Flood Vulnerability Assessment in Kogi State (Nigeria), Using Weighted Linear Combination of Multi-criteria Factors

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Abstract

Floods and flood events are major natural disasters in Nigeria and around the world, their severity and impact result in numerous troubling consequences for human development and the displacement of people. This study used geographic information systems (GIS) and remote sensing techniques to produce maps of Kogi State, Nigeria's flood risk and vulnerable areas. This research used the AHP and MIF models. Data were sourced from multiple sources and analyzed using ArcGIS 10.8 software, generating nine thematic maps showing different factors that influence flooding, including the topographic wetness index, slope, elevation, rainfall, drainage density, land use, and land cover (LULC), soil type, distance from the river and distance from the road. Thematic layers were assigned weights according to their influence on flooding in the area. The weighted overlay tool in ArcGIS 10.8 combined each thematic map with their respective assigned weights, producing the ultimate flood vulnerability map for both the Analytic Hierarchy Process (AHP) and Multi-Influence Factor (MIF) models. Flood zones were classified into four distinct classifications: low, moderate, high, and very high, according to the data analyzed that cover a significant part of the study area. According to the AHP and MIF model results, 0.66% and 2.18% of the area were classified as very high-risk zones, while 27.69% and 28.17% of the total land area were classified as high flood-vulnerable regions. The flood zones classified as moderate and low vulnerability covered 68.56% and 3.09% (according to the AHP), 59.91%, and 9.75% (according to the MIF), respectively. The results of this study will provide a framework for decision-making that can result in effective planning, allocation of resources, and creation of policies.

Keywords: *Remote sensing, GIS, Flood mapping, Hydrological modeling, AHP, MIF.*

Introduction

According to the International Strategy for Disaster Reduction (ISDR) in 2004, a flood is a temporary occurrence in which an arid region becomes wholly or partially submerged in water or encounters an overflow of water from either inland or tidal sources resulting from an abnormal or rapid accumulation of surface waters from any water storage source.

Floods are complex incidents that arise from a combination of hydrological, geological, and geomorphological factors and some other natural environmental factors, causing severe economic, social, and environmental damage (Rincon *et al*., 2018; Mukherjee and Singh, 2019; Skilodimou *et al*., 2019) influenced by continuing abuse of the environment by human (Ajiboye & Orebiyi, 2022). Food is considered the most severe global hazard in terms of its magnitude, frequency, geographical extent, impact on human life and property, and disruption of socio-economic activities in the affected regions (Blistanova *et al*., 2016; Aderogba, 2012).

Furthermore, empirical data from 1985 to 2018 indicate that Nigeria experienced a higher frequency of flood events annually than other countries in West Africa (Komolafe *et al*., 2020) while several states and cities throughout the nation have experienced the impacts of flooding in recent years, which has continued to undermine the government's ability to effectively mitigate the occurrence of flood-related disasters (Komolafe *et al*., 2015).

Despite the collective efforts of the government and numerous nongovernmental organizations (NGOs) to improve compensation and rehabilitation measures, the situation seems to be worsening daily. It has been explicitly observed that urban flooding is becoming increasingly noticeable in cities such as Lagos, Maiduguri, Aba, Warri, Benin, Ibadan, Lokoja, and other towns located on low or flat terrain with unsuitable surface drainage planning primarily due to the impact of the rainy season and the continuous obstruction of the drainage system caused by uncontrolled municipal waste disposal (Adedeji *et al*., 2012).

The objective of this study is to establish a framework that decision makers can consult with others, develop effective policies and management strategies for mitigating future occurrences of flooding toward minimizing the impact on life and property to foster a conducive and secure living environment, promoting happiness and safety among the state's people and aims to utilize geospatial technology to delineate vulnerability zones within the state.

In the years 1963, 1978, 1980, and 2011, for example, the city of Ibadan witnessed a severe flood event due to the Ogunpa River exceeding its normal threshold, resulting in substantial economic losses equalling over 30 billion naira and the unfortunate death of at least 100 people, thus attracting national and international attention leading to the establishment of the Ogunpa River as an international symbol (Adegbola & Jolayemi, 2012.

According to Komolafe *et al*. (2014), Lagos State had a total of eight significant flood events during 2011 and 2012, causing a tragic loss of over 30 lives and considerable damage to multiple homes and businesses. The impact of the flood was observed in at least 33 of the 36 states of the country, mainly caused by intense rainfall leading to loss of life and substantial damage inflicted on properties valued at billions of naira (UNCHA, 2012).

Furthermore, Guha-Sapir *et al*. (2012) highlighted in the International Disaster Database for Nigeria that the 2012 flooding event had a significant impact, affecting approximately 7,800,867 lives, with 363 fatalities, and causing an estimated economic damage of approximately $500,000.

Similarly, Kogi State has experienced a succession of flooding incidents that have resulted in significant damage to life properties, farmland, and livestock of billions of naira (Ojigi *et al*., 2013), particularly those residing close to rivers such as Niger and Benue, prompting the participation of various humanitarian organizations, including the National Emergency Management Agency (NEMA), the Red Cross, and other notable NGOs.

Managing flood risk plays a critical role in implementing measures to mitigate the effects and dangers associated with flooding, such as providing early warning systems to people who may be affected, responding promptly to control the flood, and minimizing the adverse impacts of such events that serve as a significant factor to consider for early mitigation practices (Tehrany *et al*., 2013; Kazakis *et al*., 2015).

In their study, Oriola and Chibuike (2016) focused their flood risk assessment on four primary components: Hazard Exposure, vulnerability, and performance, which provides the basis for many flood risk methodologies and evaluations, is characterized by assessing the magnitude of floods associated with various conditions relying on many data and elements, including rainfall, water runoff, socioeconomic factors, and hydrometeorological characteristics of the water body in the area of interest.

Geospatial technology has become essential to mapping flood vulnerabilities worldwide; Researchers such as Behanzin et al. (2016) and Ikirri *et al*. (2022) believe that satellite remote sensing and GIS approaches, along with the analytical hierarchical process (AHP), help assess flood risk and vulnerability, particularly in areas with obsolete data.

This choice of Multi-Influence Factor (MIF) was made due to the scarcity of historical and current flood occurrence data, which can be attributed to a lack of diligent record-keeping practices within the country, and the motivation for this research was prompted by observing the significant and terrible consequences of flooding in Kogi State in 2022, despite the provision and investment of significant sums of financing geared toward its mitigation and effective management.

Methodology

Description of the Study Area

The Kogi state is located in the north-central region of Nigeria, between latitude $6^{o}30'$ and $8^{o}45'$ and longitude $5^{o}20'$ and $7^{o}53'$; the total land area of the state is about 75,000 Km^2, out of which rivers and streams occupy 3,750 Km^2, 3,250 Km^2 of hills and mountains, and the rest of the land is primarily used for agricultural purposes (Ibitoye, 2006).

The state shares borders with Nassarawa state in the northeast, Benue state in the east, Enugu, Anambra, and Delta states in the south, Ondo, Ekiti, and Kwara states in the west, and Niger and Abuja states in the north. The climate of Kogi State is characterized by a wet and dry climate, with an annual rainfall of 1016mm to 1524mm, of which 90% occurs between April and October, and a mean annual temperature of $27.7^{o}C$ (Ifatimehin *et al*., 2009).

Based on the NPC and NBS reports, the state's population was approximately 3,314,043 individuals, with 1,672,9.3 males and 1,641,140 females, as recorded during the 2006 National Population Census and projected to be approximately 6 million as of 2023. Notably, research indicates that most of the population, approximately 70%, resides in rural areas highlighting the heterogeneity of the ethnic groups that constitute the entire state, namely, Igala (40.93%), Ebira (34.93%), Yoruba (10.73%), Nupe (4.85%), and Bassa Komo (4.07%). (Ibitoye, 2006).

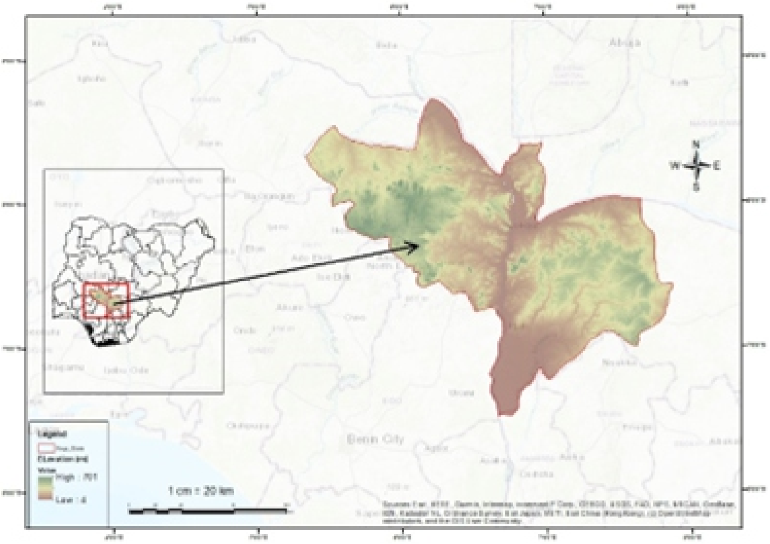

Figure 1: Map of the Kogi state (Source: Author, 2024).

Materials and Methods

Overview

The study utilized several datasets, including Landsat 8 imagery, SRTM, rainfall data, FAO/UNESCO soil data, and the Road and River shapefile. Table 1 contains detailed information on all data sets.

Table 1: Geospatial Data and Their Sources

S/N	Dataset	Scale/Resolution	Source	Coordinate system	Acquisition date
1.	SRTM DEM	30 m	United State Geological Survey (USGS) https://earthexplorer.usgs.gov/	GCE – WGS 84	2014
2.	Rainfall Data	0.25° x 0.25°	University of California Centre for Hydrometeorology and Remote Sensing (UCI CHRS) data https://chrsdata.en.uci.edu	GCE – WGS 84	2022
3.	Soil data	1:500,000	FAO / UNESCO Soil Map of the World / FAO Soil Portal		1961
4.	Landsat 8 Imagery (OLI)	30 m	United State Geological Survey (USGS) https://earthexplorer.usgs.gov/	GCE – WGS 84	2022
5.	Road and River Shapefile		DIVAS-GIS Shapefile https://www.diva-gis.org/gdata	UTM 32N	

This study used nine different thematic map layers, including the topographic wetness index (TWI), elevation, slope, rainfall, soil type, land cover, distance from river, distance from road, and drainage density which were produced by applying RS and GIS technology. LULC classification was performed using ERDAS IMAGINE software in conjunction with Google Earth images for validation.

Figure 2 presents a comprehensive description of the research methodology. The hydrology tool within the ArcGIS environment was used to extract the drainage lines from the SRTM Digital Elevation Model and the density tool was further used to derive the drainage density of the extracted drainage lines. The geology and soil type of the study area was extracted from the shapefile and converted to raster to be easy to work with, and this was done using the ArcGIS software.

Annual rainfall data for the 2022 raster dataset was converted into a point feature within the ArcGIS environment using the raster conversion tools before kriged using the interpolation tool to convert the gotten points into the final rainfall raster, and lastly, the distance maps for the river and road networks were generated using the Euclidean tool.

The flood vulnerability zonation maps, which provide the ultimate physical representation of the flood risk zones, were produced using the flood risk potential index, the AHP, and the MIF model, which was used to score thematic layers.

Figure 2: Methodology flow chart (Source: Author, 2024).

Weighting of Thematic Layers using AHP and MIF

The Analytic Hierarchical Process (AHP) has emerged as a significant model for assessing flood vulnerability zones globally, integrating GIS and RS effectively used based on expertise and offers a semiquantitative approach to decision making, providing valuable support to decision making and a method for making value-based judgements (Ouma & Tateishi, 2014; Alimi *et al*., 2022).

On the other hand, the Multi-Influence Factor (MIF) technique has a significant ability to assign weights to multiple contributing elements, taking into account the corresponding degree of influence on flood vulnerability or flood activity (Sar *et al*., 2015; Ic *et* al., 2017). According to Das and Pardeshi (2018), this knowledge of MIF requires recognising and evaluating the relationships among many elements believed to contribute to flooding, considering their mutual interaction and influence.

Figure 3 illustrates the link between flood contributing factors through major and minor lines, which accurately represent the type of influence that decides the highest and lowest ranks. The cumulative value of both major and minor influence is scored 2.0 and 1.0, respectively, while the weights are further implemented using the mathematical equation presented by Maghesh (2012) and Das and Pardeshi (2018) as presented in Equ. 1 for the relative weights, which are then used to determine the percentage score of each contributing factor.

$$Z_i = \left[\frac{X_j + Y_i}{\Sigma\,(X_j + Y_i)}\right] \times 100 \quad \text{...}(1)$$

where

X = Major interrelationship between two factors

Y = minor interrelationship between two factors

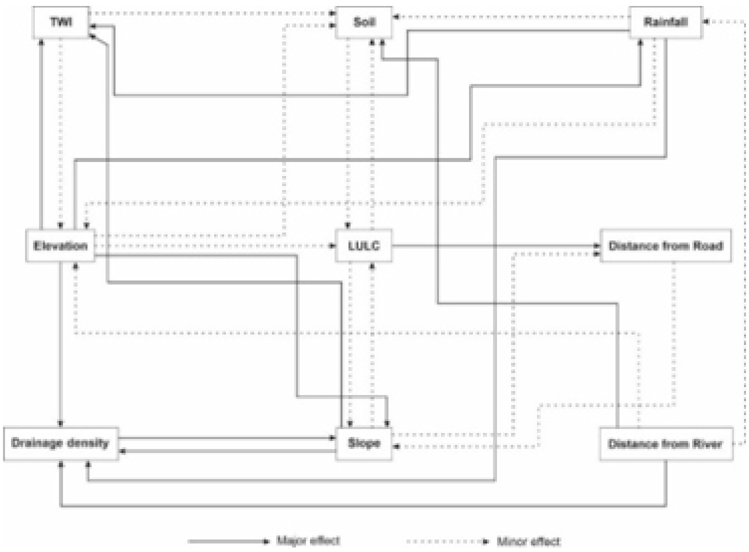

Figure 3: Interrelationship between factors (Source: Author, 2024)

Table 2: MIF influence factor score

Factors	X_j	Y_i	$X_j + Y_i$	Z_i
TWI	0	2	2	6
Elevation	8	2	10	27
Drainage density	2	0	2	5
Soil	0	2	2	5
LULC	2	2	4	11
Slope	2	2	4	11
Rainfall	4	2	6	16
Dist. By road	0	1	1	3
Dist. From the river	4	2	6	16
Total			**37**	**100**

X_j – Major effect, Y_i – Minor effect, Z_i – Proposed Score of each factor.

Delineation of Flood Vulnerability Zones

After successfully generating the thematic maps identified as contributing to flood vulnerability mapping, the thematic layers were reclassified into five major classes (Very Low, Low, Moderate, High, and Very High) to have a uniform class across the layers for proper overlay analysis in ArcGIS environment. Equation 1 was used to generate the final flood vulnerability zone after performing a weighted overlay analysis in the ArcGIS environment. The flood vulnerability zone mapping equation used to produce the final flood map according to Vignesh *et al*., (2021) is presented below;

Flood vulnerability zone (FVZM) = $\Sigma_{i=1}^{n} W_i X_j$ ……………………………..…… (2)

where

$\mathbf{W}_i$ = % weight for each thematic map layer and $\mathbf{X}_j$= reclassified map rating class

Table 3: Pairwise comparison matrix

Factors	TWI	E	S	R	L	DR	DRD	DD	ST
TWI	**1**	1	1	1	3	5	1	3	1
E	1	**1**	1	1	2	3	1	3	1
S	1	1	**1**	1	3	1	2	1	1
R	1	1	1	**1**	3	2	2	3	1
L	1/3	½	1/3	1/3	**1**	1	1/3	1	1
DR	1/5	1/3	1	½	1	**1**	1/5	1	1
DRD	1	1	½	½	3	5	**1**	3	1
DD	1/3	1/3	1	1/3	1	1	1/3	**1**	1
ST	1	1	1	1	1	1	1	1	**1**

TWI - topographic wetness index, E - elevation, S - slope, R - rainfall, L - land cover, DR - distance from river, DRD - distance from road, DD - drainage density, ST - soil type.

Results and Discussion

This research work has employed nine different flood triggering factors through proper analysis and reclassification; they were presented and further analysed to map flood vulnerability zones in Kogi State. The final result of the flood vulnerability zones was generated for the two models considered after all thematic layers were weighted according to their level of influence.

Thematic layers of flood vulnerability zone mapping contributing factors

TWI: this is a means of forecasting the amount of moisture in the soil; areas with higher TWI are likely to be wetter relative to areas with lower moisture values. Thus, in Figure 4a, the linear characteristics with the highest TWI are likely to be drainage, while those with the lowest TWI are roads and other footprints. The TWI was generated using Equation (3) as established by Beven & Kirkby (1979).

Topographic Wetness Index (TWI) = ln ($\frac{\alpha}{\tan \beta}$) ……………………………………………….. (3)

Where;

$\boldsymbol{\alpha}$ = cumulative drainage of the upslope area through a point (per unit contour length), and

$\boldsymbol{\beta}$ = slope angle at the point.

Elevation: Elevation significantly controls the possibility of floods, as water flows from high to low altitudes, and places with lower altitudes are more vulnerable to floods than those with higher elevations. Various scientists (Cao *et al*., 2016; Eguaroje *et al*., 2015; Burayu *et al*., 2023) have effectively established this notion, making elevation a critical aspect of flood mapping, and Figure 4c gives a proper display of the elevation range within the entire study area.

Slope: The slope is a representation of the the surface steepness and in many cases helps to determine the direction of the the water runoff,, and Figure 4b illustrates the slope characteristics of the study area according to their contribution to flooding (Epuh et al., 2020a, b).

Rainfall: Precipitation, especially rainfall, is a significant factor in floods, determining the intensity, timing, and scope of the floods. Understanding the link between precipitation patterns and flood dynamics is critical to successful flood risk management and disaster preparedness.

Land Use Land Cover (LULC): LULC data are significant for understanding land use, hydrology, and flood interactions. Incorporating it into flood risk assessment, hydrological modelling, urban planning, and natural resource management can help mitigate impacts and promote sustainable practices.

Distance from River Map: Flooding hazards are affected by variables such as the distance from the river, which has the potential to overflow and inundate surrounding areas. To quantify this risk, a river shapefile of the research area was acquired and buffered to produce a density line map that illustrates the five classification categories.

Distance from the Road Map: The distance from the road influences the risk of flooding, but it is less relevant than the proximity to a river or water body. Properties near highways, particularly those at lower elevations, may be more vulnerable to surface runoff after heavy rain or due to road barriers that channel water into neighbouring regions.

Drainage Density Map: Drainage density is critical for flood mapping, risk assessment, and hydrological modelling, as lower values result in less water discharge and more severe conditions (Atijosan *et al*., 2021; Salvam *et al*., 2023).

Soil Map: Soil types have an important influence on floods by altering infiltration rates, runoff creation, and soil's ability to hold onto water.

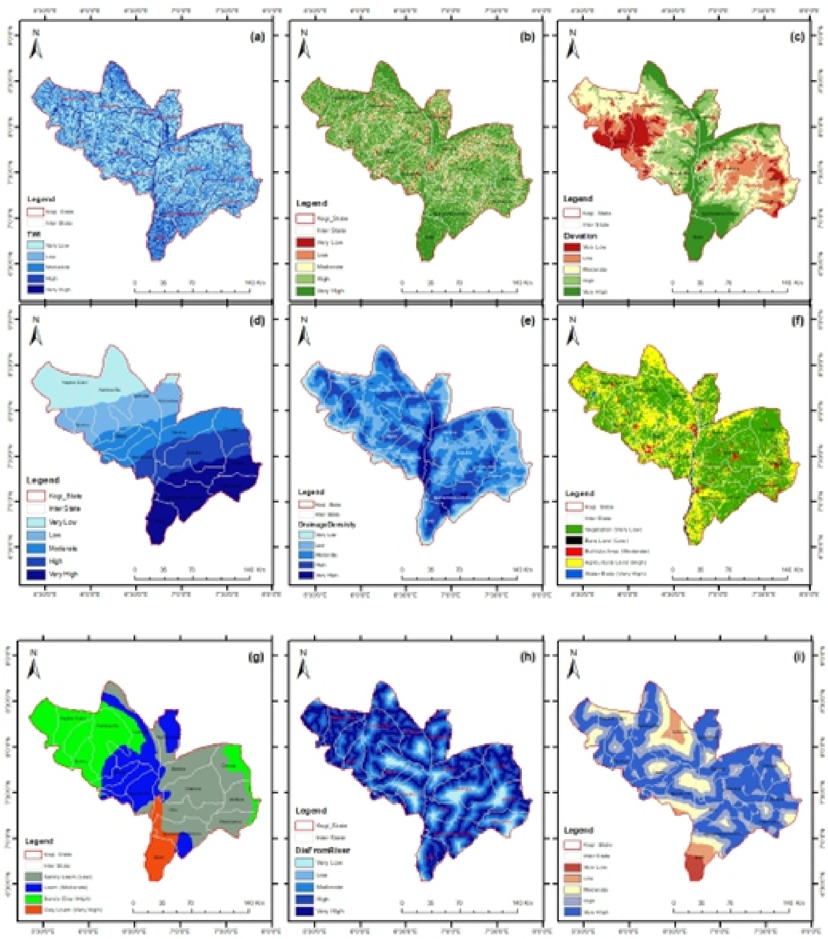

Figure 4: (a) Topographic wetness index, (b) slope, (c) elevation, (d) rainfall, (e) drainage density, (f) LULC, (g) soil type, (h) distance from river, (i) distance from road.

Final Flood Vulnerability Zone Maps.

The results of the final flood vulnerability zone map generated for both the AHP and MIF models categorized Kogi State into four main zones, namely, Low, Moderate, High, and Very high (Mandal *et al*., 2023; Rajagopalasingam *et al*., 2023) The result shows a slight change between the two models considered, which are AHP and MIF; the models predict the vulnerability zones, each with their spatial extent coverage as presented in Table 2. The results revealed that there are high to very high flood vulnerable zones in the southern part of the state and other regions along the course of the Niger and Benue rivers, which have the following local government areas such as Idah, Igalamela-odola, Ibaji and parts of Okehi, Adavi, Lokoja, Kotonkar, Basa, Omala and Ofu that are affected.

The study also reveals that Yagba west, Yagba east, Mopa-Muro, Kabba/Bu, Dekina, Ankpa, Olamabor falls into the regions of moderate flood vulnerability zone and many parts of the State were revealed from the analysis to occupy the low flood vulnerability zones. However, moderately vulnerable zones occupy the highest percentage of the results obtained from the AHP and MIF models.

As reported by Umaru and Adedokun (2020), flood and flooding activities are more prominent primarily in riverine areas, which supports the results of this analysis, where communities along the course of the Niger and Benue rivers tend to be highly venerable to flood over the years.

This also collaborates with the findings of (Ozim *et al*., 2021 and Umaru & Adedokun, 2020), suggesting that most communities or regions located on the upland of Kogi State are not found to be vulnerable to flooding compared to those located in the low land area and river areas. And it can conclude from the results of the analysis that the MIF model gives a better result and predicts more area coverage in terms of vulnerability, especially for the high and very high regions compared to the AHP model, and this can be evident from the influence that exists between the factors.

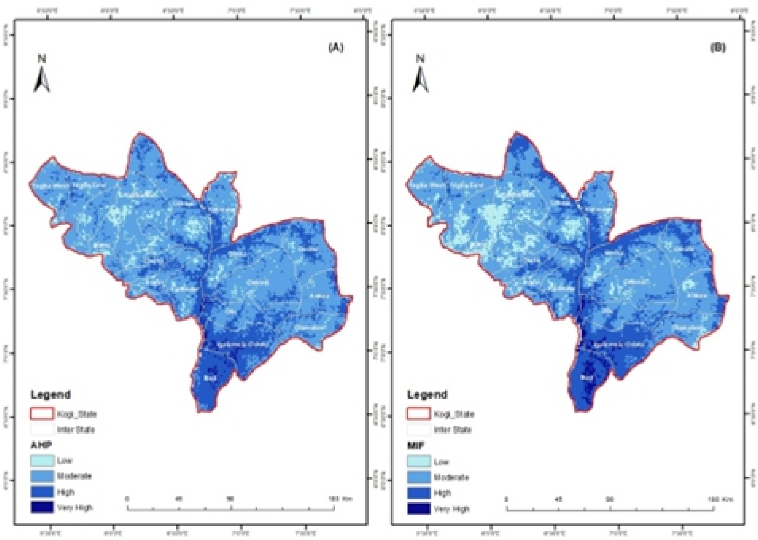

Figure 5: Flood vulnerability zones of Kogi state (A) AHP model map, (B) MIF model map.

Table 2: Flood vulnerability zones: Area and percentage distribution.

Vulnerability Level	Vulnerability Index	Area (Km^2)		Area (%)	
		AHP	MIF	AHP	MIF
Low	2	894.79	2818.75	3.09	9.75
Moderate	3	19832.33	1732.5	68.56	59.91
High	4	8010.04	8147.85	27.69	28.17
Very high	5	190.08	631.17	0.66	2.18

Conclusion

Geographic Information Systems (GIS) and Remote Sensing (RS) are extremely valuable in evolving technology, exhibiting their usefulness across numerous disciplines and greatly assisting decision making over time. Specifically, various experts and decision makers have attested to the effectiveness of GIS and RS in flood mapping.

The research findings revealed a significant propensity for flooding in the state's southern region, notably along the tributaries of the Niger and Benue rivers, identifying these regions as high and very high flood risk zones.

These research findings are significant because they can serve as a standard or guide for decision makers in developing successful measures to reduce future floods in the region. This eye-opening findings highlight the importance of proactive flood control and mitigation measures. Using GIS and RS to map flood vulnerabilities is critical, leveraging technical improvements and providing a cost-effective solution to the problem.

Additionally, proper management of the river basin and drainage to reduce the intensity of flooding and its vulnerability in Kogi state because most of the flooding events in Kogi state are not always due to heavy rainfall, but also to the release of water from the surrounding dam.

Additionally, the state government should push the collaboration of related departments such as Urban Planning, Environment, Agriculture, and Forestry to adequately plan a sustainable development plan for the identified areas likely prone to high flood events to properly implement a lasting solution to flood and flooding activities within the state.

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