FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 10, May, 2026, pp 144 – 151
DOI: https://doi.org/10.33003/fjs-2026-1010-4586

Assessment of Flood Causative Factors Using GIS-Based Multi-Criteria Analysis for Flood Hazard and Risk Mapping in Calabar South, Nigeria

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ABSTRACT

Flooding remains one of the most recurrent environmental hazards in coastal urban areas of Nigeria, causing substantial socio-economic and infrastructural losses. Despite several flood studies conducted in Nigeria, limited attention has been given to the integration of flood hazard and exposure factors for comprehensive flood risk assessment in Calabar South Local Government Area, Cross River State. This study assessed flood causative factors using Geographic Information System (GIS)-based Multi-Criteria Analysis (MCA) and the Analytic Hierarchy Process (AHP) to produce flood hazard and flood risk maps of the study area. Spatial datasets comprising elevation, slope, flow accumulation, rainfall, land use/land cover, and population density were integrated within a GIS environment. AHP was employed to determine the relative importance of the flood conditioning factors, while weighted overlay analysis was used to generate flood hazard and flood risk indices. The results indicate that elevation (0.35) and slope (0.22) constitute the most influential flood causative factors. Approximately 58.6% of the study area falls within the high and very high flood hazard classes, whereas 35.9% is classified as high to very high flood risk. The southern and central parts of Calabar South exhibit the greatest susceptibility due to low elevation, gentle slopes, poor drainage conditions, and high population concentration. The study demonstrates the usefulness of GIS-based MCA for identifying flood-prone areas and assessing spatial flood risk in data-constrained environments. However, the results should be interpreted with caution because validation using historical flood records and hydrodynamic modeling was beyond the scope of the study. The findings provide useful information for flood mitigation, urban planning, and disaster risk management in Calabar South.

Keywords: Flood hazard, Flood risk, GIS, AHP, Multi-criteria analysis, Calabar South

INTRODUCTION

Flooding is among the most destructive natural hazards worldwide and continues to increase in both frequency and severity due to climate change, rapid urbanization, and land-use transformation. Flood disasters contribute substantially to economic losses, environmental degradation, infrastructure damage, and population displacement, particularly in rapidly growing urban areas (Ali et al., 2016; Buta et al., 2020). The occurrence and magnitude of floods are controlled by a combination of natural factors, including rainfall intensity, topography, drainage characteristics, and land cover, as well as anthropogenic influences such as urban expansion and inadequate land-use planning (Vojtek & Vojtekova, 2016; Zscheischler et al., 2018).

Contemporary flood risk assessment recognizes that flood impacts are determined not only by the physical occurrence of flooding but also by the exposure and vulnerability of populations, infrastructure, and economic assets (Birkmann et al., 2015). Consequently, effective flood management requires integrated approaches that simultaneously consider hazard conditions and socio-economic exposure to support disaster risk reduction and sustainable urban development. Advances in Geographic Information Systems (GIS) and Remote Sensing (RS) have significantly improved flood hazard assessment by enabling the integration of topographic, hydrological, climatic, and land-use datasets within spatial decision-support frameworks. These approaches are particularly valuable in data-scarce environments where conventional hydrological and hydraulic modeling is limited by inadequate monitoring infrastructure (Zebisch et al., 2018; Wenk et al., 2018). Among various spatial decision-support techniques, Multi-Criteria Analysis (MCA) has gained considerable attention because it allows multiple flood conditioning factors to be standardized, weighted, and integrated according to their relative importance (Tang et al., 2018; Sword-Daniels et al., 2018).

The Analytic Hierarchy Process (AHP) is one of the most widely applied MCA techniques for flood hazard assessment because it provides a systematic framework for pairwise comparison of factors and consistency evaluation of expert judgments (Saaty, 1990; Saaty & Vargas, 2012). When integrated with GIS, AHP facilitates the development of transparent and reproducible flood hazard maps by combining flood-related variables such as elevation, slope, rainfall, flow accumulation, and land use/land cover (Peduzzi, 2019; Lauta et al., 2018). Previous studies have demonstrated the effectiveness of GIS-based AHP approaches in identifying flood-prone areas, particularly in regions where hydrological observations are limited (Jurgilevich et al., 2017; Adger et al., 2018).

In Nigeria, flooding has become increasingly severe owing to extreme rainfall events, low-lying terrain, inadequate drainage infrastructure, rapid urban growth, and poor land-use management (Batista e Silva et al., 2018). The devastating nationwide flood events of 2012 highlighted the country's vulnerability and resulted in extensive loss of lives, displacement of communities, and damage to infrastructure. Several studies have applied GIS and remote sensing techniques to flood hazard assessment in different parts of Nigeria, identifying factors such as elevation, rainfall intensity, slope, drainage characteristics, and land use as major determinants of flood occurrence (Hagenlocher et al., 2019; Sherbinin et al., 2019; Ozegin & Ilugbo, 2025). Despite these advances, many existing flood studies in Nigeria primarily emphasize flood susceptibility or hazard mapping without adequately integrating socio-economic exposure into comprehensive flood risk assessment frameworks. Furthermore, limited attention has been given to uncertainty, exposure characteristics, and the interaction between physical flood drivers and human activities, thereby restricting the usefulness of such studies for urban planning and disaster risk reduction (Ford et al., 2018).

Calabar South Local Government Area, located within the coastal environment of southern Nigeria, experiences recurrent flooding due to its low elevation, high annual rainfall, proximity to tidal water bodies, and rapid urban development. The area receives over 2,500 mm of annual rainfall and contains extensive wetlands, tidal creeks, and poorly drained lowlands that increase flood susceptibility. In addition, unplanned urban expansion, drainage obstruction, floodplain encroachment, and inadequate waste management have intensified flood occurrence and associated impacts within the area (IPCC, 2012; IASC, 2019). Recent studies have also reported significant socio-economic consequences of flooding on communities in Calabar South (Effiong et al., 2025). Although previous investigations have documented flood impacts and community vulnerability within the region, comprehensive spatial assessment integrating flood causative factors, hazard conditions, and exposure characteristics remains limited. Consequently, there is a need for an integrated approach capable of identifying flood-prone areas while simultaneously evaluating the exposure of populations and urban land uses to flood hazards.

Therefore, this study integrates Remote Sensing data, GIS-based Multi-Criteria Analysis, and the Analytic Hierarchy Process to evaluate the relative influence of flood causative factors and to generate flood hazard and flood risk maps for Calabar South Local Government Area. Specifically, the study aims to: (i) identify and evaluate the major flood causative factors influencing flood occurrence; (ii) determine the relative importance of these factors using AHP; (iii) delineate flood hazard zones using GIS-based weighted overlay analysis; and (iv) assess flood risk through the integration of flood hazard, population exposure, and land-use characteristics. The findings provide spatially explicit decision-support information for flood mitigation, urban planning, land-use regulation, and disaster risk management in coastal urban environments.

MATERIALS AND METHODS

Study Area

Calabar South Local Government Area is located in Cross River State, southern Nigeria, between latitudes 4°55′–5°00′N and longitudes 8°18′–8°22′E. The area covers approximately 264 km² and lies within the low-lying coastal plain of southeastern Nigeria (Figure 1). Elevation generally ranges below 50 m above mean sea level, with predominantly gentle slopes and extensive wetlands. The area experiences a tropical monsoon climate, with annual rainfall exceeding 2,500 mm and a prolonged rainy season from March to October. The Calabar River, tidal creeks, and coastal wetlands strongly influence local drainage conditions. Rapid urbanization, drainage obstruction, and floodplain encroachment have increased flood susceptibility within the area.

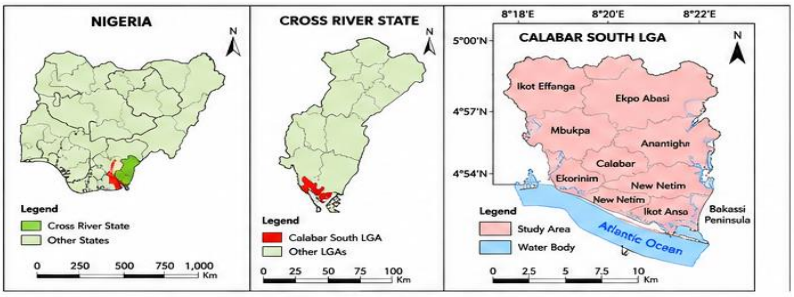

Figure 1: Map of Nigeria showing Cross River State and Calabar South Local Govt. Area

Data Sources and Preprocessing

Both spatial and non-spatial datasets were used to evaluate flood-causing factors and flood risk in Calabar South. A 30 m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model obtained from the United States Geological Survey (USGS) was used to derive elevation, slope, flow direction, and flow accumulation layers (Table 1). Although the 30 m SRTM DEM may introduce uncertainties in very low-relief coastal environments, it remains widely applied in regional flood assessment studies, particularly in data-scarce regions where high-resolution elevation data are unavailable (Vojtek & Vojtekova, 2016). Landsat 8 Operational Land Imager (OLI) imagery acquired during the dry season was used for land use/land cover classification. Mean annual rainfall data covering multiple years were obtained from the Nigerian Meteorological Agency (NiMet) to represent the long-term rainfall characteristics of the study area. Population data were obtained from the National Population Commission and projected to the study year using official growth rates. Administrative boundaries and ancillary spatial datasets were obtained from relevant government agencies. All datasets were projected to the Universal Transverse Mercator (UTM) Zone 32N, WGS 84 coordinate system and resampled to a common spatial resolution to ensure spatial consistency during analysis.

Table 1: Data Sources

Dataset	Source	Resolution	Purpose
SRTM DEM	USGS	30 m	Elevation, slope, flow accumulation
Landsat 8 OLI	USGS	30 m	Land use/land cover
Rainfall data	NiMet	Station-based	Rainfall intensity
Population data	NPC	Census	Population density
Administrative boundaries	Government agencies	Vector	Spatial reference

Derivation of Flood Causative Factors

Five flood conditioning factors were selected based on their documented influence on flood occurrence in coastal and urban environments, namely elevation, slope, flow accumulation, rainfall intensity, land use/land cover, and population exposure (Tang et al., 2018; Rohat et al., 2019).

Elevation and Slope

Elevation and slope were derived from the SRTM DEM using ArcGIS spatial analyst tools. Slope was generated from the DEM using surface analysis procedures. Lower elevations and gentle slopes were considered more susceptible to flood accumulation because they promote water stagnation and reduce runoff velocity.

Flow Accumulation

Hydrological analysis was performed through sink filling, flow direction, and flow accumulation modeling. Areas exhibiting high flow accumulation values represent runoff convergence zones and potential flood pathways.

Rainfall Intensity

Rainfall intensity was estimated from long-term rainfall records obtained from NiMet. Spatial interpolation was carried out using the Inverse Distance Weighting (IDW) technique to generate a continuous rainfall surface. IDW was selected because of its simplicity and suitability for limited station networks commonly encountered in developing regions (Pescaroli & Alexander, 2018).

Land Use/Land Cover Classification

Land use/land cover mapping was performed using supervised classification of Landsat 8 imagery. Five classes were identified: built-up areas, vegetation, forest, cultivated/bare land, and water bodies. Classification accuracy was evaluated using reference points obtained from high-resolution imagery and field observations. Overall classification accuracy and the Kappa coefficient were computed to assess the reliability of the land use map.

Standardization of Flood Conditioning Factors

The derived factor layers were standardized to a common ordinal scale of 1, 2, 5, 8, and 10, representing very low, low, moderate, high, and very high flood susceptibility, respectively. The classification thresholds were established based on hydrological relevance, existing flood studies, and natural breaks (Jenks) classification. This standardization procedure facilitates the integration of variables measured in different units into a common evaluation framework (Metin et al., 2018).

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process was employed to determine the relative importance of the selected flood causative factors. AHP provides a structured framework for pairwise comparison of criteria and consistency evaluation of expert judgments (Saaty, 1990; Saaty & Vargas, 2012). Pairwise comparisons were developed using information obtained from previous flood studies and expert knowledge of coastal flood processes. Elevation was considered the most influential factor due to its control on water accumulation within low-lying coastal terrain, followed by slope, flow accumulation, rainfall intensity, and land use/land cover. The normalized weights obtained from the pairwise comparison matrix is presented in Table 2.

Table 2: AHP-Derived Weights

Factor	Weight	Percentage (%)
Elevation	0.35	35
Slope	0.22	22
Flow accumulation	0.15	15
Rainfall intensity	0.14	14
Land use/land cover	0.14	14

The consistency of the pairwise comparisons was evaluated using the Consistency Index (CI) and Consistency Ratio (CR):

$CI = \frac{\lambda max - n}{n-1}$

$= \frac{5.21-5}{4} = 0.0525$

Random Index (RI) = 1.12 (for n = 5)

$CR = \frac{CI}{RI} = 0.047$

A consistency assessment was performed to verify the reliability of the judgments. The computed Consistency Ratio (CR = 0.047) was below the acceptable threshold of 0.10, indicating satisfactory consistency in the pairwise comparisons (Brown et al, 2018).

Flood Hazard Mapping

Flood hazard mapping was conducted using a Weighted Linear Combination (WLC) approach within the ArcGIS environment. The Flood Hazard Index (FHI) was computed using Equation (1).

$FHI = \sum_{i=1}^{n} wixi$ (1)

Where: w_i= AHP-derived weight, and x_i= standardized factor score

Flood Risk Assessment

Flood risk was assessed by integrating flood hazard with socio-economic exposure factors. Three criteria were considered which included Flood Hazard Index (FHI), Population density, and Land use/land cover

A second AHP analysis was conducted to determine their relative importance. The resulting weights were:

Flood hazard = 0.40

Population density = 0.35

Land use/land cover = 0.25

The Flood Risk Index (FRI) was calculated using a weighted linear combination approach as follows (Renner et al., 2017; Feizizadeh & Kienberger, 2017):

FRI = (0.40 × FHI) + (0.35 × Pd) + (0.25 × Lu) (2)

Where:

FHI = Flood Hazard Index

Pd = standardized population density

Lu = standardized land use/land cover

The resulting flood risk map was classified into five categories using the Jenks natural breaks method.

Validation and Sensitivity Analysis

To evaluate the reliability of the flood hazard map, areas identified as high flood hazard were compared with documented flood-prone locations and available historical flood information within Calabar South. In addition, sensitivity analysis was performed by varying the AHP weights by ±10% to examine the influence of weight uncertainty on flood hazard classification. The sensitivity analysis provides insight into the robustness of the weighting scheme and reduces the subjectivity associated with AHP-based decision-making (Feizizadeh & Kienberger, 2017).

GIS Implementation

All spatial analyses, raster processing, AHP computations, and weighted overlay operations were performed in ArcGIS. Raster layers were projected to a common coordinate system and resampled to identical spatial resolution before integration to ensure spatial consistency and analytical accuracy (Rohat et al., 2018). The final outputs consisted of flood causative factor maps, flood hazard maps, and flood risk maps that provide spatial decision-support information for flood mitigation, land-use planning, and disaster risk management in Calabar South. The general method adopted in this study is given in Figure 2.

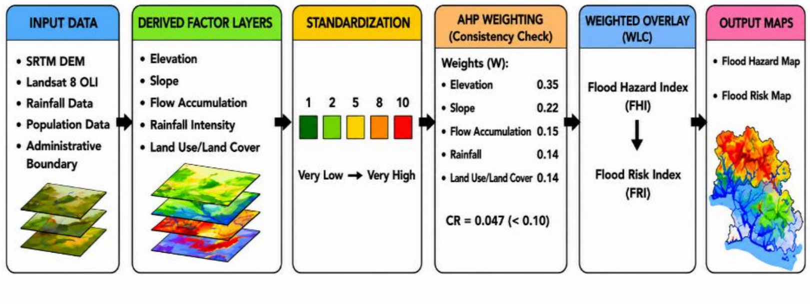

Figure 2: Methodological Framework of the Study

RESULTS AND DISCUSSION

Spatial Characteristics of Flood Causative Factors

The spatial distribution of the selected flood conditioning factors reveals substantial variation across Calabar South Local Government Area. Elevation analysis indicates that extensive portions of the southern and coastal sections occur at low elevations, generally below 50 m above sea level, thereby increasing their susceptibility to floodwater accumulation. Conversely, relatively elevated areas in the northern portion of the study area exhibit lower flood susceptibility. Slope analysis shows that the terrain is predominantly flat to gently sloping. Such low-gradient surfaces reduce runoff velocity and promote water ponding during periods of intense rainfall. Similar observations have been reported in low-relief coastal environments where minimal topographic gradients significantly influence flood generation processes (Ismail-Zadeh et al., 2017).

Flow accumulation analysis identifies major runoff convergence zones along natural drainage pathways and urban drainage corridors. Areas exhibiting high flow accumulation values correspond closely with low-lying portions of the study area, indicating potential flood concentration zones. The interpolated rainfall surface shows relatively limited spatial variability across Calabar South. This suggests that rainfall acts primarily as a triggering mechanism, while topographic and land surface characteristics largely determine the spatial distribution of flood susceptibility. Similar findings have been reported in studies emphasizing the interaction between climatic and physiographic factors in flood generation (Tang et al., 2018). Land use/land cover analysis reveals extensive built-up areas characterized by impervious surfaces, reduced infiltration capacity, and increased surface runoff. Rapid urbanization and land conversion have therefore contributed significantly to flood susceptibility within the study area. The combined influence of low elevation, gentle slopes, runoff convergence, and urban development creates favorable conditions for recurrent flooding (Figure 3).

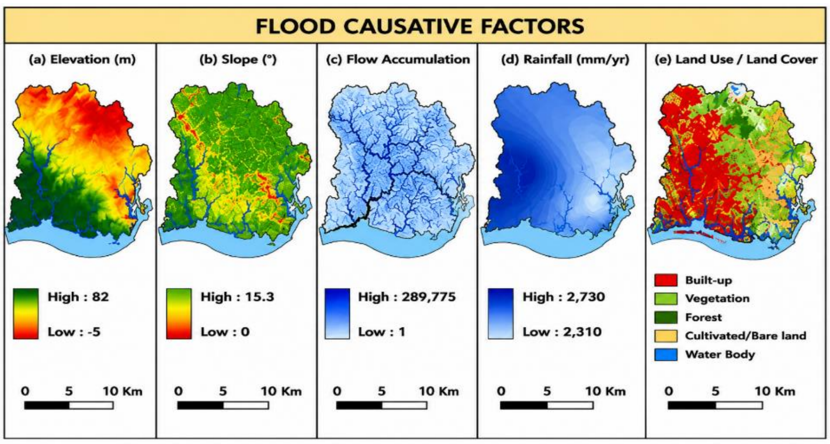

Figure 3: Spatial Distribution of Flood Causative Factors

AHP Weighting and Consistency Evaluation

The Analytic Hierarchy Process results indicate that elevation is the most influential flood conditioning factor, receiving the highest weight of 0.35, followed by slope (0.22), flow accumulation (0.15), rainfall intensity (0.14), and land use/land cover (0.14). The dominance of elevation and slope reflects the strong influence of topographic controls on flood occurrence within coastal lowland environments. Areas situated at low elevations with minimal gradients tend to retain floodwater for longer periods and experience reduced drainage efficiency. Similar observations have been reported in coastal flood studies where terrain characteristics strongly govern flood susceptibility (Ismail-Zadeh et al., 2017). The computed Consistency Ratio of 0.047 is below the acceptable threshold of 0.10, indicating satisfactory consistency in the pairwise comparisons (Saaty & Vargas, 2012). This suggests that the assigned weights are internally consistent and suitable for subsequent weighted overlay analysis. Nevertheless, AHP weighting remains partly dependent on expert judgment and may introduce some degree of subjectivity. Alternative weighting techniques could potentially yield slightly different results, emphasizing the importance of sensitivity assessment in future investigations (Feizizadeh & Kienberger, 2017).

Flood Hazard Mapping

The Flood Hazard Index map reveals considerable spatial variation in flood susceptibility across Calabar South. High and very high flood hazard zones are concentrated primarily within the southern and central portions of the study area, corresponding to areas characterized by low elevation, gentle slopes, and significant flow accumulation as presented in Table 3.

Table 3: Flood Hazard Distribution

Hazard Class	Area (km²)	Percentage (%)
Very Low	69.1	3.6
Low	225.8	11.9
Moderate	492.7	25.9
High	588.0	30.9
Very High	526.9	27.7

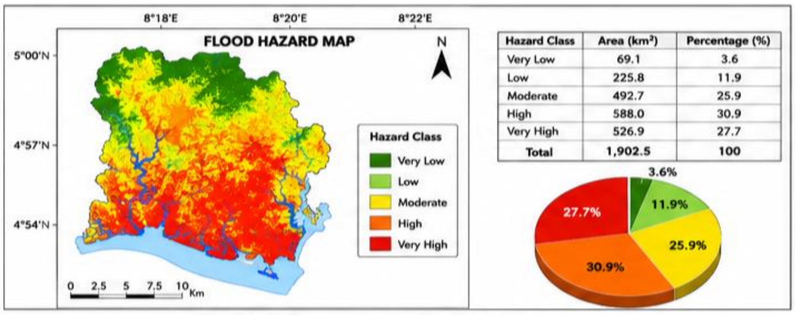

Figure 4: Flood Hazard Map and Areal Statistics

Approximately 58.6% of the study area falls within the high and very high flood hazard categories, indicating substantial exposure to flood occurrence. Moderate hazard zones occupy transitional areas with slightly improved drainage and relatively higher elevations, while low hazard zones occur mainly in the northern section. The observed spatial distribution demonstrates the significant influence of topographic and hydrological factors on flood susceptibility. Similar relationships between low elevation, poor drainage conditions, and increased flood occurrence have been reported in previous studies conducted in Nigeria and other coastal environments (Vojtek & Vojtekova, 2016; Adeboboye, Nwali & Atoki, 2024; Ozegin and Ilugbo, 2025). Although the hazard map provides valuable information regarding flood-prone areas (Figure 4), it should be interpreted with caution because the results were not validated using historical flood records, field observations, or remotely sensed flood extents. Consequently, the hazard map represents relative flood susceptibility rather than actual flood inundation extent.

Flood Risk Assessment

The Flood Risk Index was developed by integrating flood hazard, population density, and land use exposure. The resulting flood risk map demonstrates that flood risk is strongly influenced by both physical susceptibility and socio-economic exposure (Table 4).

Table 4: Flood Risk Distribution

Risk Class	Area (km²)	Percentage (%)
Very Low	479.4	25.2
Low	338.6	17.8
Moderate	401.4	21.1
High	462.3	24.3
Very High	220.7	11.6

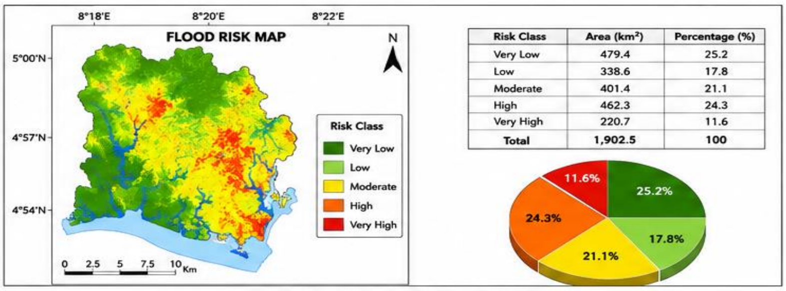

Figure 5: Flood Risk Map and Areal Statistics

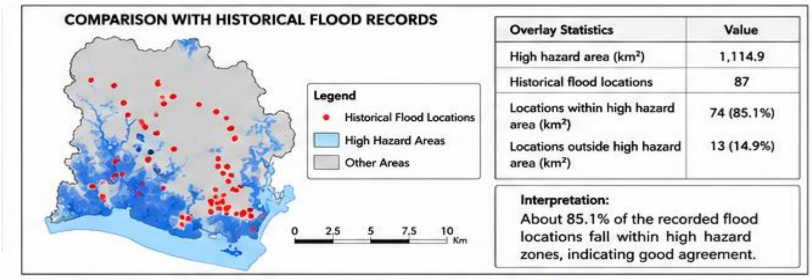

Figure 6: Validation of Flood Hazard Map with Historical Flood Records

Approximately 35.9% of the study area falls within the high and very high flood risk categories. These zones occur predominantly in densely populated urban neighborhoods located within areas of elevated flood hazard. Figures 5 and 6 indicate that physical hazard alone does not adequately explain flood risk. Areas characterized by moderate hazard conditions may still experience considerable risk if population density and urban development are high. Conversely, areas with relatively high hazard but limited exposure may experience lower overall flood risk. The findings support the concept that flood risk results from the interaction between hazard and exposure components, as emphasized by contemporary risk assessment frameworks (Birkmann et al., 2015; Sherbinin et al., 2019).

Comparison with Previous Studies

The dominance of elevation and slope observed in this study agrees with previous flood investigations conducted in coastal and low-lying environments where terrain characteristics strongly control flood occurrence (Ismail-Zadeh et al., 2017). Similarly, studies in Nigeria have identified topography, rainfall, and land use as major determinants of flood susceptibility (Ozegin and Ilugbo, 2025). The results also support findings that urban expansion and increasing impervious surfaces substantially increase flood impacts in rapidly developing cities (Aguirre-Ayerbe et al., 2018). The concentration of high-risk zones within densely populated neighborhoods demonstrates the importance of integrating socio-economic exposure into flood assessment frameworks.

Implications for Flood Management

The spatial coincidence of high flood hazard and dense urban development highlights the need for flood-sensitive land-use planning and improved drainage infrastructure within Calabar South. The identified high-risk areas may assist urban planners and disaster management agencies in prioritizing mitigation measures, regulating development within flood-prone areas, and improving emergency preparedness. GIS-based AHP-MCA methods offer practical advantages in data-scarce regions where detailed hydrodynamic modeling may not be feasible (Simmons et al., 2017). However, these approaches should be considered screening and planning tools rather than substitutes for hydraulic flood simulations.

Limitations of the Study

Several limitations should be acknowledged. First, the use of 30 m SRTM DEM data may not fully capture micro-topographic variations within the low-relief coastal environment. Second, the AHP weighting procedure incorporates expert judgment and therefore contains some degree of subjectivity. Third, the flood hazard and risk maps were not validated using historical flood records, satellite-derived flood extents, or field observations. Fourth, the study employed a static spatial approach and did not consider temporal rainfall variability or seasonal flood dynamics. Finally, hydrodynamic processes such as tidal influence, storm surge, and drainage network capacity were not explicitly modeled. Despite these limitations, the results provide useful preliminary information for identifying flood-prone areas and supporting flood risk management in Calabar South.

CONCLUSION

This study employed an integrated Geographic Information System (GIS) and Analytic Hierarchy Process (AHP)-based Multi-Criteria Analysis (MCA) framework to evaluate flood causative factors and to delineate flood hazard and flood risk zones in Calabar South Local Government Area, Cross River State, Nigeria. By integrating topographic, hydrological, climatic, land use, and population datasets, the study provides a spatial assessment of flood susceptibility and exposure within a rapidly urbanizing coastal environment. The results indicate that elevation and slope constitute the most influential physical factors controlling flood occurrence, accounting for 35% and 22% of the total AHP weights, respectively. Areas characterized by low elevation, gentle slopes, and high flow accumulation exhibit greater flood susceptibility, particularly within the southern and central portions of the study area. Approximately 58.6% of Calabar South falls within the high and very high flood hazard categories, while 35.9% of the area is classified as high to very high flood risk due to the combined effects of physical susceptibility and human exposure.

These findings are consistent with previous studies that emphasize the importance of topography, hydrological characteristics, and land-use conditions in determining flood occurrence and impacts in coastal and urban environments (Vojtek and Vojtekova, 2016; Sherbinin et al., 2019; Ozegin and Ilugbo, 2025). The study further demonstrates that flood risk within Calabar South is not solely controlled by natural factors but is intensified by population concentration, urban expansion, and increasing impervious surfaces. The principal contribution of this study lies in the integration of flood hazard and exposure components within a single GIS-based framework for Calabar South, thereby providing spatial information that can support land-use planning, flood mitigation, drainage improvement, and disaster preparedness. The resulting flood hazard and flood risk maps may therefore serve as preliminary decision-support tools for local authorities and urban planners.

Nevertheless, several limitations should be acknowledged. The use of a 30 m SRTM Digital Elevation Model may not adequately capture micro-topographic variations in the low-relief coastal terrain. In addition, the AHP weighting procedure incorporates expert judgment, which introduces some degree of subjectivity. Furthermore, the flood hazard and risk maps were not validated using historical flood records, field observations, or satellite-derived flood extents. The study also employed a static spatial approach and did not incorporate hydrodynamic modeling or temporal rainfall variability. Future studies should incorporate higher-resolution elevation datasets, historical flood inventories, hydrodynamic simulations, and sensitivity analyses to improve the reliability and predictive capability of flood assessments in coastal Nigerian cities. Despite these limitations, the study provides useful baseline information for flood management and contributes to the growing body of GIS-based flood risk studies in Nigeria.

REFERENCES

Adeboboye, A. J., Nwali, H. I. & Atoki, L. O. (2024). Flood vulnerability mapping using remote sensing and GIS techniques in some selected LGA of Anambra State. *International Journal of Multidisciplinary Research and Growth Evaluation.* 5(3).

Adger, W. N., Brown, I., & Surminski, S., (2018). 'Advances in risk assessment for climate change adaptation policy', *Philosophical Transactions of the Royal Society A*, 376(20180106).

Aguirre-Ayerbe, I., Martínez Sánchez, J., Aniel-Quiroga, Í, González-Riancho, P., Merino, M., Al-Yahyai, S., González, M., & Medina, R., (2018). 'From tsunami risk assessment to disaster risk reduction – the case of Oman', *Natural Hazards and Earth System Sciences*, 18: 2241–2260.

Ali, K., Bajracharya, R. M. & Koirala, H. L. (2016). A Review of Flood Risk Assessment. *International Journal of Environment, Agriculture and Biotechnology (IJEAB).* (1)4, http://dx.doi.org/10.22161/ijeab/1.4.62

Batista e Silva, F., Marín Herrera, M. A., Rosina, K., Barranco, R. R., Freire, S., & Schiavina, M., (2018). 'Analysing spatiotemporal patterns of tourism in Europe at high-resolution with conventional and big data sources', *Tourism Management*, 68: 101–114.

Birkmann, J., Cutter, S. L., Rothman, D. S., Welle, T., Garschagen, M., van Ruijven, B., O'Neill, B., Preston, B. L., Kienberger, S., Cardona, O. D., Siagian, T., Hidayati, D., Setiadi, N., Binder, C. R., Huges, B., & Pulwarty, R., (2015). 'Scenarios for vulnerability: opportunities and constraints in the context of climate change and disaster risk', *Climatic Change*, 133: 53–68.

Brown, K., DiMauro, M., Johns, D., Holmes, G., Thompson, D., Russell, A., & Style, D., (2018). 'Turning risk assessment and adaptation policy priorities into meaningful interventions and governance processes', *Philosophical Transactions of the Royal Society A*, (376)20170303.

Buta, C., Mihai, G. & Stănescu, M. (2020). Flood Risk Assessment Based on Flood Hazard and Vulnerability Indexes. *Ovidius University Annals Series: Civil Engineering*, Https://doi.org/10.2478/ouacsce-2020-0014

Efiong, J., Anara, D. I. & Odey, D. (2025). Effect of Demographic and Socio-Economic Factors on Community Resilience to Flood Hazard in Calabar South Local Government Area of Cross River State, Nigeria. *World Environment Journal*. 5(1).

Feizizadeh, B., & Kienberger, S., (2017). 'Spatially explicit sensitivity and uncertainty analysis for multicriteria-based vulnerability assessment', *Journal of Environmental Planning and Management*, 60(11): 2013–2035.

Ford, J.D., Pearce, T., McDowell, G., Berrang-Ford, L., Sayles, J. S., & Belfer, E., (2018). 'Vulnerability and its discontents: The past, present, and future of climate change vulnerability research', *Climatic Change*, 151: 189–203.

Hagenlocher, M., Meza, I., Anderson, C., Min, A., Renaud, F. G., Walz, Y., Siebert, S., & Sebesvari, Z., (2019). 'Drought vulnerability and risk assessments: State of the art, persistent gaps, and research agenda', *Environmental Research Letters*, 14(8): 083002.

IASC and European Commission, (2019). *INFORM Report 2019: Shared evidence for managing crises and disasters*, https://reliefweb.int/ report/world/inform-report-2019-shared-evidence-managing-crises-and-disasters.

IPCC (Intergovernmental Panel on Climate Change), (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation: A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, eds.

Ismail-Zadeh, A., Cutter, S. L., Takeuchi, K., & Paton, D., (2017). 'Forging a paradigm shift in disaster science', *Natural Hazards*, 86: 969–988.

Jurgilevich, A., Räsänen, A., Groundstroem, F., & Juhola, S., (2017). 'A systematic review of dynamics in climate risk and vulnerability assessments', *Environmental Research Letters*, 12: 013002.

Lauta, K. C., Albris, K., Zuccaro, G., & Grandjean, G. (2018). *ESPREssO Enhancing Risk Management Capabilities Guidelines*, www.espressoproject.eu.

Metin, A. D., Dung, N. V., Schröter, K., Guse, B., Apel, H., Kreibich, H., Vorogushyn, S., & Merz, B., (2018). 'How do changes along the risk chain affect flood risk', *Natural Hazards and Earth System Sciences*, 18: 3089–3108.

Ozegin, K.O. & Ilugbo, S.O. (2025). Evaluation of potentially susceptible flooding areas leveraging geospatial technology with multicriteria decision analysis in Edo State, Nigeria. *Natural Hazards Research*, 5(1): 109-133

Peduzzi, P., (2019). 'The disaster risk, global change, and sustainability nexus', *Sustainability*, 11: 957.

Pescaroli, G., & Alexander, D., (2018). 'Understanding compound, interconnected, interacting, and cascading risks: A holistic framework', *Risk Analysis*, 38(11): 2245–2257.

Renner, K., Schneiderbauer, S., Pruß, F., Kofler, C., Martin, D., & Cockings, S., (2017) 'Spatio-temporal population modelling as improved exposure information for risk assessments tested in the Autonomous Province of Bolzano', *International Journal of Disaster Risk Reduction*, 27: 470–479.

Rohat, G., Flacke, J., Dao, H., & van Maarseveen, M., (2018) 'Co-use of existing scenario sets to extend and quantify the shared socioeconomic pathways', *Climatic Change*, 151: 619–636.

Rohat, G., Flacke, J., Dosio, A., Pedde, S., Dao, H., & van Maarseveen, M., (2019) 'Influence of changes in socioeconomic and climatic conditions on future heat-related health challenges in Europe', *Global and Planetary Change*, 172: 45–59.

Saaty, T.L. (1990). An exposition of the AHP in reply to the paper "remarks on the analytic hierarchy process, *Manag. Sci*., 36 (3): 259-268

Saaty, T.L. & Vargas, L.G. (2012). *The seven pillars of the analytic hierarchy process Models, methods, concepts and applications of the analytic hierarchy process*, Springer, Boston, 23-40

Sherbinin, A., Bukvic, A., Rohat, G., Gall, M., McCusker, B., Preston, B., Apotsos, A., Fish, C., Kienberger, S., Muhonda, P., Wilhelmi, O., Macharia, D., Shubert, W., Sliuzas, R., Tomaszewski, B., & Zhang, S., (2019). 'Climate vulnerability mapping: A systematic review and future prospects', *Wiley Interdisciplinary Reviews: Climate Change*, 10(5): 1–23.

Simmons, D. C., Dauwe, R., Gyenes, Z., King, A. G., Riedstra, D., & Schneiderbauer, S., (2017). *'Qualitative and quantitative approaches to risk assessment', in: Poljanšek, K., Marin Ferrer, M., De Groeve, T., Clark, I. (eds.), Science for Disaster Risk Management 2017: Knowing better and losing less, Publications Office of the European Union*, Luxembourg, 44–58.

Sword-Daniels, V., Eriksen, C., Hudson-Doyle, E. E., Alaniz, R., Adler, C., Schenk, T., & Vallance, S., (2018) 'Embodied uncertainty: Living with complexity and natural hazards', *Journal of Risk Research*, 21(3): 290–307.

Tang, Y., Jing, J., Zhang, Z., & Yang, Y. A., (2018) 'Quantitative risk analysis method for the high hazard mechanical system in petroleum and petrochemical industry', *Energies*, 11: 1–18.

Vojtek, M. & Vojtekova, J. (2016). Flood Hazard and Flood Risk Assessment at the Local Spatial Scale: A Case Study. *Geomatics, Natural Hazards and Risk*, 7(6): 1973-1992, http://dx.doi.org/10.1080/19475705.2016.1166874

Wenk, M., Neuhold, C., & Fuchs, S., (2018). 'Zielgruppenspezifische Darstellung von Hochwassergefahren und -risiko', Österreichische *Wasser- und Abfallwirtschaft*, 70 (5–6): 328–340.

Zebisch, M., Schneiderbauer, S., Renner, K., Below, T., Brossmann, M., Ederer, W., & Schwan, S., (2018). *Risk Supplement to the Vulnerability Sourcebook.*

Zscheischler, J., Westra, S., van den Hurk, B. J. J. M., Seneviratne, S. I., Ward, P. J., Pitman, A., AghaKouchak, A., Bresch, D. N., Leonard, M., Wahl, T., & Zhang, X., (2018). 'Future climate risk from compound events', *Nature Climate Change*, 8: 469–477.