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GIS-BASED MULTI-CRITERIA DECISION ANALYSIS FOR FLOOD RISK ASSESSMENT AND MITIGATION IN URBANIZING AREAS: A CASE STUDY OF ILORIN WEST, NIGERIA

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ABSTRACT

This study addresses flood vulnerability in the rapidly urbanizing Ilorin West Local Government Area, Nigeria, through a GIS-based Multi-Criteria Decision Analysis (MCDA) approach for flood risk assessment and mitigation. Integrating key spatial factors, including distance from river channels, rainfall intensity, elevation, slope, and land use/land cover, MCDA employs a weighted overlay technique to generate a detailed flood susceptibility map. The Analytical Hierarchy Process (AHP) was utilized to assign objective weights to each criterion based on expert judgment, ensuring the robust prioritization of flood risk factors. The resulting map classifies the area into four risk categories: very high, high, moderate, and low. Findings show that 1.8% of the area, encompassing neighborhoods like Alanamu and Oloje, falls under very high flood risk, while 35.6% and 26.6% are categorized as high and moderate risk, respectively. Flood vulnerability is predominantly concentrated in low-lying riverside communities characterized by impervious surfaces and inadequate drainage. This research demonstrates the effectiveness of GIS-based MCDA as a decision-support tool for urban planners, emergency responders, and policymakers in flood risk mitigation and sustainable urban development. The study's outcomes align with Sustainable Development Goals 11 and 13, offering a replicable framework for flood risk management in urbanizing regions across sub-Saharan Africa.

KEYWORDS: *Flood, Risk, GIS, Remote sensing, AHP, Weighted overlay*

1. INTRODUCTION

Flooding represents one of the most pervasive and destructive environmental hazards worldwide, posing significant threats to human life, infrastructure, and socio-economic stability (Manzoor, Ehsan, Khan, Manzoor, Akhter, Sohail, ., ... & Abioui, 2022). Urbanizing areas, characterized by rapid population growth and dynamic land use changes, are especially vulnerable to flood risks due to increased impervious surfaces, inadequate drainage infrastructure, and altered natural hydrological processes (Feng, Zhang, & Bourke, 2021; Beshir, & Song, 2021). In such contexts, effective flood risk assessment and mitigation strategies are critical to safeguarding communities and promoting sustainable urban development (Hemmati, Ellingwood, & Mahmoud, 2020).

Ilorin West Local Government Area in Nigeria exemplifies these challenges. As part of the rapidly expanding Ilorin metropolis, it faces increased flood vulnerability driven by its low-lying topography, proximity to river channels, and intensifying seasonal rainfall patterns. Recent flood events have caused widespread damage, displacement, and socio-economic disruption, exacerbated by poorly planned urban growth and blocked drainage systems (Figure 1) (Abdulrosheed, 2019; Nigeria Hydrological Services Agency (NIHSA), 2023). Despite these pressing issues, detailed and up-to-date flood risk assessments tailored to the unique urban and hydrological characteristics of Ilorin West remain limited.

Geographic Information Systems (GIS)-based Multi-Criteria Decision Analysis (MCDA) offers a powerful framework for addressing this gap by integrating diverse spatial datasets and expert knowledge to assess flood risk systematically (Kurniawan, Sunardi, Hendarmawan, & Ridwansyah, 2024). Through the application of hierarchical weighting methods, such as the Analytical Hierarchy Process (AHP), MCDA enables objective prioritization of flood-influencing factors, including distance to rivers, rainfall intensity, terrain elevation, slope, land use, and soil characteristics in highly urbanized settings. This approach enhances the accuracy and reliability of flood susceptibility mapping and supports evidence-based mitigation planning.

Integration of GIS and MCDA has proven effective in flood risk assessments, facilitating proactive urban flood management and disaster resilience (Papaioannou, Vasiliades, & Loukas, 2015; Domakinis, 2020). However, the application of these methodologies to fast-growing Nigerian cities like Ilorin West remains underdeveloped, limiting the capacity of local authorities to implement targeted flood mitigation and urban planning policies. This study focuses on applying GIS-based MCDA coupled with AHP weighting to assess and map flood risk in Ilorin West. By incorporating spatial analysis of key flood determinants and generating a detailed flood susceptibility map, the research aims to inform urban planners, policymakers, and emergency responders. The overarching goal is to promote sustainable flood risk mitigation and enhance urban resilience to flooding in Ilorin West, aligning with global commitments to Sustainable Development Goals (SDGs) 11—Sustainable Cities and Communities—and 13—Climate Action.

Figure 1: Aerial photograph of the submerged area in Ilorin. (Abdulrosheed, 2019)

2. MATERIALS AND METHODS

2.1 Study Area

Ilorin West Local Government Area (LGA) is one of sixteen LGAs in Kwara State, situated in north-central Nigeria between latitudes 8°23'52"–8°34'32"N and longitudes 4°28'37"–4°36'01"E. With 2.6% annual population change [2006 → 2022], it covers approximately 103.5 km² Area. It has a projected population of 548,300 as per the 2006 census with 5,298/km² population density (Citypopulation, 2022). The LGA comprises twelve electoral wards, including Adewole, Alanamu, and Oloje. As part of the Ilorin metropolis, the capital of Kwara State, Ilorin West is a key socio-economic hub characterized by diverse residential, commercial, and institutional land uses and notable infrastructure such as the Kwara State Stadium. Rapid urbanization and population growth have heightened demand for housing, sanitation, and flood management services. The LGA borders Asa and Moro LGAs and forms an integral part of the broader Ilorin metropolitan area (Wikipedia contributors, 2025). Figure 2 provides a detailed map of its spatial extent and administrative wards.

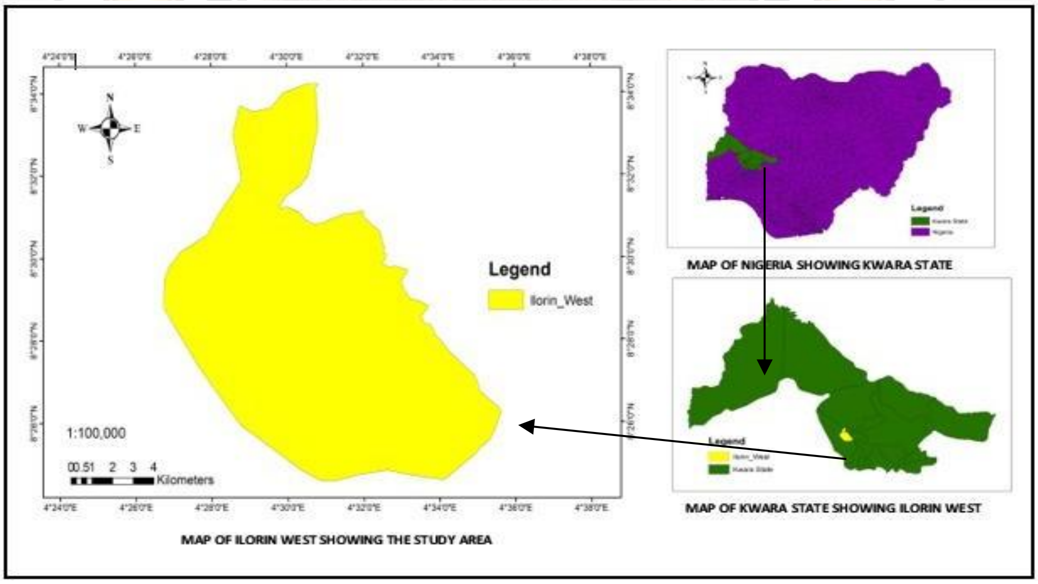

Figure 2: Map of Ilorin West Local Government

2.2 Methods

This study employs a Geographic Information System (GIS)-based Multi-Criteria Evaluation (MCE) approach to develop a detailed flood-prone area map for Ilorin West Local Government Area. The methodology integrates various geospatial datasets representing key flood-influencing factors, which are combined and analyzed to delineate flood susceptibility zones.

2.2.1 Data Acquisition and Sources

Multiple spatial datasets were acquired to capture the physical and environmental variables that contribute to flood risk. Table 1 summarizes the data types, their sources, and relevant characteristics used in the analysis

Table 1: Data types. Their sources and relevance characteristics

S/N	Data	Description	Source / Provider
1	Digital Elevation Model (DEM)	Elevation data used for terrain and slope analysis	Shuttle Radar Topography Mission (SRTM) via USGS
2	Sentinel-2A Satellite Imagery	Multispectral imagery used for land use/land cover classification	Copernicus Open Access Hub
3	Elevation	Derived from the DEM for flood risk modeling	Processed from SRTM DEM
4	Slope	Derived from DEM to assess terrain steepness and runoff potential	Processed from SRTM DEM
5	Rainfall Data	Historical rainfall intensity data for precipitation analysis	http://www.worldclimate.com
6	Land Use / Land Cover (LULC)	Classified from Sentinel-2A imagery to represent surface cover types	Processed from Sentinel-2A imagery
7	Ilorin West Local Government Boundary	Administrative boundary shapefile for study area delimitation	Surveyor General's Office, Kwara State

2.2.2 Analytical Framework

The GIS-MCE method involves the following key steps.

Data Preprocessing

All spatial datasets were projected to a common coordinate system and clipped to the study area boundary. DEM data were processed to derive slope maps, while LULC was classified into relevant categories influencing flood risk.

Criteria Selection

Based on literature and expert consultation (Udo, Etim, & Akpan, 2021; Ajayi, Oladipo, & Akinyemi, 2023), five criteria were selected for their significant influence on flood susceptibility: elevation, slope, rainfall intensity, land use/land cover, and distance from river channels.

Weight Assignment Using AHP

The Analytical Hierarchy Process (AHP) was utilized to assign weights to flood risk criteria, accurately reflecting each factor's influence. AHP is a robust multi-criteria decision-making method that systematically evaluates and integrates qualitative and quantitative factors through pairwise comparisons, enabling objective prioritization based on expert judgment and data (Saaty, 1980; Emmanuel, Baywood & Gift, 2015). Weight assignments rely on expert knowledge, literature, and analytical validation. For example, Njoku *et al*. (2018) prioritized proximity to rivers, while Samanta, Koloa, Pal & Palsamanta (2016) emphasized slope over river distance. In this study, reconnaissance surveys and secondary data highlighted that flooding mainly occurs during the rainy season in low-lying areas, emphasizing elevation and river proximity as key factors. By combining expert insights with empirical evidence through AHP, the research achieves a balanced, context-specific weighting scheme, enhancing the accuracy and reliability of the flood susceptibility assessment.

Standardization and Reclassification

Each criterion layer was reclassified into standardized flood risk classes, typically ranging from 1 to 5, to enable consistent integration during analysis. Using the Natural Breaks (Jenks) method in ArcGIS, each parameter was initially divided into five classes to capture natural variations in flood susceptibility across the study area (Njoku *et al*., 2018). An inverse ranking scheme was then applied based on each class's relative significance to flooding: the class with the lowest flood risk received a value of 1, increasing incrementally to 5 for the highest risk class. This approach ensures parameter values accurately reflect their contribution to flood vulnerability and support a meaningful weighted overlay.

For example, elevation was classified into five ranges from 264 to 366 meters. Lower elevations, more prone to flooding, were assigned a value of 5, while higher elevations received a value of 1. Similarly, slope classes ranged from 0% to 19.026%, with flatter areas (0–1.642%) given the highest susceptibility value of 5 due to slower runoff and water accumulation. Steeper slopes (5.894–19.026%) were assigned 1, indicating lower flood risk attributable to rapid drainage (Njoku *et al*., 2018; Environmental Systems Research Institute (ESRI), 2024).

This reclassification and inverse ranking process was systematically applied to all parameters, including rainfall intensity, land use/land cover, soil type, and river proximity, ensuring flood risk values truly represent their influence. Finally, these values were aggregated into broader high- and low-risk indices to generate a comprehensive composite flood susceptibility map.

2.3 Weighted Overlay Analysis

A weighted overlay analysis in GIS combined the reclassified raster layers of each criterion, multiplying each by its respective AHP-derived weight. The weighted layers were combined using GIS's Weighted Overlay tool. The sum of these weighted layers produced a composite flood risk map that integrates diverse datasets into a single, interpretable output reflecting the overall flood vulnerability. This map categorizes the study area into risk zones ranging from low to very high flood risk.

2.4 Validation

The accuracy of the flood susceptibility map was validated using a combination of historical flood occurrence records and insights from local experts familiar with the area's flood dynamics (Olabode, Ajibade, & Yinusa, 2014; NIHSA, 2023). Historical data on past flood events, including locations and severity, were compared against the mapped high-risk zones to assess spatial correspondence. Additionally, consultations with community leaders, urban planners, and disaster management officials provided qualitative validation by confirming known flood-prone neighborhoods and the timing of recurrent flooding during the rainy season. This dual validation approach ensured that the flood susceptibility map reliably reflects actual flood patterns in Ilorin West, enhancing its utility for planning and risk mitigation efforts.

3. RESULTS AND DISCUSSION

3.1 Thematic Layers for Flood Susceptibility Analysis

The spatial distribution of key flood-influencing factors in Ilorin West reveals distinct patterns relevant to flood risk assessment. Distance from river channels (Figure 3a) highlights that areas closest to rivers are critical zones for flood susceptibility. Rainfall intensity (Figure 3b) shows spatial variability, indicating that some parts receive heavier precipitation, contributing directly to flood potential. Elevation (Figure 3c) and slope (Figure 3d) maps illustrate the terrain's vertical and incline characteristics, affecting runoff and water accumulation.

The land use/land cover (LULC) classification (Figure 3e) reveals that bare earth (45.31%) and built-up areas (26.93%) dominate the landscape, contributing to impervious surfaces that exacerbate flood risk by reducing infiltration and increasing runoff. Vegetation covers 26.09% and water bodies 1.66%, both playing contrasting roles in mitigating flood vulnerability through enhanced infiltration and water storage capacity.

These foundational layers form the basis of the multi-criteria evaluation, integrating diverse factors to assess flood risk comprehensively.

Table 2: Attribute table of the land use classes

FID	Class	Area	Percentage (%)
0	Bare earth	6751.826	45.31
1	Built-up	4012.776	26.93
2	Vegetation	3887.338	26.09
3	Water	248.0102	1.66
Total		**14,899.95**	

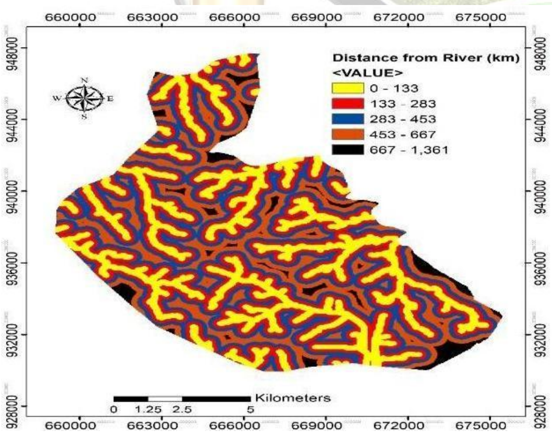

Figure 3a: Distance from river

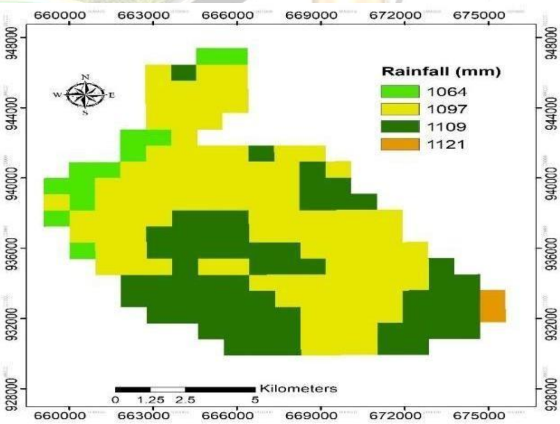

Figure 3b: Rainfall layer

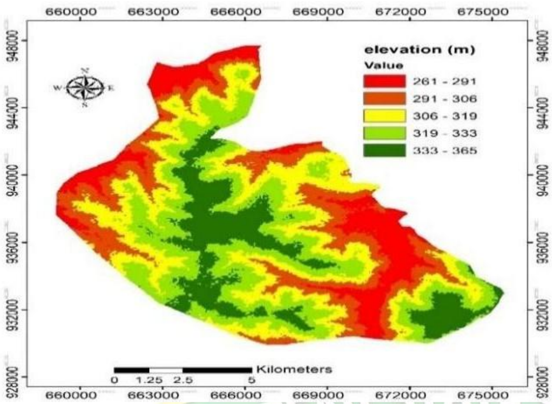

Figure 3c: Elevation layer

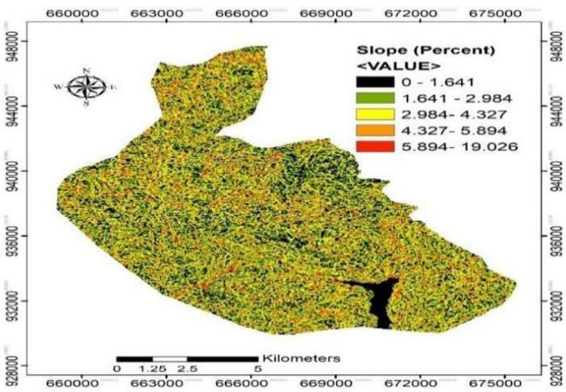

Figure 3d: Slope layer

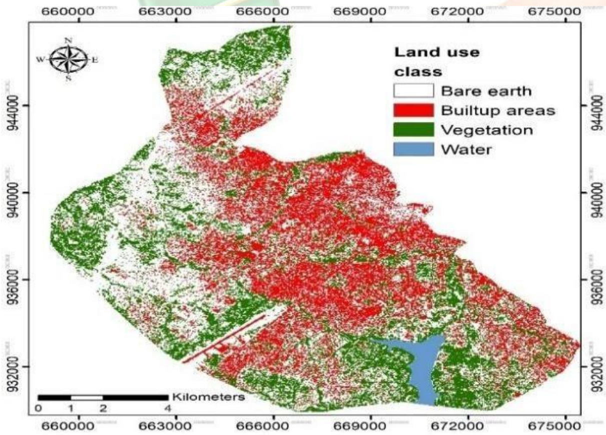

Figure 3e: Land use/land cover

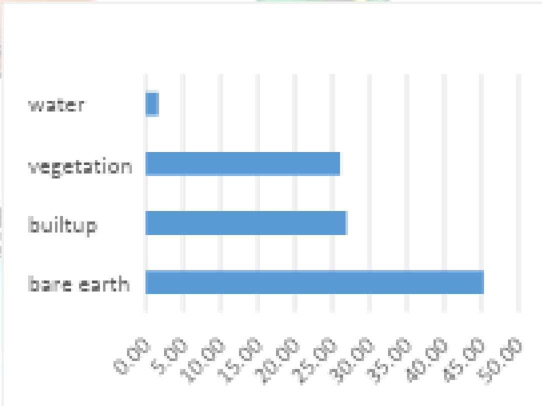

Figure 3f: Area coverage of Land use/Land cover

3.2 Reclassified Flood Susceptibility Factors

To ensure comparability and integration, each flood-influencing factor was reclassified into standardized risk classes using the Natural Breaks (Jenks) method. The classification assigns higher flood risk values to areas closest to rivers, lower elevations, flatter slopes, higher rainfall intensity, and vulnerable land cover types such as built-up and bare earth.

This reclassification, shown in Figures 3g to 3k, allows for meaningful integration via weighted overlay analysis. Assigning inverse rankings reflecting flood susceptibility ensures that the retrieved values reflect the true contribution of each factor to flood risk.

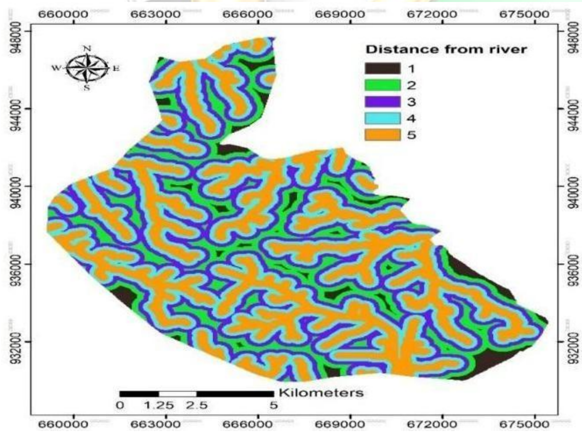

Figure 3g: Distance from river reclass

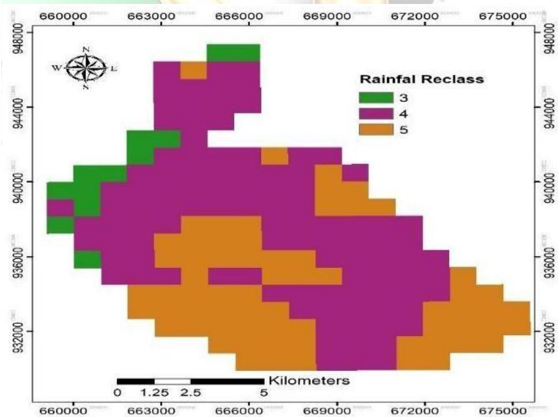

Figure 3h: Rainfall reclass

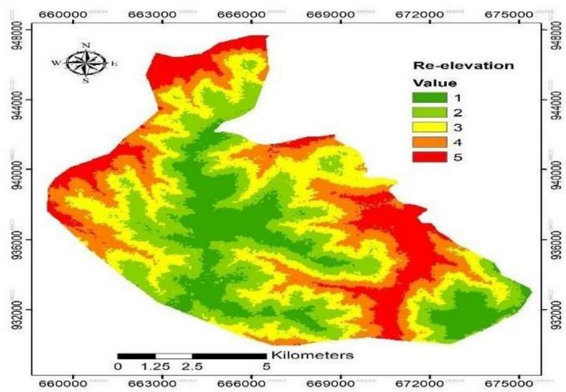

Figure 3i: Elevation reclass

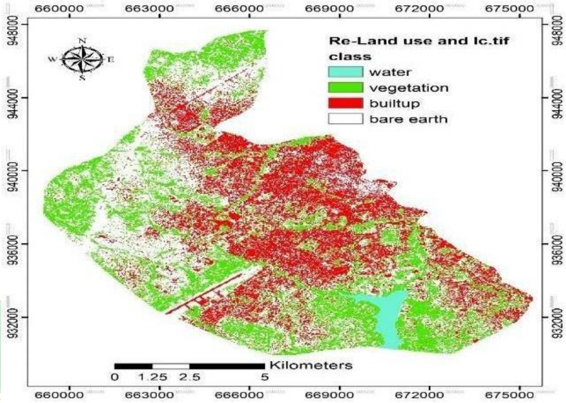

Figure 3j: Land use/land cover reclass

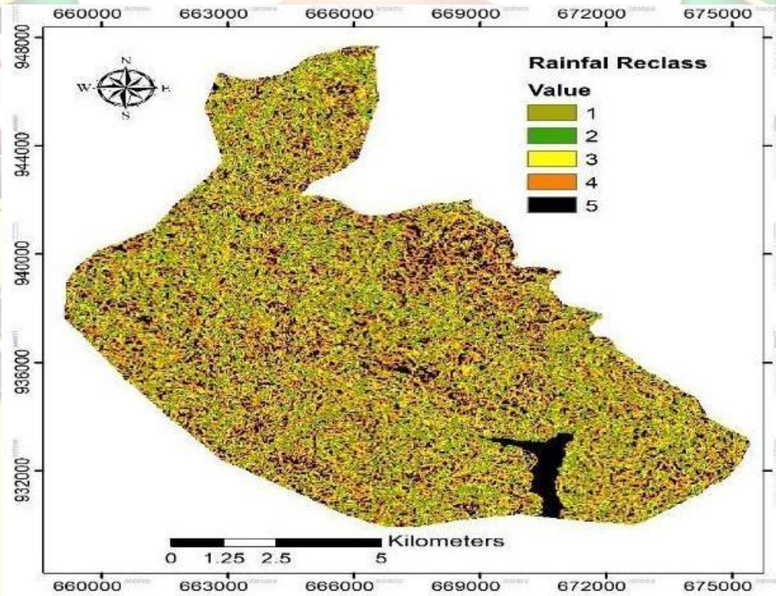

Figure 3k: Slope reclass

3.3 Weighting of Flood Risk Criteria Using AHP

Pairwise comparison through the Analytical Hierarchy Process (AHP) determined the relative importance of each flood susceptibility criterion (Table 3). Rainfall intensity emerged as the most influential factor, with a weight of 43.9%, emphasizing its dominant role in flood occurrence in Ilorin West. Land use/land cover followed with 29.8%, underscoring the impact of urbanization and surface permeability on runoff.

Slope (12.3%) and elevation (9.5%) also significantly affected flood risk, accounting for terrain characteristics that influence water flow and accumulation. Distance to streams held the lowest weight (4.5%), indicating that in this urbanizing context, proximity to water bodies is less critical than other factors like rainfall and land cover.

This weighting reflects a balanced approach combining expert judgment, empirical data, and field reconnaissance, ensuring contextual relevance for flood risk modeling. This prioritization aligns with findings from Njoku *et al*. (2018), who similarly emphasized rainfall and land use as critical factors in flood risk assessment, though weights can vary depending on local conditions and study focus (Samanta *et al*., 2016).

Table 3: AHP results from pairwise comparison

Category	Priority (%)	Rank
Rainfall	43.9	1
Land Use/Land Cover	29.8	2
Slope	12.3	3
Elevation	9.5	4
Distance to Stream	4.5	5

3.4 Flood Susceptibility Mapping and Spatial Patterns

The weighted overlay analysis produced a detailed flood susceptibility map categorizing Ilorin West into four risk zones: low, moderate, high, and very high flood risk (Figures 4 and 5). Spatially, high and very high-risk zones cluster around low-lying, riverside neighborhoods such as Alanamu, Oloje, and Wara-Osin, which are frequently inundated during heavy rainfall.

Quantitatively, about 1.8% of the study area falls under very high risk, while high and moderate risk zones cover 35.6% and 26.6%, respectively. The remaining 34.2% of the area is classified as low risk, typically corresponding to upland and vegetated areas like Babagiri, where natural drainage mitigates flood impacts.

The spatial distribution concurs with hydrological and urbanization theories: the combination of high rainfall, impervious surfaces, flat terrain, and proximity to rivers drives flood vulnerability in urbanizing contexts (Feng *et al*., 2021; Mustafa, 2018).

Table 4: Area coverage of risk level zone

Risk level	Area coverage (sq. km)	Percentage (%)
Low-risk zone	51118.2	34.2
Moderate risk zone	39699.9	26.6
High-risk zone	53225.1	35.64
Very high-risk zone	2657.7	1.8

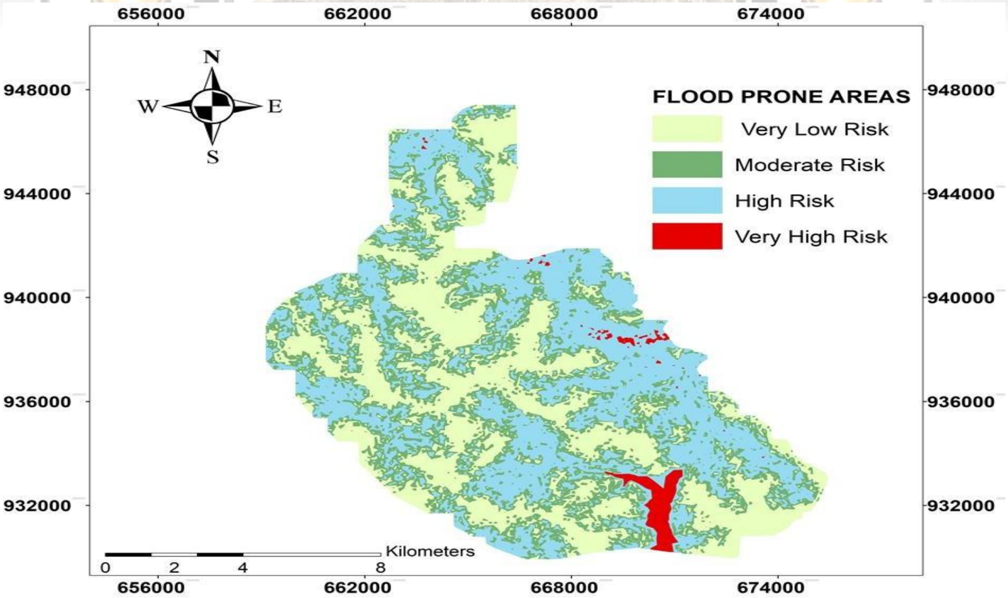

Figure 4: Flood Prone Area Map.

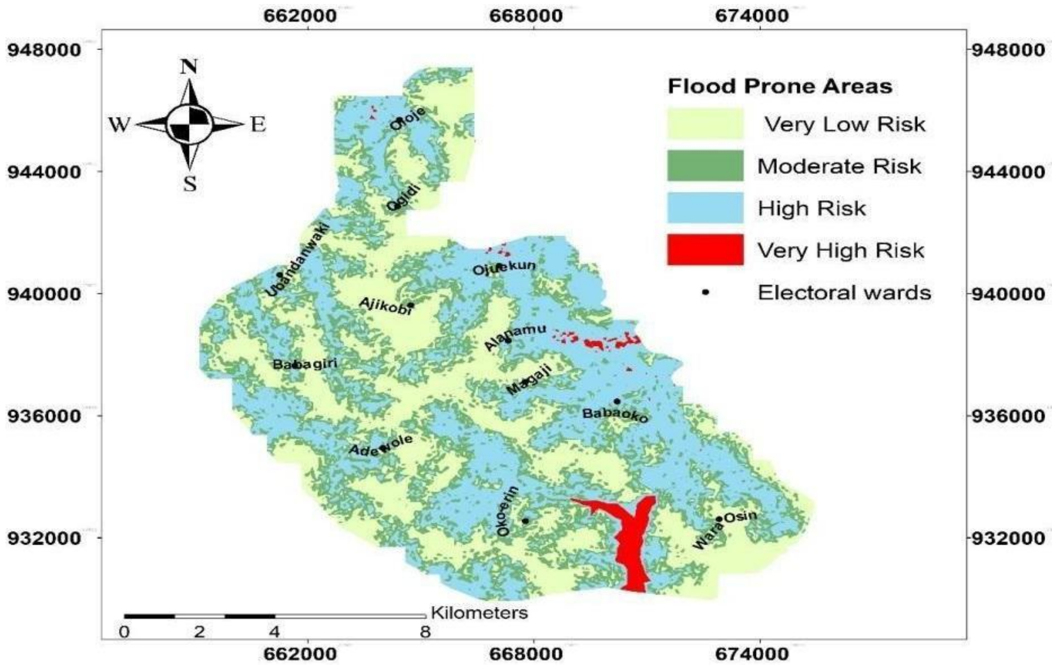

Figure 5: Flood-prone areas

3.5 The Flood Drivers and Dynamics

The results affirm that flood susceptibility in Ilorin West is controlled by a complex interaction of climatic, topographic, and anthropogenic factors. Rainfall's dominant weight reflects its direct causative link to flooding, underscoring the need for precipitation monitoring and early warning systems.

Land use/land cover's major contribution through impervious surfaces highlights the role of urban expansion in exacerbating flood risks by increasing surface runoff and reducing infiltration. This stresses the importance of sustainable urban planning and green infrastructure interventions to mitigate flood vulnerability.

Slope and elevation further influence flood dynamics by controlling runoff speed and accumulation. Flatter and lower-elevation areas tend to retain water longer, increasing flood duration and extent, while steeper slopes promote rapid drainage, lowering flood risk.

The lower priority of river proximity suggests that localized urban flooding is more strongly driven by rainfall intensity and land surface conditions than by simple distance to water bodies, a valuable insight for targeted flood management.

The identification of spatially explicit flood risk zones provides critical guidance for prioritizing flood mitigation efforts. High and very high-risk areas require urgent interventions, including drainage infrastructure upgrades, floodplain zoning, and community flood-proofing measures. The pronounced influence of land use/land cover indicates the need for integrating flood risk maps into urban land use planning to control impervious surface expansion and promote permeable landscapes.

Flood susceptibility maps also support emergency preparedness by identifying vulnerable neighborhoods for targeted early warning, evacuation planning, and public awareness campaigns, ultimately reducing flood-related losses.

Considering the dominant influence of rainfall and climate variability, integrating climate change projections into flood risk assessments is essential for future-proofing infrastructure and policies. Collectively, these findings demonstrate the utility of GIS-based MCDA as a robust decision-support tool that advances proactive, resilient flood management in rapidly urbanizing Nigerian cities like Ilorin West.

4.0 CONCLUSION

The flood-prone area map developed in this study serves as a vital tool for guiding mitigation and disaster risk reduction efforts in Ilorin West Local Government Area. It identifies high-risk and very high-risk zones, including Babaoko, Okoerin, Mogaji, Adewole, Alanamu, Oloje, Wara Osin/Egbejila, Ubandawaki, and Ojuekun, where residents are most vulnerable to flooding. The spatial analysis reveals that approximately 34% of the study area falls within low flood risk zones, 27% within moderate risk, 36% within high risk, and 2% within very high risk zones. This indicates that over half of the local government areas are susceptible to flooding to varying degrees. Given the significant proportion of flood-prone land, stakeholders must implement adequate and targeted mitigation measures to reduce flood impacts. These may include improving drainage infrastructure, enforcing land use regulations, promoting sustainable urban development, and enhancing community awareness and preparedness. By leveraging the insights from the flood susceptibility map, local authorities and planners can prioritize interventions that protect vulnerable populations and promote resilient urban growth in Ilorin West.

5. RECOMMENDATIONS AND MITIGATION MEASURES FOR FLOOD MANAGEMENT IN ILORIN WEST

Recommendations for flood management in Ilorin West include implementing structural measures such as regular dredging of the Asa River and its tributaries to increase channel capacity and reduce overflow risks, similar to practices used for the River Niger tributaries. It is also essential to construct and maintain flood control infrastructures like levees, embankments, culverts, and drainage systems to manage storm water runoff and prevent riverbank breaches. Upgrading urban drainage networks, especially in high-risk neighborhoods such as Alanamu, Oloje, and Babaoko, will facilitate rapid runoff and reduce surface flooding. Enforcing flood risk zoning and land-use regulations to restrict development within floodplains and river buffer zones, coupled with relocating vulnerable settlements to safer upland areas, is crucial. Furthermore, strengthening coordination among federal, state, and local governments, including agencies like NEMA, will enhance integrated flood risk management and emergency response. These measures will greatly reduce flood vulnerability, protect lives and property, and promote sustainable urban resilience in Ilorin West.

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