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# GIS-Based Multi-Criteria Modelling of Soil Erosion Susceptibility Using AHP in Ikere-Ekiti, Southwestern Nigeria

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## ABSTRACT

Soil erosion remains a critical environmental challenge in tropical regions, particularly in areas experiencing rapid land-use change and geomorphic instability. This study presents a GIS-based multi-criteria modelling approach for assessing soil erosion susceptibility in Ikere-Ekiti, Southwestern Nigeria. Twelve conditioning factors-land use/land cover (LULC), slope, aspect, elevation, drainage density, soil type, rainfall, Normalized Difference Vegetation Index (NDVI), geology, rainfall erosivity (R-factor), soil erodibility (K-factor), and Topographic Wetness Index (TWI)-were integrated using an Analytic Hierarchy Process (AHP) framework. Spatial datasets derived from ASTER DEM, Landsat 8 imagery, soil and geological maps, and rainfall records were standardized and weighted using pairwise comparison, with model consistency validated (CR = 0.06). A weighted overlay model was employed to generate erosion susceptibility zones. Results indicate that low and moderate susceptibility zones dominate (90.48%), while high and very high-risk areas account for 4.50% and 0.03%, respectively. High-risk zones are strongly associated with steep slopes, high drainage density, sparse vegetation, and erodible soils. The study demonstrates the robustness of GIS-based multi-criteria modelling in erosion prediction and provides a decision-support framework for sustainable land management in tropical environments.

## INTRODUCTION

Soil is a fundamental component of terrestrial ecosystems, playing a central role in biogeochemical cycling, hydrological regulation, and the provision of ecosystem services essential for environmental sustainability and human well-being (Berendse *et al.*, 2015; Bekele *et al.*, 2022). In agrarian economies, soil quality directly influences agricultural productivity, food security, and socio-economic stability (Tesema, 2015; Gashaw *et al.*, 2018). However, soil degradation defined as the deterioration of soil's physical, chemical, and biological properties has emerged as a critical global environmental issue, with soil erosion representing one of its most pervasive and detrimental forms (Meshesha *et al.*, 2012; Pal & Chakrabortty, 2022).

Soil erosion involves the detachment, transport, and deposition of soil particles by erosive agents such as water and wind. This process is governed by complex interactions among climatic factors (rainfall intensity), topography, soil characteristics, and vegetation cover, as well as anthropogenic influences including deforestation, overgrazing, and unsustainable land-use practices (Ndukwe *et al.*, 2013; Raissouni *et al.*, 2012). While erosion is a natural geomorphic process, its acceleration due to human activities has led to severe environmental and socio-economic consequences, including depletion of fertile topsoil, reduced agricultural yields, sedimentation of water bodies, and increased flood risks (Das *et al.*, 2018; Marzen *et al.*, 2019).

The impacts of soil erosion are particularly pronounced in Sub-Saharan Africa, where land degradation poses a significant threat to livelihoods dependent on rain-fed agriculture (Thiombiano & Tourino-Soto, 2007; Zanchin *et al.*, 2021). In Nigeria, erosion especially gully erosion has resulted in extensive environmental degradation, destruction of infrastructure, and loss of arable land (Ndukwe *et al.*, 2013; Ibe & Okeke, 2016; World Bank, 2021). In southwestern Nigeria, particularly Ekiti State, rapid population growth, land-use change, and geomorphological conditions have intensified erosion processes (Olorunfemi & Fasinmirin, 2017; Olorunfemi *et al.*, 2020).

Ikere-Ekiti Local Government Area represents a critical erosion-prone environment where both natural and anthropogenic factors interact to increase landscape vulnerability. The region is underlain by basement complex geology and dominated by lateritic soils, which, although relatively stable under undisturbed conditions, become highly susceptible to erosion under repeated wetting, compaction, and surface disturbance (Talabi *et al.*, 2016; Lamidi, 2022). Previous studies have identified key drivers of erosion in the area, including slope gradient, vegetation loss, inadequate drainage infrastructure, and human activities such as sand mining and road construction (Ogundare, 2016; Owolabi, 2019). Despite these contributions, existing studies in Ikere-

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Ekiti are largely descriptive and lack the integration of multiple controlling factors within a quantitative and spatially explicit modelling framework. There remains a significant gap in the application of geospatial and predictive modelling approaches to evaluate the relative influence and interaction of topographic, climatic, soil, and land-use variables on erosion susceptibility at a local scale.

To address this gap, the present study adopts an integrated modelling approach to assess soil erosion dynamics in Ikere-Ekiti. The specific objectives are to:

- Identify and quantify the key determinants of soil erosion, and
- Develop a spatially explicit erosion susceptibility map using multi-criteria and geospatial analysis techniques.

## MATERIALS AND METHODS

### Study Area

Ikere-Ekiti Local Government Area is located between latitudes 7°28'00"N and 7°38'00"N, and longitudes 5°10'00"E and 5°20'00"E (Fig. 1), at an average elevation of approximately 381 m above sea level. The area is bounded by Ado-Ekiti Local Government Area to the north, Akure North to the south, Ise/Orun to the east, and Ekiti South-West to the west. According to the 2006 national census, the population was 147,355, with projections indicating an increase to approximately 239,546 by 2025.

The study area lies within the tropical wet-and-dry climate (Köppen Aw classification), characterized by two distinct seasons: a rainy season (April–October) and a dry season (November–March). Mean annual temperature ranges between 26°C and 28°C, while annual rainfall varies from 1,300 mm to 1,600 mm. These climatic conditions support both perennial and arable agriculture, including cocoa, oil palm, yam, cassava, and maize cultivation (Ekiti State Government, 2021).

Geologically, Ikere-Ekiti is underlain by Precambrian basement complex rocks, which give rise to highly weathered tropical soils, predominantly ferrallitic soils (Oxisols and Ultisols). These soils are generally deep and well-drained but are highly susceptible to erosion when exposed due to their structural instability under intense rainfall.

Physiographically, the area forms part of the Western Uplands (Yoruba Hills), characterized by undulating to hilly terrain with isolated inselbergs and ridges, including prominent features such as Orole and Olosunta hills. The terrain covers approximately 202 km² and exhibits varying slope gradients that significantly influence runoff generation and sediment transport.

The drainage pattern is predominantly dendritic to sub-dendritic, reflecting the underlying lithology and structural controls. Streams in the area exhibit variable gradients, with steeper channels associated with rocky outcrops and gentler slopes in lowland areas, thereby influencing erosion processes and sediment redistribution.

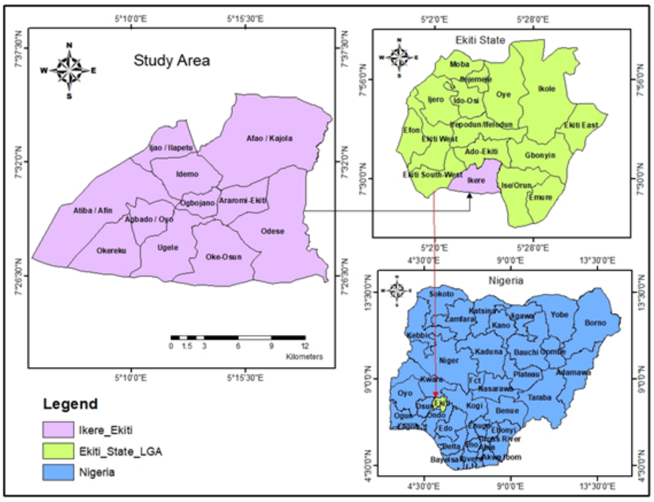


**Figure 1:** Location of the Study Area.

### Data Analysis

Assessment of soil erosion potential requires the integration of multiple environmental controls, including land use/land cover (LULC), topography, climate, soil properties, and lithology. This study employed a combination of primary and secondary datasets obtained from diverse sources (Table 1). The methodology workflow is shown in Figure 2.

LULC classification and vegetation assessment were derived from Landsat 8 OLI imagery with a spatial resolution of 30 m, acquired from the United States Geological Survey archive. A false-colour composite using bands 5 (Near Infrared: 0.845–0.885 μm), 4 (Red: 0.630–0.680 μm), and 3 (Green: 0.525–0.600 μm) was generated to enhance feature discrimination. Prior to analysis, the imagery underwent standard pre-processing procedures, including atmospheric correction, radiometric calibration, and layer stacking to improve spectral fidelity. Supervised classification was performed using the Maximum Likelihood Classifier (MLC), resulting in five LULC classes: built-up areas, vegetation, farmland, bare surfaces, and rocky outcrops. Vegetation condition was further quantified using the Normalized Difference Vegetation Index (NDVI), computed in ArcGIS from bands 4 and 5.

Topographic variables were extracted from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) at 30 m resolution, sourced from the USGS database. Using spatial analyst tools in ArcGIS 10.8, terrain derivatives including slope, aspect, elevation, drainage density, and the Topographic Wetness Index (TWI) were generated.

Primary soil data were obtained through field sampling. A total of 33 soil samples were collected across eleven administrative wards (three samples per ward) and analyzed in the laboratory to determine soil texture and organic matter content using standard procedures. Rainfall data were obtained from the Climate Research Unit archive. Both soil and rainfall datasets were spatially interpolated using the Inverse Distance Weighting (IDW) method within the GIS environment, following established approaches (Tunçay *et al.*, 2014). These datasets were subsequently used to derive the soil erodibility (K-factor) and rainfall erosivity (R-factor) components.

**Table 1:** Types and sources of data

| Data Type | Resolution | Path/Row | Source |
|---|---|---|---|
| L8OLI//TIRS | 30 M | 190/055 | https://glovis.usgs.gov |
| SRTM DEM | 30 M | - | https://glovis.usgs.gov |
| Shapefile | - | - | http://grid3.gov.ng. |
| Soil sample | - | - | Field-based measurement/lab analysis |
| Rainfall | - | - | Climate Research Unit (CRU) |
| Geology | - | - | Nigerian Geological Surveys (NGS) |

**Determination of Weights**

The Analytical Hierarchical Processing (AHP) technique, which was suggested by Saaty (1980), was adopted to rank the causative factors of soil erosion in the area. Generally, the technique involves a pairwise comparison matrix, weights calculation, and Consistency Ratio (CR) checking. The causative factors considered in this study were based on the topography, hydrological, soil characteristics, climatic factors, vegetation condition, lithology and land cover of the area. These factors include rainfall, land cover, geology, elevation, Topographic Wetness Index (TWI), Soil, Slope, drainage density, NDVI, R-factor, K-factor, and aspects, respectively. The factors and the respective properties were weighted and placed on the 1-9 scales of Saaty (1980) (Table 2).

**Table 2:** 1-9 Scales Pair-wise Comparisons

| Importance Scale | Definition of Scale |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2, 4, 6, 8 | Intermediate values |

*Source: Saaty's (1980)*

The pair-wise comparison was checked on Saaty's Consistency Ratio

$$CR=\frac{CI}{RI} \qquad (1)$$

CI = Consistency Index, and it is the reflection of the consistency of the judgment

RI = Random Index (dependents on n [sample size]).

The CI was calculated using the following formula (Consistency ratio):

$$CT=\frac{\lambda max-n}{n-1} \qquad (2)$$

Where λmax= maximum Eigen value of the matrix

The judgment was considered using CR for values between $0 \leq CR \leq 0.1$ with a value of zero (0) being the most consistent, (Saaty, 1980).

All thematic layers were reclassified based on standardized rating schemes, and a weighted overlay analysis was conducted in ArcGIS to integrate all factors and produce the soil erosion potential risk map for the study area.

## RESULTS AND DISCUSSIONS

**Land Use/Land Cover**

The land use/land cover (LULC) classification (Figure 2) identifies five dominant classes: vegetation, farmland, built-up areas, bare surfaces, and rocky outcrops. Vegetation is the most extensive class, covering 18,241.37 ha (65.4%) and predominantly corresponds to low-erosion-risk zones due to its role in reducing runoff and enhancing soil stability (Morgan, 2005). Similar relationships have been reported in southwestern Nigeria (Arekhi *et al.*, 2012; Akinyemi *et al.*, 2020).

Farmland (11.6%) exhibits moderate to high susceptibility due to soil disturbance and seasonal exposure, with risk intensifying where it coincides with steep slopes and high drainage density. Built-up areas (9.3%) influence erosion indirectly by increasing impervious surfaces and runoff, aligning mainly with moderate-risk zones. In contrast, bare surfaces (6.3%) show the highest susceptibility and strongly correspond with high and very high-risk zones due to the absence of protective cover. Rocky outcrops (7.4%) contribute minimally to direct erosion but enhance runoff concentration, influencing downslope erosion patterns.

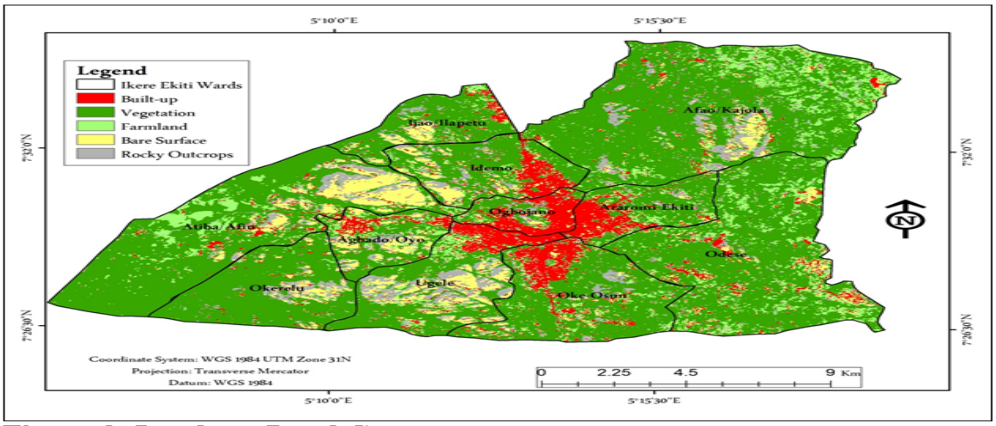


**Figure 2**: Land use/Land Cover map

### Soil Characteristics and Erodibility (K-factor)

Soil distribution (Figure 3) indicates the dominance of silt soils, followed by sandy and clay soils. Silt soils, prevalent across central and northern wards, are moderately erodible and prone to sheet erosion under intense rainfall. Sandy soils, concentrated in western and eastern areas, exhibit higher susceptibility due to loose structure and low cohesion, contributing to rill and gully formation. Clay soils, although less extensive, show lower erodibility due to higher cohesion but may promote runoff under poor drainage conditions.

The K-factor (Figure 4) reflects this pattern, with sandy soils showing the highest values (0.22–0.25), silt soils moderate values (0.20–0.21), and clay soils the lowest (0.16–0.19). These variations confirm that soil texture is a critical determinant of erosion susceptibility, particularly when combined with rainfall intensity and land cover conditions.

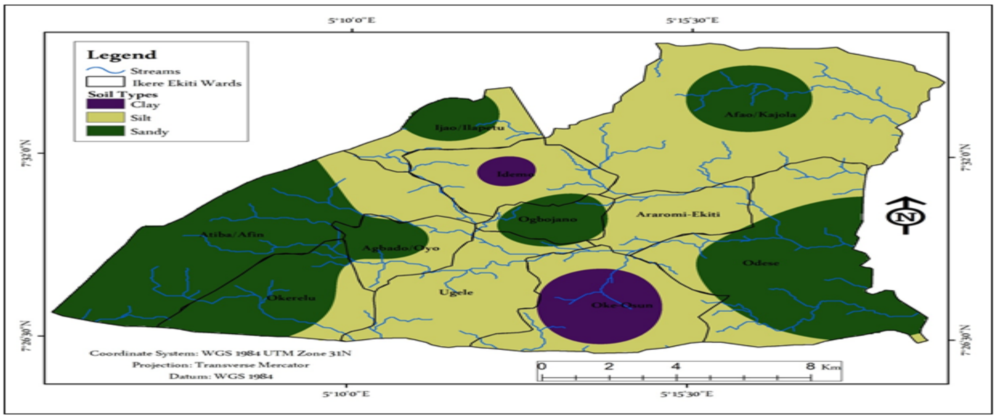


**Figure 3:** Soil Types

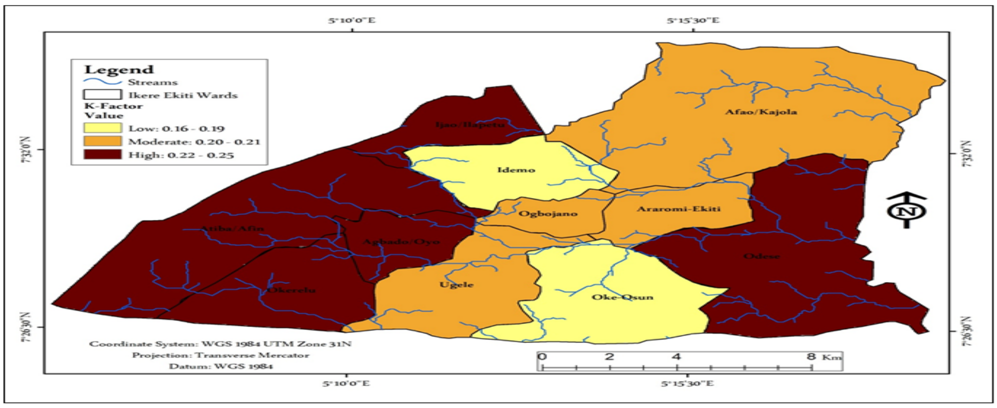


**Figure 4:** K-Factor

### Topographic Factors

### Slope, Elevation and Aspect

Slope (Figure 5) is a dominant factor influencing erosion dynamics. Low slopes (0-7.98°) dominate the area and are associated with reduced runoff velocity and lower erosion risk. Moderate slopes (7.98-20.37°) show increased susceptibility to sheet and rill erosion, while steep slopes (>20.37°) significantly enhance runoff velocity and soil detachment, corresponding closely with high-risk zones.

Elevation (Figure 6) ranges from 320 to 700 m and reflects an undulating terrain. High-elevation areas coincide with steeper slopes and increased erosion potential, while lowland zones are associated with sediment deposition and flood risks.

Aspect (Figure 7) shows a heterogeneous distribution with no dominant orientation. While its influence is less pronounced compared to slope and drainage, variations in solar exposure affect soil moisture and vegetation distribution, indirectly influencing erosion processes.

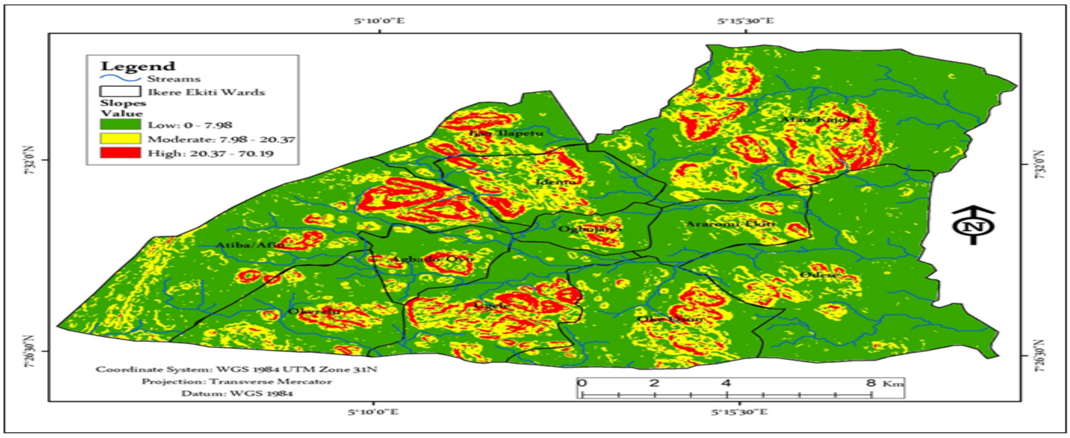


**Figure 5:** Slope map

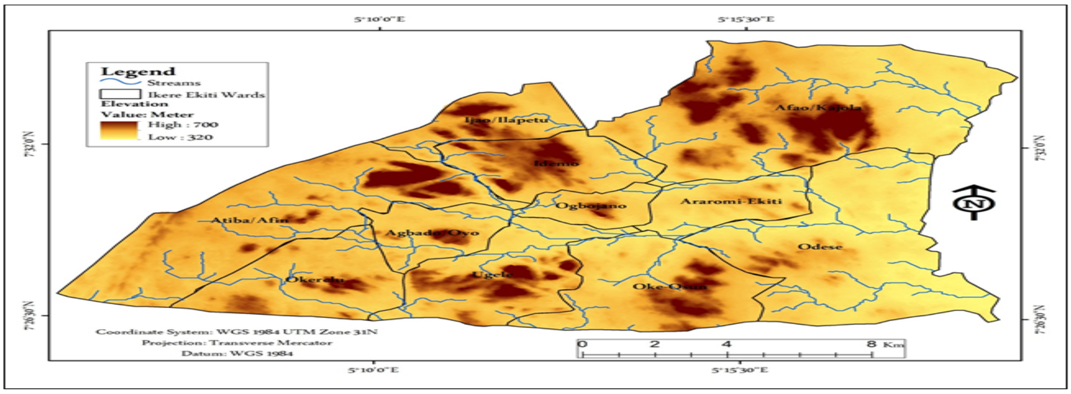


**Figure 6**: Elevation map

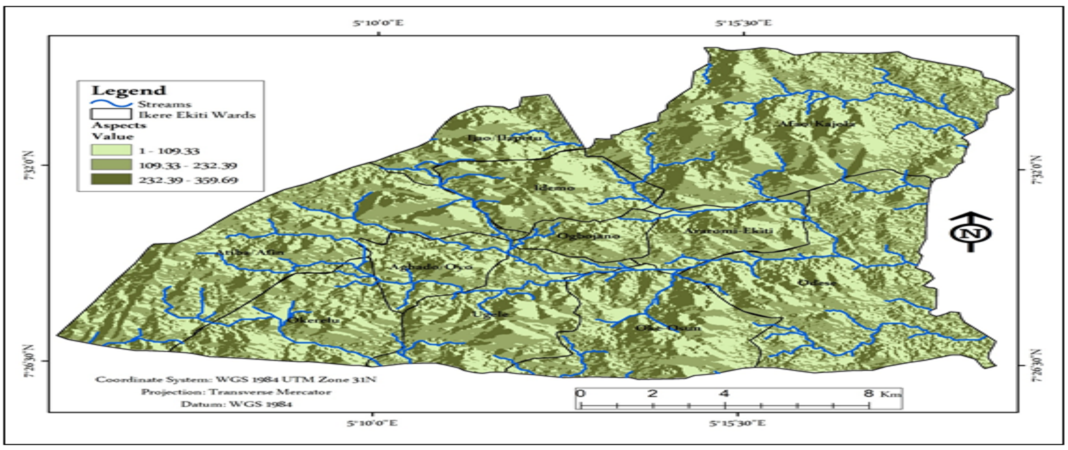


**Figure 7**: Aspects map

## Hydrological Factors

### Drainage Density and TWI

Drainage density (Figure 9) varies from low to high across the study area. High drainage density zones, concentrated along stream networks, indicate rapid runoff concentration and are strongly associated with erosion hotspots. Moderate zones represent transitional areas, while low drainage density areas correspond to reduced runoff and lower erosion risk.

The Topographic Wetness Index (TWI) (Figure 10) further highlights areas of water accumulation. High TWI values occur along valley bottoms and drainage channels, indicating zones of soil saturation and increased erosion potential. Low TWI values in upland areas reflect rapid drainage and reduced moisture retention.

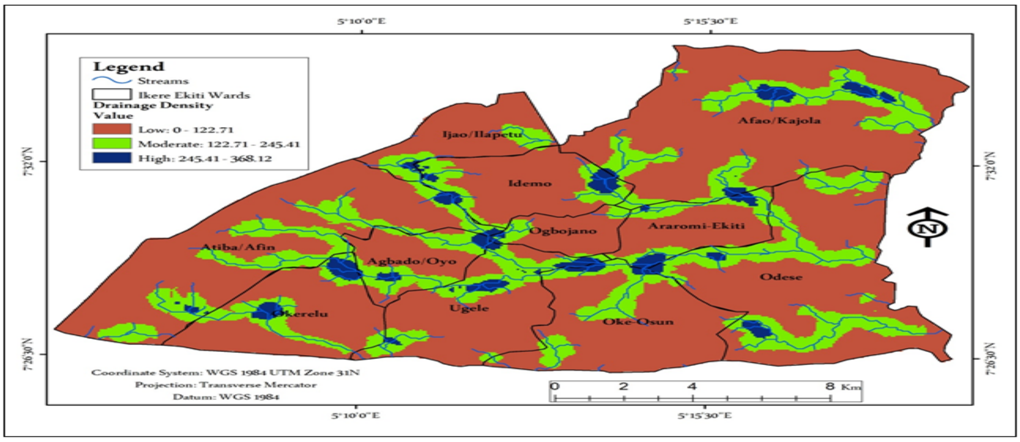


**Figure 8**: Drainage Density map

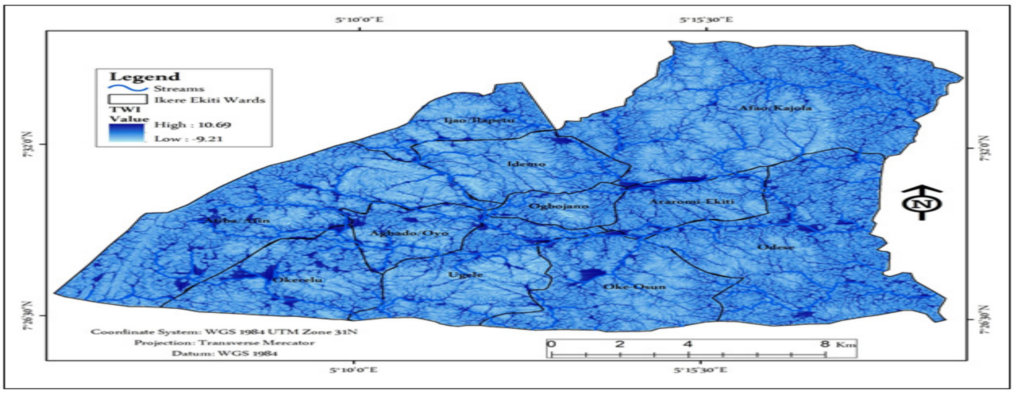


**Figure 9**: Topographic Wetness Index

### Vegetation Condition (NDVI)

The NDVI distribution (Figure 11) ranges from -0.03 to 0.48, indicating varying vegetation density. High NDVI values correspond to dense vegetation and low erosion risk, as these areas benefit from improved soil protection and reduced runoff. Conversely, low NDVI values are concentrated in urbanized and degraded zones, where reduced vegetation cover increases susceptibility to erosion.

This spatial pattern reinforces the role of vegetation as a key controlling factor in erosion processes, particularly when interacting with slope and rainfall.

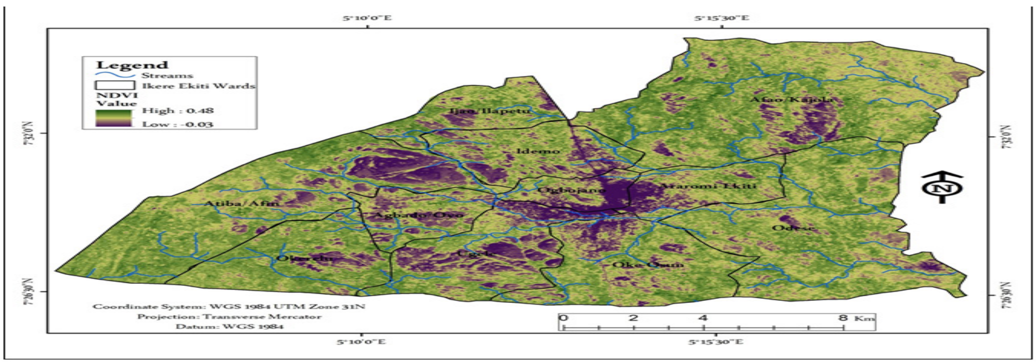


**Figure 10:** NDVI map

**Geology**

The geology of the study area (Figure 12) comprises granite, migmatite, quartzite, and associated complexes. Weathered granitic formations produce sandy soils with high erodibility, while migmatite-derived soils are structurally weak and prone to erosion under disturbance. Quartzite ridges, although resistant, promote rapid runoff due to steep slopes, increasing erosion in adjacent areas. The influence of geology is therefore indirect, operating through its control on soil formation and terrain characteristics.

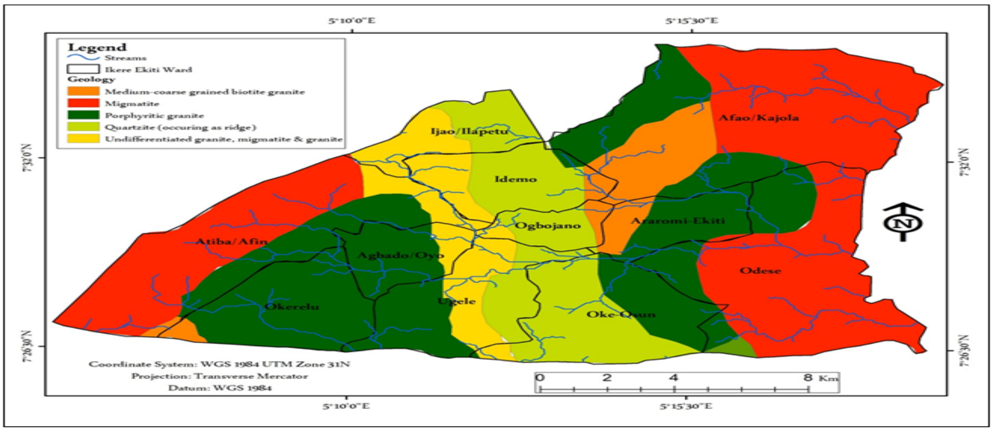


**Figure 11**: Geology map

**Rainfall Erosivity (R-factor)**

Rainfall erosivity values range from 632.50 to 742.50 (Figure 13), indicating moderate to high erosive potential. High R-factor zones, located in northern and eastern parts, correspond to areas of intense rainfall and increased erosion risk. Moderate zones dominate much of the study area, while low R-factor areas show reduced rainfall impact but remain susceptible when combined with other factors such as slope and soil type.

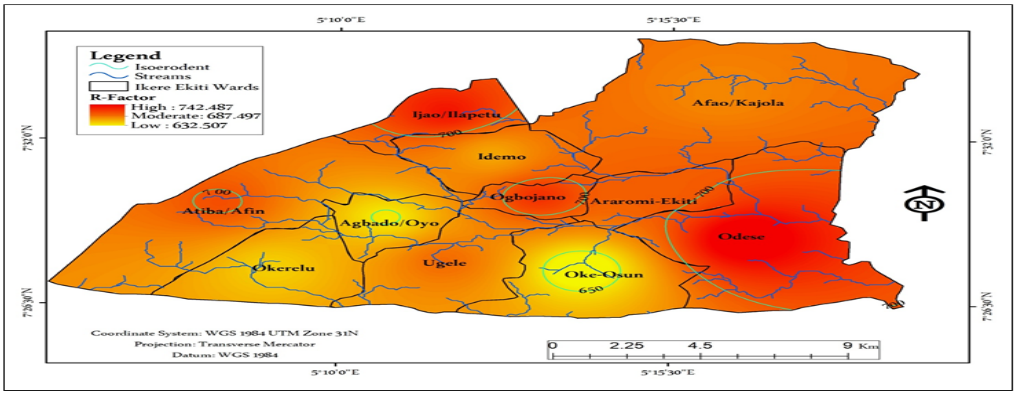


**Figure 12**: R-Factor map

**Relative Importance of Erosion Factors (AHP Results)**

The pair-wise comparison matrix and normalized weight derived from the AHP analysis (Table 3) indicates that slope (23%) is the most dominant factor controlling soil erosion susceptibility in the study area. This reflects the strong influence of terrain steepness on runoff velocity and sediment transport. Rainfall erosivity (14%) and land use/land cover (10%) also show high relative importance because of their direct effects on rainfall impact energy and vegetation protection. Other significant contributors include NDVI (9%), soil type (8%), and rainfall (8%), while Moderate influence is associated with drainage density (7%) and elevation (6%), while geology (5%), TWI (5%), aspect (3%), and soil erodibility factor (2%) contribute comparatively lower effects to erosion processes.

The derived weights satisfy the Saaty's Analytical Hierarchy Process (AHP) principle, where higher-ranked factors consistently dominate lower-ranked variables in the pair-wise comparison structure. This ranking emphasizes the dominance of topographic and hydrological controls, with land cover acting as a key modifying factor. The results are consistent with erosion modelling studies across Nigeria, where slope and rainfall are primary drivers.

The calculated Consistency Ratio (CR = 0.054) is below the acceptable threshold of 0.10 recommended by Saaty, indicating that the pair-wise judgments are logically consistent and reliable for multi-criteria decision-making. This confirms that the assigned weights for slope, rainfall erosivity, LULC, NDVI, soil type, and other conditioning factors are internally coherent and suitable for erosion susceptibility modelling.

The obtained CR value (0.054) compares favourably with values reported in previous erosion susceptibility and environmental hazard studies conducted in Nigeria and globally. For example, a recent soil erosion risk assessment in Isuikwuato, south-eastern Nigeria reported a CR value of 0.06, confirming strong consistency in expert-based weighting (Ike *et al.*, 2025). Similarly, gully erosion susceptibility mapping in Gombe State, north-eastern Nigeria achieved acceptable consistency values below the 0.10 threshold recommended for AHP applications (Igwe *et al.*, 2020).

Globally, most GIS-based AHP studies generally report CR values between 0.03 and 0.09 for reliable environmental and hazard modelling, indicating acceptable logical consistency in pair-wise comparisons (Saaty, 1980; Zhang *et al.*, 2021). Consequently, the present study demonstrates a robust and dependable weighting structure suitable for soil erosion susceptibility assessment in tropical environments.

**Table 3:** Pair-Wise Comparison Matrix and Normalized weight of Erosion Conditioning Factors

| Factors | SL | RE | LULC | NDVI | ST | RF | DD | EL | GEO | TWI | ASP | KF | Weight (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SL | 1 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 5 | 5 | 7 | 9 | 23 |
| RE | 0.5 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 5 | 7 | 14 |
| LULC | 0.33 | 0.5 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 5 | 10 |
| NDVI | 0.33 | 0.5 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 4 | 9 |
| ST | 0.33 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 4 | 8 |
| RF | 0.33 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 4 | 8 |
| DD | 0.25 | 0.33 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 4 | 7 |
| EL | 0.25 | 0.33 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 2 | 3 | 6 |
| GEO | 0.2 | 0.25 | 0.33 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 2 | 3 | 5 |
| TWI | 0.2 | 0.25 | 0.33 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 2 | 3 | 5 |
| ASP | 0.14 | 0.2 | 0.25 | 0.33 | 0.33 | 0.33 | 0.33 | 0.5 | 0.5 | 0.5 | 1 | 2 | 3 |
| KF | 0.11 | 0.14 | 0.2 | 0.25 | 0.25 | 0.25 | 0.25 | 0.33 | 0.33 | 0.33 | 0.5 | 1 | 2 |

Where SL-Slope, RE-Rainfall erosivity, LULC-Land use/Land cover, NDVI-Normalized Difference Vegetation Index, ST-Soil types, RF-Rainfall, DD-Drainage density, EL-Elevation, GEO-Geology, TWI-Topographic Wetness Index, ASP-Aspect, KF-Soil erodibility factor

### Erosion Susceptibility Mapping

The erosion susceptibility map (Figure 14) classifies the study area into five categories. Low-risk zones dominate (59.95%), followed by moderate-risk areas (30.53%), indicating generally stable environmental conditions. Very low-risk zones account for 4.99%, while high (4.50%) and very high-risk areas (0.03%) are limited but critical (Table 4).

High-risk zones are spatially clustered in areas characterized by steep slopes, high drainage density, sparse vegetation, and erodible soils, particularly in parts of Ijao/Ilapetu, Atiba/Afin, and Ugele. Moderate-risk zones form transitional belts, while low-risk areas are widely distributed across vegetated and gently sloping regions.

Despite their limited extent, high-risk zones represent key erosion hotspots with significant environmental implications, including gully formation and sediment transport. Their identification highlights priority areas for targeted soil conservation and land management interventions.

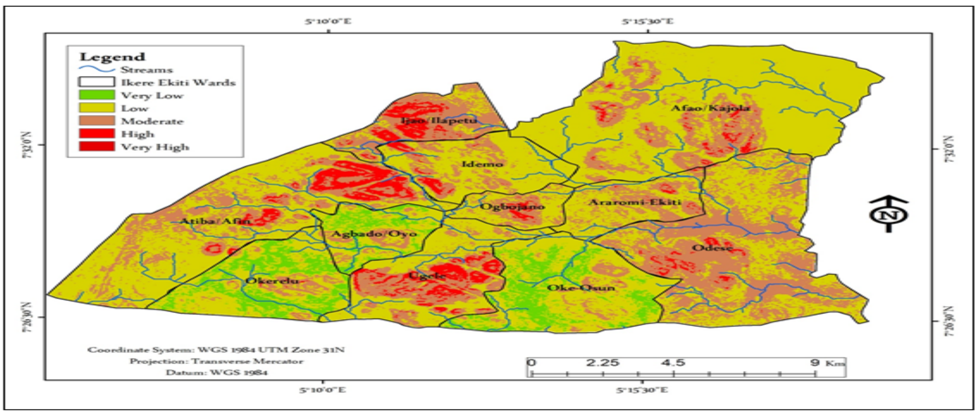


**Figure 13:** Spatial Distribution of Potential Risk Zones

**Table 4:** Potential Soil Erosion Risk Zones

| Risk Class | Risk Area (ha) | Percent (%) |
|---|---|---|
| Very Low | 1396.73 | 4.99 |
| Low | 16748 | 59.95 |
| Moderate | 8528.85 | 30.53 |
| High | 1256.8 | 4.50 |
| Very High | 4.7 | 0.03 |

**Validation**

The Receiver Operating Characteristic (ROC) curve (Figure 15) was used to evaluate the predictive performance of the erosion susceptibility model. Validation was performed using observed erosion locations and randomly generated non-erosion points. The Area Under the Curve (AUC) value obtained was 0.82, indicating good model accuracy. This demonstrates that the model reliably differentiates between erosion-prone and stable areas.

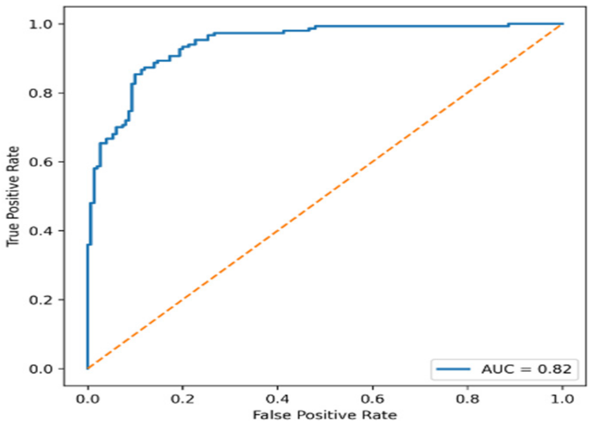


**Figure 14:** Receiver Operating Characteristic-AUC validation curve

## CONCLUSION

This study presents a comprehensive assessment of soil erosion susceptibility in Ikere Ekiti using an integrated GIS-based multi-criteria decision-making approach. By incorporating twelve environmental factors within an AHP framework, the study provides a spatially explicit understanding of erosion dynamics in a tropical basement complex terrain.

The results indicate that the study area is predominantly characterized by low to moderate erosion risk, accounting for approximately 90% of the total land area. However, localized high and very high-risk zones were identified, primarily associated with steep slopes, high drainage density, sparse vegetation cover, and highly erodible soils. These areas, although limited in spatial extent, represent critical erosion hotspots with the potential for severe land degradation, including gully formation and sediment transport.

The AHP analysis revealed that slope (23%), rainfall erosivity (14%), and land use/land cover (10%) are the most influential factors controlling erosion processes in the study area. This highlights the dominant role of topographic and hydrological processes, further exacerbated by anthropogenic land-use practices such as deforestation and intensive agriculture.

The study demonstrates that the integration of remote sensing, GIS, and multi-criteria analysis provides a robust and effective framework for soil erosion modelling. The resulting erosion susceptibility map offers valuable insights for land-use planning, watershed management, and targeted soil conservation interventions.

It is recommended that erosion control strategies-such as afforestation, contour farming, and improved drainage management-be prioritized in identified high-risk zones. Future studies should incorporate temporal analysis and field-based validation to enhance model accuracy and predictive capability.

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