FLOOD VULNERABILITY MAPPING OF ETSAKO WEST LOCAL GOVERNMENT AREA USING GEOSPATIAL INFORMATION SYSTEM

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR OF SCIENCES {BSCGEM - B.SC. GEOMATICS} DEGREE, IN THE FACULTY OF ENVIRONMENTAL SCIENCES, UNIVERSITY OF BENIN,

BENIN CITY, EDO STATE, NIGERIA.

NOVEMBER, 2025

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CERTIFICATION

This is to certify that this project was carried out by IGBAKPA, GODWIN OYOVWIKIGHO with Matriculation Number: ENV2103433 of the Department of Geomatics, Faculty of Environmental Sciences, University of Benin, Edo State, Nigeria.

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EXTERNAL EXAMINER Date

DEDICATION

I humbly dedicate this project to God almighty for his grace upon my life and to my parents Mr. Ajuechi Igbakpa and Mrs. Umukotete Igbakpa, and my beloved brothers and sisters for their support in all ramifications. May God continue to bless you all, Amen.

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ABSTRACT

Flooding remains one of the most devastating environmental hazards in Nigeria, with severe impacts on lives, livelihoods, and infrastructure. Etsako West Local Government Area (LGA) of Edo State is particularly vulnerable due to its low-lying terrain, proximity to rivers, and recurring seasonal rainfall.

This study applied Geospatial Information System (GIS) and the Analytical Hierarchy Process (AHP) to assess and map flood vulnerability across the LGA. Key geospatial and socioenvironmental indicators including elevation, slope, land use/land cover, distance to rivers, soil type, and population density, were integrated and weighted to generate a composite Flood Vulnerability Index.

The resulting map classified the area into four risk categories: very high, high, moderate, and low. Findings revealed that very high-risk zones, occupying about 22% of the land area, are concentrated in riverine communities such as Anegbette, Udaba, and Osomegbe, while high-risk areas (33%) extend across Aviele and Iyakpi. Moderate- and low-risk zones accounted for 27% and 18% respectively, with upland towns like Auchi and Jattu benefiting from higher elevation and better drainage. Notably, nearly two-thirds of the population reside within high or very high vulnerability zones, underscoring the human dimension of flood risk. The study demonstrates the effectiveness of GIS-based multi-criteria analysis for local-scale flood assessment and provides an evidence-based tool to support disaster preparedness, land-use planning, and sustainable development in Etsako West and similar flood-prone regions of Nigeria.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: RESULTS AND DISCUSSION

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

Table **Page No:**

LIST OF FIGURES

Figure **Page No:**

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Flooding is one of the most frequent and devastating natural disasters affecting millions of people worldwide (Umar and Gray, 2022). Its consequences range from the destruction of infrastructure, loss of agricultural productivity, displacement of populations, and in severe cases, loss of lives (Dalil *et. al*., 2015). The impact of flooding is exacerbated by climate change, poor urban planning, deforestation, and inadequate drainage systems, especially in developing countries (Adegboyega *et. al*., 2018). In Nigeria, floods are becoming increasingly common and severe, largely due to rapid urbanization, unregulated land use, and poor environmental management practices (Ogbonna *et al.,* 2015).

Etsako West Local Government Area (LGA), located in Edo State, southern Nigeria, is particularly vulnerable to flooding due to its proximity to major rivers, low-lying topography, and seasonal heavy rainfall. In recent years, several communities within Etsako West have experienced recurring flood events that have led to the destruction of farmlands, roads, buildings, and displacement of households (Ibanga *et. al*., 2022). The flooding problem is further aggravated by inadequate drainage infrastructure and uncontrolled settlement patterns along flood-prone zones. According to (Akhtar *et. al*., 2023), mapping flood vulnerability is an essential step toward understanding the spatial extent and severity of flood risks. It enables policy makers, urban planners, and disaster management agencies to make informed decisions concerning risk reduction, land use planning, emergency response, and resource allocation. Traditional methods of flood risk assessment are often time-consuming, labor-intensive, and limited in spatial coverage

(Sargentis *et. al*., 2025). However, with advances in geospatial technologies, particularly Geographic Information Systems (GIS), flood vulnerability mapping has become more efficient, accurate, and scalable (Leta and Adugna, 2023).

Geospatial Information Systems (GIS) provide a robust platform for collecting, analyzing, visualizing, and interpreting spatial data related to flood hazards. GIS integrates various datasets such as elevation, rainfall distribution, land use, population density, soil type, drainage networks, and historical flood records to generate comprehensive vulnerability maps (Leeonis *et. al*., 2025). These maps help to identify areas at high, medium, or low flood risk levels and can be used to guide mitigation efforts.

This study therefore aims to apply GIS-based techniques to map the flood vulnerability of Etsako West LGA. By integrating relevant geospatial data, the research seeks to produce a vulnerability map that highlights the spatial patterns of flood risk in the area. The outcome of this study will support evidence-based planning and disaster preparedness in Etsako West and similar flood-prone regions.

1.2 STATEMENT OF THE PROBLEM

The increasing frequency and intensity of flood events in Etsako West pose significant threats to socio-economic development, environmental sustainability, and public health. Despite these challenges, there is a lack of systematic and spatially detailed flood vulnerability assessments to support effective risk management in the area. Most responses to flooding in Etsako West have been reactive rather than proactive, often implemented after disasters have occurred.

Several communities continue to develop in flood-prone areas without proper consideration of the underlying risks. This has resulted in repeated loss of livelihoods, particularly for farmers whose crops are destroyed during the rainy season. Roads and bridges are often rendered impassable, cutting off communities from essential services. The absence of reliable flood maps further hampers disaster response efforts, leading to uncoordinated evacuation and relief operations.

The use of GIS for flood vulnerability mapping remains largely underutilized at the local government level in Nigeria. There is an urgent need to leverage geospatial tools to identify vulnerable areas, prioritize interventions, and build community resilience. This study addresses this gap by employing GIS to produce a flood vulnerability map of Etsako West, which will serve as a critical tool for planning and disaster risk reduction.

1.3 AIM AND OBJECTIVES

The aim of this study is to carryout flood vulnerability mapping of Etsako West Local Government

Area using Geospatial Information Systems to aid informed decision-making process.

The objectives of the project are to:

1. identify and collect relevant geospatial and socio-environmental data for flood vulnerability assessment in Etsako West LGA.

2. analyze the spatial distribution of flood vulnerability indicators using GIS and AHP techniques.

3. generate a flood vulnerability map classifying the area into different risk zones.

1.4 SCOPE AND LIMITATIONS OF THE PROJECT

This study is focused on flood vulnerability mapping within Etsako West Local Government Area (LGA) of Edo State, Nigeria. The research covers the identification, integration, and analysis of key geospatial datasets such as digital elevation models (DEM), land use and land cover (LULC), drainage networks, rainfall patterns, soil type, and population density. Using Geographic Information Systems (GIS), these variables are analyzed to produce a flood vulnerability map that categorizes areas within the LGA into low, medium, and high vulnerability zones.

The study provided a spatially explicit understanding of flood risk distribution in the area, which will be beneficial for local authorities, planners, and emergency management agencies. The analysis is conducted at the LGA scale, focusing on general patterns rather than street-level or building-level details.

Despite its relevance, the study is subject to several limitations:

The accuracy of the flood vulnerability map depends heavily on the quality and resolution of the input data. In some cases, freely available satellite data or public datasets may not reflect the most recent land use changes or topographical alterations due to erosion or construction. This study does not include detailed hydrological or hydraulic modeling (e.g., flow simulations or rainfall-runoff analysis) due to time, technical, and resource constraints. Instead, it relies on static spatial indicators of vulnerability.

While GIS provides a robust framework for spatial analysis, limited ground-truthing or field validation may limit the generalization of results. This may affect the precision of vulnerability classification, especially in areas with rapidly changing environmental conditions. Although population density will be considered, other social factors such as income levels, local preparedness, early warning systems, and institutional capacity are not deeply assessed. These factors, while crucial to vulnerability, were not included due to data unavailability.

1.5 JUSTIFICATION FOR THE PROJECT

This study is significant for several reasons. First, it provides a scientific basis for understanding the spatial dynamics of flood vulnerability in Etsako West, an area with growing concerns about recurrent flooding. Second, it introduces the use of GIS technology as a powerful tool for localscale disaster risk assessment, which can be replicated in other parts of Edo State and Nigeria at large.

The findings from this research is useful to multiple stakeholders, including government agencies, urban planners, non-governmental organizations, and community leaders. Specifically, the flood vulnerability map produced can guide land-use planning, zoning regulations, infrastructure development, and emergency response planning. It also contributes to the broader academic literature on the application of geospatial techniques in environmental risk analysis.

Furthermore, the study supports the global agenda on disaster risk reduction as articulated in frameworks such as the Sendai Framework for Disaster Risk Reduction and the United Nations

Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action).

CHAPTER TWO

LITERATURE REVIEW

2.1 CONCEPTUAL FRAMEWORK OF FLOOD VULNERABILITY

Flood vulnerability is a critical concept within the broader framework of disaster risk reduction and environmental management (Oyedele *et al*. 2022). It encapsulates the susceptibility of a community, ecosystem, or infrastructure to the adverse effects of flooding, based on a combination of physical, social, economic, and environmental factors (Jerome, 2021; Salami *et al*. 2017). The conceptual understanding of vulnerability has evolved significantly in the past decades, particularly with the integration of geospatial technologies and interdisciplinary approaches.

Flooding is a significant environmental hazard that leads to widespread destruction, particularly in flood-prone regions such as parts of Nigeria. A flood is defined as the temporary overflow of water onto land that is normally dry, caused by natural processes such as excessive rainfall, river overflow, dam failure, or tidal surges (UNISDR, 2009). Flood vulnerability, on the other hand, refers to the degree to which a population, system, or asset is likely to be affected by flood hazards.

This concept incorporates factors like exposure, sensitivity, and adaptive capacity (Balica *et al*., 2012).

The understanding of flood vulnerability requires a distinction between the physical hazard and the susceptibility of the exposed elements. Vulnerability involves human-environment interactions and reflects how social, economic, and physical systems are exposed and respond to flooding. As Cutter *et al*. (2003) pointed out, vulnerability is not only determined by geographic exposure but also by the societal capacity to respond to and recover from flood events.

Furthermore, the United Nations Office for Disaster Risk Reduction (UNISDR, 2009) classifies vulnerability into physical, social, economic, and environmental categories. This multifaceted approach to vulnerability is particularly relevant in flood-prone areas such as Etsako West LGA, where land use, population density, infrastructure, and economic activities contribute significantly to flood risk. Thus, a comprehensive understanding of flood and vulnerability concepts provides the foundation for effective vulnerability mapping using geospatial techniques.

2.2 THEORETICAL FRAMEWORK FOR FLOOD VULNERABILITY

Theoretical frameworks underpin the conceptualization and practical implementation of flood vulnerability assessments. One of the most widely recognized models is the Pressure and Release (PAR) model, which explains disaster risk as the intersection between natural hazards and underlying vulnerabilities (Wisner *et al*., 2004). The model emphasizes the root causes, dynamic pressures, and unsafe conditions that escalate risk and result in disasters. This framework is useful for understanding how historical, political, and economic factors shape community vulnerability to floods.

Another relevant theoretical model is the MOVE (Methods for the Improvement of Vulnerability Assessment in Europe) framework, which considers vulnerability as a multidimensional phenomenon, encompassing physical, social, economic, and environmental factors (Birkmann *et al*., 2013). The MOVE framework aligns well with geospatial analysis approaches because it allows the integration of diverse datasets and indicators into a cohesive vulnerability assessment.

The social-ecological systems (SES) theory also provides insight into how ecological and human systems co-evolve and influence vulnerability. This theory posits that resilience and adaptive capacity are essential components of vulnerability and that these elements are dynamic and spatially varied (Adger, 2006).

These theoretical foundations are critical for the development of flood vulnerability maps that capture not only where flooding is likely to occur but also who and what are most at risk. Integrating these theories with GIS-based tools facilitates the analysis of spatial patterns of vulnerability and informs targeted interventions in flood-prone regions such as Etsako West.

2.3 DEFINITION AND DIMENSIONS OF FLOOD VULNERABILITY

Vulnerability is broadly defined as “the conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards” (UNDRR, 2015). In the context of flooding, vulnerability is understood as the degree to which a system or population is likely to experience harm due to exposure to flood hazards (Birkmann *et al*., 2013). Vulnerability is often disaggregated into three core dimensions:

i. Exposure: The degree to which people, property, systems, or other elements are present in flood-prone areas.

ii. Sensitivity: The extent to which the exposed elements are likely to be affected (e.g., poor drainage infrastructure).

iii. Adaptive Capacity: The ability of the community or system to withstand and recover from the impacts of flooding.

These dimensions form the basis for a conceptual vulnerability function, often expressed as shown in equation 2.1:

$$V = f(E, S, AC) \tag{2.1}$$

Where: V refers to vulnerability, E signifies the exposure, S the sensitivity, and AC is the adaptive capacity

A higher value of E and S combined with a lower AC typically results in a greater level of vulnerability (Haque, 2020).

2.3.1 Factors Contributing to Flood Vulnerability

A wide range of factors contribute to flood vulnerability in a given location. These factors may be categorized into the following:

1. Physical Factors: Includes elevation, slope, soil permeability, proximity to rivers or flood plains, and urban infrastructure. Low-lying areas and regions with poor drainage systems tend to be more vulnerable (Adeoye *et al*., 2009).

2. Socioeconomic Factors: Poverty, population density, access to healthcare, literacy rate, and housing conditions. Communities with limited economic resources are less likely to invest in flood defenses or relocate from risky areas (Akeh and Mshelia, 2016).

3. Institutional and Governance Factors: The presence or absence of effective land-use policies, early warning systems, and emergency response plans can significantly influence vulnerability levels (Wisner *et al*., 2004).

4. Environmental Factors: Land degradation, deforestation, and poor waste management increase runoff and reduce natural flood buffering capacity (Adama, 2020).

2.3.2 Classification of Flood Vulnerability Indicators

Flood vulnerability assessments rely on the identification and quantification of indicators representing the dimensions mentioned in sub-section 2.1.2. Indicators are typically normalized and aggregated using a weighting system, and may include the following (Moreira et al., 2021; Nazeer and Bork, 2021):

i. Physical Indicators: Elevation, distance to river, slope gradient, flood depth ii. Social Indicators: Population density, percentage of informal settlements, education level iii.

Economic Indicators: Income level, dependency ratio, employment status iv. Environmental Indicators: Vegetation cover, land use type, soil type

An example of a weighted vulnerability index (V.I) is expressed mathematically as represented by equation 2.2:

$$V.I = \sum_{i=1}^{n} w_i x_i \qquad (2.2)$$

Where: x*i* is the normalized value of indicator *i*, w*i* implies the weight assigned to indicator *i*, n is the total number of indicators

The weights w*i* can be derived using methods such as the Analytical Hierarchy Process (AHP) or Principal Component Analysis (PCA) to ensure objectivity and relevance (Saaty, 2008).

2.3.3 Dynamic Nature of Vulnerability

It is crucial to emphasize that vulnerability is not static. It changes over time due to shifts in sociopolitical structures, environmental degradation, climate change, and technological development.

For instance, urban expansion without adequate flood mitigation measures often increases flood exposure and sensitivity. Conversely, community training, infrastructural investment, and climate adaptation can enhance adaptive capacity and reduce vulnerability (Adger, 2006).

2.3.4 Integrated Approach to Vulnerability Analysis

In recent years, there has been a growing shift towards integrated vulnerability assessment models, combining qualitative and quantitative data, and involving multiple stakeholders in the process. Such models not only consider exposure to hazards but also evaluate community resilience and capacity to respond. Tools such as the Hazard-of-Place Model Cutter *et al*., (2003) incorporate both biophysical and social dimensions of vulnerability, enabling the generation of composite maps for spatial decision-making.

Moreover, flood vulnerability assessments using GIS enable the integration of spatial datasets (e.g., land cover, elevation, settlement distribution) with socio-economic data to provide a comprehensive and visual representation of risk zones (Efraimidou and Spiliotis 2024). This helps prioritize mitigation efforts and optimize resource allocation.

2.4 OVERVIEW OF FLOODING IN NIGERIA

Flooding is one of the most prevalent and destructive natural hazards in Nigeria, frequently resulting in the loss of lives, displacement of communities, degradation of land, and damage to infrastructure (Olanrewaju *et al*., 2019; Komolafe *et al*. 2015). Due to the country's geographical location, topographical diversity, and variable climatic conditions, floods occur almost every year across different regions (Abdulrahim *et al.* 2022). The increasing frequency and intensity of flood events in Nigeria is a function of both natural and anthropogenic factors, calling for the urgent need for improved risk management and spatial planning tools such as Geospatial Information

Systems (Bello *et al*., 2024).

Naturally, the country's geographic and climatic characteristics, including intense seasonal rainfall, low-lying floodplains, and the confluence of major rivers such as the Niger and Benue, predispose many areas to flooding (Nkwunonwo *et al*., 2020). In the context of Etsako West Local Government Area (LGA), the presence of river systems and proximity to low-lying topographies contribute significantly to frequent flood events.

Anthropogenic activities, however, often exacerbate these natural vulnerabilities. Urbanization without proper land use planning, inadequate drainage systems, deforestation, and poor waste disposal contribute to increased surface runoff and blockage of natural waterways (Aderogba, 2012). Besides, climate change has intensified the hydrological cycle, resulting in erratic rainfall patterns and more frequent extreme weather events, which further heighten the risk of flooding Intergovernmental Panel on Climate Change (IPCC, 2014).

The impacts of flooding in Nigeria are multifaceted and severe. These include displacement of populations, destruction of infrastructure and farmland, spread of waterborne diseases, and disruption of economic activities. In rural LGAs like Etsako West, where agricultural activities dominate, flooding can undermine food security and exacerbate poverty levels. Hence, understanding these causes and impacts is crucial for formulating sustainable flood management and vulnerability reduction strategies.

2.4.1 Types and Causes of Flooding in Nigeria

Flooding in Nigeria occurs in various forms, including riverine flooding, flash floods, urban flooding, and coastal inundation. Each type has specific triggers and spatial characteristics:

1. Riverine Flooding: This occurs when rivers overflow their banks due to excessive rainfall upstream. Major rivers such as the Niger and Benue often experience this, particularly during the rainy season (Nkwunonwo *et al*., 2020).

2. Urban Flooding: Rapid urbanization without corresponding development of drainage infrastructure contributes significantly to flood occurrence in Nigerian cities. Poor solid waste disposal, unregulated construction, and blocked drainage channels exacerbate the problem (Lucas, 2021).

3. Flash Flooding: These are short-duration, high-intensity floods resulting from heavy rainfall. They typically affect arid and semi-arid areas and are challenging to predict (Nabinejad and Schüttrumpf, 2023).

4. Coastal Flooding: Though more prominent in southern Nigeria, sea-level rise and storm surges impact low-lying coastal states such as Lagos, Bayelsa, and Rivers (Adelekan, 2016).

The primary causes of flooding in Nigeria can be grouped into natural and human-induced factors.

Natural causes include intense and prolonged rainfall, climate variability, and soil saturation. Human-induced causes encompass poor urban planning, deforestation, improper waste disposal, and failure to maintain drainage systems (Adelekan, 2010; Adegboyega *et al*., 2018).

2.4.2 Historical Flood Events in Nigeria

Several devastating flood events have been recorded in Nigeria, highlighting the country's vulnerability. A notable example is the 2012 nationwide flood, which affected 30 out of the 36 states, displaced over 2 million people, and resulted in losses exceeding $16.9 billion National emergency Management Agency (NEMA, 2013). States along the Niger and Benue rivers were particularly hard-hit, including Kogi, Niger, Delta, and Edo States.

Etsako West Local Government Area (LGA), situated in northern Edo State and traversed by several rivers and streams, has witnessed recurring flood events. These have resulted in the submergence of farmlands, destruction of homes, and disruption of socio-economic activities. Despite these realities, flood vulnerability mapping in the area remains limited and reactive, often conducted post-disaster.

2.4.3 Impacts of Flooding on Socioeconomic and Environmental Systems

Flooding in Nigeria has multidimensional impacts, cutting across human health, the economy, infrastructure, and ecosystems:

i. Loss of Life and Property: Hundreds of lives are lost annually to floods. In 2018, floods killed 199 people and displaced over 80,000 (NEMA, 2018). Houses, schools, hospitals, and roads are often destroyed or rendered inaccessible.

ii. Agricultural and Livelihood Disruption: As a predominantly agrarian society, flood damage to crops, livestock, and irrigation systems severely affects food security and rural livelihoods. In Etsako West, farmlands adjacent to rivers are regularly inundated, resulting in income loss for farmers.

iii. Health Hazards: Floods increase the risk of water-borne diseases such as cholera, dysentery, and typhoid. Stagnant water creates breeding grounds for mosquitoes, leading to a rise in malaria cases.

iv. Environmental Degradation: Soil erosion, sedimentation, and destruction of vegetation are common flood outcomes. These environmental effects reduce land productivity and exacerbate land degradation processes.

2.5 INSTITUTIONAL AND POLICY RESPONSES TO FLOODING

The Nigerian government, in collaboration with international agencies, has implemented various policies and institutional mechanisms to manage flood risks. Notable among these is the establishment of the (NEMA, 2024) and the Nigeria Hydrological Services Agency (NIHSA, 2024), tasked with forecasting and response coordination.

In 2013, Nigeria developed a National Disaster Risk Management Policy, aimed at reducing hazard exposure and enhancing resilience. However, implementation remains weak, often due to inadequate funding, poor data management, and lack of community involvement.

State and local governments, including Edo State, have limited institutional capacity for flood management. Although agencies such as the Edo State Emergency Management Agency (ESEMA) exist, their efforts are hampered by lack of accurate geospatial data, poor coordination, and weak enforcement of building codes.

2.4 CLIMATE CHANGE AND FLOOD RISK IN NIGERIA

Climate change is expected to intensify flood risk in Nigeria by altering rainfall patterns and increasing the intensity and frequency of extreme weather events. According to the Intergovernmental Panel on Climate Change (IPCC, 2022), West Africa is highly vulnerable to climate-induced floods due to its high population density and dependency on climate-sensitive sectors such as agriculture and water resources.

Studies show that Nigeria has experienced a general increase in annual rainfall variability over the past three decades (Ugwu, 2024; Awode *et al*., 2025). In regions such as Etsako West, early or late onset of rainfall and unseasonal downpours have led to unexpected flooding, with significant consequences on the local population and environment (Onakuse, 2015).

2.5 APPLICATION OF GIS IN FLOOD VULNERABILITY MAPPING

Geographic Information System (GIS) is a critical tool in flood vulnerability mapping due to its ability to capture, analyze, and visualize spatial data. GIS enables researchers and planners to identify flood-prone areas, assess risk levels, and make informed decisions regarding disaster preparedness and mitigation. The integration of remote sensing data with GIS facilitates multicriteria analysis (MCA), which is particularly useful in identifying vulnerability hotspots and prioritizing intervention measures (Dano *et al*., 2014).

In the Nigerian context, GIS has been increasingly used in flood risk and vulnerability studies, offering significant insights into spatial patterns of flood occurrence and potential damage (Adedoja *et al*., 2023). The ability of GIS to handle large datasets, including topography, land use, hydrology, and socio-economic factors makes it indispensable for generating accurate and dynamic flood vulnerability maps.

For areas like Etsako West, the use of GIS can support the delineation of risk zones and guide the allocation of resources for disaster response. When integrated with community-based data and field surveys, GIS enhances participatory flood risk assessment, allowing for tailored interventions. Ultimately, GIS facilitates proactive planning and policy-making aimed at reducing flood vulnerability.

2.6 THE NEED FOR GIS-BASED FLOOD VULNERABILITY MAPPING

Conventional flood response mechanisms in Nigeria have proven to be reactive rather than proactive (Bello et al., 2024). There is an urgent need for spatially-informed flood management approaches that can aid in risk zoning, infrastructure planning, and early warning systems. Geospatial tools such as GIS and Remote Sensing provide the technical capacity to model floodprone areas, assess vulnerability, and inform policy (Akintola, 2024).

GIS-based flood mapping allows integration of multiple datasets such as topography, land use, rainfall, population density, and infrastructure into a unified platform for spatial analysis. In the context of Etsako West, such approaches can offer a powerful decision-support tool for local authorities and disaster managers (Oyewola, 2019).

2.7 FLOOD VULNERABILITY MAPPING IN ETSAKO WEST LGA

Flood vulnerability mapping in Etsako West Local Government Area (LGA) is essential due to the area's recurrent flood events, largely attributed to its geomorphology, proximity to river systems, and inadequate infrastructural development. Studies have noted that the LGA is frequently impacted by seasonal floods which disrupt transportation, displace residents, and damage farmlands (Ajibade *et al.,* 2013). These challenges necessitate spatially explicit tools such as flood vulnerability maps to aid in risk assessment and mitigation planning.

Flood vulnerability mapping in this region typically integrates physical indicators (e.g., elevation, land use, slope, proximity to rivers) and socio-economic variables (e.g., population density, poverty levels, building types) to develop comprehensive risk profiles (Akpodiogaga and Odjugo, 2010). Such integration allows planners to differentiate between areas with similar flood hazards but varying levels of vulnerability due to differing adaptive capacities.

Although few studies have focused specifically on Etsako West, similar works in adjacent LGAs in Edo State have demonstrated the effectiveness of GIS-based flood mapping in identifying atrisk communities and prioritizing intervention zones (Okoduwa and Gbakeji, 2019). These efforts underscore the need for localized flood vulnerability assessments, considering the unique geographic and socio-economic characteristics of the area.

Moreover, the increasing availability of high-resolution satellite imagery and digital elevation models (DEMs) enhances the accuracy of flood mapping. When combined with participatory GIS, where local knowledge is incorporated, the maps become more robust and grounded in reality

(Nkwunonwo et al., 2020). Therefore, developing detailed flood vulnerability maps for Etsako West LGA is a critical step in fostering disaster resilience and supporting sustainable development efforts in the region.

2.8 INDICATORS AND MODELS USED IN FLOOD VULNERABILITY ASSESSMENT

Flood vulnerability assessment relies on a variety of indicators and modeling approaches to quantify the extent of risk and susceptibility across different geographical areas. These indicators typically fall into three categories: physical (e.g., elevation, slope, distance to rivers), social (e.g., population density, education level, access to health facilities), and economic such as., income levels, housing quality) (Balica *et al*., 2009). The use of composite indices that integrate these variables enables the development of more holistic flood vulnerability maps.

One widely applied method in geospatial flood assessment is the Analytic Hierarchy Process (AHP), a multi-criteria decision-making tool that allows for the systematic comparison and weighting of indicators based on expert judgment (Saaty, 1980). In flood-prone areas like Etsako West LGA, AHP has proven effective for prioritizing vulnerability factors and producing weighted spatial layers in GIS environments. For example, studies have shown how AHP can integrate layers such as land use, rainfall intensity, drainage patterns, and infrastructure distribution to assess flood-prone zones (Dano *et al*., 2019).

Another popular model is the Flood Vulnerability Index (FVI), developed by Balica *et al*. (2012), which quantifies vulnerability using a formula that includes exposure, susceptibility, and resilience factors. This model has been adapted for various geographic contexts, including urban and rural environments in Nigeria, by selecting locally relevant indicators.

Hydrologic and hydraulic models such as HEC-RAS and SWAT are also employed to simulate flood events and estimate inundation extents, although their application often requires extensive datasets and calibration (El-Haddad *et al*., 2025). More recently, machine learning models like Random Forest and Artificial Neural Networks have been introduced in flood vulnerability studies due to their capacity to handle complex, non-linear relationships among variables (Khosravi *et al*., 2019).

Ultimately, the selection of appropriate indicators and models depends on data availability, scale of analysis, and the specific objectives of the vulnerability assessment. For Etsako West LGA, a combination of multi-criteria GIS modeling and socio-economic data can produce robust and actionable flood vulnerability maps.

2.9 MODEL VALIDATION AND ACCURACY ASSESSMENT

Validation of flood vulnerability maps is critical to ensuring their reliability and applicability in real-world decision-making (Islam *et al*., 2025). It involves comparing the predicted vulnerability zones with observed flood extents derived from historical flood records, high-resolution satellite imagery such as, Sentinel-1, Landsat), or in-situ ground-truthing data. The process ensures that the spatial predictions made by the model are both meaningful and actionable (Tehrany *et al*., 2014).

Among the commonly used methods for evaluating model accuracy is the confusion matrix, which compares predicted flood vulnerability classes with actual observed classes to compute metrics such as overall accuracy, user's accuracy, producer's accuracy, and the Kappa coefficient. The Kappa statistic, in particular, accounts for the possibility of agreement occurring by chance and is considered robust in evaluating classification performance. A Kappa value above 0.80 indicates strong agreement between predicted and observed data (Congalton and Green, 2019).

Another powerful tool is the Receiver Operating Characteristic (ROC) curve, which plots the true positive rate against the false positive rate across various threshold settings. The Area Under the Curve (AUC) is used as a summary metric: values closer to 1.0 indicate excellent predictive performance. In flood risk studies, an AUC value above 0.8 is generally considered acceptable (Hinge *et al*., 2024).

Furthermore, advanced validation techniques such as cross-validation and bootstrapping are gaining prominence in recent literature, particularly when machine learning algorithms are involved. These techniques help to ensure that the model is not overfitted to the training data and performs well on unseen data (Youssef *et al*., 2016).

Validation efforts also benefit from the use of high-resolution post-event flood maps derived from radar imagery (e.g., Sentinel-1 SAR), which can penetrate cloud cover and provide accurate flood extent delineations. Incorporating community-based flood reports through participatory mapping can further strengthen the model's real-world relevance, especially in data-scarce settings like Etsako West LGA (Tascón-González *et al*., 2020). In summary, rigorous model validation enhances the reliability of flood vulnerability assessments and supports effective flood risk communication and planning.

2.10 REVIEW OF RELATED LITERATURE AND CASE STUDIES

Numerous studies across Nigeria and globally have employed geospatial tools to assess and map flood vulnerability, providing valuable insights into best practices and methodological approaches. These studies highlight the diverse range of indicators, modeling techniques, and contextual factors that influence flood vulnerability, many of which are relevant to Etsako West LGA.

In Nigeria, Lawal *et al*. (2012) applied GIS techniques to assess flood vulnerability in Ibadan, integrating topographic, hydrological, and socio-economic data. Their study demonstrated the power of GIS-based overlay analysis in identifying high-risk zones, thereby informing policy and disaster preparedness. Similarly, Adedeji *et al*. (2012) examined flood vulnerability in Lokoja, Kogi State, emphasizing the influence of river proximity, unregulated urban development, and poor drainage infrastructure on flood exposure.

Internationally, studies such as that by Kazakis *et al*. (2015) in Greece applied a modified Flood Vulnerability Index (FVI) integrating both physical and socio-economic indicators. Their work revealed the importance of considering local adaptation capacity and infrastructure resilience in mapping vulnerability. In South Asia, Dutta *et al*. (2003) utilized hydrodynamic modeling and remote sensing to simulate flood extent and assess community-level risk in Bangladesh, an approach that could be adapted to flood-prone areas of Nigeria with adequate hydrological data.

Closer to Edo State, Okoduwa and Gbakeji (2019) conducted a GIS-based flood risk assessment in Auchi and its environs, employing AHP to weight factors such as slope, land use, and rainfall distribution. Their findings confirmed the utility of AHP-GIS integration in producing accurate flood risk maps and informed targeted recommendations for flood mitigation.

These case studies emphases the adaptability of geospatial methodologies to different environmental and socio-economic contexts. They also reveal a growing trend toward combining technical GIS tools with participatory approaches to improve the relevance and accuracy of vulnerability assessments. For Etsako West LGA, drawing from these examples can help tailor a locally sensitive, technically sound framework for flood vulnerability mapping.

Despite the growing use of geospatial tools in flood vulnerability studies, several data and knowledge gaps persist that undermine the accuracy and effectiveness of such analyses, particularly in local government areas like Etsako West. One significant limitation is the quality and resolution of available spatial data. Most studies rely on Shuttle Radar Topography Mission (SRTM) Digital Elevation Models (DEMs) at 30-meter resolution, which, while accessible, often lack the precision required for detailed floodplain analysis in small-scale or urbanized environments (Abdulkadir *et al.,* 2021). Higher-resolution DEMs such as LiDAR or UAV-derived models are rarely available in Nigeria due to cost and technical barriers.

Another critical gap is the insufficient incorporation of socio-economic and community-based vulnerability indicators. While physical parameters like elevation, slope, and rainfall are frequently mapped, social determinants such as poverty levels, age distribution, and housing quality are often overlooked or poorly represented due to limited availability of granular census or survey data (Nkwunonwo *et al*., 2020). This underrepresentation hinders a holistic understanding of vulnerability, particularly in rural areas where adaptive capacity is highly variable.

Moreover, many studies lack ground-truthing or field validation of their spatial models, which affects the reliability of flood risk outputs. As observed by Matori *et al*. (2014), field-based verification greatly enhances the credibility of GIS-based vulnerability assessments. Another gap lies in the limited use of temporal data. Most analyses are cross-sectional, focusing on a single year or event, rather than incorporating historical flood records or simulating future scenarios under climate change projections.

Furthermore, the integration of remote sensing indices such as NDVI (Normalized Difference Vegetation Index) and TWI (Topographic Wetness Index) remains underutilized in many Nigerian flood vulnerability studies, despite their proven value in identifying surface saturation and vegetation cover, which influence flood behavior (Lawal *et al*., 2012). Finally, there is a methodological gap in stakeholder engagement. Few studies include local communities or decision-makers in the mapping process, which limits the usability of outcomes for policy and disaster planning. Addressing these data and knowledge deficits is essential for producing more accurate, equitable, and actionable flood vulnerability maps in areas like Etsako West LGA.

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA DESCRIPTION

3.1.1 Geographical and Environmental Characteristics of Etsako West LGA

Understanding the geographical and environmental attributes of Etsako West Local Government Area (LGA) is crucial for effective flood vulnerability mapping. The spatial heterogeneity of the area, including its topography, hydrology, land use, and climatic conditions, significantly influences flood patterns and impacts. Etsako West is one of the 18 LGAs in Edo State, Nigeria, and is characterized by diverse physical and environmental features that interact to shape the flood risk profile of the region.

3.1.2 Location and Topography

Etsako West LGA is located in the northern part of Edo State, Nigeria. It lies approximately between latitudes 7°10'N; 7°45'N and longitudes 6°15'E; 6°45'E. The LGA shares boundaries with Etsako Central, Etsako East, Owan East, and Akoko-Edo LGAs. The administrative headquarters is in Auchi, a major urban center in the region. Topographically, the area features a varied landscape, with elevations ranging between 150 and 300 meters above sea level. The terrain consists of undulating plains interspersed with isolated hills and escarpments, particularly in the southern parts. These variations in elevation influence the flow of surface water and contribute to localized flood zones, especially in the lower-lying valleys and floodplains. Figure 3.1 shows the map of the study area.

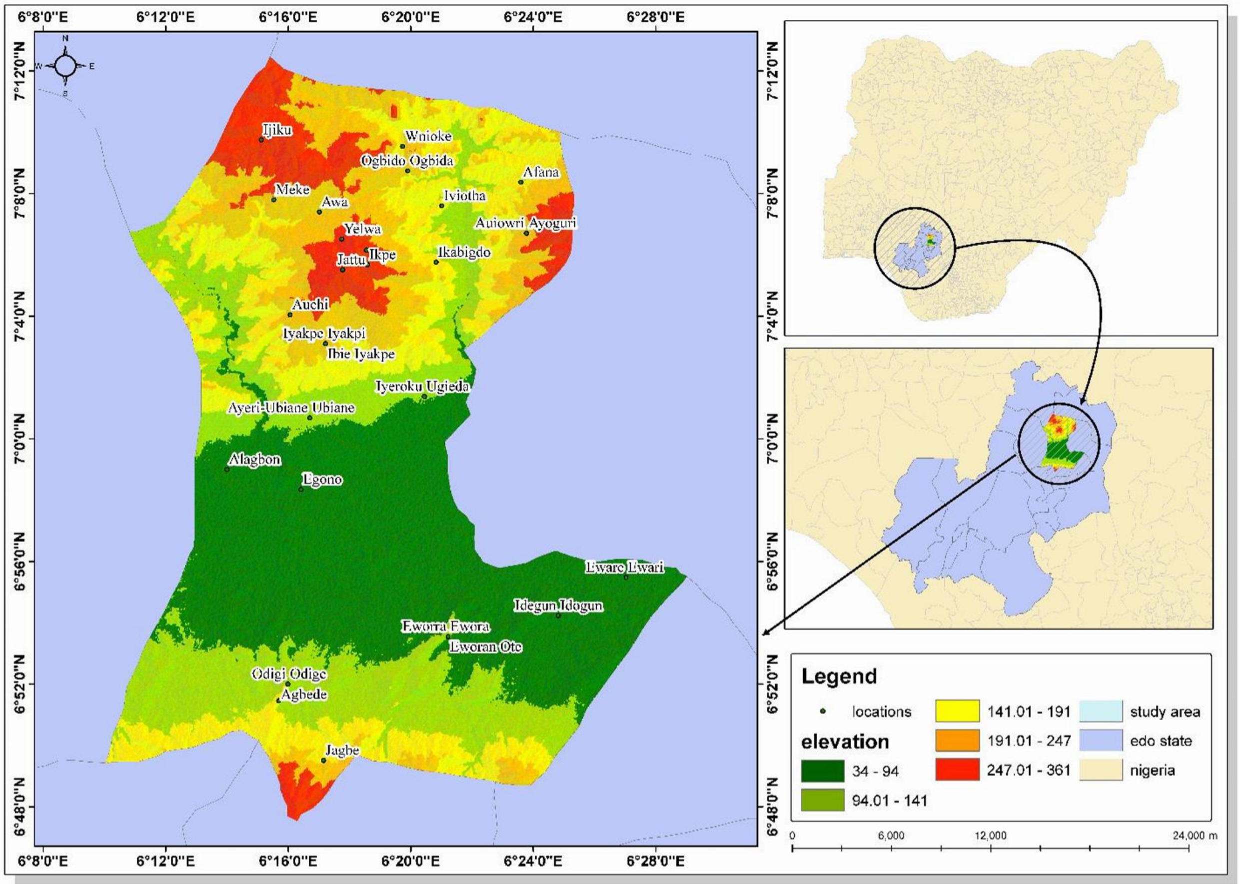

Figure 3.1: Map of the Study Area

3.1.2 Climate and Rainfall Patterns

Etsako West falls within the tropical wet-and-dry climatic zone, characterized by distinct wet (April to October) and dry (November to March) seasons. The area experiences an average annual rainfall of about 1,200 to 1,800 mm, with peak precipitation occurring in July and September (NIMET, 2020). The intensity and duration of rainfall are critical drivers of flood events in the region. During peak rainfall months, runoff exceeds the infiltration capacity of the soil, especially in urbanized or compacted areas, leading to surface water accumulation and flash floods. The rainfall-runoff relationship is often expressed using the Rational Method represented by equation

3.1:

$$Q=CIA \tag{3.1}$$

Where: Peak discharge (m^3/s), Runoff coefficient (dimensionless), Rainfall intensity (mm/hr), and Drainage area (hectares)

In areas with poor drainage and high impervious surface cover, the runoff coefficient tends to be high, increasing the volume of water contributing to floods.

3.1.3 Hydrological Features

The hydrological network in Etsako West comprises several rivers, streams, and tributaries, most notably the River Niger, which lies to the east of the LGA. Other significant rivers include the Oshi, Orle, and Osome, which traverse various parts of the LGA and serve as primary conduits for surface water drainage.

Flooding frequently occurs along the floodplains of these rivers, particularly in communities such as Anegbette, Agbede, and Jagbe. During periods of heavy rainfall or upstream discharges, these rivers overflow their banks, inundating surrounding settlements and farmlands. The floodplain dynamics are also influenced by soil saturation levels, vegetation cover, and the presence of wetlands.

3.1.4 Land Use and Land Cover (LULC)

Land use patterns in Etsako West include residential, agricultural, commercial, and forested areas. Urbanization is concentrated around Auchi and its environs, while agriculture dominates the rural landscape, with crops such as cassava, maize, yam, and rice (Oyegun and Adeyemo, 1999).

Deforestation and land conversion for agriculture have significantly reduced the vegetative buffer zones that naturally regulate runoff. The removal of forest cover increases surface runoff and soil erosion, both of which contribute to flood risk. Remote sensing-based land use classification can help identify vulnerable zones, and GIS can be employed to perform change detection analysis over time.

The Normalized Difference Vegetation Index (NDVI) is often used to assess vegetation cover, calculated as shown in equation 3.2:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \qquad (3.2)$$

Where: NIR indicates Near Infrared reflectance and RED signifies Red reflectance

Low NDVI values (< 0.2) typically indicate bare or impervious surfaces, which are more prone to generating runoff.

3.1.5 Soil Characteristics and Drainage

The soils in Etsako West range from sandy loam to clayey textures. Sandy soils generally allow for greater infiltration, reducing surface runoff, whereas clayey soils have low permeability, promoting surface water accumulation. Soil texture and structure also influence drainage capacity. Poorly drained soils, especially in depressions and valley bottoms, become saturated quickly and serve as hotspots for flood occurrence. The USDA Soil Classification and the FAO Digital Soil Map provided data layers that was integrated into GIS models to assess flood vulnerability (FAO, 2012; USDA, 2020).

3.2 DATA SOURCES

Table 3.1 shows the data sources from where this project leverage. The data was integrated into ArcGIS 10.4 environment for further analysis.

Table 3.1: Description of Data Sources

Data Type	Description	Source
DEM (30m)	Elevation and slope derivation	SRTM or ASTER
Landsat 8 OLI	LULC classification	USGS Earth Explorer
Soil Data	Permeability	FAO HWSD (2021)
River network	Proximity analysis	Digitized from topographic maps
Population data	Density mapping	National Population Commission
Historical flood data	Validation and calibration	NEMA (2022) reports, field surveys

3.3 PRE-PROCESSING AND DATA PREPARATION

3.3.1 Digital Elevation Model (DEM)

This is where information related to terrain characteristics will be extracted. For example, we can extract slope (S) and elevation (E) using terrain analysis tools in GIS. Areas <150 m elevation and slope <5% are considered flood-prone (Tehrany *et al.*, 2014). Equation 3.3 can be used for this purpose.

$$Slope = \tan_{-1} \quad xz + \quad yz \tag{3.3}$$

Where: ∂z/∂x and ∂z/∂y are elevation differences along x and y.

3.2.3 Land Use and Land Cover (LULC) Classification

Supervised classification using Maximum Likelihood Classifier (MLC) Categories: Water bodies, built-up, forest, agriculture, bare land. Post-classification accuracy assessment was carried out using equation 3.4 (Congalton and Green, 2019):

$$Overall = \frac{Correctly\ Classified\ Pixels}{Total\ \mathrm{Re}\, ference\ Pixels} \quad 100$$

$$= \frac{p_{\_} - p_{e}}{1 - p_{e}} \qquad (3.4)$$

Where: p_o is the observed agreement and p_e is the expected agreement by chance.

3.2.4 Proximity Analysis

Buffering of river channels at 500 m to define flood-prone proximity zones was performed at this stage using equation 3.5:

$$Buffer_r = d \quad 500m\ from\ river\ lines \qquad (3.5)$$

3.3. CRITERIA SELECTION AND STANDARDIZATION

3.3.1 Criteria Used

The following criteria (factors) were used for the project the geospatial and socio-environmental indicators for vulnerability assessment.

i. Elevation ii.
Slope iii. LULC iv.
Distance to river

v. Soil permeability vi.
Population density Each criterion is standardized to a common scale (1 to 5) using reclassification based on vulnerability thresholds. Equation 3.6 is used to derive the linear normalization.

$$X = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \tag{3.6}$$

3.4 MULTI-CRITERIA EVALUATION (MCE) AND WEIGHTING

3.2.4 Analytical Hierarchy Process (AHP)

Under this sub-section, the pairwise comparison matrix built using Saaty’s 9-point scale. The Consistency Index (CI) and Consistency Ratio (CR) checked. Acceptable if CR < 0.1 (Saaty, 1980). Equation 3.7 is suitably used for this task.

$$CI = \frac{{}_{\min} - n}{n-1}, \quad CR = \frac{CI}{RI} \qquad (3.7)$$

Where: λmax is the principal eigenvalue, n is the number of criteria, RI is the Random Index from Saaty’s table.

3.4.2 Weighted Overlay

Each standardized criterion layer is multiplied by its AHP-derived weight as shown in equation 3.8:

$$FVI(x, y) = \sum_{i=1}^{n} W_i \quad C_i(x, y) \qquad (3.8)$$

Where: FVI is the Flood Vulnerability Index, Wi is the Weight of criterion *i*, *Ci*(*x,y*) is the Criterion value at pixel (*x,y*).

3.5. FLOOD VULNERABILITY MAPPING

Classification and flood vulnerability zoning was done using natural breaks (Jenks) at equal interval. The final composite map was re-classified into the following categories:

i. Very Low ii.
Low iii.
Moderate iv.
High

v. Very High vulnerability zones

3.6. VALIDATION AND ACCURACY ASSESSMENT

3.6.1 Confusion Matrix and Kappa Statistic

As discussed earlier in section 3.2.3.

3.6.2 ROC and AUC

According to Bui *et al*. (2024), the area under curve was calculated using equation 3.7.

$$AUC = \,^{1}_{0}\, TPR(FPR)\; dFPR \qquad (3.7)$$

Where: TPR is the True Positive Rate while FPR is the False Positive Rate

3.6.3 Ground-Truthing

Overlay map with field-verified flooded 20 locations data, acquired with the aid of hand-held GNSS receiver. To verify the accuracy of the input data (land cover, settlements, drainage, etc.). This was used to validate the flood vulnerability map by checking if areas classified as high/low risk correspond to actual on-ground conditions.

3.7 TOOLS AND SOFTWARE USED

ArcGIS / QGIS: was used for spatial analysis, map generation.

SNAP: was used for image processing.

Google Earth Engine: was aid in LULC processing.

Excel was adopted for AHP weighting, statistical analysis.

GPS: This was used for field data validation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 PRESENTATION OF GEOSPATIAL AND SOCIO-ENVIRONMENTAL RESULTS

The geospatial datasets provided critical insights into the physical setting of Etsako West Local Government Area and their implications for flood vulnerability. Figure 4.1 shows the map of reclassified elevation range while Table 4.1 shows the reclassified elevation result of geospatial data analysis.

(i) Elevation

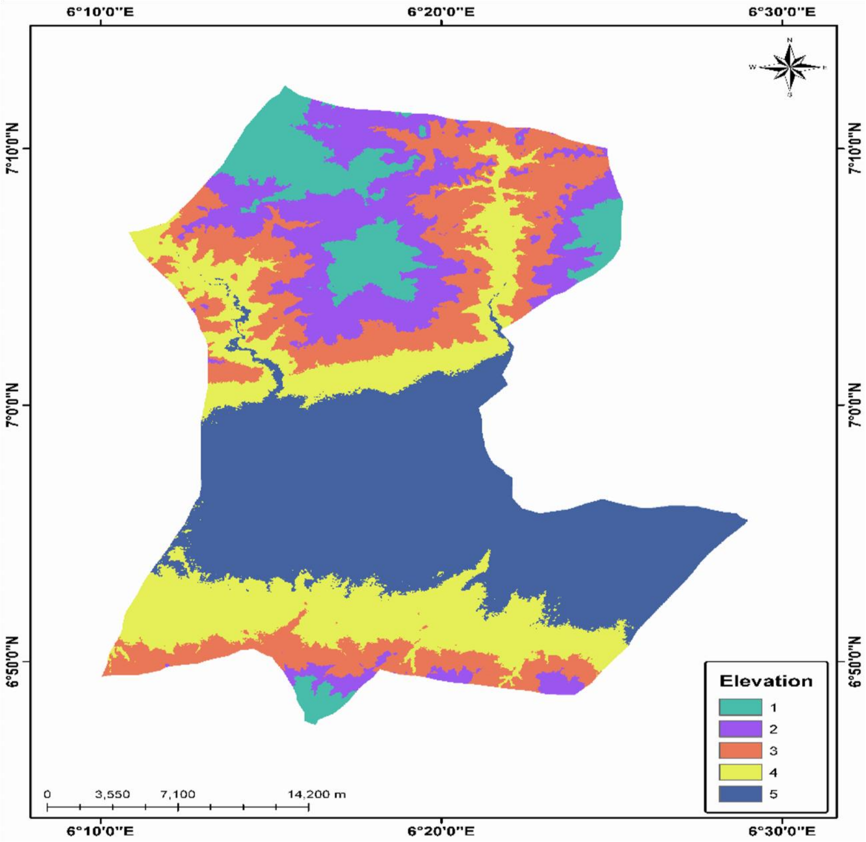

Figure 4.1: Reclassified Elevation Map of Flood Vulnerability

Table 4.1 Elevation Geospatial Data Analysis Result

Elevation Range	Reclassified Value	Remarks
34 - 94	5	Very High vulnerability
94 – 141	4	High vulnerability
141 – 191	3	Moderate vulnerability
191 – 247	2	Low vulnerability
247 - 361	1	Very Low vulnerability

(ii) Slope

Figure 4.2 shows the slope categories across the LGA. The dominance of flat to gentle slopes (0–5%) is clearly visible in central and riverine zones, aligning with the very high and high vulnerability classes in Table 4.2. These flat terrains encourage water stagnation and poor drainage, significantly increasing flood susceptibility. Steeper slopes, mostly in upland regions, are less extensive and correspond to low and very low vulnerability classes. This spatial pattern confirms that slope directly amplifies the flood risk in lowland settlements.

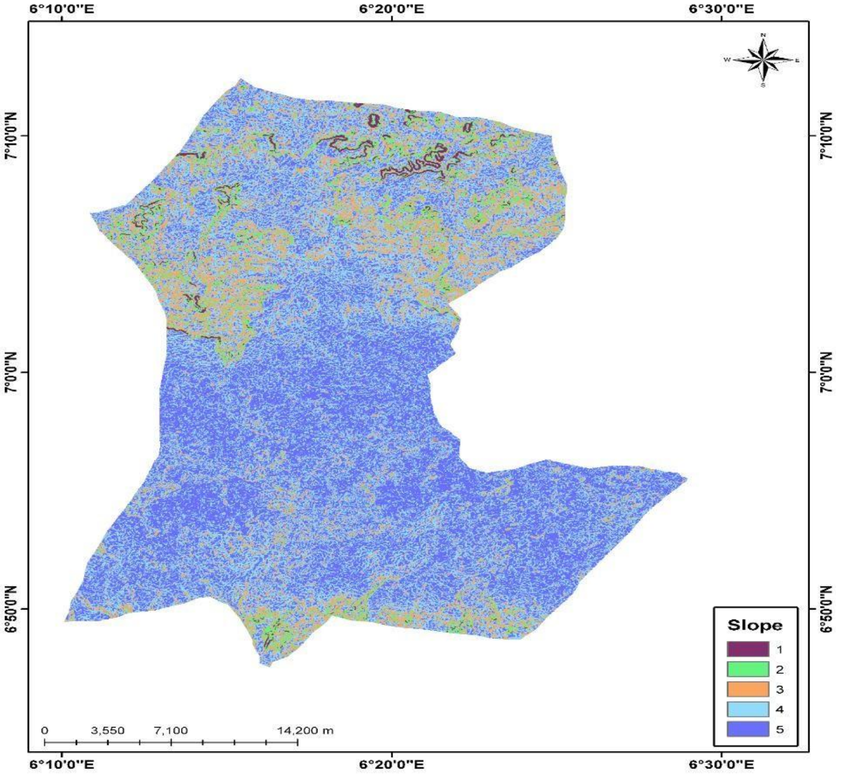

Figure 4.2: Reclassified Slope Map of Flood Vulnerability

Table 4.2: Slope (%) Geospatial Data Analysis Result

Slope Range	Reclassified Value	Remarks
0 – 2.3	5	Very High vulnerability
2.3 – 4.6	4	High vulnerability
4.6 – 7.86	3	Moderate vulnerability
7.86 – 13.68	2	Low vulnerability
13.68 - 34.54	1	Very Low vulnerability

(iii) Land Use Land Cover

Figure 4.3 illustrates the distribution of land use and land cover categories. The map shows that agricultural lands and built-up areas dominate the floodplains, which fall under the moderate to high vulnerability classes in Table 4.3. Water bodies, mostly aligned with the River Niger and its tributaries, represent zones of very high vulnerability. In contrast, forested uplands appear in isolated patches and fall into the very low vulnerability category. This confirms that socioeconomic activities such as farming and settlement are directly concentrated in flood-prone areas.

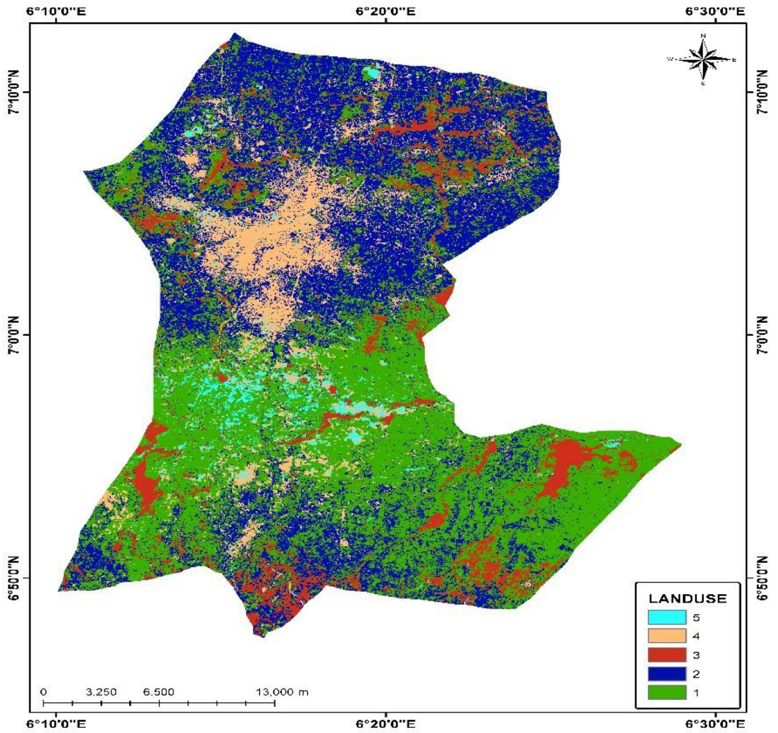

Figure 4.3: Reclassified LULC Map of Flood Vulnerability

Table 4.3: LULC Geospatial Data Analysis Result

LULC Category	**Reclassified Value**	**Remarks**
Water bodies	5	Very High vulnerability
Built-up	4	High vulnerability
Agriculture	3	Moderate vulnerability
Bare land	2	Low vulnerability
Forest	1	Very Low vulnerability

(iv) Distance to River

Figure 4.4 presents the spatial relationship between communities and their proximity to major rivers. The map shows that settlements located within 0–500 m from rivers (very high vulnerability, Table 4.4) are concentrated in Anegbette, Udaba, and Osomegbe. These communities face recurrent flooding as they lie directly within the River Niger floodplain. Communities situated farther away, particularly those beyond 1,700 m, fall into low or very low vulnerability zones. This map demonstrates how drainage proximity intensifies exposure to flood hazards.

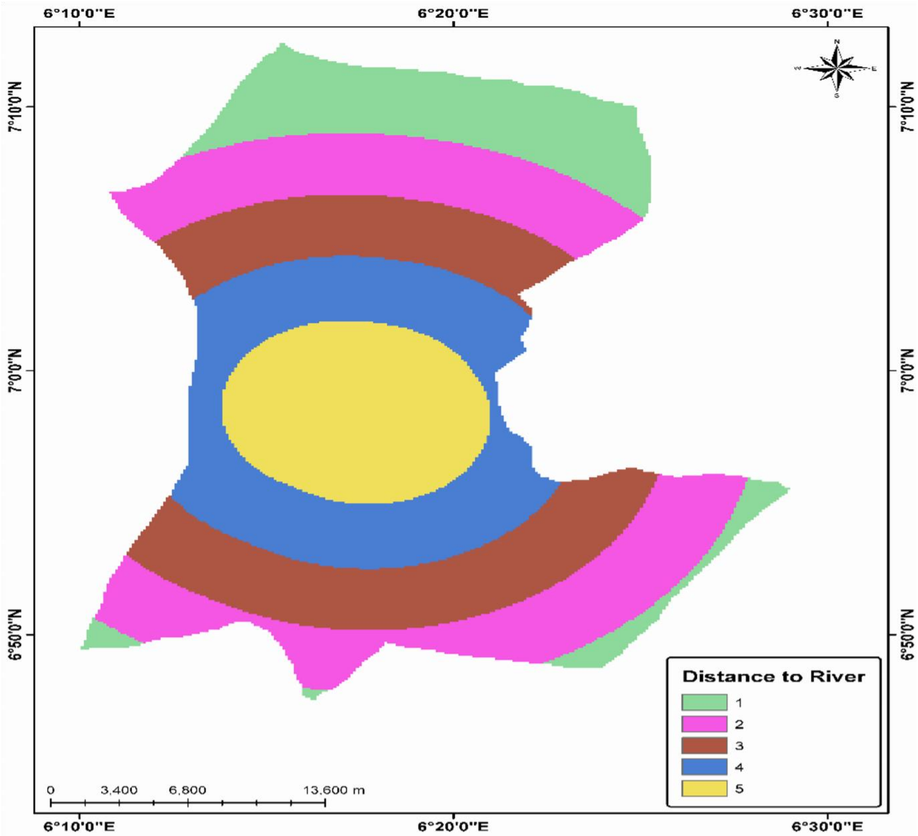

Figure 4.4: Reclassified Distance to River Map of Flood Vulnerability

Table 4.4: Distance to River Geospatial Data Analysis Result

Distance Range (m)	Reclassified Value	Remarks
0 - 542.39	5	Very High vulnerability
542.4 - 949.19	4	High vulnerability
949.2 - 1,337.91	3	Moderate vulnerability
1,337.92 - 1,726.62	2	Low vulnerability
1,726.63 - 2,305.18	1	Very Low vulnerability

(v) Soil Map

Figure 4.5 shows the distribution of soil types in the LGA. Clay loam soils, concentrated in the floodplains, correspond to high vulnerability as indicated in Table 4.5, due to their poor infiltration capacity and tendency to retain water. Loam soils, moderately distributed, represent areas of moderate vulnerability, while sandy loam soils, found mostly in uplands, correspond to low vulnerability. This spatial evidence confirms that soil permeability plays a critical role in differentiating flood-prone from less flood-prone zones.

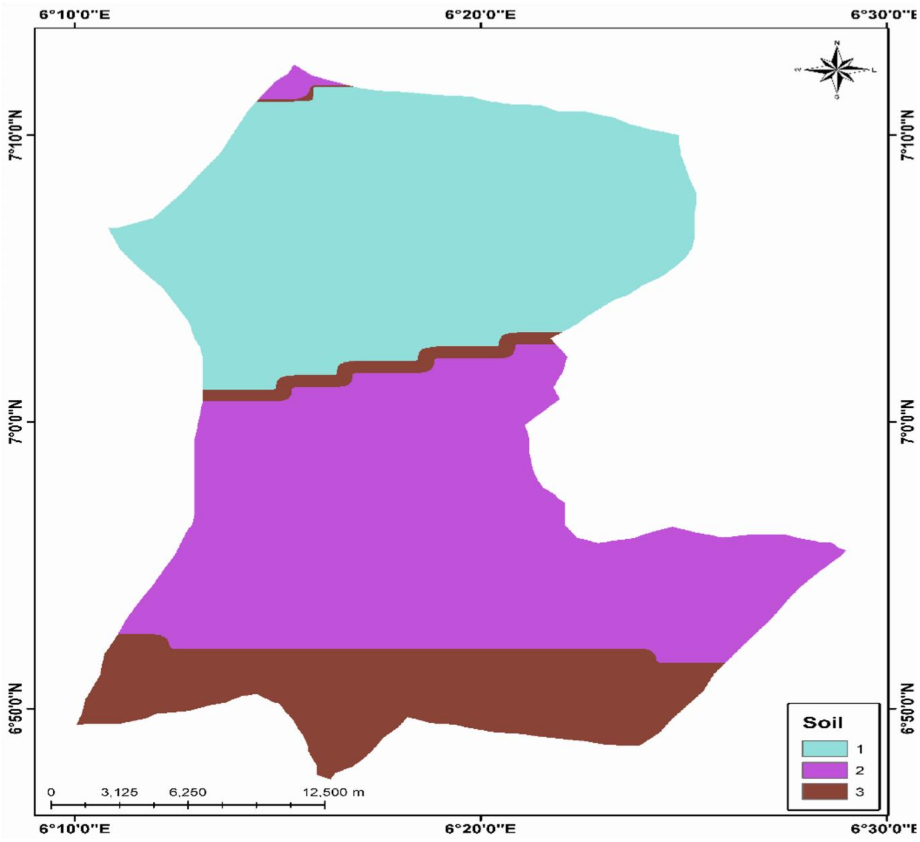

Figure 4.5: Reclassified Soil Map of Flood Vulnerability

Table 4.5: Soil Type Geospatial Data Analysis Result

Soil Type	**Reclassified Value**	**Remarks**
Clay loam	3	High vulnerability
Loam	2	Moderate vulnerability
Sandy loam	1	Low vulnerability

(vi) Population

Figure 4.6 highlights the distribution of population density across the LGA. High population clusters are visible in Auchi, Jattu, and Aviele, which align with the very high and high vulnerability classes in Table 4.6. These towns overlap with flat terrain and areas near river channels, compounding their flood exposure. Lower density settlements, often scattered in rural uplands, fall into the low vulnerability category. The figure underscores that human exposure, rather than just physical terrain, is a major factor that determines the overall risk to floods.

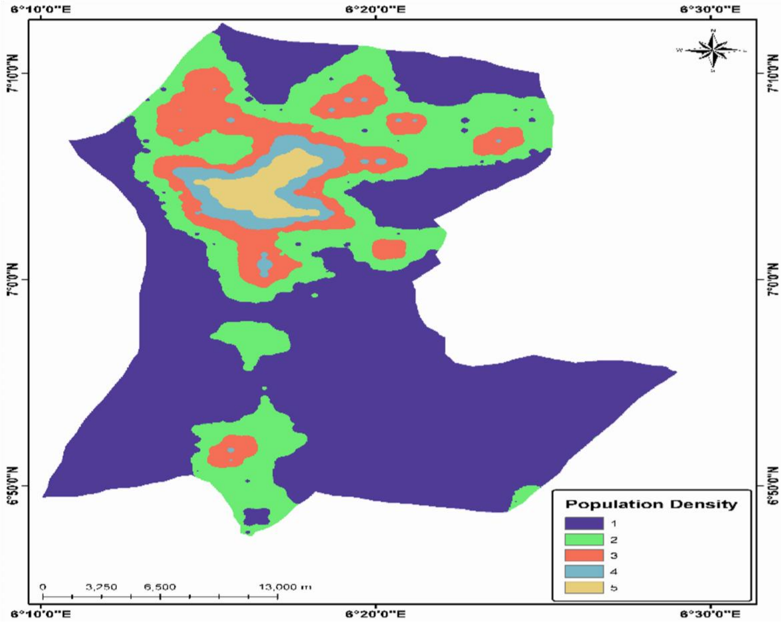

Figure 4.6: Population Map

Table 4.1: Population Geo-environmental Data Analysis Result

Density Range	Reclassified Value	Remarks
1,605.19 - 2,639.04	5	Very High vulnerability
1,001.26 - 1,605.18	4	High vulnerability
540.63 - 1,001.25	3	Moderate vulnerability

223.31 - 540.62	2	Low vulnerability
28.81 - 223.3	1	Very Low vulnerability

(vii) Conditioning Factors Results

Table 4.7 presents the relative weights assigned to each conditioning factor for the study. The weights, totaling 1.00 (or 100%), were determined based on their perceived influence on flood susceptibility. The factors are ranked in order of their relative importance. Elevation received the highest weight with a value of 0.25, indicating it was considered the most significant conditioning factor. This was followed by Slope and Distance to River, both with a weight of 0.20. Land Use/Land Cover (LULC) was assigned a weight of 0.15, while Soil Permeability and Population Density were given the lowest weights at 0.10 each.

Table 4.7 Conditioning Factors Relative Weights

S/No	Conditioning Factor	Relative Weight
1	Elevation	0.25
2	Slope	0.20
3	LULC	0.15
4	Distance to River	0.20
5	Soil Permeability	0.10
6	Population Density	0.10
Total		**1.00 (100%)**

4.2 SPATIAL DISTRIBUTION OF FLOOD VULNERABILITY INDICATORS

The Analytic Hierarchy Process (AHP) was applied to assign weights to the flood vulnerability indicators based on their relative importance. Spatial distribution maps were generated to illustrate how each factor contributes to flood vulnerability.

(i) Elevation Vulnerability Map

Figure 4.7 presents the elevation vulnerability map of Etsako West LGA. It shows that areas along the River Niger floodplain fall within the very high and high vulnerability categories, reflecting the low elevation ranges identified in Table 4.1. Upland regions appear as low to very low vulnerability zones. The map confirms that flood risk is strongly elevation-dependent, with the most severe risks concentrated in riverine communities such as Anegbette and Udaba.

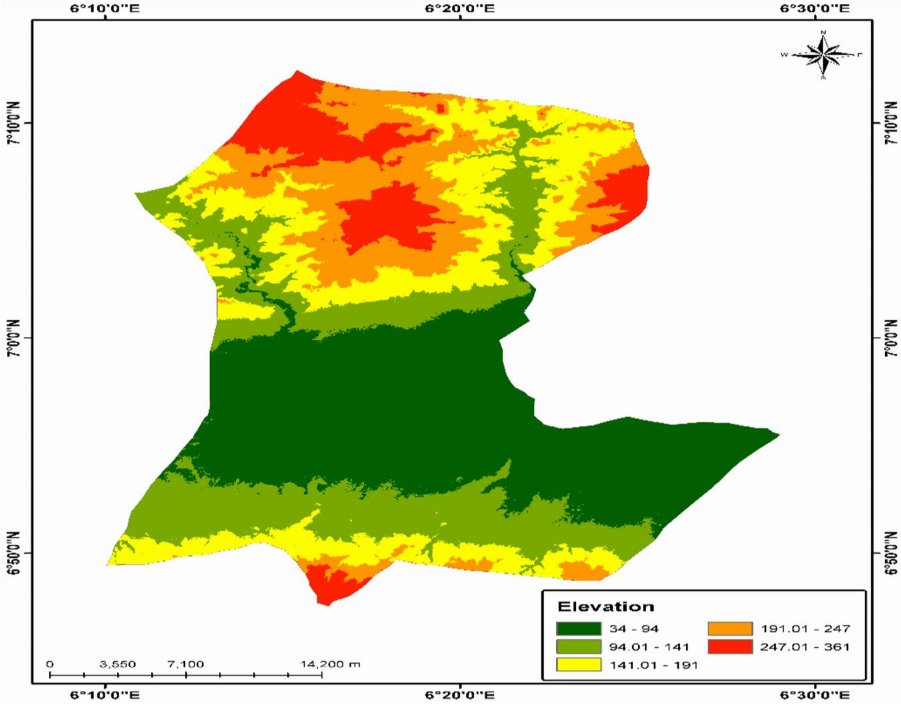

Figure 4.7: Elevation Vulnerability Map

(ii) Slope Vulnerability Map

Figure 4.8 shows the slope vulnerability distribution across the LGA. The map reveals that the majority of the central floodplain is dominated by flat to gentle slopes (0–5%), corresponding to the very high and high vulnerability categories in Table 4.2. Steeper slopes appear in the northern and western uplands, showing low or very low vulnerability. This spatial pattern demonstrates that slope interacts with elevation to compound flood exposure in lowland settlements.

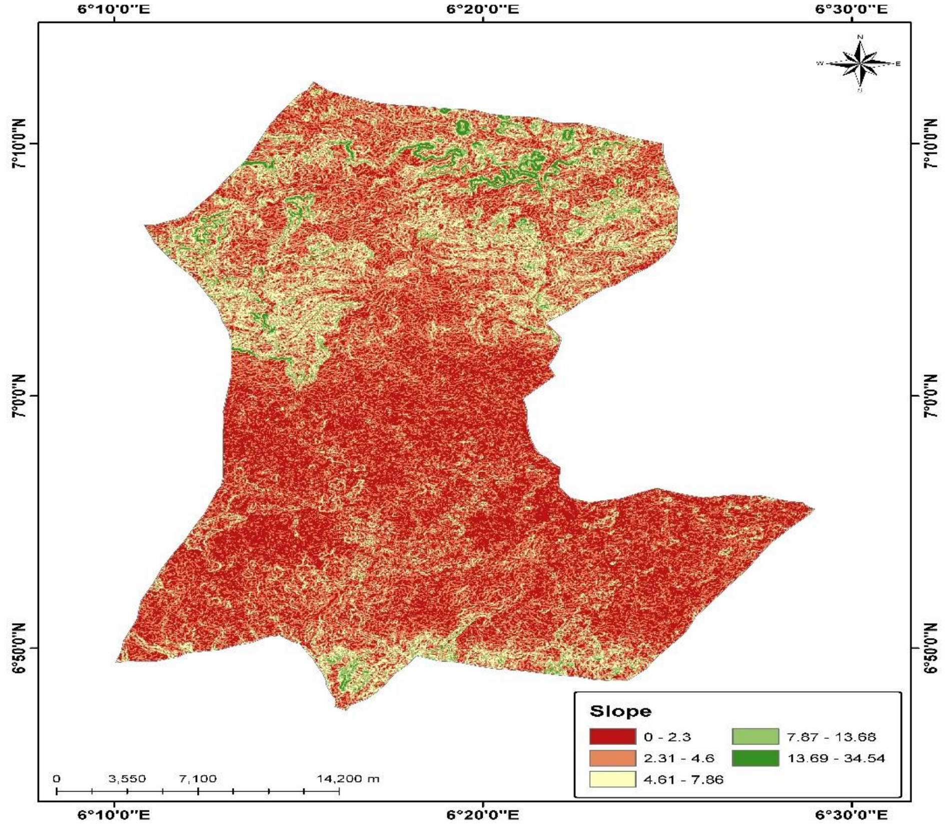

Figure 4.8: Slope Vulnerability Map

(iii) Land Use Land Cover Vulnerability Map

Figure 4.9 highlights the vulnerability of different LULC categories. Farmlands and built-up areas are mapped in the high and very high vulnerability zones, while water bodies appear in the extreme vulnerability class. Forested uplands, which provide some natural protection, are mapped in low vulnerability zones. The figure supports the observation in Table 4.3 that land use practices intensify exposure, especially where human settlements and agriculture dominate floodplains.

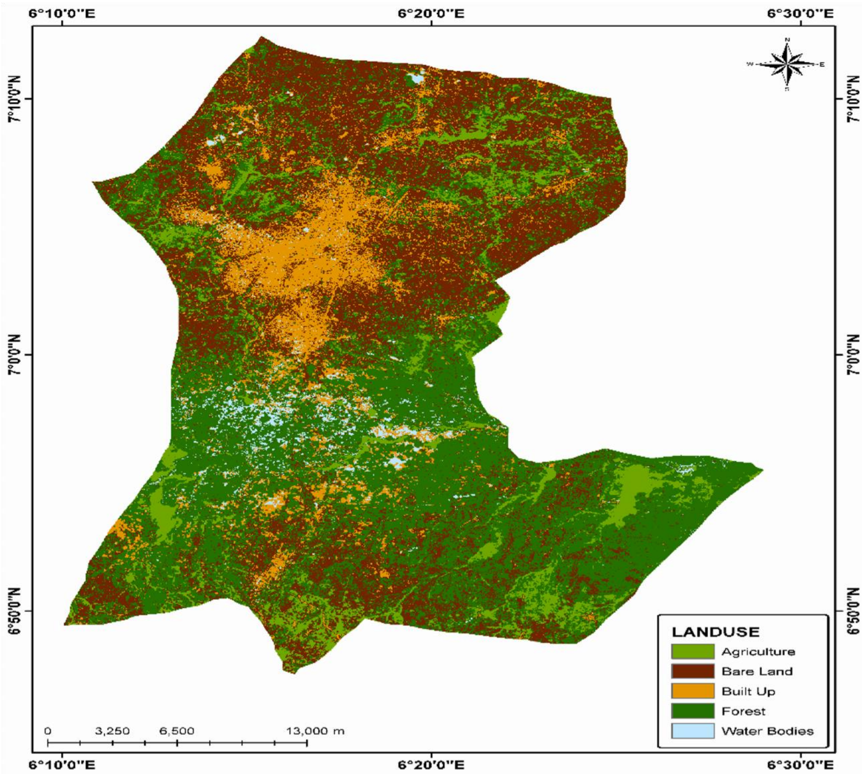

Figure 4.9: Land Use Land Cover Vulnerability Map

(iv) Distance to River

Figure 4.10 shows the relationship between river proximity and flood vulnerability. Communities within 0–500 m of major rivers are clearly mapped in the very high vulnerability category, while areas located beyond 1,700 m fall within low and very low categories. This distribution aligns with Table 4.4, demonstrating that drainage proximity remains a key spatial determinant of flood risk.

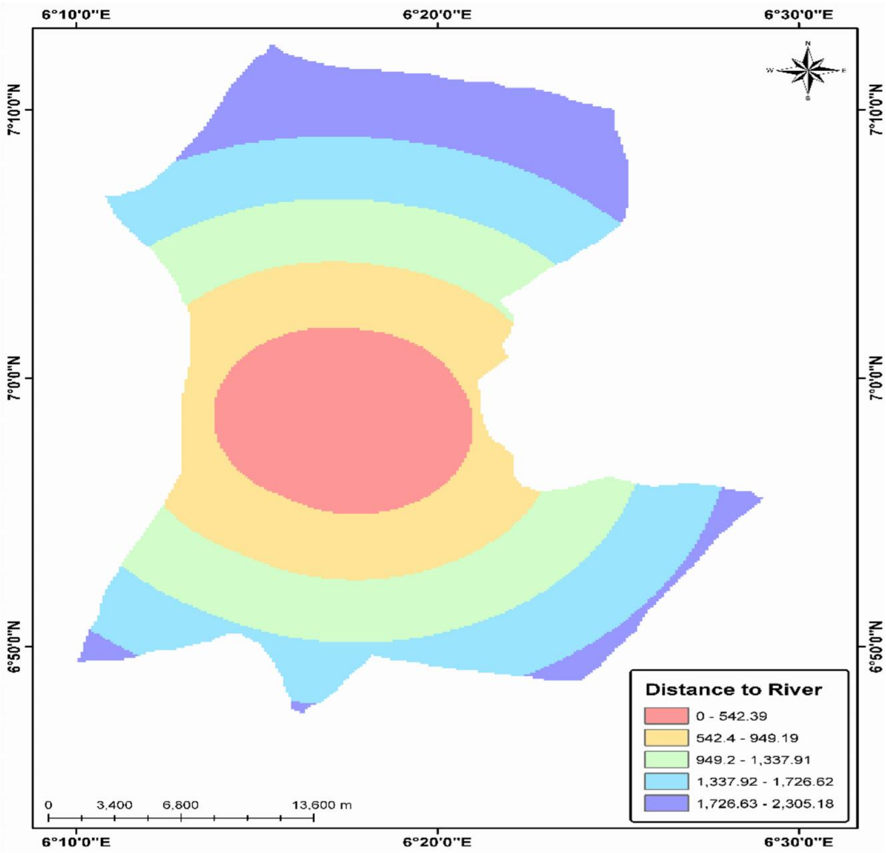

Figure 4.10: Distance to River Vulnerability Map

(v) Soil Vulnerability

Figure 4.11 depicts the vulnerability classification of soils across the LGA. Floodplains dominated by clay loam are mapped in high vulnerability classes, while sandy loam zones, mostly upland, fall into the low category. The map matches the soil classification in Table 4.5, showing that soil permeability strongly influences the distribution of flood-prone zones.

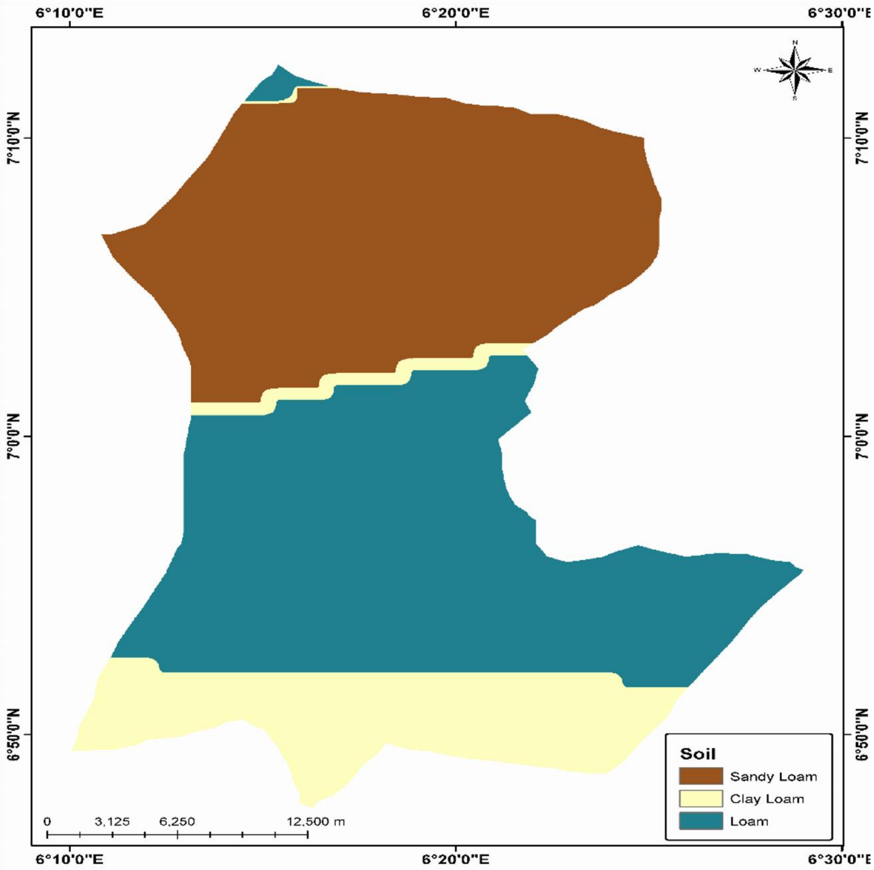

Figure 4.11: Soil Vulnerability Map

(vi) Population Vulnerability

Figure 4.12 highlights the population vulnerability distribution. The map shows that high-density settlements such as Auchi, Jattu, and Aviele fall in the very high and high vulnerability zones, while sparsely populated rural areas fall into low categories. This matches Table 4.6, which shows that human exposure significantly magnifies flood risk.

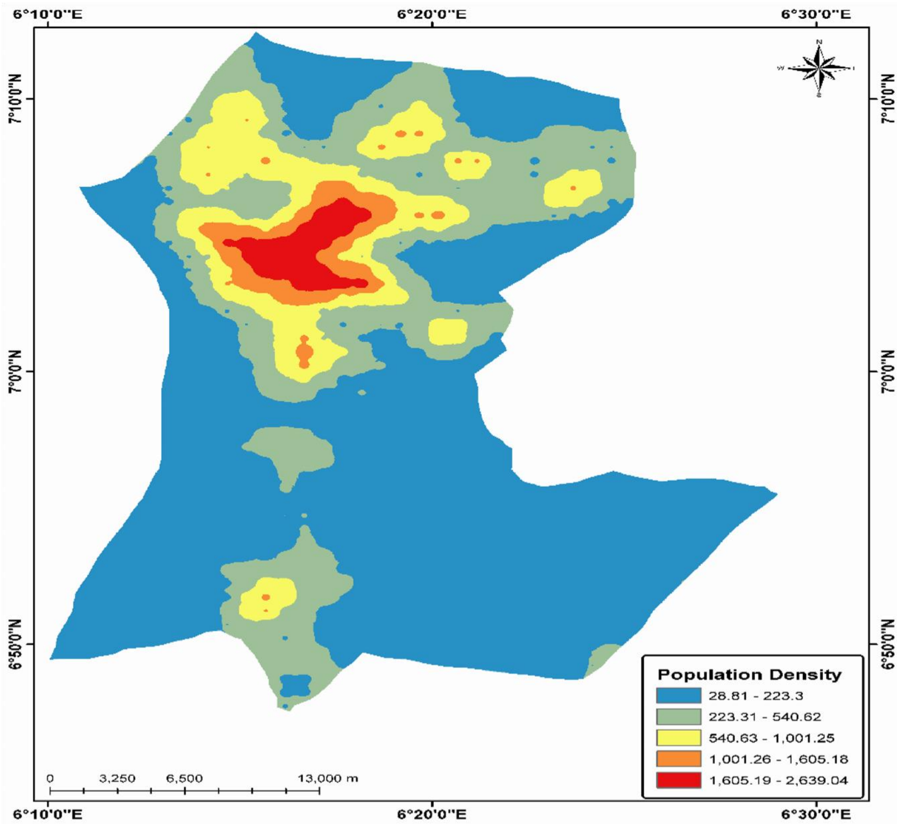

Figure 4.12: Population Density Vulnerability Map

4.3 FLOOD VULNERABILITY MAP AND CLASSIFICATION OF RISK ZONES

The final flood vulnerability map was generated through the weighted overlay of all indicators using the assigned AHP weights. The LGA was classified into four risk categories: very high, high, moderate, and low. Results show that very high-risk zones occupy approximately 22 percent of the land area, predominantly in riverine communities such as Anegbette, Udaba, and Osomegbe. High-risk areas cover about 33 percent of the LGA and include wards such as Aviele and Iyakpi, where low slopes and poor drainage conditions prevail. Moderate-risk zones account for 27 percent of the land area, forming a transitional belt between floodplains and uplands. Low-risk areas, making up the remaining 18 percent, are largely situated in upland towns such as Auchi and Jattu, which benefit from better drainage infrastructure and higher elevation. Statistical analysis further revealed that nearly two-thirds of the population of Etsako West reside within either the high or very high flood vulnerability zones. Table 4.8 is the summary of vulnerability and risk zones from the study. The results of this study is in tandem with the studies of Abubakar *et al*, 2025 Nouhou *et al*.2025; Okafor *et al*. 2024; Ogundolie *et al*. 2024) who discovered the percentage of susceptibility to flood as similar in all aspect of the investigated variables and/or factors.

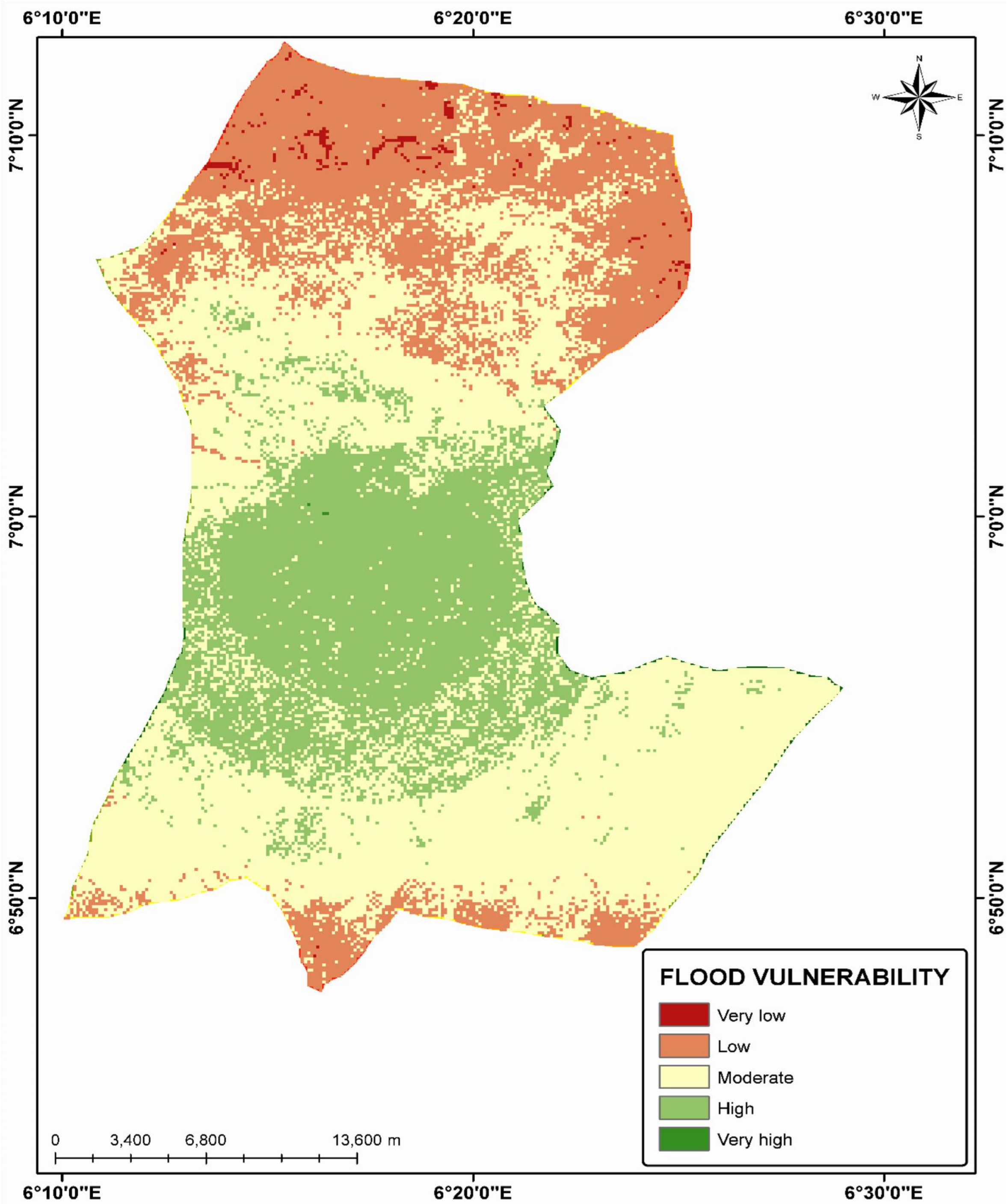

Figure 4.5: Flood Vulnerability Risk Map of Etsako West LGA

Table 4.8: Percentage Land Area and Population in Each Flood Risk Zone

Vulnerability Zone	% of Land Area	% of Population	Example Communities
Very High	22	35	Anegbette, Udaba, Osomegbe
High	33	29	Aviele, Iyakpi
Moderate	27	21	Transition belt settlements
Low	18	15	Auchi, Jattu

Table 4.8 indicates that nearly two-thirds of the LGA population reside within high or very high flood vulnerability zones, underscoring the human risk dimension of flooding in the area.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study has demonstrated the application of Geographic Information System (GIS) and the Analytical Hierarchy Process (AHP) in assessing and mapping flood vulnerability in Etsako West Local Government Area of Edo State, Nigeria. By integrating critical geospatial and socioenvironmental indicators such as elevation, slope, land use/land cover, soil type, river proximity, and population density, the study successfully produced a flood vulnerability map that delineates areas into very high, high, moderate, and low risk zones.

The results revealed that about 55% of the LGA falls within the high and very high vulnerability categories, with riverine communities such as Anegbette, Udaba, and Osomegbe most exposed. Conversely, upland areas like Auchi and Jattu are relatively safer due to favorable topography and drainage conditions. Importantly, nearly two-thirds of the population resides within zones classified as highly vulnerable, highlighting the urgent need for proactive flood risk management. Generally, the study confirms that flooding in Etsako West is driven not only by natural factors such as topography and rainfall but also by human-induced factors including land use practices and settlement patterns. The GIS-based framework adopted here provides an effective, adaptable tool for disaster preparedness, land-use regulation, and sustainable development planning. If properly utilized by government agencies, urban planners, and emergency managers, the results can guide interventions aimed at reducing flood impacts, safeguarding livelihoods, and enhancing community resilience.

5.2 RECOMMENDATIONS

1. Based on the findings of this study, the following recommendations are proposed to mitigate flood vulnerability and enhance resilience in Etsako West Local Government Area: Enforce zoning laws to restrict settlement and farming activities within high-risk floodplains, particularly around Anegbette, Udaba, and Osomegbe.

2. Promote sustainable land-use practices such as agroforestry and controlled deforestation to reduce surface runoff. Upgrade and expand drainage systems, especially in densely populated areas like Auchi, Aviele, and Jattu. Incorporate flood-resilient designs into road, bridge, and housing construction projects to reduce damages during flood events.

3. Establish community-based early warning systems and evacuation plans to ensure timely response to flood threats. Strengthen the capacity of local disaster management agencies through training, funding, and provision of modern equipment.

4. Conduct regular sensitization campaigns to educate residents on flood risks, preparedness, and safe practices during emergencies. Encourage community participation in flood risk reduction programs to foster ownership and sustainability.

5. Strengthen collaboration between government agencies, NGOs, and research institutions to implement integrated flood management strategies. Mainstream flood risk reduction into broader development policies, aligning with the Sendai Framework and Sustainable Development Goals (SDGs).

6. Support high-resolution data acquisition (e.g., LiDAR, UAV surveys) to improve flood modeling accuracy. Expand future studies to include socio-economic indicators such as income, health access, and adaptive capacity for a more holistic assessment.

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