Journal Homepage: www.ijarpr.com ISSN: 3049-0103 (Online)

International Journal of Advance Research Publication and Reviews

Vol 02, Issue 07, pp 472-495, July 2025

A Geospatial Multi-Criteria Approach for Landslide Susceptibility Assessment within Afikpo South Local Government Area, Ebonyi State

Obeji, C. O[1] and Idhoko, K. E[1].

[1]Department of Surveying and Geoinformatics, Nnamdi Azikiwe University Awka, Nigeria.

ABSTRACT

Landslides constitute one of the most destructive geomorphic processes, exerting far-reaching socio-economic and environmental impacts in susceptible regions worldwide. The frequency and magnitude of landslide occurrences have increased significantly in recent decades, driven by evolving climatic patterns and intensifying anthropogenic interventions on environmentally sensitive terrains. This study aimed at a geospatial multi-criteria approach for landslide susceptibility assessment within Afikpo South Local Government Area, Ebonyi State. Its objectives are to: identify and select the key conditioning factors influencing landslide risk in the study area; assess and rank the relative importance of the conditioning factors using the Entropy Weighting; classify the ranked conditioning factors based on their levels of landslide risk and delineate landslide risk zones through a weighted linear combination. The methodology incorporated five conditioning factors: slope, elevation, rainfall, aspect, and geology. Spatial datasets were standardized, reclassified, and weighted using Entropy weighting to produce a composite landslide susceptibility index. The results generated through Weighted Linear Combination (WLC) analysis delineated five risk zones: Very Low Risk, Low Risk, Moderate Risk, High Risk, and Very High Risk. Spatial analysis revealed that the Very Low and Low Risk zones collectively covered over 82% of the study area, indicating widespread terrain stability. Conversely, High and Very High-Risk zones accounted for only 5.91% of the land area, predominantly situated in the southern and southeastern regions, where steep slopes, weathered lithologies, and intensified rainfall exposure elevate the likelihood of slope failure. It is recommended that the landslide susceptibility zones delineated in this study should be adopted by local planning authorities as a basis for regulating infrastructure development. Construction activities should be restricted or closely monitored in high and very high-risk areas to prevent loss of lives and property.

Keywords: Landslide Susceptibility Mapping, Geospatial Analysis, Multi-Criteria Decision Making (MCDM), Entropy, Afikpo South,

1. INTRODUCTION

Landslides are a pervasive form of geomorphic hazard involving the downslope movement of soil, rock, and debris under the influence of gravity. These events are typically triggered by a range of natural and anthropogenic factors including intense rainfall, deforestation, slope saturation, population pressure, and unregulated land-use changes. The impacts of landslides are multifaceted, resulting in fatalities, destruction of infrastructure, environmental degradation, and disruption of socio-economic activities (Glade, Anderson, and Crozier, 2005). Increasing climate variability, particularly shifts in rainfall intensity and distribution, has contributed to the heightened frequency and severity of landslide events globally (Intergovernmental Panel on Climate Change [IPCC], 2021).

While landslide occurrences are relatively less frequent in Nigeria compared to other geologically active regions, the southeastern part of the country especially Ebonyi State exhibits considerable susceptibility. The region’s vulnerability is attributed to its rugged topography, including steep slopes and undulating terrain, as well as anthropogenic influences such as road excavation, agriculture on marginal lands, and poorly planned settlements. Within this context, Afikpo South Local Government Area (LGA) presents a critical case for investigation. The area is characterized by complex slope geomorphology and human-induced land alterations that increase the likelihood of slope failures. Notably, the Ogwuma Edda community has experienced repeated episodes of soil instability, especially during the wet season when increased rainfall saturates the soil, decreasing shear strength and triggering landslides (Ezezika and Adetona, 2011).

Despite the evident hazard exposure, systematic studies focusing on landslide susceptibility in Afikpo South LGA remain scarce. This knowledge deficit constrains local capacity to implement spatially informed hazard mitigation strategies and restricts the development of comprehensive land-use frameworks. As settlements expand toward steeper terrain, the absence of spatial risk models undermines disaster preparedness and resilience planning. There is, therefore, an urgent need to apply geospatial analytical techniques that can synthesize multiple conditioning factors into a coherent susceptibility model.

A growing body of research supports the use of Geographic Information Systems (GIS) and Remote Sensing (RS) in terrain-based hazard assessment. These tools enable the integration of thematic variables such as slope, elevation, geology, aspect, and rainfall within a spatially explicit framework. One particularly useful approach in this regard is contour-based modeling, which utilizes topographic contour lines to derive slope angles and elevation differentials that directly influence slope stability. Studies by Gupta and Joshi (1990) and Ayalew, Yamagishi, Marui, and Kanno (2005) have demonstrated the effectiveness of integrating contour-based data into GIS environments for identifying landslide-prone areas. In the Ethiopian highlands, Ayalew et al. (2005) successfully applied a GIS-based weighted linear combination method to map landslide susceptibility, while Gupta and Joshi (1990) used a similar approach in the Ramganga catchment of the Indian Himalayas.

The application of these models is especially pertinent to Afikpo South LGA, which exhibits comparable geophysical features. The region’s steep gradients, structural geology, and erosional patterns warrant a tailored susceptibility model grounded in empirical data. This study adopts a multi-criteria evaluation framework that leverages entropy weighting to assess landslide susceptibility. By integrating geospatial data layers slope, elevation, aspect, geology, and rainfall this research aims to delineate risk zones and inform targeted intervention strategies.

This approach aligns with global best practices in disaster risk reduction as outlined by the United Nations Office for Disaster Risk Reduction (UNDRR, 2015). The output of this study not only provides a spatial decision support system for stakeholders within Afikpo South but also contributes to the broader discourse on sustainable development planning in environmentally sensitive areas. Moreover, it offers a transferable methodology applicable to other regions of Nigeria that are character

Landslides constitute one of the most destructive geomorphic processes, exerting far-reaching socio-economic and environmental impacts in susceptible regions worldwide. The frequency and magnitude of landslide occurrences have increased significantly in recent decades, driven by evolving climatic patterns and intensifying anthropogenic interventions on environmentally sensitive terrains (Sophonou, Adimora, and Ekpenyong, 2015). In Nigeria, the southeastern geopolitical zone, particularly Ebonyi State, has shown heightened exposure to landslide events. This vulnerability has been linked to factors such as intensified precipitation regimes, slope instability, deforestation, and the prevalence of unregulated land-use practices (Ezezika and Adetona, 2011).

Afikpo South Local Government Area typifies this high-risk landscape due to its topographic complexity, characterized by steep gradients, variable relief, and seasonal rainfall intensity. These physiographic attributes, when coupled with unsustainable land-use practices, create conditions conducive to recurrent slope failures. A critical area of concern is the Ogwuma Edda community, where repeated landslide episodes have resulted in the destruction of infrastructure, displacement of residents, and the disruption of essential socio-economic functions. The obliteration of roads, residential structures, arable farmland, and public service institutions such as schools and health centers has amplified the community's vulnerability to environmental hazards.

Despite the evident and growing threat posed by landslides in Ogwuma Edda, existing response mechanisms remain largely reactive, fragmented, and devoid of spatial intelligence. Advanced predictive and geospatial modeling frameworks are yet to be adequately integrated into local hazard management protocols. Meanwhile, poor land management practices including slash-and-burn agriculture on steep terrains, deforestation, and unplanned settlements persist in the absence of regulatory enforcement or coordinated mitigation strategies.

Institutional limitations, a lack of public awareness, and the absence of data-driven models have hindered efforts to establish effective landslide risk reduction policies in the region. Compounding this is the neglect of proven slope stabilization interventions such as reforestation, terracing, and engineered drainage infrastructure. Consequently, land-use planning remains inadequate, while risk mitigation strategies are disconnected from spatial analysis and environmental data integration.

The present study seeks to address these deficiencies by proposing a geospatial multi-criteria framework for assessing landslide susceptibility within Afikpo South Local Government Area. By leveraging geographic information systems (GIS), remote sensing, and multi-criteria evaluation techniques, the study aims to produce a spatially explicit risk model that delineates zones of varying susceptibility. This approach will provide empirical evidence necessary for informed planning, targeted interventions, and policy development geared towards reducing landslide-induced vulnerabilities, particularly in Ogwuma Edda and similar high-risk settlements.

2. MATERIALS AND METHODS

2.1 Study Area

Afikpo South Local Government Area (LGA) is located in the southeastern region of Nigeria, within Ebonyi State. Geographically, it lies approximately between latitudes 5°47′N and 5°52′N and longitudes 7°55′E and 8°00′E. The LGA shares boundaries with Afikpo North to the north, Ivo LGA to the west, and the Cross River State to the east and south, specifically across the Aboine and Cross River floodplains. Its administrative headquarters is situated in Nguzu Edda. The strategic location of Afikpo South makes it a transitional ecological zone, linking the inland rainforest belt to the riverine lowlands of southeastern Nigeria. The area spans a landmass of approximately 379 km² and comprises several autonomous communities, among which Ogwuma Edda is particularly significant due to its recurrent environmental hazards such as landslides.

The topography of Afikpo South is characterized by a rugged terrain with highly variable elevation and slope profiles. The region is defined by steep slopes, undulating hills, and deep valleys, with altitudes ranging from 15 meters in the lowland riverine areas to over 280 meters above sea level in the upland zones. This sharp relief variation contributes to slope instability, especially during the rainy season when soils become saturated. The presence of escarpments, dissected hilltops, and narrow ridge lines further enhances the geomorphological susceptibility to mass movements. The steep gradients, particularly in communities such as Ogwuma Edda, serve as a major predisposing factor for landslide occurrences, especially in the absence of effective slope management or vegetation cover.

Land use in Afikpo South LGA is predominantly rural and agricultural. The majority of residents engage in subsistence farming, with yam, cassava, maize, and rice as major crops. Agricultural practices often occur on marginal lands, including hill slopes, due to limited flat terrain. Such activities frequently involve the clearance of natural vegetation, leaving slopes exposed to erosion and surface runoff. In addition to farming, settlements are scattered and often situated on elevated areas for flood avoidance, but this increases exposure to landslide risks. Infrastructure development is gradually expanding, particularly in the form of access roads, schools, and health facilities. However, the absence of spatial planning and environmental impact assessments in many construction projects has intensified land degradation. The rapid encroachment into geologically unstable zones for housing and farming has further compounded the susceptibility of the area to landslides, especially in high-risk locations such as Ogwuma Edda.

2.2 Data Acquisition

Data required for the landslide susceptibility assessment were obtained from both satellite-based remote sensing platforms and institutional repositories. These datasets were selected to reflect the geophysical and environmental conditions of Afikpo South Local Government Area and were integrated within a geospatial framework to support the multi-criteria analysis.

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), with a spatial resolution of 30 meters, was used as the foundational topographic dataset. The SRTM DEM was accessed from the United States Geological Survey (USGS) EarthExplorer portal. This dataset provided the necessary topographic parameters required for modeling key landslide conditioning factors. Specifically, slope, elevation, and aspect were derived from the DEM through surface analysis tools in a Geographic Information System (GIS) environment. The slope map was generated using the slope function, which calculates the maximum rate of change in elevation from each raster cell to its neighbours. Aspect was computed to determine the compass direction that each slope face, which is critical in understanding differential solar radiation and moisture retention. Elevation values were used directly to categorize terrain height variability, which influences slope stability and water accumulation.

Rainfall data were acquired from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) platform. CHIRPS combines satellite imagery with in-situ station data to produce high-resolution precipitation datasets at 0.05° (~5 km) spatial resolution. For this study, annual cumulative precipitation data averaged over a recent 10-year period (2014–2023) were downloaded to reflect prevailing climatic conditions contributing to landslide initiation. The dataset was resampled and clipped to match the spatial resolution and extent of the study area using bilinear interpolation. The precipitation raster was then integrated into the modeling framework as a key hydrometeorological factor influencing slope failure potential.

Geological data were obtained from the Nigerian Geological Survey Agency (NGSA), which provided vector-format geological maps at a scale of 1:100,000. These maps contain lithological information describing rock types and structural configurations across Afikpo South LGA. The geological units were digitized and subsequently converted into raster format for integration with other conditioning layers. Each lithological class was assigned a susceptibility rating based on its known mechanical properties and weathering characteristics, which are recognized determinants of landslide vulnerability.

2.3 Identification and Preparation of Landslide Conditioning Factors

Landslide susceptibility assessment fundamentally relies on identifying and analyzing terrain, climatic, and geological parameters that contribute to slope instability. For this study, five conditioning factors were identified and selected based on their theoretical relevance, empirical association with historical landslide occurrences, and data availability for the Afikpo South Local Government Area. These factors include slope, rainfall, geology, elevation, and aspect. Each of these variables has been demonstrated in prior research to influence the likelihood, intensity, and spatial distribution of landslide events, especially in tropical and subtropical environments such as southeastern Nigeria.

1. Slope Gradient

Slope gradient is a critical factor in landslide analysis, as it directly determines the gravitational force acting on soil and rock materials on a hill or terrain surface. Steep slopes are inherently more susceptible to mass movement due to increased shear stress and reduced slope stability. For this study, slope data were extracted from the SRTM 30-meter resolution DEM using the “Slope” tool in ArcGIS. The resulting slope raster was then categorized into five classes using the Jenks natural breaks method to delineate levels of landslide risk. These classes ranged from gentle slopes, representing lower susceptibility, to very steep slopes, representing higher susceptibility to failure.

2. Rainfall Intensity

Rainfall plays a triggering role in landslide dynamics, particularly through processes such as soil saturation, increased pore-water pressure, and hydraulic loading of slopes. Prolonged or intense precipitation events can initiate landslides, especially in areas with antecedent wet conditions and friable soil structures. Rainfall data used in this study were derived from the CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) dataset, which integrates satellite imagery with in-situ observations to produce spatially continuous rainfall surfaces. Using the Inverse Distance Weighting (IDW) interpolation technique, the raw rainfall point data were converted into a raster format. Annual average precipitation was then classified into five risk classes to reflect varying degrees of landslide susceptibility due to rainfall input.

3. Geological Formation

Geology is a foundational factor in determining slope material strength, permeability, and structural weaknesses such as faults and fractures. Different rock types exhibit varied resistances to weathering and erosion. In areas where the underlying geology comprises weathered sedimentary or metamorphic rocks, landslides are more frequent due to reduced cohesion and shear strength. Geological data for Afikpo South LGA were obtained from the Nigerian Geological Survey Agency and digitized into vector format using ArcGIS. Lithological units were identified and classified into five susceptibility categories based on established relationships between rock types and landslide occurrences. These vector layers were converted to raster format and incorporated into the multi-criteria analysis.

4. Elevation

Elevation reflects the vertical position of land surfaces and influences hydrological flow, vegetation distribution, and slope morphology. Areas at higher elevations often exhibit increased precipitation rates, steeper gradients, and complex terrain characteristics, all of which can enhance landslide susceptibility. Elevation data were derived directly from the same SRTM DEM used for slope analysis. The elevation raster was segmented into five classes based on altitudinal thresholds observed in southeastern Nigeria and existing studies on terrain-induced hazards. The classified elevation map provided an important input for assessing relative landslide vulnerability in areas of varied terrain relief.

5. Aspect (Slope Orientation)

Aspect refers to the compass direction that a slope faces and is significant in determining the distribution of solar radiation, soil moisture, vegetation cover, and microclimatic conditions across a landscape. In Nigeria's humid tropics, south-facing slopes often receive more moisture-laden winds, while north-facing slopes receive less direct sunlight, leading to variations in evapotranspiration and soil stability. Aspect was calculated using the "Aspect" tool in ArcGIS from the DEM dataset. The output values, originally ranging from 0° to 360°, were grouped into cardinal directions (e.g., north, northeast, east) and then reclassified into five categories based on susceptibility contributions informed by previous geomorphological studies. Slopes with orientations that enhance soil saturation or reduce drying potential were classified as more susceptible to failure.

6. Spatial Harmonization of Thematic Layers

All thematic layers representing the conditioning factors were spatially standardized in terms of projection (WGS 1984 UTM Zone 32N), extent, and resolution (30 meters) to ensure accurate overlay and pixel-based analysis. The layers were also aligned using the raster snapping and resampling tools in ArcGIS to eliminate geometric discrepancies and spatial misalignment that could compromise the integrity of the multi-criteria analysis.

7. Justification for Conditioning Factor Selection

The selection of these specific conditioning factors was based on their relevance in landslide modeling as demonstrated in several empirical and data-driven studies (Ayalew, Yamagishi, Marui, and Kanno, 2005; Bui, Tuan, Hoang, and Pham, 2018; Chen, Xie, and Du, 2021). Furthermore, the chosen factors reflect a balance between physical environmental parameters and anthropogenic pressures relevant to the terrain, climate, and land use dynamics of Afikpo South LGA. These factors not only have individual contributions to slope instability but also exhibit synergistic interactions that necessitate integrated modeling through entropy-based weighting and overlay techniques.

2.4 Data Reclassification and Standardization

In order to integrate the diverse conditioning factors into a coherent geospatial multi-criteria model for landslide susceptibility assessment, it was necessary to standardize and reclassify the various raster datasets into a uniform evaluation scale. Each factor derived from raw geospatial inputs such as Digital Elevation Models, interpolated rainfall surfaces, and digitized geological maps exhibited intrinsic differences in units, ranges, and value distributions. Reclassification and standardization facilitated the transformation of these heterogeneous datasets into comparable ordinal scales, ensuring that their relative influence on landslide susceptibility could be consistently quantified and aggregated in the ensuing modeling steps.

1. Reclassification Process

Reclassification involved converting continuous or categorical raster values of each conditioning factor into discrete susceptibility classes on a scale of 1 to 5, where the value '1' indicated very low landslide susceptibility and '5' represented very high susceptibility. This transformation was implemented using the "Reclassify" tool in ArcGIS Pro.

The reclassification thresholds for each factor were determined using a combination of domain-specific literature benchmarks, statistical distribution analysis (e.g., natural breaks/Jenks optimization), and expert interpretation of terrain characteristics in the context of the Afikpo South LGA landscape.

For instance, slope values were divided into five intervals: flat to gentle slopes (0°–5°) were assigned a risk value of 1, while steep to very steep slopes (greater than 30°) received a value of 5, reflecting increased gravitational stress on soil materials. Rainfall data, measured in millimeters per year, were similarly segmented into five intervals using the natural breaks method to capture variations in precipitation levels. Elevation and aspect datasets were classified based on their influence on hydrological runoff and solar exposure, respectively. Geology was reclassified according to the inherent stability of each lithologic unit, as established in previous geotechnical studies and regional landslide susceptibility literature.

2. Standardization Process

Following reclassification, standardization was carried out to normalize all raster layers into a common decision-support format suitable for multi-criteria overlay analysis. This process ensured that each raster cell carried a value on the same ordinal scale (1 to 5), eliminating disparities due to differing units or magnitudes in the original data.

Standardization was particularly important for implementing the Entropy Weighting method, which requires consistent input scales for calculating entropy values and weights. Each reclassified layer was therefore converted into a standardized raster layer where every pixel corresponded to a susceptibility rank between 1 and 5. This allowed each cell in the spatial domain to be evaluated under the same metric across all thematic layers.

To avoid positional misalignment, all reclassified rasters were resampled to a uniform spatial resolution of 30 meters and aligned using the "Snap Raster" function to ensure congruence across the entire analysis extent. Raster values were further verified for consistency by overlaying sample points and conducting zonal statistics to cross-check class assignments.

3. Output of Reclassification and Standardization

The final output of this process comprised five standardized raster layers representing slope, rainfall, elevation, aspect, and geology. Each of these layers had a uniform pixel size, coordinate reference system (WGS 1984 UTM Zone 32N), and value range from 1 to 5. These layers formed the basis for computing the entropy-based weights and for executing the weighted linear combination during the susceptibility zonation phase.

2.5 Entropy Weighting Method (EWM)

The Entropy Weighting Method is a statistical technique used to measure the degree of disorder or variability in a dataset. It is based on the assumption that a factor with higher variation contributes more information and should therefore be given a higher weight. The entropy method relies on the information theory principle that uniform distributions provide less useful information than skewed distributions.

The steps involved in entropy weighting were as follows:

1. Each reclassified raster dataset was normalized by dividing each pixel value by the total sum of all pixel values in the layer. This produced a normalized decision matrix where the sum of pixel values for each layer equalled one.

2. The entropy value ($\boldsymbol{ej}$) for each conditioning factor was calculated using the formula:

$$e_j = -k\sum_{i=1}^{m} p_{ij} \cdot \ln(p_{ij}), \quad \text{where } k = \frac{1}{\ln m} \qquad \ldots(1)$$

Here, pij represents the normalized value of the ith pixel in the jth factor, and m is the total number of observations (pixels).

3. The degree of diversification for each factor was derived as:

$$dj = 1 - ej \qquad \ldots(2)$$

This value indicates the discriminative power of each factor. Higher values imply higher spatial variability and therefore more influence on the final output.

4. The final entropy-based weight for each factor was computed as:

$$wj = \frac{d_j}{\sum d_j} \qquad \ldots(3)$$

2.6 Landslide Risk Zonation and Area Calculation

Landslide risk zonation was executed through a weighted linear combination (WLC) approach, which integrated the standardized raster layers of the selected landslide conditioning factors with their corresponding entropy-derived weights. This process aimed to produce a composite susceptibility index map that quantitatively represented the spatial variability of landslide risk across Afikpo South Local Government Area.

1. Weighted Linear Combination

The WLC technique involved a cell-by-cell multiplication of each standardized raster layer by its respective weight, followed by summing the products to generate a landslide susceptibility index (LSI) value for every spatial unit. The general formulation used was:

$$LSI = \sum (Wi \times Xi) \qquad \ldots(4)$$

Where:
LSI = Landslide Susceptibility Index

Wi = Entropy-derived weight of the $i - th$ factor

Xi = Standardized raster value of the $i - th$ factor for each pixel

The five conditioning factors included in the model were slope, rainfall, elevation, aspect, and geology. Each raster layer had values on a standardized scale of 1 to 5, and the entropy weights were derived based on the variability of each factor's contribution across the study area. The raster calculator in ArcGIS Pro was employed to perform the mathematical overlay, ensuring pixel-wise consistency in all operations.

The output from this calculation was a continuous raster dataset representing the LSI values ranging from low to high susceptibility. These values were then reclassified into five discrete susceptibility zones: very low, low, moderate, high, and very high risk. The reclassification was conducted using the natural breaks (Jenks) method to objectively partition the LSI values into optimal classes based on internal variance minimization.

2. Risk Zone Mapping

Following the reclassification of the LSI raster, each class was symbolized using a unique color scheme for visual interpretation and cartographic representation. The landslide risk zones were mapped to show their spatial distribution across the entire extent of Afikpo South LGA. Particular attention was given to areas with high and very high susceptibility zones, which were highlighted for priority mitigation and planning interventions.

To maintain spatial integrity, the final classified risk map was projected using the WGS 1984 UTM Zone 32N coordinate reference system and clipped to the official boundary shapefile of Afikpo South LGA. The map layout was finalized using standard cartographic elements, including legend, scale bar, north arrow, and metadata description.

3. Area Calculation of Susceptibility Classes

To determine the extent of each landslide susceptibility zone in square kilometers, the reclassified LSI map was subjected to zonal analysis. The “Zonal Histogram” and “Zonal Geometry as Table” tools in ArcGIS were used to extract the pixel counts associated with each susceptibility class. The computed areas were tabulated and further represented as percentages of the total study area to support comparative interpretation and prioritization.

3. RESULTS

3.1 Identification and Preparation of Thematic Layers of Landslide Conditioning Factors

In addressing the first objective of this study, five core thematic layers were identified and prepared to support the landslide susceptibility assessment for Afikpo South Local Government Area, Ebonyi State. These layers include slope, rainfall, geology, elevation, and aspect. The selection of these conditioning factors was guided by their geomorphological relevance, empirical association with landslide occurrences, and their frequent application in regional-scale landslide hazard modeling within similar physiographic environments.

Each of these factors exerts spatial and physical influence on slope stability by affecting either the mechanical properties of the terrain or the hydrological conditions conducive to mass movement. For instance, slope and elevation determine gravitational stress and runoff behavior; geology influences material strength and weathering susceptibility; rainfall introduces hydrodynamic triggers; and aspect modifies moisture retention and vegetation cover based on solar exposure.

The preparation of the thematic layers was undertaken using a combination of Remote Sensing (RS) datasets and Geographic Information System (GIS)-based spatial analysis techniques. All input datasets were processed into raster format, ensuring uniform cell resolution to maintain analytical consistency. The layers were standardized to a common spatial reference system, specifically WGS 1984 UTM Zone 32N, and clipped precisely to the administrative boundary of Afikpo South LGA. This geospatial harmonization was essential to facilitate accurate integration within the multi-criteria overlay operations subsequently employed in the landslide susceptibility modeling.

The slope layer (Figure 1) was derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a spatial resolution of 30 meters. The slope gradient was computed using the slope analysis function in ArcGIS, which converted elevation values into degrees of inclination. The resulting slope map was then reclassified into defined categories reflecting varying degrees of terrain steepness. Within the context of landslide susceptibility assessment, slope is a critical conditioning factor as it directly influences the gravitational forces acting upon surface materials. Steeper slopes are more prone to instability due to increased shear stress and reduced material cohesion, thereby elevating the likelihood of mass movement.

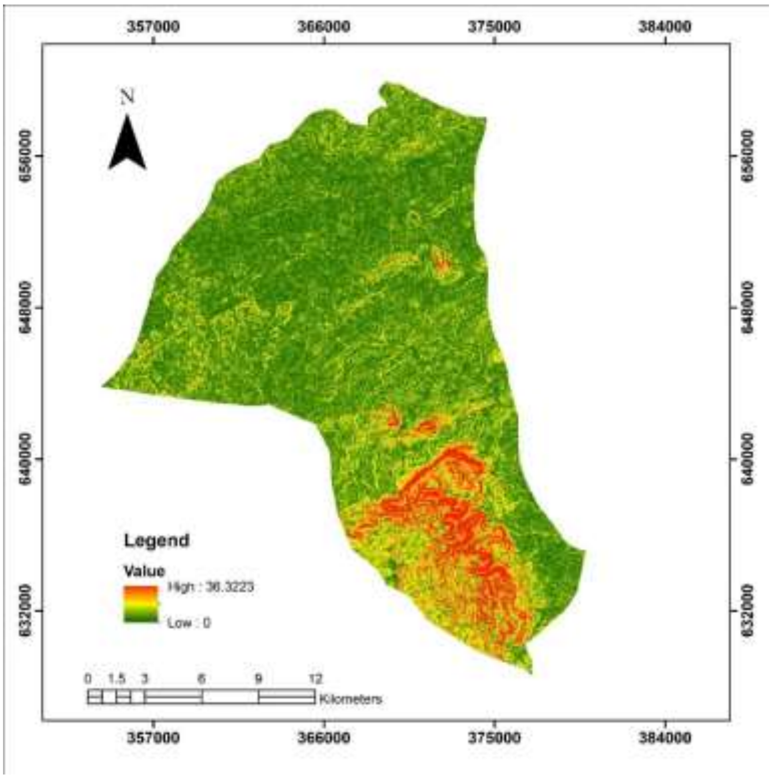

Figure 1: Slope Data

The rainfall layer (Figure 2) was developed using data obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), which provides high-resolution precipitation estimates at a spatial resolution of 0.05 degrees (approximately 5 km). The average annual rainfall values were extracted and spatially interpolated across the study area using the Inverse Distance Weighting (IDW) technique in ArcGIS to generate a continuous rainfall surface. This raster was subsequently reclassified into classes based on precipitation intensity ranges relevant to landslide studies.

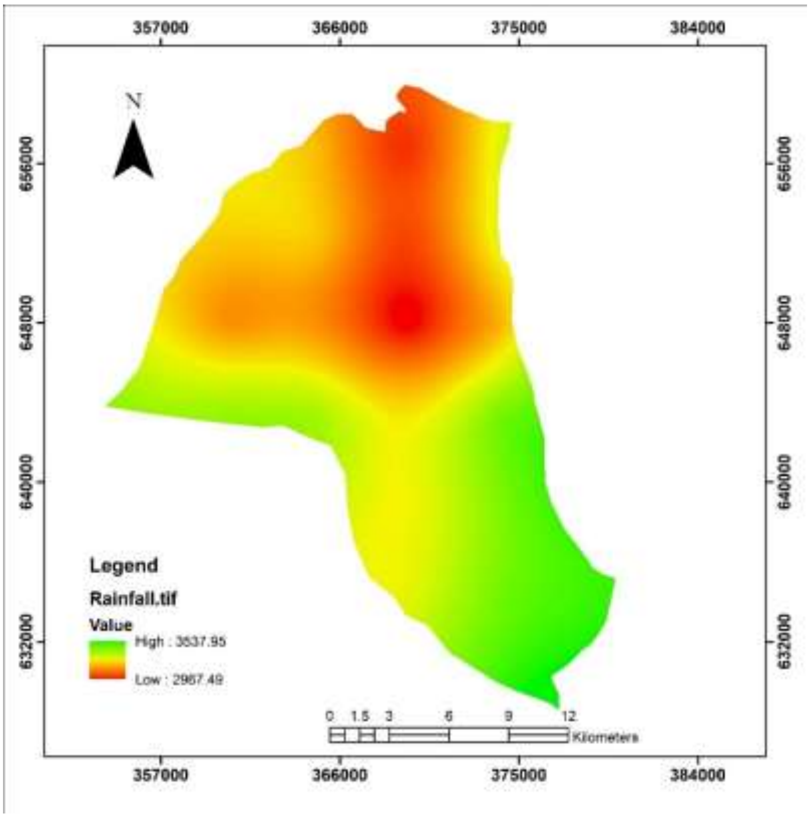

Figure 2: Rainfall Data

The geology layer (Figure 3) was extracted from the digitized geological map provided by the Nigerian Geological Survey Agency (NGSA). This vector-based map was georeferenced and converted into raster format using ArcGIS, with categorical values assigned to different lithological units present within Afikpo South Local Government Area. The classified raster delineates the spatial distribution of distinct geologic formations, and other sedimentary units characteristic of the southeastern Nigerian terrain.

Geology is a fundamental landslide conditioning factor, as the physical and mechanical properties of bedrock and unconsolidated materials significantly influence slope stability. Lithologies vary in terms of cohesion, permeability, weathering susceptibility, and structural integrity.

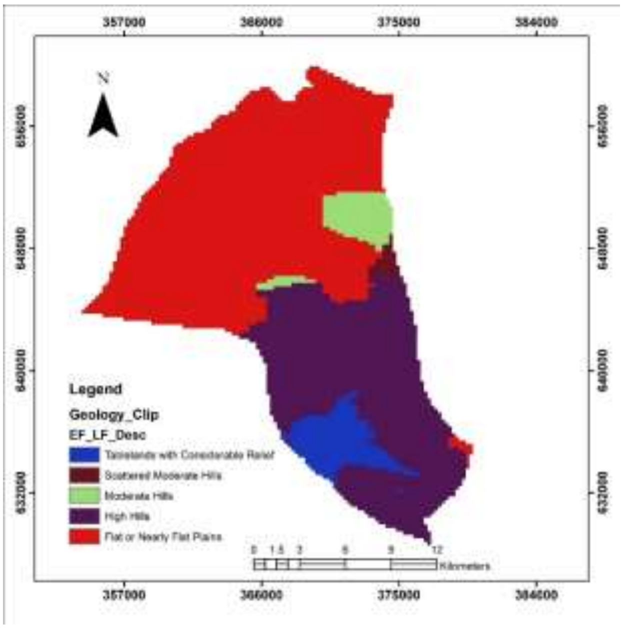

Figure 3: Geology Data

The elevation layer (Figure 4) was generated from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a spatial resolution of 30 meters. The elevation data were processed using ArcGIS to produce a continuous raster surface representing altitude variations across Afikpo South Local Government Area. The elevation values were subsequently reclassified into discrete classes based on elevation thresholds relevant to landslide studies.

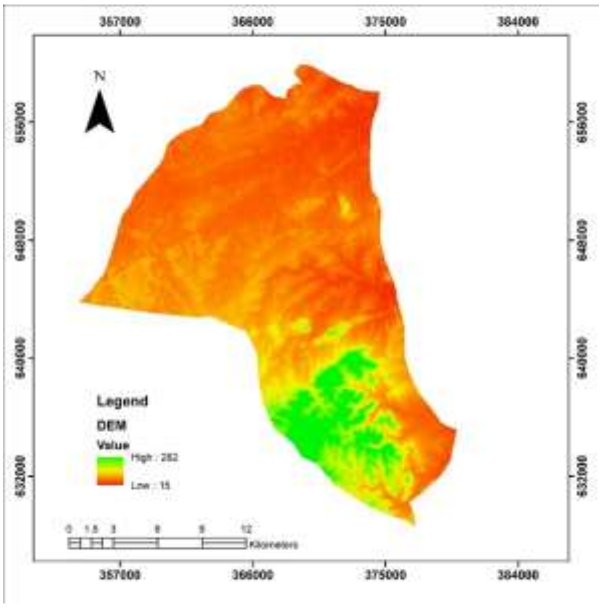

Figure 4: Elevation Data

The aspect layer (Figure 4.5) was derived from the 30-meter resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) using the aspect analysis tool in ArcGIS. This layer represents the compass direction that each slope surface faces, ranging from 0° to 360°, and was reclassified into categorical zones including north, northeast, east, southeast, south, southwest, west, and northwest-facing slopes.

Aspect influences landslide susceptibility primarily through its control on microclimatic conditions, particularly solar radiation exposure, soil moisture retention, and vegetation cover.

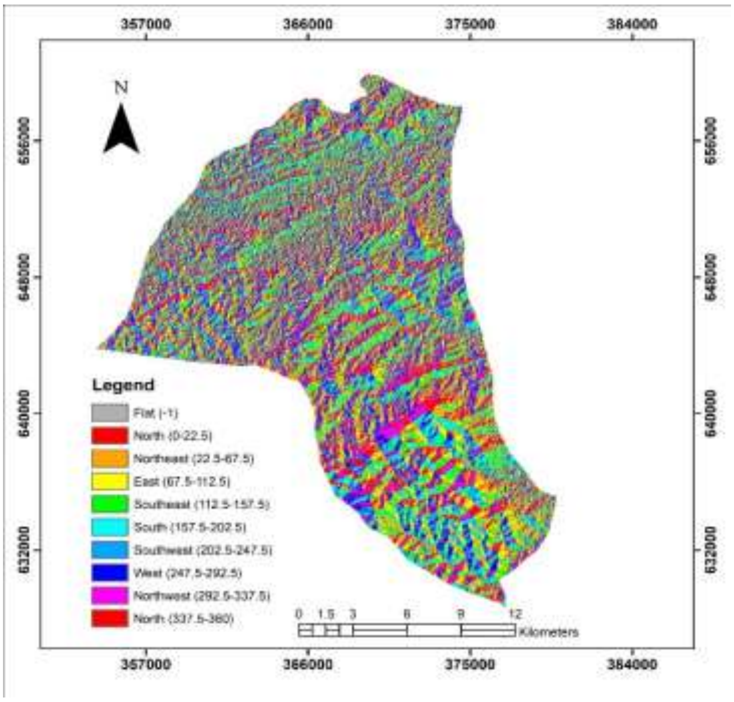

Figure 5: Aspect Data

A summary of the thematic layers, their data sources, derivation techniques, and justification for inclusion is presented in Table 1.

Table 1: Summary of Landslide Conditioning Factors and Justification for Inclusion

S/N	Thematic Layer	Source/Derivation Method	Relevance to Landslide Assessment
1	Slope	Generated from DEM	Slope gradient directly influences the gravitational driving force acting on surface materials. Steeper slopes increase shear stress and susceptibility to mass wasting processes, making this variable a principal factor in landslide modeling.
2	Rainfall	CHIRPS Precipitation Dataset	Precipitation acts as a primary triggering agent for landslides by increasing pore water pressure and reducing shear strength in soil and rock masses. CHIRPS data provide spatially distributed rainfall patterns necessary for evaluating hydrological triggers.
3	Geology	NGSA geological maps	Lithological composition and structural characteristics significantly determine material strength, weathering susceptibility, and permeability. The geologic setting delineates zones with inherent structural weaknesses prone to slope failure.
4	Elevation	Generated from DEM	Elevation affects both climatic conditions and potential energy within the landscape. It also governs spatial variation in vegetation and human activity, which are relevant to slope stability and landslide occurrence.

5	Aspect	Generated from DEM	Aspect determines the direction a slope faces, which in turn affects microclimate variables such as solar radiation, soil moisture retention, and vegetation growth. These micro-environmental conditions influence weathering rates and slope hydrology, thereby impacting landslide likelihood.

3.2 Reclassification and Standardization of Landslide Conditioning Factors

To enable the effective integration of the multiple thematic layers required for landslide susceptibility mapping in Afikpo South Local Government Area, all landslide conditioning factors were reclassified and standardized onto a uniform interpretative scale. This standardization was necessary to ensure that the influence of each factor on slope instability is evaluated consistently across the entire study area. In this study, five critical conditioning factors slope, rainfall, geology, elevation, and aspect were reclassified into a common susceptibility scale ranging from 1 to 5, with the following interpretations:

1. 1 corresponds to Very Low Risk,
2. 2 corresponds to Low Risk,
3. 3 corresponds to Moderate Risk,
4. 4 corresponds to High Risk, and
5. 5 corresponds to Very High Risk.

This classification approach is grounded in geospatial modeling best practices and supported by established empirical frameworks in landslide susceptibility assessment literature.

The reclassification process was implemented in a GIS environment using raster-based spatial analysis tools. For each thematic layer, original data values were extracted from remotely sensed and geospatial datasets, and subsequently categorized into the five defined risk classes. Threshold values for reclassification were determined based on the physical and environmental significance of each variable in relation to slope failure dynamics. For example, steeper slopes were assigned higher risk values, while flatter areas were classified under lower risk classes. Similarly, lithologies with high weathering potential or low shear strength were designated as higher-risk geological units.

This standardized classification allowed for direct comparison and overlay of the raster layers within a common spatial framework. It also ensured that each factor contributed proportionally and meaningfully to the final susceptibility model, particularly during the execution of the weighted overlay analysis. The detailed rationale for the reclassification of each factor is provided in subsequent sections, where the specific geospatial behavior and landslide relevance of each thematic layer are discussed.

The slope layer was reclassified into five risk categories based on defined threshold intervals of slope gradient (in degrees), reflecting the influence of terrain steepness on landslide susceptibility within Afikpo South Local Government Area. This reclassification was implemented in a GIS environment using raster-based spatial analysis tools to convert continuous slope values into discrete classes that represent relative risk levels.

Slope values ranging from 0 to 2.74 degrees were assigned a risk value of 1, corresponding to the Very Low Risk category. These gentle slopes are characterized by minimal gravitational force acting on surface materials, resulting in stable terrain with negligible likelihood of slope failure.

Slope gradients falling within the range of greater than 2.74 to 5.6 degrees were classified as Low Risk, with a reclassified value of 2. While slightly steeper than the previous category, these slopes still exhibit generally stable conditions under natural circumstances, with limited potential for landslide initiation. The Moderate Risk category was designated to slopes ranging greater than 5.6 to 9.9 degrees, reclassified with a value of 3. These slopes mark a transitional zone where gravitational forces begin to significantly influence surface material movement, particularly under conditions of prolonged rainfall or disturbance.

Slopes between greater than 9.9 and 16.39 degrees were classified as High Risk, with a reclassified value of 4. These slopes are steep enough to facilitate mass movement processes, especially when combined with weak lithology or hydrological saturation. They represent terrain where slope instability becomes a prominent geomorphic concern. Finally, slopes greater than 16.39 up to 36.32 degrees were assigned the highest reclassification value of 5, corresponding to the Very High-Risk category. These steep slopes are inherently unstable and highly susceptible to landslides, particularly during heavy rainfall events or in the presence of unconsolidated geologic materials. The reclassification of the slope layer into these categories provided a structured basis for quantifying terrain instability and integrating the slope factor effectively into the landslide susceptibility model, see table 2 and figure 6.

Table 2: Slope Reclassification Range

Slope Range (°)	Reclassified Risk Value	Risk Description
0 – 2.74	1	Very Low Risk
>2.74 – 5.6	2	Low Risk
>5.6 – 9.9	3	Moderate Risk
>9.9 – 16.39	4	High Risk
>16.39 – 36.32	5	Very High Risk

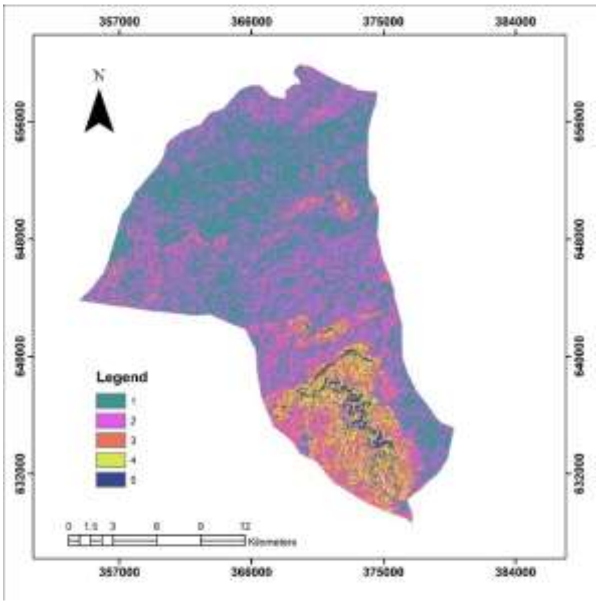

Figure 6: Reclassified Slope Data

The aspect layer was reclassified into five directional categories based on azimuthal orientation, with each direction assigned a corresponding landslide risk value. This classification reflects the influence of slope orientation on microclimatic conditions, moisture retention, and vegetation growth all of which modulate terrain stability and susceptibility to slope failure. The reclassification was performed by converting continuous aspect values, measured in degrees from 0° to 360°, into standardized risk classes for subsequent integration into the landslide susceptibility model.

Surfaces identified as flat, with an aspect value of -1, were assigned a risk value of 1, corresponding to the Very Low Risk category. These areas typically lack directional slope and therefore do not experience significant gravitational stress or directional weathering, resulting in minimal landslide potential.

Slopes facing the north (0°–22.5° and 337.5°–360°) were classified as Low Risk with a reclassified value of 2. Northern aspects in this geographic setting typically receive less direct solar radiation, which helps retain moisture and support vegetative cover, but they are not inherently unstable unless other contributing factors are present.

Northeast-facing slopes (22.5°–67.5°) were assigned a Moderate Risk classification, with a reclassified value of 3. These slopes experience a moderate level of solar exposure and may exhibit fluctuating moisture conditions, which can contribute to moderate terrain instability, especially in areas with vulnerable lithology.

East-facing slopes (67.5°–112.5°) received a risk value of 4, indicating a High-Risk designation. These slopes are subject to early morning solar radiation, which can induce thermal expansion and contraction, affecting surface cohesion and promoting slope instability, particularly when compounded by shallow soil profiles.

Southeast-facing slopes (112.5°–157.5°) were classified as Very High Risk, with a reclassification value of 5. In the southeastern Nigerian context, these aspects tend to receive prolonged exposure to solar radiation and moisture-laden winds, leading to increased evapotranspiration, weathering, and degradation of slope materials, making them particularly prone to landslide occurrence.

Slopes oriented toward the south (157.5°–202.5°) were also classified as High Risk, with a reclassification value of 4, due to similar exposure dynamics that promote surface drying and material desiccation, weakening the structural integrity of slope-forming materials.

The southwest category (202.5°–247.5°) was assigned a Moderate Risk value of 3, reflecting variable solar exposure and moderate susceptibility to instability. West-facing (247.5°–292.5°) and northwest-facing (292.5°–337.5°) slopes were both classified as Low Risk, each with a risk value of 2, as these orientations typically experience less intense solar heating and more favorable moisture retention, see table 3 and figure 7.

Table 3 Aspect Reclassification

Aspect Direction	Degree Range	Reclassified Risk Value	Risk Description
Flat	-1	1	Very Low Risk
North	0–22.5 and 337.5–360	2	Low Risk
Northeast	22.5–67.5	3	Moderate Risk
East	67.5–112.5	4	High Risk
Southeast	112.5–157.5	5	Very High Risk
South	157.5–202.5	4	High Risk

Southwest	202.5–247.5	3	Moderate Risk
West	247.5–292.5	2	Low Risk
Northwest	292.5–337.5	2	Low Risk

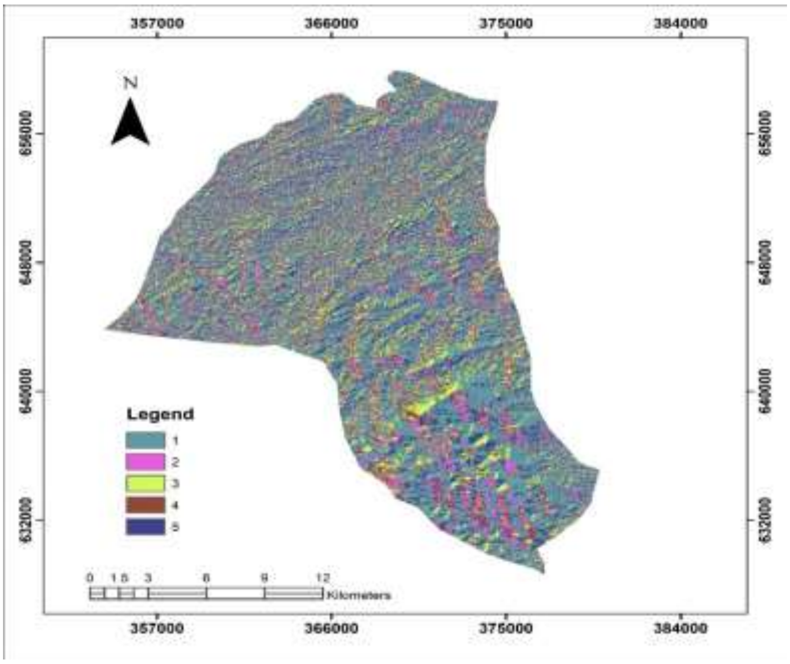

Figure 7: Reclassified Aspect Data

The geology layer was reclassified based on the morphological characteristics of the geological terrain units present within Afikpo South Local Government Area. Flat or nearly flat plains were assigned a risk value of 1, corresponding to the Very Low Risk category. These areas are typically underlain by stable and laterally extensive lithological formations, with minimal relief and limited gravitational stress, making them highly resistant to slope failure processes.

Scattered moderate hills, characterized by isolated elevations with gentle to moderate slopes, were reclassified with a risk value of 2, indicating a Low-Risk designation. Although such terrains may exhibit localized slope instability, the overall geologic and topographic context remains relatively stable.

Moderate hills were assigned a risk value of 3, corresponding to the Moderate Risk category. These areas generally consist of weathered bedrock or stratified formations with moderate relief, where the combination of slope gradient and material properties can increase the potential for landslide initiation under adverse hydrological or anthropogenic conditions.

Tableland with considerable relief was reclassified as High Risk with a risk value of 4. These terrains typically feature broad, elevated surfaces dissected by valleys and escarpments. The complexity of slope transitions and structural discontinuities in these regions can lead to reduced slope stability, particularly under intense rainfall or land-use alteration.

High hills, representing steep and elevated terrain with significant vertical relief, were classified under the Very High-Risk category with a risk value of 5. These areas are highly prone to landslides due to their steep slopes, potential for high runoff accumulation, and susceptibility to structural failure, especially where the geologic formations are fractured, weathered, or poorly consolidated, see table 4 and figure 8.

Table 4 Geology Reclassification

Geological Terrain Unit	Reclassified Risk Value	Risk Description
Flat or nearly flat plains	1	Very Low Risk
Scattered moderate hills	2	Low Risk
Moderate hills	3	Moderate Risk
Tableland with considerable relief	4	High Risk
High hills	5	Very High Risk

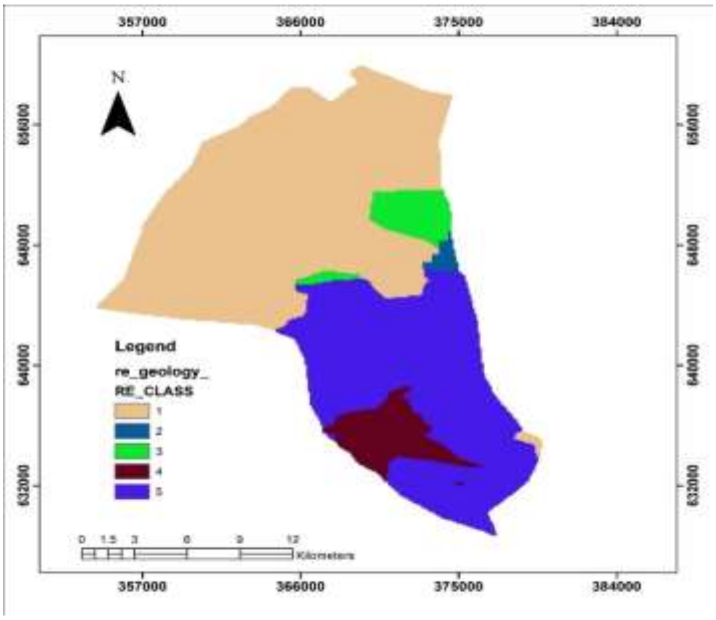

Figure 8: Reclassified Geology Data

The rainfall layer was reclassified into five categories based on the distribution of average annual precipitation values across Afikpo South Local Government Area. Rainfall values ranging from 2967.48 mm to 3090.53 mm were assigned a reclassification value of 1, corresponding to the Very Low Risk category. Areas within this range receive comparatively lower precipitation, which results in reduced soil saturation and minimal hydrological pressure on slope materials, thereby limiting landslide potential.

Values between 3090.53 mm and 3191.19 mm were classified as Low Risk, with a risk value of 2. These areas experience slightly increased rainfall, which may begin to influence soil moisture content and pore water pressure, though not yet at levels likely to induce widespread instability.

Rainfall between 3191.19 mm and 3287.39 mm was categorized under the Moderate Risk class, assigned a risk value of 3. These zones represent transitional areas where elevated precipitation levels could significantly contribute to increased slope saturation, especially in conjunction with steep gradients or weak geological formations. The range of 3287.39 mm to 3392.53 mm was reclassified as High Risk, with a risk value of 4. In these areas, rainfall intensity is sufficient to trigger slope failure under susceptible terrain conditions due to prolonged infiltration and subsequent loss of shear strength in slope materials.

Finally, the highest rainfall values, ranging from 3392.53 mm to 3537.95 mm, were assigned a risk value of 5, representing the Very High-Risk category. These areas are most susceptible to landslides due to the cumulative effect of high rainfall, which increases hydrological loading, enhances soil saturation, and reduces material stability, particularly where slope and lithological conditions are unfavorable, see table 5 and figure 9.

Table 5: Reclassification of Rainfall

Rainfall Range (mm)	**Reclassified Risk Value**	**Risk Description**
2967.48 – 3090.53	1	Very Low Risk
>3090.53 – 3191.19	2	Low Risk
>3191.19 – 3287.39	3	Moderate Risk
>3287.39 – 3392.53	4	High Risk
>3392.53 – 3537.95	5	Very High Risk

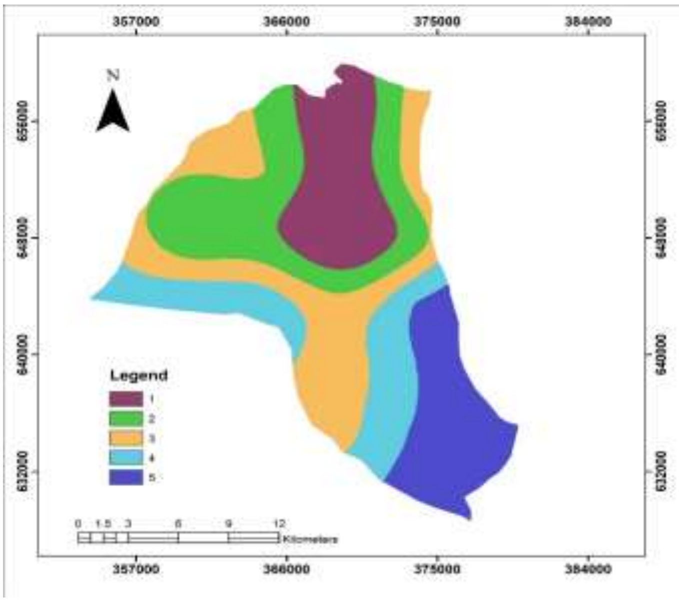

Figure 9: Reclassified Rainfall Data

The elevation layer was reclassified into five distinct categories to represent the varying degrees of landslide susceptibility associated with altitudinal variation within Afikpo South Local Government Area. Elevation values between 15 meters and 49 meters were reclassified with a risk value of 1, corresponding to the Very Low Risk category. These low-lying areas are generally flat or gently sloping and thus exhibit minimal gravitational influence on slope materials. As such, they are the least susceptible to landslide occurrences.

The next range, greater than 49 meters to 78 meters, was assigned a risk value of 2, denoting Low Risk. These zones present slightly elevated terrain but still maintain moderate relief and limited topographic stress, contributing only marginally to slope failure potential.

Elevation values between greater than 78 meters and 121 meters were categorized as Moderate Risk, with a reclassified value of 3. These mid-elevation regions represent transitional zones where slope angle and relief begin to increase, thereby enhancing the potential for mass movement, particularly when combined with saturated soil or unstable geology.

Areas with elevation values ranging from greater than 121 meters to 172 meters were reclassified with a risk value of 4, indicating High Risk. This category includes steeper and more rugged terrain where gravitational forces are more pronounced, significantly elevating the likelihood of slope instability.

The highest elevation class, from greater than 172 meters up to 282 meters, was assigned the maximum risk value of 5, corresponding to the Very High-Risk category. These areas are typically associated with the steepest slopes, highest relief energy, and more active geomorphological processes. Consequently, they represent the zones most prone to landslides, particularly under high rainfall conditions or anthropogenic disturbances, see table 6 and figure 10.

Table 6: Reclassification of Elevation

Elevation Range (m)	Reclassified Risk Value	Risk Description
15 – 49	1	Very Low Risk
>49 – 78	2	Low Risk
>78 – 121	3	Moderate Risk
>121 – 172	4	High Risk
>172 – 282	5	Very High Risk

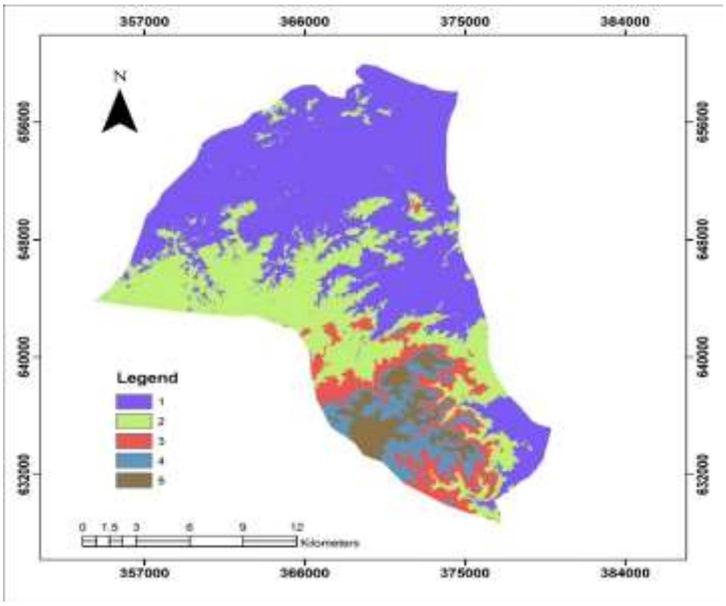

Figure 10: Reclassified Elevation Data

3.3 Weight Derivation for Landslide Conditioning Factors

In landslide risk mapping using GIS-based multi-criteria analysis, the reliability of the final model is significantly influenced by the assignment of appropriate weights to each of the contributing factors. Weight derivation is the process of determining the relative importance of various thematic layers that affect the availability and accumulation of groundwater. In this study, seven key conditioning factors were considered based on their theoretical relevance and observed influence on groundwater occurrence in similar geologic and climatic settings. These factors include slope, land use/land cover (LULC), geology, soil, drainage density, lineament density, and rainfall.

Each of these layers was generated in raster format using geospatial data sources such as satellite imagery, digital elevation models (DEMs), and thematic maps. However, due to the spatially variable influence of these factors, it became necessary to quantify their relative significance in an objective and structured manner. This study adopted the Entropy Weighting Method, which is an objective and data-driven technique.

3.3.1 Entropy Weighting Method

The Entropy Weighting Method is a quantitative and objective approach rooted in information theory, and it is particularly useful in multi-criteria decision-making (MCDM) scenarios where the spatial variability of data plays a crucial role. The fundamental idea behind the entropy method is that the greater the variation (or dispersion) in the values of a criterion, the more information it provides, and hence the more influence it should carry in the final decision-making process. In contrast, factors with uniform values across the study area contribute little useful information for distinguishing between zones of varying groundwater potential.

To implement this method, the raster pixel values of each of the five conditioning factors were extracted for analysis. These raw raster values were organized into a decision matrix, where each row represents a spatial unit (pixel) and each column corresponds to a thematic layer. In order to ensure comparability across the different factors, the data were normalized by dividing each pixel value by the sum of all pixel values for that factor, producing a proportional value for each spatial unit.

The output of this analysis is presented in Table 7 and figure 11, which shows the entropy values, diversification scores, and resulting weights for all seven groundwater conditioning factors.

Table 7: Entropy Weighting Results

Factor	Entropy	Diversification	Weight
Slope	0.973472	0.026528	0.174683
Rainfall	0.988694	0.011306	0.074448
Geology	0.924109	0.075891	0.499724
Elevation	0.978467	0.021533	0.14179
Aspect	0.983393	0.016607	0.109355

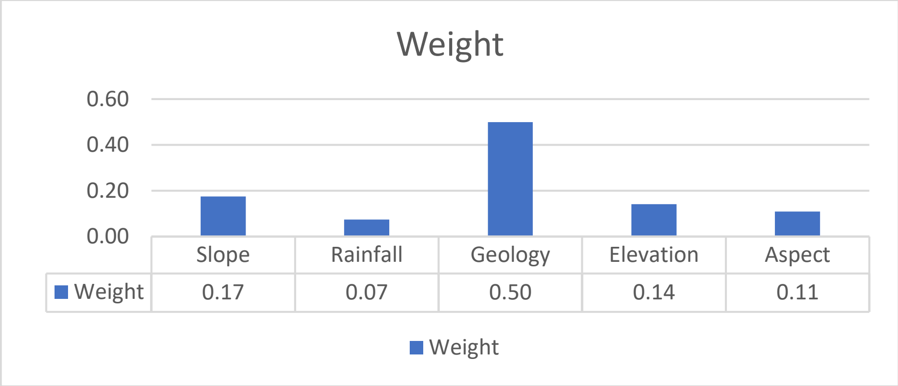

Figure 11: Entropy Weight Distribution

The geology layer exhibited the lowest entropy value of 0.9241, indicating the highest degree of informational diversity among all variables. The corresponding diversification measure was 0.0759, which translates into the highest normalized weight of 0.4997. This result implies that geological characteristics within the study area exert a relatively strong influence on landslide susceptibility. The slope factor recorded an entropy value of 0.9735, which corresponds to a diversification degree of 0.0265. This yields a normalized weight of 0.1747. Although slope is often considered a primary factor in landslide generation due to its direct relationship with gravitational stress and terrain inclination, the relatively high entropy indicates that slope values are more evenly distributed across the study area, reducing their contrast and hence, their relative weight in the model.

The elevation raster yielded an entropy value of 0.9785 with a diversification score of 0.0215, resulting in a weight of 0.1418. Elevation influences hydrological gradients and vegetation patterns, which in turn affect slope hydrodynamics and soil cohesion. However, similar to slope, its higher entropy value implies limited discriminatory power across the spatial domain, thereby reducing its influence in the WLC model.

The aspect layer produced an entropy of 0.9834, associated with a diversification value of 0.0166 and a normalized weight of 0.1094. Aspect affects microclimatic conditions such as sunlight exposure, evapotranspiration, and moisture retention, which can alter soil weathering and vegetation growth. However, the limited spatial variability of aspect within the study area reduces its overall contribution to the landslide susceptibility model.

Lastly, the rainfall layer showed the highest entropy value of 0.9887, signifying the lowest degree of spatial variation among all variables. The resulting diversification index was 0.0113, and its corresponding weight was 0.0744. Although rainfall is a well-documented trigger of landslide events, the relatively uniform precipitation pattern across the study area diminishes its influence in the entropy-based weighting scheme. The entropy method relies on the variability of input data; hence, uniformly distributed variables contribute less to the weighted model irrespective of their theoretical relevance.

The final entropy-derived weights demonstrate that geology is the most influential conditioning factor in the study area, accounting for nearly half of the total weight, followed by slope and elevation. Aspect and rainfall had lesser influence due to their comparatively low spatial variability. These weights were used in the Weighted Linear Combination (WLC) approach to produce a composite landslide susceptibility index, where each thematic layer is multiplied by its corresponding weight and summed to generate the final risk map.

3.4 Analysis of Landslide Risk Zonation

The landslide susceptibility map of Afikpo South Local Government Area (LGA) delineates five distinct zones classified by varying levels of landslide risk: Very Low Risk, Low Risk, Moderate Risk, High Risk, and Very High Risk, see figure 12.

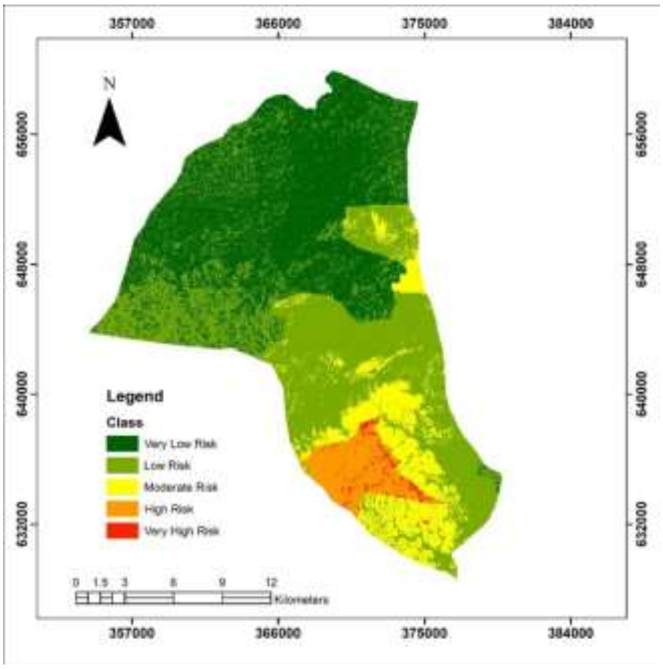

Figure 12: Landslide Risk in Afikpo South LGA

Spatially, the Very Low Risk and Low Risk zones dominate the northern and northwestern portions of the LGA. These areas are represented by deep green and light green tones respectively, and they are characterized by relatively gentle terrain, homogeneous geological formations, and minimal anthropogenic disturbances. These regions contain stable lithologies and low slope gradients, which contribute to their overall geotechnical stability.

The Moderate Risk zones, shown in yellow, appear in scattered patches across the central and southeastern sections of the LGA. These areas exhibit moderate slope inclinations, transitional lithologies, and localized variations in land use, which collectively increase their susceptibility to slope failure under certain environmental triggers, such as intense rainfall events.

More notably, the High Risk and Very High-Risk zones, highlighted in orange and red respectively, are concentrated in the southern and southeastern sectors of the map. These zones coincide with areas of steeper terrain and complex geological structures, where the potential for mass movement is significantly elevated. These locations include regions where slope angles are sharp, soil cohesion is low, and hydrological saturation can rapidly increase due to intense precipitation. The spatial extents of each zone were calculated in square kilometers and are presented alongside their corresponding percentage coverage in Table 8.

Table 8: Area Coverage of Landslide Risk Zones

Groundwater Potential Zone	Area (km^2)	Percentage (%)
Very Low Risk	150.746	40.30
Low Risk	155.996	41.71
Moderate Risk	45.160	12.07
High Risk	19.707	5.27
Very High Risk	2.399	0.64

From table 8, the results reveal a distinct gradation of risk levels, expressed in terms of land area coverage and corresponding percentages, which provides insight into the extent of terrain stability across the region.

The Very Low Risk zone occupies approximately 150.746 km², accounting for 40.30% of the total land area. The predominance of this category indicates that a substantial portion of the LGA is relatively secure from landslide hazards and is potentially suitable for infrastructural development and agriculture, with minimal geohazard constraints.

The Low-Risk zone covers an even slightly larger area of 155.996 km², which represents 41.71% of the total landmass. While slightly more susceptible to slope instability than the very low-risk areas, this zone still exhibits favourable conditions for land use. Its moderate topography and relatively stable substrate contribute to its low-risk classification. The combined coverage of the very low and low-risk zones together constituting over 82% of the study area indicates that the majority of Afikpo South LGA falls within terrain categories that are not presently predisposed to significant landslide activity under normal environmental conditions.

The Moderate Risk zone spans approximately 45.160 km², amounting to 12.07% of the total area. This classification signifies transitional terrain where slope failure potential increases due to a combination of moderate slope angles, variable lithology, or hydrological and anthropogenic factors. These areas require monitoring and more detailed site-specific assessments, particularly if any development or land alteration activities are to be considered.

The High-Risk zone is considerably more restricted, occupying just 19.707 km², which constitutes 5.27% of the landscape. This zone likely comprises areas with steeper gradients, fractured or weathered bedrock, and poor vegetation cover, which collectively exacerbate slope instability. The terrain within this category necessitates immediate attention, especially in the context of land use planning, infrastructure siting, and hazard mitigation.

Finally, the Very High-Risk zone is the least extensive, covering only 2.399 km² or 0.64% of the total area. Despite its limited spatial coverage, this zone represents the most hazardous terrain in terms of landslide occurrence. These areas are typically characterized by steep slopes, highly weathered or unconsolidated materials, and intensified hydrological conditions. The presence of this category, although marginal in area, poses significant implications for human safety and environmental stability, particularly if settlements or critical infrastructure exist within or near these zones.

4. CONCLUSION

The application of GIS-based spatial analysis and the entropy weighting method enabled the development of a data-driven landslide susceptibility model for Afikpo South LGA. The study demonstrated that landslide vulnerability within the region is predominantly governed by geological structure, terrain inclination, and elevation. The integration of multi-thematic layers and the derivation of objective weights ensured that the resulting risk map accurately reflects the spatial variability of conditioning factors.

The resultant susceptibility zoning map provides a detailed spatial framework for understanding the distribution of landslide-prone areas across the LGA. The findings confirm that the majority of the region is not immediately at risk under prevailing environmental conditions. However, specific high-risk corridors exhibit clear potential for future slope failure, particularly under extreme rainfall events or human-induced modifications. The susceptibility map thus serves as a valuable decision-support tool for land use regulation, environmental management, and hazard mitigation planning.

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