



## Impact of Drainage Density and Geological Factors on Flood Risk: A Comprehensive Study of Abia State

Odoh, Benard Ifeanyi and Nwokeabia, Charity Nkiru\*

Received: June 21, 2024 / Accepted: August 31, 2024

© REJOST 2024

### Abstract

Abia State in Southeastern Nigeria is characterized by diverse topography, variable rainfall, and significant urbanization, all contributing to its flood risk profile. This study aims to assess flood risk across Abia State by analyzing drainage density, slope, land use/land cover (LULC), rainfall distribution, and proximity to water bodies to categorize flood risk levels and provide insights for targeted flood mitigation. A comprehensive spatial analysis was conducted using data on drainage density, slope, LULC, rainfall, and proximity to rivers. Drainage density was classified into five categories, and areas were mapped to highlight varying flood risk levels. Slope data helped determine terrain's influence on runoff, while LULC data assessed the impact of urbanization and vegetation on flood susceptibility. Rainfall patterns were analyzed to identify regions prone to flooding, and the relationship between proximity to water bodies and flood risk was also evaluated. Results revealed that 50.07% of Abia State is at moderate flood risk, 53.46% at high flood risk, and 34.41% at very high flood risk. High-risk areas are characterized by dense drainage networks, steep slopes, significant rainfall, and close proximity to water bodies. Aba North, Aba South, and Oboma Ngwa are among the most vulnerable regions, while areas with low drainage density and gentle slopes are the least prone to flooding. The study underscores the importance of improved drainage infrastructure, urban planning, and flood management, particularly in high-risk zones. The findings provide critical insights for enhancing resilience and mitigating the impacts of flooding in Abia State, offering a novel approach to regional flood risk assessment.

---

✉ Nwokeabia, Charity Nkiru: [cn.nwokeabia@unizik.edu.ng](mailto:cn.nwokeabia@unizik.edu.ng)

Department of Geophysics, Faculty of Physical Sciences, Nnamdi Azikiwe University, Awka, Nigeria

---

**Keywords:** Hydrological Modeling, Rainfall Distribution, Slope Analysis, Spatial Analysis

## 1.0 Introduction

Flood risk assessment is a critical aspect of environmental management, particularly in regions where the natural and built environments are increasingly vulnerable to flooding (Chukwuma *et al.*, 2021). As climate change intensifies and urbanization continues to expand, the frequency and severity of floods have become more pronounced, necessitating a deeper understanding of the factors that influence flood risk (Mashi *et al.*, 2020). Among these factors, drainage density and geological characteristics play pivotal roles in shaping the hydrological responses of landscapes, directly impacting flood risk levels (Gabriel *et al.*, 2020).

Drainage density, a measure of the total length of streams and rivers within a given area, is a fundamental characteristic of a watershed. It reflects the degree to which water is channeled through the landscape, influencing how quickly and efficiently water is transported during precipitation events (Kudamnya *et al.*, 2021). Areas with high drainage density tend to have a more extensive network of streams and rivers, which can facilitate rapid runoff and potentially lead to flash floods (Ogarekpe *et al.*, 2020). Conversely, regions with low drainage density may experience slower water movement, which can reduce the immediate flood risk but may contribute to prolonged flooding in certain circumstances (Olabode *et al.*, 2020). The significance of drainage density in flood risk assessment lies in its ability to predict how a watershed will respond to rainfall, particularly in terms of the speed and volume of water that reaches the main channels (Alam *et al.*, 2021). This predictive capability is essential for developing effective flood mitigation and management strategies.

Geological factors are equally critical in determining flood risk, as they influence both the physical structure of the landscape and the behavior of water within it. The geology of an area dictates the permeability and porosity of

the ground, which in turn affects infiltration rates and groundwater flow (Frey *et al.*, 2021). Areas with highly permeable soils, such as sand or gravel, allow water to infiltrate quickly, reducing surface runoff and potentially lowering flood risk. In contrast, regions dominated by impermeable materials, such as clay or bedrock, tend to generate more surface runoff, increasing the likelihood of flooding (Tirpak *et al.*, 2021). The geological structure can influence the topography and slope of the land, further impacting water flow and accumulation. Steep slopes, for instance, can accelerate runoff, leading to a higher risk of flash flooding, while flat terrains may encourage water pooling, resulting in prolonged flooding (Egbueri & Igwe, 2020).

The relationship between drainage density and geological factors is complex and mutually influential, playing a critical role in flood risk. High drainage density often results from steep slopes and impermeable geology, leading to rapid runoff and increased flood potential (Olla *et al.*, 2020). Conversely, low drainage density is typically associated with permeable soils and gentle slopes, promoting infiltration and reducing flood risk. Understanding these interactions is vital for accurate flood risk assessment, enabling a nuanced analysis of landscape responses to hydrological events (Echendu, 2020). Flood risk assessment integrates various data and analytical methods. Traditional models rely on hydrological simulations that incorporate drainage density and geological characteristics to enhance prediction accuracy (Komolafe *et al.*, 2020; Chukwuma *et al.*, 2021). Advances in remote sensing and GIS have revolutionized the analysis of drainage density and geology, allowing for precise mapping and quantification of landscape features (Ijaware, 2020). These tools offer insights into water distribution, geological variations, and their influence on flood risk (Rowland & Okpobiri, 2021; Ogungbade *et al.*, 2022). The

implications of drainage density and geological factors extend beyond immediate flood risks, shaping long-term regional vulnerability, land use patterns, and infrastructure resilience (Njoku *et al.*, 2020). Effective flood risk management requires understanding these factors to plan sustainable development and adapt to future climate change impacts (Obi *et al.*, 2021).

Drainage density and geological factors are integral components of flood risk assessment, providing critical insights into how landscapes respond to hydrological events. By examining the interplay between these elements, researchers can improve the accuracy of flood risk models, leading to more effective flood management strategies (Olabode *et al.*, 2020). As climate change and urbanization continue to increase the frequency and severity of floods, the need for comprehensive flood risk assessments that incorporate drainage density and geological factors will only become more pressing. Through the integration of advanced technologies and a deeper understanding of these critical factors, it is possible to develop more resilient and sustainable approaches to managing flood risk in vulnerable regions. This study aims to assess flood risk across Abia State by analyzing multiple critical factors, including drainage density, slope, LULC, rainfall distribution, and proximity to water bodies. By evaluating these elements, the research seeks to categorize flood risk levels and provide valuable insights for developing targeted and effective flood mitigation strategies, ultimately enhancing resilience and safety within vulnerable communities across the state.

## 2.0 Research Area

Abia State is located between latitudes 4°45'N and 6°07'N and longitudes 7°00'E and 8°10'E as shown in Figure 1b. This strategic location places the state within the heart of the Igbo-speaking region of Nigeria, contributing to its

cultural and economic significance. The central location of Abia within the southeastern region makes it a crucial link between the South-South and North-Central geopolitical zones of Nigeria see Figure 1a. Abia State is a mix of urban and rural settlements, with a significant proportion of the population residing in rural areas. Aba, located in the southern part of the state, is the largest urban center and serves as the commercial and industrial hub of the state. These areas are characterized by agricultural activities, low population density, and limited infrastructure. Rural communities in these LGAs are engaged in subsistence farming, with cassava, yam, and oil palm being the major crops cultivated.

Abia State features diverse topography with elevations ranging from 122 to 244 meters above sea level. Highland areas, particularly in Isuikwuato and Bende LGAs, contrast with the lowlands of Ukwu East and Ukwu West, influencing agriculture, settlements, and infrastructure. The state's drainage system is shaped by rivers like the Imo and Aba, which are vital for irrigation and transportation but also, contribute to seasonal flooding in low-lying regions such as Oboma Ngwa. Abia's tropical rainforest climate, with annual rainfall between 2,000 mm and 2,500 mm, supports agriculture, including crops like cassava and palm oil. Despite an extensive road network, poor road conditions, particularly in rural areas, challenge transportation and trade, though ongoing rehabilitation efforts aim to improve accessibility.

The geology of Abia State, Nigeria, is characterised by a diverse range of formations, reflecting the region's complex geological history as shown in Figure 2. The Benin Formation, a major geological unit, dominates the state's surface geology, consisting mainly of unconsolidated sands, clay, and shale with intercalations of limestone. This formation is critical to the region's groundwater resources.

In addition to the Benin Formation, alluvial silts, clays, and organic matter. These deposits are widespread, particularly in river valleys and floodplains, consisting of sands, silts, clays, and organic matter. These deposits are significant for agriculture and support the state's floodplains.

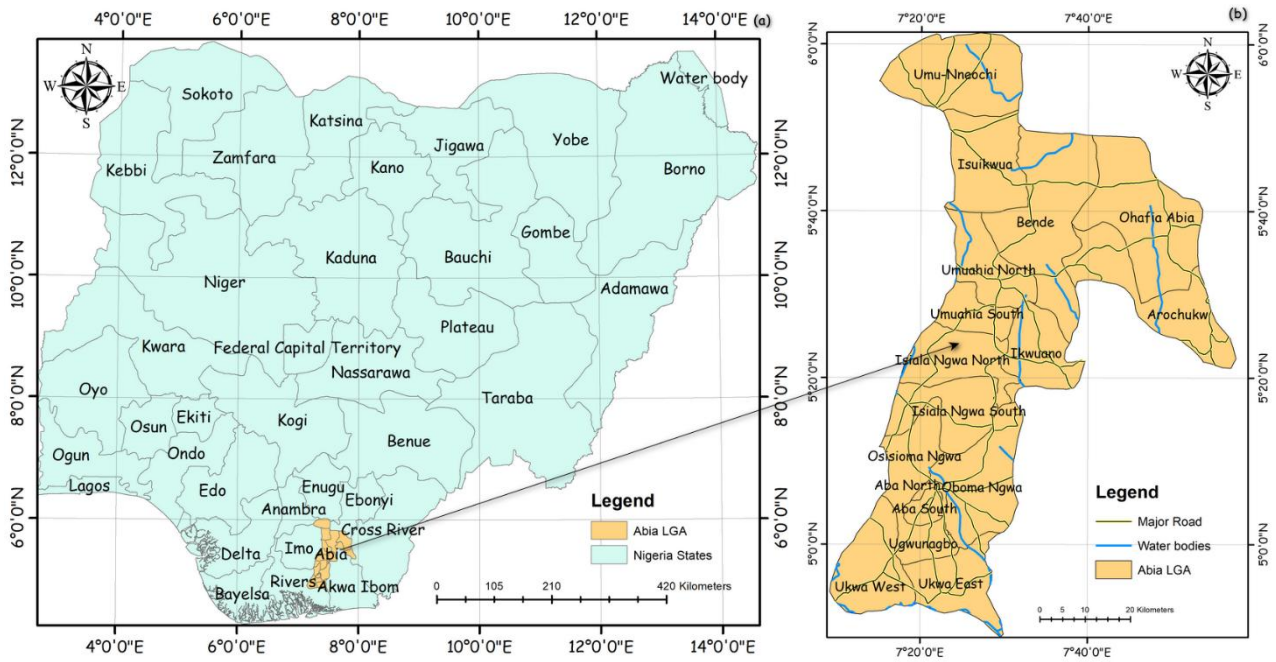


Figure 1: (a) map of Nigeria (b) map of the study area Abia state with water bodies and road networks

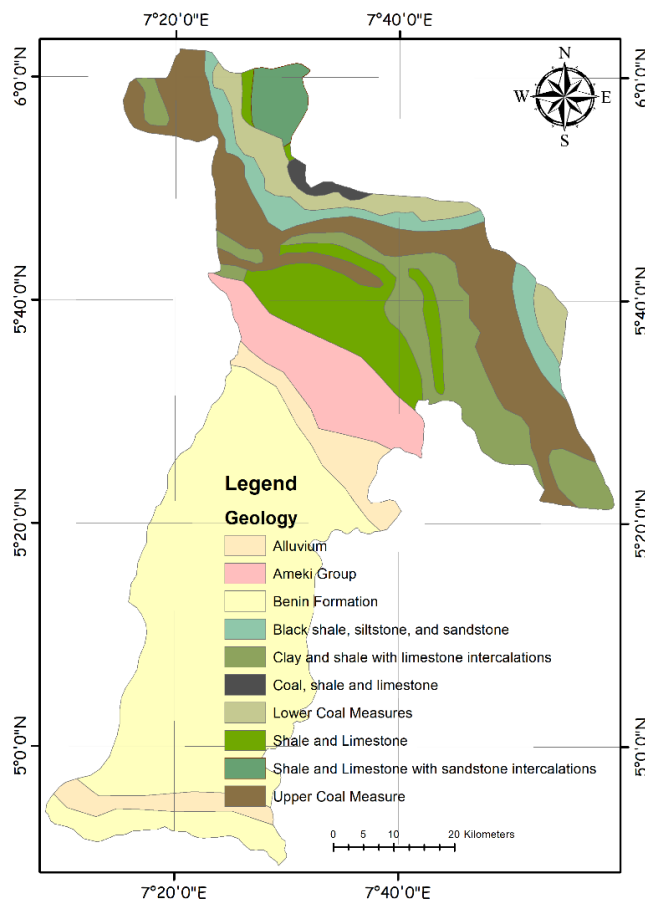


Figure 2: Geology map of the study area

The Ameki Group, known for its shale and limestone composition, is also prominent in Abia State. It includes intercalations of sandstone and is typically found in the southern part of the state. This group belongs to the Tertiary period and contributes to the state's sedimentary structure. The Lower and Upper Coal Measures, featuring coal, shale, and limestone, are present, particularly in the northern regions, providing a record of the state's ancient depositional environments. Black shale, siltstone, and sandstone formations further characterise the geology, reflecting Abia State's rich sedimentary history. Abia State's geology includes a mix of formations that influence its topography, natural resources, and susceptibility to environmental hazards such as flooding.

### 3.0 Methodology

This research relies on diverse data sources to achieve its objectives, incorporating remote sensing data, GIS-based raster and vector data, meteorological data, and other ancillary sources. These datasets are crucial for comprehensive analysis and understanding of the study area's flood dynamics and environmental characteristics.

#### 3.1 Materials

##### 3.2 Remote Sensing Data

The study utilises satellite imagery, primarily from the Landsat 8 Operational Land Imager (OLI), obtained from the United States Geological Survey (USGS). This imagery is instrumental in providing detailed land use and land cover data, enabling the analysis of landscape changes over time. Additionally, Shuttle Radar Topography Mission (SRTM) elevation data from the USGS was used to generate slope and elevation models. These models are essential for understanding the topography of the basin, which significantly influences flood dynamics and water flow patterns (Ekeu-Wei & Blackburn, 2020). The spatial analysis of infrastructure and hydrography within the study area was further

supported by road network and river shape files, also sourced from the USGS.

##### 3.3 Geomorphological Data

The geomorphological aspects of the basin were studied using soil data from the Food and Agriculture Organisation (FAO). The 2020 Digital World Soil Map provided by FAO offered detailed insights into soil types and properties. Understanding soil characteristics is critical for assessing flood risk, as factors such as permeability and infiltration rates directly impact runoff and flood potential. These soil data are vital for planning agricultural activities and implementing effective flood management strategies.

The data collected for this study cover a wide range of sources and types, each playing a unique role in a comprehensive analysis of the study area. Remote sensing data provides critical insights into land use, land cover, and topographic features, while meteorological and hydro-meteorological data offer detailed information on rainfall patterns and stream flow (Isagba *et al.*, 2021). The inclusion of demographic data helps in understanding population dynamics, while geomorphological data offers a deeper understanding of soil characteristics. Ancillary data from stakeholder engagements add qualitative perspectives to the analysis. This multi-faceted approach ensures a robust and holistic understanding of the study area, facilitating effective GIS analysis and supporting the achievement of the research objectives.

### 3.2 Methods

The data acquisition phase concentrated on gathering essential information crucial for flood risk assessment, encompassing various types of data:

1. **Precipitation Data:** Sourced from the Nigerian Meteorological Agency (NiMet), this data spans 36 years and was used to analyze rainfall patterns,

- helping to identify trends and anomalies that are critical in flood risk assessment.
2. **River Data:** Collected to map the hydrological network, this data helps understand the flow dynamics within the study area, which is essential for identifying potential flood zones.
  3. **Road Data:** Acquired to evaluate how infrastructure impacts flood dynamics and emergency response. This data helps in assessing the role of transportation networks in either exacerbating or mitigating flood risks.
  4. **Sentinel-2 Imagery:** Utilized for detailed land cover and land use analysis, this multispectral imagery provided high-resolution data essential for understanding the interaction between land use patterns and flood risk.
  5. **Drainage Density:** Calculated to assess the concentration of drainage features within the area, which significantly influences runoff and flood potential.
  6. **Slope:** Derived from the SRTM DEM, the slope data was used to evaluate the steepness of the terrain, which affects the velocity and direction of surface water flow.
  7. **Elevation:** Also obtained from the SRTM DEM, this data was crucial in determining the relative height of land surfaces, which influences the direction and depth of floodwaters.

**Table 1:** Data Type and Sources of Data

S/N	Data Category	Data Type	Data Source
1	Satellite imagery	Land use and land cover data	<a href="https://www.usgs.gov/">https://www.usgs.gov/</a>
2	GIS data	SRTM Elevation data	<a href="https://www.usgs.gov/">https://www.usgs.gov/</a>
		Slope, Road Network shapefile, River shapefile	<a href="https://www.usgs.gov/">https://www.usgs.gov/</a>
3	Hydro-meteorological data	Rainfall data (2023)	<a href="https://crudata.uea.ac.uk/cru/data/hrg/">https://crudata.uea.ac.uk/cru/data/hrg/</a>

Following data acquisition, a series of image pre-processing techniques were applied. These included radiometric correction, geometric correction, and atmospheric correction, all of which were crucial for enhancing the clarity and accuracy of the imagery. These corrections ensured that the analyses conducted on the imagery would be based on refined, reliable visual information. Once pre-processing was completed, the study advanced to the image classification stage using the maximum likelihood method for supervised classification. This involved creating signature samples for each land cover and land use category identified in the imagery. These samples were then used to categorize and delineate distinct patterns, resulting in a detailed dataset that captured the spatial distribution of various land

cover and land use categories across the study area. Subsequently, road and river data were converted into raster formats, and Euclidean distances were computed to analyze proximity relationships and their potential impacts on flood dynamics. This transformation was vital for integrating vector data into the raster-based analysis framework, ensuring consistent analysis across different data types.

### 3.3 Generation of Thematic Maps for Flood Risk Assessment

Thematic maps play a critical role in flood risk assessment by visually representing the physical and environmental factors that contribute to flood hazards. In this study, thematic maps for drainage density, slope, LULC, rainfall, and soil were generated for Abia State, Nigeria, using GIS techniques and

various datasets, including SRTM DEM and Landsat-8 OLI satellite imagery. The methodology began with the acquisition of essential data, including soil data, precipitation data, river and road networks, Sentinel-2 imagery, and SRTM DEM, encompassing the entire study area in Abia State. This comprehensive and high-resolution dataset was meticulously compiled to form the foundation for the subsequent analyses. By integrating these diverse data sources, the study aimed to create accurate thematic maps that could effectively capture the various factors influencing flood risks in the region (Ighile & Shirakawa, 2020). The thematic maps created in this study not only highlight areas susceptible to flooding but also provide valuable insights for flood risk management and mitigation strategies. The integration of GIS techniques with high-quality data ensures that these maps are precise and reliable, making them indispensable tools for decision-makers and planners in Abia State.

### 3.3.1 Drainage Density

Drainage density (Dd) is a crucial metric that measures the total length of streams per unit area within a watershed, providing significant insights into flood potential. To create the drainage density map, drainage networks were extracted from the SRTM DEM through hydrologic analysis in ArcGIS (Sikakwe, 2020). These networks were then utilized to calculate drainage density using the following equation (Equation 1):

$$D_d = \frac{\sum_{i=1}^n L_i}{A} \quad (1)$$

where  $\sum_{i=1}^n L_i$  represents the total length of streams (L) in the area, and A denotes the total area (L<sup>2</sup>). The resulting drainage density map identifies areas with varying densities of drainage networks, thereby highlighting regions with different potentials for runoff and flooding.

### 3.3.2 Slope

Slope is crucial for assessing flood risk because it influences the speed and direction of surface runoff. To create the slope map, the SRTM DEM data were first pre-processed in ArcGIS to eliminate depressions using sink and fill techniques. The slope map was then generated based on the following equation 2:

$$Slope = \frac{100 \times \sqrt{(DX)^2 + (DY)^2}}{Pixel\ size\ (DEM)} \quad (2)$$

The LULC map was developed using Landsat-8 OLI imagery from 2020 and a supervised classification approach. The maximum likelihood classification method was chosen for its accuracy in distinguishing different land cover types. This map categorizes the study area into various land use types, such as urban areas, agricultural land, forests, and water bodies, providing essential insights into the relationship between land use and flood risk.

### 3.3.3 Land Use and Land Cover (LULC)

The LULC map was created using Landsat-8 OLI imagery from 2020, applying a supervised classification approach. The maximum likelihood supervised classification (MLSC) method was employed for its precision in identifying various land cover types. The resulting map classifies the study area into different land use categories, including urban areas, agricultural land, forests, and water bodies (Akaolisa *et al.*, 2023). This classification is crucial for understanding how land use interacts with flood risk.

### 3.3.4 Rainfall

The rainfall map was created using annual average rainfall data for the year 2023 from the CRU website. This data was spatially interpolated with the Inverse Distance Weighted (IDW) technique in ArcGIS.

### 3.3.5 Elevation

Elevation plays a critical role in flood risk assessment as it influences the potential energy available for water flow and affects the direction and speed of runoff. To create the

elevation map, SRTM-DEM data were used to extract elevation values across the study area. These values were then categorized into different elevation classes, helping to identify low-lying areas that are more susceptible to flooding compared to higher regions (Mohanty *et al.*, 2020). The resulting elevation map offers a clear visualization of the terrain's topography, which is essential for understanding flood dynamics and developing effective flood mitigation strategies.

### 3.3.6 Distance to River

Proximity to rivers is a crucial factor in determining flood risk, as areas closer to rivers are generally more prone to flooding. To create the distance-to-river map, river network data were sourced from hydrographic datasets and topographic maps. The Euclidean Distance tool in ArcGIS was employed to calculate the shortest distance from each cell in the study area to the nearest river (Njoku *et al.*, 2020). This map classifies areas based on their proximity to rivers, with those closer to rivers assigned higher flood risk values. The distance-to-river map is vital for assessing the vulnerability of different regions to riverine flooding and plays a key role in prioritizing areas for flood prevention and mitigation efforts.

### 3.3.7 Distance to Road

Road networks can both contribute to and mitigate flood risks, depending on their design and location. Roads often act as barriers to natural water flow, which can increase flood risk in certain areas. On the other hand, well-designed drainage systems along roads can help reduce flood risk. To create the distance-to-road map, road network data were sourced from local government GIS databases. The Euclidean Distance tool in ArcGIS was used to calculate the distance from each cell to the nearest road. This map categorizes areas based on their proximity to roads, with shorter distances indicating a higher potential impact from road-related flood risks. The distance-to-road map is

crucial for understanding how transportation infrastructure interacts with flood hazards and is instrumental in planning effective flood mitigation strategies.

### 3.4 Flood Hazard Assessment Model

The Weighted Linear Combination (WLC) approach was employed to generate the thematic map of flood risk. This method involves calculating a weighted average of continuous data, which has been standardized to a common numeric range. Decision makers assign weights to each criterion based on the relative importance of each attribute considered in the analysis. The weighted criteria are then combined by applying the assigned weights and summing them to produce a composite flood risk map. This process is mathematically represented in Equation (3).

$$S = \sum(W_i \times X_i) \quad (3)$$

where  $S$  is the flood risk suitability,  $W_i$  is the weight assigned to factor  $i$ , and  $X_i$  is the criterion score of factor  $i$ . The methodology employed in this study involved a systematic approach to flood risk assessment by reclassifying seven key environmental factors: Land Use and Land Cover (LULC), Drainage Density, Distance to Road, Distance to River, Slope, Annual Rainfall, and Elevation. Each factor was reclassified on a scale of 1 to 5, reflecting its contribution to flood risk. Expert consultation was used to assign specific weights to these factors: LULC (10%), Drainage Density (15%), Distance to Road (5%), Distance to River (20%), Slope (10%), Annual Rainfall (25%), and Elevation (15%). These weights were then incorporated into a weighted overlay table within ArcGIS.

Using the Weighted Overlay tool in ArcGIS, the layers representing these factors were combined according to their assigned weights, resulting in a composite flood risk map. This map effectively highlights areas of varying flood risk, providing crucial insights into flood-prone regions. The generation of thematic maps



through GIS techniques, combined with expert-driven weighting and modeling, forms a robust framework for assessing flood risks. This comprehensive approach ensures precise identification of flood-prone areas, thereby supporting the development of effective flood management and mitigation strategies in Abia State, Nigeria. The integration of diverse datasets with advanced analytical methods underscores the potential of GIS in enhancing disaster resilience and preparedness. The methodology in this study was both systematic and comprehensive, encompassing steps such as data acquisition, pre-processing, classification, extraction of environmental factors, standardization, and modeling. These steps collectively provided a strong foundation for flood risk assessment using GIS. The integration of various datasets, along with expert evaluations, ensures that the analysis is both thorough and accurate, which is essential for effective flood management and mitigation efforts in Abia State, Nigeria.

## 4.0 Results and Discussion

### 4.1 Drainage Density Distribution

The analysis of drainage density across Abia, Southeastern Nigeria, reveals significant variations that are crucial for assessing flood risk in the region. Drainage density is a key parameter in hydrological studies as it indicates the closeness of spacing of stream channels and reflects the potential for surface runoff and flood risks. The drainage density values within the study area were categorized into five classes, as shown in Table 2.

**Table 2:** Drainage Density Distribution

Drainage Density (1/km)	Area (km <sup>2</sup> )
16.55 - 52.15	357.04
52.15 - 87.75	987.55
87.75 - 123.35	1476.46
123.35 - 158.95	1395.21
158.95 - 194.55	509.24

Figure 3 illustrates the spatial distribution of

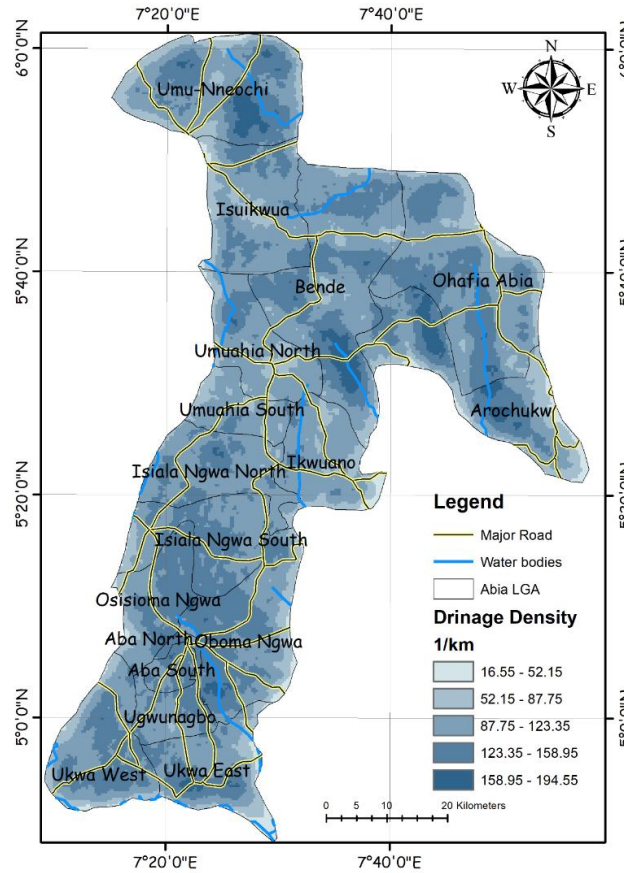
drainage density within the study area, highlighting regions with varying levels of flood risk. Areas with higher drainage density, particularly those falling within the 158.95 - 194.55 1/km range, are more prone to flooding. These areas cover approximately 509.24 km<sup>2</sup> and represent zones where the potential for surface runoff is highest due to the dense network of stream channels. The largest portion of the study area, covering 1476.46 km<sup>2</sup>, falls within the 87.75 - 123.35 1/km drainage density range. These regions, while not as flood-prone as those with higher drainage densities, still present a moderate risk for flooding, especially during heavy rainfall events. The regions with the lowest drainage density (16.55 - 52.15 1/km) and covering 357.04 km<sup>2</sup> have the least flood risk. However, it is important to note that these areas may still experience localized flooding depending on other factors such as soil saturation and rainfall intensity. The distribution of drainage density across Abia State suggests that flood risk is not uniform, with certain areas requiring more intensive flood management strategies.

### 4.2 Slope Distribution

The slope analysis of Abia State, Southeastern Nigeria, was conducted as part of a comprehensive flood risk assessment. Slope is a critical factor influencing surface runoff, soil erosion, and water accumulation, all of which contribute to flood risk. The slope data for the study area, presented in Table 3, reveals a varied topography, which has significant implications for flood risk management.

As shown in Table 3, the majority of the study area (approximately 4415.97 km<sup>2</sup>) is characterized by slopes ranging from 13.53 to 42.08 degrees, indicating a predominantly steep terrain. This steep terrain is typically associated with faster surface runoff, which can lead to reduced infiltration and increased flood potential in lower-lying areas (Wang & Chen, 2021). The areas with the steepest slopes are

likely to experience higher erosion rates and floods during heavy rainfall events (Gallage *et al.*, 2021).



**Figure 3:** Drainage Density Map of the study area

**Table 3:** Slope Distribution in the study area

Slope (Degree)	Area (Km <sup>2</sup> )
0 - 2.31	0.09
2.31 - 4.62	1.81
4.62 - 8.08	20.45
8.08 - 13.53	271.91
13.53 - 42.08	4415.97

Conversely, areas with gentler slopes, particularly those between 0 and 8.08 degrees (which collectively cover approximately 22.35 km<sup>2</sup>) are less likely to contribute to rapid runoff. These regions may have a higher capacity for water infiltration, potentially reducing flood risk. However, in cases of prolonged rainfall, these areas could still experience flooding due to water accumulation, particularly if drainage systems are inadequate. Figure 4, which illustrates the slope distribution across the study area, visually reinforces the

dominance of steep slopes in Abia State. The concentration of steep slopes in the state suggests that flood risk management strategies should prioritize these areas, focusing on erosion control measures, the construction of retention basins, and the maintenance of natural vegetation cover to mitigate runoff (Mueller & Grams, 2021). The slope analysis highlights the need for targeted flood risk management in Abia State, particularly in areas with steep slopes.

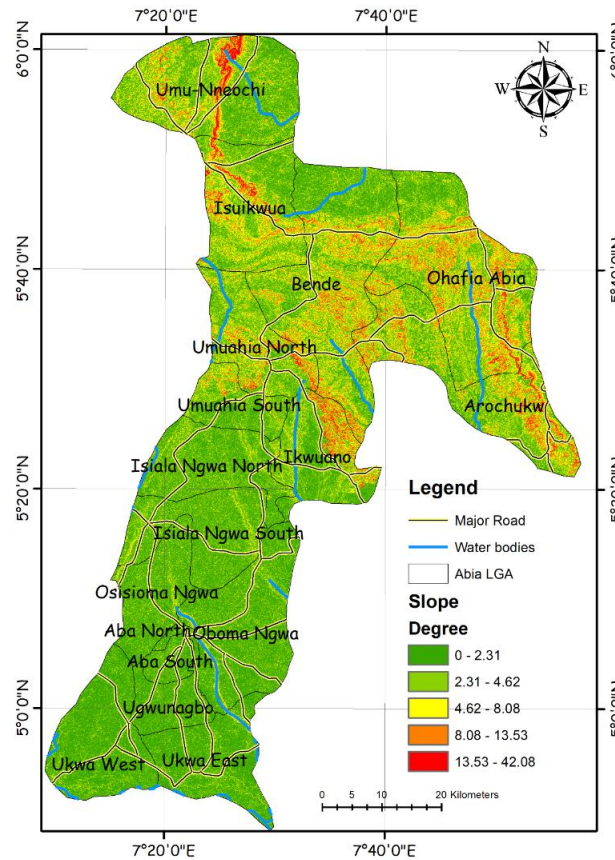


Figure 4: Spatial distribution of Slope

#### 4.3 LULC Analysis and Implications for Flood Risk

The LULC analysis of Abia State reveals significant insights into the potential flood risk within the region. As shown in Table 4, the LULC types vary considerably in their spatial extent, with trees covering the largest area (3,276.68 km<sup>2</sup>) and bare ground the smallest (0.92 km<sup>2</sup>). Built-up areas, which encompass urban and semi-urban regions, account for 889.79 km<sup>2</sup>, indicating a substantial degree of urbanization in parts of the state. Crops cover 50.63 km<sup>2</sup>, while rangelands occupy 490.56 km<sup>2</sup>, reflecting the importance of agriculture and grazing in the state's economy.

Water bodies, though covering a relatively small area (12.59 km<sup>2</sup>), are crucial in understanding flood dynamics. The presence of water bodies, combined with the 2.24 km<sup>2</sup> of flooded vegetation, highlights areas that are potentially susceptible to flooding.

Table 4: LULC Types and Their Spatial Extent in Abia State, Nigeria

LULC Type	Area (km <sup>2</sup> )
Water	12.59
Trees	3276.68
Flooded vegetation	2.24
Crops	50.63
Built Area	889.79
Bare ground	0.92
Rangeland	490.56

Flooded vegetation is typically associated with waterlogged soils and low-lying areas that are prone to flooding; especially during heavy rainfall (Tsyganskaya *et al.*, 2019). The distribution of built-up areas is particularly significant in flood risk assessment. Urbanization increases the number of impervious surfaces, reducing infiltration and increasing surface runoff, which can exacerbate flood events (Mahmoud *et al.*, 2016). The substantial area of built-up land in Abia State, particularly in flood-prone regions, underscores

the need for effective urban planning and flood management strategies. Figure 5, which illustrates the LULC distribution across the study area, provides a visual representation of these dynamics. It is evident that the built-up

areas are concentrated in regions that may be vulnerable to flooding, particularly if coupled with inadequate drainage infrastructure. The LULC analysis highlights the critical areas that require attention in flood risk management.

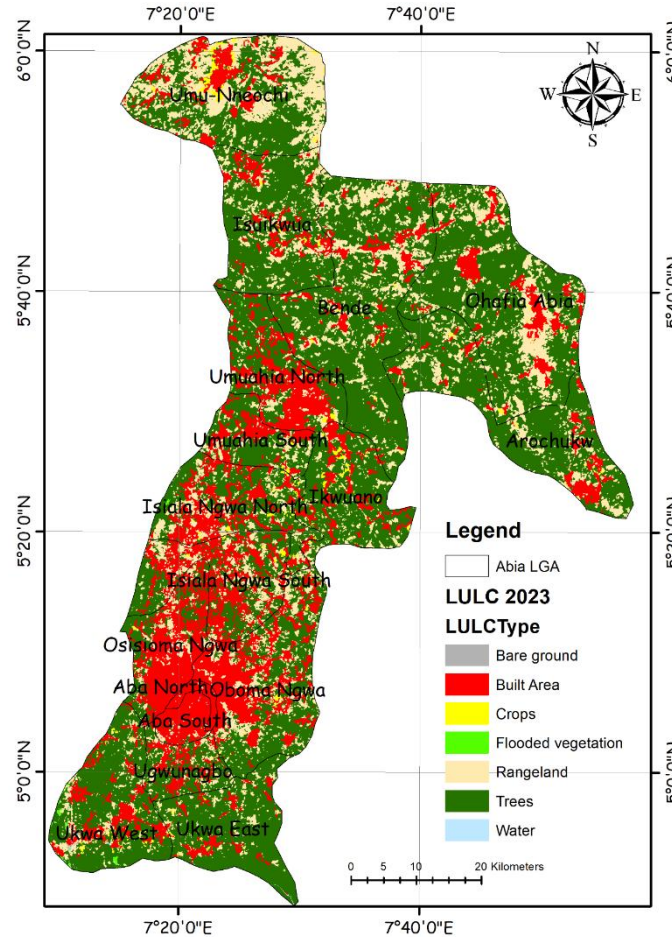


Figure 5: LULC Distribution in Abia State, Southeastern Nigeria

**4.4 Annual Rainfall Distribution and Implications for Flood Risk in Abia State**

The distribution of annual rainfall across Abia State, Southeastern Nigeria, reveals significant variability, which has direct implications for flood risk assessment. The annual rainfall ranges from 2102.00 mm to 2351.78 mm, with distinct spatial patterns that can influence the susceptibility of different areas to flooding. Table 5 shows that the area receiving the lowest annual rainfall, between 2102.00 mm and 2151.95 mm, covers approximately 932.16 km<sup>2</sup>. This lower rainfall zone is less likely to experience severe flooding but may still be at

risk, depending on other factors such as topography and drainage capacity.

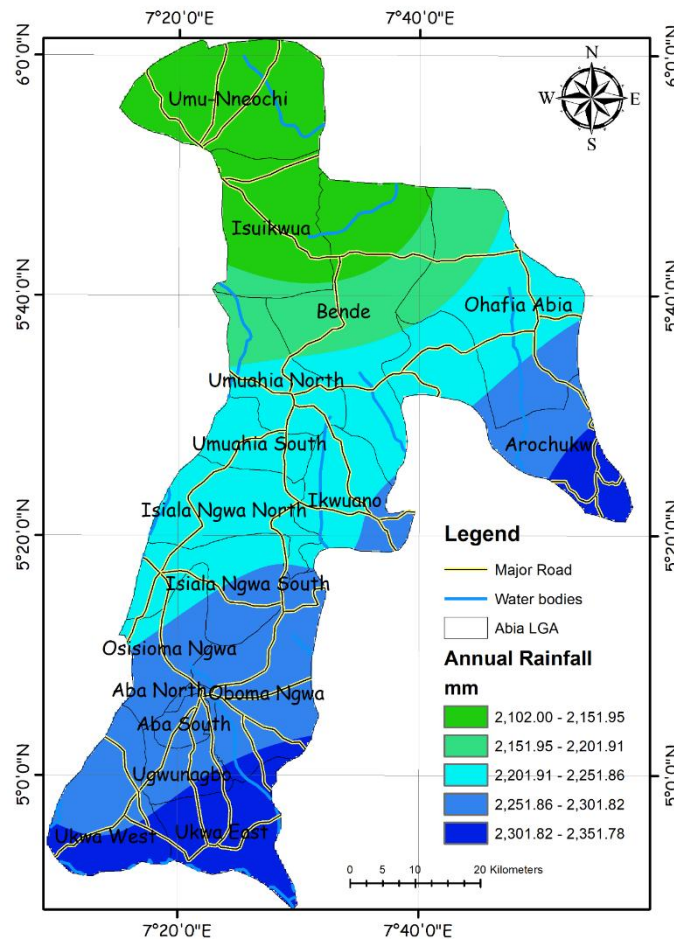
**Table 5:** Annual Rainfall Distribution across Abia State

Annual Rainfall (mm)	Area (km <sup>2</sup> )
2102.00 - 2151.95	932.16
2151.95 - 2201.91	539.46
2201.91 - 2251.86	1516.18
2251.86 - 2301.82	1224.25
2301.82 - 2351.78	511.66

The largest area, 1516.18 km<sup>2</sup>, falls within the rainfall range of 2201.91 mm to 2251.86 mm, indicating a broad region that could be more susceptible to moderate flooding, especially

during peak rainy seasons. Areas receiving the highest rainfall, ranging from 2301.82 mm to 2351.78 mm, cover 511.66 km<sup>2</sup>. These regions are of particular concern for flood risk due to the higher volume of precipitation. The

combination of intense rainfall and potentially inadequate drainage infrastructure in these areas could lead to frequent and severe flooding events, impacting both urban and rural communities.



**Figure 6:** Annual Rainfall Distribution in Abia State, Southeastern Nigeria

The variation in rainfall across Abia State underscores the need for localized flood risk management strategies. Regions with higher rainfall should prioritize the development of efficient drainage systems and flood barriers to mitigate the impact of potential floods. Additionally, urban planning in areas such as those receiving over 2251.86 mm of rainfall should consider flood risk in the design and construction of infrastructure.

#### 4.5 Elevation Analysis for Flood Risk Assessment

The elevation profile of Abia State,

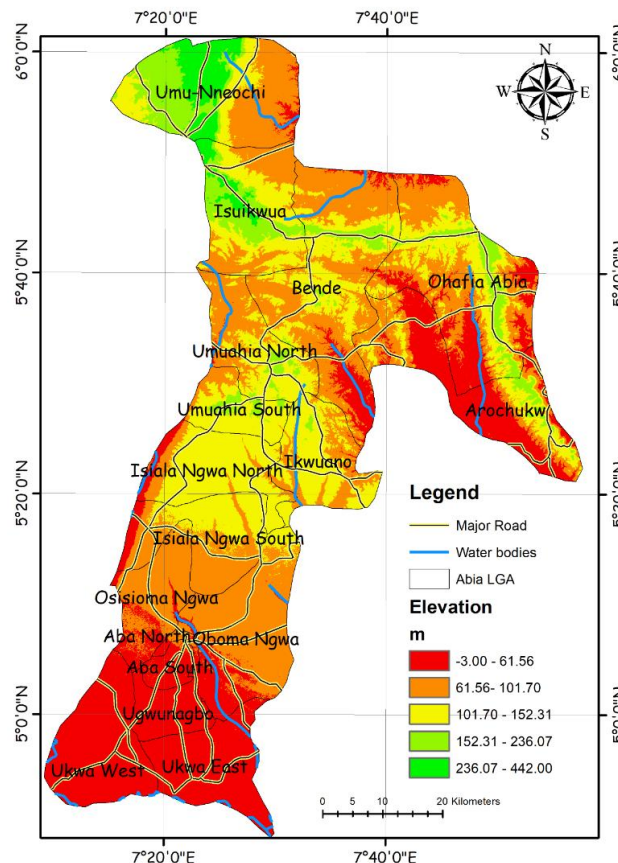
Southeastern Nigeria, plays a critical role in determining flood risk within the region. The study area exhibits considerable variation in elevation, ranging from low-lying areas near sea level to higher terrains exceeding 400 meters. The elevation data has been categorized into five distinct classes, as presented in Table 6. As shown in Table 6, the vast majority of the study area, approximately 4,397.70 km<sup>2</sup>, lies within the elevation range of 152.31 to 442.00 meters. The areas with lower elevations, particularly those between -3.00 and 101.70 meters, are relatively small, encompassing only 82.89 km<sup>2</sup> of the total study area.

**Table 6:** Elevation Distribution of the Study Area

Elevation (m)	Area (km <sup>2</sup> )
-3.00 - 64.56	12.87
61.56 - 101.70	70.02
101.70 - 152.31	242.79
152.31 - 236.07	2046.02
236.07 - 442.00	2351.68

These lower elevation zones are primarily found in the southern and western parts of the state, areas that are more susceptible to flooding, especially during the rainy season. The elevation map (Figure 7) further illustrates the distribution of elevation classes across Abia State. It highlights the concentration of higher elevations in the northern and eastern regions

of the state, particularly around Isuikwuato and Bende LGAs. These areas, due to their higher elevation, are less prone to flooding but are important for understanding the topographical influences on drainage and flood dynamics. The discussion of elevation in the context of flood risk is crucial because lower-lying areas are typically more vulnerable to flooding. The small area of land within the -3.00 to 64.56 meters elevation range represents the most critical flood-prone zones. Conversely, the larger expanse of land at elevations above 152.31 meters provides natural protection against flooding, although localized flood risks may still exist due to other factors such as drainage density and land use.

**Figure 7:** Elevation Map of the Study Area

#### 4.6 Flood Risk Assessment Based on Proximity to Rivers

Flood risk assessment in Abia State, Southeastern Nigeria, was carried out by analyzing the proximity of different areas to rivers within the region. The spatial analysis

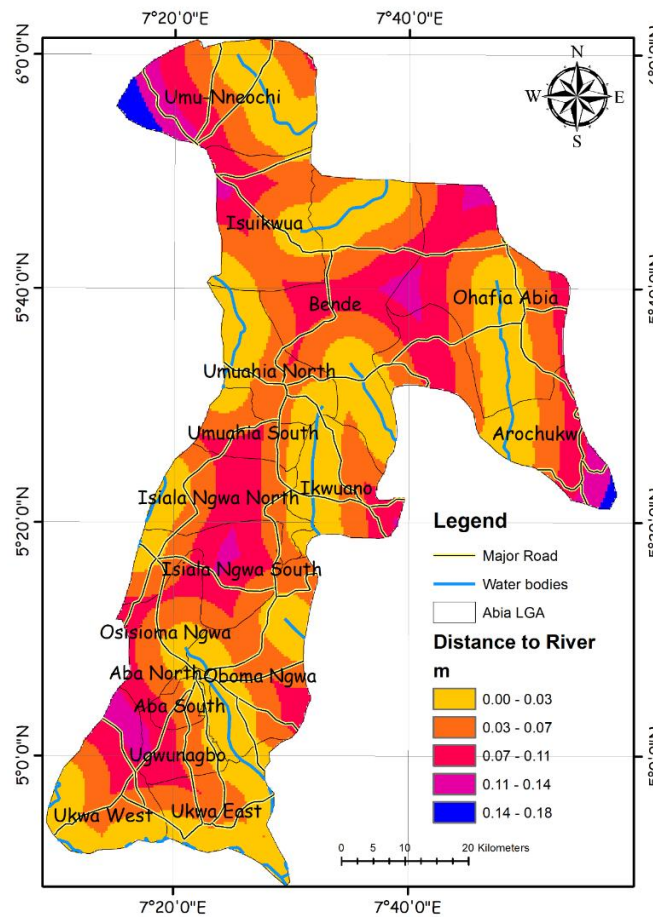
considered distances ranging from 0.00 to 0.18 meters to determine the area's most susceptible to flooding. The results, as illustrated in Table 7 and Figure 8, highlight the relationship between distance from rivers and the spatial extent of potentially flood-prone areas. Table 7 provides

a detailed breakdown of the areas categorized by their proximity to rivers. The data reveals that the smallest area (32.42 km<sup>2</sup>) is found within the closest distance range of 0.00 to 0.03 meters from the river. This suggests that only a minimal portion of the state falls within this high-risk flood zone. As the distance increases, the area covered by each range expands significantly. For instance, the area between 0.11 and 0.14 meters from the river covers the largest extent, totaling 1,746.76 km<sup>2</sup>. This pattern indicates that a vast portion of the state lies in moderately low-risk zones, with

relatively fewer areas in the immediate vicinity of rivers, which are more vulnerable to flooding.

**Table 7:** Area Distribution by Distance to Rivers in Abia State, Southeastern Nigeria

Distance to river (m)	Area (km <sup>2</sup> )
0.00 - 0.03	32.42
0.03 - 0.07	199.23
0.07 - 0.11	1056.35
0.11 - 0.14	1746.76
0.14 - 0.18	1689.45



**Figure 8:** Spatial Distribution of Flood Risk Based on Distance to Rivers in Abia State, Southeastern Nigeria

The spatial distribution shown in Figure 8 aligns with these findings, depicting a concentration of high-risk flood zones close to riverbanks. The gradual increase in area with distance from rivers suggests that flood risk diminishes as one moves away from the river

channels. This information is critical for urban planning, especially in areas where population density and economic activities are high.

**4.7 Flood Risk Assessment Based on Proximity to Road**

The analysis of the distance to roads within

Abia State, Southeastern Nigeria, reveals a significant variation in land area distribution, which is crucial for flood risk assessment. As depicted in Table 8 and Figure 9, the largest proportion of the area, approximately 2748.10 km<sup>2</sup>, is located within 0.09 to 0.11 meters from roads. This indicates that a substantial part of the region is relatively distant from major roadways, which may influence flood management strategies and emergency response.

Conversely, the area within 0.00 to 0.02 meters from roads is significantly smaller, at 32.97 km<sup>2</sup>. This close proximity to roads suggests that these areas may be more accessible for flood monitoring and management, but they represent a minimal portion of the total land area.

The range of 0.06 to 0.09 meters from roads encompasses the largest land area (1307.96 km<sup>2</sup>), highlighting a significant portion of the study area. This distance suggests that a considerable number of areas potentially vulnerable to flooding are located at this distance from roads. These regions may experience challenges in accessing flood relief and infrastructure development due to their relative distance from transportation routes.

**Table 8:** Distribution of Land Area by Distance to Road

Distance to Road (m)	Area (km <sup>2</sup> )
0.00 - 0.02	32.97
0.02 - 0.04	154.22
0.04 - 0.06	479.80
0.06 - 0.09	1307.96
0.09 - 0.11	2748.10

The data indicates that flood risk assessment should prioritize areas within 0.04 to 0.09 meters from roads, as these regions collectively cover a substantial area (approximately 1787.76 km<sup>2</sup>). These areas are more likely to face challenges in flood management due to their significant distance from major roads, which can impede both preventive measures and emergency responses.

#### 4.8 Flood Risk Assessment in Abia, Southeastern Nigeria

The flood risk assessment for Abia State, Southeastern Nigeria, evaluates the potential for flooding across different areas of the state. This analysis categorizes flood risk into five levels: Very Low, Low, Moderate, High, and Very High. The results, presented in Table 9 and Figure 10, reveal a diverse range of flood risks across the state.

**Table 9:** Flood Risk Classification by Area

Flood Risk Level	Area (km <sup>2</sup> )	Percentage (%)
Very Low	267.89	10.53
Low	795.08	30.54
Moderate	1305.75	50.07
High	1399.76	53.46
Very High	905.27	34.41

The flood risk assessment reveals that a significant portion of Abia State is categorized under Moderate to Very High flood risk levels, indicating a substantial vulnerability to flooding. The Moderate flood risk area is the largest, covering approximately 50.07% of the state. This suggests that nearly half of Abia is at a moderate risk of flooding, influenced by factors such as elevation, drainage patterns, and weather conditions. The High flood risk category, encompassing 53.46% of the state, highlights areas that are particularly susceptible to severe flooding. This is consistent with the findings that regions with higher elevation and less effective drainage systems are more prone to flooding during heavy rainfall periods. The Very High flood risk areas, covering 34.41% of the state, are concentrated in low-lying zones and areas with poor drainage infrastructure, exacerbating the risk of severe flood events. Conversely, the Very Low flood risk area is relatively small, covering only 10.53% of Abia State. This limited area suggests that effective flood management practices and favorable topographical conditions contribute to a lower flood risk in these regions.



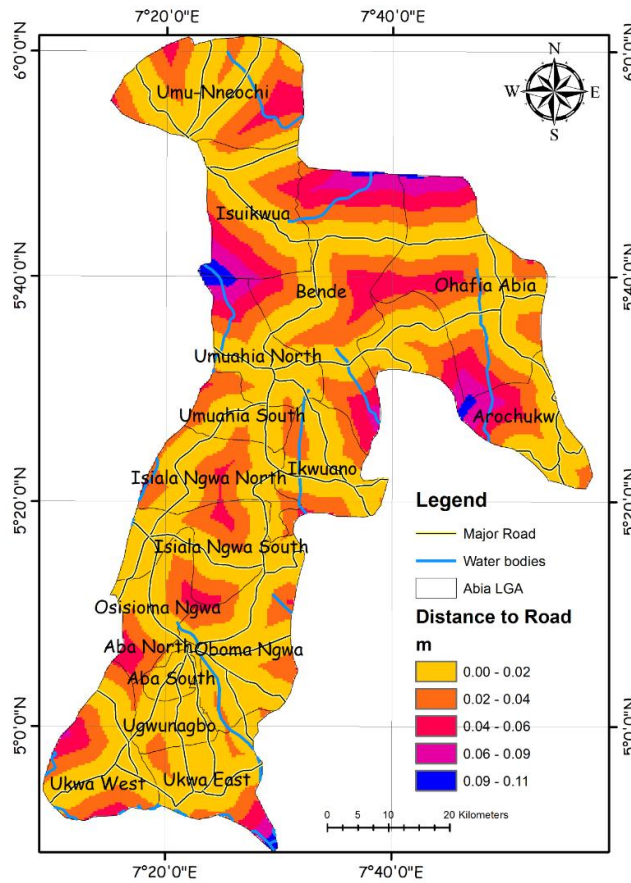


Figure 9: Distance to Road in the Study Area

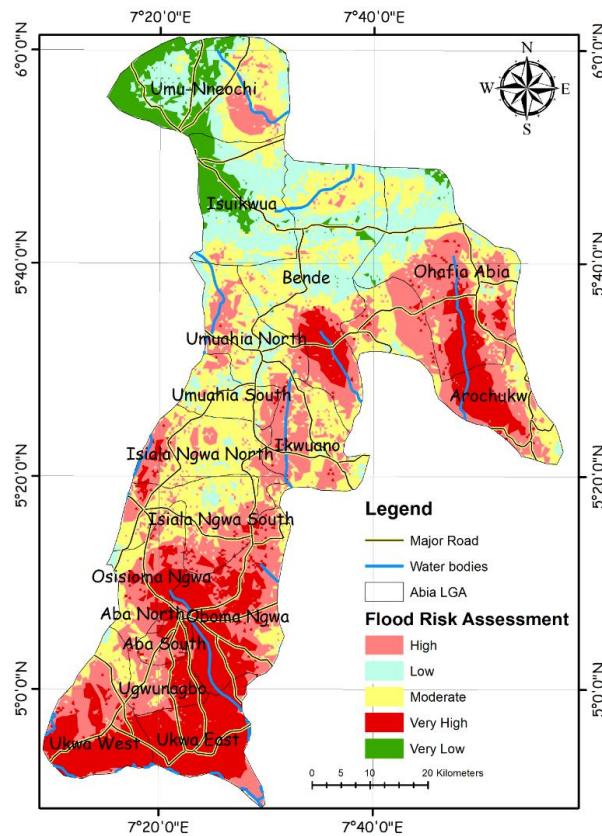


Figure 10: Flood Risk Assessment Map of Abia State

The distribution of flood risk levels underscores the need for targeted flood management strategies. Areas identified with High and Very High flood risks, such as parts of Aba North, Aba South, and Oboma Ngwa, require immediate attention to improve drainage systems and implement flood mitigation measures. Conversely, regions with Moderate and Low flood risks, including parts of Isiala Ngwa North and South, should focus on maintaining their current flood management practices to prevent future escalation of flood risks. The flood risk assessment for Abia State highlights significant variations in flood risk levels across the region. With over half of the state experiencing High to Very High flood risks, it is crucial for flood management strategies to be tailored to the specific needs of each area. Addressing these risks through improved infrastructure and proactive management can help mitigate the impacts of flooding and enhance resilience in flood-prone areas.

## 5.0 Conclusion

The flood risk assessment of Abia State, Southeastern Nigeria, provides crucial insights into regional flood susceptibility by examining factors such as drainage density, slope, LULC, rainfall, elevation, and proximity to rivers and roads. The findings indicate that a substantial portion of the state is at significant risk of flooding, with notable differences across various regions. Areas with high drainage density, particularly those within the 158.95 - 194.55 1/km range, are identified as high-risk zones due to their dense network of stream channels, which enhances surface runoff. These areas, covering approximately 509.24 km<sup>2</sup>, have a heightened potential for flooding. In contrast, the majority of the state, encompassing 1476.46 km<sup>2</sup>, falls within the 87.75 - 123.35 1/km drainage density range, representing a moderate risk. Regions with the lowest drainage density, covering 357.04 km<sup>2</sup>, experience the least flood risk but may still face

localized flooding under certain conditions. Slope data further clarifies flood risk, with steep terrain (13.53 to 42.08 degrees) accelerating surface runoff and erosion, leading to higher flood potential in lower-lying areas. Conversely, gentler slopes (0 - 8.08 degrees) reduce rapid runoff but can still be vulnerable to flooding during intense rainfall events. The LULC analysis highlights that urbanization, covering 889.79 km<sup>2</sup>, exacerbates flood risk due to increased impervious surfaces that hinder water infiltration. High rainfall areas (2301.82 mm to 2351.78 mm), particularly those with 511.66 km<sup>2</sup> of the highest precipitation, are more susceptible to severe flooding. Elevation also influences flood dynamics, with lower-lying regions (elevations -3.00 to 101.70 meters) being more prone to flooding, while higher elevations (152.31 to 442.00 meters) offer some natural protection. Proximity to rivers and roads indicates that areas close to riverbanks face higher flood risks. These findings underscore the necessity for targeted flood management strategies, including improved drainage infrastructure, effective urban planning, and flood defenses, especially in high-risk zones. Tailored interventions are essential to mitigate flooding impacts and enhance resilience across Abia State.

To mitigate flood risks in Abia State, it is essential to prioritize infrastructure improvements in high-risk areas. This includes enhancing drainage systems, constructing flood barriers, and implementing effective urban planning. Special attention should be given to regions with high drainage density, steep slopes, and significant urbanization.

## Reference

Akaolisa, C. C., Agbasi, O. E., Etuk, S. E., Adewumi, R., & Okoli, E. A. (2023). Evaluating the Effects of Real Estate Development in Owerri, Imo State, Nigeria: Emphasizing Changes in Land Use/Land Cover (LULC). *Journal of*

- Landscape Ecology*, 16(2), 98–113. <https://doi.org/10.2478/jlecol-2023-0012>
- Alam, A., Ahmed, B., & Sammonds, P. (2021). Flash flood susceptibility assessment using the parameters of drainage basin morphometry in SE Bangladesh. *Quaternary International*, 575–576, 295–307. <https://doi.org/10.1016/j.quaint.2020.04.047>
- Chukwuma, E., Okonkwo, C., Ojediran, J., Anizoba, D., Ubah, J., & Nwachukwu, C. (2021). A GIS based flood vulnerability modelling of Anambra State using an integrated IVFRN-DEMATEL-ANP model. *Heliyon*, 7(9), e08048. <https://doi.org/10.1016/j.heliyon.2021.e08048>
- Echendu, A. J. (2020). The impact of flooding on Nigeria's sustainable development goals (SDGs). *Ecosystem Health and Sustainability*, 6(1). <https://doi.org/10.1080/20964129.2020.1791735>
- Egbueri, J. C., & Igwe, O. (2020). The impact of hydrogeomorphological characteristics on gully processes in erosion-prone geological units in parts of southeast Nigeria. *Geology Ecology and Landscapes*, 5(3), 227–240. <https://doi.org/10.1080/24749508.2020.1711637>
- Ekeu-Wei, I. T., & Blackburn, A. G. (2020). *Catchment-Scale Flood Modelling in Data-Sparse Regions Using Open-Access Geospatial Technology*. <https://doi.org/10.20944/preprints202007.0207.v1>
- Frey, S., Miller, K., Khader, O., Taylor, A., Morrison, D., Xu, X., Berg, S., Hwang, H. T., Sudicky, E., & Lapen. (2021). Evaluating landscape influences on hydrologic behavior with a fully integrated groundwater – surface water model. *Journal of Hydrology*, 602, 126758. <https://doi.org/10.1016/j.jhydrol.2021.126758>
- Gabriel, A. T., Yusuf, M. B., Bwadi, B. E., & Clement, Y. G. (2020). Morphometric Analysis and Flash Floods Assessment of River Taraba Basin in Taraba State, Nigeria. *European Scientific Journal ESJ*, 16(20). <https://doi.org/10.19044/esj.2020.v16n20p158>
- Gallage, C., Abeykoon, T., & Uchimura, T. (2021). Instrumented model slopes to investigate the effects of slope inclination on rainfall-induced landslides. *SOILS AND FOUNDATIONS*, 61(1), 160–174. <https://doi.org/10.1016/j.sandf.2020.11.006>. [High-resolution gridded -datasets \(uea.ac.uk\) https://www.usgs.gov/](https://www.usgs.gov/uea.ac.uk)
- Ighile, E. H., & Shirakawa, H. (2020). A STUDY ON THE EFFECTS OF LAND USE CHANGE ON FLOODING RISKS IN NIGERIA. *Geographia-Technica*, 15(1), 91–101. [https://doi.org/10.21163/gt\\_2020.151.08](https://doi.org/10.21163/gt_2020.151.08)
- Ijaware, V. (2020). GIS based Flood Vulnerability Studies for Ife Central Local Government Area, Osun State, Nigeria. *Deleted Journal*, 4(1), 160–171. <https://doi.org/10.36263/nijest.2020.01.0184>
- Isagba, E. S., Izinyon, O. C., Emeribe, C. N., Uwadia, N. O., & Ezech, C. U. (2021). Estimation of stream discharge of ungauged basins using NRCS-CN and remote sensing methods: A case study of Okhuwan and Okhaihe catchments, Benin City, Edo State, Nigeria. *International Journal of Water Resources and Environmental Engineering*, 13(3), 165–183. <https://doi.org/10.5897/ijwree2021.1014>

- Komolafe, A. A., Awe, B. S., Olorunfemi, I. E., & Oguntunde, P. G. (2020). Modelling flood-prone area and vulnerability using integration of multi-criteria analysis and HAND model in the Ogun River Basin, Nigeria. *Hydrological Sciences Journal*, 65(10), 1766–1783. <https://doi.org/10.1080/02626667.2020.1764960>
- Kudamnya, E. A., Edet, A., & Ekwere, A. S. (2021). Analysing principal components of physiographic factors affecting groundwater occurrences within Keffi, North-Central Nigeria. *The Egyptian Journal of Remote Sensing and Space Science*, 24(3), 665–674. <https://doi.org/10.1016/j.ejrs.2021.08.005>
- Mahmoud, M. I., Duker, A., Conrad, C., Thiel, M., & Ahmad, H. S. (2016). Analysis of Settlement Expansion and Urban Growth Modelling Using Geoinformation for Assessing Potential Impacts of Urbanization on Climate in Abuja City, Nigeria. *Remote Sensing*, 8(3), 220. <https://doi.org/10.3390/rs8030220>
- Mashi, S. A., Inkani, A. I., Obaro, O., & Asanarimam, A. S. (2020). Community perception, response and adaptation strategies towards flood risk in a traditional African city. *Natural Hazards*, 103(2), 1727–1759. <https://doi.org/10.1007/s11069-020-04052-2>
- Mohanty, M. P., Nithya, S., Nair, A. S., Indu, J., Ghosh, S., Bhatt, C. M., Rao, G. S., & Karmakar, S. (2020). Sensitivity of various topographic data in flood management: Implications on inundation mapping over large data-scarce regions. *Journal of Hydrology*, 590, 125523. <https://doi.org/10.1016/j.jhydrol.2020.125523>
- Mueller, E. R., & Grams, P. E. (2021). A Morphodynamic Model to Evaluate Long-Term Sandbar Rebuilding Using Controlled Floods in the Grand Canyon. *Geophysical Research Letters*, 48(9). <https://doi.org/10.1029/2021gl093007>
- Njoku, C. G., Efiog, J., & Ayara, N. a. N. (2020). A Geospatial Expose of Flood-Risk and Vulnerable Areas in Nigeria. *International Journal of Applied Geospatial Research*, 11(3), 87–110. <https://doi.org/10.4018/ijagr.20200701.oa1>
- Obi, R., Nwachukwu, M. U., Okeke, D. C., & Jiburum, U. (2021). Indigenous flood control and management knowledge and flood disaster risk reduction in Nigeria's coastal communities: An empirical analysis. *International Journal of Disaster Risk Reduction*, 55, 102079. <https://doi.org/10.1016/j.ijdrr.2021.102079>
- Ogarekpe, N. M., Obio, E. A., Tenebe, I. T., Emenike, P. C., & Nnaji, C. C. (2020). Flood vulnerability assessment of the upper Cross River basin using morphometric analysis. *Geomatics Natural Hazards and Risk*, 11(1), 1378–1403. <https://doi.org/10.1080/19475705.2020.1785954>
- Ogungbade, O., Ariyo, S. O., Alimi, S. A., Alepa, V. C., Aromoye, S. A., & Akinlabi, O. J. (2022). A combined GIS, remote sensing and geophysical methods for groundwater potential assessment of Ilora, Oyo central, Nigeria. *Environmental Earth Sciences*, 81(3). <https://doi.org/10.1007/s12665-022-10199-x>
- Olabode, O. F., Oluwaniyi, O. E., Adebayo, Q. A., & Asiwaju-Bello, Y. A. (2020). Morpho-lithostructural analysis of Ala River basin for flood risk assessment: geospatial techniques intervention. *Earth Science Informatics*, 13(3), 773–794. <https://doi.org/10.1007/s12145-020-00457-6>

- Olla, O. O., Adeniran, K. A., Kasali, M. Y., & James, D. (2020). Determination of Physiographic Characteristics of an Ungauged Watershed in North Central Nigeria. *IOP Conference Series Earth and Environmental Science*, 445(1), 012026. <https://doi.org/10.1088/1755-1315/445/1/012026>
- Rowland, E. D., & Okpobiri, O. (2021). Floodplain Mapping and Risks Assessment of the Orashi River Using Remote Sensing and GIS in the Niger Delta Region, Nigeria. *Journal of Geographical Research*, 4(2), 10–16. <https://doi.org/10.30564/jgr.v4i2.3014>
- Sikakwe, G. U. (2020). Geospatial applications in delineating groundwater prospect zones in a hard rock terrain: an integrated approach. *Environmental Earth Sciences*, 79(21). <https://doi.org/10.1007/s12665-020-09235-5>
- Tirpak, R. A., Winston, R. J., Feliciano, M., Dorsey, J. D., & Epps, T. H. (2021). Impacts of permeable interlocking concrete pavement on the runoff hydrograph: Volume reduction, peak flow mitigation, and extension of lag times. *Hydrological Processes*, 35(4). <https://doi.org/10.1002/hyp.14167>
- Tsyganskaya, V., Martinis, S., & Marzahn, P. (2019). Flood Monitoring in Vegetated Areas Using Multitemporal Sentinel-1 Data: Impact of Time Series Features. *Water*, 11(9), 1938. <https://doi.org/10.3390/w11091938>
- Wang, J., & Chen, L. (2021). The effect of hillslope geometry on Hortonian rainfall-infiltration-runoff processes. *Journal of Hydrology*, 594, 125962. <https://doi.org/10.1016/j.jhydrol.2021.125962>