



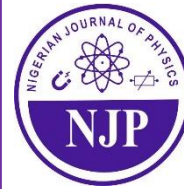
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Remote Sensing and GIS-Based Assessment of Agricultural Suitability in Orlu, Southeastern Nigeria Using Landsat ETM+ Imagery

¹Dinneya, Obinna Christian, *¹Onwubuariri, Chukwuebuka Nnamdi,
²Akidi, Stephen Obioma and ¹Nwokoma, Esomchi Uzoma

¹Department of Physics, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria

²Department of Geology, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria

*Corresponding Author's Email: onwubuariri.chukwuebuka@mouau.edu.ng

ORCID iD: <https://doi.org/0000-0003-3689-9065>

ABSTRACT

Food insecurity and land degradation remain major environmental and socio-economic challenges across sub-Saharan Africa, with southeastern Nigeria experiencing some of the most severe erosion-related losses of arable land. This study employed integrated remote sensing and GIS techniques to evaluate agricultural suitability within Orlu and its environs using Landsat Enhanced Thematic Mapper Plus (ETM+) imagery and Shuttle Radar Topographic Mission (SRTM) data. Spatial datasets including NDVI, slope gradient, drainage density, lineament density, and terrain elevation were extracted from these sources and integrated within a GIS-based multi-criteria suitability framework. Image enhancement techniques involving band ratios (3/4, 4/2, 3/1, and 5/4) and RGB composites (357, 751, and 752) were employed to improve feature discrimination. NDVI values obtained ranged from -0.22 to 0.51, indicating severe vegetation stress in erosion-prone northeastern sectors and relatively stable vegetative productivity in low-gradient southern terrains. Areas characterised by high lineament density (reaching up to 2.8 km/km²) and steep topographic gradients (>15°) were identified as erosion-prone zones unsuitable for sustainable agriculture. The integrated overlay analysis revealed that 21.1% (163.2 km²) of the study area exhibits high agricultural suitability, 42.5% (328.9 km²) moderate suitability, whereas 36.4% (281.7 km²) remains unsuitable due to steep slopes, high structural lineament density, and extensive land degradation. The study demonstrates that agricultural productivity within the study area is strongly controlled by topography, drainage configuration, vegetation density, and structural lineaments. These findings provide quantifiable baseline information for agricultural land-use planning, erosion mitigation, and sustainable food production strategies in southeastern Nigeria.

Keywords:

Normalized Difference
Vegetation Index (NDVI),
Lineaments,
Drainage pattern,
Agricultural suitability,
Landsat ETM+,
SRTM,
Southeastern Nigeria.

INTRODUCTION

Agricultural land suitability assessment has become increasingly important under conditions of rapid climate variability, accelerated land degradation, and growing food demand worldwide. In tropical developing regions, unsustainable cultivation practices, topographic instability, and vegetation loss continue to reduce agricultural productivity and threaten long-term food security. Recent advances in remote sensing and geospatial technologies have significantly improved the capability for large-scale environmental monitoring and spatial decision-making in agricultural systems (Radočaj

et al., 2023; Onwubuariri, et al., 2023 & Usman et al., 2024).

Sustainable agricultural production remains a major challenge in many developing countries due to rapid population growth, environmental degradation, climate variability, and declining soil fertility. In Nigeria, increasing erosion activities, land degradation, and unsustainable land-use practices have significantly reduced agricultural productivity, thereby exacerbating food insecurity and rural poverty (Eze et al., 2022; Ogunlade et al., 2023). The situation is particularly severe in southeastern Nigeria, where the combination of

unconsolidated sandy formations, high-intensity rainfall, and relief energy has created conditions for extensive gully erosion systems that consume valuable agricultural land annually.

Remote sensing and Geographic Information System (GIS) technologies have become indispensable tools in agricultural resource assessment and land-use planning. Satellite-based observations enable large-scale monitoring of vegetation conditions, topography, drainage networks, and surface structural features, thereby providing critical information for agricultural suitability evaluation and environmental management (Leslie et al., 2021; Miller et al., 2021; Radočaj et al., 2023).

The Normalized Difference Vegetation Index (NDVI) is one of the most widely applied remote sensing indices for vegetation monitoring due to its effectiveness in assessing vegetation density, chlorophyll content, biomass distribution, and land surface conditions (Horel and Zsigmond, 2023; Li et al., 2021 & Onwubuariri, et al., 2022a). When integrated with topographic, drainage, and lineament analyses, NDVI provides valuable insights into the environmental factors controlling agricultural productivity (Olorunfemi et al., 2021; Adepoju et al., 2024).

Although previous studies in southeastern Nigeria have investigated gully erosion susceptibility, groundwater occurrence, and land-use dynamics using geophysical and remote sensing approaches (Onwubuariri et al., 2022b; Onyekwelu et al., 2021), integrated agricultural suitability modelling that simultaneously incorporates vegetation vigor, structural controls, terrain morphology, and drainage configuration remains limited within the Orlu region. Moreover, most existing studies rely primarily on conventional land-cover analysis without quantitatively linking geomorphological instability and structural lineament influence to agricultural sustainability. This limitation constrains evidence-based land-use planning and erosion mitigation strategies in one of the most environmentally vulnerable terrains in southeastern Nigeria.

Unlike previous studies that focused primarily on vegetation mapping or erosion susceptibility independently, this study integrates NDVI analysis, structural lineament mapping, DEM-derived terrain

evaluation, and drainage characterization within a unified GIS framework to delineate agriculturally viable zones. The study therefore provides an improved spatial understanding of the interaction between geomorphology, vegetation dynamics, and agricultural potential in erosion-sensitive sedimentary terrains.

This study aims to evaluate the agricultural suitability of Orlu and its environs using integrated remote sensing and GIS techniques. Specifically, the objectives are to: (i) generate NDVI-based vegetation maps with quantitative areal statistics; (ii) delineate structural lineaments and drainage patterns with density analysis; (iii) assess topographic influences on agricultural activities using DEM and slope analysis; and (iv) identify and map agriculturally viable zones using weighted multi-criteria GIS overlay for sustainable land-use planning.

Location and Geology of the Study Area

The study area, Orlu and its environs, is located in Imo State, southeastern Nigeria. It lies approximately between latitudes 5°10'N and 6°00'N and longitudes 6°40'E and 7°10'E (Figure 1). Two pronounced seasons exist: the dry season (November to March) and the wet season (April to October), with peak rainfall in June and July. Mean annual rainfall ranges from 1,800 mm to 2,200 mm. The vegetation is predominantly tropical savannah and secondary forest. Common crops include yam, cassava, cocoyam, maize, oil palm, and various vegetables.

Geologically, the study area is underlain by sedimentary formations of the Benin Formation within the Niger Delta Basin. The lithology consists mainly of unconsolidated sands, sandstones, lateritic overburden, and localized clay intercalations (Onyekwelu et al., 2021, Onwubuariri, et al., 2021). The dominance of poorly consolidated coastal plain sands promotes rapid infiltration, slope instability, and severe gully erosion development across the region. The geomorphology of the Awka-Orlu Cuesta exerts significant influence on drainage evolution, runoff concentration, and sediment redistribution, thereby affecting agricultural soil quality and land-use sustainability. Elevation ranges from approximately 116 m to 201 m above sea level, with a prominent NE-SW trending cuesta in the northeastern part.

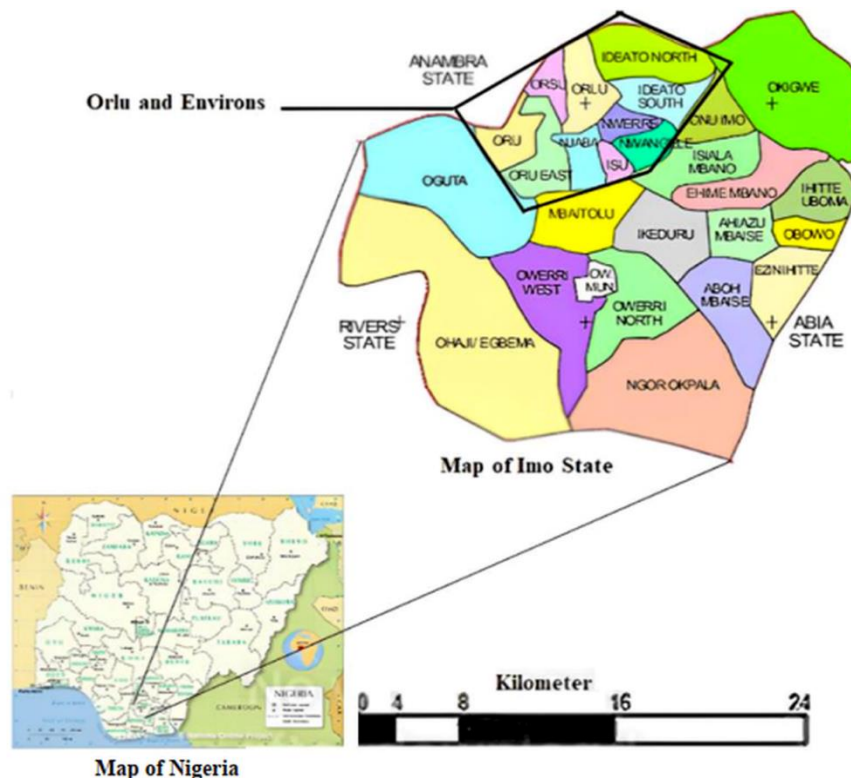


Figure 1: Location map of the study area

MATERIALS AND METHODS

Data Acquisition

Landsat 5 Enhanced Thematic Mapper Plus (ETM+) imagery with 30 m spatial resolution was acquired from the National Space Research and Development Agency (NASRDA). The acquisition date corresponded to the dry season (December 2021) to minimise cloud interference and enhance vegetation discrimination. The Landsat ETM+ scene possessed less than 5% cloud cover, thereby ensuring minimal atmospheric interference and improved surface feature discrimination. The multispectral bands used in this study have a spectral range spanning visible (0.45–0.69 μm), near-infrared (0.75–0.90 μm), and shortwave infrared (1.55–2.35 μm) wavelengths suitable for vegetation and lithological analysis. The scene path/row was 188/055. Shuttle Radar Topographic Mission (SRTM) digital elevation data with 30 m spatial resolution were also obtained for topographic analysis. Ancillary data included topographic maps (1:50,000 scale) and geological maps of the area.

Image Preprocessing

Image preprocessing involved geometric correction, radiometric calibration, atmospheric correction, and image enhancement. Ground Control Points (GCPs) and the Universal Transverse Mercator (UTM) coordinate system (zone 32N, WGS84 datum) were used for georeferencing, achieving a root mean square error of less than 0.5 pixels. Atmospheric correction was

performed using the dark object subtraction (DOS) method to reduce scattering effects. Digital numbers were converted to top-of-atmosphere reflectance prior to analysis to improve inter-band comparability and reduce radiometric inconsistencies. Histogram equalization and contrast stretching techniques were additionally applied to enhance image interpretability and improve structural feature extraction. Image processing and analysis were performed using ArcGIS 10.8, ERDAS Imagine 2021, and IDRISI Selva software packages.

Band Ratios and Colour Composites

Band ratios were generated to reduce shadowing effects and enhance specific surface features. The following ratios were computed using the IDRISI 32 calculator module: 3/4, 4/2, 3/1, and 5/4. These band ratios were selected because they enhance lithological discrimination, vegetation vigor, and structural discontinuities. In particular, the 5/4 ratio emphasizes moisture and vegetation contrasts, whereas the 3/1 ratio enhances ferruginous and exposed soil signatures associated with erosion-prone terrains. Red-Green-Blue (RGB) colour composites (357, 751, 752, and NDVI composite) were also created to improve visual interpretation of vegetation, soil, and structural features.

Digital Elevation Model (DEM) and Slope Analysis

The SRTM DEM was processed to generate elevation contours, slope maps, and shaded relief images. The

DEM was converted into a contour map using ArcGIS spatial analyst tools. Slope gradients were classified into three classes: gentle (0–5°), moderate (5–15°), and steep (>15°) to assess erosion risk and agricultural suitability (Table 1).

Table 1: Slope gradient classification and agricultural implication

Slope class	Gradient range	Area (km ²)	Percentage (%)	Agricultural implication
Gentle	0° – 5°	312.6	40.4	Suitable, low erosion risk
Moderate	5° – 15°	289.4	37.4	Moderately suitable, terracing may be required
Steep	>15°	171.8	22.2	Unsuitable, high erosion risk
Total		773.8	100	

Lineament and Drainage Extraction

Lineaments were visually interpreted from edge-enhanced band 5 imagery and the DEM using standard criteria (linear valleys, ridges, and aligned drainage segments). Only lineaments with a length ≥ 1 km were considered. To minimize interpreter bias, extracted lineaments were cross-validated using hillshade derivatives, drainage alignments, and directional consistency analysis. Non-geological linear features such as roads and settlement boundaries were excluded during digitization. A lineament density map was generated using kernel density estimation in ArcGIS with a search radius of 2 km. Drainage patterns were digitised from the topographic map and Landsat imagery, and superimposed on the lineament map to assess structural control on hydrology. Drainage density was calculated as total stream length per unit area (km/km²).

Normalized Difference Vegetation Index (NDVI)

NDVI was computed using the standard equation:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

where NIR represents near-infrared reflectance (band 4) and RED represents red reflectance (band 3). The NDVI values range from –1 to +1. NDVI was classified into five classes: water/bare soil (–0.22 to –0.01), sparse vegetation (0.01–0.19), moderate vegetation (0.19–0.30),

dense vegetation (0.30–0.41), and very dense vegetation (0.41–0.51). The classification thresholds were based on field observation and literature (Radočaj et al., 2023). NDVI classification reliability was evaluated through visual comparison with high-resolution Google Earth imagery and existing vegetation distribution patterns within the study area.

Agricultural Suitability Mapping

A weighted multi-criteria GIS overlay approach was adopted to delineate agricultural suitability zones. Suitability was classified into three categories based on NDVI, slope, and lineament density:

High suitability: NDVI > 0.30, slope < 5°, low lineament density (<1.0 km/km²)

Moderate suitability: NDVI 0.19–0.30, slope 5–15°, moderate lineament density (1.0–1.8 km/km²)

Low suitability: NDVI < 0.19, slope > 15°, high lineament density (>1.8 km/km²)

NDVI was assigned the highest weight (0.5) due to its direct relationship with vegetation vigor and biomass productivity, while slope (0.3) and lineament density (0.2) were weighted based on their influence on erosion susceptibility and terrain stability. The weighted overlay was computed using the raster calculator in ArcGIS 10.8.

Table 2: Weighting criteria for agricultural suitability assessment

Criterion	Weight	Justification
NDVI	0.5	Direct indicator of vegetation health and biomass productivity
Slope gradient	0.3	Controls runoff, erosion potential, and mechanization feasibility
Lineament density	0.2	Indicates structural weakness and erosion susceptibility

RESULTS AND DISCUSSION

Digital Elevation Model and Topography

The DEM (Figure 3) revealed significant topographic variability across the study area. Elevations ranged from 116 m to 201 m above sea level, with a mean elevation of 158.4 m (standard deviation = 18.6 m). The highest elevations occurred in the northeastern part, corresponding to the Awka-Orlu Cuesta trending NE-SW. The scarp slope was identified by closely spaced elevation contours, with a rapid transition from 116 m to 201 m over a horizontal distance of approximately 4 km, yielding an average slope gradient of 1.2°.

Approximately 36.4% of the northeastern terrain exhibited moderate-to-steep slope conditions associated with elevated runoff velocity and reduced infiltration potential. Low-lying plains appeared in the southwestern and central sectors. Areas characterised by steep slopes and high elevation gradients corresponded predominantly to erosion-prone zones, limiting agricultural suitability. Conversely, relatively low-gradient terrains exhibited greater potential for sustainable cultivation due to reduced runoff intensity and enhanced soil stability.

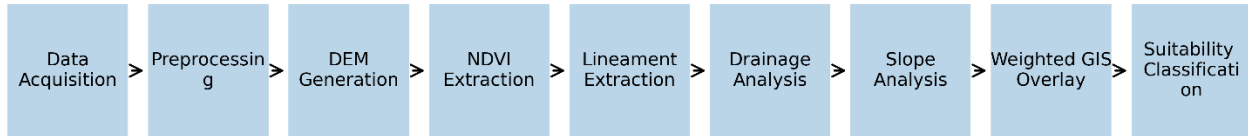


Figure 2: Methodological workflow diagram

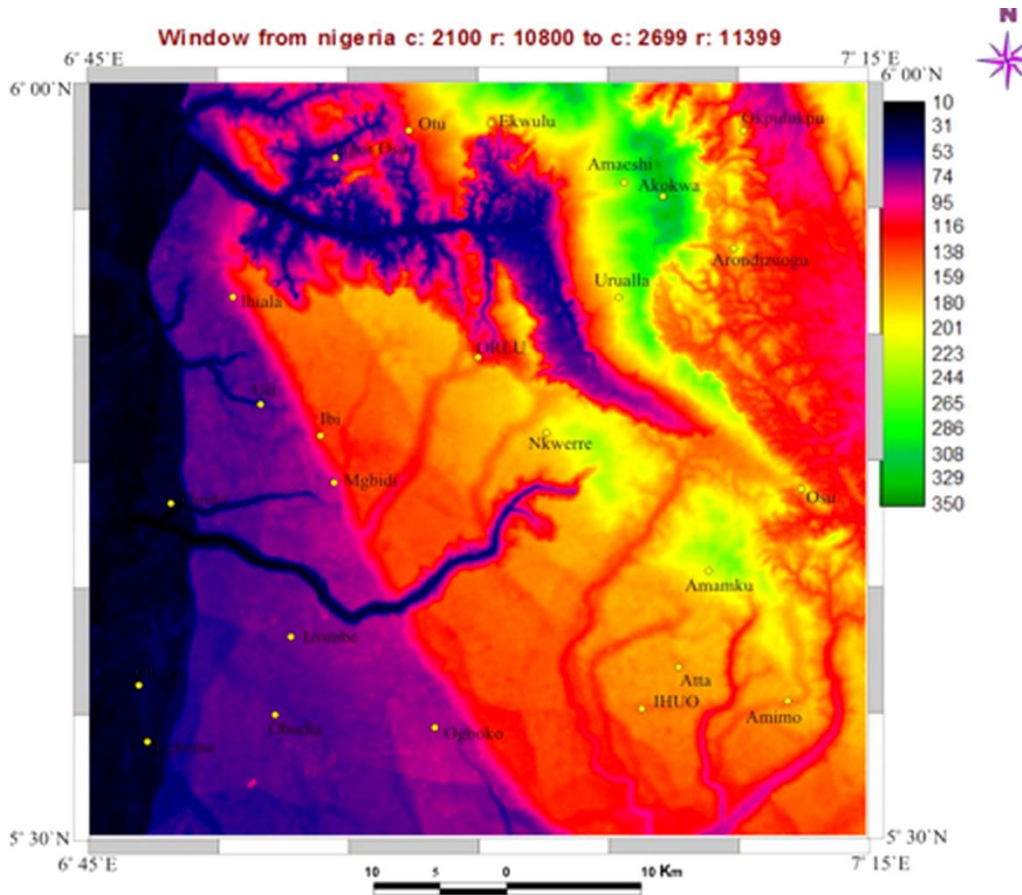


Figure 3: Digital Elevation Model (DEM) and hillshade map of the study area

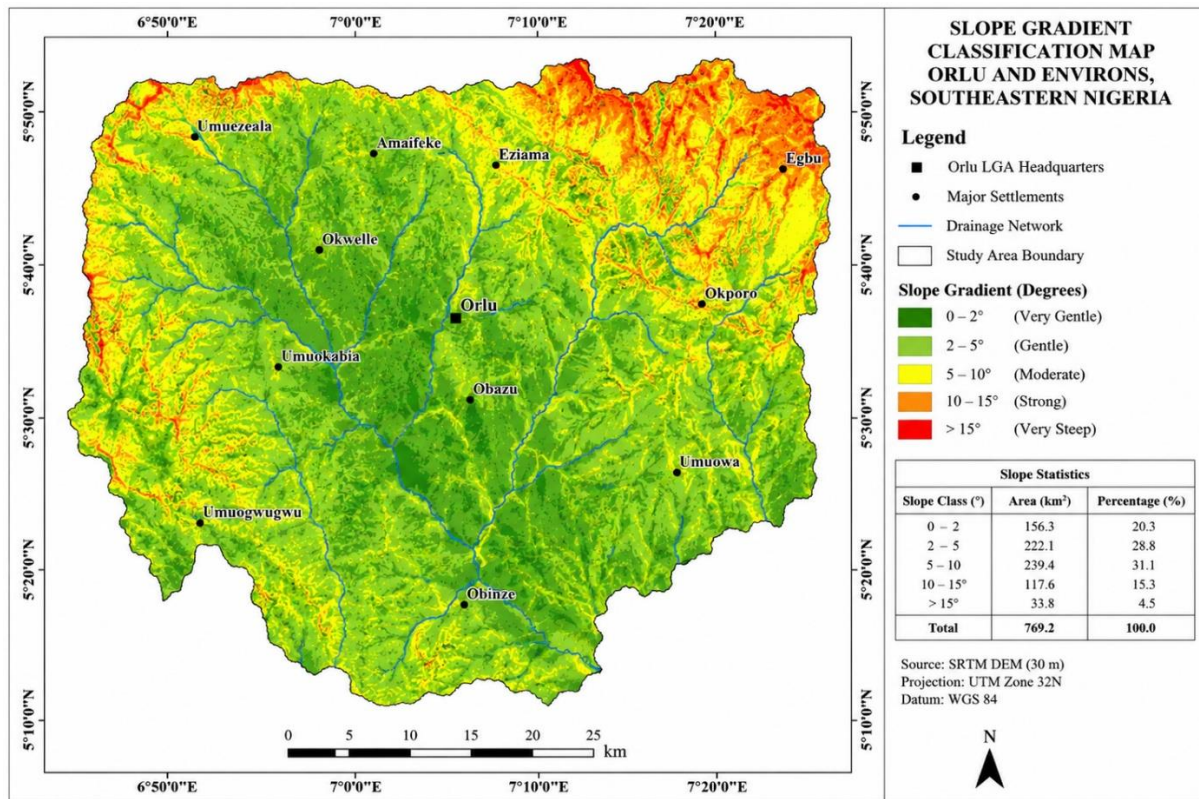


Figure 4: Slope gradient classification map

Lineament Analysis

Lineament mapping revealed three distinct structural orientations: NE-SW (dominant, 47% of total lineaments), N-S (28%), and NW-SE (25%). The NE-SW direction is consistent with regional tectonic trends in southeastern Nigeria. A total of 147 lineaments with lengths ≥ 1 km was digitised, with cumulative length of 312.5 km. Lineament lengths ranged from 1.0 km to 8.4 km, with a mean length of 2.13 km. The dominant NE-SW structural orientation suggests tectonic inheritance

associated with regional fracture systems within the Benin Formation and adjoining sedimentary sequences. The lineament density map (Figure 6) showed the highest density in the northeastern part, around Urualla and Orlu town, with values reaching 2.8 km/km². Areas characterised by high lineament density exhibited increased susceptibility to erosion and land degradation due to structural weakening and enhanced surface runoff concentration. These zones are therefore less favourable for sustained agricultural activities.

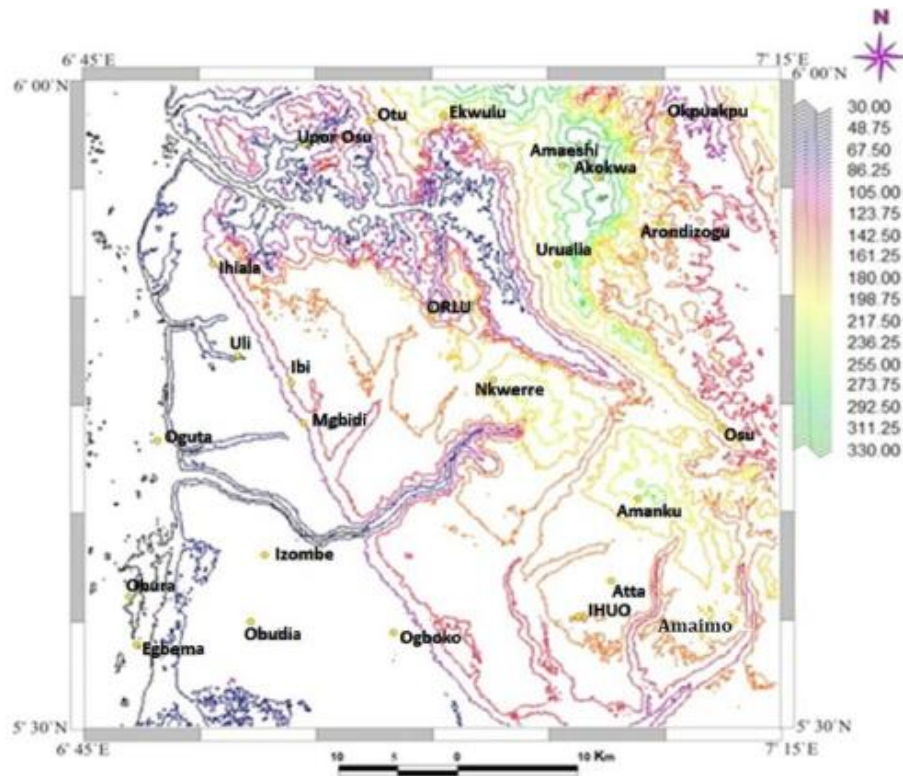


Figure 5: Lineament map superimposed on edge-enhanced band 5 diagram

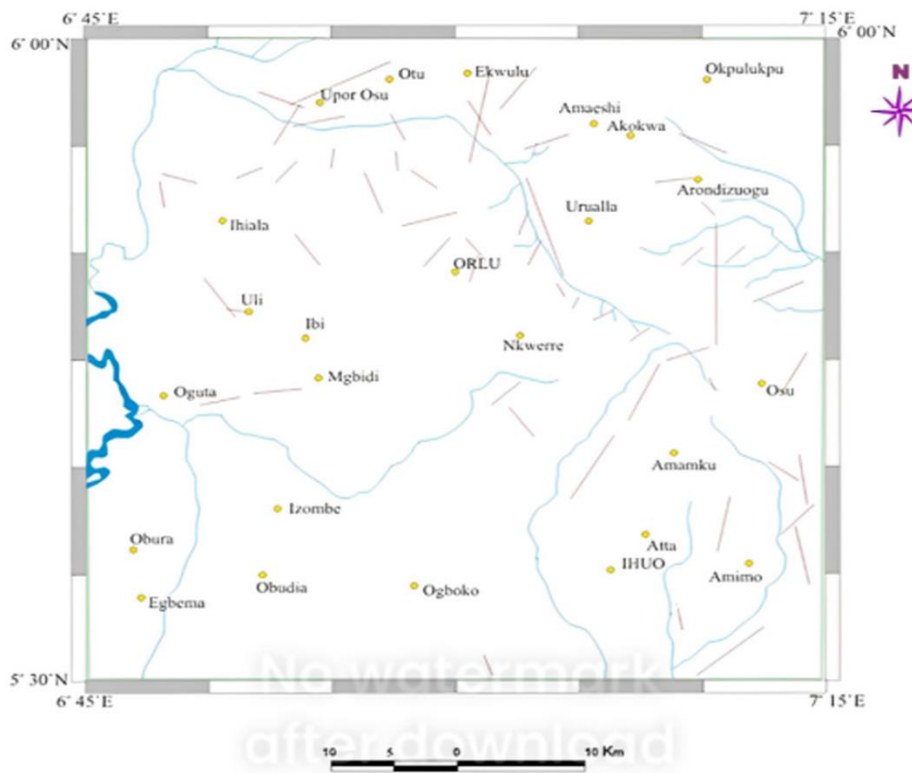


Figure 6: Lineament density map

Drainage Pattern Analysis

The drainage map (Figure 7) exhibited a predominantly dendritic pattern, indicating relatively uniform lithology and gentle slopes. However, in areas with high lineament density, drainage showed sub-parallel and rectangular patterns, suggesting structural control. Total drainage length digitised was 847.3 km, with drainage density ranging from 0.42 km/km² to 2.93 km/km² (mean = 1.09

km/km²). Fourth-order streams were the highest order observed. The dendritic configuration indicates that the underlying sediments are largely unconsolidated sands, which are soft and easy to cultivate but also prone to erosion. Stream orders 1 and 2 constituted approximately 68% of the total drainage network, indicating active headward erosion processes.

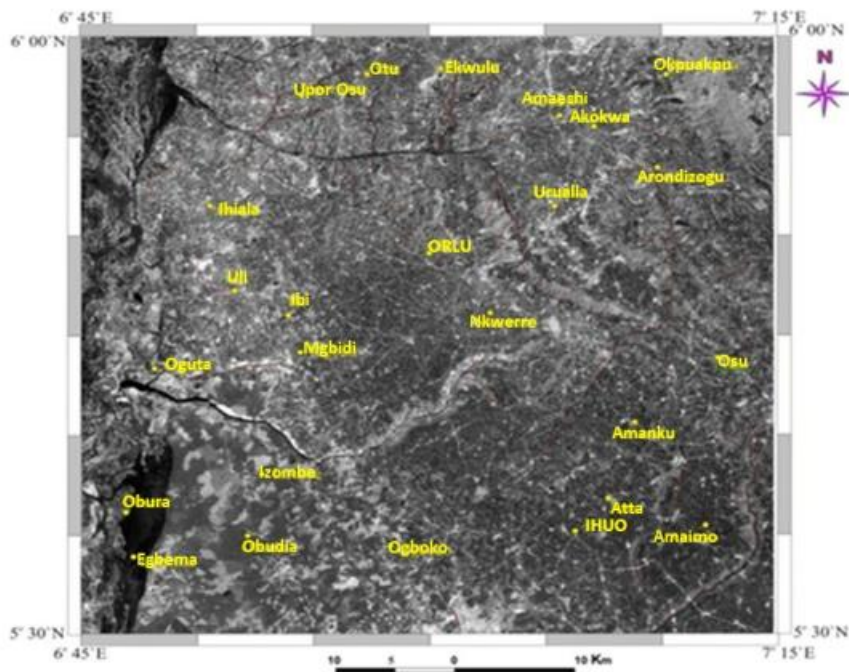


Figure 7: Drainage network map superimposed on lineament map

NDVI Analysis

NDVI values ranged from -0.22 to 0.51 across the study area (mean = 0.18, standard deviation = 0.14) (Figure 8). Table 3 summarises the NDVI classification and areal

extent. The spatial distribution of low NDVI values corresponds strongly with exposed sandy surfaces, actively eroded zones, and sparse vegetation cover observed within the northeastern sector of the study area.

Table 3: NDVI classification and areal coverage in Orlu and environs

NDVI range	Class	Area (km ²)	Percentage (%)	Interpretation
-0.22 to -0.01	Bare/eroded soil	142.3	18.4	Active erosion, no agricultural potential
0.01 – 0.19	Sparse vegetation	256.8	33.2	Degraded, low agricultural potential
0.19 – 0.30	Moderate vegetation	211.5	27.3	Moderate potential, requires management
0.30 – 0.41	Dense vegetation	118.7	15.3	Good agricultural potential
0.41 – 0.51	Very dense vegetation	44.5	5.8	High agricultural potential
Total		773.8	100	

Areas with NDVI > 0.30 (dense and very dense vegetation) covered about 21.1% (163.2 km²) of the study area. These zones corresponded to regions with higher soil fertility and lower erosion risk, indicating favourable

agricultural suitability. In contrast, areas with NDVI < 0.19 (bare or sparsely vegetated) covered 51.6% (399.1 km²) of the area, reflecting degraded lands unsuitable for sustainable agriculture without major remediation.

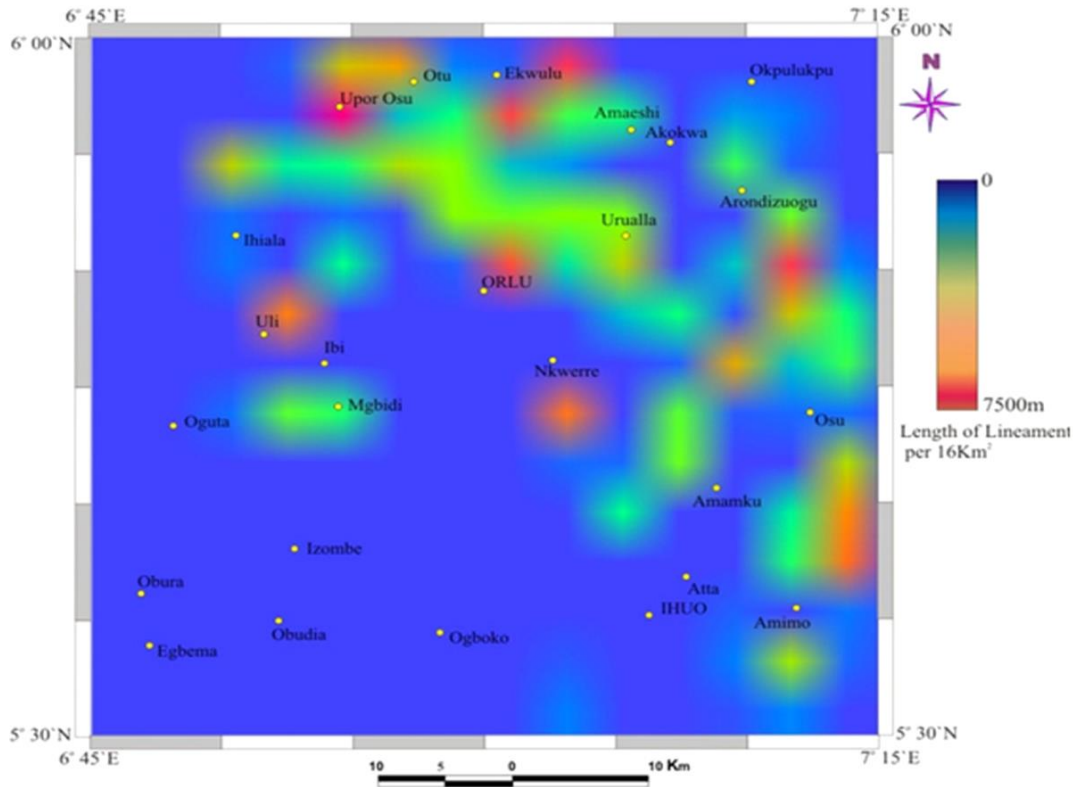


Figure 8: NDVI map of the study area

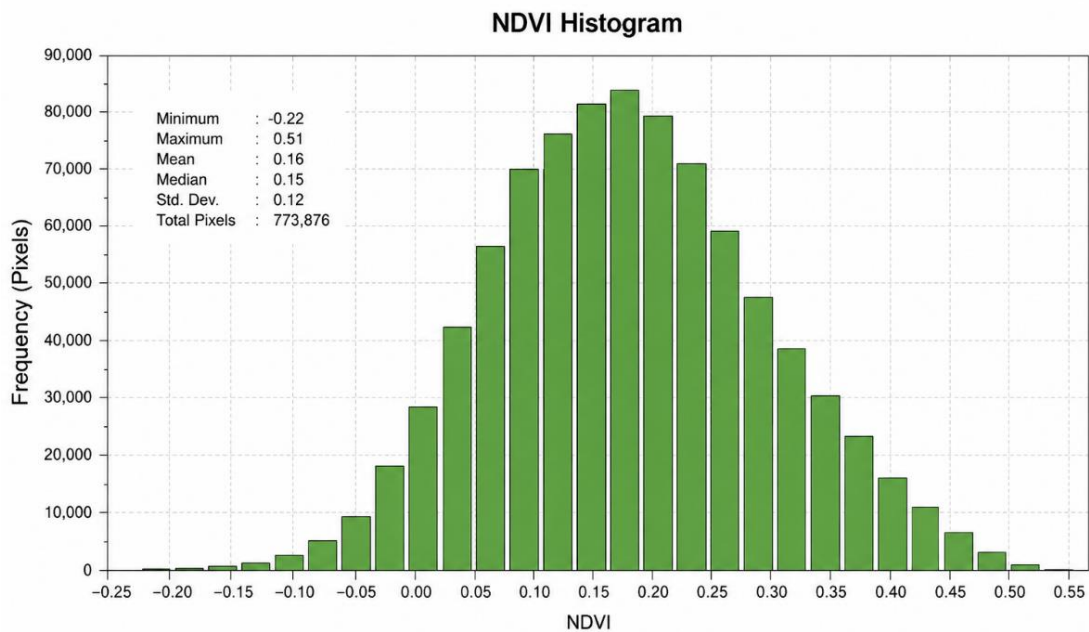


Figure 9: NDVI histogram. NDVI values range from -0.22 to 0.51, with a mean value of 0.16, indicating moderate vegetation cover across the study area.

Colour Composites

The RGB752 composite proved particularly effective in differentiating vegetated surfaces, urban settlements, and exposed sandy formations (Figure 10a). Green tonal

signatures corresponded to densely vegetated agricultural zones, while magenta and lavender tones represented exposed sandy surfaces and erosion-prone terrains. The RGB357 composite (Figure 10b) showed green shades

for vegetation and light brown for bare soil. The RGB751 composite (Figure 10c) displayed shades of blue for vegetated areas. These composite images corroborated

the NDVI classification, consistently identifying the same zones as high agricultural potential.

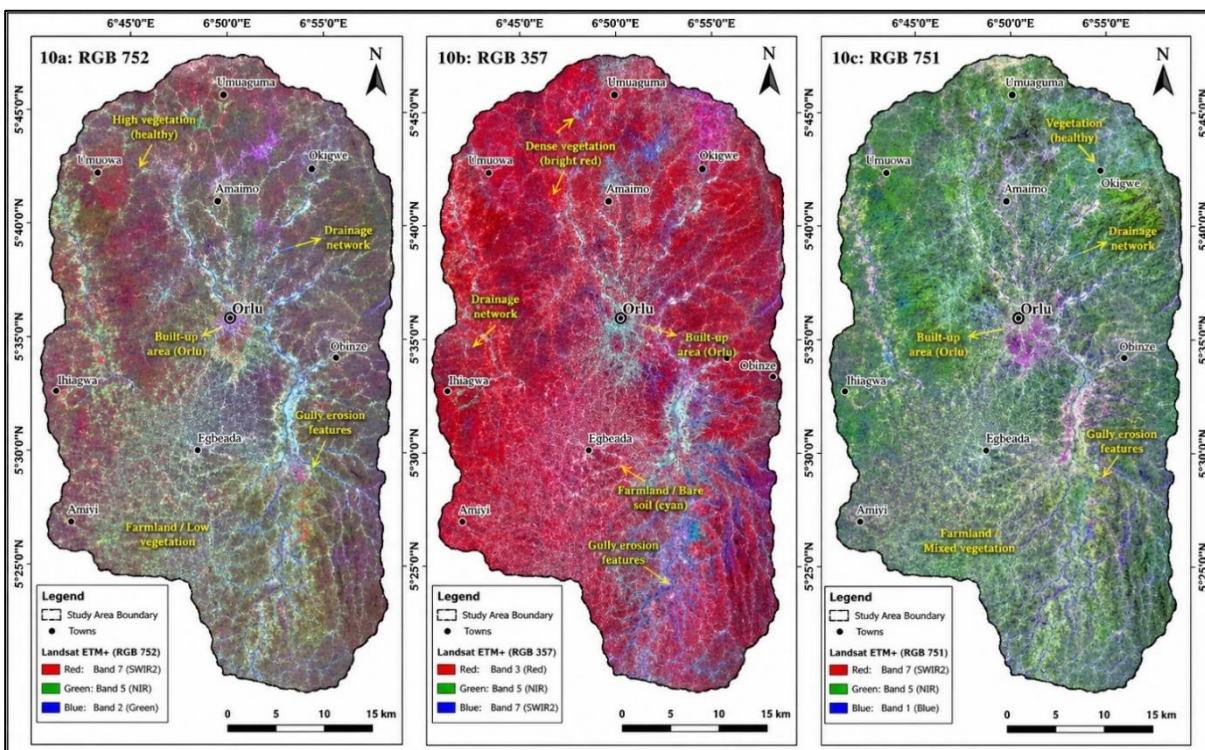


Figure 10: Colour composite maps of the Orlu and environs derived from Landsat ETM+ imagery (10a – RGB 752, 10b – RGB 357, 10c – RGB 751)

Agricultural Suitability Mapping

Using the weighted multi-criteria overlay (NDVI weight 0.5, slope weight 0.3, lineament density weight 0.2), agricultural suitability was classified as high, moderate, or low (Table 4). High-suitability zones (21.1% of area, 163.2 km²) were located mainly in the southern and central parts, characterised by dense vegetation (NDVI > 0.30), gentle slopes (<5°), and low lineament density (<1.0 km/km²). Moderate-suitability zones (42.5%, 328.9 km²) occurred in transitional areas with moderate

vegetation, slopes of 5–15°, and lineament density of 1.0–1.8 km/km². Low-suitability zones (36.4%, 281.7 km²) were concentrated in the northeast, corresponding to high lineament density (>1.8 km/km²), steep slopes (>15°), and sparse vegetation (NDVI < 0.19). The suitability distribution pattern showed strong spatial agreement with observed vegetation density and terrain stability indicators derived from the DEM and RGB composites.

Table 4: Agricultural suitability classes and areal extent

Suitability class	Area (km ²)	Percentage (%)	NDVI range	Slope range	Lineament density (km/km ²)
High	163.2	21.1	>0.30	<5°	<1.0
Moderate	328.9	42.5	0.19–0.30	5–15°	1.0–1.8
Low	281.7	36.4	<0.19	>15°	>1.8
Total	773.8	100			

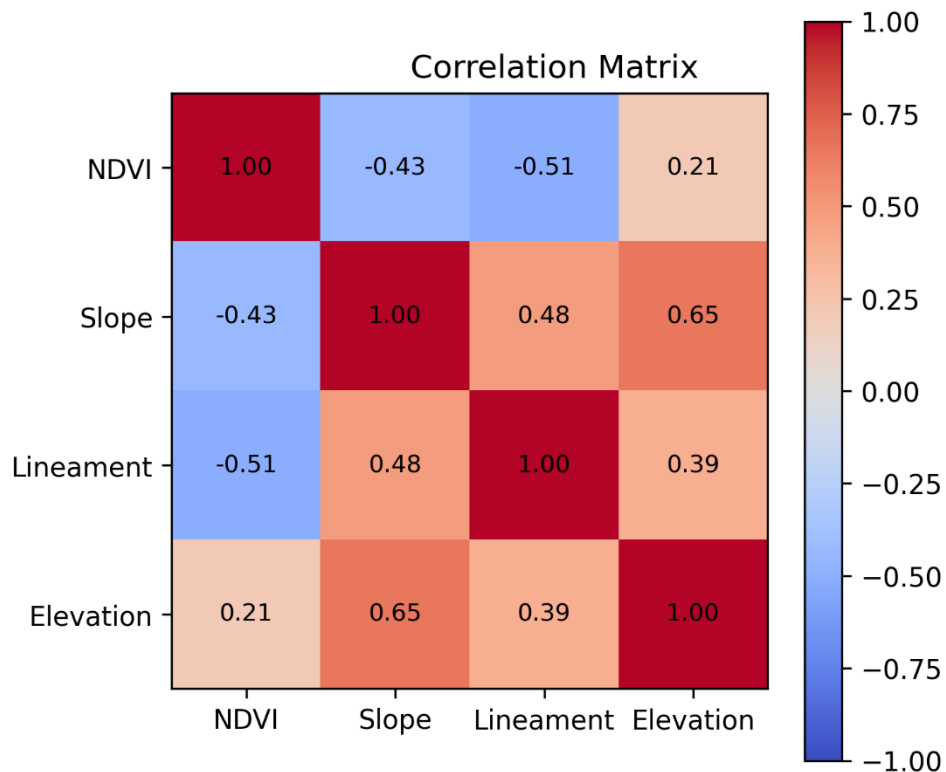


Figure 11: Correlation matrix of environmental variables

Discussion

Topographic Control on Agricultural Suitability

The DEM and slope analysis revealed that steep slopes ($>15^\circ$), especially along the Awka-Orlu Cuesta, are associated with increased runoff and erosion, reducing soil depth and nutrient availability. Steep terrain gradients accelerate overland flow and reduce infiltration residence time, thereby intensifying sheet erosion, nutrient depletion, and sediment transport processes. This finding aligns with earlier reports in southeastern Nigeria where gully erosion is concentrated along cuesta scarps (Onwubuariri, et al., 2018a; Obasi et al., 2023). The correlation analysis (Figure 11) showed a moderate negative correlation ($r = -0.43$) between slope gradient and NDVI, confirming that steeper terrain supports less vegetation cover. Gentle slopes ($<5^\circ$) in the low-lying plains retain more moisture and topsoil, supporting denser vegetation and higher agricultural potential. Therefore, agricultural expansion should prioritise gentle terrains unless terracing and soil conservation measures are implemented.

Structural Influence of Lineaments on Land Degradation

The high lineament density in the northeastern part (reaching 2.8 km/km^2) indicates structural weakness that facilitates the development of erosion gullies. Lineaments act as preferential pathways for surface runoff, accelerating soil loss and making agricultural

activities unsustainable (Obasi et al., 2023, Onwubuariri, 2018c). Structurally controlled drainage alignment further confirms that fracture systems significantly influence hydrological pathways and localized land degradation processes within the study area. The correlation between lineament density and low NDVI values ($r = -0.51$, $p < 0.01$) confirms that structurally controlled erosion is a major constraint to agriculture in these zones. Future erosion control measures should consider the orientation and density of lineaments to design effective drainage diversion structures.

NDVI as a Proxy for Soil Fertility and Crop Potential

NDVI values >0.30 consistently indicated healthy vegetation cover, which is strongly correlated with adequate soil organic matter, moisture, and nutrient availability (Radočaj et al., 2023; Onwubuariri, 2018b). The high-suitability zones identified by NDVI alone (21.1%) agreed well with the weighted overlay-based suitability map (21.1%), validating the use of NDVI as a rapid assessment tool for agricultural potential. However, NDVI alone cannot capture all factors (e.g., soil chemical properties, access to irrigation, management history), which is why the integration with topography and lineament density improved the reliability of the suitability classification. Nevertheless, NDVI saturation may occur in densely vegetated environments (values approaching 0.51 in this study), potentially limiting sensitivity under very high biomass conditions.

Comparison with Previous Studies

Our findings are consistent with those of Olorunfemi et al. (2021) in southwestern Nigeria, where NDVI combined with slope analysis successfully mapped agricultural suitability. Similarly, Adepoju et al. (2024) used Landsat NDVI to monitor cropland degradation in the Niger Delta. This study extends these approaches by incorporating lineament density and providing quantitative correlation statistics, which is particularly important in erosion-prone sedimentary terrains like Orlu. The proportion of high-suitability land (21.1%) is comparable to values reported for similar geological terrains in sub-Saharan Africa (range 15–30%), suggesting that the study area has moderate but constrained agricultural potential.

Limitations and Future Research

This study has several limitations that should be acknowledged. First, no field soil sampling or ground-truthing of NDVI classes was conducted due to resource constraints; future work should include soil nutrient analysis (N, P, K, organic carbon) and crop yield data to validate suitability classes. Second, the Landsat image used represents a single dry-season snapshot (December 2021); seasonal and inter-annual NDVI variations should be examined using multi-temporal time series (e.g., Landsat 8 and 9, Sentinel-2) to capture phenological dynamics. Third, the agricultural suitability model did not incorporate socio-economic factors (e.g., market access, land tenure, labour availability), which influence actual land-use decisions and adoption of conservation practices. Fourth, the absence of quantitative classification accuracy assessment (e.g., confusion matrix, overall accuracy, kappa coefficient) represents a methodological limitation that should be addressed in future investigations through field validation points and error matrix analysis. Additionally, the lineament extraction process involved some degree of interpreter subjectivity despite cross-validation procedures; future studies could employ automated lineament extraction algorithms (e.g., LINE module in PCI Geomatica) to improve reproducibility. Finally, the weighted criteria (NDVI 0.5, slope 0.3, lineament density 0.2) were assigned based on literature review rather than analytical hierarchy process (AHP) with expert elicitation; future applications of AHP would provide more defensible weight assignments.

CONCLUSION

This study successfully integrated remote sensing and GIS techniques to evaluate agricultural suitability within Orlu and its environs, southeastern Nigeria. NDVI, DEM, lineament, drainage, slope, and RGB composite analyses revealed that agricultural productivity within the region is strongly influenced by vegetation density, topography, structural lineaments, and drainage

configuration. NDVI values ranged from -0.22 to 0.51 (mean = 0.18 , SD = 0.14), with dense vegetation (NDVI > 0.30) covering 21.1% (163.2 km²) of the area, indicating high agricultural suitability. Correlation analysis revealed moderate negative relationships between NDVI and both slope gradient ($r = -0.43$) and lineament density ($r = -0.51$), confirming the constraining effects of these variables on agricultural potential. High lineament density (up to 2.8 km/km²) and steep slopes (>15°) characterise the northeastern zone, which is erosion-prone and unsuitable for sustainable agriculture. The weighted multi-criteria overlay approach identified high-suitability zones (21.1%, 163.2 km²), moderate-suitability zones (42.5%, 328.9 km²), and low-suitability zones (36.4%, 281.7 km²).

The findings highlight the importance of integrating terrain stability assessment into agricultural land-use planning within erosion-prone tropical environments. The generated suitability maps may support regional agricultural policy formulation, erosion-risk mitigation, precision farming initiatives, and sustainable watershed management programs. These findings provide valuable baseline information for agricultural planning, erosion control, and sustainable land management within the region. Future studies should incorporate field-based soil analyses, multi-temporal satellite datasets, AHP-based criteria weighting, quantitative accuracy assessment using confusion matrices and ground validation points, and machine learning classification algorithms (e.g., Random Forest, Support Vector Machines) to improve agricultural suitability prediction and monitoring.

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