



RESEARCH ARTICLE

## Geospatial Optimization of Marginal Lands for Sustainable Cassava Production: A Hybrid GIS-MCDA Framework for Sub-Humid West Africa.

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### Abstract

Land suitability analysis is critical to optimising agricultural productivity, particularly for cassava (*Manihot esculenta* Crantz), a key staple crop underpinning food security across sub-Saharan Africa. This study integrates Geographic Information Systems (GIS) with the Analytical Hierarchy Process (AHP) to systematically assess land suitability for cassava cultivation in Atiba Local Government Area (LGA), Oyo State, Nigeria. Nine biophysical and physiochemical criteria like soil type, land use/land cover (LULC), geology, stream order, river proximity, rainfall, road accessibility, slope, and elevation were evaluated and weighted through pairwise comparison. A consistency ratio of 0.06 confirmed the reliability of the AHP weighting. Weighted overlay analysis in ArcGIS produced a five-class suitability map across the 165,362.91-ha study area. Results show that 79.54% of the area is suitable for cassava cultivation: 7.55% (12,490.1 ha) highly suitable, and 71.99% (119,049.0 ha) moderately suitable. Highly suitable zones are concentrated in the central belt near settlements such as Aboke, Oseyemi, and Ago, reflecting optimal combinations of loamy soil, adequate rainfall (2,000–3,700 mm), gentle slope (5–20%), and road proximity. Only 1.58% of land was classified as very low suitability. These findings provide an evidence base for precision agricultural planning, offering actionable guidance to farmers, policymakers, and investors in Oyo State. The AHP-GIS framework applied here is scalable and replicable across cassava-producing regions in Nigeria.

### ARTICLE HISTORY

Received: 20 May 2026

Accepted: 29 May 2026

Published: 26 June 2026

### KEYWORDS

Spatial Decision Support Systems (SDSS)  
 Analytical Hierarchy Process (AHP)  
 Weighted Overlay Analysis  
*Manihot esculenta*  
 Sub-Saharan Africa.

**Citation:** Ibrahim A., Iyiola F. O., Salawu I. O., Omale D., Idoko I. A., Ogunsola R.O. & Oduyemi A.T. (2026). Geospatial Optimization of Marginal Lands for Sustainable Cassava Production: A Hybrid GIS-MCDA Framework for Sub-Humid West Africa. *Journal of Geomatics and Environmental Research*, 9(1), Pp 266-280

## 1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the most important tuber crop in Nigeria and the third-largest source of carbohydrates in the world after rice and maize. Nigeria produces over 34 million tonnes annually, making it the world's largest cassava producer. Beyond subsistence nutrition, cassava generates income for smallholder farmers, serves as raw material for starch, alcohol, and animal feed industries, and provides over 15% of daily caloric intake across Africa (Borku, 2025; Immanuel *et al.*, 2024; Mohidin, 2024).

Despite this importance, cassava productivity remains well below its genetic potential. Inadequate site selection is among the most persistent constraints: farmers frequently cultivate cassava on marginal land without systematic knowledge of soil suitability, drainage patterns, or climatic adequacy (Howeler, 2017; Ngongo, 2022; Ofem, 2025). Amao and Awoyemi (2008) attributed low adoption of improved cassava varieties in Nigeria partly to a lack of information about suitable cultivation conditions available to farmers (Abdoulaye *et al.*, 2014; Akinwole *et al.*, 2025; Onyemauwa, 2020). Ande *et al.* (2011)

confirmed that production has consistently failed to meet demand across the continent (Edamisan *et al.*, 2020; Amelework *et al.*, 2022; Borku, 2025).

Geographic Information Systems (GIS), combined with Multi-Criteria Evaluation (MCE), offer a powerful solution (Tzioutzios & Kastridis, 2020; Ibrahim *et al.*, 2024; Balogun, 2025; Abdou & Martin, 2026). GIS-based land suitability analysis can integrate multiple spatial datasets like soil, slope, rainfall, geology, land cover into coherent decision maps that identify optimal production zones (Ennaji, 2018). The Analytical Hierarchy Process (AHP), introduced by Saaty (1977, 1980), provides a mathematically rigorous mechanism for deriving criterion weights through pairwise comparison, and is now widely applied in agricultural land suitability assessments globally (Stofkova *et al.*, 2022; Malczewski, 2004).

In Nigeria, land suitability studies using GIS-MCE have been conducted for various crops across several states (Babalogbon, 2018; Tenkap & Balogun, 2020; Ahmed *et al.*, 2024; Ibrahim *et al.*, 2024; Balogun *et al.*, 2025), yet systematic assessment for cassava in Oyo State, particularly at the local government level using an AHP integrated GIS model to produce a detailed land suitability map for cassava cultivation considering standard biophysical and socio-economic components, remains relatively scarce. Atiba LGA, a predominantly rural agricultural area with over 200 villages and significant cassava-growing potential, represents an important gap. The area is characterised by diverse topography, soil types, and rainfall distribution patterns that necessitate a structured evaluation framework.

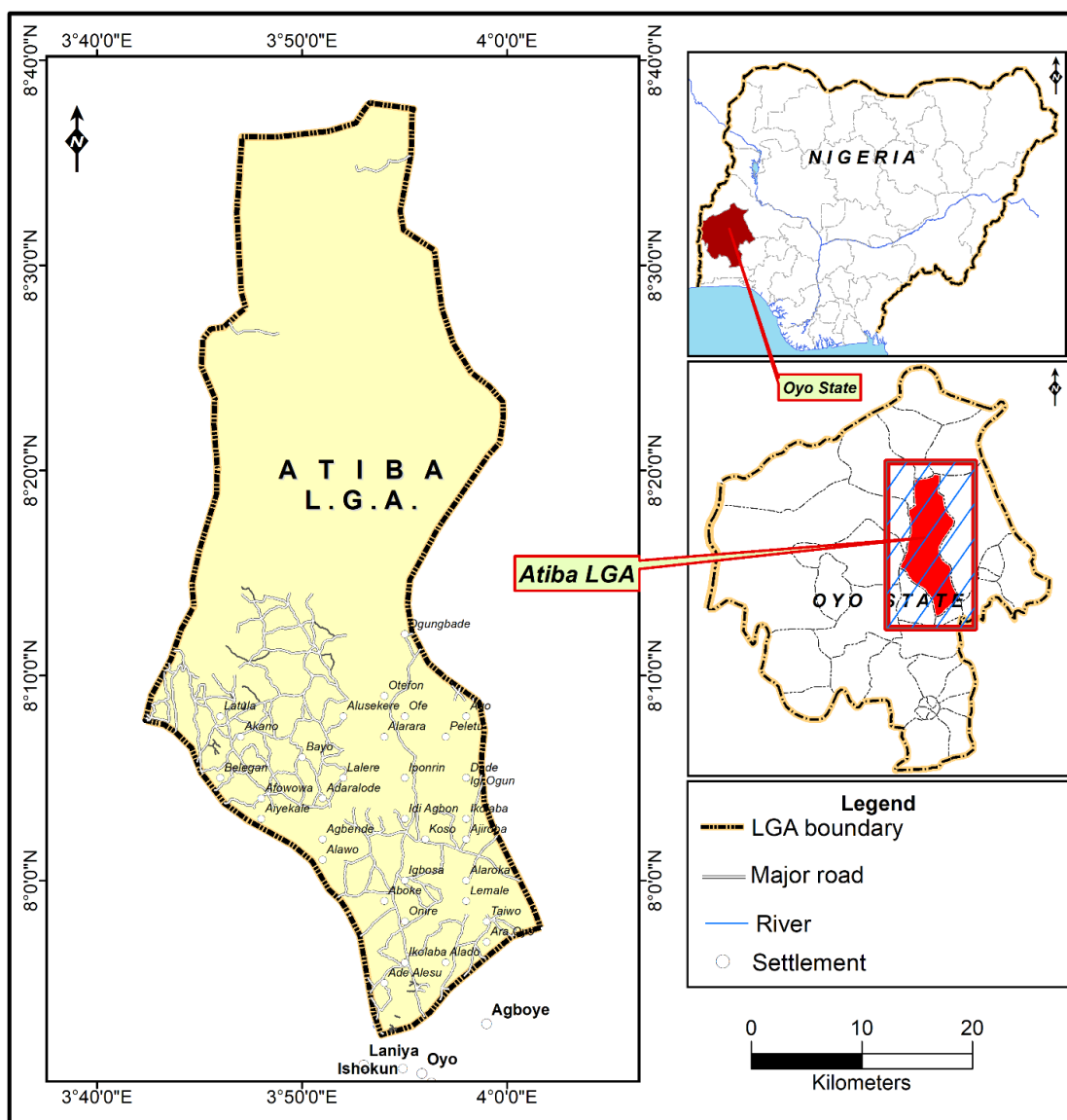
## 2. MATERIALS AND METHOD

### 2.1 Study Area

Atiba Local Government Area is located in Oyo State, southwestern Nigeria, within the coordinates 7°50'30" to 8°40'00"N and 3°57'00" to 4°10'00"E. The LGA covers a total land area of 2,197.53 km<sup>2</sup> and had a census population of 168,246 in 2006, estimated at approximately 240,500 currently. The administrative headquarters is at Ofa-Mefa.

The area lies within the Guinea Savanna agro-ecological zone, characterised by a tropical climate with distinct wet and dry seasons. Mean annual rainfall ranges from 2,000 to 3,700 mm, with temperatures averaging 22.4°C (minimum) to 31.4°C (maximum). Relative humidity ranges from 61.9% to 98%. Soils are predominantly sandy loam, classified under four FAO soil units: Ferric Luvisols (LF1), Plinthic Luvisols/Lithosols/Gleyic Luvisols (LF26-a), Ferric Acrisols/Lithosols/Eutric Gleysols (LF49), and Lithosols/Luvic Arenosols (LF64-1a). Vegetation ranges from dense forest in the north to cultivated arable land in the centre and built-up areas in the south.

Economic activity in the LGA is predominantly agrarian, centered on traditional farming of cassava, maize, and yam. The area contains several farm settlements and has been identified by the Oyo State government as a potential agribusiness hub, making it an ideal candidate for systematic agricultural suitability assessment.



**Figure 1.** Study Area showing Atiba LGA in Oyo. (Source: Author’s Lab, 2026)

## 2.2 Data Source and Acquisition

A combination of secondary spatial datasets was compiled for the study. An Ikonos satellite image (0.5 resolution) was sourced from the Office of the Surveyor-General of the Federation, Abuja, and supplemented by concurrent Google Earth Pro imagery to serve as primary spatial references. A scanned analogue map was obtained from the Atiba LGA Town Planning Office and georeferenced using ground control points collected with a handheld GPS. Meteorological data (January 2021–September 2022) were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, while soil classification data were derived from the FAO World Soil Map. Topographic layers, specifically slope and elevation, were derived from a 30m resolution Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM). Crucially, the transport infrastructure and hydrological networks were developed entirely from scratch through manual, hand-drawn on-screen heads-up digitization within the GIS environment. Rather than relying on existing open-source vector databases, which frequently omit minor agricultural paths or suffer from spatial displacement. All road networks and river channels were digitized completely by hand directly from the high-resolution georeferenced imagery. This painstaking manual extraction process ensured that localized, fine-scale drainage pathways and minor farm tracks vital to post-harvest cassava transport were accurately captured for subsequent Euclidean distance buffer modeling.

## 2.3 Data Processing

The study adopted the three-phase database design model to accommodate the processed data (Martinez-Mosquera *et al.*, 2020; Bhojaraju, 2003; Kufoniyi, 1998): conceptual, logical, and physical. Nine vector entities were defined: LGA boundary, road network, slope, soil, land use, stream order, geology, elevation, and rainfall. Entity-relationship modelling was performed to define spatial and attribute relationships. The physical database was implemented as a geodatabase in ArcGIS, with all datasets projected to the Universal Transverse Mercator (UTM) coordinate system, Zone 31N, WGS 1984 datum.

Data processing included georeferencing, on-screen digitization in ArcGIS, image classification using supervised maximum likelihood classification, rasterization, and spatial data cleaning. Land use/land cover was classified into five categories: agricultural land (41%), dense vegetation (50%), bare ground (6%), built-up area (2%), and water body (1%).

### 2.3.1 Land Use/Land Cover Classification

It is important to delineate and prioritise spatially suitable land parcels land for this purpose, hence, land use/land cover classification. To achieve this, the satellite imagery was subjected to geometric and radiometric consistency across the multi-temporal dataset, and a rigorous pre-processing workflow was adopted to ensure accuracy. Initially, the satellite imagery was spatially subsetted (clipped) to isolate the designated Area of Interest (AOI). To establish a standardized spatial reference system for integration with other spatial data, the datasets were re-projected to the Geographic Coordinate System (GCS), specifically the World Geodetic System 1984 (WGS 84) datum.

Land use and land cover mapping was executed utilizing the parametric Maximum Likelihood Classification (MLC) algorithm. This supervised classifier calculates the probability that a given pixel belongs to a specific LULC class based on training statistics, assuming a multivariate normal distribution of the spectral bands. The decision rule is defined as:

$$g_i(x) = \ln P(w_i) - \frac{1}{2} \ln |\Sigma_i| - \frac{1}{2} (x - m_i)^T \Sigma_i^{-1} (x - m_i) \dots\dots\dots \text{Equation 1}$$

Where  $g_i(x)$  is the classification score for pixel vector  $x$  in class  $i$ ,  $P(w_i)$  is the a priori probability of class  $i$ ,  $\Sigma_i$  is the covariance matrix of class  $i$ , and  $m_i$  is the mean vector of class  $i$ . The pixel is assigned to the class that maximizes  $g_i(x)$ .

### 2.3.2 Suitability Criteria and Classification

Nine criteria (Soil type, Land Use/Land Cover, Geology, Stream Order, River Proximity, Rainfall, Road Accessibility, Slope, Topography) were selected based on FAO (1976) land evaluation guidelines and literature review (Abdullahi *et al* 2022; Mugiyo *et al.*, 2021; Purnamasari *et al.*, 2018). Soil data was used to determine the nutrient availability, texture, and root development potential of the area, whereas Land Use/Land Cover was used to exclude restricted zones and identify available agricultural land. The geology dictates underlying parent material, weathering, and mineral composition, while stream order indicates surface water hierarchy, volume, and drainage network capacity. River Proximity ensures accessible surface water for irrigation and processing needs, and Rainfall provides vital moisture during the critical early growth stages. Road Accessibility lowers transportation costs and reduces post-harvest spoilage risks, whereas Slope Influences soil erosion rates and farm mechanization viability. Topography governs localized microclimates, solar exposure, and water accumulation.

Each criterion was reclassified into five suitability classes (1 = very low to 5 = highly suitable) according to cassava agronomic requirements. The classification thresholds are presented in Table 1.

**Table 1.** Suitability classification criteria for cassava cultivation in Atiba LGA

Criterion	Highly Suitable (5)	Moderately Suitable (4)	Marginally Suitable (3)	Not Suitable (1–2)
Slope (%)	5–10	3–4	0–2	> 20
Rainfall (mm)	1,200–1,800	1,801–2,200	2,201–2,500	<700or>2,500
Road Distance (m)	< 500	500–1,000	1,000–2,000	> 2,000
River Distance (m)	< 500	500–1,000	1,000–1,500	> 2,000
Elevation (m)	230–300	301–340	341–400	> 540

### 2.3.3 Analytical Hierarchy Process Weighting

The Analytical Hierarchy Process (AHP) method (Saaty, 1977) was used to derive relative weights for all nine criteria. A 9×9 pairwise comparison matrix was constructed by domain experts and reviewed against published literature, using Saaty's 1–9 importance scale. The normalized weight vector was computed by calculating the principal eigenvector of the comparison matrix. Soil type received the highest weight (31%), reflecting its dominant influence on cassava yield, followed by LULC (22%), geology (15%), stream order (11%), river proximity (8%), rainfall (5%), road accessibility (4%), slope (3%), and elevation (2%). The computed consistency ratio (CR = 0.06) was well within the acceptable threshold of 0.10, confirming the logical consistency of judgments (Table 2).

$$CR = \frac{CI}{RI} \dots\dots\dots \text{Equation 2}$$

Where *CI* is the Consistency Index, which measures the deviation from perfect consistency. *RI* is the Random Index, which represents the consistency index of a randomly generated pairwise comparison matrix of the same size.

**Table 2.** AHP criterion weights and consistency verification

Criterion	Weight (%)	Rank	Rationale
Soil Type	31	1	Primary yield determinant
Land Use / Land Cover	22	2	Current land availability
Geology	15	3	Soil parent material
Stream Order	11	4	Drainage capacity
River Proximity	8	5	Irrigation potential
Rainfall	5	6	Moisture availability
Road Accessibility	4	7	Market access/logistics
Slope	3	8	Erosion/tillage feasibility
Elevation	2	9	Microclimate variation
Consistency Ratio (CR)	0.06	—	Acceptable (< 0.10)

## 2.4 Suitability Map Creation

Individual raster layers were reclassified in the ArcGIS Spatial Analyst module using the suitability thresholds in Table 1 so that all criteria can be in the same unit, to be accepted by the weighted overlay model (Dano *et al.*, 2011). Restricted areas (water bodies and existing built-up land) were excluded from analysis using a Boolean mask. The weighted overlay function combined all reclassified layers using the AHP-derived weights, producing a continuous suitability surface subsequently classified into five discrete categories (Ibrahim *et al.*, 2024; Abawa *et al.*, 2024): Highly Suitable ( $S_1$ ), Moderately Suitable ( $S_2$ ), Marginally Suitable ( $S_3$ ), Low Suitability ( $N_1$ ), and Very Low Suitability ( $N_2$ ), aligned with FAO (1976) land evaluation nomenclature.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Evaluation Criteria and Suitability Thresholds for Cassava Cultivation

The multi-criteria evaluation (MCE) framework required the standardization and classification of nine biophysical and socio-economic criteria into four distinct Food and Agriculture Organization (FAO) suitability classes: Highly Suitable ( $S_1$ ), Moderately Suitable ( $S_2$ ), Marginally Suitable ( $S_3$ ), and Not Suitable ( $N$ ). The specific spatial thresholds established for each criterion are detailed subsequently.

#### 3.1.1 Topographic Factor: Slope and Elevation

Topographic features exert a profound influence on soil erosion, water retention, and farm mechanization viability. The slope parameter was bounded between 0% and 20% for potential cultivation. An optimal terrain configuration characterized by gentle slopes (5% to 10%) was classified as highly suitable ( $S_1$ ). Flat to nearly level terrains (3% to 4%) were designated as moderately suitable ( $S_2$ ), while minimal slopes (0% to 2%) were considered marginally suitable ( $S_3$ ) due to potential waterlogging risks. Slopes exceeding 20% were classified as not suitable ( $N$ ) owing to accelerated risks of soil erosion and degradation under tillage. For elevation, a preferential vertical zone was identified between 230m and 300m above sea level as ( $S_1$ ). Altitudes ranging from 301m to 340m exhibited moderate suitability ( $S_2$ ), whereas elevated terrains between 341m and 540m were classified as not suitable ( $N$ ), likely due to increased ruggedness and microclimatic variations, see figure 4.

#### 3.1.2 Hydro-Climatic Factors: Rainfall, Stream Order, and River Proximity

Rainfall thresholds were segmented to match the moisture requirements of cassava during its critical growth phases. Regions receiving annual precipitation between 3100mm and 3700mm were classified as ( $S_1$ ), providing optimal moisture for tuber development. Lower precipitation bands between 2000mm and 2700mm were categorized as ( $S_2$ ). Proximity to surface water networks (rivers and high-order streams) served as a proxy for dry-season irrigation potential and processing water accessibility. Buffer zones less than 500m from these hydrological networks were classified as ( $S_1$ ), zones between 500m and 1000m as ( $S_2$ ), and regions between 1000m and 1500m as ( $S_3$ ). Areas situated beyond a 2000m buffer were deemed not suitable ( $N$ ) due to the logistical and economic constraints of transporting water. See figures 6, 7 & 8.

#### 3.1.3 Socio-Economic Factor: Road Accessibility

Proximity to transport infrastructure is vital to minimize post-harvest deterioration of the highly perishable cassava roots. Buffer analysis revealed that land within 500m of existing road networks was highly suitable ( $S_1$ ), facilitating rapid market access. Suitability decreased to moderate ( $S_2$ ) between 500m and 1000m, and to marginal ( $S_3$ ) between 1000m and 2000m. Regions farther than 2000m from road infrastructure were categorized as not suitable ( $N$ ) due to prohibitive transport overheads, see figure 5.

### 3.2 Baseline Spatial Constraints: Land Use/Land Cover (LULC) and Soil Distribution

#### 3.2.1 LULC Spatial Characterization

The LULC spatial analysis of Atiba Local Government Area (LGA) demonstrated a distinct tri-zonal macro-distribution: a prominent forest reserve dominates the northern sector, arable lands characterize

the central region, and urban built-up areas cluster within the southern portion. Quantitatively, dense vegetation constitutes the largest land cover class, spanning 85,689.0 Ha, 50% primarily concentrated in the north, followed closely by agricultural land at 68,260.4 Ha, 41%. Bare ground accounts for 9668.2 Ha, 6%, while built-up infrastructure accounts for 1704.7 Ha, 2%, and open water bodies 1089.3 Ha, 1% comprise minor spatial footprint portions across the LGA, see figure 2.

### 3.2.2 Soil Typology and Mapping Units

The edaphic characteristics within the study area were categorized into four distinct soil mapping units based on their morphological and taxonomic profiles (Table 3). Unit LF1 is exclusively characterized by Ferric Luvisols, which generally possess favorable structural stability for root crop development. Unit LF26-a exhibits a complex association of Plinthic Luvisols, Lithosols, and Gleyic Luvisols, indicating localized drainage impediments and shallow profiles. Unit LF-49 comprises an intricate mix of Ferric Acrisols, Lithosols, Eutric Gleysols, and Plinthic Luvisols, indicating low base saturation alongside hydromorphic properties. The final unit, LF 64-1a, is composed of a Lithosol and Luvic Arenosol association, presenting structural challenges due to coarse textures and restricted soil depth, see figure 3.

**Table 3.** Soil Characteristics Suitability

Soil Mapping Unit	Soil Taxonomic Composition	Agricultural Implication for Cassava
LF1	Ferric Luvisols	Highly favorable; good structural stability and root penetration.
LF26-a	Plinthic Luvisols, Lithosols, Gleyic Luvisols	Moderately favorable; restricted by shallow depth and poor drainage.
LF-49	Ferric Acrisols, Lithosols, Eutric Gleysols, Plinthic Luvisols	Marginally favorable; limited by high acidity and low base saturation.
LF 64-1a	Lithosols, Luvic Arenosols	Generally, Not Suitable; limited by coarse textures and shallow profiles.

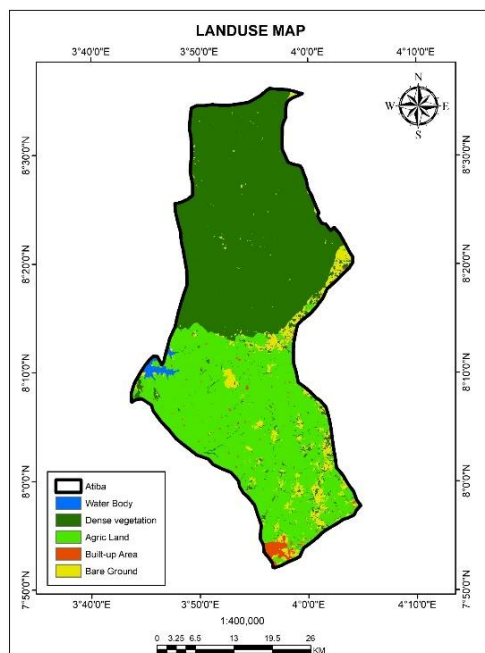


Figure 2: Land Use/Land Cover

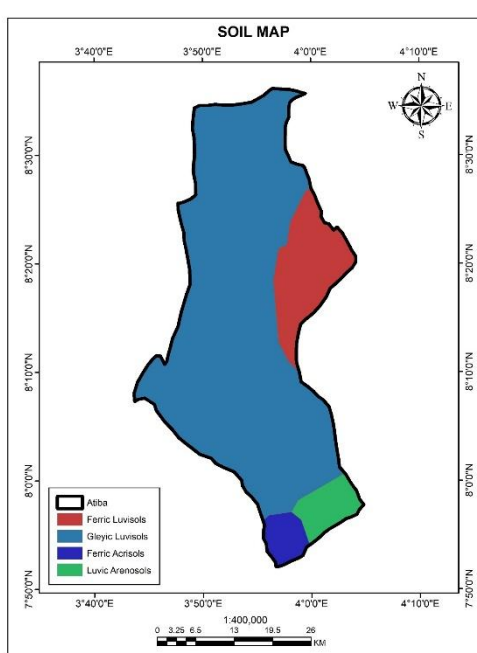


Figure 3: Soil Characteristics

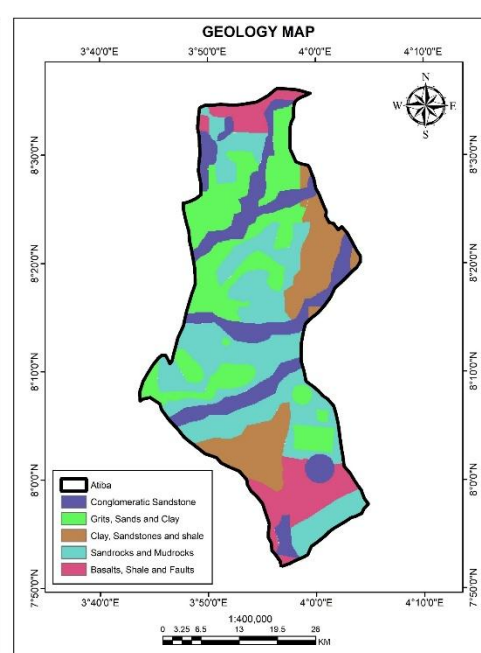


Figure 4: Geology

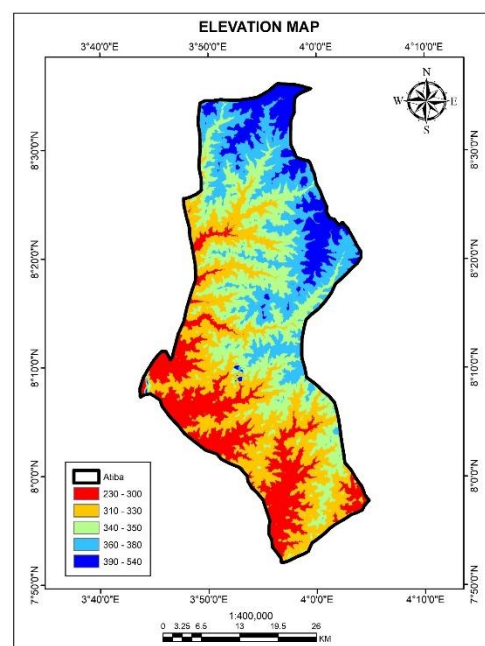


Figure 5: Topography

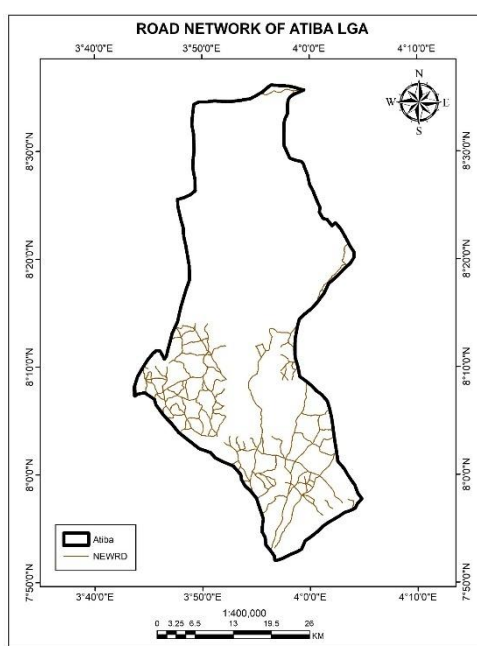


Figure 6: Road Network

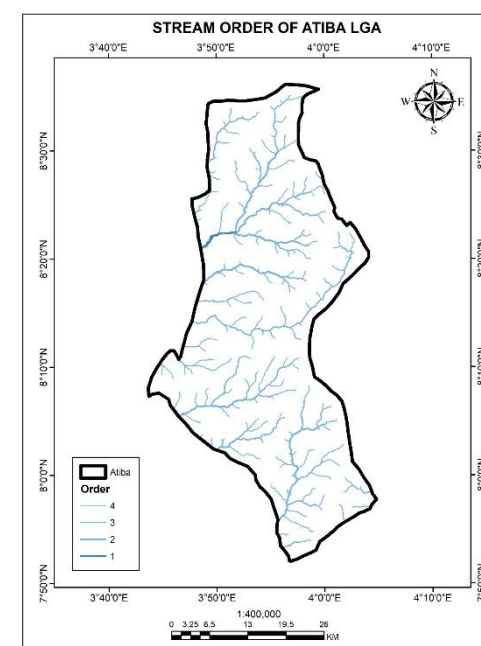


Figure 7: Stream Order

### 3.3 Suitability Assessment Result

The weighted overlay analysis produced a suitability surface across 165,362.91 ha. Results are presented in Table 4 and summarised below. The dominant suitability class is Moderately Suitable (S2), covering 71.99% of the study area, confirming widespread agronomic potential for cassava throughout Atiba LGA.

**Table 4.** Final Suitability Class Result.

Suitability Class	FAO Class	Area (Ha)	Percentage (%)
Highly Suitable	S1	12,490.1	7.55
Moderately Suitable	S2	119,049.0	71.99
Marginally Suitable	S3	30,808.7	18.63
Low Suitability	N1	405.5	0.25
Very Low Suitability	N2	2,608.5	1.58
TOTAL	—	165,362.9	100.00

### 3.4 Spatial Distribution of Suitability Zones

Highly suitable areas ( $S_1$ : 12,490.1 ha, 7.55%) are concentrated in the central zone of the LGA, near the settlements of Aboke, Oseyemi, Aba-Oke, and Ago. These zones are characterised by Ferric Luvisol soils with good drainage, gentle slopes (5–10%), rainfall within the optimal range (3,100–3,700 mm), and proximity (< 500 m) to both road networks and river systems—a favourable convergence of all high-weight criteria.

Moderately suitable land ( $S_2$ : 119,049.0 ha, 71.99%) is broadly distributed across the agricultural belt and areas adjacent to the Old Oyo National Park buffer zone, including the vicinity of Ogungbade. These areas satisfy most agronomic criteria but are moderated by slightly suboptimal soil types or greater distances from road networks. Marginally suitable areas ( $S_3$ : 30,808.7 ha, 18.63%) occur largely along ecotones between the forested northern zone and the agricultural belt, where soil nutrient conditions and drainage constraints begin to limit productivity.

Low and very low suitability areas ( $N_1+N_2$ : 3,014 ha combined, 1.83%) are confined to the vicinity of Osefa, Aba, and Oloko, where a combination of restrictive land use (existing settlements and water bodies), poor drainage, and inadequate road access converges. These areas are effectively unsuitable for cassava cultivation without substantial investment, see figure 7.

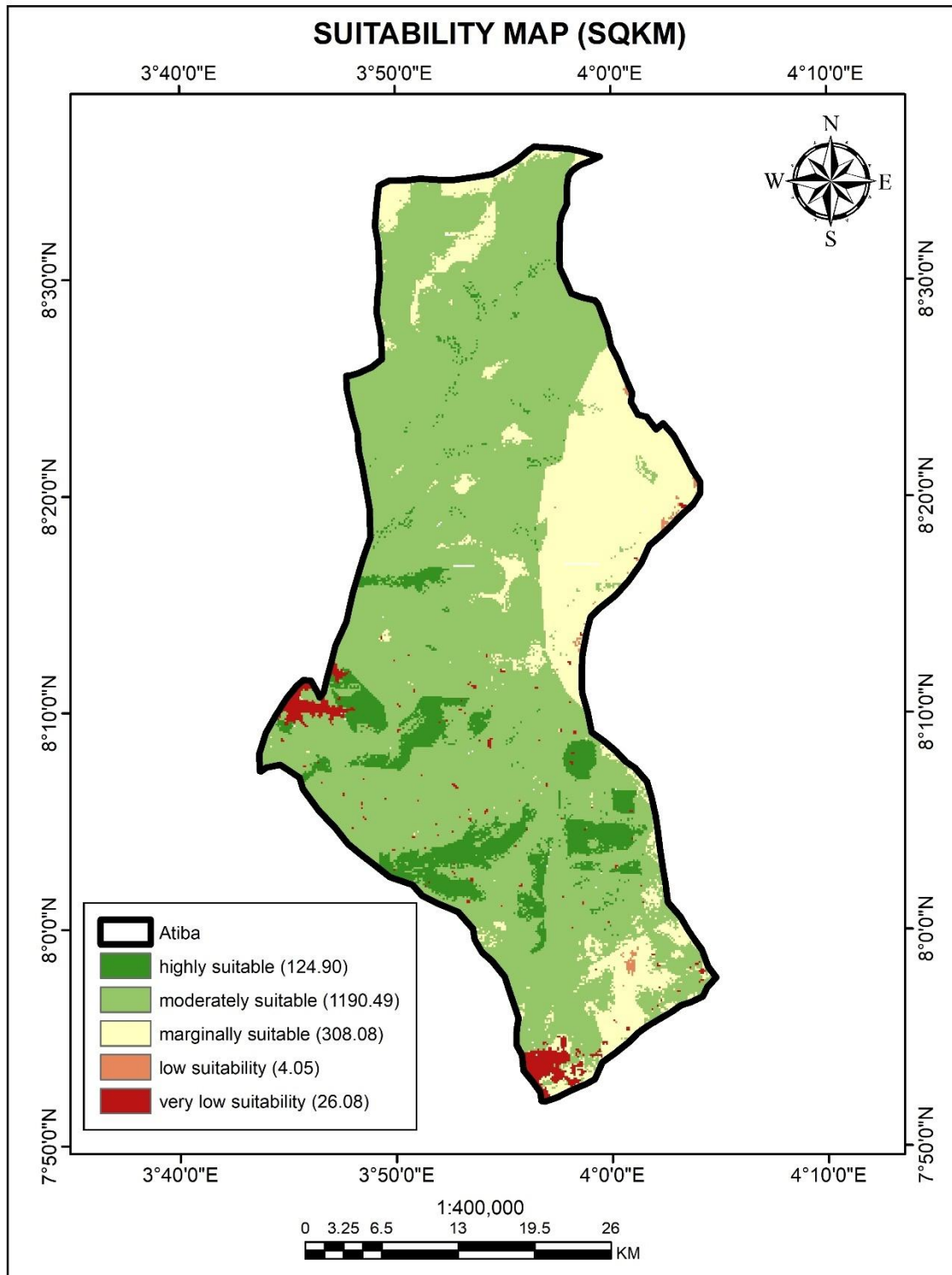


Figure 8. Final Suitability Map

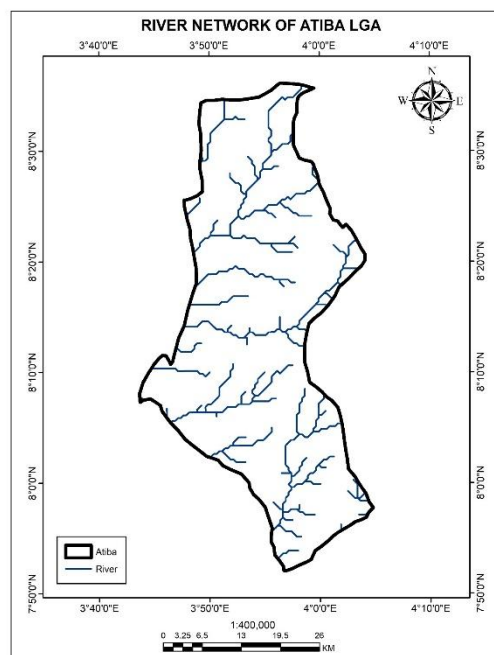


Figure 9. River Network

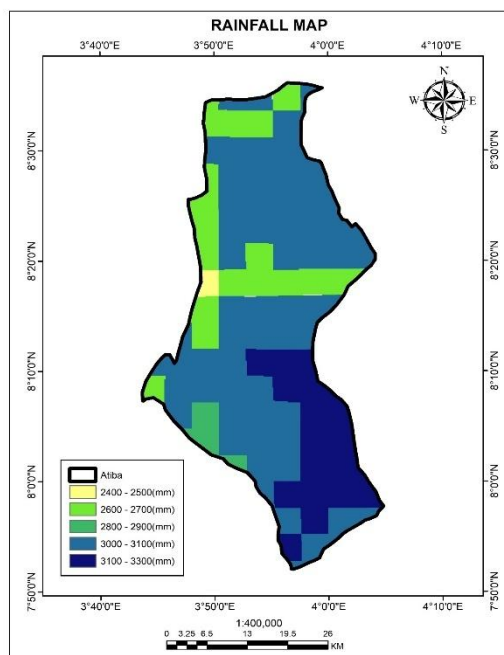


Figure 10. Rainfall

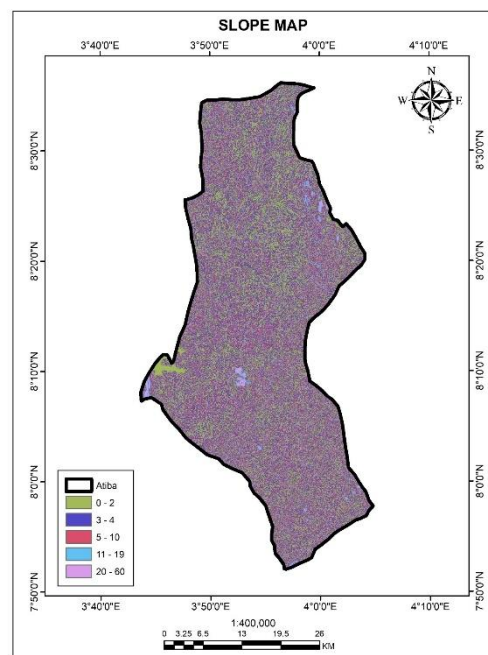


Figure 11. Slope

### 3.5 Discussion

The finding that 79.54% of Atiba LGA is suitable for cassava cultivation ( $S_1 + S_2$ ) represents a significant and actionable result for agricultural planning in Oyo State. The dominance of the Moderately Suitable class indicates that while highly optimal conditions are spatially limited, broad-scale improvement through targeted inputs—particularly fertilisation of Ferric Acrisol and Plinthic Luvisol areas—could shift large portions of  $S_2$  land towards higher productivity, approaching  $S_1$ -class yields.

The high criterion weight assigned to soil type (31%) in the AHP model reflects established agronomic science: cassava yields are strongly constrained by soil texture, drainage, and nutrient availability, particularly nitrogen, phosphorus, and potassium. Sandy loam soils, which characterise much of Atiba LGA's arable belt, support adequate root development but are susceptible to nutrient leaching, consistent with broader findings on cassava soil nutrition in the literature (Oshunsanya & Nwosu, 2018). The integration of geology as the third-highest criterion (15%) captures the role of parent material in determining long-term soil fertility trajectories.

Compared to analogous GIS-AHP suitability studies in Nigeria and across Africa, the result pattern is consistent. Ajala *et al.* (2020) found similar distributions across Kwara State, with moderate suitability dominating. Purnamasari *et al.* (2018), applying a comparable approach in Indonesia, found that spatial proximity to water and roads had less relative weight than soil properties, a finding replicated here. The relatively low weight for road access (4%) in this study reflects cassava's characteristic resilience as a subsistence crop that is cultivated even in less accessible areas, though road proximity remains essential for the commercial cassava value chain.

An important limitation of this study is its exclusive reliance on physical parameters. Chemical soil properties (pH, nutrient content, and organic matter) and biological parameters (pest pressure and mycorrhizal associations) were not incorporated due to data constraints. Future studies should integrate soil laboratory analysis and field validation to refine suitability classifications. Additionally, weather data were interpolated from state-level records at IITA rather than localised weather stations; the establishment of agro-meteorological stations within Atiba LGA would substantially improve the accuracy of rainfall-based suitability modelling.

The study also identifies a scalability advantage inherent in the AHP-GIS framework. The database structure, criterion hierarchy, and analytical workflow can be readily adapted to other cassava-

producing LGAs in Oyo State and beyond, enabling state-wide or national suitability mapping with relatively modest additional data collection effort.

The established biophysical thresholds mirror the ecoclimatic tolerances of cassava (*Manihot esculenta*), while simultaneously accounting for the local geo-environmental realities of Atiba LGA. The optimal slope classification, 5% to 10%, aligns with standard agricultural landscape criteria, ensuring adequate natural surface drainage without triggering severe sheet erosion, a critical consideration given that cassava requires well-drained profiles to mitigate root rot vulnerabilities. Conversely, classifying completely flat terrains 0% to 2% as merely marginal ( $S_3$ ) represents an intentional modelling choice to safeguard against waterlogging conditions common to low-gradient tropical catchments.

The LULC distribution highlights a critical land management trade-off. While 41% 68,260.4 Ha of the LGA is already active agricultural land and highly receptive to optimized cassava production, the dense forest cover 50% in the northern region must be treated as an absolute constraint. Encroaching into these northern forest reserves for cassava cultivation would contradict sustainable development paradigms, meaning agricultural intensification efforts must focus on existing arable lands and viable bare ground (6%).

Edaphically, the soil mapping units present varying levels of suitability for cassava root penetration and bulking. Ferric Luvisols (LF1) offer superior physical properties compared to the shallow Lithosols and sandy Luvic Arenosols present in unit LF 64-1a, which suffer from poor nutrient retention and restricted root zones.

Furthermore, the integration of road network proximity 500m for ( $S_7$ ) resolves a major socio-economic barrier in cassava supply chains. Because harvested cassava roots undergo rapid physiological post-harvest deterioration within 48 to 72 hours, clustering highly suitable zones along transport corridors is necessary to ensure economic viability and reduce post-harvest losses.

The structural distribution of land suitability classes identified within Atiba LGA conforms to regional geographic and edaphic trends observed across similar crop-modeling studies in Nigeria. For instance, the 79% of land categorized as moderately to highly suitable in this study mirrors findings by Akinwole *et al.* (2025) in Southwest Nigeria, where favorable agro-climatic conditions and extensive arable footprints consistently yield high cassava suitability indices.

However, a distinct contrast is evident when comparing these results to more restricted agro-ecological zones. In the hydromorphic and coastal terrains of Southern Cross River State, Ofem *et al.* (2025) noted that a significant percentage of land is limited to marginal suitability ( $S_3$ ) or deemed temporarily non-suitable ( $N_1$ ) due to severe soil drainage impediments and prolonged waterlogging, which trigger root rot. Similarly, in the semi-arid northern reaches of Nigeria, land suitability is often constrained by truncated rainfall windows and coarse soil textures (Seko *et al.*, 2022).

The comparatively higher suitability percentages achieved in this study underscore that while edaphic parameters (such as the Ferric Luvisols found in mapping unit LF1) dictate local yield boundaries, the combination of favorable topographic positioning (5% to 10% slopes) and a high proximity to transportation networks remains the primary driver for optimizing highly viable ( $S_7$ ) cassava production zones in the sub-region.

### 3.5.1 Chronological Anomalies and Agronomic Suitability Alignments

A notable point of discussion is the high localized rainfall maximum (3,100 to 3,700mm) recorded within the study area during the 2021–2022 temporal window. From an agronomic standpoint, cassava (*Manihot esculenta*) is classically categorized as a drought-tolerant crop with an optimal annual precipitation baseline spanning 1,000 to 2,000mm. Sustained precipitation exceeding 2,500mm typically poses an edaphic threat by inducing sub-surface waterlogging, which accelerates root rot and severely hinders tuberous root bulking. The hyper-humid spikes observed in our raw meteorological dataset represent a distinct macro-climatic anomaly specifically driven by the multi-year regional *La Niña* phase of 2021–2022 rather than the stable historical climatology of Oyo State.

Consequently, while these short-term empirical spikes forced localized departures from standard crop tolerance profiles, the multi-criteria evaluation matrix was intentionally calibrated against established FAO bioclimatic thresholds. This adjustment ensures that the final predictive suitability map reflects long-term geographical realities rather than transient, interannual weather extremes.

#### 4. CONCLUSION

This study has demonstrated that GIS-integrated AHP multi-criteria analysis is a robust, reproducible, and cost-effective tool for agricultural land suitability assessment at the local government scale. Over 79% of Atiba LGA (131,539 ha) is agronomically suitable for cassava production, confirming the significant unrealised agricultural potential in the area. Soil type is the dominant determinant of cassava land suitability (weight: 31%), followed by land use/land cover (22%) and geology (15%), in line with agronomic evidence. Highly suitable zones (S1: 12,490 ha) are concentrated in the central agricultural belt near Aboke, Oseyemi, and Ago, providing specific priority sites for intensified production investment. The AHP-GIS methodology, with a consistency ratio of 0.06, provides a scientifically credible and replicable framework transferable to other cassava-producing regions of Nigeria. Future research should incorporate chemical and biological soil parameters, field validation surveys, and time-series LULC change analysis to further refine and update the suitability model. While this study establishes a robust regional framework for land suitability mapping using the Analytical Hierarchy Process (AHP), a primary limitation remains the exclusion of fine-scale soil chemical dynamics, such as pH, macronutrient (NPK) availability, and organic matter fractions, which directly influence crop physiological yield. To bridge this gap, future iterations of this research should evolve into an integrated, multi-tier agro-ecological decision support tool. This can be achieved by coupling the regional macro-scale AHP terrain surface model developed herein with high-resolution digital soil databases, such as localized SoilGrids or regional African Soil Information Service (AfSIS) products, to account for baseline edaphic variations. Furthermore, to move toward real-time precision agriculture, future workflows should ingest localized, high-frequency data streams from proximal soil sensing instruments, including portable near-infrared (NIR) spectrometers and mobile electrochemical sensors. Dynamically updating the GIS-based multi-criteria matrix with these real-time soil chemistry variables will transform the static suitability map into a predictive, precision-driven decision support system capable of guiding farmers on site-specific fertilizer application, soil amendment protocols, and sustainable crop management.

##### 4.1 Policy Implications for Regional Agricultural Planning and Value-Chain Development

The spatial disparities and suitability configurations mapped in this study offer a data-driven framework for strategic agricultural planning by the Oyo State Ministry of Agriculture and Rural Development. By isolating highly suitable ( $S_1$ ) zones alongside infrastructural and ecological constraints, this model supports three critical policy interventions: first, prioritizing the zoning of micro-processing centers within high-suitability clusters along transport corridors to mitigate the rapid 48-to-72-hour post-harvest deterioration of cassava roots; second, promoting sustainable agricultural intensification on existing active cropland (41%) using biofortified inputs optimized for dominant Ferric Luvisols, thereby safeguarding the northern forest reserves (50%); and third, implementing agro-ecological risk management by restricting agricultural investments and financing in non-suitable ( $N$ ) zones prone to excessive slopes or poor drainage, thereby maximizing regional economic and ecological returns.

##### 4.2 Study Limitations and Temporal Considerations

While the biophysical and socio-economic criteria mapped in this study provide a high-fidelity baseline for current cassava suitability, the utilization of a short-term rainfall dataset (2021–2022) introduces localized temporal limitations. Precipitation patterns within the sub-region exhibit prominent interannual and decadal variability, often influenced by global macro-climatic anomalies such as the multi-year *La Niña* phase characterising the 2021–2022 window. According to World Meteorological Organization (WMO) standards, a 30-year climatological baseline is ideal to capture long-term precipitation trends and cyclical extreme events. Consequently, the rainfall thresholds modelled herein should be interpreted as a contemporary snapshot of agro-ecological suitability rather than an immutable long-term projection. Future iterations of this suitability model will integrate multi-decadal downscaled climate data and predictive climate change scenarios to evaluate how shifting precipitation regimes will impact cassava distribution over extended temporal horizons.

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