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Use of a GIS-Based AHP and Parametric Square Root Method for Land Suitability Assessment of Groundnut (*Arachis hypogea L.*) on Gurumpawo Toposequence

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Abstract

This study assessed the cultivation potential of groundnut (*Arachis hypogaea* L.) along Gurumpawo toposequence, Ganye, Adamawa State, using the parametric square root method (SRM) and the Analytical Hierarchy Process (AHP). Sustainable groundnut production in the area is threatened by declining soil fertility and topographic variability, while site-specific suitability information for precision land management remains inadequate. In addition, limited studies have compared the performance and spatial reliability of conventional parametric and multi-criteria decision models for groundnut suitability assessment across the toposequence. This study determined selected soil properties and compared the spatial outputs of SRM and AHP for sustainable land-use planing. A digital elevation model was used to delineate crest, upper, middle, and lower slopes, as well as floodplain units within a 100 ha landscape using ArcGIS 10.7.1. Soil samples were analyzed for texture, pH, electrical conductivity, organic carbon, available phosphorus, total nitrogen, cation exchange capacity, and base saturation. Suitability assessment was conducted using SRM based on profile data, whereas AHP utilized auger-based spatial datasets. Spatial comparisons of suitability class geometries and area coverage were performed on ArcGIS, and the agreement between the two models was tested using Pearson's Chi-square (X^2). Soils across the toposequence were characterized by low fertility, with organic carbon (<10 g/kg), total nitrogen (<1.50 g/kg), and available phosphorus (<10 mg/kg), although pH was neutral (6.6-7.3) and base saturation exceeded 70%. The SRM identified slope and drainage as critical limiting factors and classified most areas as marginally (S3) to moderately suitable (S2). In contrast, AHP produced relatively optimistic suitability ratings, with most areas classified as highly suitable (S1) to moderately suitable (S2) due to its compensatory structure. The SRM should be prioritized to identify field-specific limitations, while AHP should be applied for broader precision-agriculture planning and long-term suitability assessment.

Keywords: Gurumpawo, Geometry, AHP, SRM, Mapping unit, Groundnut

Introduction

Sub-Saharan Africa (SSA) faces profound food insecurity associated with soil degradation, the peculiar aftermath of climate change, and exacerbated by rising population and historically poor agricultural practices (Dimkpa *et al*., 2023). Furthermore, uncontrolled population growth results in widespread hunger, poverty, diseases and poor land utilization and management. As the demand for food increases, land and soil mismanagement issues are occurring at an alarming rate. This situation has led to a series of threats within Sub-Saharan countries due to increasing population growth and food demand (Rilwani and Ikhuoria, 2011). Among the countries bedeviled by these challenges, Nigeria faces significant agricultural and land management constraints that continue to limit food production and sustainability.

Despite its contribution to the economy, Nigeria's agricultural sector faces many challenges that impact its productivity. These include poor land tenure system, low level of irrigation farming, climate change, and land degradation. Other challenges include low technology, high production costs, and poor distribution of inputs. These issues have stifled agricultural productivity and increased food imports due to population growth, resulting in declining levels of food sufficiency. Efforts are therefore geared towards increasing agricultural productivity to meet domestic food demand and export need, while reducing land degradation through sustainable management of natural resources, reducing erosion, and climate change mitigation. In response to the growing need for food security and sustainable agricultural production in Nigeria, attention has increasingly focused on economically important crops such as groundnut.

Groundnut (*Arachis hypogaea* L.) is an oil seed that is also used as a food crop, and in fact as a cash crop in many parts of Nigeria (Ajibade *et al.,* 2023). According to Godfrey *et al.* (2020), the numerous uses of groundnut over the years have positioned it as an important crop for domestic consumption and export. Nigeria has consistently maintained its leading position in Africa for groundnut production, accounting for 39% of the continent's overall output, owing to the combined efforts of commercial and subsistence growers (Ajibade *et al.,* 2023). The FAO (2022) has shown that Nigeria ranked the highest groundnut producer in the African continent with production that ranged between 3.3 to 4.2 million tons from 2012 and 2022, spanning a period of about ten (10) years. Despite this potential, groundnut yield in this region is significantly low (964 kg/ha) when compared to the United States with 3500 kg/ha (Njoki *et al.,* 2024). This disparity in groundnut productivity could partly be linked to poor or inappropriate suitability assessment of land potentials, since proper land suitability evaluation helps identify the best farm sites for cultivation with minimized input cost and improved yield performance (Hegde *et al.,* 2017; Animashaun *et al.,* 2026).

Given the importance of groundnut to food security and economic development, assessing land suitability for its sustainable cultivation becomes expedient. Land suitability assessment matches land characteristics with crop requirements to determine production potential. The framework developed by FAO provides the basis for most evaluations, emphasizing the role of soil, climate, and topography in determining suitability classes (FAO, 1976; Singha and Swain, 2016; Abate and Anteneh, 2024). Therefore, land assessed and utilized according to its capability classes to produce crops, is more likely to sustain higher crop productivity while minimizing environmental degradation (Shah and Wu, 2019).

To achieve reliable land suitability assessment, several methodological approaches have been developed and applied over the years. The square root method (SRM) is one of the parametric approach used to aggregate suitability factors, particularly when decision-makers require a relatively simple approach for combining multiple layers of information. Parametric methods assign numerical ratings (0-100) to land characteristics such as soil, climate, and topography, and combine them into a suitability index. The SRM modifies the influence of limiting factors by incorporating the minimum rating and multiplicative interactions among variables affecting the crop in focus (Juita *et al.,* 2023). Accordingly, the SRM integrates climatic, topographic and soil ratings into a single suitability index in which the most limiting factor has the strongest influence on the final suitability class, consistent with the principle of limiting factors in soil productivity (Sys *et al.,* 1991; FAO, 1976, Maniyunda and Gwari, 2014, Juita *et al.,* 2021; Maniyunda and Ya'u, 2023).

Although the parametric methods remain widely used in land assessment, advances in geospatial technologies have encouraged the integration of MCDM approaches for improved suitability assessment. Land suitability assessment has evolved from qualitative frameworks to quantitative MCDM. Multi-criteria suitability evaluation in Geographic Information Systems (GIS) enables the assessment of landscape suitability for specific land uses based on factors such as slope, elevation, soil characteristics, and proximity to water bodies and roads (Khoi and Murayama, 2010). This approach enables a comprehensive understanding of landscape features and their impact on soil properties, facilitating informed decision-making in soil studies and land management (Tamene *et al*., 2017). The GIS-based Analytic Hierarchy Process (AHP) is one of the most widely used multi-criteria suitability evaluation techniques for crop suitability assessment. The AHP framework converts complex multi-criteria judgments into a structured decision-making process through pairwise comparisons, relative weighting, and suitability ranking of land characteristics such as soil properties, slope, climate, drainage, and nutrient availability (Mustafa and Mehmet, 2023).

Several studies have identified the major environmental and soil factors influencing groundnut suitability and productivity across different agro-ecological zones. Researches have shown that groundnut requires well drained, sandy loam to loam textured soils and moderate fertility for optimal yield (Maniyunda and Gwari, 2014; Tukur *et al.,* 2024; Nwaoba *et al.,* 2024). Parametric evaluations conducted in Nigeria showed that soil texture, drainage, and nutrient status were the dominant factors influencing suitability classes for groundnut production (Osujieke *et al.,* 2022). Similarly, studies conducted in West Africa indicated that sandy to sandy loam soils with good aeration favor pod development and reduce disease incidence, thereby enhancing suitability for groundnut cultivation (Diallo *et al.,* 2016). These findings aligned with parametric models in which individual factors are rated and combined, while the lowest rating determines overall suitability, as described by Sys *et al.* (1991).

On the other hand, applications of AHP specifically for groundnut suitability assessment have also been widely reported. In Myanmar, AHP integrated with the FAO framework was used to evaluate suitability for crops including groundnut by combining biophysical factors such as soil, slope and climate with socio-economic considerations. The study revealed that most land units were moderately suitable (S2) for groundnut cultivation (Linn, 2020). Similarly, a study carried out in Ghana integrated AHP with GIS to generate land suitability indices for maize and groundnut production. Factors such as precipitation, soil type, organic matter, slope, and land use were weighted, and the results were linked with actual yield data to estimate potential productivity (Salifu *et al.,* 2022). In Ethiopia, multi-criteria evaluation through AHP identified soil texture, drainage and rainfall as dominant factors controlling groundnut suitability (Moisa *et al.,* 2022).

Despite the increasing knowledge and application of SRM and AHP in land suitability studies, comparative evaluation of their spatial performance for groundnut cultivation across toposequences in Northeast Nigeria and specifically in the study area, remains limited. Therefore, this study assessed the suitability of land for groundnut cultivation in the study area using SRM and AHP models and compared their spatial outputs for sustainable land-use planning and management.

METHODOLOGY

Description of the Study Area

The study was carried out in Gurumpawo, Ganye Local Government Area of Adamawa State, Nigeria. The area lies between Latitude 8° 26'51.01" N to 8° 27'13.12" N and Longitude 11° 55'43.31" E to 11° 55'54.71" E, covering a total area of 100 hectares. Figure 1 shows the satellite map of the study area highlighting key geographical features.

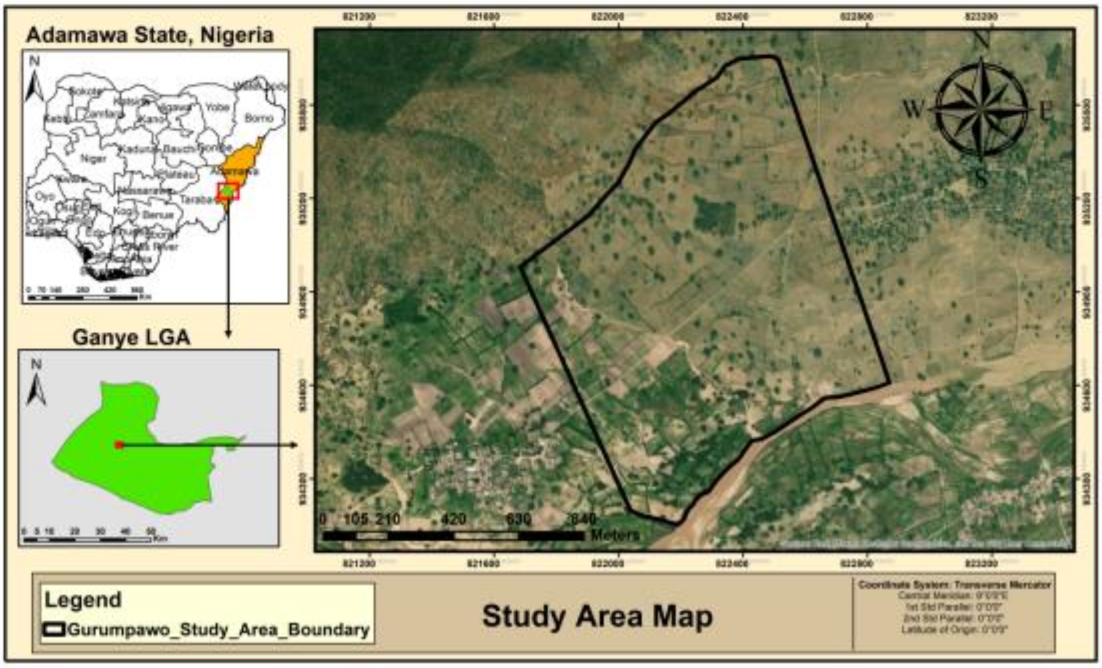

Figure 1: Satellite Imagery Map of the Study Area

The geology of the study area is part of the Nigerian subterranean basement complex. Gurumpawo lays within the region of crystalline basement rocks that shares borders with the Cameroonian Republic. This region is characterized by precambrian rocks, such as granites, gneisses, and migmatites, which are found in the larger Adamawa Massif region (Ahmed *et al.,* 2017). The region is predominated by biotite, quartz, muscovite, feldspar, plagioclase minerals of the granitic rocks exposed in the region from petrographic analysis carried out by Obiefuna *et al.* (2012). The climate of the area exhibits a West African Savannah climate characterized by consistently high temperatures influenced by intense solar radiation and its continental location. While, temperatures peak between January and April (30-35°C), with brief reductions during the onset of the rainy season and the Harmattan period (October-February). Rainfall, critical for the region's rainfed agriculture-dependent economy, ranges from 1500 to 1800 mm annually, concentrated between May and October, with August and September experiencing the highest precipitation. This bimodal seasonal pattern is driven by the interplay of dry, desert-derived Harmattan winds and moisture-laden Atlantic Ocean air masses. The weather of the study area is presented in Figure 2. The average rainfall in the area is 26 days, that is; 193 mm (7.6 inches) per month while the driest months falls in January, November and December an average of 1mm (0.0 inches) of rainfall during this period.

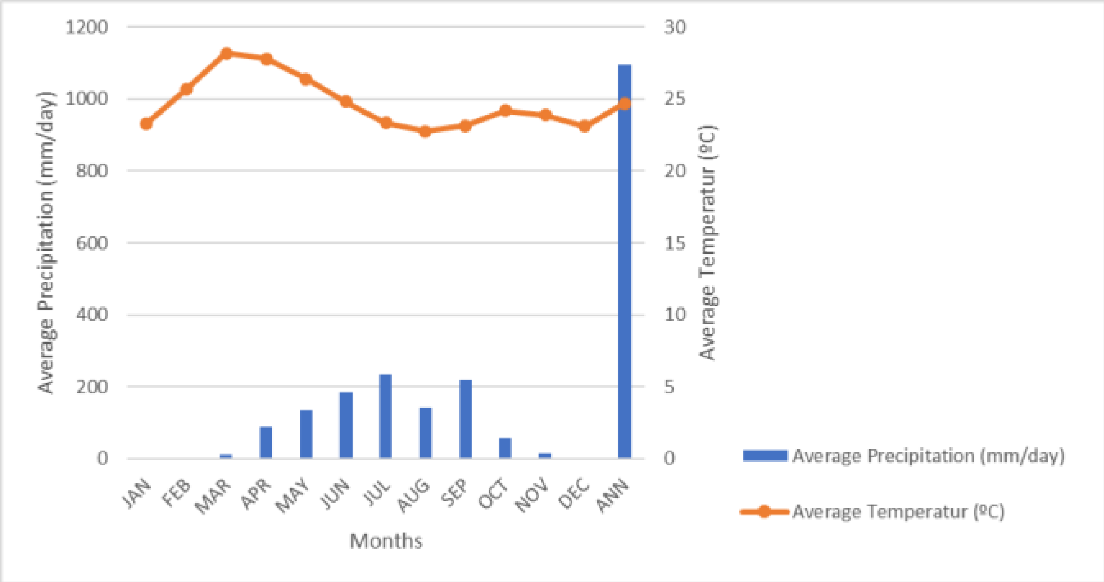

Figure 2: Monthly Mean Rainfall and Temperature Data form 2020 - 2024
Source: NASA Power Weather Data, (2024)

Desk Work

Digital elevation model (DEM) was downloaded from the United States Geological Survey (https://earthexplorer.usgs.gov/) using the Shuttle Radar Topography Mission/ Arc-Second Digital Terrain Elevation Data-Global (SRTM/Arc-Second Global) at 30 m resolution. The DEM was used to classify the toposequence into crest, upper, middle and lower slopes and, floodplain as described by Soil Science Division Staff (2017) using elevation on ArcGIS 10.71. A basemap was generated for field survey from a 100 ha to facilitate the field survey and sampling design. The lower slope represented the largest unit, accounting for 33.18 ha of the total landscape. Figure 3 shows the elevation of the study area. Two (2) pedons were identified on each topographic unit for field survey and geographic positioning system (GPS) coordinates of 50 auger observation points at a rigid grid interval of 139 m was generated using the Vector Tool functions on ArcGIS, then the basemap (Figure 4) was produced for the field survey.

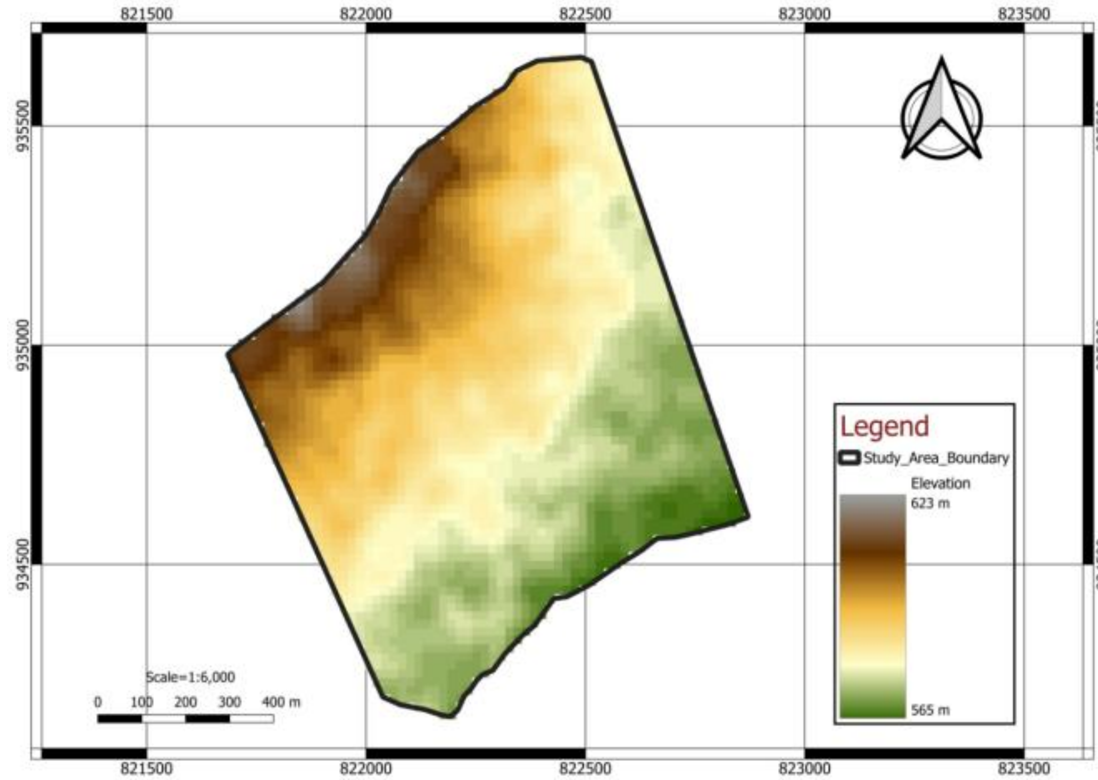

Figure 3: Elevation Map of the Study Area
Source: EarthExplorer, SRTM; Map by Gisilanbe, S.A. (2026)

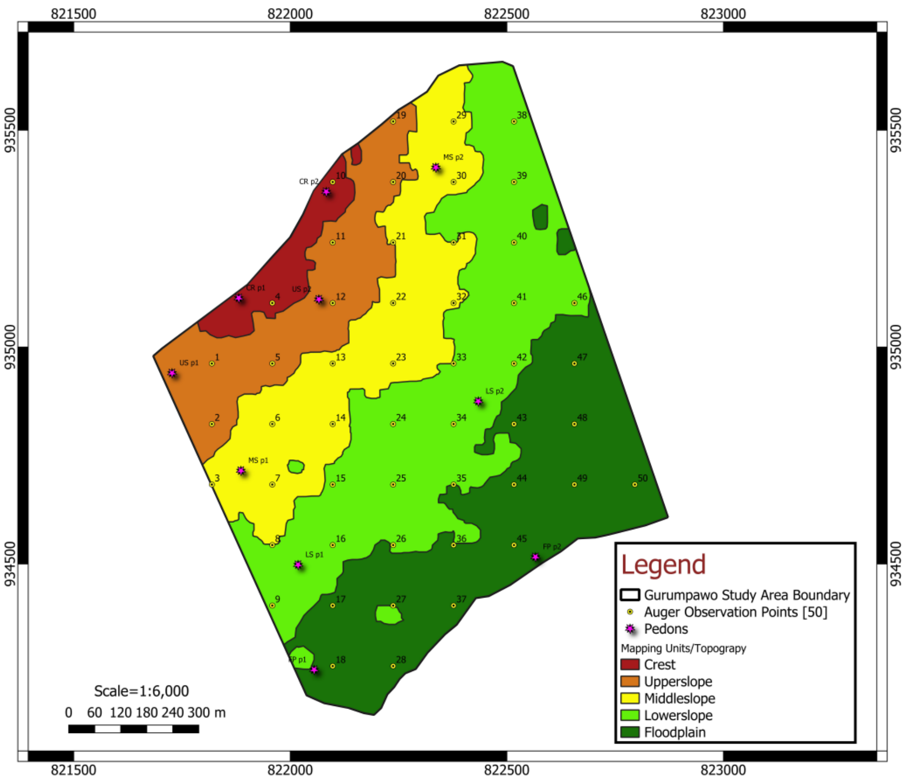

Figure 4: Basemap of the Study Area

Field Work and Sampling

The basemap was uploaded on the Avenza Maps software and used to aid field observation by ground-truthing. Afterwards, a topo-map was generated to depict the different toposequence units (crest, upper, middle, lower slopes and floodplain) and their corresponding soil characteristics (depth, texture, drainage, topography and slope). Two (2) profile pits were sited and dug on each soil unit identified, making a total of ten (10) profile pits from five (5) mapping units. The profile pits were dug using the standard dimensions of 2 x 1.5 x 2 meters. Soil samples were collected from each of the diagnostic horizons of the pits and described according to FAO (2006) guidelines. These samples were well-labeled and placed in clean polythene bags as described in the Soil Survey Staff (2014). Additionally, the fifty (50) auger observation points on Avenza Maps App was used to identify the locations and facilitate collection of soil surface samples (0-30 cm) in the field.

Raster Digitization and Area Calculations

Following the field survey, the boundaries of the identified landscape units were digitized in ArcGIS to generate polygon shapefiles that represented the mapping units. Delineation was guided by field observations and topographic characteristics following the guidelines outlined by Soil Science Division Staff (2017). The resulting spatial layers were symbolized and classified using appropriate colour symbology and legends to distinguish the different mapping units.

Soil Physical and Chemical Analysis

The collected soil samples from the fields were air-dried at room temperature in the laboratory until constant weight was obtained. The samples were gently crushed using a pestle and mortar and sieved through a 2 mm stainless steel sieve as described in the Soil Survey Staff (2014). The soil samples were kept in dry and clean plastic bags for subsequent soil physical and chemical analysis in the laboratory. Standard laboratory procedures were followed to determine selected soil physical, chemical properties. Soil particle size distribution was determined by the hydrometer method following the modified Bouyoucos procedure described by Beretta *et al.* (2014). The air-dried soil samples were dispersed with a chemical dispersing agent and mechanically shaken. The suspension was transferred to a sedimentation cylinder, and the hydrometer readings were taken at specified intervals to determine the proportions of sand, silt and clay based on Stokes' law. Soil textural classes were subsequently assigned using the USDA textural triangle. The pH of the soils in water solution was measured in a 1:2.5 soil to water suspension ratio using a glass rod and electrode pH meter (Thomas, 1996). Electrical conductivity (EC) was determined by the use of electrode method as described by the Soil Survey Staff (2014). Soil organic carbon (SOC) was determined using Walkley and Black wet oxidation method as described by Nelson and Sommers (1982). The method involved oxidation of organic carbon with 1 N potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid solution (H_2SO_4 96%), followed by back-titration of the excess dichromate with ammonium ferrous sulphate solution. Total Nitrogen was analyzed using the Kjeldahl digestion, distillation and titration method as described by Black (1965). Soil available phosphorus was determined using Bray-1 extraction method described by Bray and Kurtz (1945), by employing 0.03 M NH_4F and 0.025 M HCl as the extracting solution. The extract was reacted with ammonium molybdate reagent to develop a blue colour, and phosphorus concentration was subsequently determined colorimetrically using a spectrophotometer at 660 nm. The cation exchange capacity (CEC) was determined through leaching the soils with 1N NH_4AOC according to Rhoades (1982).

Percentage base saturation was determined in the laboratory by using NH_4OA_C Ammonium (acetate) as described by Soil Survey Staff (2014). The following formula was used:

$\%BS=(A/B)*100$

Where: A = NH_4OA_C Extractable Bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) (cmol (+) kg^{-1}).

B = CEC-7 (cmol (+) kg^{-1}).

The exchangeable sodium percentage was calculated as proportion of CEC (NH_4OAc) occupied by sodium cations as follows:

$$ESP=\frac{Exchangeable\ sodium}{\text{CEC } (NH_4OAc)} * 100$$

METHOD OF SOIL SUITABILITY ASSESSMENT

Square Root Parametric Procedure

The soil suitability evaluation was carried out using guidelines for soil suitability evaluation (FAO, 1976; Sys, 1991; FAO, 2006) using the profile pit data. Some key environmental factors were considered in the evaluation, including climate data (annual rainfall, and temperature), topography (slope) and soil properties relevant to groundnut suitability. The criteria that were employed for the evaluation of soils were soil depth, soil texture, slope, drainage, pH, available P, organic carbon, total nitrogen, cation exchange capacity and base saturation.

The square root multiplication approach of the parametric method was adopted to assess the suitability of soils for groundnut. To obtain the crop suitability rating (index of productivity) for each land unit, the land qualities of the soil units that were considered critical or limiting the crop suitability were selected for the assessment according to procedure adopted by Maniyunda *et al.* (2023) and the final suitability class was arrived at by matching the most limiting land quality with the crop requirements. Equation 1 was used to obtain the overall suitability index (Sys *et al.,* 1993; Ziadat, 2010; Maniyunda *et al.,* 2023) which is presented as:

$$SI = A\{\sqrt[2]{B/100*C/100*D/100*E/100*F/100}\} \quad \text{..... eq. 1}$$

Where SI is the soil suitability index (%), and A is Climate (c); B is Soil physical condition (s); C is Wetness (w); D is Chemical fertility (f); E is Toxicity (t); and F is Erosion hazard (e). These represents the characteristics ratings (%) of factors considered in the study. Land evaluation was carried out for current (actual) and potential suitability for groundnut cultivation. For the current (actual) suitability index, key critical chemical soil fertility properties were used for the calculations but these were not used to determine potential suitability land use assessment. The suitability classes were categorized as S1, S2, S3, N1 and N2, corresponding to suitability index (%) values of 100 - 76, 75 - 50, 49 - 25, 24 - 15 and 14 - 0, respectively (Table 1). The rating for groundnut requirements is presented in Table 2.

Table 1: Class rates of soil suitability classes and agricultural uses

Class	Suitability class	Percentage rate (%)
Class 1 (S1)	Highly suitable	76 – 100
Class 2 (S2)	Moderately suitable	50 – 75
Class 3 (S3)	Marginally suitable	25 – 49
Class 4 (N1)	Currently not suitable	15 – 24
Class 5 (N2)	Permanently not suitable	0 – 14

Source: Modified from FAO (1976)

Analytic Hierarchy Process (AHP)

For the suitability analysis, GIS aided AHP software program using ArcGIS was used from the data obtained from soil auger observation points (0-30 cm). The AHP adopted the fuzzy logic model for evaluating the soil suitability for the crop. The AHP which was proposed by Saaty (1977), was used through a pairwise comparison technique to assign individual parameter's weights for each factor. The field surveys, expert's opinion and literature reviews (Ennaji *et al.* 2018; Zolekar 2018; Roy and Saha 2018; Akpoti *et al.* 2019) was utilized in choosing the ranks of influencing parameters and the sub-classes.

The AHP depended on the pairwise comparison matrices to assign weights for every factor controlling the suitability analysis in this study. These matrices compared the different parameters to each other and then gave values (weights) according to their relative importance. These values ranged from 1 to 9, where 1 meant that the two parameters compared had the same impact and, 9 revealed that one parameter was particularly more important than the other as described by Saaty and Vargas (2001).

Table 2: Rating for Groundnut Requirement

Land Quality	Diagnostic Factor	Unit	Factor Rating			
			S1	**S2**	**S3**	**N**
Groundnut						
A) Climate (c)						
	Rainfall	(mm)	700-1000	500-700	350-500	<350
	Temperature	ºC	24-30	22-23, 31-33	20-21, 34-40	<20,>40
B) Physical Condit. (s)						
	Effect. Depth	Cm	>75	51-75	25-50	<25
	Texture	Class	LS,SL,L	SiCL, CL, SCL,SiL	C,SiC, SC	C>60%, S
	Structure	Class	Well dev.	Mod. dev.	Weak dev.	Weak dev.
C) Wetness (w)						
	Drainage	Class	Well drained	Mod. drained	Poorly drained	V. poorly drained
D) Chemical Fert. (f)						
	Soil Reaction	pH	6.0-8.0	8.1-8.5,5.5-5.9	>8.5, <5.5	-
	Base saturation	%	>50	35-50	25-35	<25
E) Toxicity (t)						
	Salinity	dS/m	<2.0	2.0-4.0	4.0-8.0	>8.0
	Sodicity	%	<5	5-10	10-15	>15
F) Erosion Hazard (e)						
	Slope	%	<3	3-5	5-10	>10

Source: Modified from Sys *et al.* (1991) and Naidu *et al.* (2006)

Table 3 shows the fundamental scale by Saaty and Vargas. Then, the weight of each factor was calculated based on the values given to this factor in comparison to all other factors using equation 2 and 3. Consistency ratio (CR) was computed to measure the consistency of comparison of the criteria (Kahsay *et al.,* 2018). The CR of the matrix is referred to as:

$CR = CI/RI$ ……….. eq. 2

Where consistency index is $CI = (\lambda_{max-n})|(n-1)$……….. eq. 3

and, *RI* is that the random index (Table 4) while λmax is the highest eigenvalue and *n* is the number of factors used in the analysis. Therefore, where CR <0.1, the conclusion was accepted (Li *et al.* 2017; Kahsay *et al.* 2018). Finally, suitability index was calculated based on ratings of all factors.

After weighting each parameter using AHP, spatial interpolation (30m pixel size) using ArcGIS software was employed to drive raster layers for each criterion. The spatial interpolation was carried out using ordinary kriging method.

Table 3: The Fundamental Scale by Saaty and Vargas (2001)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over Another
5	Essential or strong importance	Experience and judgment strongly favor one activity over Another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of tile highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

Source: Saaty and Vargas (2001)

Table 4: Random Consistency Index (RI) for Criteria

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51	1.52	1.54	1.56	1.58

Source: Saaty and Vargas (2012)

The kriging process involves several steps: first, constructing a semi-variogram to model spatial dependence; second, using the semi-variogram model to estimate the kriging weights; and finally applying these weights to predict unsampled points (Douzouné *et al.,* 2024). Then calculation of the $Z'(x_0)$, the predicted soil property at unsampled location x_0, and by $\sigma_k^2(x_0)$, the error variance of the prediction computed at each sampled location using measured values, $Z(x_i)$ (i = 1; 2; n), was carried out by means of the following equation:

$$Z'(x_0) = \sum_{i=1}^{n} \lambda i Z(x_i)$$

……….eq. 4

Where:

$Z'(x_0)$ this is the estimated value of the soil properties at location x_0.

λi this is the kriging weights for the sampled locations i.
$Z(x_i)$ this is the measured values of the soil properties at the sampled locations i.
n this is the number of sampled locations.

$$\sigma_k^2(x_0) = \mu + \sum_{i=1}^{n} \lambda i \gamma(x_0 + x_i) \quad \ldots\ldots\ldots\ldots \text{eq. 5}$$

Where:
$\sigma_k^2(x_0)$ is the kriging estimation variance at the prediction location x_0
n is the number of neighboring sampled points used in the estimation.
μ this is the range constant in the process.
λi this is the kriging weight.
x_i is the location of the i^{th} sampled point.
γ this is the semi-variogram values corresponding to the distance between $x_0 + x_i$.

Then, values in raster layers were reclassified to a common suitability class (S1 for highly suitable, S2 for moderately suitable, S3 for marginally suitable, N1 for temporally not suitable and N2 permanently not suitable). Finally, the weighted overlay method was employed to generate the overall suitability raster layer. The reclassified raster layers was overlayed by multiplying each raster cell suitability value by its layer weight (using the corresponding weight value in Table 5) and totaling the values to drive the map of overall suitability for each selected crop as described by Tadesse and Negese (2020).

$$LS = \sum_{i=0}^{n} WiXi \quad \ldots\ldots\ldots\ldots \text{eq. 6}$$

Where;
LS is the land suitability,
Wi is the weight of factor,
Xi is the criterion score of factor i,
n is the number of criteria considered.

Table 5: Class rates of soil suitability classes and corresponding weight value

Class	Suitability class	Corresponding weight value
Class 1 (S1)	Highly suitable	4
Class 2 (S2)	Moderately suitable	3
Class 3 (S3)	Marginally suitable	2
Class 4 (N)	Currently not suitable	1

Source: Modified form FAO (1976)

Comparison of AHP and Square Root Methods (SRM)

A comparison of the two methods was carried out on the ArcGIS software. This was done by separately calculating the total area of each mapping unit for AHP and SRM from the final suitability raster maps of groundnut. The results of the calculated area for each mapping unit showed the total area (in hectares) suitable for the crop and the corresponding suitability class for each method, hence the outcome of their performance stated.

On the ArcGIS, each of the suitability classes for groundnut showed the total area covered when selected for each method (AHP and square root) hence, their performance recorded. Afterwards, statistical comparison using Pearson's Chi-square (X^2) test of independence was carried out to evaluate the degree of agreement or difference between the geometry of the AHP and SRM. The Pearson's Chi-square (X^2) test of independence was carried out to determine whether the choice of the land suitability model, statistically significantly influenced the distribution of the suitability classes (highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and currently not suitable (N)) across the toposequence using equation 7. Therefore, null hypothesis stated that the suitability class distributions produced by AHP and SRM were not significantly different, whereas the alternative hypothesis stated that significant differences existed between the two methods. The statistical significance determined by Chi-square (X^2) test was considered significant at $p < 0.001$. The stated null hypothesis of no difference between the suitability classifications generated by AHP and SRM was rejected when the observed p-value was less than the specified significance level. Similar method was used by Zhai *et al.* (2025), they used chi-square to compare site assessment and land evaluation models for capability classification in agricultural zones.

$$X^2 = \sum \frac{(0_i - E_i)^2}{E_i} \text{ ..... eq. 7}$$

Where:
X^2 = The Chi-square test statistic.
$\sum$ = The summation symbol (sum of all categories).
O_i = The Observed area values (i.e., AHP and SRM geometries).
E_i = The Expected frequencies (the average value).

RESULTS AND DISCUSSION

Delineation of Mapping Units

The result of the reclassified DEM and digitized raster showed that the toposequence was delineated into crest, upper, middle and lower slopes, as well as floodplain and the total area of each mapping unit is presented in Table 6. The result of the calculated total area was 100.00 ha and each mapping unit showed that GPW1 (crest) was 4.12 ha, GPW2 (upper slope) 13.68 ha, GPW3 (middle slope) 20.70 ha, GPW4 (lower slope) 33.18 ha and GPW5 (floodplain) recorded 28.32 ha, respectfully. The mapping units, corresponding topographic, morphological and physical characteristics of the study area is shown in Figure 6.

Table 6: Mapping Units/Topography and Total Area Coverage

Topography	Mapping Units	Area (ha)	Percentage coverage (%)
Crest	GPW1	4.12	4.12
Upper slope	GPW2	13.68	13.68
Middle slope	GWP3	20.70	20.70
Lower slope	GPW4	33.18	33.18
Floodplain	GPW5	28.32	28.32
	Total	100.00	100.00

The delineation of the study into five (5) distinct mapping units presents a framework for sustainable soil management opportunities. The mapping unit's dominance of the GPW4 and GPW5 of over 61% of the total area, presents huge opportunities for arable crop cultivation. The large part of the mapping unit was deposition area which serves as sink for water and nutrients that could support crop cultivation.

Similar reports were documented by De Caires *et al.* (2025) in their investigation of landscape variability using slope gradient extracted from DEM with high resolution (2m) using ArcGIS. Similarly, Nelson (2021), used GIS-derived topographic layers like DEM for elevation, slope, curvature and remote sensing data for topographic land delineation into mapping units and showed the potentials of the environment in British Columbia.

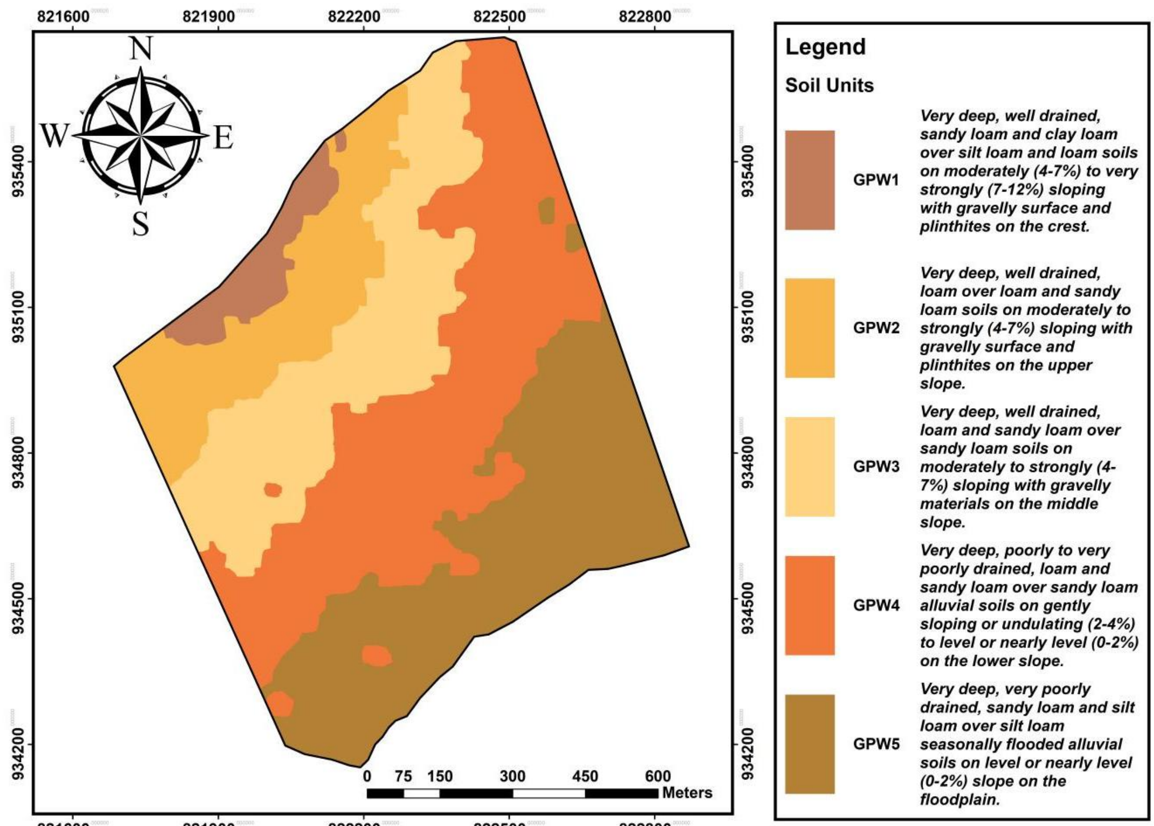

Figure 6: Mapping Units and Corresponding Characteristics of Gurumpawo Toposequence

Land Qualities

The results of land qualities for the mapping units of the study area is presented in Table 6. The results indicated that rainfall was 1095 mm average and temperature was 24.7 ^oC and the effective depth was >150 cm; which indicated that the soils were very deep across the landscape. The very deep soils might be due to stable geomorphlogy in which the weathering and pedogenic processes were rapid above the erosion rate from the high slope environment. This result could also be because of high rate of weathering and deposition from higher altitude where there was rapid breakdown of the parent materials, including parent materials that were eroded from higher altitude and were redeposited vertically downward in the profiles. Similar very deep soil profiles were reported by AmdeMichael (2024) and Gambo *et al.* (2025) on landscapes.

The soils in GPW1 to GPW3 were well drained, GPW4 ranged from poorly drained to very poorly drained and GPW5 had a very poorly drained condition. The soil texture ranged from sandy loam to clay and loam in GPW1 while GPW2 was predominantly loam, GPW3 and GPW4 recorded a loam to sandy loam texture, and GPW5 had a sandy loam to silt loam texture. This suggesting that the profiles in GPW1 to GPW3 had favorable aeration and good water movement that could support variety of crops while soils in GPW4 and GPW5 suggests

Table 6: Land Qualities for the Soil Mapping Units of the Survey Area

Land Qualities/characteristics	Diagnostic factor	Unit	GPW1	GPW2	GPW3	GPW4	GPW5
A) Climate (c)							
	Rainfall	(mm)	1095	1095	1095	1095	1095
	Temperature	(ºC)	24.7	24.7	24.7	24.7	24.7
B) Soil physical condition (s)							
	Soil Eft. depth	(cm)	>100	>100	>100	>100	>100
	Soil texture	Class	SL,CL,L	L	L, SL,	L,SL	SL,SiL
C) Wetness (w)							
	Drainage	Class	Well drained	Well drained	Well drained	Poorly to V. poorly drained	V. poorly drained
D) Chemical fertility (f)							
	pH		6.58-6.67	6.02- 6.13	5.89 -6.01	6.04-6.38	6.71-6.65
	Total N	(g/kg)	0.34-0.56	0.22-0.17	0.20-0.14	0.25	0.45-0.50
	Av. P	(mg/kg)	47.51-13.03	1.72-1.89	5.49-2.40	10.98-3.26	6.17-5.66
	Organic C	(g/kg)	9.38-10.77	6.98-0.45	3.80-6.70	6.46-9.70	10.59-10.05
	Base saturation	(%)	42.04-87.57	58.07-67.66	52.81-61.02	24.72-42.30	49.68-51.56
	CEC	cmol/kg	9.74-22.88	7.57-10.45	11.90-5.17	14.19-14.44	10.27-8.32
E) Toxicity (t)							
	Salinity	dS/m	0.12-0.15	0.09-0.20	0.36-0.17	0.05-0.35	0.11-0.40
	Sodicity	(%)	11.5-1.62	3.17-1.91	2.19-4.45	1.76-2.08	2.92-5.05
F) Erosion (e)							
	Slope	(%)	7-12	4-7	4-7	0.2-2-4	0-2

higher water retention but lower aeration in the unit, which could reduce root respiration for some sensitive crops. These textures are often the results from alluvial deposition. These results were consistent with findings of Surwase *et al.* (2023) on a landscape.

Generally, the soil pH (H_2O) were rated moderately acid (5.6-6.0) to slightly acid (6.1-6.5) and neutral (6.6-7.3) with few variations across the landscape while the EC were rated low and non saline (<2.00 dS/m). These results suggests that the soils could support groundnut cultivation as the crop could be cultivated in variety of soil pH. Reports by Sreekumar and Sanil (2021) suggested that soil pH between 5.5 and 7.0 were optimum for crop performance. Similarly, Jayasree *et al.* (2022) stated that soil pH on landscapes generally falls within a range suitable for plant growth. Soils were generally low in OC (<10 g/kg), TN (<1.50 g/kg) and Av.P (<10.00 mg/kg) across the landscape. These results could be due to intense cultivation activities in the study area and agrees with the findings of Shobayo and Hussaini (2024) reported low OC contents and soil fertility due to continuous cultivation. The soil CEC were also generally rated low (<12.0 cmol/kg) across the toposequence which could be due to the low OM and clay contents as observed by Regassa *et al.* (2023). However, PBS were generally rated high (>70%), pointing to the soils potentials for fertility. Osinuga *et al.* (2020) reported high BS on a toposequence and attributed it to high weathering of minerals similar to findings in this study.

Groundnut SRM suitability classification

The results for groundnut suitability classification for actual and potential suitability is presented in Table 7. The results revealed that GWP1 was classified as moderately suitable (S2te) with suitability index of 60.62% and limitations in toxicity (sodicity) and erosion hazard for actual suitability class while, potential suitability improved in the suitability index score of 70.00%. The moderate suitability of this unit (GWP1) indicated that the soils had generally favorable characteristics for groundnut cultivation, but the sodium levels might affect soil structure, water infiltration, aeration and root development. Groundnut performs best in well-aerated soils with unrestricted root and pod development; therefore, sodicity may reduce crop performance by causing soil dispersion and crusting. The erosion hazard in the unit further suggests susceptibility to surface soil losses, which could remove nutrient-rich surface horizons and reduce soil productivity. The improvement of the suitability index under potential conditions suggests that these limitations were manageable through appropriate interventions such as gypsum application, organic matter incorporation, conservation tillage, contour farming and other erosion control measures. Similarly, GPW2 and GPW3 were also classified moderately suitable (S2e) with index score of 70.00% and erosion hazard was the limitation recorded for the units. The relatively high suitability indices for these unites indicated that soil physical and chemical properties generally meet the requirements for groundnut cultivation in the area. However, the presence of erosion risk could be associated with slope gradient and runoff processes in the area that accelerated the removal of surface soils and plant nutrients. Groundnut is particularly sensitive to soil degradation due to pod development which occurs below the soil surface and requires stable soil conditions. The continuous erosion in the area might therefore reduce rooting depth, nutrient availability, and moisture retention, which could ultimately affect groundnut yields. The persistence of erosion as the dominant limitation highlighted the importance of adopting soil and water conservation measures such as contour ridging, cover cropping, mulching and strip cropping to maintain long-term productivity in these units. The soils in GPW4 were classified as marginally suitable (S3w) with suitability index of 48.99% (Figure 7) and limitation of wetness for both actual and potential suitability class. These results showed soil moisture increase down slope and indicated transport and deposition activities. In the same way, soils in GPW5 were also classified as marginally suitable (S3sw) with limitations in soil physical condition (silt loam) and wetness and a suitability index score of 34.29% for both actual and potential suitability

(Figure 8). The marginal suitability could be attributed to poor drainage conditions from seasonal flooding and accumulation of water down slope. Osujieke *et al.* (2022) reported that drainage as a critical factor for groundnut cultivation.

Table 7: Land Suitability Classification (Actual and Potential) for Groundnut

Mapping Unit	Climate	Soil Physical Condition	Wetness	Chemical Fertility	Toxicity	Erosion Harzard	Actual Suitability		Potential Suitability	
	(c)	(s)	(w)	(f)	(t)	(e)	Suitability index	Suitability class	Suitability index	Suitability class
	A	B	C	D	E	F	(%)		(%)	
GPW1	100.00	100.00	100.00	100.00	75.00	49.00	60.62	S2te	70.00	S2e
GPW2	100.00	100.00	100.00	100.00	100.00	49.00	70.00	S2e	70.00	S2e
GPW3	100.00	100.00	100.00	100.00	100.00	49.00	70.00	S2e	70.00	S2e
GPW4	100.00	100.00	24.00	100.00	100.00	100.00	48.99	S3w	48.99	S3w
GPW5	100.00	49.00	24.00	100.00	100.00	100.00	34.29	S3sw	34.29	S3sw

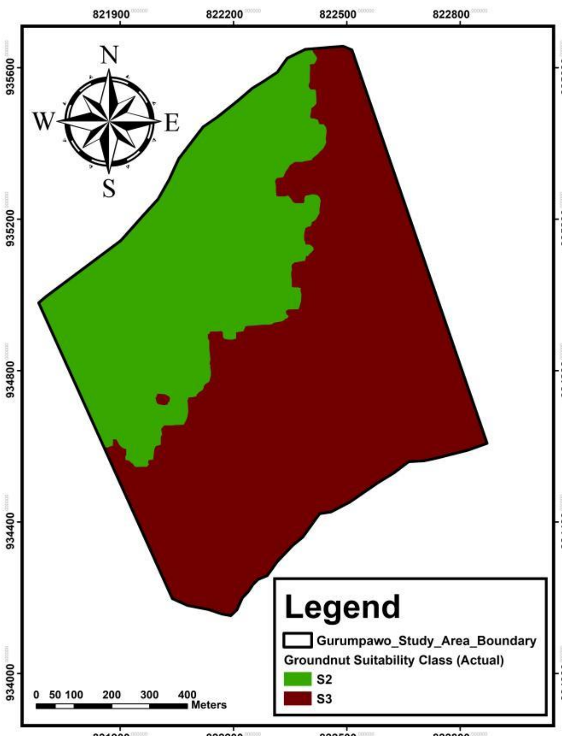

Figure 7: Groundnut SRM Suitability (Actual) Map

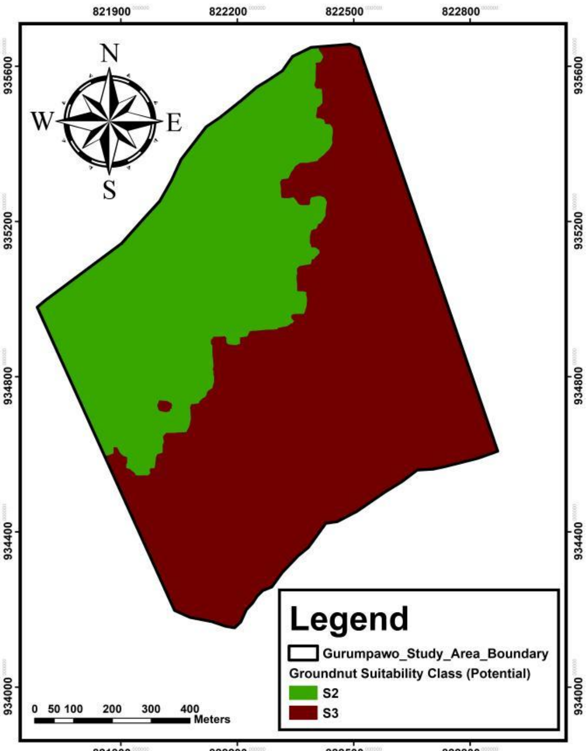

Figure 8: Groundnut SRM Suitability (Potential) Map

The lower slope environment soils in mapping units GPW4 and GPW5 were marginally suitable (S3) because of wetness and soil textures limitations as a result of deposition of materials from seasonal flooding in the units which influenced the moisture content and textural distributions. Groundnuts plant, develops pods underground and the heavy silt/clayey surface horizons, mostly silt loam textures of the lower slopes (GPW5) posed some physical challenges to pod formation and expansion, increased the risk of fungal diseases and pod rot of the crop due to poor drainage conditions. Tukur *et al.* (2024) reported that groundnut cultivation performed optimally in well drained, sandy loam to loam texture as against silt loam texture.

Management of these soils should focus on digging ditches to collect water and improve aeration in the soils,

construction of drainage channels, planting groundnut on ridges and carefully timing sowing dates before the rain gets established and saturation sets-in in GPW4 and GPW5 to encourage aeration in the soils for pod development and reduce the risk of root rot. The area could be considered for cultivation of other water loving crops such as rice and sugar cane. Similar results were reported by Jayesree *et al.* (2022) who found marginally suitable (S3wf) in the lower slope for groundnut due to wetness and low OC contents. In contrast, Meena *et al.* (2017) found the upper slopes soils were marginally suitable (S3) for groundnut due to slope and erosion hazards.

Groundnut AHP suitability classification

The results for pairwise comparison matrix for groundnut suitability is presented in Table 8 and the main criteria ranking for groundnut suitability is presented in Table 9. Results for groundnut pairwise comparison for the principal eigenvalue recorded a 9.40 while the pairwise consistency ratio was

0.035 (3.50%). These results imply that matching of the criteria through pairwise comparison was reasonable and consistent, and since the CR was <0.1, the result is accepted. The results of the ranking indicated that texture recorded the highest ranking in terms of importance for groundnut suitability with 31.20% followed by soil pH with a 22.20% while rainfall was in third place on the ranking scale with 15.50%. Linn (2020) showed that texture and rainfall were major considerations for AHP analysis in groundnut suitability assessment in dry zone of Mandalay Region, Myanmar.

Subsequently, the sequence of the ranking were; temperature (10.80%), depth (7.40%), drainage (5.10%), CEC (3.50%) and Av.P (2.50%) while, the least ranked importance was OC with a 1.80% (Figure 9). These results could be due to the importance of soil texture and soil pH required for germination, establishment and pod formation of groundnut. The soil texture could enable the pod's physiology and formation ease, when the soils were relatively loose textured than in clayey textured and compacted soils. Groundnut through the root nodules could fix nitrogen that would improve soil OC, hence the least score allocation for OC recorded for the crop. Salifu *et al.* (2022) reported that soil type, precipitation, OM and continuous cultivation contributed to AHP suitability analysis of groundnut in Ghana, West Africa.

Additionally, the results might be due the pegging process for underground pod formation of groundnut which could be promoted by ideal soil texture, hence the high ranking. Thereafter flowering stage, groundnut stalks (pegs) must then penetrate the soils to grow the nuts; and the sandy loam textures and mostly neutral soil pH recorded for the study area could promote this process and this could have been the reason for the high suitability in the vast major of the landscape, hence the high priority rankings of texture and soil pH.

Table 8: Pairwise Comparison Matrix for Groundnut Suitability

	Texture	pH	Rainfall	Temperature	Depth	Drainage	CEC	Av.P	OC
Texture	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
pH	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
Rainfall	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00
Temperature	0.25	0.33	0.50	1.00	2.00	3.00	4.00	5.00	6.00
Depth	0.20	0.25	0.33	0.50	1.00	2.00	3.00	4.00	5.00
Drainage	0.17	0.20	0.25	0.33	0.50	1.00	2.00	3.00	4.00
CEC	0.14	0.17	0.20	0.25	0.33	0.50	1.00	2.00	3.00
Av.P	0.12	0.14	0.17	0.20	0.25	0.33	0.50	1.00	2.00
OC	0.11	0.12	0.14	0.17	0.20	0.25	0.33	0.50	1.00
Weight	0.312	0.222	0.155	0.108	0.074	0.051	0.035	0.025	0.018

Principal eigenvalue = 9.401

Consistency Ratio (CR) = 3.5% (0.035)

Table 9: Main Criteria Ranking for Groundnut Suitability

Criteria	Priority (%)	Rank
Texture	31.20	1
pH	22.20	2
Rainfall	15.50	3
Temperature	10.80	4
Depth	7.40	5
Drainage	5.10	6
CEC	3.50	7
Av.P	2.50	8
OC	1.80	9
Total	100.00	

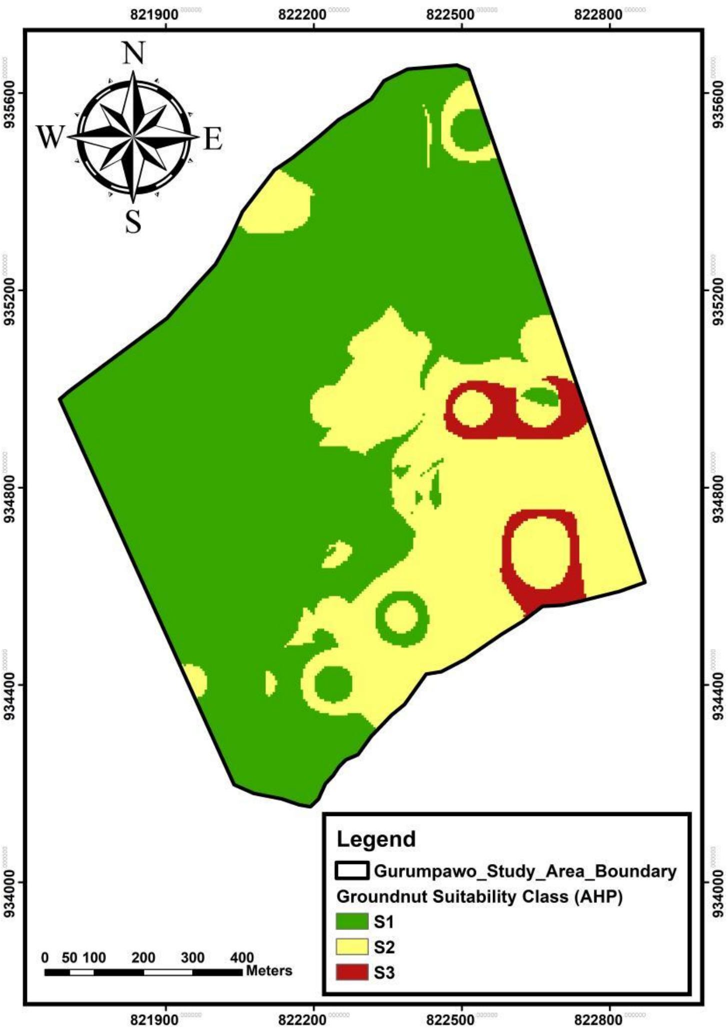

Figure 9: Groundnut AHP Suitability Classification Map

The moderate suitability (S2) of the soils observed in some lower slope environment could be because of high soil pH and poor drainage of the environment that could affect the pegging process of groundnut which can lead to pod rot hence, the lower suitability rating. Similar AHP ratings were reported for a legum by Sadiq *et al.* (2023) and they found priority ranking for drainage, soil pH, slope and SOC using a GIS-based multi-criteria approach in Northern, Nigeria. Moisa *et al.* (2022), identified soil texture and rainfall as dominant factors for groundnut suitability. To manage these soils, use of minimum tillage especially in the sandy loam soils of the upper slopes environment will reduce risk of leaching and erosion hazards. Addition of OM could improve soil conditions ideal for groundnut cultivation. Addition of Ca materials like gypsum could improve the high acidic condition observed and improve groundnut podding, effectively lowering the risk of empty pods.

AREA GEOMETRIC COMPARISON OF AHP AND SRM

The results of the comparison of AHP and SRM for groundnut is presented in Table 10 while the results of the chi-square statistical test for groundnut is presented in Figure 10. The results revealed that AHP recorded opposite figures for total area covered for highly and marginally suitable classes. While AHP model recorded 66.21 ha for highly suitable (S1) class, SRM recorded zero meanwhile, the SRM recorded a 61.50 ha coverage against the zero coverage by AHP model. Despite these variations, the two models had a close call when they both score moderate suitability (S2) with a 30.31 ha (AHP) and 38.50 ha (SRM) respectively.

These results might be due to the ability of AHP model to combine the pairwise comparison and weighted overlay accuracy, which comprehensively calculated the suitability of groundnut in the study area than the SRM that was based more on the limitations of the landscape than its potentials. This implies that groundnut

Table 10: Groundnut Area Geometric Comparison of AHP and SRM

Suitability Class	Area AHP (ha)	Area SRM (ha)
Highly Suitable	66.21	-
Moderately suitable	30.31	38.50
Marginally Suitable	3.48	61.50
Total	100.00	100.00

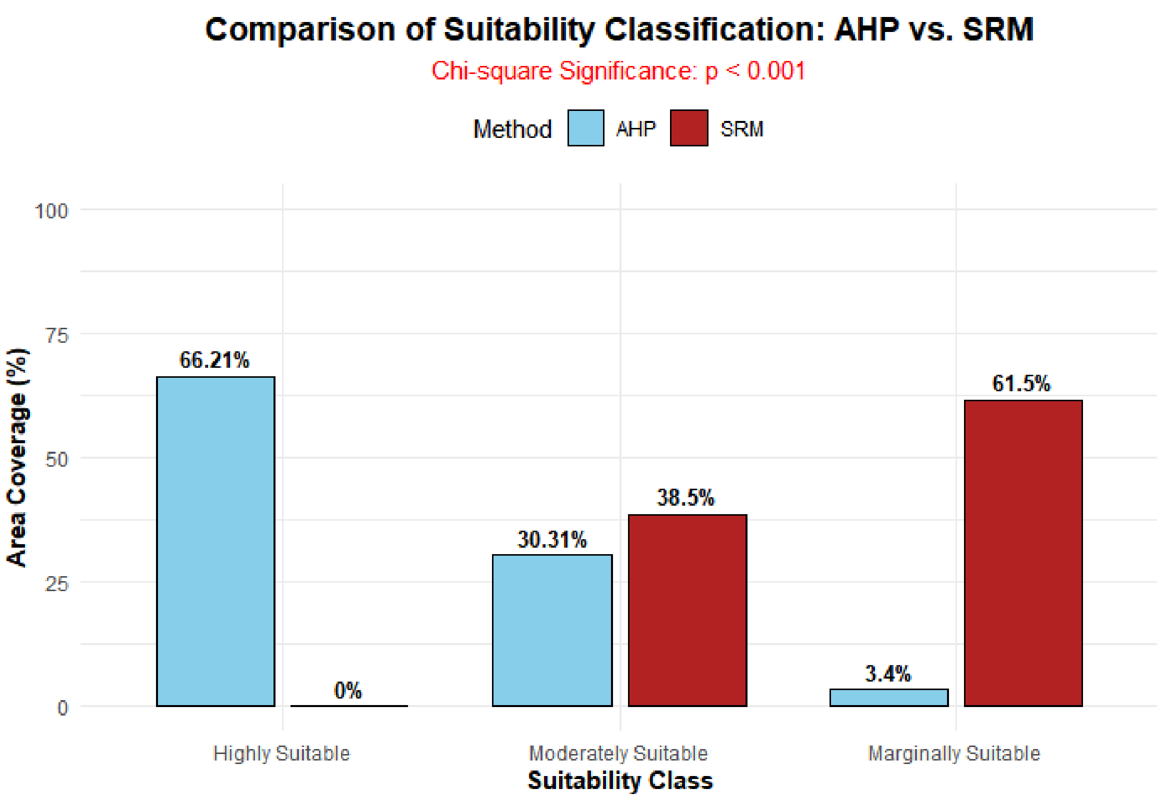

Figure 10: AHP vs SRM Chi-square Statistical Test for Groundnut

$X^2 = 119.20^{***}$ ($p<0.001$)
p-value = $p<2.2\times10^{-16}$
Chi-square Tabular value= 13.82 (df =2)

limitations observed on the landscape did not outweigh the potentials of the field as determined by AHP model while SRM insisted on addressing limitations observed for high yields to be achieved. The chi-square statistical analysis results revealed that the gap between AHP and SRM in calculating the suitability of groundnut was highly significant due to the high chi-square value of $X^2 = 119.20$ ($p<0.001$) and the chi-square p-value of $p<2.2\times10^{-16}$. This high chi-square value confirmed that the disparity between the two models in classifying the land's suitability for groundnut involved the choice of the models and not just the crops ratings or soil properties alone.

CONCLUSION

This study digitally delineated Gurumpawo toposequence in to topographic units and carried out a detailed survey using a rigid grid, and determined selected physical and chemical properties of the study area. The topographic units were digitized into five (5) mapping units namely: GPW1 (4.12 ha, 4.12%), GPW2 (13.68 ha, 13.68%), GPW3 (20.70 ha, 20.70%), GPW4 (33.18 ha, 33.18%) and GPW5 (28.32 ha, 28.32%). The study revealed a strong relationship between topography and soil properties and their potential for arable crop cultivation. The soils of the study area across the landscaped revealed a generally low fertility levels for most of the soil nutrients (OC <10 g/kg, TN <1.50 g/kg and Av.P <10.00 mg/kg). However, the soils were generally neutral in soil pH H_2O (6.6-7.3) and had high base saturation (>70%).

The assessment of land suitability using SRM and AHP provided clear variation of the two methods. The SRM proved to be a more conservative method of suitability assessment which highlighted critical limitations (erosion hazards and poor nutrients) in the crest, upper and middle slopes (GPW1 to GPW3) to poorly drained soils in the lower slope (GPW4) and floodplain (GPW5); that resulted in marginally suitable (S3) classification for the crop. In comparison, the AHP model offered a more optimistic and compensatory approach which identified majority of the study area as highly suitable (S1) or moderately suitable (S2) for groundnut; as it weighted climatic conditions, soil texture and soil depth more heavily than poor chemical properties or drainage limitations. Therefore, while SRM was essential for identification of specific risks or limitations on the toposequence for groundnut cultivation, the AHP model provided a more comprehensive assessment of land suitability by incorporating and weighting multiple environmental factors, making it potentially useful for landscape-scale agricultural planning by its ability to recognize the overall landscape potentials for the crop, although further validation using crop performance data is required. The differences between AHP and SRM have important agronomic implications. While SRM emphasized limiting factors such as erosion, wetness, and sodicity, thereby providing a more conservative assessment of groundnut suitability, AHP integrated multiple weighted criteria and identified a larger proportion of the landscape as suitable for cultivation. Consequently, the SRM may be more useful for identifying field-level management limitations, whereas AHP may support broader land-use planning and prioritization of areas for agricultural sustainable development. The contrasting outputs highlighted the importance of considering both overall land potential and specific soil limitations when making decisions regarding sustainable groundnut cultivation. It is recommended that researchers, project planners and financially capable farmers should prioritize the use of AHP suitability assessment for long-term precision agricultural investment.

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