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Flood Vulnerability Assessment of Delta State Utilizing Remote Sensing and Geographic Information System (GIS)

[1*]Eyeta, O. K., [1]Alalade, A. S. and [2]Momohjimoh, B.
[1]Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria
[2]Department of Geomatics, Faculty of Environmental sciences, University of Benin, Benin City, Edo State, Nigeria

Corresponding Author: kereneyeta@gmail.com

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Abstract

Flooding represents a significant global hazard with far-reaching socio-economic and environmental impacts. To effectively manage and mitigate these risks, accurate and timely flood vulnerability assessment is crucial. This research is aimed at assessing the vulnerability of Delta state to flooding, using remote sensing data and GIS-based techniques to delineate the flood prone areas within the study area. Six critical flood conditioning factors were employed to comprehensively analyze flood vulnerability within the study area. These factors encompassed slope, drainage density, elevation, flow direction, Soil and Land use. The Analytical Hierarchy Process (AHP) was applied to assign appropriate weights to each factor, reflecting their relative significance in contributing to flood vulnerability.By combining these weighted factors, the study generated a map of flood vulnerability, depicting the varying degrees of vulnerability among communities in the study area. Findings revealed that 4.3, 8.9 and 86.8 % of the entire study area were lowly vulnerable, moderately vulnerable and highly vulnerable respectively to flood. The study concluded that majority of the area in the Delta state is risky to flood. The resulting flood vulnerability map serves as a valuable resource for local authorities, emergency responders, and urban planners, providing a clear and actionable insight into the flood risks faced by different regions within the study area.

1. Introduction

Natural disasters pose a significant global challenge, occurring with increasing frequency and causing extensive damage. Among all natural disasters, floods have the highest damage potential worldwide and impact the largest population. Globally, there is clear evidence that the number of affected individuals and economic damages resulting from floods are increasing at an alarming rate. Floods have taken numerous lives, displaced millions, and caused the destruction of properties and degradation of nearby farmlands. They stand as the most frequent and devastating natural disaster in the world [1]. Globally, more than 70 million individuals face the risk of encountering floods annually, while an excess of 800 million people reside in regions susceptible to flooding, causing substantial damages and disturbances to societal functions [2].

Numerous definitions of floods have emerged over time. [3]provides an account defining floods as the overflow of water bodies, such as rivers and lakes, surpassing their natural boundaries and submerging the surrounding land. [4] describes flooding as the presence of excessive water flowing onto dry terrain. According to [5], the European Union (EU) floods directive characterizes floods as a significant volume of water covering land.

Ogundele *et al*. describe floods as an ongoing environmental issue that consistently threatens humanity. This environmental hazard frequently arises at the intersection of anthropogenic, climatic, and hydrological factors [6]. Importantly, this issue is escalating due to the rising global temperatures, leading to increased rainfall, greater evaporation of water bodies, glacier melt, and consequently, higher sea levels. This, in turn, results in the inundation of lands situated near these bodies of water [7].

Floods frequently occur in flat or low-lying regions when the ground becomes saturated and water either cannot run off, or cannot run off quickly enough to prevent accumulation. Subsequently, this can lead to river flooding when water drains away from the flooded flat terrain into nearby rivers and streams. Flooding is a natural phenomenon and may occur repeatedly for a river or stream. Flooding is a natural event and could be a recurring event for a river or stream. Additionally, flooding can be triggered by substantial or sustained rainfall that surpasses the soil's ability to absorb it and the flow capacity of rivers, streams, and coastal regions. Other causes of flooding include fluvial flooding, groundwater, surface water runoff and sewer flooding. [8].

Reports indicate that floods are responsible for roughly one-third of all fatalities, one-third of all injuries, and one-third of all property damage arising from natural disasters [9]. Nations like Bangladesh, Pakistan, Nepal, and India have witnessed some of the most catastrophic flooding events in history. Additionally, notable incidents include the 2011 Asian tsunami and the 2013 hurricane and flooding in the Philippines. In Nigeria, the situation mirrors global trends. Frequent floods in various regions of the country have resulted in significant socioeconomic harm, injuries, and loss of life. The adverse impacts of these floods encompass the loss of human lives, destruction of properties, disruptions to public transportation systems, interruptions in power supply, damage to crops, and livestock losses [10]. The floods in Nigeria in 2022 had a widespread impact on various regions of the country. According to data from the Federal Government, these floods resulted in the displacement of over 1.4 million people, the loss of more than 603 lives, and injuries to over 2,400 individuals. Furthermore, approximately 82,035 houses suffered damage, and 332,327 hectares of land were also adversely affected [11]. Although Nigeria usually encounters seasonal flooding, this particular flood event marked the most severe one in the country since the 2012 floods [12]. By October, the floods had resulted in the complete or partial destruction of more than 200,000 homes. Additionally, on October 7th, a tragic incident occurred when a boat, carrying people attempting to escape the floodwaters, capsized on the Niger River, leading to the unfortunate loss of 76 lives. The 2012 Nigeria floods began in early July 2012, resulting in the unfortunate loss of 363 lives and the displacement of over 2.1 million individuals as of November 5, 2012. According to the National Emergency Management Agency (NEMA), these floods impacted 30 out of Nigeria's 36 states, with the most severely affected areas being Kogi and Benue States. These floods were described as the most severe in four decades and had a profound impact on an estimated seven million people. The estimated damages and losses caused by the floods amounted to N2.6 trillion [13].

The significance of appraising and predicting flood dangers has substantially increased to facilitate appropriate flood management and conscientious environmental protection. An evaluation of flood risks, known as a flood risk assessment, is crucial for assessing the risks of flooding, particularly in regions with residential, commercial, and industrial land usage. This assessment is submitted alongside development proposals in areas prone to flooding, aiming to prevent unsuitable development in high-risk zones and direct development away from the most precarious areas. Moreover, flood risk assessments assist insurers in precisely evaluating flood risks in specific locations, aiding in the determination of suitable insurance premiums. The continuous monitoring and assessment of an area's susceptibility to flooding is necessary for devising strategies in response to unforeseen flood incidents. This proactive approach empowers responsible authorities to adequately prepare for flood-related perils. Consequently, the creation of a comprehensive flood risk map becomes imperative in identifying flood-prone regions and ensuring effective and prudent land use planning. There is a pressing need to plan and prepare for potential future flooding events by gauging the potential extent of flooding and consistently monitoring the area. This proactive strategy serves to forestall future flooding and assists land planning authorities in making informed decisions to minimize losses during flood occurrences [14].

The significance of employing geo-information technologies in flood research cannot be overstated. According to Cinque et al., Geographic Information System (GIS) technology, in conjunction with other technologies, plays a pivotal role in flood intelligence. This involves collecting and evaluating flood-related data to empower emergency managers in ascertaining the actual or potential impact of flooding on a community. GIS has become a powerful information integration system, which can be used to map the evaluated results gotten from AHP analysis. The Analytic Hierarchy Process (AHP) is a full-bodied and elastic tool for dealing with multifaceted decision problems, this method divides a complex system into a hierarchical system of elements which usually include purposes, assessment, standards, and alternatives. It also allows for multiple decisions using criteria and prioritization. in addition, the Analytic Hierarchy Process (AHP) has become a useful tool for qualitative and quantitative assessment to attain a meaningful decision-making process [15]. Flood hazard mapping is a crucial element of sound land use planning in flood-prone regions. It generates user-friendly charts and maps that allow administrators and planners to quickly identify high-risk areas and prioritize their efforts in terms of mitigation and response. [16]; [17]. This research is aimed at assessing the vulnerability of Delta state to flooding, using remote sensing data and GIS-based techniques to delineate the flood prone areas within the study area.

2. Materials and Methods

2.1. The study area

Delta State is a state in the South-South geopolitical zone of Nigeria. The State spans an area of approximately 18,050 square kilometers, with over 60% comprising land. Positioned between latitudes 5°00' and 6°45' E and longitudes 5°00' and 6°30' N, it is situated in the country's Midwest. Edo State borders the north and west, while Anambra, Imo, and Rivers States flank the east, and Bayelsa State lies to the southeast. To the south, the Bight of Benin stretches across about 160 kilometers of the state's coastline. Notably, Delta State boasts a predominantly flat terrain, devoid of significant elevations. Its landscape encompasses an extensive coastal strip intertwined with a network of small rivers and streams, forming an integral part of the Niger Delta. In terms of area, Delta State ranks as the 23rd largest among the 36 states in Nigeria, accommodating a population of more than 5.6 million residents as of 2016, making it the twelfth most populous state. From a geographical standpoint, the state's topography is characterized by the Central African mangroves in the southwest coastal region and the Nigerian lowland forests throughout most of the remaining area. Additionally, a small portion of the Niger Delta swamp forests can be found in the far southern region. Noteworthy hydrological features include the River Niger and its distributary, the Forçados River, which flow along the state's eastern and southern borders, respectively. The city of Warri and the coastal zones are intersected by the Escravos River, while numerous smaller distributaries of the Niger River intricately weave through a substantial portion of the western Niger Delta. .

An important characteristic of the Climate of Delta State is flooding. A prominent feature of Delta State's climate is its susceptibility to flooding. The environmental makeup of the region encompasses abundant precipitation, classifying it, alongside other states within the Niger-Delta region of Nigeria, as an expanse of lowland rainforests, freshwater swamps, and mangrove swamps. The River Niger irrigates the state's eastern boundary and empties into the ocean through various tributaries such as the Forcados, Escravos, and Warri rivers, as well as numerous creeks, including the Bomadi creeks, among others. Originating from the north and northeast respectively, Rivers Jamieson and Ethiope converge to create the Benin River, which eventually flows into the sea in the western part of the state.

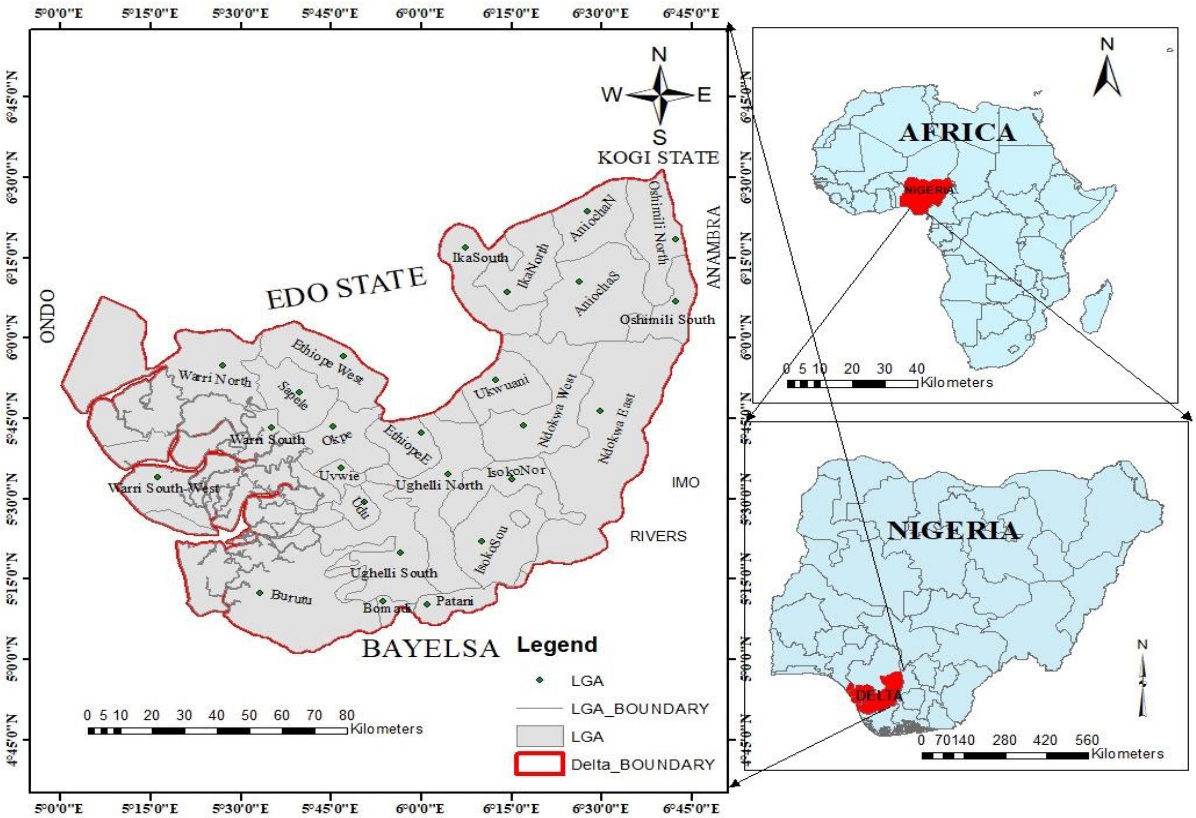


Figure 1: Map of the study area

2.2 Flood Conditioning Factors and Their Method of Processing

This study made use of ranking methods of the vulnerability factors which is embedded in Analytical Hierarchy Process (AHP). AHP is a multi-criteria decision-making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information [17]. Ranking method was adopted because the criterion weights are usually determined in the consultation process with choice or decision makers which resulted in ratio value assigned to every criterion map. In ranking method, every criterion under consideration is ranked in the order of the decision maker's preference. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance for causing flood.

Due to their relevance to flooding, six flood conditioning factors were selected for the spatial modeling. These are: Slope, Drainage Density, Elevation, Flow direction, Soil and Land use. All of the floods conditioning factors were processed in the GIS software.

2.2.1. Elevation or Relief Map
Elevation mostly affects flooding in an inverse way, i.e., flood frequency increases with decreasing elevation meaning that lower elevations are more susceptible to flooding. The elevation map of the study area was extracted from the Digital Elevation Model (DEM) of Delta State, Nigeria. Reclassify function was used to reclassify the DEM based on elevation level into five (5) group which was named: Very High, High, Moderate, Low, and Very Low respectively.

2.2.2. Slope Map
Another significant physical predisposition for flooding is slope. The slope degree map was generated from the DEM layer.

2.2.3. Land use/land cover Map
The land use/land cover map was generated from the satellite imageries. The area in square kilometer of each land use type was computed. The major land use identified were water bodies, forested areas, built up areas, bare land areas and agriculture.

2.2.4. Soil Map
A scanned image of the soil map of Nigeria was georeferenced and digitized. The study area layer was then used to clip the vector layer (digitized soil map) and the vector soil map was then converted to raster, using the ―Polygon to raster feature in ArcGIS.

2.2.5. Flow Direction Map
Flow direction maps are essential tools in flood susceptibility mapping because they predict the paths that surface water will follow during rainfall events or when river overflows based on the topographic characteristics of the landscape. The DEM dataset was analyzed to calculate the direction in which water flows from each cell based on the steepest downhill slope.

2.2.6. Drainage Density Map
Areas with high drainage density have a dense network of streams, rivers, and drainage channels. This means that there are numerous flow paths for water to follow during rainfall events or when rivers overflow. This results in increase in surface runoff and thus increased probability of flooding. Lower drainage density can reduce the risk of flash flooding because water is not as efficiently funneled into rivers and streams, allowing more time for infiltration and surface water dispersion. The drainage density map was done using the "Line Density" tool in the ArcGIS software. The surface area of the catchment and the total length of the stream network were also calculated.

2.3 Classification of Flood Conditioning Factors

In order for the conditioning factors to be comparable, they were reclassified to five susceptibility classes as very high (5), high (4), moderate (3), low (2), and very low (1) based on their potential contributions to flooding and other criteria mentioned earlier. The classes for the flood conditioning factors were adjusted according to the natural breaks (Jenks) grading method. This classification is shown in the table below:

Table 1: Classes of the conditioning factors, their estimated ratings, and relative importance

Factor	Class	Rating	Relative importance
Slope	0.0-17.9996	5	6
	17.9997-35.9992	4	
	35.9993-53.9989	3	
	53.9991-71.9985	2	
	71.9986-89.9982	1	
Drainage density	0-36.069	1	5
	36.07-72.137	2	
	72.138-108.21	3	
	108.22-144.27	4	
	144.28-180.34	5	
Elevation	-19-43	5	4
	43.1-109	4	
	109.1-171	3	
	171.1-221	2	
	221.1-291	1	
Flow direction	0-70	1	3
	70-150	2	
	150-900	3	
	900-6000	4	
	6000-30600	5	
Soil	1193	5	2
	1386	4	
	1545	3	
	1556	2	
	1559	1	
Land use	Vegetation	1	1
	Bare land	2	
	Settlement	3	
	Agricultural Area	4	
	Water body	5	

2.4 Multi-Criteria Decision Analysis: Analytical Hierarchy Process (AHP)

The parameter weights can be assigned through the AHP technique which is multi-criteria decision analysis. The pairwise comparison process is the main part of AHP technique that assigns numbers for representing data to determine each parameter weight. The values and criteria of the parameters are given for indicating its relative importance between two parameters. The relative importance of the selected conditioning factors was assigned based on the empirical knowledge and recent studies. It ranges from 6 (highest importance) to 1 (lowest importance). To estimate the weight for each flood conditioning factor, the technique of pairwise comparison known as the AHP was used. The relative weights were derived by taking the principal eigenvector of a square reciprocal 6 × 6 matrix of pairwise comparison between the criteria. The pairwise comparison matrix is shown in the table below:

Table 2: Pair-wise comparison matrix

Factors	**Slope**	**River network density**	**Distance from rivers**	**Flow accumulation**	**Elevation**	**Curve numbers**
Slope	1	2	3	4	5	6
Drainage density	0.5	1	2	3	4	5
Elevation	0.33	0.5	1	2	3	4
Flow Direction	0.25	0.33	0.5	1	2	3
Soil	0.2	0.25	0.33	0.5	1	2
Land use	0.167	0.2	0.25	0.33	0.5	1

The normalized factor weights, and final weights (W_i) were calculated by the approximation method and is shown in the table below:

Table 3**:** The normalized factor weights, and final weights (Wi)

Factors	**Slope**	**River network density**	**Distance from rivers**	**Flow accumulation**	**Elevation**	**Curve numbers**	**Weight (W_i)**
Slope	0.408	0.467	0.423	0.369	0.323	0.286	**0.379**
River network density	0.204	0.233	0.282	0.277	0.258	0.238	**0.249**
Distance from rivers	0.136	0.117	0.141	0.185	0.194	0.191	**0.161**
Flow accumulation	0.102	0.078	0.071	0.092	0.129	0.143	**0.102**
Elevation	0.082	0.058	0.047	0.046	0.065	0.095	**0.065**
Curve numbers	0.068	0.051	0.035	0.031	0.032	0.048	**0.044**

After completing the AHP, the consistency ratio (CR) was calculated in order to examine the consistency of the developed ratings. The formula for calculating consistency ratio is shown in equation 1:

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

Where RI is the random index which depends on the number of conditioning factors used and CI is the consistency index and is given by equation 2:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

Where n is the number of conditioning factors and λ_{max} is the average value of the consistency vector. According to [18], the average value of the consistency vector should be less than 0.1 for the AHP to be consistent.

In this case, our value of λ_{max} was calculated to be 6.122 and therefore, CI was calculated using equation 2

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{6.122 - 6}{6-1} = 0.0244$$

From equation (1),

$$CR = \frac{CI}{RI}$$

The table for random index RI is shown below:

Table 4: Various numbers of factors and their corresponding Random Index RI

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

[19]

The value of random index (RI) for six factors is 1.24, so then, CR was calculated using equation 1

CR = $\frac{0.0244}{1.24}$ = 0.01968

This value of CR is less than 0.1 so this confirms the consistency of the ratings used.

2.5 Generation of Flood Susceptibility Map:

After each flood conditioning factor had been generated into separate raster files and been successfully classified into 5 classes, the weights of each factor as obtained earlier was multiplied by the corresponding flood conditioning factor map in the raster calculator in the QGIS software to get the final flood susceptibility map.

After the flood susceptibility map had been created, the natural breaks (Jenks) grading method was used to classify the final flood susceptibility map into 5 different classes which were Very high, High, Moderate, Low and Very Low susceptibility to flooding.

Table 5**:** Jenks natural breaks grading of flood susceptibility map

Flood Susceptibility Range	**Class**
3.619-4.87	5 – Very High
3.049-3.610	4 – High
2.597-3.049	3 – Moderate
2.173-2.597	2 – Low
1.379-2.173	1 – Very Low

3. Results and Discussion

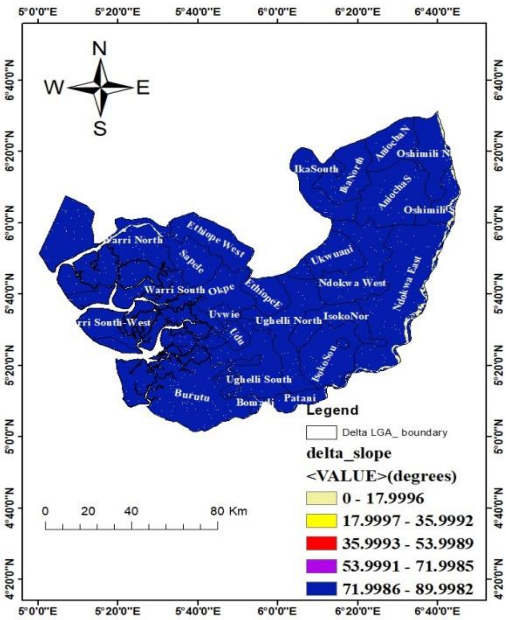


Figure 2a**:** Slope **map**

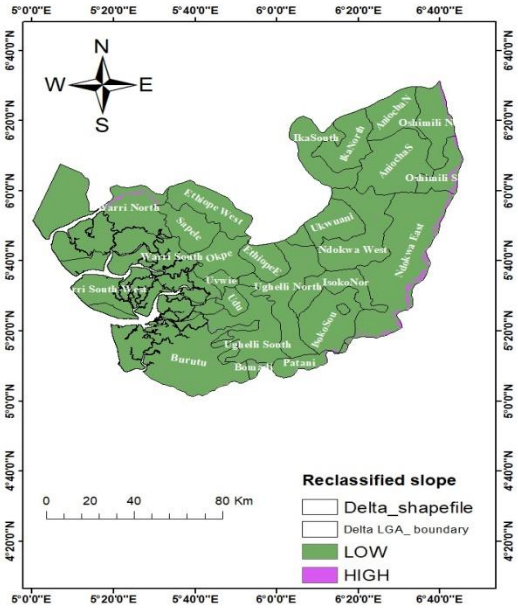


Figure 2b: Reclassified slope map

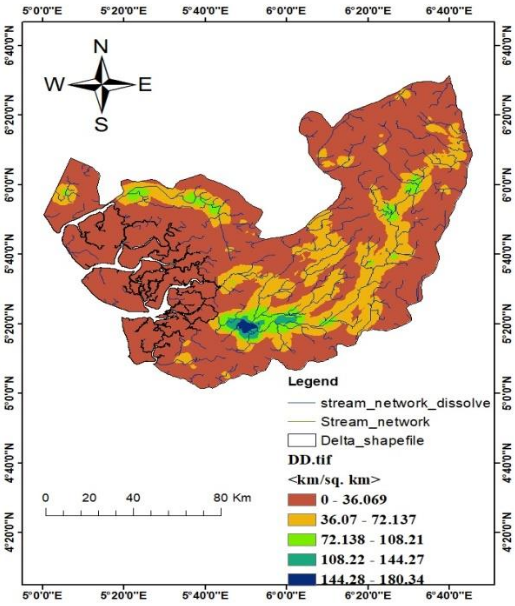


Figure 3a: Drainage Density Map

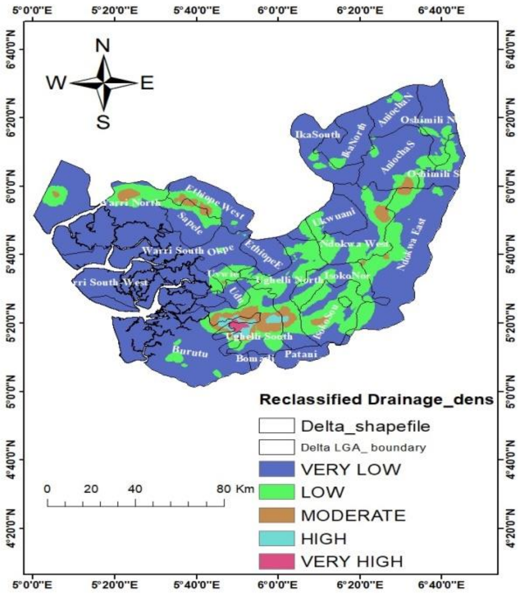


Figure 3b: Reclassified Drainage Density Map

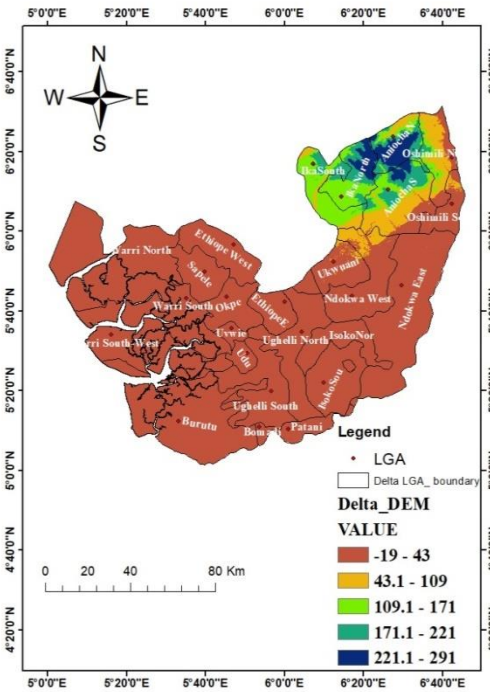


Figure 4a: Elevation Map

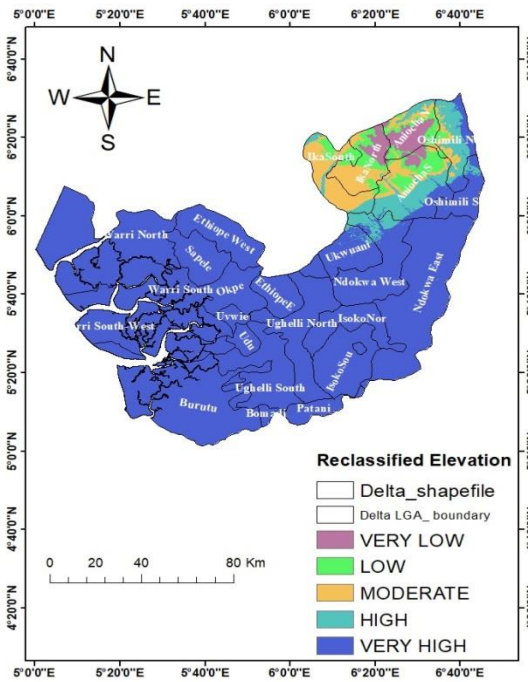


Figure 4b: Reclassified Elevation Map

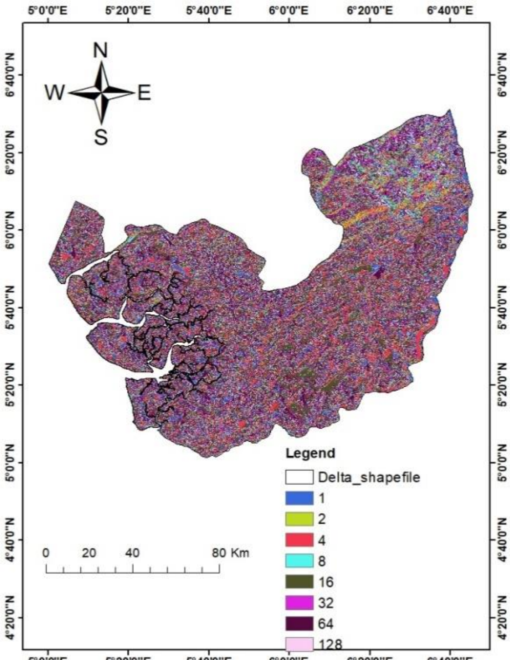


Figure 5a: Flow Direction map

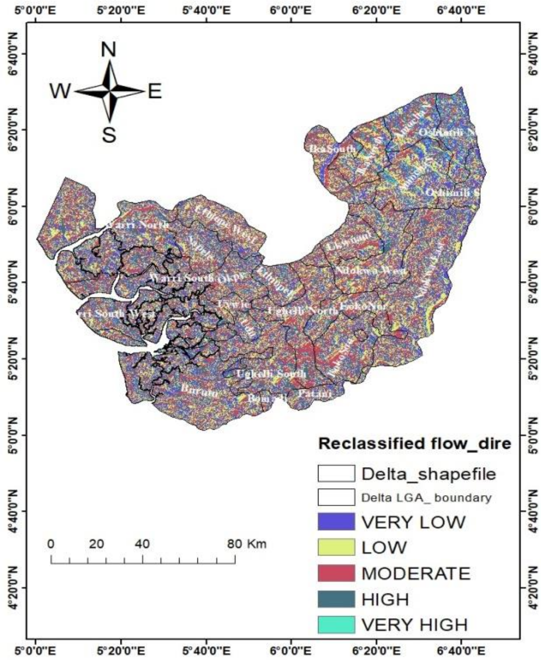


Figure 5b: Reclassified Flow Direction map

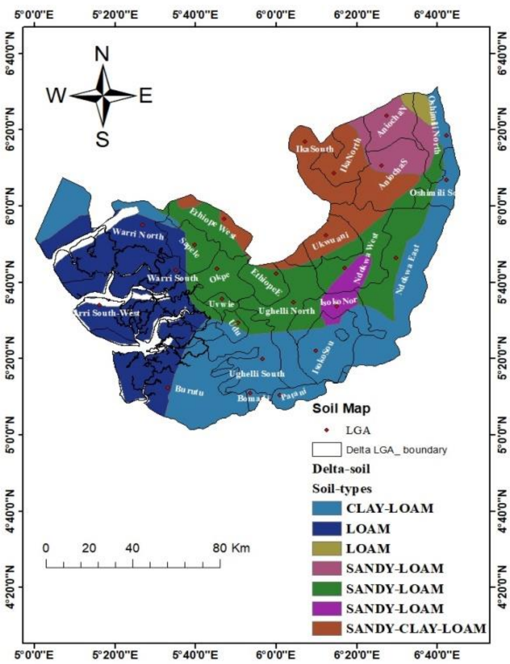


Figure 6a: Soil map

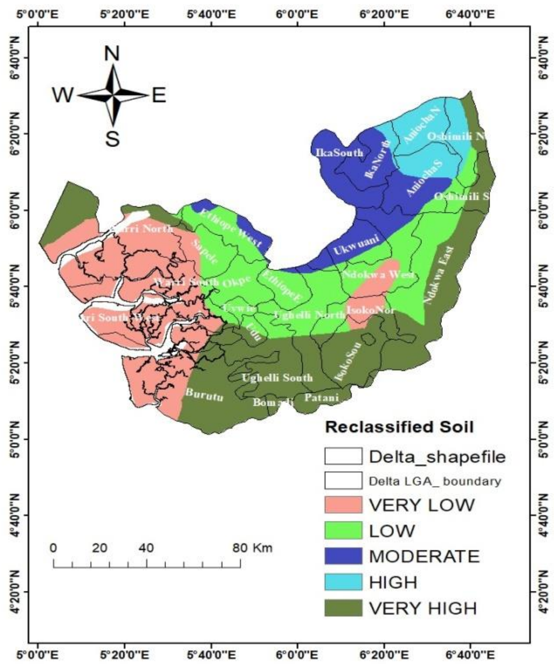
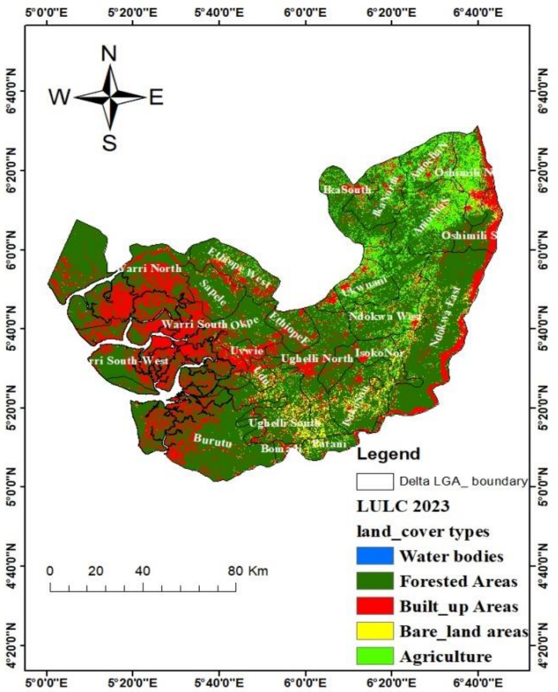


Figure 6b**:** Reclassified soil map



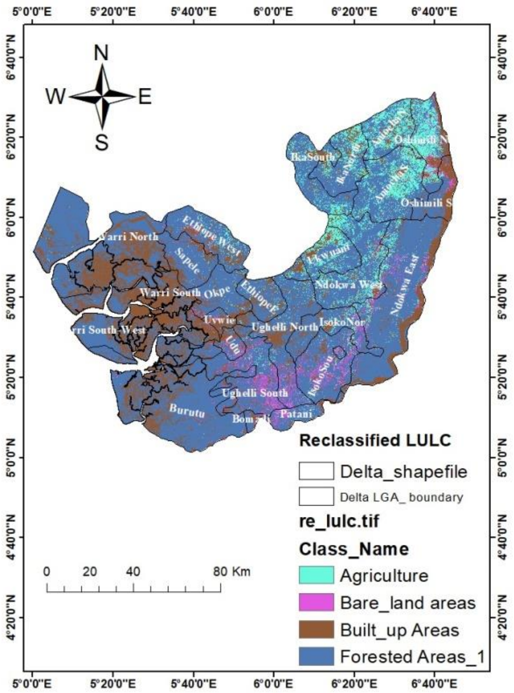


Figure 7a: Land Use/ Land Cover map Figure 7b: Reclassified Land Use/ Land Cover map

3.1 Flood vulnerability*:*

After applying the weighting sum of all conditioning factors, the final map of flood vulnerability was obtained as shown in Figure 8 below. Table 6 presents the flood vulnerability levels of communities within Delta State. The analysis showed that the areas that have very low and low vulnerability to flood were 247.77 km^2 (1.4 %) and 513.24 km^2 of the entire area respectively. The moderate vulnerability area covered 1575.22 km^2 (8.9%). The high vulnerability areas covered a spatial extent of 4689.97 km^2 (26.5%), while the very high vulnerability areas covered 10671.89 km^2 (60.3%). This imply that areas with high and very high vulnerabilities covered 86.8% of the entire study area, which means majority of the part of the study area is prone to flood considering the above factors.

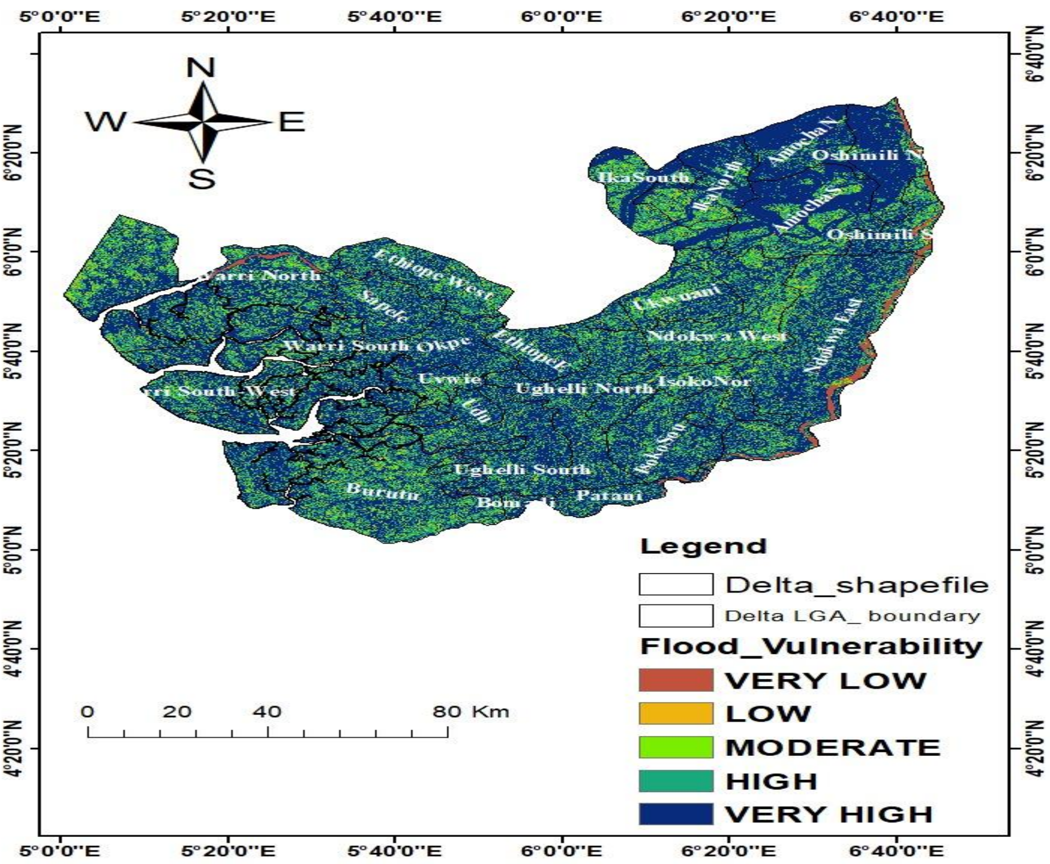


Figure 8: Flood vulnerability map of Delta State

Table 6: Final Flood Vulnerability

Flood Vulnerability Level	Spacial Extent (sq. km.)	Percentage (%)
Very low	247.77	1.4
Low	513.24	2.9
Moderate	1575.12	8.9
High	4689.97	26.5
Very high	10671.89	60.3
Total	17698	100

4. Conclusions

The aim of the research has been achieved by producing a flood vulnerability map of the study area showing various degrees of flood risk and that such information can be useful in safeguarding the lives and properties of inhabitant living in Delta State and to reduce high risk occurrences of flood disaster within the area. Thus, appropriate and early solution could be implemented and can increase public awareness of flood event.

Some of these recommendations will aid in solving the flood problems:

1. Flood-prone regions must not be designated for residential, industrial, or any other private use. Rather, they should be entrusted to the state authorities for proper management and control.
2. Effective land use planning can significantly mitigate the negative impacts of flooding. Adopting suitable land use planning in flood-prone areas is advised. While the optimal approach would involve complete relocation of inhabitants from flood-prone regions, it might not always be feasible due to financial constraints. However, altering the functional features of floodplain areas remains a viable option.
3. Planting vegetation can serve as a natural barrier against flooding, lessening the speed of water flow.
4. Embankments and other structural flood control measures should be constructed at area of high risk.
5. Flood insurance policies must be implemented for the benefit of commercial and industrial recipients.

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