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Original Research Article

GIS-Based Land Suitability Assessment for Rice Cultivation in *Rafin Kada* Floodplains, *Wukari*, Nigeria

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Abstract

Sustainable rice intensification in tropical floodplains requires precise evaluation of land resources to guide expansion and management decisions. This study integrated Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP) to assess land suitability for rainfed rice (Oryza sativa) cultivation in the *Rafin Kada* Floodplain, Taraba State, Nigeria. Eleven criteria, including soil physical and chemical properties, topography, climate, and remote-sensing indices, were standardised and weighted to generate a composite suitability map. Rainfall (0.258) and temperature (0.184) received the highest AHP weights, reflecting their controlling influence on paddy systems in tropical environments. Texture (0.142), depth (0.098), and slope (0.064) followed in importance, while chemical attributes such as pH and CEC were uniform but critical to long-term soil fertility. The results showed that 27% (220.5 ha) of the area was highly suitable (S1), 46% (379.4 ha) moderately suitable (S2), and 27% (224.6 ha) marginally suitable (S3), with constraints primarily related to drainage, CEC, and NDVI variability. Sensitivity analysis showed strong model stability, with the S1 class remaining unchanged under 20% weight variation and spatial disagreement limited to 0.2% of the study area. The integration of NDVI and TWI improved the spatial representation of vegetation vigour and wetness conditions beyond conventional FAO guidelines, confirming that combining GIS and AHP can effectively reveal spatial heterogeneity even within physiographically uniform floodplains. The study recommends targeted management interventions, such as bunding, drainage improvement, and organic matter incorporation, to enhance marginal areas. Future research should integrate multi-seasonal remote sensing data and machine learning to improve predictive reliability across tropical lowland systems.

Keywords: Analytical Hierarchy Process, Decision-support system, Land evaluation, Remote sensing indices, Rice productivity, Soil fertility.

INTRODUCTION

In Nigeria, where rice (*Oryza sativa*) is both a staple and a strategic food crop, inadequate assessment of land suitability continues to hinder efforts toward achieving self-sufficiency. Despite being Africa's leading rice producer, domestic output still barely meets half of national demand (Musa et al., 2024). Expansion of cultivation areas alone cannot guarantee increased yields unless guided by a clear understanding of the agro-ecological conditions that determine crop performance. Identifying lands that are inherently suitable for rice production is therefore central to sustainable agricultural planning and food security.

Land suitability evaluation provides a scientific basis for determining how well land characteristics meet crop requirements (Food and Agriculture Organization [FAO], 2016). In rice-based systems, productivity is governed largely by soil texture, drainage, pH, and cation exchange capacity (Xue et al., 2023; Maniyunda and Ya'u, 2023), alongside climatic variables such as rainfall and temperature that regulate water availability. Recent advances in remote sensing, including the Normalised Difference Vegetation Index (NDVI) and Topographic Wetness Index (TWI), now enable the integration of vegetation and hydrological dynamics into suitability assessments, especially in floodplain environments where field data are often limited (Zhang et al., 2017; Xue et al., 2023).

However, rice expansion in Nigeria still relies heavily on traditional land-selection practices, often lacking quantitative geospatial analysis to support efficient land use. This has led to uneven productivity, underutilization of fertile floodplains, and the cultivation of marginal lands prone to degradation. The integration of field observations with Geographic Information System (GIS) techniques provides a robust means of overcoming this challenge by combining spatial data layers into objective, reproducible suitability maps (Haripavan et al., 2025).

The Analytic Hierarchy Process (AHP), a multi-criteria decision-making (MCDM) approach, enhances this integration by assigning relative weights to environmental factors based on expert judgment and literature-based rankings (Ho, 2008; Akıncı et al., 2013). When combined with GIS, AHP enables spatial prioritisation of land resources, thereby improving agricultural decision-making and policy formulation (Xue et al., 2023).

Rafin Kada, located within the *Wukari* province of *Taraba* State, encompasses extensive floodplains that offer significant potential for irrigated rice production. Yet, no detailed spatial assessment has been conducted to evaluate its land suitability for rice cultivation. Previous GIS-AHP studies have focused primarily on the northern plains of *Kudan* LGA in *Kaduna* State and other regions (Sadiq et al., 2023), leaving the *Rafin Kada* Floodplains largely unassessed. This research therefore addresses this empirical gap by providing the first spatially explicit rice-suitability evaluation for the region, offering local-scale evidence to guide sustainable agricultural intensification and land-use planning. The novelty of this work is reflected in its refined GIS-AHP framework, which integrates high-resolution remote-sensing indices with field-validated soil and climatic parameters to deliver a more detailed assessment of floodplain agro-ecology than previous studies. In addition, the incorporation of TWI and vegetation metrics into the weighting process

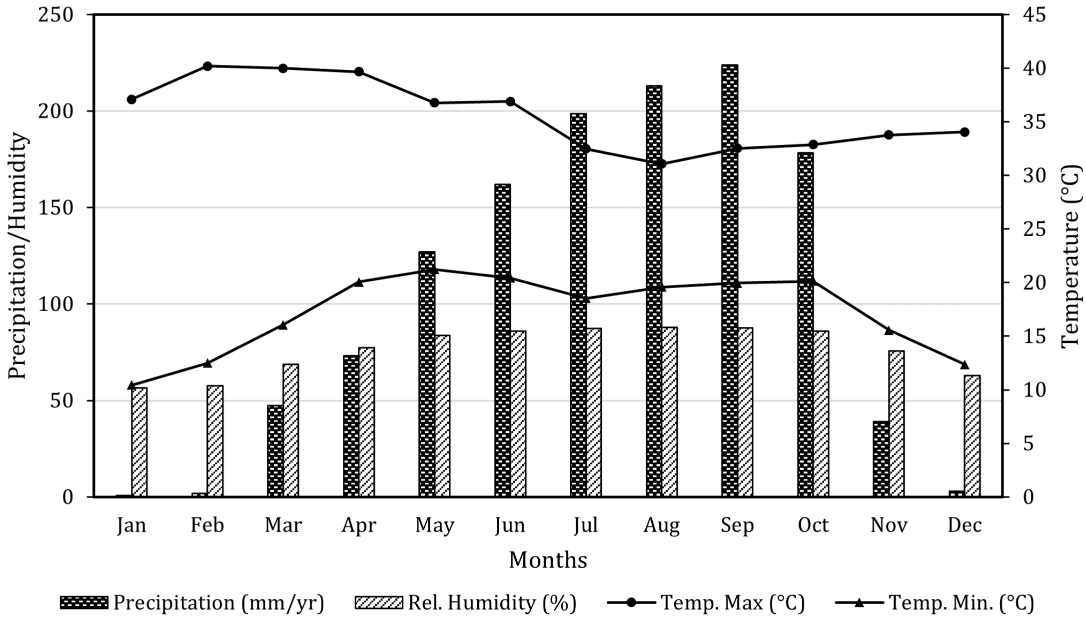


Figure 1: Climatic variables of *Rafin Kada* (1994–2024).
Source: NASA Prediction of Worldwide Energy Resources (POWER) database, averaged for coordinates 9.87°N, 7.70°E. Dataset represents long-term mean annual rainfall, temperature, and relative humidity derived from satellite-based reanalysis (1994–2024).

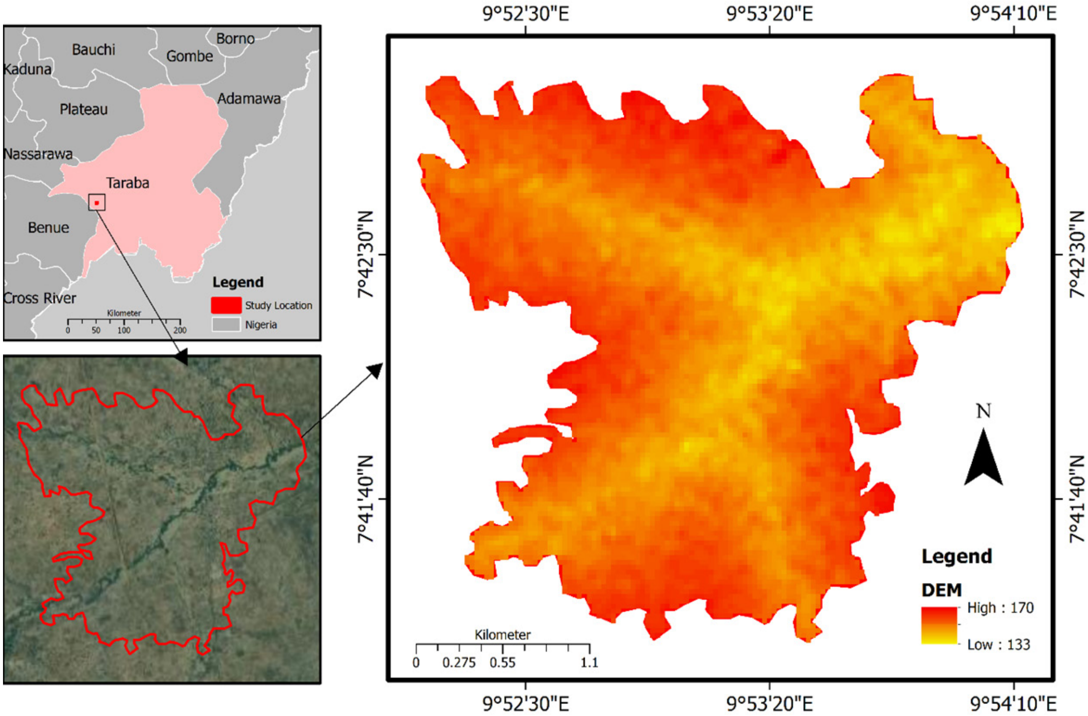


Figure 2: Location and digital elevation model (DEM) of the study area.
Source: Shuttle Radar Topography Mission (SRTM 30 m DEM, United States Geological Survey [USGS], 2024) and authors' GPS-based field boundary delineation (2025). Authors' GIS processing (2025) based on Shuttle Radar Topography Mission (SRTM 30 m Digital Elevation Model) data obtained from the USGS Earth Explorer, combined with administrative boundary data from GADM database of Global Administrative Areas (2024) and base map imagery from Esri World Imagery.

enables the development of a hydrologically responsive suitability model not previously applied in the region.

This study is guided by the hypothesis that integrating soil, climatic, and remote-sensing parameters through the AHP will reveal spatial heterogeneity in land suitability across the *Rafin Kada* Floodplains, despite their apparent physiographic uniformity. The objectives are to characterise the soil physical and chemical properties affecting rice production across the floodplain, integrate climatic, topographic, and remote-sensing datasets with these field observations, and develop a GIS-AHP based model to delineate land-suitability zones for sustainable rice production in *Rafin Kada*.

MATERIAL AND METHODS

Study Area

Rafin Kada is located in *Wukari* Local Government Area of *Taraba* State, Nigeria, within the tropical savanna climate zone. It lies less than 15 km from *Donga* town, near the *Wukari–Donga* boundary. The area experiences distinct wet and dry seasons that strongly influence agricultural practices (Awwal et al., 2025). Long-term climatic data (1994–2024) show an average annual rainfall of about 1,268 mm, concentrated between May and October, with relative humidity ranging from 50% to 78% and a mean annual temperature of approximately 26 °C (Figure 1).

The study area extends from 9°52′8.01″ N, 7°43′6.95″ E to 9°54′12.01″ N, 7°41′10.95″ E, covering 824.5 ha. Its relief is low and gently undulating, with elevations generally below 250 m above sea level (Figure 2). The floodplain soils, developed from alluvial deposits and subject to seasonal inundation, provide favourable conditions for rice cultivation. Agriculture dominates local livelihoods, with rice, maize, and guinea corn being the principal crops.

Field Survey and Soil Sampling

The study area was surveyed and subdivided into mapping units based on physiographic characteristics such as elevation and drainage. Two soil profile pits were excavated in each mapping unit, resulting in six representative profiles across the floodplain (Figure 3). Although this density is relatively low, it was considered adequate because of the area's minimal topographic variation and homogeneous parent material. Each profile therefore represented a distinct physiographic zone with internally consistent soil conditions. Soils were described in situ following United State Department of Agriculture (USDA) procedures

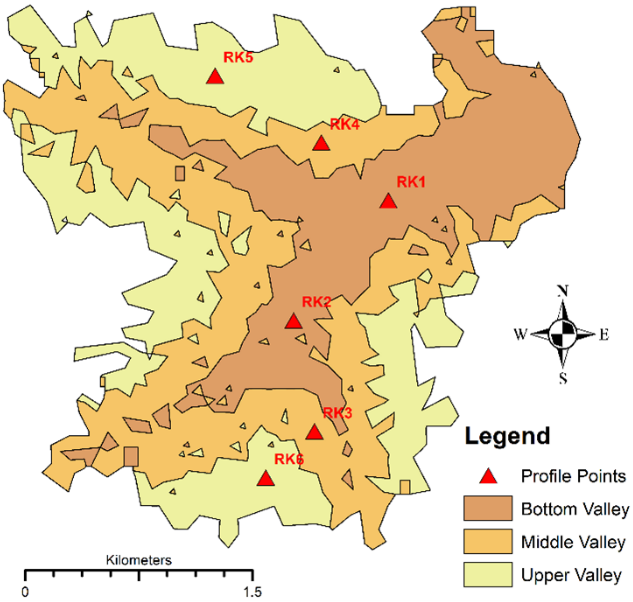


Figure 3: Mapping units and soil profile pit locations in the study area.
Source: Authors' field survey (2025). Mapping units delineated from SRTM-derived elevation and drainage layers validated through ground observation.

(USDA, 2017), and samples were collected from all genetic horizons for laboratory analysis.

Soil Physical and Chemical Analysis

Soil samples were air-dried, crushed, and sieved through a 2 mm mesh prior to analysis. Particle-size distribution (sand, silt, and clay) was determined using the hydrometer method, and texture classes were identified according to the USDA textural triangle. Soil pH was measured in a 1:2.5 soil-to-water suspension using a pH meter. Cation exchange capacity (CEC) was determined by the ammonium acetate (NH_4OAc) method at pH 7, while exchangeable bases (Ca, Mg, K, and Na) were extracted with 1 N NH_4OAc and quantified using atomic absorption spectrophotometry. Sodium adsorption ratio (SAR) was calculated from ion concentrations expressed in mmol L^{-1}, and soil organic carbon (SOC) was determined using the Walkley-Black

Table 1. Land characteristics and suitability criteria for rice cultivation.

Factor	S1 (100)	S2 (85)	S3 (60)	N (40)
Climate (*c*)				
Annual rainfall (mm)	>1200	1000–1200	800–1000	<800
Mean Temperature (°C)	27–32	22–27	15–-22	<15
Soil Physical Characteristics (*s*)				
Effective soil depth (cm)	>100	75–100	50–75	<50
Texture Class	C, CL, SC, SiC	SCL, SiL, L	SL, LS	S
Slope (%)	0-1	1 3	3 5	>5
Soil Chemical Status (*f*)				
pH	5.2–7.5	5.0–5.2 7.5–8.0	4.5–5.0 8.0–8.5	<4.5 >8.5
CEC (cmol (+) kg^{-1})	>20	12–20	6–12	<6
Soil toxicity (*t*)				
Salinity (ECe) (dSm^{-1})	<3	3–6	6–10	>10
SAR (mmol/L)	<3	3–6	6–10	>10
Remote Sensing Indices (*r*)				
NDVI	>0.5	0.3–0.5	0.1–0.3	<0.1
TWI Value	>10	7–10	4–7	<4

Source: Adapted and modified from Sys et al. (1993) and Xue et al. (2023). **Note:** S1 – Highly suitable; S2 – Moderately suitable; S3 – Marginally suitable; N1 – Not suitable; C – clay; L – loam; S – sand; Si – silt; NDVI – Normalised Difference Vegetation Index; TWI – Topographic Wetness Index.

Table 2. Summary of Datasets used for the Suitability Assessment and their Sources

Data Type	Resolution / Formula	Date/Coverage	Source
Climate data	gridded reanalysis data	1994–2024 (long-term mean)	NASA POWER (https://power.larc.nasa.gov/data-access-viewer/)
DEM	30 m spatial resolution	2024	USGS Earth Explorer (SRTM) (https://earthexplorer.usgs.gov/)
Landsat-8 OLI Imagery	30 m multispectral (path 187, row 54)	August, 2024	USGS Earth Explorer (https://earthexplorer.usgs.gov/)
Slope	30 m resolution	2024	Derived from DEM
NDVI	$= ln\left(\frac{A}{\tan\beta}\right)$	August, 2024	Derived from Landsat imagery
TWI	$= ln\left(\frac{A}{\tan\beta}\right)$	2024	Derived from DEM
Soil data	Field and laboratory analyses	2024	Field survey by authors

Note: DEM – Digital Elevation Model; NDVI – Normalized Difference Vegetation Index; TWI – Topographic Wetness Index. B4 – Band 4, B8 – Band 8; A – upslope contributing area (m^2); β – the slope angle (radians). NASA POWER – National Aeronautics and Space Administration Prediction of Worldwide Energy Resources SRTM – Shuttle Radar Topography Mission; USGS – United States Geological Survey

oxidation method. All analyses followed standard procedures outlined by Uyovbisere et al. (2013).

Suitability Criteria and Mapping

Land suitability for rice cultivation was assessed using five factor groups: (i) climatic factors (c: rainfall, temperature), (ii) soil physical properties (s: texture, slope, drainage), (iii) soil chemical status (f: pH, CEC), (iv) soil toxicity indicators (t: EC, SAR), and (v) remote-sensing indices (r: NDVI, TWI). Following the FAO land evaluation framework. Each factor was classified into four suitability categories viz: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N1).

The inclusion of remote-sensing indices improved the spatial precision of the assessment by capturing vegetation vigour and surface moisture gradients that influence rice growth. Class definitions for conventional soil and climatic parameters were adapted from Sys et al. (1993), while NDVI thresholds were derived from vegetation-productivity relationships (Qiu et al., 2015). TWI classes were established based on topographic moisture gradients relevant to paddy suitability as described by Gracia et al. (2024) and Lu et al. (2025). The suitability criteria ratings adopted in this study are summarised in Table 1.

Remote-Sensing Derivatives

Satellite and elevation data were processed in ArcGIS environment. Landsat-8 OLI imagery (path 187, row 54) acquired in August 2024, representing the peak vegetative stage of the wet season, was used to compute NDVI, while SRTM DEM data were used to generate TWI. The summary of data used for this study is presented in Table 2. Raster layers for all suitability criteria were subsequently reclassified according to the thresholds defined in Table 1.

AHP Weighting and Overlay Procedure

Prior to geospatial integration, weights were assigned to each suitability factor using the AHP. AHP is a multi-criteria decision-making technique that systematically assigns relative weights to factors based on expert judgment and pairwise comparisons, enabling objective evaluation and prioritisation of complex criteria (Saaty, 1980). In this study, pairwise comparisons were conducted among all criteria using the Saaty (1–9) scale, where a score of 1 indicates equal importance and 9 represents extreme importance of one factor over another (Saaty, 1980). The pairwise judgments were informed by expert consultation and previous AHP-based agricultural suitability studies (Akıncı et al., 2013; Xue et al., 2023). The resulting pairwise comparison matrix (Table 3) served as the foundation for weight derivation.

The matrix was then normalized by dividing each cell by the column sum, followed by averaging the rows to obtain the priority weights for each criterion. The Consistency Index (CI) and Consistency Ratio (CR) were calculated to test logical coherence among judgments, using Equations (1) and (2).

$$CI = \frac{\lambda max - n}{n-1} \quad \text{Equation (1)}$$

Where, λ max represents the largest eigenvalue of the pairwise comparison matrix, n denotes the number of classes, and

Table 3. Pairwise Comparison Matrix for Rice Suitability Criteria in *Rafin Kada*

Criteria	Rainfall	Temp.	Texture	Depth	Slope	TWI	NDVI	EC	pH	CEC	SAR
Rainfall	1	2	3	4	5	5	6	4	5	6	6
Temp.	0.5	1	2	3	4	4	5	3	4	5	5
Texture	0.33	0.5	1	3	3	4	4	3	3	4	4
Depth	0.25	0.33	0.33	1	3	3	3	2	3	3	3
Slope	0.2	0.25	0.33	0.33	1	2	2	2	2	2	2
TWI	0.2	0.25	0.25	0.33	0.5	1	2	2	2	2	2
NDVI	0.17	0.2	0.25	0.33	0.5	0.5	1	2	2	2	2
EC	0.25	0.33	0.33	0.5	0.5	0.5	0.5	1	2	2	2
pH	0.2	0.25	0.33	0.33	0.5	0.5	0.5	0.5	1	2	2
CEC	0.17	0.2	0.25	0.33	0.5	0.5	0.5	0.5	0.5	1	2
SAR	0.17	0.2	0.25	0.33	0.5	0.5	0.5	0.5	0.5	0.5	1

Source: Authors' computation (2025) using expert judgment supported by literature-based rankings

$$CR = \frac{CI}{RI} \quad \text{Equation (2)}$$

Where RI refers to the ratio index over the average value of CI for random matrices, as determined using the Saaty scale (Ho, 2008). Finally, all weighted and standardised raster layers were integrated in ArcGIS using the Weighted Linear Combination (WLC) technique to produce the composite rice suitability map for the *Rafin Kada* floodplains.

Calculation of Area Proportions

After the weighted overlay, all reclassified suitability maps were analysed to determine the spatial extent of each suitability class (S1, S2, S3, and N1). Area statistics were computed in ArcGIS using spatial analysis tools such as "Zonal Statistics as Table" and "Calculate Geometry" to quantify the total land area (in hectares) occupied by each class. The proportional distribution of each class was then calculated as:

$$Percentage = \left(\frac{Area\ of\ class}{Total\ area}\right) \times 100 \quad \text{Equation (3)}$$

These computed proportions formed the basis of the suitability statistics presented in the Results section.

Sensitivity Analysis and Model Validation

To evaluate the stability of the Multi-Criteria Decision-Making (MCDM) results and address the inherent subjectivity associated with the AHP weightings, a spatial sensitivity analysis was performed. A "One-at-a-Time" (OAT) sensitivity approach was adopted, focusing on the five most influential criteria, which accounted for around 75% of the model's total weight. These weights were systematically perturbed by adding and subtracting 20% from their original values. To maintain the fundamental requirement of the AHP, where $\Sigma(wi) = 1.0$, the weights of the remaining criteria were adjusted proportionally using the following formula:

$$w'_j = (1 - w'_i) \times \frac{w_j}{1 - w_i} \quad \text{Equation (4)}$$

Where *w'i* is the perturbed weight of the target criterion, *w'j* is the original weight of the *j-th* criterion, and *w'j* is its new normalised value. The Weighted Overlay tool within the GIS environment was re-executed for both the +20% and −20% weight scenarios. The resulting raster layers were then compared to the baseline suitability map to quantify the shift in land area across the suitability classes. Finally, the Cell Statistics tool was employed to calculate the pixel-by-pixel level of agreement between the extreme scenarios and identify areas where the suitability classification differed (disagreement) or remained identical across weight variations (agreement).

RESULTS AND DISCUSSIONS

Soil Physical Properties

The soils of *Rafin Kada* show distinct textural variations across the floodplain (Table 4). Profiles in the middle and bottom valleys (RK 1 to RK 4) are dominated by clay loam (CL) and clay (C) textures, whereas the upper valley profiles (RK 5 and RK 6) are sandy clay loam (SCL) and clay loam (CL) in the surface horizons. Higher clay content in the middle and lower valleys (37.4–46%) enhances water retention and nutrient-holding capacity, which is critical for paddy rice systems (Xue et al., 2023). In contrast, upper valley soils with higher sand content (47.7–48.2%) have lower water-holding capacity and indicating a need for water management interventions (Qusai et al., 2025).

Table 4. Soil Properties Relevant to Rice Suitability Analysis in *Rafin Kada*, Taraba State

Horizon	Depth (cm)	Sand	Silt (%)	Clay	Texture Class	pH	EC (dS m⁻¹)	CEC (cmol kg⁻¹)	SAR (mmol L⁻¹)
RK 1: Bottom Valley (9° 53′ 30.96″ N, 7° 42′ 25.28″ E)									
Ap	0–32	35.1	27.5	37.4	CL	6.79	0.11	10.15	1.25
Bg	32–56	32	26	42	C	6.6	0.11	11.2	1.3
BCg	56–89	30	24	46	C	6.5	0.12	12.8	1.38
2BCg	89–145	35.2	25	39.8	CL	7.1	0.12	12.1	1.5
RK 2: Bottom Valley (9° 53′ 10.73″ N, 7° 41′ 59.63″ E)									
Ap	0–35	40.2	26	33.8	CL	6.6	0.13	11.5	1.3
Bwg	35–78	38	25	37	CL	6.8	0.15	12.3	1.38
BCg	78–110	36.2	27.3	36.5	CL	7.1	0.1	12.8	1.21
2BCg	110–150	35	28.4	36.6	CL	7.2	0.14	12.8	1.1
RK 3: Middle Valley (9° 53′ 15.17″ N, 7° 41′ 35.95″ E)									
Ap	0–20	36.8	27.2	36	CL	6.56	0.1	10.69	1.28
Bg	20–57	34	25	41	C	6.4	0.12	11.8	1.33
BCg	57–121	32	22	46	C	6.3	0.14	12.5	1.4
RK 4: Middle Valley (9° 53′ 16.65″ N, 7° 42′ 37.61″ E)									
Ap	0–21	42	22.5	35.5	CL	6.22	0.12	9.24	1.3
Bt	21–45	40.1	21.5	38.4	CL	6.78	0.12	10.24	1.5
Btg	45–92	38	18	44	C	6.83	0.21	12.43	1.6
Bt2	92–132	41	19	40	C	7.1	0.2	12.23	1.34
RK 5: Upper Valley (9° 52′ 53.96″ N, 7° 42′ 51.91″ E)									
Ap	0–18	47.7	22.6	29.7	SCL	7.1	0.12	10.5	1.32
Bt	18–45	40	20	40	C	6.9	0.15	11.5	1.38
Btc	45–132	38	18	44	C	6.8	0.18	12	1.45
RK 6: Upper Valley (9° 53′ 4.81″ N, 7° 41′ 26.09″ E)									
Ap	0–25	48.2	24	27.8	SCL	6.8	0.09	9.87	1.23
Bt	25–69	43	22.3	34.7	CL	6.5	0.12	10.4	1.38
Btw	69–126	44	22.4	33.6	CL	6.6	0.18	13.1	1.45

Notes: EC = electrical conductivity; CEC = cation exchange capacity; SAR = sodium absorption ration; Textural Notations = C – Clay; L – loam; S – Sand. **Source:** Authors' Field and Laboratory Analysis (2025)

Soil Chemical Properties

Soil pH range across all profiles were neutral to slightly acidic (6.22 to 7.2). This range is optimal for rice growth, as rice thrives in slightly acidic to neutral conditions where nutrient availability remains high (Awwal and Maniyunda, 2023). The comparatively lower pH values (6.22) in the Ap horizon of the middle valley suggest possible leaching of basic cations in this position, which may require periodic evaluation to maintain soil fertility over time. Generally, pH was noted to increase with increasing depth down the profile, indicating a potential accumulation of basic cations which may contribute to long-term soil buffering capacity (Kicińska et al., 2022). No pH values below 5.5 were recorded, implying negligible risk of aluminium toxicity, which typically constrains root growth in more acidic tropical soils (de Moraes et al., 2023).

The CEC values in the study area ranged between 9.24 and 13.1 cmol kg⁻¹, with a consistent trend of higher CEC in subsurface horizons, particularly in profiles with higher clay content, which is a trend noted in many tropical soils (Awwal, 2021). Cation exchange capacity is a crucial index for nutrient availability in paddy rice. Therefore, periodic incorporation of organic matter, such as compost or crop residues, may be necessary to sustain long-term soil fertility in these areas.

Soil Toxicity Indicators

The EC values presented in Table 4 are consistently low, ranging from 0.09 to 0.21 dS m⁻¹ across the study area. This implies that salinity is not a constraint in these soils. Rice is moderately salt-sensitive, with yield reductions occurring at EC levels above 3 dS m⁻¹ (Chen et al., 2021). The observed low EC values across all profiles indicate a generally non-saline environment; however, the slightly higher values in deeper horizons of the middle valley position, reaching 0.21 dS m⁻¹ suggest possible salt accumulation, which should be monitored, especially under prolonged flooded conditions.

The SAR values are consistently low (1.1 to 1.6 mmol L^{-1}), indicating that sodium is not a significant threat to soil structure or permeability. In rice-growing regions, SAR values above 13 mmol L^{-1} can lead to sodic conditions, affecting soil aeration and root penetration (Peng et al, 2025). The consistently low SAR across all profiles confirms that these soils are well-suited for rice production without an immediate need for intervention. These combined results place the floodplain within an optimal range of chemical and salinity tolerance for rice, supporting its classification as S1 for EC and SAR.

Suitability Criteria and Spatial Mapping

The reclassified suitability maps (Figure 4) illustrate the spatial distribution of climatic, soil, and remote-sensing parameters influencing rice production.

Climatic Suitability of *Rafin Kada* for Rice Production

Rainfall (1,268 mm yr^{-1}) and mean temperature (26.3 °C) both classified as S1 (highly suitable) across the entire study area. The uniformity of these parameters suggests climatic conditions are not limiting factors in the region. In tropical systems where irrigation infrastructure is often limited, rainfall serves as the primary water source for maintaining the shallow flooded conditions necessary for paddy development. Continuous water availability enhances nitrogen mineralisation, suppresses weed competition, and stabilises soil temperature, all of which contribute to higher yields (Rosenberg et al., 2025). Similarly, the annual mean temperature of 26.3°C places the entire area in the S1 category based on the suitability criteria (Table 1), reinforcing the region's climatic suitability for rice production.

Soil Property Suitability for Rice Production in *Rafin Kada*

Soil texture was rated highly suitable (S1) for approximately 599.3 ha (73%) of the area, while 27% were moderately suitable (S2) due to higher sand content and reduced moisture retention potential (Figure 4c, Weil and Brady, 2017). Slope analysis showed that 52% of the area was flat (S1), and 48% moderately sloping (S2), implying minimal erosion risk and favourable conditions for surface water management through bunding (Figure 4d, Patil et al., 2011).

Since rice thrives in flat or gently sloping areas, regions classified as S2 may require water management strategies such as bunding to mitigate runoff and erosion (Patil et al., 2011). Soil depth exceeded 100 cm throughout the floodplain, classifying as S1, consistent with deep alluvial soils favourable for rice rooting and nutrient storage (Figure 4e, Obasi and Obasi, 2022).

For soil cation exchange capacity (CEC), the entire area falls under S3, indicating marginal nutrient-holding capacity. While lower CEC may reduce nutrient retention, it also minimises fertiliser leaching, a factor beneficial for rice production. Other properties, such as soil pH sodium adsorption ratio (SAR), and electrical conductivity (EC), were not limiting for rice growth and were equally categorised as S1 (Figure 4).

Their consistently low values across the floodplain suggest minimal salinity and sodicity risks, indicating that the soils maintain a favourable ion balance and permeability essential for stable root respiration and nutrient exchange under flooded conditions.

Vegetation and Hydrological Indices

NDVI results showed 487.3 ha (59%) of the area as S1, 313.9 ha (39%) as S2, 15.6 ha (2%) as S3, and 7.7 ha (1%) as N1. The few low-NDVI areas likely reflect fallow or degraded land. TWI results indicated that 4.95 ha (1%) were S1, 27.3 ha (3%) were S2, and 792.25 ha (96%)

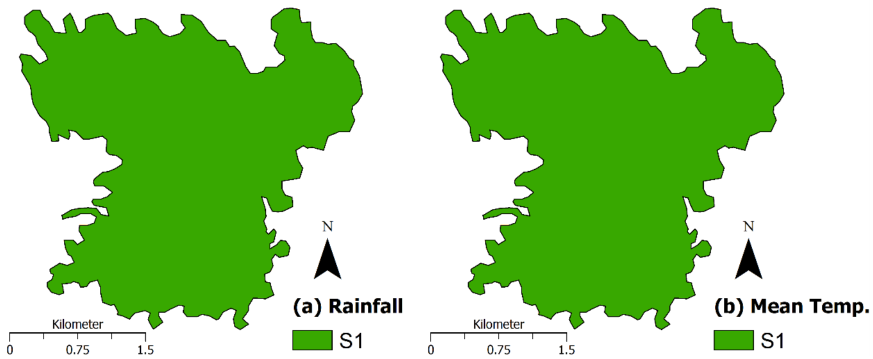
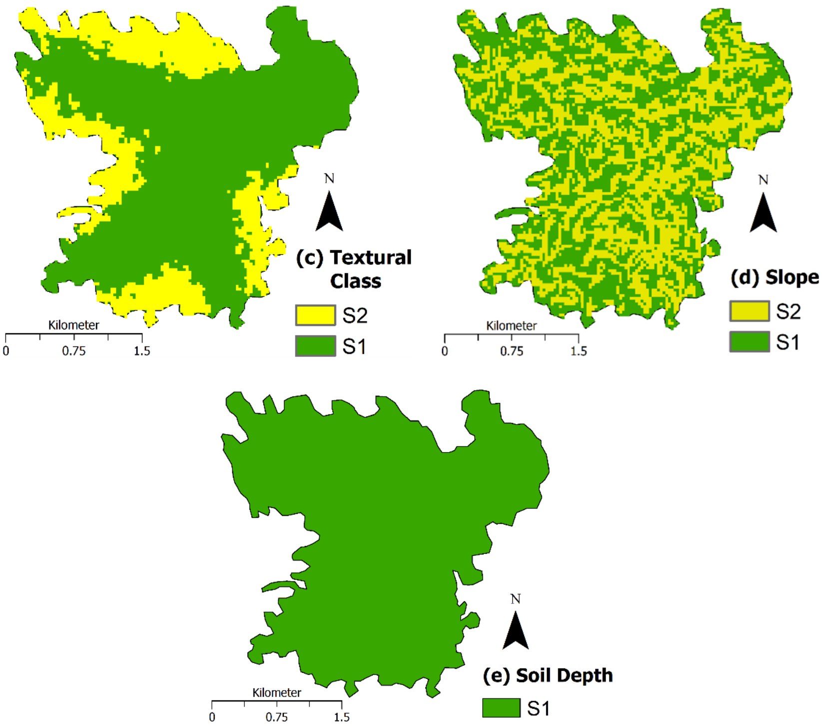
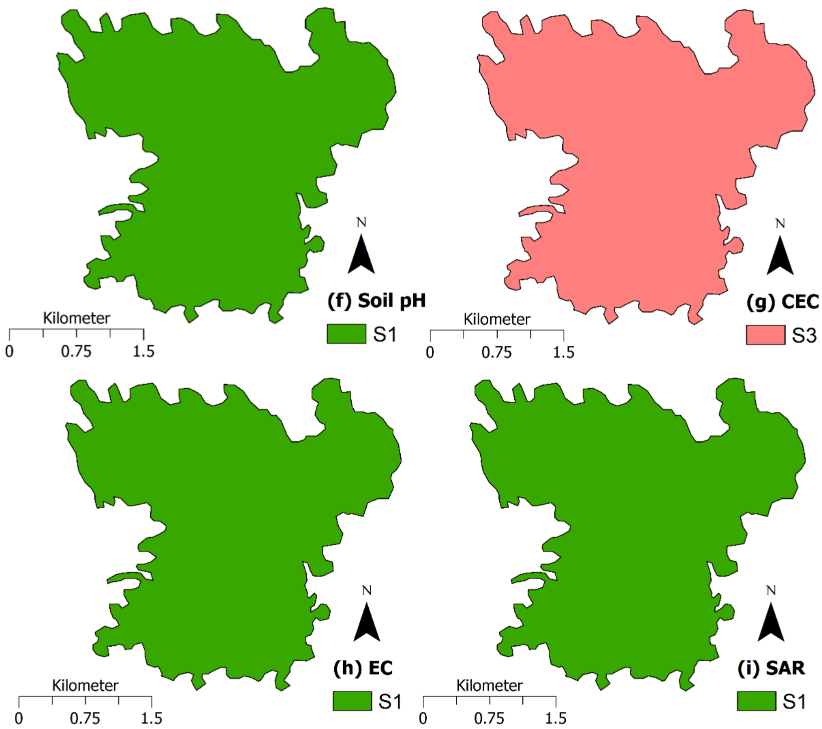


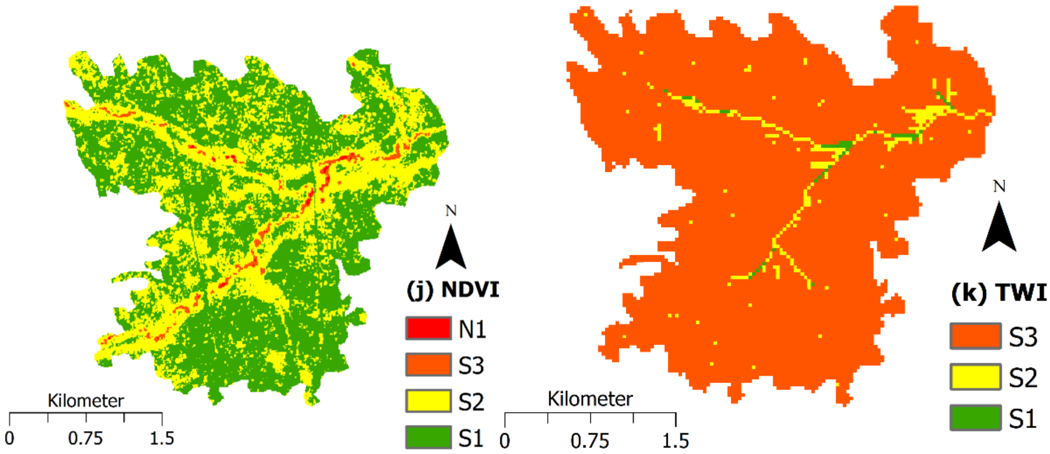
Figure 4: Reclassified suitability maps of (a) Rainfall (b) Mean Temperature for rice cultivation in the *Rafin Kada* floodplain, showing spatial distribution of suitability classes (S1 – highly suitable) used in the final weighted overlay analysis.
Source: Authors' GIS-based analysis (2025) using climate data derived from NASA POWER viewer



Cont'd Figure 4: Reclassified suitability maps for (c) Soil Texture (d) Slope (e) Soil Depth for rice cultivation in the *Rafin Kada* floodplain, showing spatial distribution of suitability classes (S1 – highly suitable, S2 – moderately suitable) used in the final weighted overlay analysis.
Source: Authors' GIS-based analysis (2025) using ArcGIS 10.5; derived from field data, and SRTM 30 m DEM, reclassified according to the criteria in Table 1.



Cont'd Figure 4: Reclassified suitability maps of (f) Soil pH (g) Cation exchange capacity (CEC) (h) Electrical conductivity (EC) (i) Sodium absorption ratio (SAR) for rice cultivation in the *Rafin Kada* floodplain, showing spatial distribution of suitability classes (S1 – highly suitable, S3 – marginally suitable) used in the final weighted overlay analysis.
Source: Authors' GIS-based analysis (2025) using ArcGIS; derived from field data and reclassified according to the criteria in Table 1.



Cont'd. Figure 4: Reclassified suitability maps of (j) Normalized Difference Vegetation Index (NDVI) (k) Topographic wetness index (TWI) in the *Rafin Kada* floodplain, showing spatial distribution of suitability classes (S1 – highly suitable; 2 – moderately suitable; S3 – marginally suitable; N1 – not suitable) used in the final weighted overlay analysis.
Source: Authors' GIS-based analysis (2024) using ArcGIS 10.5; derived from field data Landsat-8 OLI imagery reclassified according to suitability thresholds in Table 1.

were S3, showing that most areas experience moderate to low water accumulation. This limited hydrological convergence corresponds to the floodplain's gentle gradients and permeable alluvial deposits, which limit surface ponding except in shallow depressions. This suggests that vegetation vigour is more strongly influenced by land management practices, cropping intensity, or previous cultivation cycles than by inherent soil chemical conditions (Lu et al., 2025).

AHP Weighting and Suitability Overlay

The AHP determined the relative importance of the selected criteria (Table 5). Rainfall (0.281) ranked highest, closely followed by temperature (0.184), reflecting their foundational roles in sustaining paddy systems. The dominance of climatic factors in suitability studies has been widely reported, as climate provides the fundamental energy and moisture regimes that govern crop growth, soil moisture dynamics, and evapotranspiration balance (Ezra et al., 2023).

Although climatic variables in the study area are spatially uniform, their inclusion in the weighting structure remains critical, as they establish the baseline environmental adequacy against which all other soil and terrain criteria are evaluated. This ensures that the influence of physical and chemical soil attributes on rice suitability is interpreted relative to a context of sufficient rainfall and temperature for paddy viability.

Soil texture (0.142) followed, emphasising its control over water retention and aeration within the root zone.

Table 5. Normalized Scores of the AHP Matrix and Final Priority Weights

S/N	Criteria	Priority Weight
1	Rainfall	0.258
2	Temperature	0.184
3	Texture	0.142
4	Depth	0.098
5	Slope	0.064
6	TWI	0.056
7	NDVI	0.049
8	EC	0.049
9	pH	0.039
10	CEC	0.032
11	SAR	0.028
Consistency Index (CI)		0.992
Consistency Ratio (CR)		0.066

Note: EC – electrical conductivity; TWI – topographic wetness index; CEC – cation exchange capacity; SAR – sodium absorption ratio. **Source:** Authors' computation (2024), using expert judgment supported by weight rankings from Akıncı et al. (2013), and Xue et al. (2023).

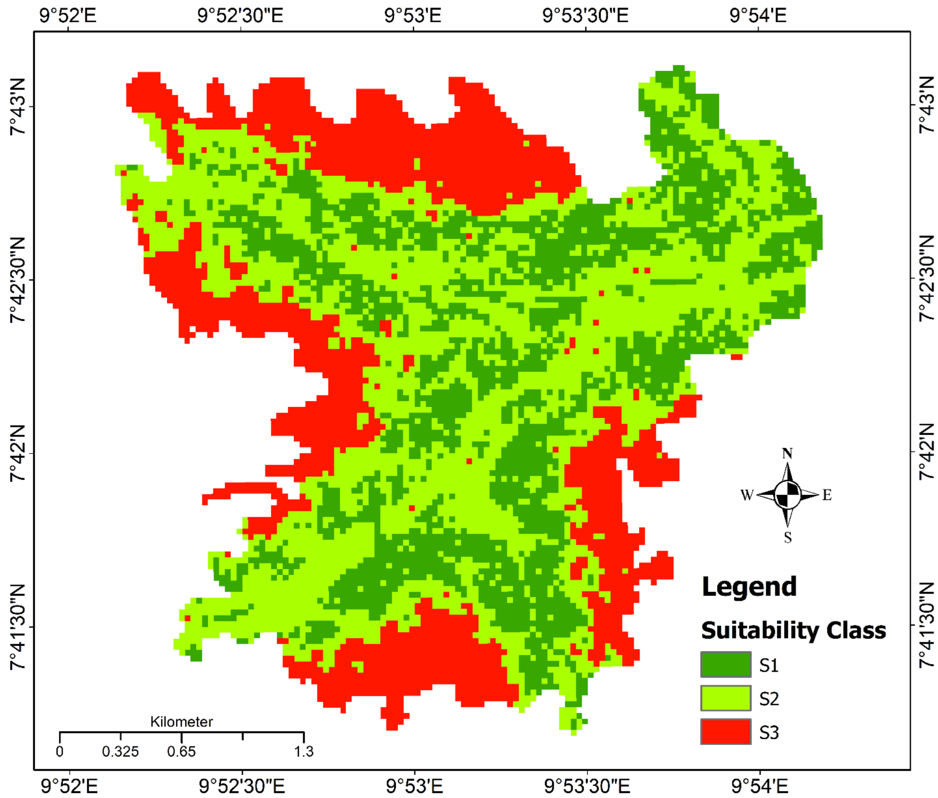


Figure 5: Final Suitability Map for Rice Production in the Floodplains of *Rafin Kada*
Source: Authors' GIS–AHP weighted overlay (2025).

Soil depth (0.117) and slope (0.064) were also influential, underscoring the significance of soil physical tilth and rooting depth in overall nutrient retention, stability, and ease of water management essential for sustaining flooded paddy conditions. The chemical and toxicity indicators (pH, EC, and SAR) were generally adequate across the floodplain, underscoring their relatively uniform weights. However, CEC was classified as marginally suitable (S3) across the area. This implies that sustained productivity in such soils may require regular incorporation of organic residues to improve nutrient retention and maintain long-term soil quality.

Remotely sensed indicators utilised in this study (i.e., TWI and NDVI) ranked moderately in the weighting hierarchy (0.056 and 0.049, respectively), highlighting their supplementary role in representing surface hydrology and vegetation vigour. While not as dominant as climatic or soil physical parameters, these indices improve spatial precision by capturing micro-variations in surface moisture and vegetation condition that influence rice growth, particularly under rainfed tropical systems with limited irrigation infrastructure.

Matrix Consistency Evaluation

To verify the reliability of the pairwise comparisons, the CI and CR were computed as indicated in Table 5. The resulting CI (0.992) and CR (0.066) indicate that the matrix was within the acceptable threshold ($CR < 0.10$), confirming that the judgments were logically consistent. This consistency ensures that the derived weights accurately reflect the relative influence of each criterion on rice suitability. Hence, the weighting structure can be confidently applied in the weighted overlay analysis for spatial suitability mapping.

Composite Suitability Classification

The weighted overlay in ArcGIS integrated all standardised layers to produce the final rice suitability map (Figure 5). Highly suitable areas (S1) were concentrated in the lower and middle valley positions, covering 220.5 ha (27%) of the floodplain. These zones exhibited optimal combinations of texture, pH, rainfall, and drainage conditions, requiring minimal intervention for rice production.

Moderately suitable areas (S2) occupied 379.4 ha (46%), limited primarily by lower CEC, moderate slopes, and NDVI variation. Here, soil fertility enhancement through organic matter incorporation and improved bunding can enhance yield. Marginally suitable zones (S3) covered 224.6 ha (27%) in the western and southern sections, constrained by coarse texture and reduced moisture retention.

The spatial pattern observed in *Rafin Kada* indicates that the floodplain is generally favourable for rice

Table 6. Summary of Land Suitability Classes in the Floodplains of *Rafin Kada*

Suitability Class	Area (ha)	Percentage
S1	220.5	27%
S2	379.4	46%
S3	224.6	27%

Note: S1 – Highly suitable; S2 – Moderately suitable; S3 – Marginally suitable. Area and percentages derived from reclassified composite maps using the "Zonal Statistics as Table" and "Calculate Geometry" functions in ArcGIS.

cultivation under current environmental conditions. However, texture variability and moderate CEC remain critical constraints requiring management. The predominance of moderately suitable zones mirrors findings from similar GIS–AHP rice studies in *Kudan* LGA, *Kaduna* State (Sadiq et al., 2023), confirming that even within physiographically uniform floodplains, micro-variations in soil and hydrology strongly influence suitability outcomes.

Sensitivity Analysis and Model Robustness

The sensitivity analysis revealed a high degree of stability in the suitability model (Table 7; Figure 6). Notably, the S1 (Highly Suitable) class remained completely unchanged at 237.89 ha despite a 20% variation in the primary criteria weights. The most notable variation occurred between the S2 and S3 classes, involving only 1.63 ha, which represents about 0.2% of the total study area. This outcome demonstrates the stability and robustness of the AHP framework applied in this study and further supports the acceptable CR obtained earlier. Similar findings have been reported in land suitability studies where stable outputs under weight perturbation were interpreted as evidence of model reliability and consistency (Saaty, 1980; Malczewski, 2004).

Cell by cell statistics were further employed to quantify the spatial agreement between the positive and negative weight simulations (Figure 6a). The analysis showed a total spatial agreement of 822.88 ha, accounting for 99.8% of the study area, whereas spatial disagreement was limited to only 1.62 ha. The extremely low disagreement indicates that the environmental covariates, rather than the assigned expert weights alone, were the dominant factors controlling the observed suitability patterns across the landscape. This observation agrees with previous GIS-based multi-criteria suitability studies, which noted that robust environmental datasets often exert greater influence on model outputs than moderate changes in weighting schemes (Eastman, 2016; Feizizadeh & Blaschke, 2013).

The complete stability of the S1 class is particularly important for land use planning because it confirms that the delineation of highly suitable rice cultivation zones is reliable and insensitive to minor variations in expert

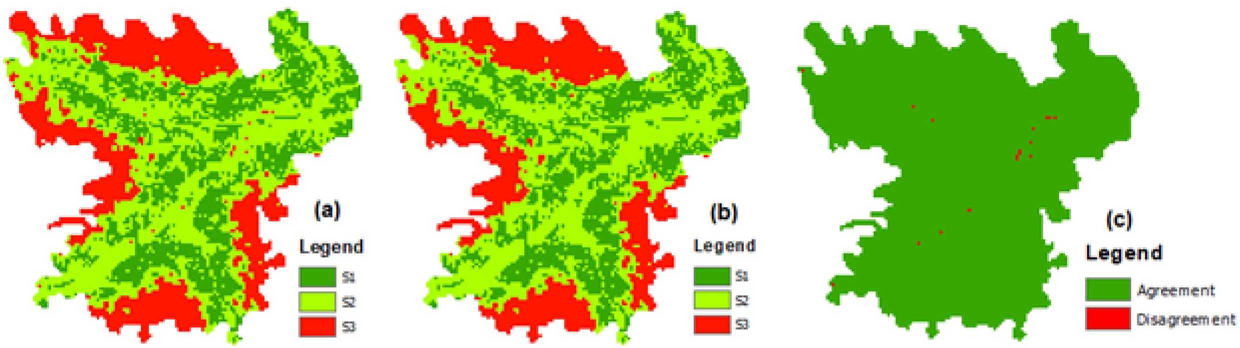


Figure 6: Maps of spatial sensitivity to weight variation and comparative agreement
(a) Suitability map with +20 weight adjustment; (b) Suitability map with -20% weight adjustment; (c) Spatial agreement map showing stable versus transitional pixels.

Table 7. Stability of Suitability Classes under Weight Fluctuations (±20%)

Suitability Class	Area at +20% (ha)	Area at –20% (ha)	Absolute Change (ha)
S1	237.89	237.89	0
S2	357.51	355.88	1.63
S3	229.1	230.73	1.63
Total Area	824.5	824.5	--

Note: S1 – Highly suitable; S2 – Moderately suitable; S3 – Marginally suitable. Area and percentages derived from reclassified composite maps using the "Zonal Statistics as Table" and "Calculate Geometry" functions in ArcGIS.

judgment. Such robustness reduces concerns regarding subjectivity commonly associated with expert-based weighting approaches and demonstrates that the generated suitability maps can serve as dependable tools for evidence-based agricultural planning and decision making. Similar conclusions were reached by Saaty (1980) in foundational AHP studies emphasising the importance of consistency and sensitivity testing in strengthening confidence in decision support models.

CONCLUSION

This study evaluated the suitability of the *Rafin Kada* floodplain for rice cultivation using an integrated GIS-AHP framework that combined soil, climatic, terrain, and remote sensing criteria. Rainfall and temperature were uniformly suitable, confirming that climatic factors are not limiting. Highly suitable zones (27%) occurred mainly in lower and middle valley positions with favourable soil depth, texture, and pH, while moderately suitable areas (46%) were constrained by slope, CEC, and drainage. Marginally suitable zones (27%) were influenced by poor drainage and low vegetation vigour. These findings demonstrate that integrating geospatial and decision analysis tools can effectively reveal spatial heterogeneity in land suitability even within physiographically uniform floodplains.

Sensitivity analysis further demonstrated a high degree of model robustness. The S1 class remained unchanged under a 20% variation in criteria weights, while spatial disagreement between positive and negative weight simulations accounted for only 1.62 ha (0.2%) of the study area. This suggests that the suitability patterns were driven primarily by environmental covariates rather than weighting variations, thereby increasing confidence in the stability of the generated suitability zones. Nevertheless, the suitability maps should be interpreted as spatial decision support tools, particularly in relation to local-scale variability and seasonal dynamics.

Beyond biophysical suitability, the practical expansion of rice production in Nigeria remains constrained by broader socioeconomic and institutional challenges, including fragmented land tenure systems, weak rural land use planning structures, limited mechanisation, high labour costs, inconsistent fertiliser and seed supply, poor rural road networks, and unstable market systems. In Taraba State, the generated suitability maps may therefore be most useful to agricultural development agencies, extension services, and local planning authorities as a preliminary framework for targeting interventions and improving resource allocation. Future studies should incorporate time series remote sensing, denser field sampling, machine learning approaches, and socioeconomic indicators to strengthen predictive reliability and implementation relevance.

CONFLICT OF INTEREST

The authors declare no conflicts of interest concerning the research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors have followed ethical standards in conducting the research and preparing the manuscript.

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