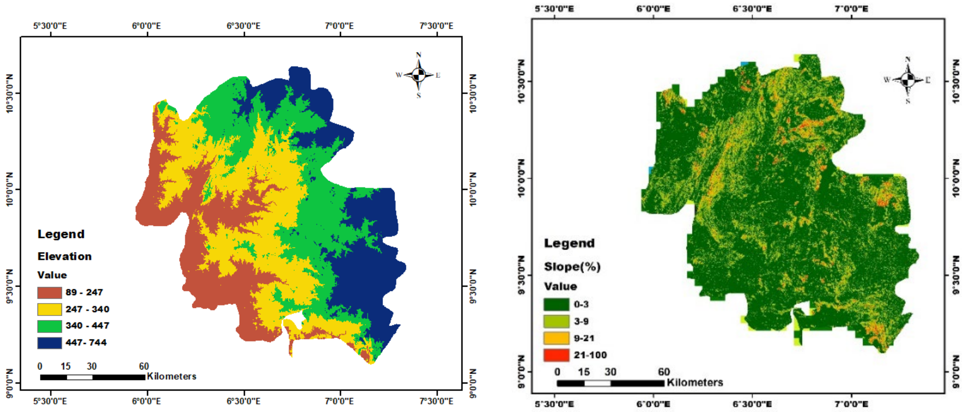


Figure 6 Topographic (elevation and slope)

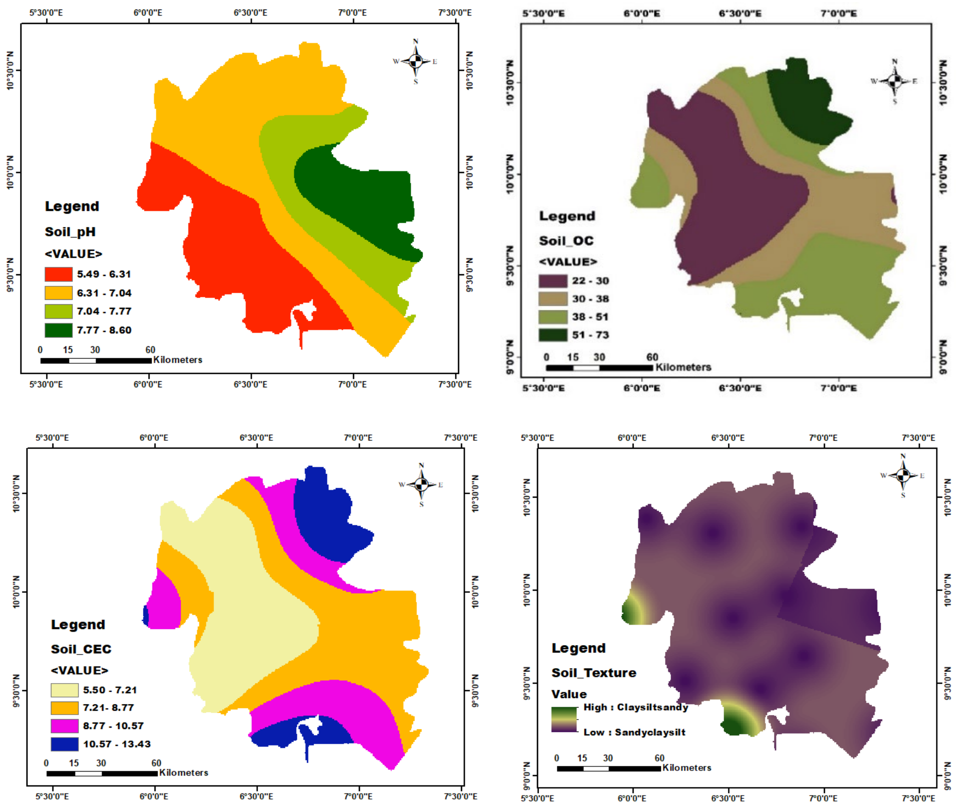


Figure 7 Thematic map for soil (pH, OC, CEC, and texture)

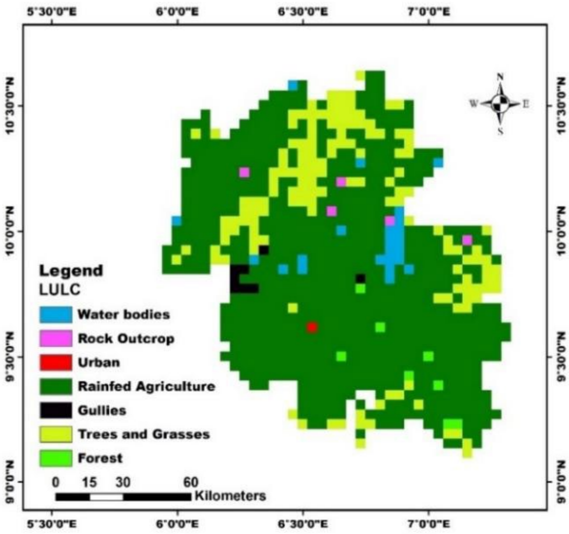


Figure 8 Land use/ land cover

**Table 12 LULC and percentage area of coverage**

| Classes | Area (km$^2$) | Percent |
|---|---|---|
| Water bodies | 414.37 | 2.55 |
| Rock Outcrop | 90.08 | 0.55 |
| Urban | 18.02 | 0.11 |
| Agriculture | 12827.35 | 79.02 |
| Gullies | 144.13 | 0.89 |
| Trees and grasses | 2594.30 | 15.98 |
| Forest | 144.13 | 0.89 |

### 3.4 Land suitability analysis for maize and groundnut in NEN

The land suitability assessment results for groundnut reveal that 51% (8,363.8 km²) of the total area (16,232.36 km²) is classified as highly suitable (S1) (refer to Table 13). The land within this S1 class is characterized by sub-criteria attributes, including a mean annual rainfall of 1017-1203 mm, mean temperatures ranging from 26.50°C to 28.15°C, soil pH levels between 5.8 and 6.2, organic carbon (OC) content of 22-74 g kg$^{-1}$, cation exchange capacity (CEC) of 12-13.43 cmol(+)kg$^{-1}$, soil textures of SCLSi and CLSSi, slopes of 0-2%, and elevations from 89 to 500 m. In comparison, 29% of the land (4,695.46 km²) is classified as moderately suitable (S2), characterized by soil pH levels of 6.3 to 6.5, CEC values ranging from 12 to 18.89 cmol(+)kg$^{-1}$, soil textures of SCLSi and CLSSi, and slopes between 2%-6%. Approximately 3% (458.54 km²) is deemed marginally suitable (S3), while 17 % (2,714.56 km²) is considered not suitable (NS) for groundnut cultivation.

For maize, 52% (8,382.14 km²) of the area is classified as highly suitable (S1), featuring mean annual rainfall of 1017-1203 mm, mean temperatures from 26.50 to 28.15°C, soil pH of 5.8 to 6.0, OC levels between 22 and 74 g kg$^{-1}$, CEC values of 13-13.43 cmol(+)kg$^{-1}$, soil textures of SCLSi and CLSSi, slopes of 0-2%, and elevations ranging from 89 to 500 m. About 30% (4,878.88 km²) is classified as moderately suitable (S2), while 10% (1,705.77 km²) is marginally suitable (S3), and 8% (1,265.57 km²) is not suitable (NS) for maize cultivation.

Overall, rainfall, temperature, OC, and elevation attributes are highly suitable for both groundnut and maize and remain consistent across all land units and suitability classes. As a result, variations in the suitability levels of each land unit for these crops depend primarily on soil pH, CEC, texture, and slope. The spatial distribution of land suitability classes for both groundnut and maize is illustrated in Figure 9. An earlier study by Kenzong et al. (2022) found that slope significantly influences land suitability for maize production in the Foumbot Agricultural Basin in the Western Highlands of Cameroon. They reported that 11% of the area is very highly suitable, 29% is highly suitable, 38% is moderately suitable, 20% is marginally suitable, and only the remaining 1% falls into the non-suitable class. This study is also consistent with the report by Abegunde et al. (2015) on land suitability analysis for maize in the Egbeda local government area of Oyo State, Nigeria, which indicated that 26.8 % of the land was highly suitable, 64.8% moderately suitable, and 8.4% marginally suitable. The findings of Sathiyamurthi et al. (2024) indicated that a soil that is highly suitable for maize will be highly suitable for ground.

**Table 13 Land size and percentage of suitability class for groundnut and maize crop**

| | | Groundnut | | Maize | |
|---|---|---|---|---|---|
| S/N | Suitability class | Area (Sq.km) | Percentage | Area (Sq.km) | Percentage |
| 1 | Highly suitable | 8363.80 | 51 | 8382.14 | 52 |
| 2 | Moderately suitable | 4695.46 | 29 | 4878.88 | 30 |
| 3 | Marginally suitable | 458.54 | 3 | 1705.77 | 10 |
| 4 | Not suitable | 2714.56 | 17 | 1265.57 | 8 |
| | Total | 16232.36 | 100 | 16232.36 | 100 |

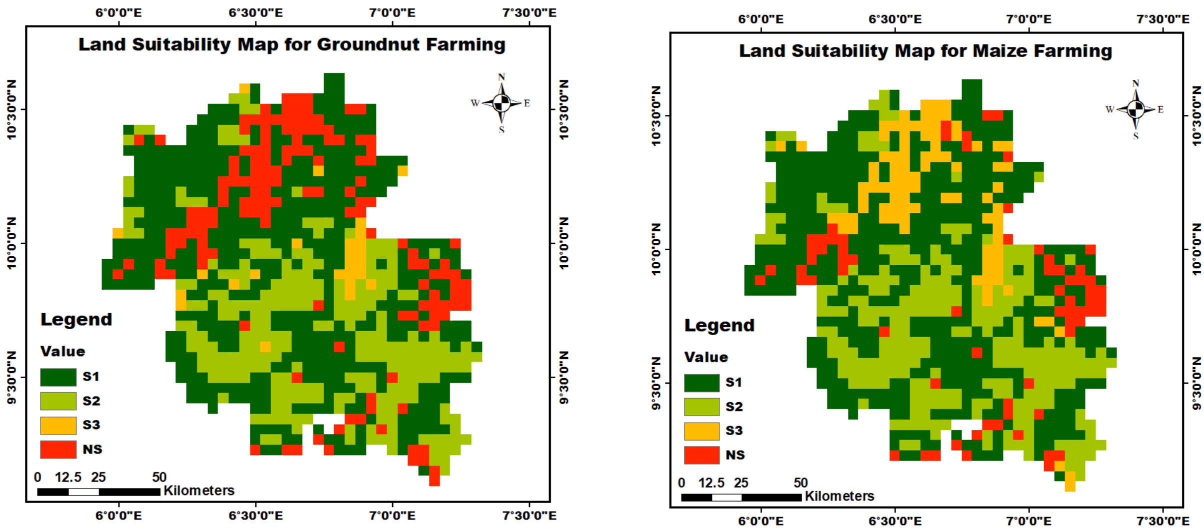


Figure 9 Final land suitability map for groundnut and maize

## 4 Conclusion

Identifying land suitability for specific crops is crucial for informed decision-making to optimise land utilization while preserving environmental health. This study evaluates the land suitability of Niger East, Nigeria, for groundnut and maize cultivation utilizing the Analytical Hierarchy Process (AHP). The analysis incorporated three primary criteria and six sub-criteria, with the weighting determined by their respective impacts on crop-land suitability classifications. Data processing was conducted using ArcGIS to visually represent each land unit's suitability. The findings reveal that climatic factors, specifically rainfall (weighting of 0.324) and temperature (weighting of 0.227), are the most significant determinants for both crops. In contrast, elevation was identified as the least impactful factor (weighting of 0.027). Additionally, soil characteristics, including pH levels, were recognized as critical limiting factors, presenting a spectrum from non-suitable to highly suitable classifications across the studied area. The final suitability maps indicate that 51% of the land is classified as highly suitable for groundnut, with 29% deemed moderately suitable. For maize, 52% of the area is categorized as highly suitable, while 30% is moderately suitable. Marginally suitable and not suitable classifications of 3% and 17% were noted for groundnut while 10% and 8% were the respective classes recorded for maize. This study is a valuable resource for strategic land use planning, offering insights into the limiting factors that require consideration to enhance land compatibility with specific crop requirements.

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