International Journal of Multidisciplinary Research and Growth Evaluation.

Assessment of Flood Impact in Nsukka Local Government area of Enugu State Using Remote Sensing and GIS Approach

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Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 7.98
Volume: 06
Issue: 06
November - December 2025
Received: 07-09-2025
Accepted: 06-10-2025
Published: 19-11-2025
Page No: 774-786

Abstract

Flooding has emerged as a persistent environmental challenge in Nsukka Local Government Area of Enugu State, driven by rapid urban expansion, land-use transformation and alterations in natural drainage systems. This study assesses the spatial pattern, magnitude and distribution of flood impact in Nsukka using an integrated Remote Sensing and Geographic Information Systems approach. Seven conditioning factors comprising elevation, slope, drainage density, flow accumulation, land use and land cover, the Normalized Difference Water Index and the Topographic Wetness Index were generated and analyzed within a multi-criteria evaluation framework. Each factor was reclassified and weighted using the Analytical Hierarchical Process supported by consistency assessment to determine its relative influence on flood susceptibility. The weighted overlay procedure produced a flood-hazard map delineating five classes of vulnerability. The spatial results reveal that moderate hazard zones dominate the landscape, while high and very high hazard zones occur mainly within low-lying and densely settled areas characterized by gentle slopes, high runoff concentration and extensive surface exposure. The study demonstrates that terrain configuration and anthropogenic land-surface modification remain the strongest drivers of flood impact in Nsukka. The findings provide a scientifically grounded basis for flood-risk mitigation, land-use regulation and developmental planning across the LGA.

Keywords: Flood Impact; Remote Sensing; GIS; Multi-Criteria Evaluation; Nsukka LGA

1. Introduction

Flooding remains one of the most destructive environmental hazards affecting communities in both developed and developing nations, producing extensive socio-economic disruptions, infrastructure damage and adverse ecological consequences (Nkeki, Henah and Ojeh, 2013) [9]. Nigeria has experienced an escalation in flood frequency and magnitude over the past three decades due to climate variability, land-use transformation and rapid population growth (Umar, 2023) [11]. The southeastern region, including Enugu State, has become increasingly vulnerable as urban expansion intensifies pressure on natural drainage systems, resulting in heightened runoff, reduced infiltration and recurrent inundation (Chigbu, Mbah and Anyanwu, 2018) [3]. Nsukka Local Government Area exemplifies this pattern, where urbanization, deforestation and unregulated land conversion have significantly altered hydrological balances, creating complex conditions that aggravate flood impacts (Ife-Adediran, Owoola and Fuwape, 2018) [5]. The need for precise and spatially explicit flood-impact assessment in Nsukka LGA has become urgent. Flooding in the area frequently disrupts transportation networks, degrades agricultural land, damages residential zones and threatens human safety (Emmanuel and Balogun, 2025) [4]. Effective mitigation requires a comprehensive understanding of the factors influencing flood susceptibility, including terrain characteristics, hydrological behaviour and surface conditions. Remote sensing and Geographic Information Systems (GIS) provide robust analytical capabilities for examining these factors, enabling integration of multi-source datasets such as Digital Elevation Models, land-use imagery, hydrological indices and surface reflectance values to delineate vulnerable areas (Raufu, Mukaila, Olaniyan and Awodele, 2023; Abubakar, Abdullahi, Ahmed, Suleiman, Musa, Lawal and Aliyu, 2025) [10, 1].

Scientific evidence has consistently shown that elevation, slope, drainage density, flow accumulation and land-use patterns exert substantial influence on flood generation and propagation (Iro, 2025). Terrain variables such as slope and elevation determine runoff velocity and concentration, while drainage network characteristics influence peak discharge and flow direction (Jonathan and Han, 2019) [7]. Land-use transitions, particularly the conversion of vegetated surfaces to impervious structures, intensify surface runoff, reduce infiltration capacity and increase the likelihood of flash floods (Blackmore, Thomas and Gemmell, 2016) [2]. Hydrological indices derived from remote sensing, including the Normalized Difference Water Index (NDWI) and the Topographic Wetness Index (TWI), further support flood prediction by quantifying surface moisture, wetness potential and contributing area saturation (Memon, Rehman, Baig and Sahito, 2015) [8].

Previous studies in Nigeria have documented the effectiveness of combining remote sensing and GIS with multi-criteria decision-making techniques to generate accurate flood-hazard maps (Nkeki, Henah and Ojeh, 2013; Raufu, Mukaila, Olaniyan and Awodele, 2023) [9, 10]. However, many earlier assessments applied generalized datasets or broad-scale watershed analyses that do not capture local variations in landscape structure, settlement patterns or hydrological response specific to Nsukka LGA. A significant knowledge gap therefore exists regarding high-resolution, spatially explicit flood-impact modelling within this locality. A methodology capable of integrating high-quality spatial datasets with analytical procedures such as the Analytical Hierarchical Process (AHP) is necessary for generating reliable flood-hazard outputs that can guide informed planning and mitigation.

This study, seeks to fill this gap by identifying key conditioning factors, generating thematic layers, computing relative weights through AHP and producing a spatially detailed flood-hazard map. The integration of hydrological, topographical and land-surface variables produces a comprehensive representation of flood dynamics within the study area. The outcomes are expected to contribute substantially to flood-risk management, land-use planning and disaster-preparedness strategies in Nsukka LGA and wider southeastern Nigeria.

2. Materials and Methods

2.1. Study Area

Nsukka Local Government Area is situated within the northern part of Enugu State in southeastern Nigeria and forms a significant administrative and ecological unit within the region. The area lies within coordinates that approximate latitudes 6° 51′ N to 6° 59′ N and longitudes 7° 16′ E to 7° 28′ E. Nsukka covers an estimated landmass of about 1,810 square kilometers and shares boundaries with Igbo-Etiti to the south, Igbo-Eze South to the north, Uzo Uwani to the west and Isi-Uzo to the east. The town of Nsukka serves as the administrative headquarters and hosts major institutional, commercial and residential developments.

The climate of the area follows the humid tropical pattern typical of southeastern Nigeria, characterized by distinct wet and dry seasons. The wet season spans April to October and features high rainfall intensity influenced by moisture-laden southwesterly winds originating from the Atlantic Ocean. The dry season extends from November to March and is influenced by the northeasterly Harmattan winds that bring dry continental air. Mean annual rainfall values range between 1,500 mm and 2,000 mm, with peak rainfall occurring in the months of July and September. Average temperatures remain relatively high throughout the year, often ranging from 26°C to 32°C, with slight seasonal fluctuations. The combination of high rainfall and moderate evaporation potential creates conditions favourable for rapid runoff generation, particularly in disturbed landscapes.

The geology of Nsukka is dominated by sedimentary formations of the Lower Benue Trough. The principal lithologic units include the Ajali Sandstone and the Nsukka Formation, which consist of friable sandstones, shale intercalations and lateritic overburden. These geologic units influence soil characteristics and hydrological behaviour across the area. The soils are generally sandy to loamy, with moderate to high permeability in vegetated zones and poor infiltration capacity in compacted or exposed surfaces. These soil attributes contribute significantly to the spatial variability in flood response.

The topography of Nsukka is defined by an undulating terrain with elevations ranging from approximately 130 m in the depressional basins to more than 580 m in the upland ridges. The northern and central sectors exhibit broad low-lying plains that accumulate runoff during intense rainfall events, while the surrounding highlands encourage downslope drainage into these basins. The slope gradients vary from level to moderately steep, creating a mixed geomorphic environment that influences the pattern and spread of floodwater. Drainage within the area follows a dendritic network controlled by the natural slope of the terrain. Numerous first and second order streams drain into larger channels which direct flow toward the lower elevation zones, increasing the susceptibility of these areas to seasonal flooding.

Land use in Nsukka reflects a combination of residential development, institutional land parcels, agricultural fields, exposed surfaces and pockets of natural vegetation. Expanding built-up areas associated with the presence of the University of Nigeria Nsukka and related commercial activities have intensified surface impermeability, altered drainage pathways and increased the volume and velocity of surface runoff. Vegetation is concentrated mainly in less developed peripheries, though significant portions have been cleared for cultivation, settlement and infrastructural expansion. The spatial distribution of land-use types contributes appreciably to the hydrological response of the landscape during rainfall events.

The demographic profile of the area features a rapidly growing population driven by urbanization, academic activities and commercial inflows. Increasing population density has heightened pressure on land resources and generated unregulated developments within flood-prone zones. The combined influence of physical, environmental and socio-economic factors makes Nsukka a suitable location for flood-impact studies, requiring spatially driven analysis to guide planning decisions and disaster risk reduction strategies.

2.2. Materials

The secondary data employed in this investigation comprised the following: (i) Landsat ETM imagery of the study area, obtained at a spatial resolution of 30 m; (ii) the Shuttle Radar Topography Mission (SRTM) DEM covering the study region at 30 m resolution; (iii) ArcGIS 10.2 software; (iv) Microsoft Office software; and (v) a laptop computer (Compaq brand). The specific names, types, spatial resolutions, dates and sources of the datasets are summarized in Table 1.

Table 1: Data types and sources

S/NO	Data name	Data type	Resolution	Date	Source
1	Landsat 7 ETM	Secondary data	30 m	2023	USGS
2	SRTM	Secondary data	30 m	2023	USGS

2.3. Data Processing

1. Image Enhancement and Georeferencing

The Landsat 7 ETM imagery was subjected to enhancement procedures to improve the visual distinction of spatial features. The imagery was subsequently georeferenced to convert it into real-world coordinate space. The Universal Transverse Mercator (UTM) coordinate system (Zone 31 North) and the WGS 84 datum were assigned within ArcGIS 10.2, selected for its use of linear metric units and its wide adoption within geospatial analyses (Wilford, 1977).

2. Land Use and Land-Cover Classification

The geo-referenced Landsat imagery (30 m resolution) was clipped to the delineated study area and mosaicked where necessary. The clipped image was overlaid on the study area boundary. An unsupervised classification approach (e.g., ISO-Cluster algorithm) was applied to the image in order to delineate six land-use/land-cover (LULC) classes: waterbody, wetland, forest, agriculture, bare surface and built-up areas. The classification process comprised the following sequential tasks: acquisition of the satellite image; creation of a composite band stack (e.g., false-colour composite) in ArcGIS; clipping to the study area using the Extract by Mask tool; unsupervised classification using the Image Classification tool; re-assignment of spectral clusters to meaningful LULC categories; assignment of symbology to each class; calculation of the area and percentage for each class; and preparation of a map layout (title, legend, scale bar, north arrow) for presentation.

3. Generation of Elevation and Slope Maps

A digital elevation model (DEM) was extracted from the SRTM 30 m dataset within ArcGIS 10.2. From the DEM, slope and elevation maps of the study area were derived using the spatial analysis tools available in ArcGIS. The processing framework included: reading the DEM raster; using the Slope tool (Spatial Analyst toolbox) to compute the slope raster (in degrees or percent rise); and generating the elevation raster if further processing or summaries were required.

4. Drainage Density Computation

Using the SRTM DEM data, hydrological modelling was conducted in ArcGIS 10.2 via the Spatial Analyst toolkit: the sequence comprised Fill (to remove sinks), Flow Direction, Flow Accumulation, Raster Calculator (to derive stream raster), Stream Order, and Stream to Feature conversion. The resulting vector and raster outputs were used to compute drainage density for the study area.

5. Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) was computed in the remote-sensing environment in order to detect open water features and enhance their delineation (Memon *et al.*, 2015) [8]. The steps included: acquisition of multispectral satellite data having green and near-infrared (NIR) bands; extraction of band reflectance values for each pixel; computation of the NDWI as

$$\text{NDWI} = \frac{\text{Green}-\text{NIR}}{\text{Green}+\text{NIR}}$$

Interpretation thresholds were applied: values > 0.3 indicated likely open water; values between 0.0 and 0.3 represented moist soil, wet vegetation or shallow water; negative values corresponded to dry land, soil or dense vegetation.

6. Topographic Wetness Index (TWI)

The DEM processed earlier was further used to compute the Topographic Wetness Index (TWI) for the study area. Processing steps included activation of the 3D Analyst extension in ArcMap; removal of terrain sinks; calculation of Flow Direction and Flow Accumulation rasters; calculation of the Slope raster (in radians) using the Slope tool; and finally entering the expression

$$\text{TWI} = \ln!\left(\frac{\text{Flow Accumulation}}{\tan(\text{Slope}_{\text{rad}})}\right)$$

into the Raster Calculator to produce the TWI raster, which serves for identifying zones of potential soil saturation or runoff accumulation.

7. Derivation of Criterion Weights Using the Analytic Hierarchy Process (AHP)

A hierarchical decision-framework was developed for the six thematic maps derived earlier. The process followed the methodology outlined by Thomas L. Saaty (1980). First, the problem was defined and decomposed into thematic layers each containing distinct features or classes. Pair-wise comparison matrices were then generated, utilizing the 1–9 intensity scale, by which a score of 1 denotes equal importance and 9 signifies extreme preference of one attribute over another. The corresponding fundamental scale was adapted from Saaty (1980). Subsequently the consistency ratio was verified and normalized weights were computed for each thematic layer.

3. Results

3.1. Identification of Different Conditioning Factors for Assessing Flood Impact in The Study Area.

The selection of the conditioning factors (criteria) for this study was based on literature review, expert opinion and available data for the study area. As earlier mentioned, seven conditioning factors were considered for the purpose of this study. The various data required for this study were collected and processed in the GIS environment to obtain thematic layers of the conditioning factors. The different criteria identified were considered as the main factors necessary for assessing flood impact and measuring its hazard for the study. The factors include; elevation, drainage density, normalized differential water index (NDWI), slope, topographic weighted index (TWI), flow accumulation and land cover/land use. All criteria were later reclassified, and a weighted overlay was used to assign preference value to different classes.

3.2. Generation and reclassification of thematic layers for the identified factors

3.2.1. Elevation

Table 1: Unified preference value for elevation

S/N	Elevation(m)	Preference Value	Flood Hazard class
1	130-250	5	Very High
2	260-320	4	High
3	330-390	3	Moderate
4	400-460	2	Low
5	470-580	1	Very low

The elevation of the study area was derived from SRTM DEM which acquired from USGS website is shown in Figure 1. The elevation was reclassified based on their effect on flooding. Areas with the least elevation were ranked 5 while areas with the highest elevation were ranked 1. White colour in Figure 1 shows elevation ranges between 470m-580m which was rank as highest due to its contribution to flooding, cherry cola shows elevation between of 400m-460m, green shows elevation within 330m-390m, light blue shows elevation range of 250m-320mand light blue shows elevation range of 230m-130m. Table 1 shows the elevation ranges, preference value, and flood hazard class of the elevation criteria.

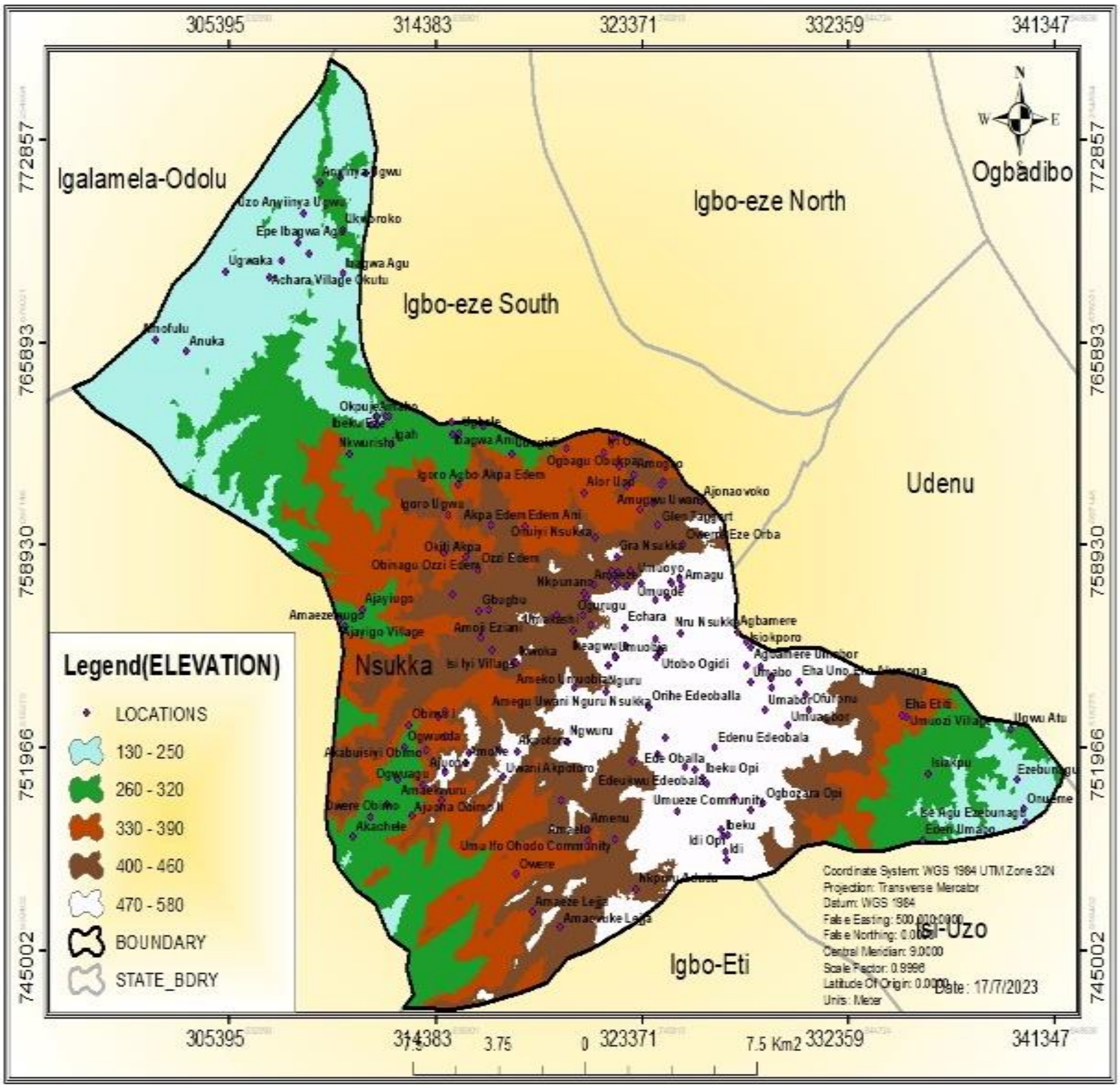

Fig 1: Elevation map of the study area.

3.2.2. Slope

The slope map (Figure 2 and table 2) indicates that low slope areas (0 to 120) are flood prone. Moderate slope areas (1.121 to 3.035) are less vulnerable to flood while high slope areas ranging from 3.005 to 11.861 are not vulnerable to flood. The slope is the ratio of steepness or the degree of inclination of a feature relative to the horizontal plane. According to Jonathan and Han (2019) [7], slope is one of the most important and reliable factors to take into account when dealing with flooding. As the slope degree or depreciate, flooding increases. The ratio of a feature's steepness or degree of inclination in relation to the horizontal plane is another name for this. It is typically expressed as a percentage or degree. The slope map of the region, which was generated using a digital elevation model with a resolution of 30 meters and was measured in percentage, is depicted in Figure. Contour lines derived from the topographical map can be used to generate slope or it can be achieved directly using a digital elevation model (DEM). The slope classification in Nsukka LGA is shown in Table 2 with preference value of percentage of slope areas with the lowest degree of slope (0-200) were ranked high preference value for slope while areas with 1400-3000 were ranked lowest. The slope map demonstrates that the Amaeze, Ubogidi and Ibeku region is level, Ngwuru and Eden region is on a very gentle slope, Amoji and Ibimo 1 regions are on a gentle slope, Ogwuagu and Isiakpu regions are in the sleep area.

Table 2: Slope classification and Unified preference value in NSUKKA LGA

S/N	Slope(percentage)	Terminology	Preference value	Flood hazard class
1	0 – 200	Level	5	Very high
2	210– 420	Very gentle slope	4	High
3	430 – 760	Gentle slope	3	Moderate
4	770 – 1300	Moderate slope	2	Low
5	1400 – 3000	Steep slope	1	Very low

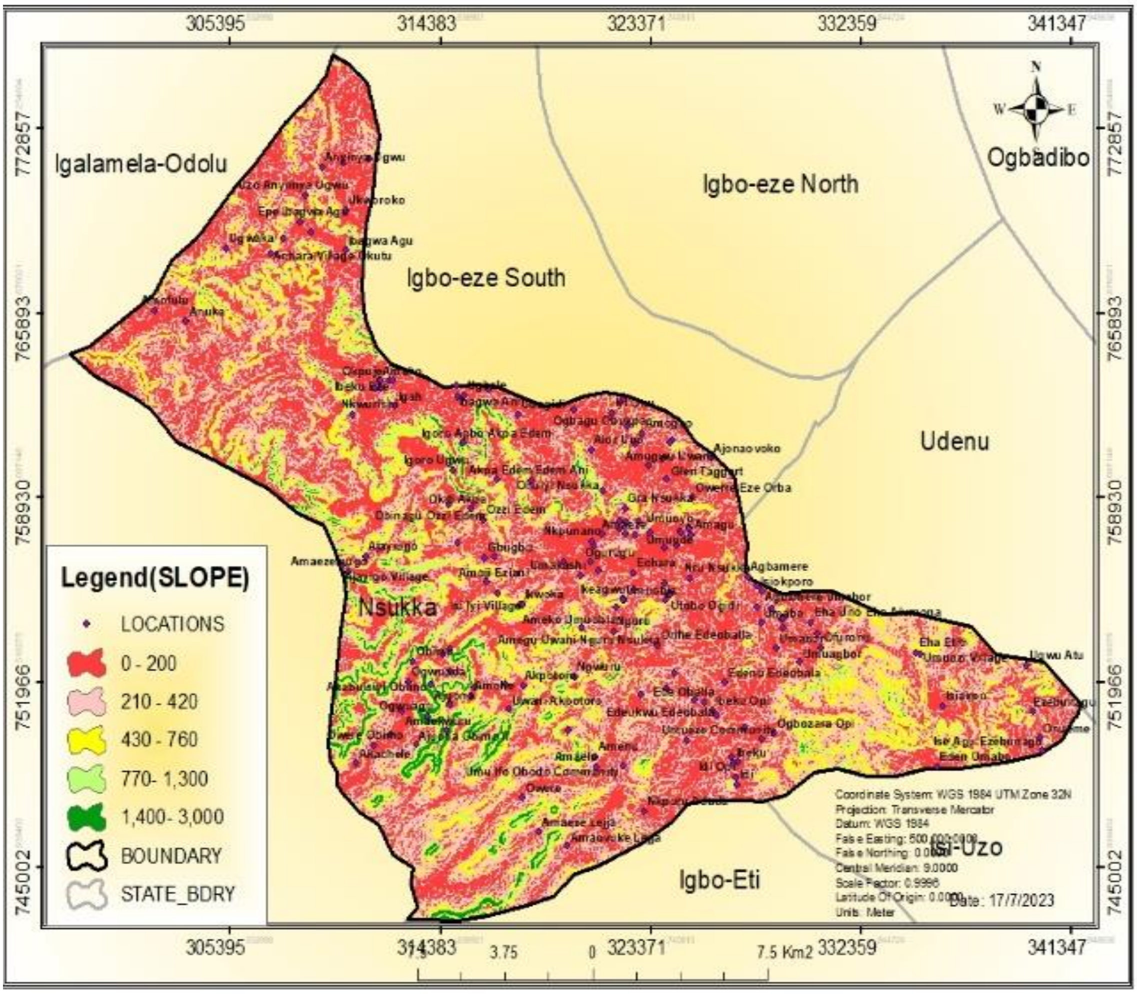

Fig 2: Slope map of the study area.

3.2.3. Flow Accumulation

The Flow Accumulation function was used to generate the convergence point for the surface run-off in different basin in the study area. The buildings and other structures that concentrate within the basin are naturally more vulnerable to flood. There is High Accumulation Rate around the White Areas (Yellow Circle) while The Black Surrounding stands for low accumulation rate. Areas where flow accumulation is high are usually at higher risk and more vulnerable to flood. Such areas serve as a convergence point for surface run-off. Figure 3 shows the flow accumulation map. Experience shows that these areas with high flow accumulation experience flash flood annually.

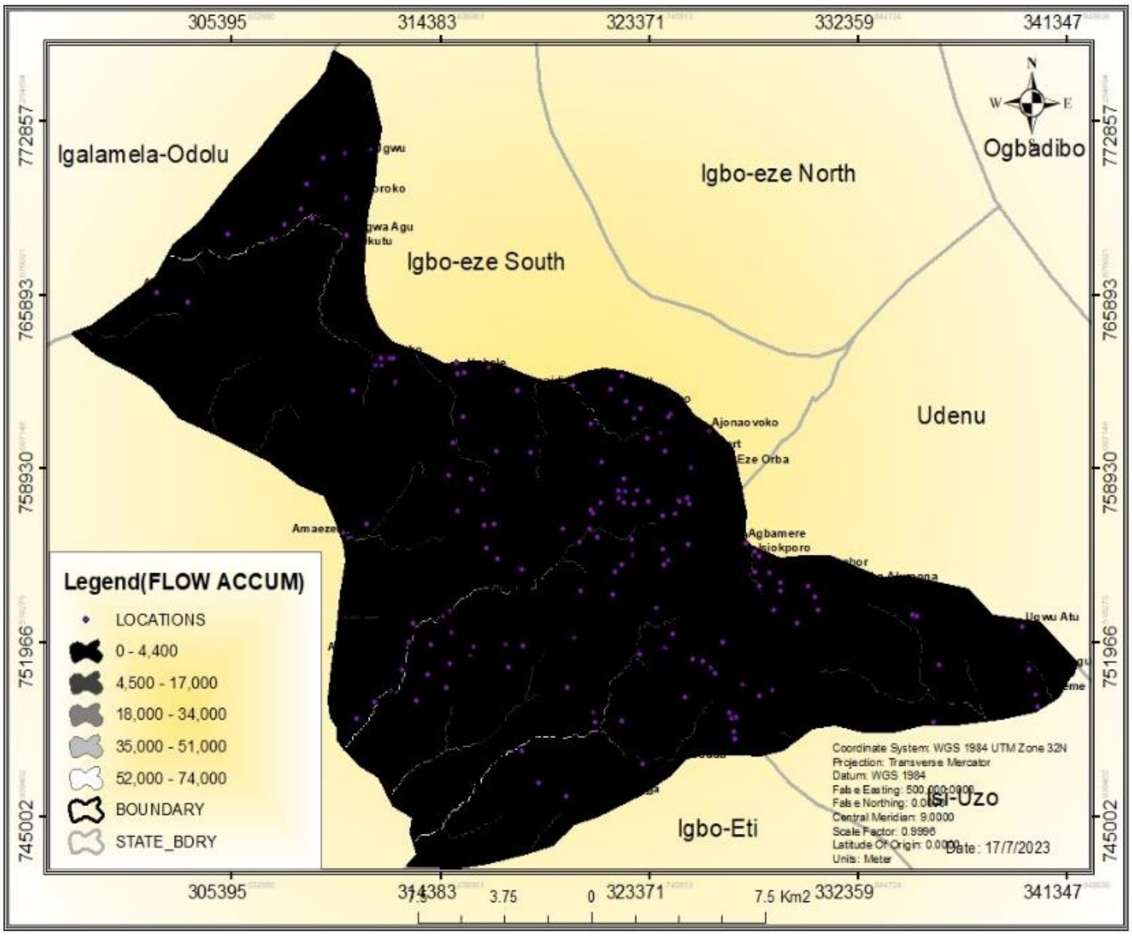

Fig 3: Flow accumulation map of the study area.

3.2.4. Land Use/Land Cover

Figure 5 is a classified Operational Landsat Image (OLI-TIRS) for the year 2023; the image was classified into 4 classes of land use land cover of the study area. The classification was done with ERDARS IMAGINE 2015 software using supervised classification scheme. The red class represents the settlement area, yellow indicates the exposed surface areas, green is the vegetation cover and Seville orange is the bare soil. Vegetation and forests increase the infiltration and storage capacities of the soils. Further, they cause considerable retardance to the overland flow. Thus, the vegetal cover reduces the high flood. This effect is usually very pronounced in small catchments of area.

Land use and Land cover map is one of the important factors consider in this present analysis to determine the flood vulnerability case in Nsukka. The landuse map vulnerability to flood was determined according to the vulnerability levels assigned to each Landuse identified in the study area. Table 3 explained the types of landuse discovered and the spatial extent of each of them. The settlement and exposed surface have the highest spatial extent 20945.12haand 12819.78ha respectively, followed by vegetation having9010.44ha. The analysis also revealed that bare soil recorded in the area is very low 6953.49ha which can be attributed to urbanization and other anthropogenic activities in the area. The distribution of the Land use/Land cover map, depicted in Figure 4. Exposed surface and bare soil dominate the Land use/Land cover map of Nsukka, which is depicted in the figure 5 below in many areas around the north-west portion of the study area.

Table 3: Statistical analysis of Land use/land cover of Nsukka for 2023.

Land cover / Land use Class of the study area.			
S/N	**Class Name**	**Area(ha)**	**Area (%)**
1	Settlement	20945.52	42.12
2	Vegetation	9010.44	18.12
3	Exposed surface	12819.78	25.78
4	Bare soil	6953.49	13.98
	Total	49729.23	100

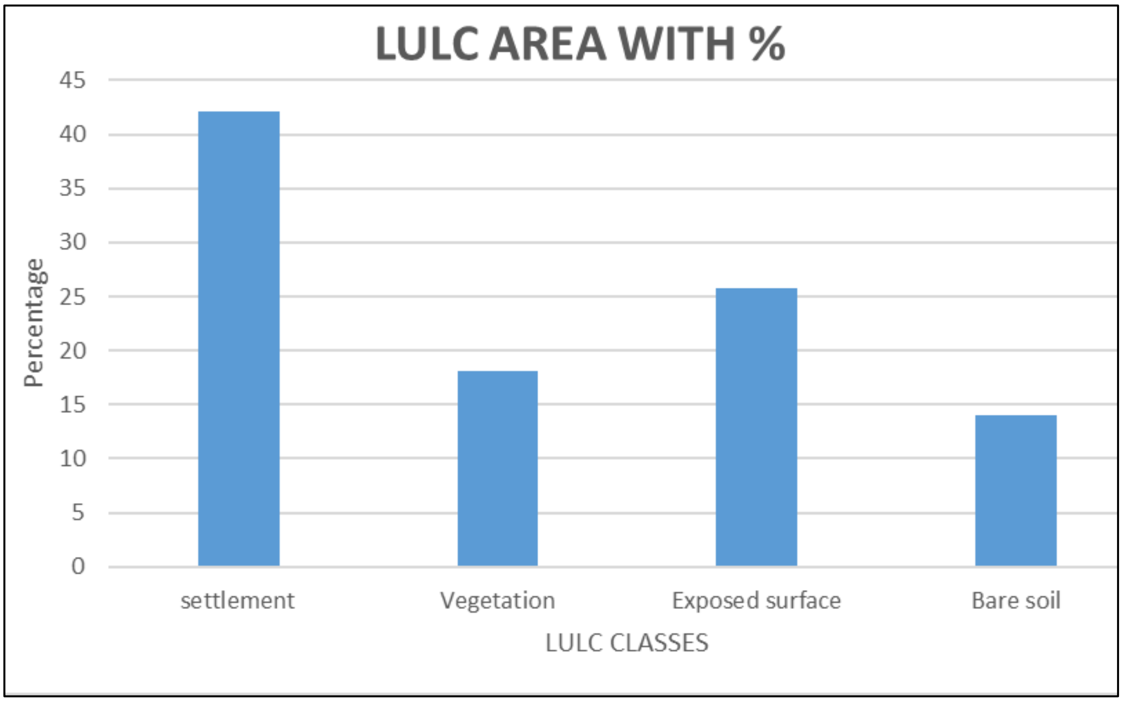

Fig 4: Bar chart depicting LULC classes and its percentage.

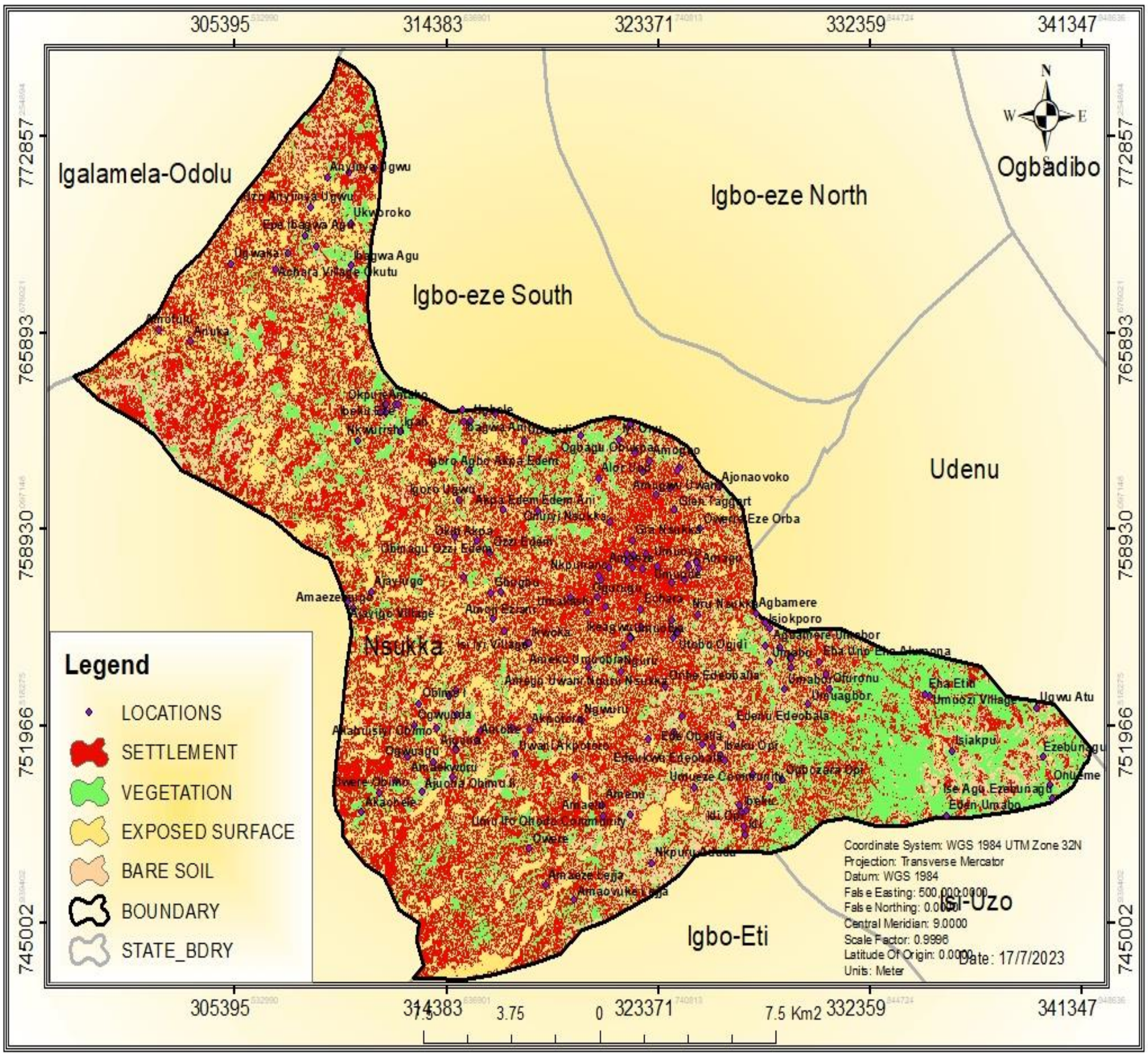

Fig 5: Land use /Land cover map of the study area.

3.2.5. Drainage Density

Drainage density (DD) is the ratio of the sum length of streams in the watershed over its contributing area. Drainage density influences the water output and sediment from the system. Low drainage density area is commonly found in high permeable soil and high-density vegetation; high drainage density area is commonly found in the impermeable surface material (e.g., rocky hill slopes), arid area and areas with sparse vegetation cover. The seepage thickness arrangement of the review region was seen to be impacted by the low alleviation of the area, which demonstrated dendritic and less equal example of the seepages in South to North heading. Seepage thickness is a proportion of how well or ineffectively a waste framework is depleted by stream channels. Drainage density has two influences regarding peak of the flood, direct (e.g., the length of stream network and hillslope paths) and indirect (e.g., geomorphology). Figure 6 displays the drainage density; it was generated from GSI DEM. We extracted the elevation from the DEM data and created the stream from the elevation map. We generated the stream order and calculated the catchment area. Rationing the stream total length and catchment area followed.

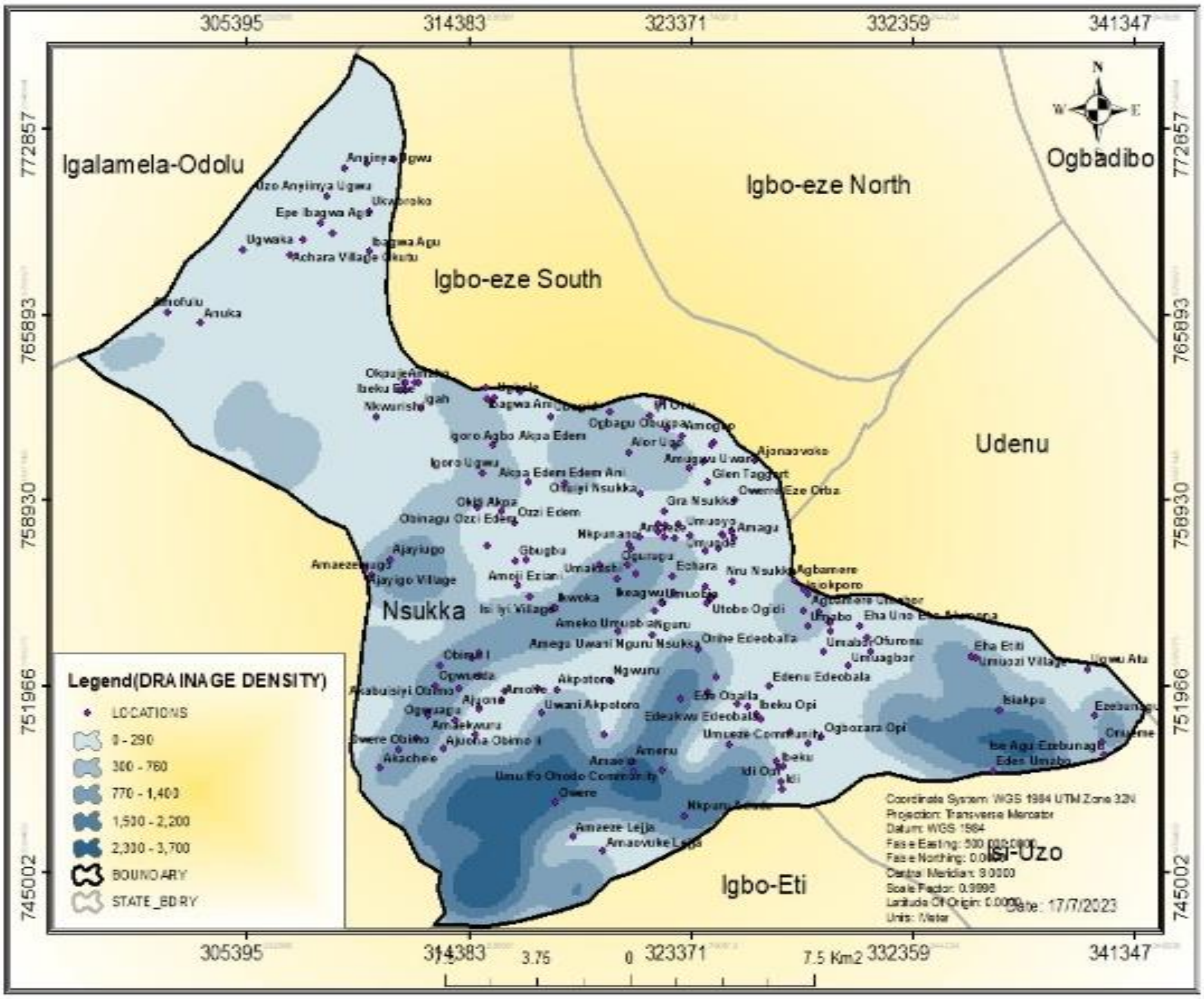

Fig 6: Drainage density of the study area

3.2.6. Normalized Difference Water Index (NDWI)

There are various vegetation records created to gauge vegetation cover with the Remote Detecting imagery. A vegetation file is a number that is produced by a mix of Remote Detecting groups. The most well-known phantom record used to assess vegetation cover is the Normalized Difference Vegetation Index (NDVI). McFeeters (1996) developed a record like the NDVI, which is known as the NDWI. In Remote Sensing, the Normalized Difference Water Index (NDWI) is being used to better define open water features and increase their presence. The large portion of the review region is paddy fields, since vegetation has moderately high reflectance in NIR locale, so the NDWI couldn't consider water under vegetation and eventually misjudge the immersed region (Memon *et al*., 2015) [8]. Aversion to the water considered paddy fields as an area of water bodies (Blackmore *et al*, 2016) [2]. It is very strong index to for plant water stress. This can be used to isolate water from non-water area, see figure 7.

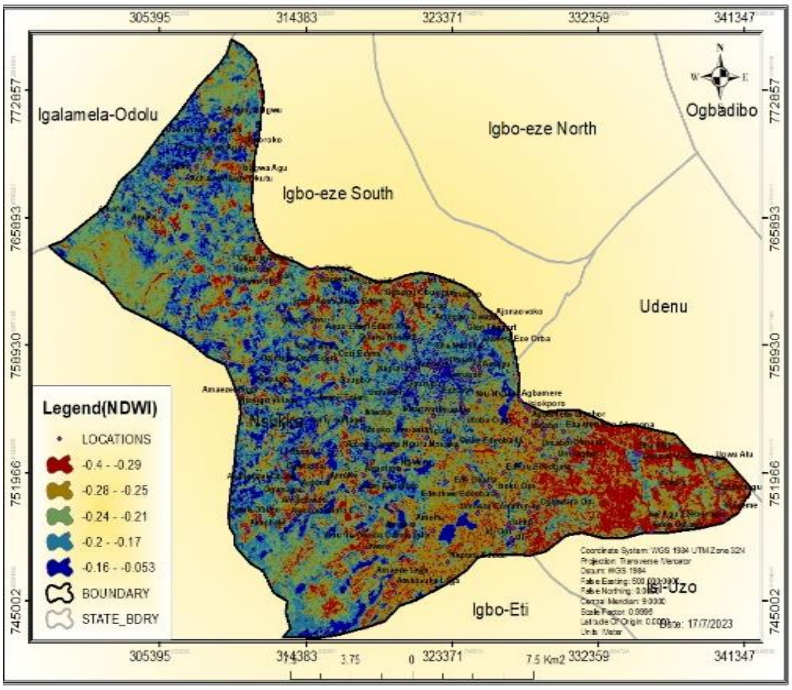

Fig 7: Normalized difference water index map of the study area.

3.2.7. Topographic weight index

Once the upslope contributing area raster (*a*) and the slope raster (tan β) are generated, these layers are combined on a cell-by-cell basis using the TWI equation. The end result is a TWI raster in which each cell is assigned a wetness indicator value [$I=\ln(a/\tan\beta)$]. TWI provides important information at very low cost compared to detailed hydrologic and hydraulic studies and is an excellent planning tool. Cells with a lower esteem address region with steepest incline and will more often than not be edges or peaks present on the scene. Cells with a lower index value represent areas with steepest slope and tend to be ridges or crests present on the landscape. Higher cell values represent areas with increased accumulated runoff potential. These areas are identified by a low slope and large upslope contributing areas, see figure 8.

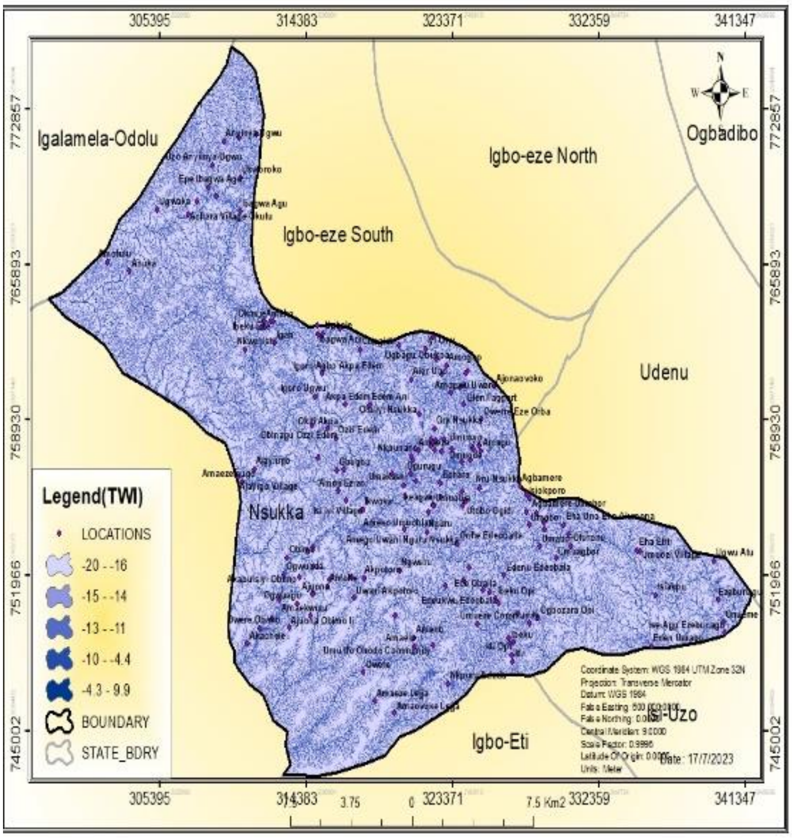

Fig 8: Topographic weight index map of the study area.

3.3. Weights of Criteria Computation Using Analytical Hierarchical Process (AHP) (objective III)

AHP is utilized to work out weight of rules for direction, the general significance of highlights of every individual parameter to flood weakness planning not entirely set in stone. Every one of the flood weakness factors was weighted utilizing AHP. Processes required for the task of loads to measures are: a pair-by-pair comparison matrix, as well as the calculation of the consistency index and ratio, see table 4.

Table 4: Normalized Weight Assessment by Ranking

S/N	Factors	Values	Ranking	% Influence	Vulnerability
1	Elevation	131 - 253	5	35.09	Highest
		253- 322	4		High
		322 - 391	3		Moderate
		391- 458	2		Low
		458 - 584	1		Lowest
2	Slope	0 - 200	5	25.95	Highest
		210 - 420	4		High
		430 - 760	3		Moderate
		770 - 1,300	2		Low
		1,400 - 3,000	1		Lowest
3	Flow Accumulation	0 - 4,400	1	5.94	
		4,500 - 17,000	2		
		18,000 - 34,000	3		
		35,000 - 51,000	4		
		52,000 - 74,000	5		
4	Land Use/Land Cover	SETTLEMENT	2	12.47	Moderate
		VEGETATION	1		Low
		EXPOSED SURFACE	3		High
		BARE SOIL	4		Highest
5	TWI	-20 - -16		2.31	
		-15 - -14			
		-13 - -11			
		-10 - -4.4			
		-4.3 - 9.9			
6	Draiange Density	0 - 290	1	14.62	Very Low
		300 - 760	2		Low
		770 - 1,400	3		Moderate
		1,500 - 2,200	4		High
		2,300 - 3,700	5		Very High
7	NDWI	-0.4 - -0.29	5	3.62	
		-0.28 - -0.25	4		
		-0.24 - -0.21	3		
		-0.2 - -0.17	2		
		-0.16 - -0.053	1		

Table 6 and 7 shows the results of the pairwise comparison and the interpretation of symbols (Normalized principal Eigenvector) used in depicting the different factors.

Table 6: Matrix of pair-wise comparisons of the seven (7) criteria for the AHP process

Matrix		DRAINAGE DENSITY 1	SLOPE 2	ELEVATION 3	LULC 4	NDWI 5	TWI 6	ACCUMULATION 7	0 8
DRAINAGE DENSITY	1	1	1/5	1/3	2	5	9	3	-
SLOPE	2	5	1	1/2	2	5	5	5	-
ELEVATION	3	3	2	1	5	9	7	5	-
LULC	4	1/2	1/2	1/5	1	5	9	3	-
NDWI	5	1/5	1/5	1/9	1/5	1	3	1/2	-
TWI	6	1/9	1/5	1/7	1/9	1/3	1	1/5	-
ACCUMULATION	7	1/3	1/5	1/5	1/3	2	5	1	-
0	8	-	-	-	-	-	-	-	1

Table 7: Interpretation of criteria symbols (Normalized principal Eigenvector

Factor No	Factors	Weight (%)
1	Drainage density	14.62
2	Slope	25.95
3	Elevation	35.09
4	LULC	12.47
5	NDWI	3.62
6	TWI	2.31
7	Flow Accumulation	5.94

3.4. Weighted Overlay for Flood Hazard Mapping

Multi-Criteria Analysis was applied in producing and combining spatial data describing causative factors. In the first part, the flood risk factors were produced as a numerically map layer describing the study area. All criteria (flood risk factor maps) were combined by weighted overlay analysis where continuous criteria (factors) were standardized to a common data model that was in raster layer with a common resolution and analytical hierarchical process method was used, where, every criterion under consideration is ranked in the order of universally acceptable flood risk influence. To generate criterion values for each evaluation unit, each factor was weighted accordingly to the estimated significance for causing flooding. With this method, 1 was the least important and 5 was the most important factor. The criterion maps in raster grids were mathematical processed and spatial analyst tool in ArcGIS 10.5 version was used. The weighted overlay tool of ArcGIS software combined the weight and ratio of each susceptibility factor through multiplying of their calculated ratio to determine its total weight. We applied the weighted overlay method in creating the flood hazard map. In order to perform this analysis, we estimated the weights of the seven criteria identified as contributing factors to flooding in the area. The AHP and Shannon Entropy weighting methods were used for the weight estimation, and eventually, a combined (Hybrid) weight was adopted in our hazard map production.

Five qualitative-based flood vulnerable zones were identified in this study, as shown in Figure 9. As we can see from this figure, flood-prone areas based on the severity of the flood as very high (red), high (yellow), moderate (light- green), low (light-blue), and very low (pick) were identified. The corresponding percentage of the vulnerable areas to the qualitative classifications are 4.66 %, 17.23%, 40.72%, 25.52%, and 11.86%. Also, the area covered were estimated as, the very high hazard areas covered 2319.0 ha, the high hazard areas covered 8570.0ha, the moderate hazard areas covered 20250.23ha and the low hazard areas covered 12690.0ha as shown in Table 8. The percentage of various classes of flood hazard is shown in table 7 as well as bar chart to present the result.

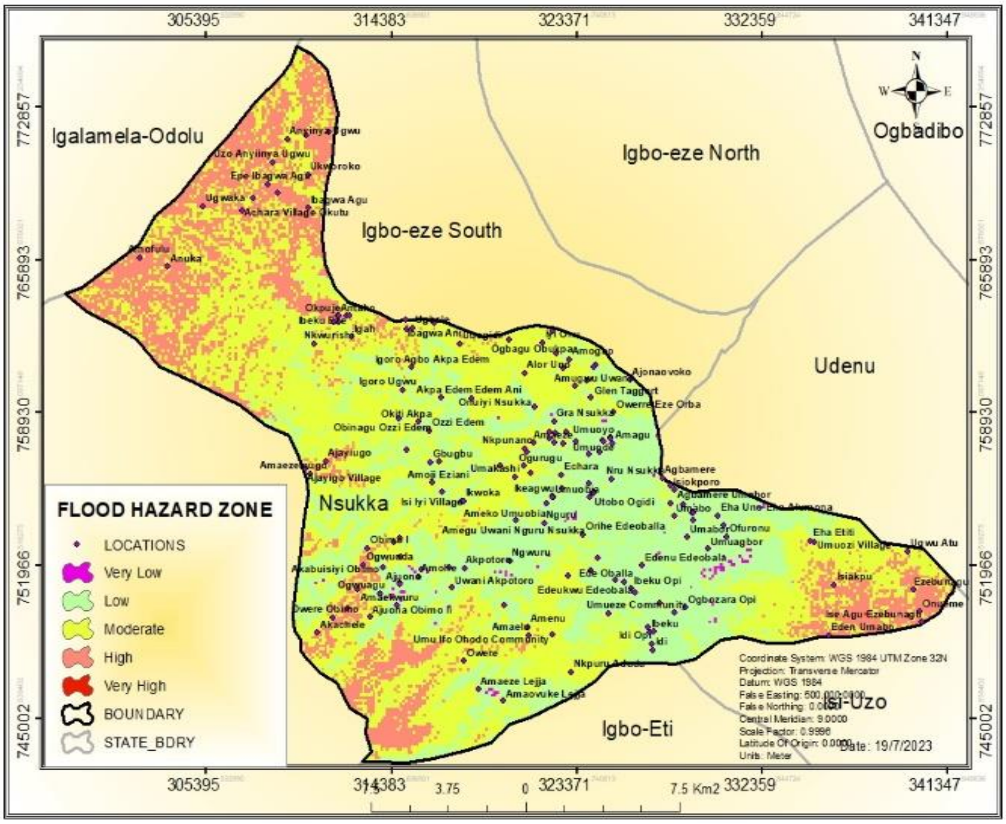

Fig 9: Flood Impact map of Nsukka LGA.

Table 8: Flood vulnerability area

Flood Hazard classes	Area(ha)	Percentage%
Very low	5900	11.86425
Low	12690	25.51819
Moderate	20250.23	40.72098
High	8570	17.23333
Very High	2319	4.663253
Total	49729.23	100

4. Discussion of Results

The spatial analysis of flooding within Nsukka LGA demonstrates that the geomorphic and environmental characteristics of the landscape strongly influence the distribution and magnitude of flood susceptibility. The integration of elevation, slope, drainage density, flow accumulation, land use and land cover, NDWI and the topographic wetness index enabled a multi-dimensional evaluation of the physical factors governing flood dynamics in the area. The discussion presented here synthesizes the thematic layers and weighted analysis outputs to elucidate the mechanisms underlying the identified flood hazard zones.

4.1 Influence of Topography on Flood Susceptibility

The elevation model reveals that low-lying terrain between 130 m and 250 m exhibits the highest susceptibility to flooding. The transition from very low hazard in the upper highlands to very high hazard in the depressional zones corresponds to the natural drainage direction and the gravitational migration of surface runoff. Areas within the 470 m to 580 m band demonstrate negligible vulnerability, confirming that topographic prominence facilitates rapid overland flow and reduced water retention. The slope analysis supports this observation. Level and very gentle slopes dominate the central and southern parts of the LGA and coincide with the flood-prone localities such as Amaeze, Ubogidi and Ibeku. These areas exhibit minimal gradient, which slows the velocity of overland flow, increases infiltration limits and enhances surface water ponding. Moderate to steep slopes in regions such as Ogwuagu and Isiakpu demonstrate very low flood susceptibility because the steeper gradients promote downslope water evacuation. This agrees with established hydrological principles that associate gentle slopes with extended runoff residency and higher inundation probability. The combined interpretation of elevation and slope therefore shows that topographic controls are the dominant determinants of flood occurrence in Nsukka.

4.2 Hydrological Controls: Flow Accumulation and Drainage Density

The flow accumulation pattern reveals several convergence zones that function as receiving points for large volumes of surface runoff. These areas consistently experience annual flash flooding due to cumulative contributions from upstream catchments. The high accumulation cells correspond with zones of low elevation and gentle slope, which confirms the interplay between terrain configuration and basin hydrodynamics. Drainage density also exerts a significant influence on flood potential. Areas of low drainage density, particularly those characterized by permeable soils and notable vegetation cover, demonstrate lower hazard because the subsurface infiltration capacity is comparatively high. Conversely, high drainage density values are associated with shallow soils, exposed surfaces and reduced infiltration, leading to high runoff coefficients. The dendritic drainage pattern observed across the LGA suggests that water channels coalesce rapidly during rainfall events, thereby amplifying peak discharge and exacerbating downstream flooding. The spatial heterogeneity of drainage density therefore contributes to the varying magnitude of flood impact across the landscape.

4.3 Vegetation, Surface Exposure and Land Use Patterns

The land use and land cover distribution shows that exposed surfaces and settlement areas occupy the widest proportions of the landscape, accounting for more than sixty percent of the total area. These land cover types exhibit low infiltration because of soil compaction, impervious construction materials and land degradation. Their dominance therefore elevates flood susceptibility significantly, particularly in northern and central zones of Nsukka where exposed surfaces and bare soils are concentrated. Vegetation cover occupies a smaller proportion of the area and serves as an environmental buffer where soil structure, organic content and root networks improve infiltration and reduce runoff. The limited extent of vegetation, as revealed in the results, indicates that nature-based flood attenuation functions are restricted. This aligns with the high hazard levels identified in densely settled zones where natural surfaces have been replaced by impervious infrastructure. The spatial configuration of urban expansion and exposed surfaces therefore constitutes an anthropogenic driver of flood risk in the area.

4.4 Water Presence and Soil Wetness Distribution

The NDWI map demonstrates the distribution of surface water and moisture-rich areas. Cells with high NDWI values correlate with locations of recurrent saturation, wetlands and minor depressions. These areas align with the zones of high flow accumulation and gentle slope, indicating that saturation potential is influenced by both hydrologic convergence and limited drainage efficiency. The NDWI results further suggest that localized inundation persists even after rainfall cessation due to the slow redistribution of water across flat terrain. The topographic wetness index provides clearer evidence of areas likely to experience persistent surface wetness. High TWI values identify terrain positions with low slope angles and large upslope contributing areas, making them natural receptacles for runoff. These zones coincide with the moderate and high hazard classes mapped in the weighted overlay, confirming that topographic control of soil moisture accumulation plays a major role in the spatial pattern of flood impact.

4.5. Weighted Prioritization of Flood Conditioning Factors

The Analytical Hierarchy Process reveals the relative significance of each factor. Elevation is the most influential parameter with a weight of 35.09 percent, while slope ranks second with 25.95 percent. This high weighting validates the earlier discussion that terrain configuration fundamentally governs flood potential within the study area. Drainage density and land use follow with moderate weights, indicating their contributory but spatially variable influence. Flow accumulation, NDWI and TWI carry lower weights, indicating that although these factors are relevant, their relative impact is secondary to the dominant topographic controls.

The consistency of the AHP judgments, validated through the normalized eigenvector, strengthens the reliability of the weight assignment and confirms that the methodological structure accurately reflects the hydrological realities of Nsukka LGA.

4.5 Spatial Pattern of Flood Hazard Zones

The weighted overlay result classifies Nsukka into five hazard categories. Moderate hazard zones dominate with 40.72 percent of the total area, reflecting the widespread presence of gentle slopes and mid-range elevations. Low hazard zones occupy 25.52 percent of the area, indicating that parts of the landscape possess favorable drainage and slope characteristics. High hazard zones account for 17.23 percent of the total area and are concentrated around drainage convergence zones and densely settled surfaces. The spatial configuration of these zones confirms the influence of both natural drainage patterns and anthropogenic alteration of the landscape. Very high hazard zones represent only 4.66 percent of the total area, yet these locations pose significant risk due to their recurrent inundation and low-lying terrain. The low proportion does not diminish their importance because these zones typically contain high densities of vulnerable infrastructure and population. Very low hazard zones represent 11.86 percent of the area and are concentrated in higher elevation ridges and zones with steep slope gradients. These areas demonstrate effective natural drainage and minimal water retention, confirming their environmental suitability as safe locations during intense rainfall.

4.6 Implications of the Spatial Flood Pattern

The results demonstrate that flood hazard in Nsukka is controlled predominantly by topographic gradients, anthropogenic land surface changes and hydrological convergence. Areas undergoing rapid urbanization without appropriate drainage infrastructure face elevated risks. Likewise, communities located within depressional topography remain highly vulnerable due to natural water concentration processes. The dominance of moderate hazard zones indicates that much of the LGA possesses inherent geomorphic sensitivity, requiring strategic land management and infrastructural interventions to reduce future flood damage.

5. Conclusion

The assessment of flood impact in Nsukka LGA demonstrates that the spatial distribution of flood hazards results from a complex interaction of topographic, hydrological and land use characteristics. The integrated analysis of elevation, slope, flow accumulation, drainage density, land use and land cover, NDWI and the topographic wetness index provided a coherent framework for interpreting how geomorphic structure and anthropogenic modification influence flood behaviour within the area. The elevation and slope factors exhibited the strongest influence on flood susceptibility, confirming that the terrain configuration governs surface runoff pathways, water concentration patterns and the degree of inundation. The prominence of low-lying and gently sloping terrain across large portions of the study area created natural conditions conducive to extended water retention and recurrent flooding. Land use dynamics further intensified hazard levels, particularly in zones dominated by settlements, exposed surfaces and bare soils. These areas displayed reduced infiltration potential and higher runoff volumes, indicating that ongoing urbanization continues to alter the hydrological balance of the landscape. Hydrological indices, particularly flow accumulation and drainage density, highlighted specific locations where surface water converges rapidly during rainfall, producing high localised flood intensity. The NDWI and TWI results complemented this understanding by identifying moisture-saturated and low-gradient zones where water persists long after rainfall episodes. The application of the Analytical Hierarchy Process established a rational method for weighting the conditioning factors, producing a flood hazard map that reflects both physical realities and consistent methodological judgement. The resulting classification identified moderate hazard zones as the most extensive category, followed by low and high hazard zones, with very high hazard zones forming smaller pockets within the most vulnerable low-lying terrain. This distribution pattern demonstrates that Nsukka LGA requires targeted mitigation strategies tailored to the varying degrees of hazard severity.

The findings therefore provide a scientifically grounded basis for guiding land use planning, infrastructural development and disaster risk management across the LGA. The study establishes the importance of integrating geospatial data, multi-criteria evaluation and hydrological reasoning in flood assessment, offering a valuable reference for future environmental management initiatives in the region.

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How to Cite This Article

Igbokwe JI, Agu MU, Oburo AC, Oliha AO. Assessment of Flood Impact in Nsukka Local Government Area of Enugu State Using Remote Sensing and GIS Approach. Int J Multidiscip Res Growth Eval. 2025;6(6):774-786.