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Research Article

Application of Remote Sensing and Geographical Information System (GIS) in Flood Vulnerability Mapping: A Scenario of Akure South, Nigeria

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Abstract

In flooding, dry land capable of residential, agricultural, and other economic activities is submerged by overflowing water. This causes loss of lives, properties, and destruction of infrastructure. This study applies remote sensing and GIS techniques to produce a flood vulnerability map of the Akure South metropolis. For this study, satellite image data (Landsat 8), location map of Akure South metropolis, SRTM DEM, rainfall data, soil data, and GPS coordinates; acquired during the field survey were integrated to map areas vulnerable to flooding. Using Pairwise Comparison, the various weights of factors constituting flood in the area were acquired. A weighted linear combination and analytical hierarchical process were used to produce the flood hazard and flood vulnerability map. ArcGIS Pro 2.7.3 software was used in spatial and attribute data acquisition, processing, and information presentation. The flood vulnerability results indicated that the very high vulnerability zone occupied 13.9% of the study area, while high vulnerability zone occupied 25.5%. Moderate vulnerability zone occupied 36.8% while low vulnerability zone occupied 23.8% of the study area. The study shows that, remote sensing and GIS can be effectively implemented to analyse and provide results on flood vulnerability required for prompt and effective decision-making on floods.

Keywords: AHP, Flood, GIS, Land use, Remote sensing, Vulnerability

Introduction

Flooding is considered one of the most common natural disasters that affect societies around the world, estimated that more than a third of the world's land mass is flood prone, affecting approximately 82% of the world's population (Argaz et al., 2019; Shantosh et al., 2011). Flood risk involves many traits which include structural and erosion damage, contamination of food and water, disruption of socioeconomic activity, including transport and communication, as well as loss of life and property (Herath, 2003; Hewitt and Burton, 1971). In Nigeria, floods are the most frequent and severe natural hazards that have significantly affected lives and properties (Olorunfemi et al., 2020). Some of the factors that cause flood disasters include land flooding due to heavy rainfall, climate change, and blocked drainage with refuse, construction of buildings across drainage, inadequate drainage networks, and increased population in urban areas (Direk et al., 2012). These factors do not act independently, and flood disasters usually occur from a combination of several of them (Muhammad and Iyortim, 2013; Adeoye et al., 2009). Furthermore, urbanization results in the conversion of agricultural land, natural vegetation, and wetlands to built-up environments and the construction of natural drainages, as well as an increase in the population of those living in flood-vulnerable areas such as flood plains and riverbeds (Menteş et al., 2019; Muhammad and Iyortim, 2013; Adeoye et al., 2009).

According to Anih (1997), urbanization is a great contributor to flooding. He stated that as urbanization intensifies, natural surfaces are replaced by buildings, paved roads, and concrete surfaces that do not allow water to percolate easily into the ground, and these resulted in a large proportion of the rainfall which should normally infiltrate the soil or intercepted by the vegetation but is immediately available for surface runoff which end up in streams and rivers, thus generating excess water for flooding adjacent flood plains. Adeleye and Rustum (2011) analyzed the causes of flood problems in Lagos Nigeria, with the aim of recommending sustainable management solutions to them. Their study revealed that, climate change or unusually high rainfall is not the primary cause of the flooding problem in Lagos but increased urbanization lax planning laws in relation to the city are to blame. In order to curb the menace of flood risk, detailed knowledge on the expected frequency, character, and magnitude of events in an area as well as the vulnerability of the people, buildings, infrastructures, and economic activities in a potentially dangerous zones need to be obtained. However, Ifatimehin (2009) opined that this detailed knowledge is always lacking in most urban centers of the developing world, especially Nigeria.

One way to mitigate the effects of a flood is to ensure that all areas that are vulnerable are identified and adequate precautionary measures are taken to ensure adequate preparedness, effective response, rapid recovery, and effective prevention. Before these could be done, information is required on important flood risk identification, which are elevation, slope orientation, proximity of built-up areas to drainages, network of drains, presence of buffers, extent of inundation, cultural practices, as well as attitudes and perceptions (Ifatimehin and Ufuah, 2006; ICPR, 2002). To get information on most of these, and identify areas that are vulnerable to floods, reliable techniques of collecting and analyzing geospatial information are required. In this regard, an integrated approach of the knowledge of remote sensing and Geographical Information System (GIS) can be used to investigate and map out areas that are less or more vulnerable to flooding. Remotely sensed imagery and GIS can be very effective in identifying the spatial component of floods for management (Moazzam et al., 2018). Remote sensing offers a synoptic view of the spatial distribution and dynamics of hydrological phenomena such as flood and erosion. They are used to measure and monitor the extent of flooded areas, provide a quantifiable estimate of the land area and infrastructure affected by flooding and erosion (Onuigbo et al., 2017; Muhammad and Iyortim, 2013; Izinyon and Ehiorobo, 2011).

Flooding is a common occurrence in many parts of Ondo state, especially Akure. At the peak of the rainy season, Akure people hardly sleep because of the heavy flooding that adversely affect them. The rapid rate of land use and population growth over the years has now led to uncontrolled and uncoordinated development of the suburbs, swamps, flood plains, and natural drainage channels, thereby aggravating the risk of flood disaster in the area. Flood disasters are bound to increase in the future with increasing land use; therefore, the need for proper monitoring, evaluation, and demarcation of flood-prone areas for effective flood mitigation is essential. Therefore, this study used the integration of remote sensing and GIS as a valuable tool for identifying and monitoring flood vulnerability zones in Akure. This was achieved by defining different levels of flood vulnerability in the study area and determining the effect or impact of floods on different land cover to produce a flood vulnerability map of the study area.

Study Area

The study area is Akure South Local Government area, Ondo State in South-Western part of Nigeria. It lies between latitude 7°5’23.62’’N to 7º21’12.972’’N and longitude 5°20’46.975”E to 5°10’9.953”E with a mean altitude of 353metres above the sea level. It has an area of 331sq.km and a population of 353,211 at the 2006 census, which is projected to 618,570 at 2016. The study area is composed of lowlands and rugged hills with granitic outcrops in several places. Akure is a microcosm of the Nigeria nation situated in the high forest zone (or rainforest) in the southwest region. The climate of the area consists of two peaks of rainy season with short and long dry seasons. The rainy season begins in March to mid-July and from late August to mid-November. The little/short dry season occurs between mid-July and early August; the long dry season begins from late November to March.

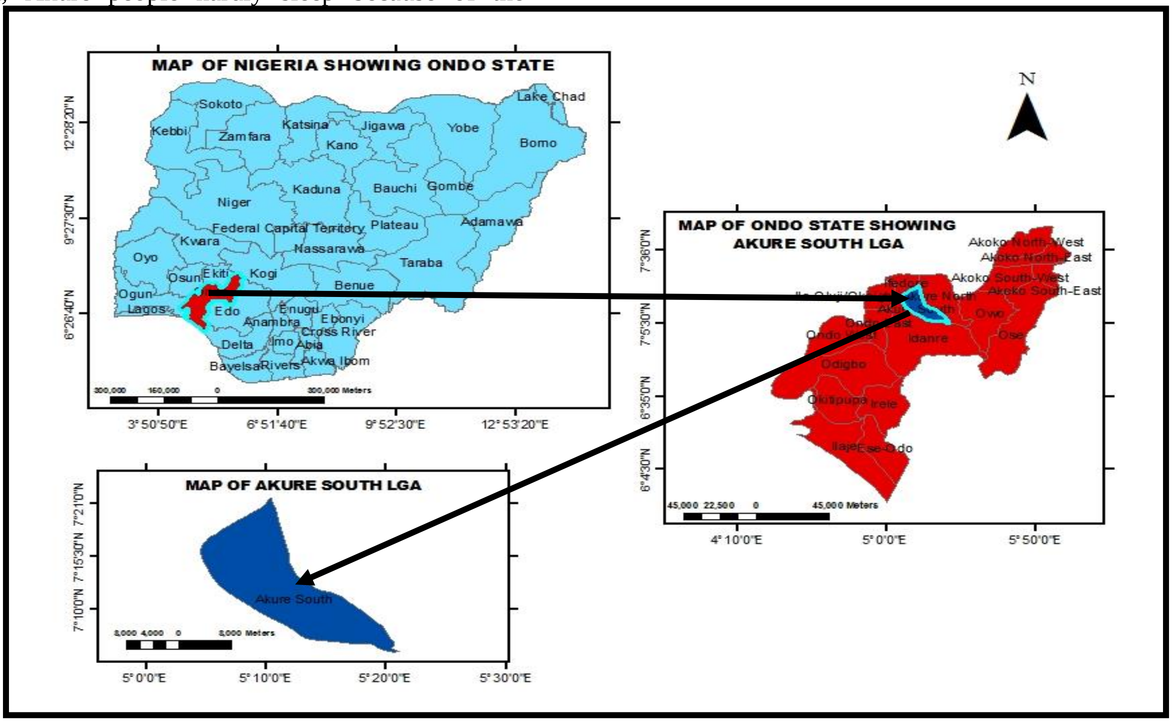

Fig. 1: Map showing the location of the study area.

Materials and Methods
Methodology

In order to carry out this research methodologically, data acquisition is the primary operation as far as digital mapping or GIS operation is concerned. The data used in this study include both primary and secondary data. The primary data included Ground Control Points (GCPs) acquired using GPS**.** The secondary data used were Shuttle Radar Topography Mission (SRTM) Digital elevation model (DEM) data, Tropical Rainfall Measuring Mission (TRMM), Landsat8, soil vector map, and the administrative map of the area. Table 2 shows the data used to perform this work.

Table 1: Data used for the study

Data	Resolution	Year	Sources
SRTM	30m	2020	United States Geological Survey (USGS)
Landsat8	30m	2020	United States Geological Survey (USGS)
Rainfall	30m	2020	Tropical Rainfall Measuring Mission (TRMM)
Soil Map		2018	Nigerian Geological Survey
Administrative map			Remote sensing and GIS department FUTA.
GPS coordinates			

In order to determine the flood vulnerability areas in the study area, six thematic-layer factors were created in a GIS environment using the ArcGIS Pro software. Flood vulnerability factors used in this study were chosen based on personal study, discussion with residents, and according to literature surveys (Ogato et al., 2020; Ouma and Tateishi, 2014). The factors are rainfall distribution, land use and land cover, slope, elevation, drainage density, and soil type. For the estimation of the flood vulnerability areas, the metropolis of Akure-South was classified into four regions with varying levels of flood vulnerability (very high, high, moderate, and low). This classification is carried out by considering the flood vulnerability factors and assigning relative weights to them using the Analytical Hierarchical Process (AHP) based multi-criteria decision making. AHP is a method of decision-making that is based on people's actual capacity to make important choices. Before coming to a consensus or making a decision, it enables the active participation of decision-makers in thoroughly understanding all viable options (Estoque and Murayama, 2010). A pairwise comparison technique is used in the AHP implementation to determine the relative importance to achieving the goal. Similarly, to know how the alternatives' rankings (i.e., the competing options under consideration) are determined, the priorities for the alternatives are determined through pairwise comparisons of how well they perform against each criterion (Ouma and Tateishi, 2014; Saaty, 2008).

In this study, each vulnerability factor was ranked according to the decision maker's preference using the four vulnerability levels as a framework for ranking. Each factor was weighted based on its estimated impact of causing flooding in order to produce criterion values for each evaluation unit. With weights of 1 being the least important and 4 being the most important factor, the inverse ranking was used for some of these factors. Using the Weighted Linear Combination (WLC) method, all the map layers (the factors) were overlaid in the final GIS spatial analysis for flood vulnerability zones simulation.

Results and Discussion
Flood Vulnerability Factors

Rainfall Distribution Factor
One of the main factors contributing to floods is heavy rainfall. When natural watercourses are unable to transport excess water, flooding is the most frequently the result of heavy rainfall. Excessive rainfall is linked to floods; any water that does not quickly percolate further into the ground, flows downward as runoff (Ouma and Tateishi, 2014). In this study, the daily rainfall data for 2020 was derived from the TRMM data for the study area. The average daily rainfall was calculated and interpolated in a GIS environment using the kriging method and a raster layer of the rainfall data was generated. The rainfall value ranges from 1229mm to 1255mm (Table 4), with the higher values located in the northern part of the study area. The rainfall distribution raster was reclassified into four classes with the least rainfall being assigned the value of 1 and the highest rainfall assigned the value of 4. Figure 2 shows the rainfall factor map.

Land use and Land cover Factor
Numerous experts working in the field of flood hazard management believe that changes in land use and land cover are one of the main causes of flooding. This is the case due to the fact that the factor not only takes into account the current use of the land, pattern, and type of use, but also the significance of that use in relation to soil stability and infiltration (Ogato et al., 2020; Ouma and Tateishi, 2014; Mngutyo and Ogwuche, 2013). The land cover classes of the study area were produced from the Landsat 8 satellite imagery covering the area. Unsupervised classification technique with ISO cluster classifier was used. A minimum of eight classes and a maximum of 12 classes were entered into the classification

environment. Reclassification was carried out to ensure that only four classes have the capability of increasing and decrease the rate of flooding are produced. The four classes are forest, grassland, bare ground, and built-up area. The built-up area was assigned the value of 4 because areas with high number of settlements are at the risk of flood and the areas with less settlement have low risk to flood. Figure 3 shows the map of the land cover factor.

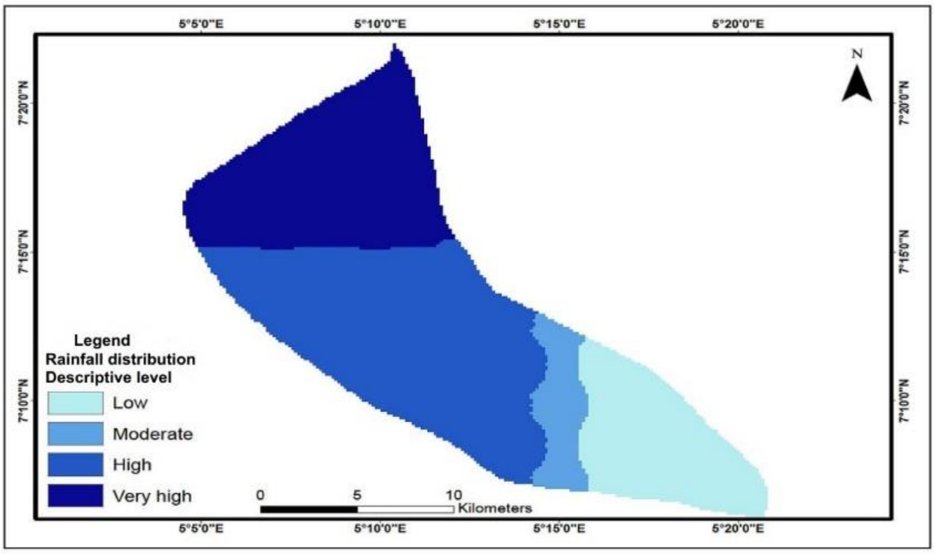

Fig. 2: Rainfall distribution map.

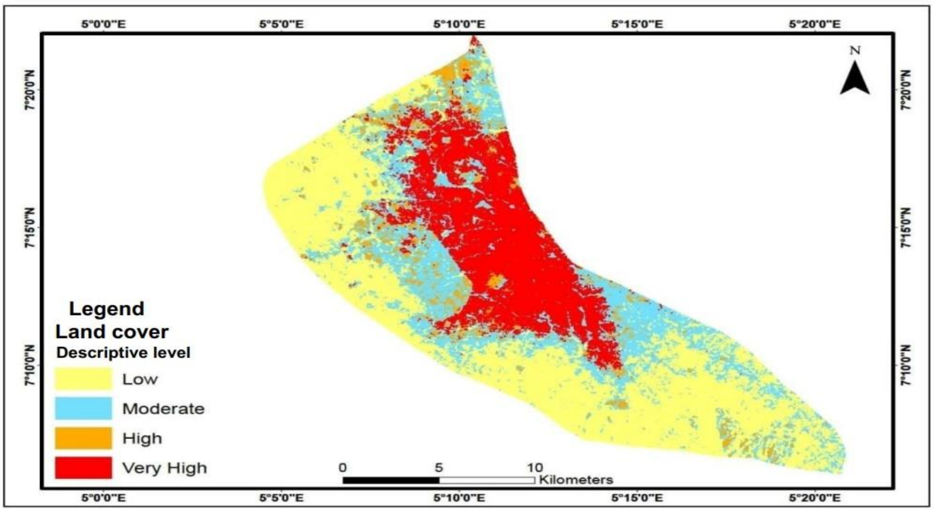

Fig. 3: Land cover map

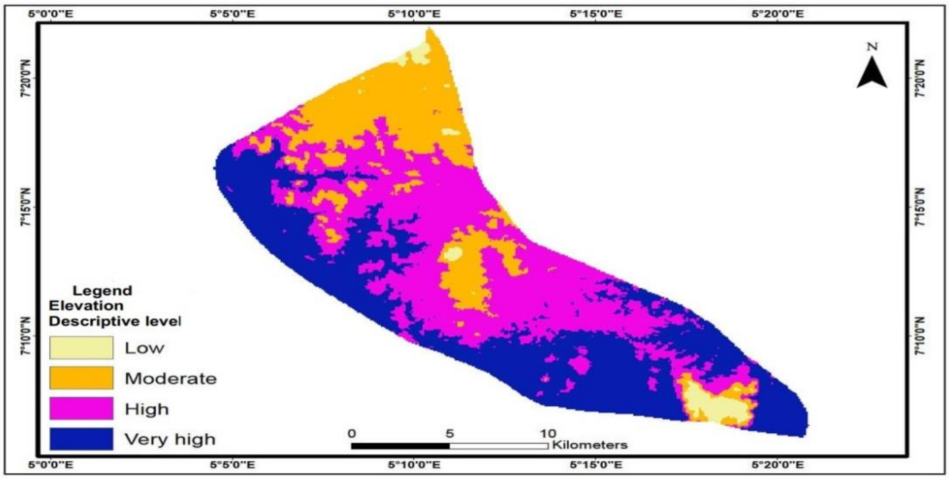

Fig. 4: Elevation map

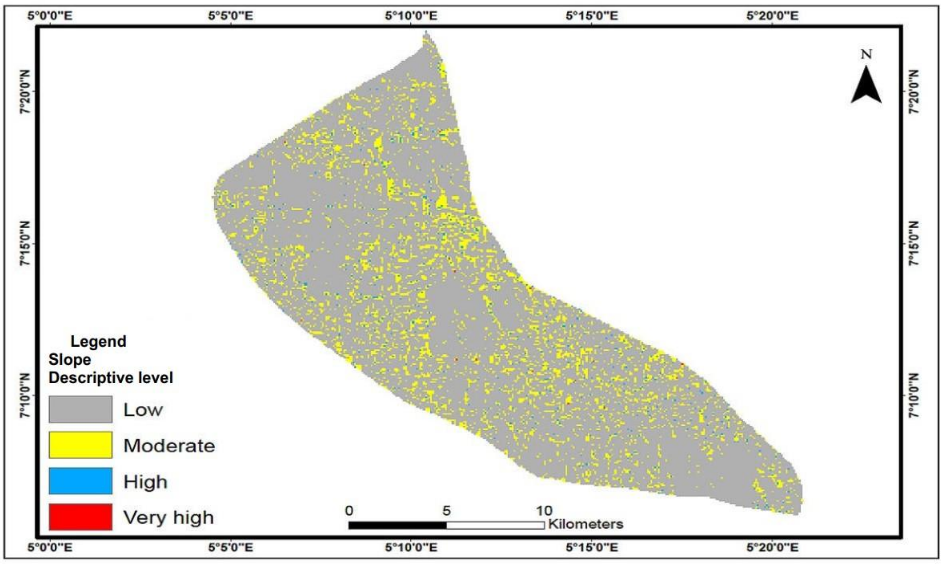

Fig. 5: Slope map

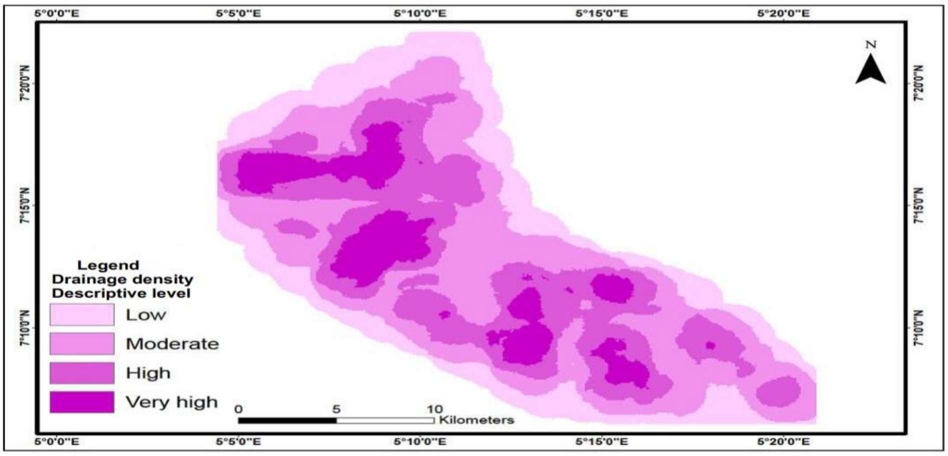

Fig. 6: Drainage density map

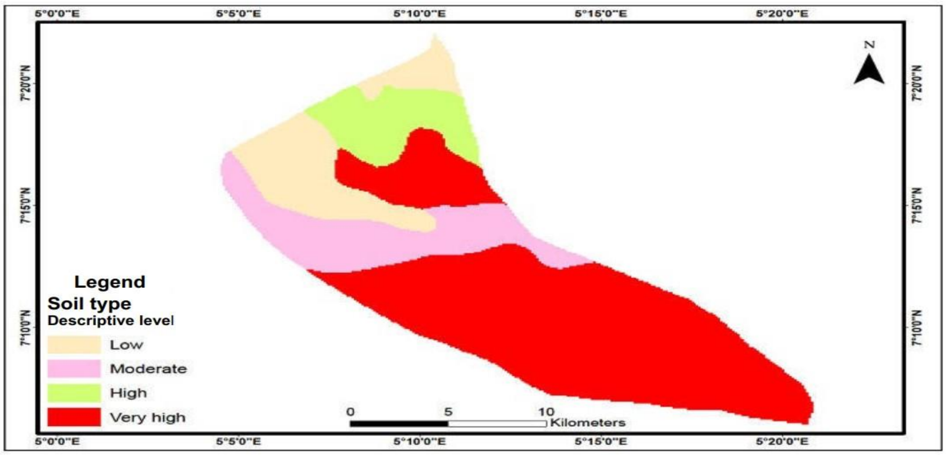

Fig. 7: Soil type map

Elevation and Slope Factor

Elevation and slope play an important role in flood vulnerability and in the determination of areas that are susceptible to flooding. Elevation controls the movement of the water flow direction and intensity of the water level, while slope defines the rate and period of water flow. Flooding occurs when water flowing quickly over a smooth or flat surface, while a rougher surface can take longer to respond to flooding. Flat terrain is vulnerable to water logging, whereas steeper slopes are more vulnerable to surface runoff (Ouma and Tateishi, 2014). The elevation and slope factor were derived from the SRTM DEM data of the study area and were reclassified into four classes. The slope class having the lowest value was given a higher rank of 4 due to terrain, while the class having the highest value was assigned a lower rank of 1 due to surface run-off. Figures 4 and 5 show the reclassified elevation and slope map factor.

Drainage Density Factor

The relationship between infiltration and drainage density is inverse. Greater drainage density denotes high runoff for basin areas and geologically erodible materials, and less risk of flooding. As a result, the drainage density rating drops as drainage density rises (Ogato et al., 2020; Wondim, 2016). The drainage density map was extracted from the SRTM DEM, and the layers were classified into four classes. The drainage density class having the lowest value was given higher rank of 4 because it has a very high vulnerability to flooding while the class having the highest value was assigned a lower rank of 1 because of low vulnerability. Figure 6 shows the reclassified drainage density map factor.

Soil Factor

The rainfall-runoff cycle is directly impacted by soil properties in a watershed, and soil moisture prior to a rain event (Ogato et al., 2020). The ability of the soil to absorb water will be significantly influenced by the structure and infiltration capacity of the soil. The capacities of different types of soil vary. As soil infiltration capacity declines and surface runoff increases the likelihood of flooding increases (Ogato et al., 2020; Ouma and Tateishi, 2014). In this study, the soil type map was derived from the Nigeria Geological Survey map. The soil map shows the variability of the types of soil in the study area. The soil types were classified into four classes, which are stony sandy loam, gravelly sandy clay loam, stony sandy clay and gravelly sandy clay. Weights were assigned to each of the classes based on their capacity to generate flood. The soil type with the highest potential to produce a very high flood rate is ranked 4, while the soil type with the lowest potential to produce a flood rate is ranked 1. Figure 7 shows the reclassified soil type map.

Pairwise Comparison and Ranking of the Criteria

The results of the pairwise comparison and ranking of the criterion that was obtained through the multi-criteria decision making are presented in Table 2. Table 3 shows the determination of the relative weights of the criterion, where C1 = Rainfall; C2 = land cover; C3 = Slope; C4 = Elevation; C5= Drainage density; and C6 = soil type.

Table 2: Pairwise comparison matrix of the six criteria for the AHP process

	C1	C2	C3	C4	C5	C6
C1	1.00	2.00	3.00	4.00	5.00	6.00
C2	0.50	1.00	1.50	2.00	2.50	3.00
C3	0.33	0.67	1.00	1.33	1.67	2.00
C4	0.25	0.50	0.75	1.00	1.25	1.50
C5	0.20	0.40	0.6	0.80	1.00	1.20
C6	0.17	0.33	0.5	0.67	0.83	1.00
SUM	**2.45**	**4.90**	**7.35**	**9.80**	**12.25**	**14.70**

The pair-wise comparison matrix and factor map are used to determine each factor's weight and ranking. Absolute numbers between 0 and 1 that represent the priorities are called weight values. The assumption made when using a weighted linear combination is that the total weights add up to 1. When a factor has a higher weight value, it has more importance or influence on the study as a whole. As can be seen from the factor weights discovered for this study area, the rainfall factor has the highest weights, indicating that it contributes more to flooding in the area than the other factors. Table 4 lists a summary of vulnerability factors, their weights, and rankings. The flood vulnerability map of the study area was created using the data from the table.

Table 3: Relative weights for each criterion

	C1	C2	C3	C4	C5	C6	WEIGHTS	PERCENT%
C1	0.41	0.41	0.41	0.41	0.41	0.41	0.41	41%
C2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	20%
C3	0.13	0.14	0.14	0.14	0.14	0.14	0.14	14%
C4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	10%
C5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	8%
C6	0.07	0.07	0.07	0.07	0.07	0.07	0.07	7%
SUM	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table 4: Weighted flood vulnerability ranking for the study area

Rainfall distribution (mm)	Ranking decision	Relative weight	Flood vulnerability class
1,229-1,234	1		Low
1,235-1,241	2		Moderate
1,242-1 ,249	3	0.41	High
1,250-1,255	4		Very high
Slope (degree)	**Ranking decision**	**Relative weight**	**Flood vulnerability class**
0	4		Very high
1-81	3	0.20	High
82-87	2	0.20	Moderate
88-90	1		Low

Land use	Ranking decision	Relative weight	Flood vulnerability class
Forest	1		Low
Bush land	2	0.14	Moderate
Bare surface	3	0.14	High
Built-up Area	4	0.14	Very high
Soil Type	**Ranking decision**	**Relative weight**	**Flood vulnerability class**
Gravelly Sandy Clay	1		Low
Gravelly Sandy Clay Loam	2	0.10	Moderate
Stony Sandy Clay	3	0.10	High
Stony Sandy Loam	4	0.10	Very high
Drainage density (m)	**Ranking decision**	**Relative weight**	**Flood vulnerability class**
1-48	4		Very high
49-100	3	0.08	High
101-152	2	0.08	Moderate
153-212	1	0.08	Low
Elevation (m)	**Ranking decision**	**Relative weight**	**Flood vulnerability class**
266-325	4		Very high
326-360	3	0.07	High
361-417	2	0.07	Moderate
418-564	1	0.07	Low

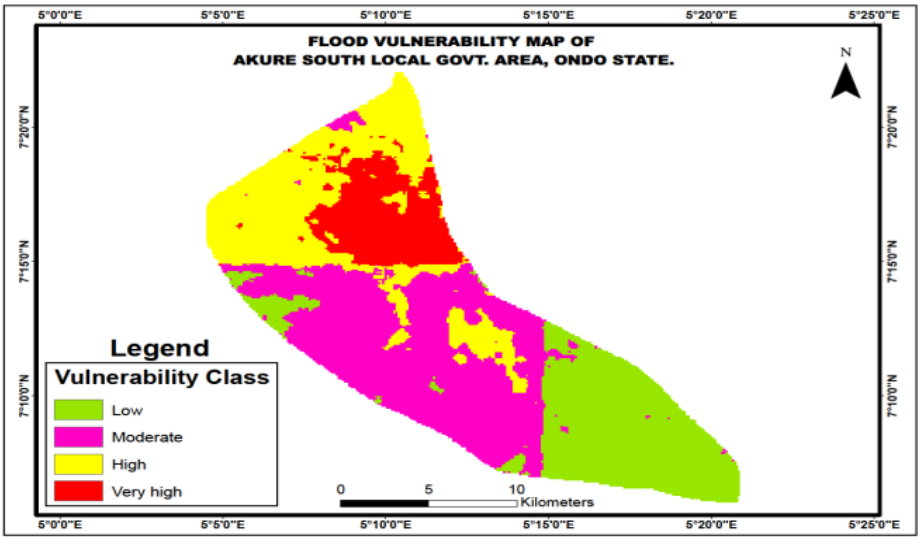

Fig. 8: Flood vulnerability map of Akure South Local Government

Table 5: Flood vulnerability zone distribution

Category	Area (km²)	Area (%)
Very High	46.78	13.9
High	85.83	25.5
Moderate	123.51	36.8
Low	79.91	23.8
Total	336.03	100.0

Flood Vulnerability Mapping for Akure South

After determining the weights of the vulnerability factors, a multi-criteria evaluation is carried out using the specific weights for each factor and all the reclassified factors were overlaid against each other in ArcGIS environment to create the flood vulnerability map of Akure South LGA as shown in Figure 8. The result of the overlay analysis produced a layer showing four risk zones: namely very high vulnerability, high vulnerability, moderate vulnerability, and low vulnerability flood zones in the study area. The results indicated that the very high vulnerability zone occupied 13.9% of the entire study area, covering an area of 46.78km^2, while the high vulnerability zone occupied 25.5%, covering an area of 85.83km^2. The moderate vulnerability zone occupied 36.8% covering 123.51km^2, while the low vulnerability zone occupied 23.8% covering an area of 79.91km^2. This distribution is also represented in Table 5.

Assessment of the Flood Vulnerability Map

To assess the validity of the flood vulnerability map, the location of the past flood incidents was acquired using GPS by visiting the area. These past flood positions were superimposed on the flood vulnerability map that was produced. Table 6 shows the horizontal position of these locations, as well as the actual zone where they fall on the flood vulnerability map. The entire past flood points in Table 6 are located on the very high flood vulnerability areas, according to the result, which reveals the reliability of the flood vulnerability map applied in this study.

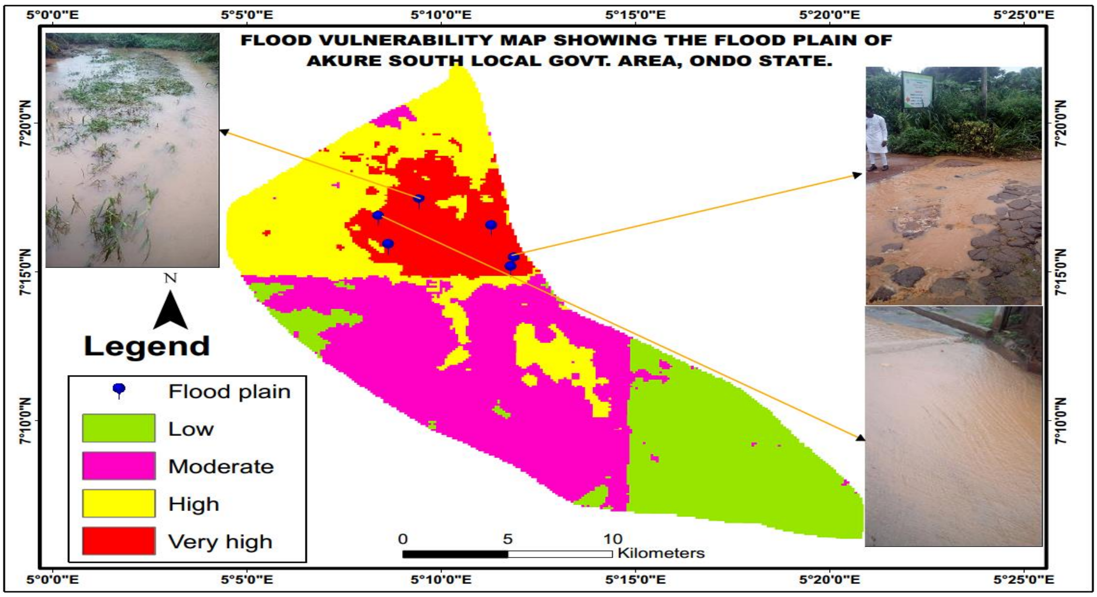

Fig. 9: Flood vulnerability map of Akure South Local Government showing past flooding areas

Table 6: Past flood incidents position and locations on the generated flood vulnerability map generated

GPS points	Easting (mE)	Northing (mN)	Location in the generated flood vulnerability map zones
Point 1	742530.513	802223.921	Very high
Point 2	741614.327	804740.280	Very high
Point 3	742689.845	802783.583	Very high
Point 4	738168.681	806383.034	Very high
Point 5	736251.565	805309.416	Very high
Point 6	736735.652	803561.3412	Very high

Conclusions

Based on the findings of this study, the objective of the study 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 inhabitants living in Akure South LGA and reducing high-risk occurrences of flood disaster within the area. The flood vulnerability mapping results indicated that the very high-vulnerability zone occupied 13.9% of the entire study area, covering an area of 46.78km^2, while the high vulnerability zone occupied 25.5%, covering an area of 85.83km^2. The moderate vulnerability zone occupied 36.8% covering 123.51km^2 while the low vulnerability zone occupied 23.8% covering an area of 79.91km^2.

The flood vulnerability maps are a valuable tool for planners, insurers, and emergency services to assess flood risk. Policy makers need to assess risk for more than one consequence to take appropriate actions in alleviating the problem. In light of above discussion, flood risk mapping, being an important measure of the flood management technique will go a long way in reducing flood damages in areas frequently affected. Flood frequency analysis combined with GIS was found to be very important in mapping out the likely inundated areas of a given catchment. This study has been able to show the usefulness of remote sensing and GIS technologies in classifying and identifying areas with very high, high, moderate and low vulnerability to flooding within the study area. The study concludes by proffering some recommendations aimed at addressing the issue of flooding within Akure South L.G.A as follows.

i. Developmental projects on flood prone areas should be critically analyzed based on the effective factor causing flood in order to mitigate the hazard.
ii. Appropriate land use planning should be adopted in flood prone areas to reduce the adverse effects of flooding.
iii. The Ministry of Environment should enforce the prevention of the dumping of refuse along/in river courses.
iv. Vegetation should be planted to act as flood breaks, reducing the flow velocity.
v. Embankments and other structural flood control measures should be constructed in areas of high risk.

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