



Land Cover Dynamics and Flood Vulnerability Assessment in Calabar Metropolis Using GIS-Based Spatial Modelling

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Abstract

Flooding represents a recurrent environmental hazard in Calabar Metropolis, Southern Nigeria, driven by anthropogenic alterations to the landscape and natural geomorphological predispositions. This study applies geospatial analytical techniques to investigate the spatial patterns of land cover, model flood risk zones, and evaluate land use exposure to flooding hazards. Five major land cover types vegetation, built-up areas, water bodies, bareground, and cropland were mapped and quantified using remote sensing data. Vegetation dominated the land cover, occupying 59.61% of the total area, followed by built-up areas at 24.51%. A spatial model integrating slope, elevation, land cover, drainage proximity, and hydrographic features delineated four flood risk zones: very high, high, moderate, and low. The results revealed that 72.44% of the area falls under the very high-risk category, affecting both urban infrastructure and ecological zones. Detailed overlay analysis showed that 73.72% of vegetation and 6.37% of built-up areas are situated in very high-risk zones. Built-up areas dominated both moderate and low-risk zones, suggesting that strategic urban planning may mitigate flood impacts. The findings underscore the role of land use configuration in flood risk distribution and provide evidence-based insights for land management and disaster mitigation policies in the region.

Keywords: Land Use/Land Cover, Flood Vulnerability, Gis-Based Modelling, Calabar Metropolis, Spatial Exposure Analysis

1. Introduction

Urban flooding has emerged as one of the most recurrent and disruptive environmental hazards globally, with particularly severe consequences in rapidly urbanizing regions such as sub-Saharan Africa. The vulnerability of urban areas to flooding is intrinsically linked to the transformation of land surfaces, where vegetated and permeable landscapes are replaced by impervious infrastructure such as roads, buildings, and pavements. This alteration reduces infiltration capacity and increases surface runoff, thereby overwhelming existing drainage systems and elevating flood risks (Douglas *et al.*, 2008; Weng, 2001) ^[4, 15].

In Nigeria, the incidence of urban flooding has escalated in frequency and intensity over the past two decades, largely due to unregulated urban growth, poor infrastructure, and the effects of climate variability (Adeoye *et al.*, 2009; Adelekan, 2010) ^[1, 2]. Calabar Metropolis, located in Cross River State, exemplifies this trend, having experienced multiple flood events that have disrupted socio-economic activities, damaged infrastructure, and displaced communities. Despite the region's natural endowment in terms of water bodies and vegetation cover, the increasing encroachment into ecologically sensitive zones has compromised the urban environment's hydrological balance (Nwilo *et al.*, 2012) ^[6].

A comprehensive understanding of land use and land cover (LULC) dynamics is essential for flood risk assessment because the spatial distribution of surface features such as built-up areas, vegetation, bareground, and water bodies significantly influences hydrological processes, including infiltration, runoff, evapotranspiration, and storage (Ghoneim *et al.*, 2011; Alaghmand *et al.*, 2010) ^[5, 3]. Vegetation, for instance, plays a key role in enhancing infiltration and regulating microclimates, while impervious surfaces accelerate runoff and reduce groundwater recharge. Furthermore, the topographical characteristics of an area, including elevation and slope, determine the direction and accumulation of surface water, thereby influencing the spatial manifestation of flood hazards (Ouma & Tateishi, 2014) ^[13].

Geographic Information Systems (GIS) and remote sensing technologies offer robust tools for the spatial modeling of flood hazards by integrating multiple geospatial variables, including terrain characteristics, hydrological features, and land use patterns (Jeb & Aggarwal, 2008; Zhou *et al.*, 2015) ^[12, 16]. These technologies facilitate the generation of thematic maps, flood risk zoning, and exposure analysis, which are critical for informed decision-making, particularly in urban planning and disaster risk reduction.

The necessity for spatially explicit flood vulnerability assessments in Calabar Metropolis has become increasingly urgent, given the region's topographical complexity and growing urban pressure. The presence of multiple rivers, low-lying floodplains, and inadequate stormwater infrastructure exacerbates the risk of pluvial and fluvial flooding. Moreover, informal settlements that often emerge in marginal lands lack resilient building structures and are more exposed to flood events, compounding the vulnerability of low-income populations (Pelling, 2003; UN-Habitat, 2014) ^[14, 9]. This study is designed to achieve three primary objectives. First, it investigates the current spatial pattern and areal extent of land cover types within Calabar Metropolis using classified satellite imagery. Second, it models flood risk zones through a weighted overlay approach that synthesizes terrain, hydrology, and land use factors. Third, it assesses the exposure of different land cover types to varying flood risk levels, thereby identifying critical zones that require targeted interventions. The research findings are expected to provide empirical evidence for land use planning, infrastructure development, environmental management, and disaster preparedness in Calabar Metropolis.

This study contributes to the growing body of literature on urban flood modeling and aligns with global efforts toward sustainable urbanization and climate resilience by leveraging spatial analytical methods, as emphasized in the United Nations Sustainable Development Goals (SDG 11: Sustainable Cities and Communities). The application of GIS-based modeling in this context not only enhances local flood preparedness but also offers a replicable framework for other urban areas facing similar challenges in Nigeria and beyond (Isioye & Akinyede, 2012; Yankson & Gough, 1999) ^[11, 10].

2. Materials and Methods

2.1 Study Area

Calabar Metropolis, the capital of Cross River State in southeastern Nigeria, lies between latitudes 4°54'N and 5°08'N and longitudes 8°18'E and 8°30'E. It comprises two major local government areas: Calabar Municipal and Calabar South. The metropolis is bounded by the Great Kwa River to the east and the Calabar River to the west, both of which significantly influence its hydrological and ecological characteristics. The terrain of Calabar is predominantly low-lying and gently undulating, with elevations ranging between 10 m and 50 m above sea level. The region falls within the humid tropical rainforest zone and experiences a bimodal rainfall regime, with peak precipitation occurring between June and September. Annual rainfall exceeds 3000 mm, and this high precipitation, coupled with poor drainage and rapid urbanization, renders the area highly susceptible to flooding. The land use pattern in Calabar reflects an evolving urban landscape characterized by mixed residential zones, commercial and administrative centers, riverine ecosystems, undeveloped vegetation, and scattered farmlands. The

expansion of built-up areas into natural floodplains has been particularly problematic, especially in informal settlements with limited drainage infrastructure. The hydrological vulnerability of Calabar is further amplified by inadequate solid waste management, which often leads to blocked drainage channels, compounding the severity of flood events.

a. Data Sources

The study utilized a combination of remotely sensed data, ancillary spatial datasets, and field-collected data for analytical modeling:

1. **Satellite Imagery:** High-resolution Landsat 8 Operational Land Imager (OLI) imagery was obtained for the year of analysis. The image was downloaded from the United States Geological Survey (USGS) Earth Explorer portal.
2. **Digital Elevation Model (DEM):** Shuttle Radar Topography Mission (SRTM) 30-meter resolution data was employed to extract elevation and slope information.
3. **Hydrological and Drainage Data:** Derived from the DEM using hydrological modeling tools within ArcGIS.
4. **Land Use Reference Data:** Ground truth points were collected using handheld GPS for supervised classification accuracy assessment.

b. Image Preprocessing and Land Cover Classification

The Landsat imagery underwent preprocessing to correct for atmospheric, radiometric, and geometric distortions. Radiometric correction was applied to normalize reflectance values, and geometric correction aligned the imagery to the Universal Transverse Mercator (UTM) projection (Zone 32N, WGS 84 datum). Subsets of the study area were extracted using administrative boundaries obtained from the Office of the Surveyor-General of the Federation.

Supervised classification was performed using the Maximum Likelihood Classifier (MLC) algorithm within the ArcGIS 10.7 platform. Five thematic land cover classes were defined: Bareground, Built-up Area, Cropland, Vegetation, and Water Body. Ground control points and high-resolution Google Earth imagery were used to validate classification results. A confusion matrix was generated to evaluate classification accuracy, with overall accuracy and kappa coefficient computed.

c. Flood Risk Modelling

Flood risk assessment was conducted using a Multi-Criteria Evaluation (MCE) approach through weighted overlay analysis. The flood risk model incorporated five key factors, selected based on their hydrological significance and availability of spatial data:

1. **Elevation:** Derived from the SRTM DEM and reclassified into five elevation bands using the Jenks Natural Breaks method.
2. **Slope:** Calculated using the ArcGIS slope function and categorized into five gradient classes to capture surface runoff potential.
3. **Land Cover:** Classified land use types were assigned risk weights based on their permeability and runoff generation potential.
4. **Proximity to Water Bodies:** A Euclidean distance function was applied to delineate areas near rivers and streams, with proximity classes reflecting potential inundation zones.
5. **Drainage Density:** Drainage networks were extracted

from the DEM using the Flow Direction and Flow Accumulation tools. Drainage density was computed and reclassified into weighted intervals.

Each layer was standardized to a common scale of 1 to 5, representing increasing flood risk potential. Weights were assigned using the Analytic Hierarchy Process (AHP) developed by Saaty (1980), informed by expert judgment and literature benchmarks (Ouma & Tateishi, 2014; Zhou *et al.*, 2015) [13, 16]. The final flood risk index (FRI) was computed using the following equation:

$$FRI = w_1E + w_2S + w_3LU + w_4D + w_5DD \quad (1)$$

Where:

FRI = Flood Risk Index

E = Elevation

S = Slope

LU = Land Use

D = Distance to Water Body

DD = Drainage Density

wi = Weight assigned to each factor

The resultant flood risk surface was classified into four categories: Very High, High, Moderate, and Low Risk Zones. Each class was visualized as a thematic map for interpretation.

d. Land Cover Exposure Analysis

A spatial overlay of the flood risk map with the classified land cover map was conducted using the Zonal Statistics tool. This analysis computed the area (in km²) and proportional exposure of each land cover type within the defined flood risk classes. The exposure analysis aimed to quantify the vulnerability of specific land use types particularly vegetation and built-up areas to flood hazards, which is essential for planning mitigation strategies and prioritizing intervention zones.

3. Results

The results of the geospatial analysis are presented in three main sections: land cover classification and distribution, spatial flood risk modeling, and land cover exposure to flood vulnerability. The findings demonstrate the interconnectedness of land cover dynamics and hydrological susceptibility, providing critical insight for spatial planning and flood mitigation in Calabar Metropolis.

e. Land Cover Classification and Spatial Distribution

The classified land cover map revealed five major thematic classes within Calabar Metropolis: Vegetation, Built-Up Area, Water Body, Bareground, and Cropland. These categories reflect both natural surface conditions and anthropogenic modifications across the urban landscape. The classification results indicated that vegetation is the dominant land cover type, occupying approximately 188.98 km², which corresponds to 59.61% of the total study area. This class comprises dense forests, grasslands, and semi-natural green spaces, primarily located on the peripheries and in undeveloped zones of the metropolis. Vegetation serves critical hydrological functions, including enhancing infiltration, moderating evapotranspiration, and providing ecological resilience against flooding. Built-up areas, constituting residential, commercial, and

transport infrastructure, accounted for 77.71 km² or 24.51% of the total land area. This land cover class is concentrated within the urban core and major road corridors, reflecting the spatial extent of urban expansion and impervious surface proliferation. The high concentration of impervious surfaces in built-up zones contributes significantly to reduced infiltration rates and heightened surface runoff, thereby increasing flood vulnerability.

Water bodies comprising rivers, creeks, streams, ponds, and seasonal wetlands occupied 43.92 km², representing 13.85% of the study area. These hydrological features serve as natural drainage outlets and floodwater retention basins, playing a buffering role during high precipitation events. However, their adjacency to flood-prone terrain necessitates monitoring to prevent overflow and encroachment.

Bareground areas, encompassing exposed soil, undeveloped plots, and cleared construction zones, covered 5.54 km² (1.75%). These surfaces lack vegetative cover and are typically associated with high erosion potential and rapid runoff generation, especially during intense rainfall. Finally, cropland the least represented class accounted for only 0.89 km² (0.28%), indicating limited agricultural activity within the urban fabric. The spatial distribution and areal coverage of each land cover class are summarized in Table 1 and figure 1.

Table 1: Land Cover Types and Areal Extent in Calabar Metropolis

Land Cover Type	Area (km ²)	Percentage (%)
Vegetation	188.98	59.61
Built-Up Area	77.71	24.51
Water Body	43.92	13.85
Bareground	5.54	1.75
Cropland	0.89	0.28

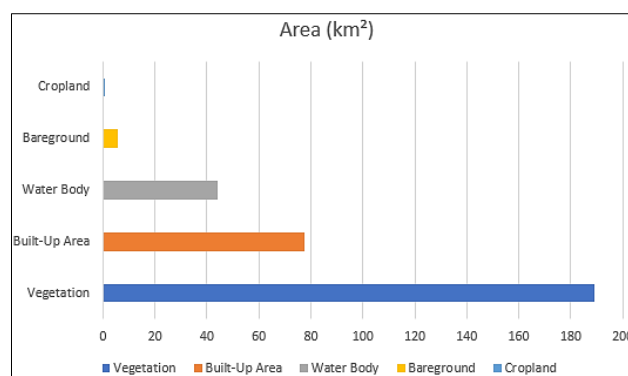


Fig 1: Landcover/landuse Distribution in Calabar Metropolis

This pattern illustrates a landscape in transition, where natural vegetative cover continues to dominate but is increasingly fragmented by urban sprawl and infrastructural development.

f. Flood Risk Modelling

The flood risk model integrated terrain, land cover, hydrological, and infrastructural variables to delineate zones of differential flood susceptibility. The model categorized the study area into four flood risk classes: Very High Risk, High Risk, Moderate Risk, and Low Risk.

The analysis revealed that the Very High-Risk zone covers 229.66 km², representing an overwhelming 72.44% of the total land area. These areas are characterized by low

elevation, flat terrain, proximity to riverine systems, and high concentrations of impervious surfaces. The combination of these factors leads to poor drainage and frequent inundation during peak rainfall events.

The High-Risk zone accounts for 20.77 km² (6.55%). These areas typically lie adjacent to major rivers and within transitional zones of urban-rural interfaces. While less vulnerable than the very high-risk category, these areas remain susceptible to flooding during periods of elevated river discharge or in cases of drainage failure.

Moderate Risk areas occupy 37.64 km², constituting 11.87% of the study area. These zones are generally located in slightly elevated or vegetated areas with improved infiltration capacity and drainage networks. Flooding in these areas tends to be seasonal and less severe but may become critical during prolonged or extreme rainfall.

Low-Risk zones cover 28.95 km² (9.13%). These areas are located on higher ground or in regions with effective natural or engineered drainage systems. The probability of flooding in these zones is minimal under standard climatic conditions. The spatial extent of each risk zone is presented in Table 2 and figure 2.

Table 2: Flood Risk Zones in Calabar Metropolis

Risk Zone	Area (km ²)	Percentage (%)
Very High Risk	229.66	72.44
High Risk	20.77	6.55
Moderate Risk	37.64	11.87
Low Risk	28.95	9.13

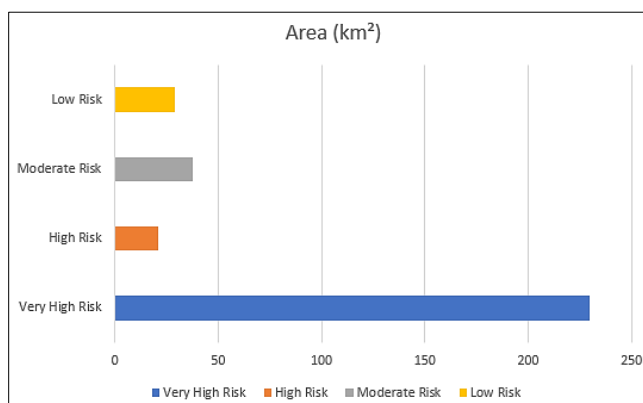


Fig 2: Flood Risk Zone Distribution in Calabar Metropolis

The predominance of very high-risk areas within the city underscores the urgent need for structural and non-structural flood mitigation measures, including the reinforcement of drainage networks, implementation of flood zoning regulations, and promotion of nature-based solutions such as urban reforestation and wetland conservation.

g. Land Cover Exposure to Flood Vulnerability

The spatial overlay of land cover classification with flood risk zones provided a detailed assessment of how different land surface categories are exposed to varying degrees of flood vulnerability across Calabar Metropolis. This analytical step was instrumental in identifying the extent to which each land cover type coincides with flood-prone areas, offering a data-driven basis for targeting mitigation efforts, infrastructure protection, and environmental conservation. By categorizing the land cover exposure across the four flood risk zones Very High, High, Moderate, and Low the analysis revealed the

differential susceptibility of both natural and built environments to flood hazards within the city's boundaries.

1. Exposure within Very High-Risk Zones

Within the very high-risk flood zone, vegetation emerged as the most affected land cover type, occupying approximately 169.29 square kilometers, which accounts for 73.72 percent of the land area categorized under this risk level. This considerable spatial presence of vegetated land within high flood-prone regions suggests that extensive tracts of forested and grassland areas in Calabar are situated within low-lying floodplains or along riparian corridors where floodwaters naturally accumulate. Although vegetation generally supports infiltration and flood attenuation, its location in these vulnerable hydrological contexts exposes it to recurrent inundation and degradation.

Water bodies constituted the second most exposed category in the very high-risk zone, covering 43.75 square kilometers, representing 19.05 percent of this classification. This figure illustrates the logical overlap between natural drainage features such as rivers, streams, and wetlands and regions of intense flood susceptibility. Built-up areas followed with a total of 14.62 square kilometers, equivalent to 6.37 percent of the very high-risk zone. This degree of exposure is particularly alarming, as it indicates that significant portions of urban infrastructure including residential, commercial, and transportation networks are located in zones where the likelihood of frequent and severe flooding is extremely high. Bareground and cropland appeared to a much lesser extent in these zones, covering 1.44 square kilometers (0.63 percent) and 0.39 square kilometers (0.17 percent), respectively. Although their proportions are marginal, their presence in such high-risk flood zones may exacerbate localized runoff and erosion, particularly in the absence of vegetative cover or engineered flood mitigation systems.

2. Exposure within High-Risk Zones

The high-risk flood zones also exhibited significant exposure of vegetation and built-up surfaces, albeit to a lesser degree than the very high-risk areas. Vegetation accounted for 12.74 square kilometers or 61.35 percent of the high-risk zones. This continued prominence reflects the presence of green spaces and forested margins in proximity to flood-sensitive terrain. Built-up areas occupied 7.28 square kilometers, amounting to 35.07 percent of this flood category. The relatively high percentage of urban infrastructure within the high-risk zone indicates an ongoing expansion of settlements into marginal lands that lack adequate hydrological buffering. Bareground and cropland in this zone covered 0.61 square kilometers (2.91 percent) and 0.06 square kilometers (0.27 percent), respectively. Water bodies were the least represented, occupying only 0.07 square kilometers (0.32 percent). These findings suggest that the majority of high-risk zones are shared between human-altered landscapes and transitional ecological zones that may not be resilient enough to withstand prolonged flood exposure.

3. Exposure within Moderate Risk Zones

In the moderate flood risk zones, built-up areas overwhelmingly dominated, occupying 29.89 square kilometers, which corresponds to 79.42 percent of this risk class. This spatial pattern suggests that a substantial portion of Calabar's urban infrastructure is situated in moderately vulnerable zones, possibly due to strategic land use decisions

favoring elevated or better-drained sites. Vegetation was the second most prominent land cover within the moderate risk zone, covering 5.95 square kilometers, equivalent to 15.80 percent. The continued presence of vegetation in these areas supports the hydrological resilience of the terrain by moderating runoff and enhancing infiltration.

Bareground and cropland contributed minor exposures, at 1.63 square kilometers (4.32 percent) and 0.14 square kilometers (0.38 percent), respectively. Water bodies were almost negligible in this category, with only 0.01 square kilometers (0.03 percent), reflecting the tendency of water systems to occupy more vulnerable terrains in lower floodplains.

4. Exposure within Low-Risk Zones

Low-risk flood zones were predominantly characterized by built-up areas, which occupied 25.89 square kilometers,

translating to 89.44 percent of the land within this category. This trend strongly suggests that urban development in Calabar has partly aligned with terrain features that naturally confer flood resistance, such as elevated or well-drained zones. The prevalence of urban infrastructure in safer areas reflects some level of spatial planning or topographic advantage.

Vegetation, bareground, and cropland were present in much smaller proportions within the low-risk zone. Vegetation accounted for 0.89 square kilometers (3.08 percent), bareground covered 1.86 square kilometers (6.42 percent), and cropland constituted 0.30 square kilometers (1.05 percent). The distribution of these land cover types in low-risk zones may enhance the resilience of these areas by contributing to water retention, erosion control, and landscape stability, see table 3 and figure 3.

Table 3: Summary of Land Cover Exposure Across Flood Risk Zones in Calabar Metropolis

Risk Zone	Built-Up (km ²)	Vegetation (km ²)	Water Body (km ²)	Bareground (km ²)	Cropland (km ²)
Very High Risk	14.62	169.29	43.75	1.44	0.39
High Risk	7.28	12.74	0.07	0.61	0.06
Moderate Risk	29.89	5.95	0.01	1.63	0.14
Low Risk	25.89	0.89	0.00	1.86	0.30

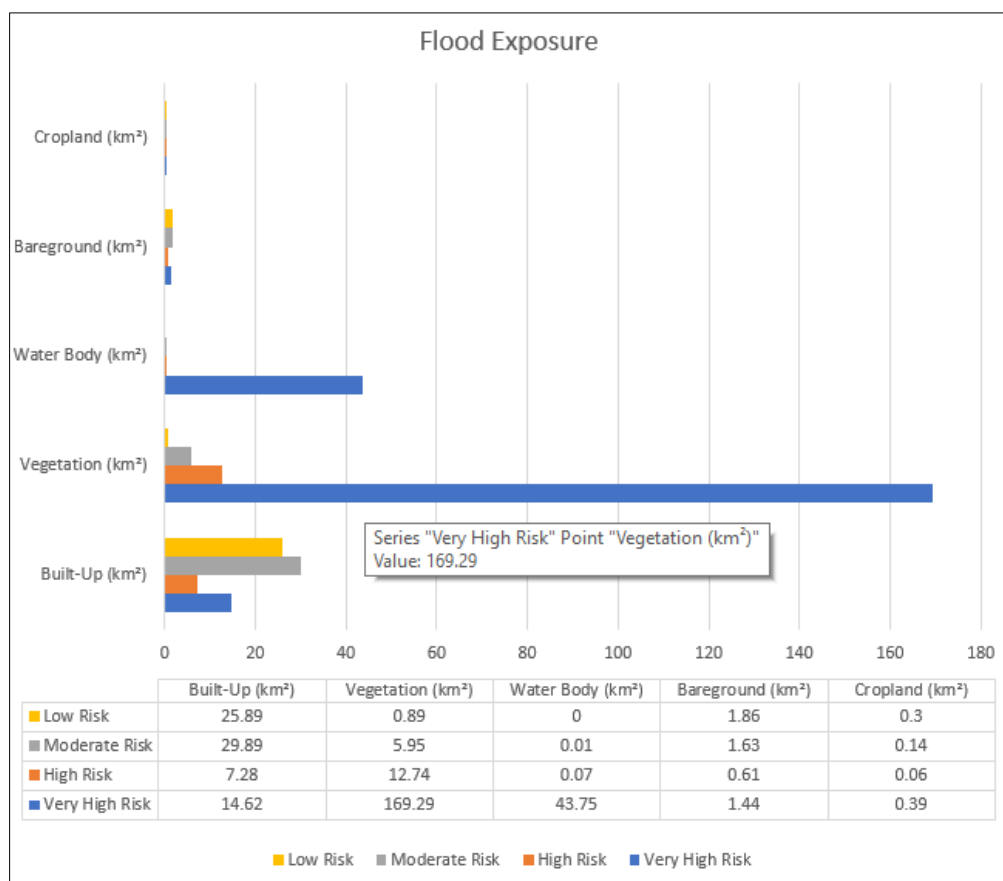


Fig 3: Flood Exposure Distribution

The analytical results underscore a critical spatial imbalance, where high-value ecological assets such as forests and water bodies are extensively exposed to very high and high flood risks, while safer zones are predominantly occupied by planned urban development. This inverse relationship between ecological value and flood safety calls for the integration of risk-sensitive land use planning and green infrastructure design. Moreover, the widespread exposure of

built-up areas across all flood risk zones highlights the systemic vulnerability of Calabar's urban environment to flooding. The implications of these findings necessitate targeted policy interventions, including the enforcement of zoning laws, investment in resilient drainage infrastructure, and strategic afforestation programs within riparian and low-lying regions.

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