GEOSPATIAL ANALYSIS OF FLOOD RISK AREAS IN MAIDUGURI METROPOLIS, BORNO STATE, NIGERIA

By

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ABSTRACT

Floods are devastating natural hazards that cause loss of lives, displace communities, and disrupt economic growth. Geospatial analysis can identify flood-prone areas and inform policy decisions. The study presents a geospatial analysis of flood risk areas in Maiduguri Metropolis, Borno State, Nigeria, using a quantitative research approach based solely on secondary data. Data sources included SRTM 30M Digital Elevation Model (DEM), Landsat 30m imagery, rainfall records, and Nigeria shapefiles. These datasets were analyzed using ENVI 5.3 and ArcMap 10.8, to identify key flood-inducing factors such as elevation, slope, drainage density, distance from rivers, Topographic Wetness Index (TWI), land use/land cover (LULC), and rainfall distribution. The Analytical Hierarchy Process (AHP) was used to rank these factors, followed by Multi-Criteria Analysis (MCA) to generate a flood risk map. The findings revealed that more than 70% of the metropolis is located in high to very high flood risk zones, mainly due to low elevation, gentle slopes, and close proximity to rivers. Rainfall emerged as the most prominent flood causative factor, followed by TWI and elevation. The study also observed significant urban expansion, with built-up areas increasing from 21.7% in 2004 to 61.3% in 2024, accompanied by a sharp decline in agriculture and vegetative land. This rapid urbanization strongly correlates with increased flood vulnerability, as evidenced by a high R^2 value (0.997) linking urban land use change to flood events, flood risk analysis showed that 41.9% of the area falls within moderate flood-prone zones, 28.9% within high-risk zones and only 29.2% in low-risk zones. These findings underscore the urgent need for flood mitigation strategies, including extended drainage system, early warning mechanisms and strategic urban planning.

Keywords: Flood Risk, Geospatial Analysis, Maiduguri Metropolis

INTRODUCTION

Floods have been a troubling natural hazard that disrupts human activities and socioeconomic development and growth. It occurs when there is an imbalance (rainfall greater than infiltration) between rainfall intensity and infiltration rate into the ground, coupled with associated factors. According to Djimesah et al. (2018), it is the result of excessive overflow of water onto land, which is usually dry. Today, factors such as climate change, rapid urbanization, deforestation, and inadequate drainage systems are largely attributed to the increasing frequency and intensity of flood events, which result in the loss of lives and properties and homes, pose challenges to the socioeconomic status, and affect food security in the affected area (Gifsep, 2023). For instance, the National Emergency Management Agency (NEMA, 2022), reported that floods in 2022 alone affected over 3.2 million people, destroying critical infrastructure and disrupting livelihoods in Nigeria. Therefore, its harmful impacts should not be overlooked.

Maiduguri Metropolis, the capital of Borno State, has become a vulnerable hotspot for urban flooding due to the rapid urbanization of the city and climate change. Musa et al. (2020) evaluated the impact of flooding on urban development in Maiduguri, highlighting the need for effective drainage systems and flood control measures. Floods in the metropolis are one of the most recurring and destructive natural disasters. In general, the frequent and exaggerated floods seen in metropolis and other cities have also been paired with poor drainage systems in place, uncontrolled construction on flood lines and changes in climate trends (Kaka et al., 2019).

Historically, Maiduguri has witnessed several devastating flood events, and one of the most well-known floods was in 2012 when torrential rains caused the River Ngadda to overflow its banks, spilling over large volume of water into the city (NEMA, 2012). During this flood, more than 30,000 people were estimated to have been affected by flooding in Borno State, while Maiduguri alone accounted for over 15,000 internally displaced persons (IDPs) (NEMA, 2012). Numerous houses were destroyed by water, farmland turned into lakes, and public facilities were greatly damaged, worsening the situation of communities that have already been struggling due to Boko Haram terrorism according to the report. Nilsson et al. (2016) evaluated the impact of flooding on agricultural productivity in the Lake Chad Basin, highlighting the need for climate-smart agriculture practices.

In addition, in 2019 there was a widespread flood in the area. A report from the Borno State Emergency Management Agency (BOSEMA) showed that more than 2,000 families were affected, six people were reported to have died, and properties worth more than 350 million were destroyed (BOSEMA, 2019). Recently, in 2022, severe rain was flooded with areas such as Bulumkutu, Gwange, and Dala, how poorly dried urban setups complicated risks, which affected hundreds of inhabitants (NEMA, 2022). In September 2024, the metropolis experienced its most devastating floods in three decades, which began with the failure of the Alau Dam after heavy rain. This disaster drowned about 40% of the city, caused the displacement of more than 400,000 inhabitants and death of at least 150 people (NEMA, 2024). Kundzewicz et al. (2014) discussed the challenges of flood management in developing countries, highlighting the need for a comprehensive approach that incorporates climate change projections and socio-economic factors.

Past studies have investigated the metropolis' physical and geospatial factors, which include terrain-related factors of flood risk (Jimme et al., 2019; Kaka et al., 2019), physiography (Sambo & Ikusemoran, 2022), flood-prone areas along major waterways (Obroh & Sambo, 2022), amongst others; there remains a knowledge gap to be filled. A comprehensive geospatial flood risk analysis from this study integrates multiple physical (topographic) and hydrological factors (e.g., topographic wetness index, land use/land cover, drainage networks, elevation, slope, rainfall, distance from rivers, and built-up areas), providing a holistic flood risk model of the study area.

This study aims to conduct a geospatial analysis of flood risk areas in Maiduguri Metropolis, Borno State. The specific objectives are to identify topographic and hydrological factors contributing to flooding, create a flood risk map of the study area and assess the relationship between urban land use changes and flood risk.

THE STUDY AREA

Maiduguri Metropolis is geographically located on Latitudes 11°25′58.8″N and 11°31′55.2″ N; and 13°09′00″E and 13°16′12.0″E. Maiduguri, the capital of Borno State, is situated in northeastern Nigeria. The city is bounded by several Local Government Areas (LGAs), including East: Gwoza LGA, North: Konduga LGA, South: Jere LGA and parts of Konduga LGA and West: Jere LGA and parts of Magumeri LGA. Maiduguri is a significant commercial centre and the largest city in Borno State, with an estimated population of approximately 1.2 million people (World Bank, 2023). The Maiduguri metropolis covers an area of approximately 543 km² (Fig. 1).

The climate of the area is classified as a semi-arid (Sahelian) climate, characterized by two main seasons: dry (October to May) and wet (June to September). The area is marked by an average annual rainfall of between 500-650 mm, with rainy season starting from June to September. The peak of rainfall in the area is usually recorded in August. The rains are often brief and heavy, which usually led to short periods of flooding (Kaka et al., 2019). The average annual temperature in the metropolis is between 27°C and 33°C, with the hottest months usually from March to May (which would have up to 4°C) and the coldest months are December and January with temperature as low as 15°C at night due to Harmattan winds (Shetima, 2018).

The topography of the metropolis lies at an average of about 320m above mean sea level, and generally has flat to gently undulating terrain. The metropolis is drained by seasonally flowing rivers, whose peak flows are recorded during the rainy season in the month of July and August. The main river is River Ngadda with Ngaddabul as its major tributary (Kaka et al., 2019).

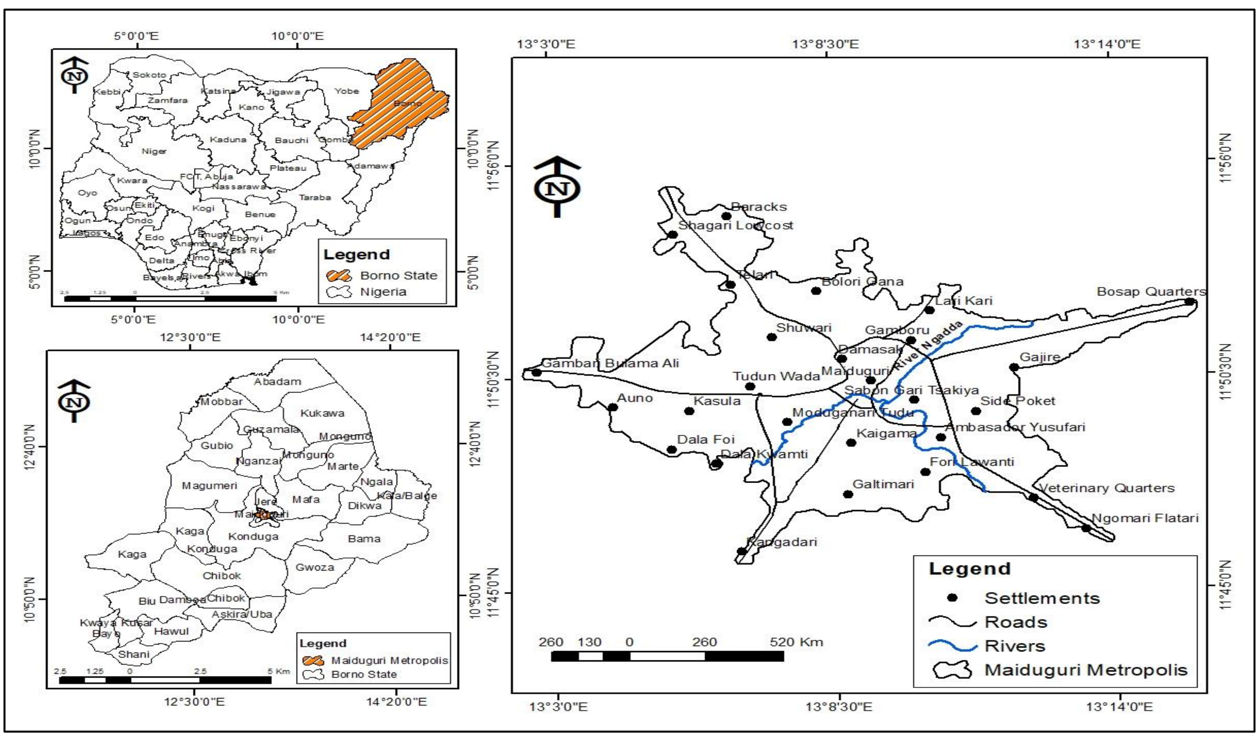

Fig. 1: The Study Area
Source: Administrative Map of Borno State

The Maiduguri's drainage system and hydrology is unique with a network of drainage channels, including the Ngadda River, which flows through the city (Bukar et al. 2025) Heavy rainfall and inadequate drainage infrastructure lead to frequent flooding while limited rainfall and over-extraction of groundwater contribute to water scarcity. Rapid urban growth puts pressure on existing infrastructure with farming and livestock grazing affecting water resources and drainage extraction of sand from rivers and streams altering the hydrology (Buba et al., 2024) These factors contribute to Maiduguri's environmental challenges, highlighting the need for sustainable management and planning.

MATERIALS AND METHODS

This study adopted the quantitative research design, which involves the techniques of measurement and calculation of data to produce quantifiable values for decision-making (Kothari, 2007). This study made use of solely secondary data. These data include the Shuttle Radar Topography Mission (SRTM) 30 m Digital Elevation Model (DEM) of 2024, Landsat imageries (2004, 2014, and 2024), building and study area shapefiles, and rainfall data of 2024. The Landsat imageries and SRTM DEM were obtained from the USGS website, a shapefile from Google Maps, and the rainfall data from the Climate Research Unit (CRU). From the SRTM DEM, the Topographic Wetness Index (TWI), elevation, slope, distance from river, and drainage density of the study area were derived. The Landsat data were used to derive the land use and land cover of the area, while rainfall data were used to model the distribution of rain across the area. The software used for the analyses was ENVI (version 5.3) and ArcMap (version 10.8). The following analyses were executed to achieve the stated objectives of the study. AHP ➜ MCA in ArcMap ➜ Flood Risk Map Production.

Analytical Hierarchy Process (AHP) for Ranking Causative Factors of Flood

The first analysis executed to identify the causative factors of flood in the study area was AHP. This analysis involves a pair-wise comparison matrix, weights calculation, and Consistency Ratio (CR) checking. This helps achieved the stated objective one of the study. The AHP was made in 1980 to establish a relationship between all identified factors using a couple of comparison matrix proposed by Thomas Saaty. The relationship between factors and their respective properties was weighed and ranked on Saaty’s (1980) 1-9 scales (see Table 1). The identified factors considered for this study are broadly grouped into topographic and hydrologic in nature (TWI, elevation, slope, drainage density, land use land cover, rainfall, and distance from rivers); justified based on their key roles on flood occurrence in the study area.

Generally speaking, there is no accepted causative factors of flooding exist in literature that should be applied in an MCA flood assessment, however, some geomorphological factors adopted by many studies (Ashwajit et al., 2015; Danumah et al., 2016; Rahmati et al., 2016; Samanta et al., 2016; Laka et al., 2023;), reported that the factors important in flood risk mapping include elevation, slope percentage, drainage density, soil types, distance from rivers, land use/land cover, altitude, and the size of the watershed, amongst others. The rating of the identified flood causative factors was based on literature views, as well as evaluation of their respective measures and influences on flood occurrence. The Eigenvector estimation method was utilized to estimate the respective weights of the causative factors. Each of the flood causative factors was modeled as thematic maps for easy understanding of their spatial distribution in the study area.

Table 1: 1-9 Scales Pair-wise Comparisons

Importance Scale	Definition of Scale
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

Source: Saaty's (1980)

The pair-wise comparison was checked on Saaty's Consistency Ratio

$$CR = \frac{CI}{RI} \qquad 1.1$$

Where:
CI = Consistency Index, and it is the reflection of the consistency of the judgment
RI = Random Index (dependents on n [sample size]).

The CI was calculated using the following formula:

$$CI = \frac{\lambda max - n}{n - 1} \qquad 1.2$$

Where: λmax = maximum Eigen value of the matrix

The judgment was considered using CR for values between $0 \leq CR \leq 0.1$ with a value of zero (0) being the most consistent (Saaty, T. L. (1980)).

Multi-Criteria Analysis (MCA) Using ArcMap

The second analysis executed to achieve the stated objective two of the study was MCA using the Spatial Analyst Tools (SATs) in ArcMap. This involves the integration of the derived AHP weights of the identified causative factors of flood to pinpoint the spatial location of the flood risk zones in the study area. It is a decision-making criterion that transforms the factors weights that contribute to flood using overlay and raster calculator technique in ArcMaps. The MCA involves the reclassification of the different causative factors of floods in the study area into five (5) Likert scales based on their influence on flood occurrence (see Table 2).

The flood risk map produced from the weighted overlay process was then reclassified into three main risk classes: low, moderate, and high, respectively. From the flood risk map and LULC (2004-2024), the relationship between urban and use changes (independent variable) and flood vulnerability (dependent variable) in the study area was determined. Linear regression analysis was utilized determine if there is a statistically significant relationship between urban land use changes and flood vulnerability. This was done by converting the reclassified flood risk map from raster to polygon, as well as LULC (2004-2024).

Table 2: Risk Rating Flood Causative Factors based on Influence

Causative Factors	Unit	Risk Class Rating	Risk Scales
TWI	Level	Very Low	1
LULC	Level	Low	2
Drainage Density	m/km	Moderate	3
Rainfall	mm/month	High	4
		Very High	5
		Very High	5
		High	4
Elevation	m	Moderate	3
Slope	%	Low	2
Distance from River	m	Very Low	1

Source: Saaty's (1980)

RESULTS AND DISCUSSION

Causative Factors of Flood in Maiduguri metropolis

The tables below highlight the causative factors of flooding in Maiduguri metropolis, including Elevation, Slope, Topographic Wetness Index, Drainage Density, Distance from River, Rainfall and Land use Land cover. These factors are presented with their respective values, risk ratings, area (km²), and percentage of affected area in Maiduguri metropolis.Table 3 presents the elevation characteristics of the study area, highlighting altitude variations that influence surface runoff patterns and flood susceptibility

Table 3: Elevation as a Causative Factor of Flood

Value	Risk Ratings	Area(Km)^2	%
< 319	Very High	20.5	13.3
319-324	High	41.7	29.4
325-330	Moderate	21	13.2
331-335	Low	28.7	17.6
336-361	Very Low	42.7	26.5
	-	**154.6**	**100**

The findings in Table 3 revealed that 42.7% of the areas (Barracks, Bolori Gana, Telari, Gajire, Lari Kari, Bosap, etc.) lie within low elevation zones (< 324 m above sea level), covering 62.2 km² of the total land area. These areas (Figure 2) are found in high to very high flood risk zones. In contrast, 46.1% of the areas (Ngomari Flatari, DalaFoi, Kasula, Uno, Gambari Balami, Ali, etc.) lie above 330 m above sea level and are typically found in the low to very low flood risk zones.

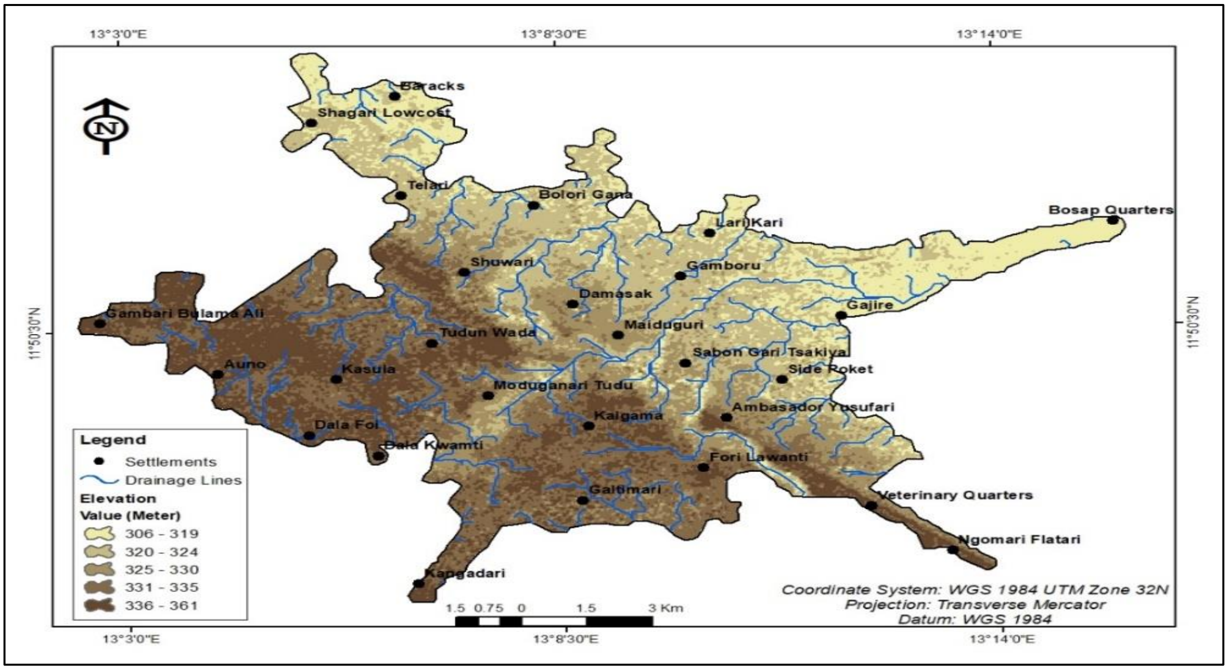

Fig. 2: Elevations of Maiduguri Metropolis

This result is consistent with what Li et al. (2011) and Ologunorisa (2009) reported. They found that low-lying and flat terrain significantly increases flood susceptibility due to reduced water runoff and accumulation of rainwater. While elevation is a significant factor, Afifi and Warner (2008) argue that human adaptive capacity (infrastructure, drainage, preparedness) can mitigate topographic disadvantages.

The distribution of slope across the study area, which plays a critical role in flood occurrence, is summarized in Table 4

Table 4: Slope as a Causative Factor of Flood

	Values	Risk Ratings	Area (km^2)	%
Slope	0-1.53	Very High	50.2	32.4
	1.54-3.56	High	59.4	38.4
	3.57-5.86	Moderate	31.0	20.1
	5.87-9.55	Low	12.0	7.8
	9.56-32.5	Very Low	2.0	1.3
	-	**-**	**154.6**	**100**

Table 4 revealed that over 70% of the Maiduguri Metropolis lies within the high to very high flood risk zones **(**<3.56%), while areas within low to very low flood risk zones (steeper slopes >5.87%) made up of 9.1% of the city. However, these areas (Figure 3) would experience rapid runoff and flash-flood. The vast majority of the city (70 %+) is on gentle slopes that allow for slow-moving or stagnant water, attract water accumulation and flooding. These areas typically have poor drainage capacity, making them vulnerable to prolonged flood events, especially during heavy rainfall.

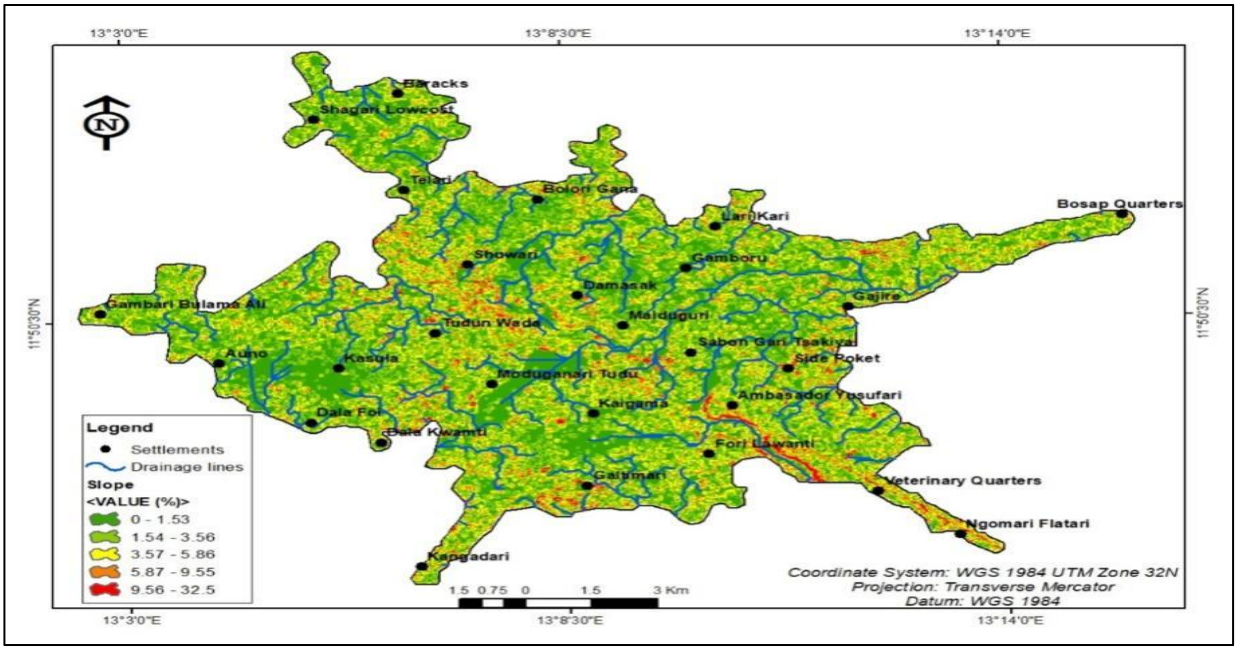

Fig. 3: Slope of Maiduguri Metropolis

The Topographic Wetness Index is a key topographic factor influencing flooding, and its spatial characteristics within the study area are presented in Table 5

Table 5: TWI as a Causative Factor of Flood

	Values	Risk Ratings	Area (km^2)	%
	-7.04- -4.05	Very Low	67.6	43.7
	-4.04- -2.37	Low	34.6	22.4
TWI	-2.36- -0.38	Moderate	25.2	16.4
	-0.381-2.23	High	21.1	13.6
	2.24-8.83	Very High	6.1	3.9
	-	**-**	**154.6**	**100**

The findings in Table 5 revealed that 66.1% of the Metropolis lies in low-risk (dry) zones based on TWI. These areas (Figure 4) have less flood risk potential, while 17.5% of the Metropolis lies in high to very high flood-prone (wet) areas. Fenta et al. (2017) applied TWI in Addis Ababa and identified it as a top hydrologic factor in urban flooding; just as Beven and Kirkby (1979)**,** who introduced TWI, found it to be a reliable predictor of surface saturation zones, which often precede flood events.

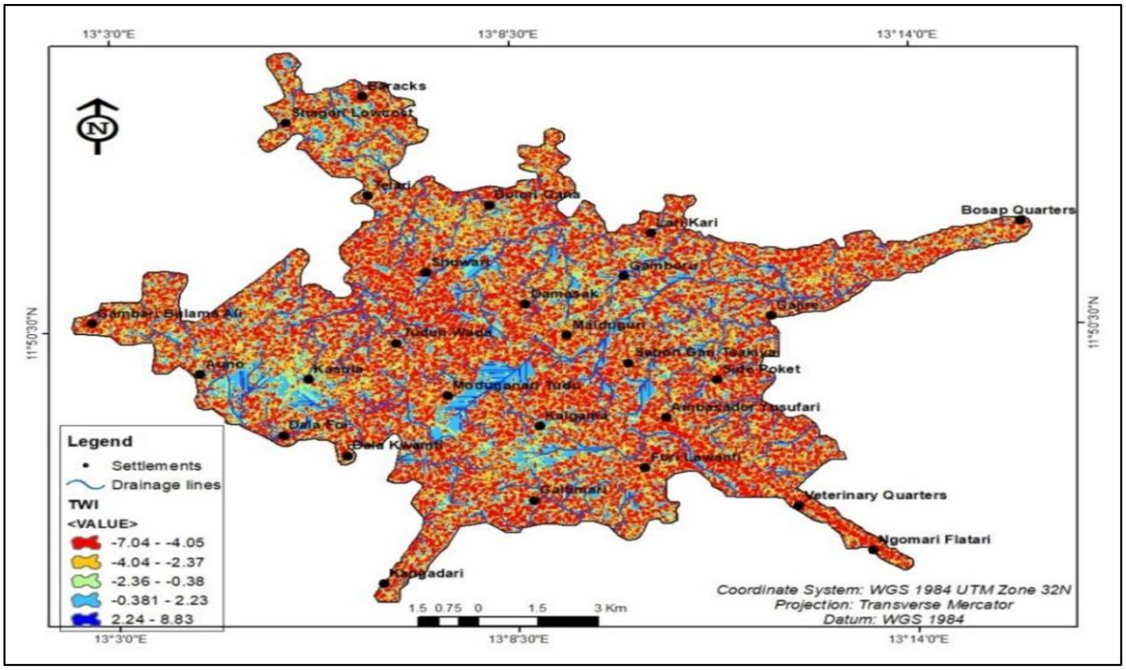

Fig. 4: Topograhic Wetness Index of Maiduguri Metropolis

Drainage Density characteristics of the study area as a causative factor of flooding is presented in Table 6.

Table 6: Drainage Density as a Causative Factor of Flood

	Values	Risk Ratings	Area (km²)	%
Drainage Density	0-85.3	Very Low	32.5	21.1
	85.4-171	Low	36.7	23.7
	172-256	Moderate	41.2	26.6
	257-341	High	31.5	20.4
	342-426	Very High	12.7	8.2
	-	**-**	**154.6**	**100**

The findings of drainage density presented in Table 6 revealed that 44.8% (69.2 km²) of the Metropolis lies within the very low to low drainage density (0–171 m/km²), while over 28.6% of the Metropolis lies within the high to very high flood-prone zone based on drainage density. With low drainage density zones dominating (44.8%), it means drainage density would not be the key factor to flood in the city. This finding aligns with existing literature suggesting that low drainage density areas tend to have slower runoff and less flood risk (Kumar et al., 2018). However, it's also important to note that other factors like rainfall intensity, land use, and topography can still contribute significantly to flood risk, even in areas with low drainage density (Odoh & Nwokeabia, 2024).

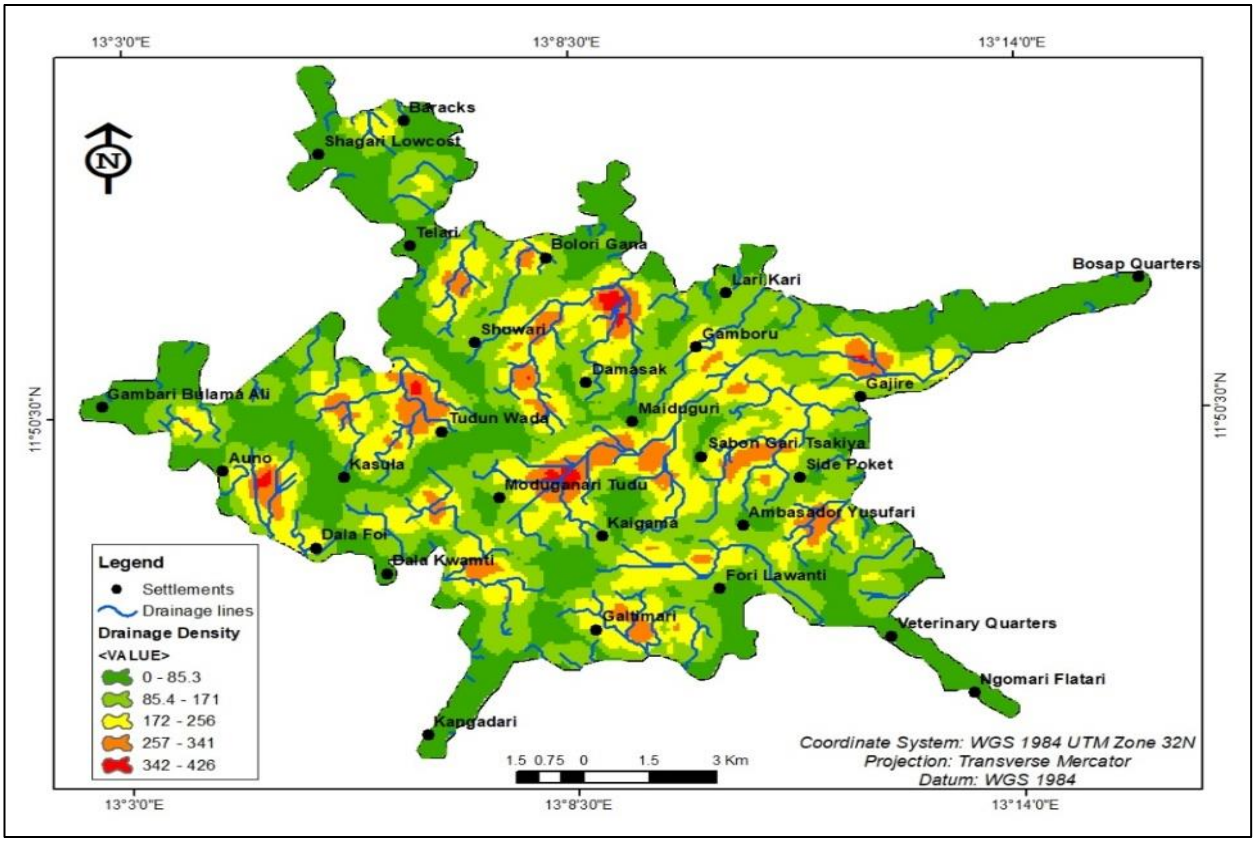

Fig. 5: Drainage Density of Maiduguri Metropolis

Distance from river is a critical hydrological factor influencing flood occurrence, as areas closer to river channels are more susceptible to inundation during high-flow events. Table 7 presents the distance-from-river classification used in this study.

Table 7: Distance from Rivers as a Causative Factor of Flood

	Values	Risk Ratings	Area (km^2)	%
Distance from Rivers	0-500	Very High	80.1	51.8
	501-1000	High	51.3	33.2
	1001-1500	Moderate	19.4	12.5
	1501-2000	Low	2.9	1.9
	342-426	Very Low	0.9	0.6
	-	**-**	**154.6**	**100**

The research results presented in Table 7 revealed that more than 85% (131.4 km^2) of the Maiduguri Metropolis lies within 1km of a river distance, placing a significant portion of the city at high to very high flood risk. This indicates extensive exposure of the majority of the areas of the Metropolis to river-related flood hazards. The findings further revealed that only 2.5% (3.8

km²) of the Metropolis is farthest from rivers, falling in the categories of low to very low flood risk zones. These areas have minimal fluvial flood risk; however, they may be vulnerable to urban flooding and poor internal drainage, but not river overflow (Figure 6). Sadoff et al. (2015) emphasize river proximity as a strong determinant of flood exposure, particularly in urban floodplains, which supports this finding.

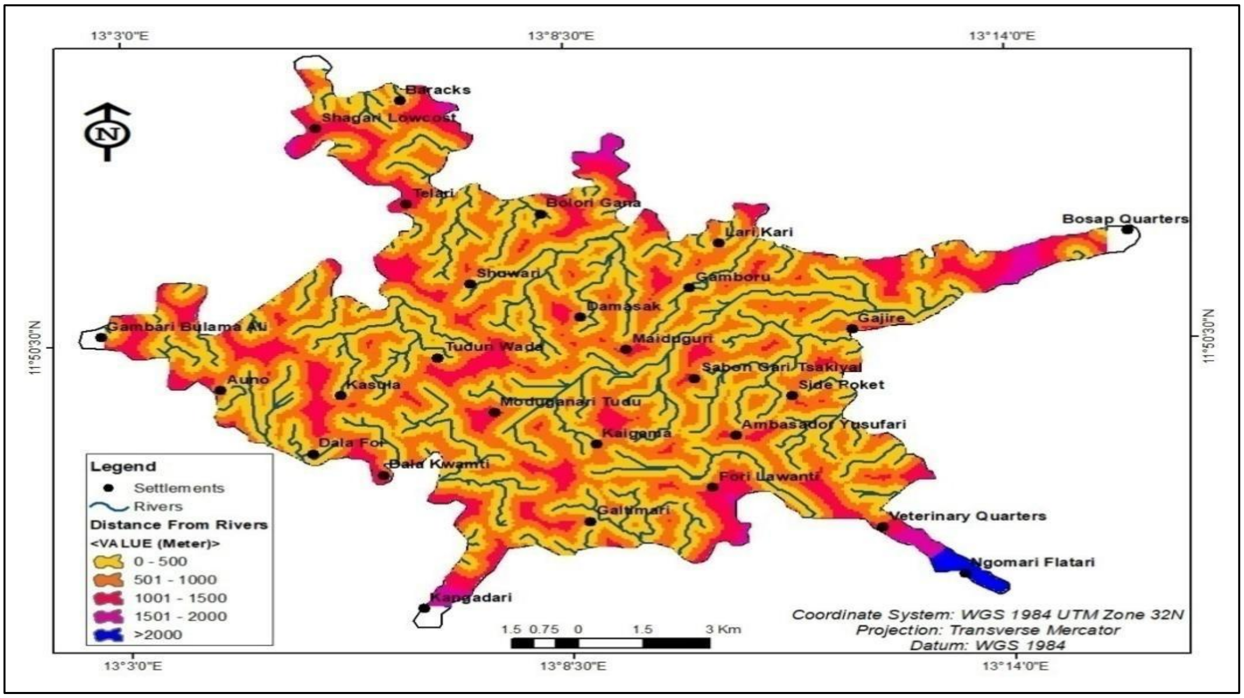

Fig. 6: Distance from Rivers in Maiduguri Metropolis

The amount of Rainfall Distribution across the study area is presented in Table 8.

Table 8: Rainfall as a Causative Factor of Flood

	Values	Risk Ratings	Area (km^2)	%
Rainfall	< 500	Very Low	11.3	7.3
	500-505	Low	46.7	30.2
	506-511	Moderate	44.2	28.6
	512-517	High	23.5	15.2
	>517	Very High	28.9	18.7
	-	**-**	**154.6**	**100**

The findings presented in Table 8 revealed that about 34% (over 50 km^2) of the Maiduguri Metropolis falls within high and very high rainfall zones, increasing flood potential. 37.5% (58 km^2) falls within low and very low rainfall zones. Usually, rainfall alone does not cause flooding, but interact with other factors such as Elevation, Slope, Topographic Wetness Index, Drainage Density, Distance from River and Land use Land cover to determine impact. It was observed that rainfall in the area decreases from west to the east (Figure 7).

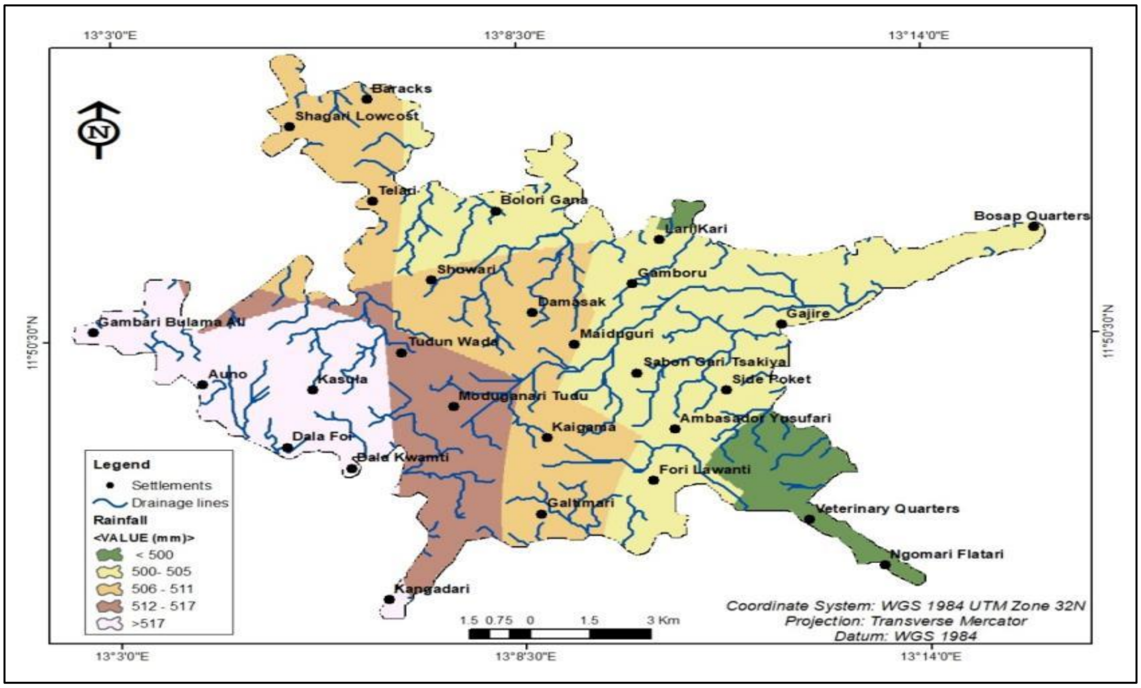

Fig. 7: Rainfall Distribution in Maiduguri Metropolis

The different classes of Land Use and Land Cover of the study area is highlighted in Table 9

Table 9: Land Use/Land Cover as a Causative Factor of Flood

	Class	Risk Ratings	Area (km^2)	%
	Built-up	High	11.3	7.3
	Vegetation	Very Low	46.7	30.2
LULC 2024	Water Bodies	Very High	44.2	28.6
	Bare Land	High	23.5	15.2
	Agricultural Land	Moderate	28.9	18.7
	-	**-**	**154.6**	**100**

Table 9 presents how each Land Use/Land Cover (LULC) class in 2024 contributes to flood risk levels in Maiduguri Metropolis based on their physical characteristics and hydrological response. The findings revealed that more than half of the Maiduguri Metropolis' land area is exposed to elevated flood risks; a high to very high-risk zones (influenced by Built-up + Water Bodies + Bare Land = 51.1%). These susceptible areas call for urgent flood control measures, especially in places around water channels and developed areas. Conversely, 37.5% of the Metropolis falls within the low to very low flood risk zones.

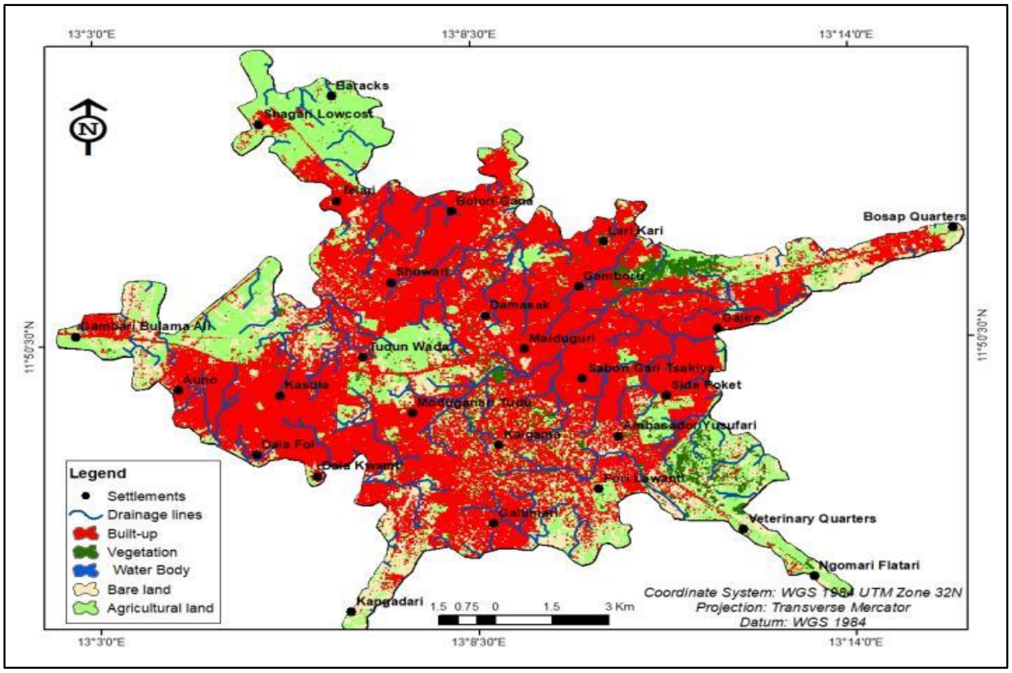

Fig. 8: Land Use/Land Cover of Maiduguri Metropolis as at 2024

All the causative factors of flood in the study area were ranked, and the result is presented in Table 10.

Table 10: Rank of Factors of Flood in the Study Area

Matrix	**Rank**	TWI	Rainfall	Elevation	Slope	LULC	Distance from Rivers	Drainage density	others	**normalized principal Eigenvector**
		1	2	3	4	5	6	7	8	
TWI	2nd	1	3	5	5	3	3	3	1	19.32%
Rainfall	1st	1/3	1	9	5	9	3	5	5	23.18%
Elevation	3rd	1/5	1/9	1	5	3	7	1/5	8	11.03%
Slope	5th	1/5	1/5	1/5	1	5	2	2	5	7.95%
LULC	6th	1/3	1/9	1/3	1/5	1	5	1/3	3	5.17%
Distance from Rivers	7th	1/3	1/3	1/7	1/2	1/5	1	1/5	4	4.21%
Drainage density	4th	1/3	1/5	5	1/2	3	5	1	3	10.58%
others		1	1/5	1/8	1/5	1/3	1/4	1/3	1	18.56%

Ranked Factors Based on AHP Weight (%). Source: Saaty's (1980)

The findings from the pair-wise comparison matrix from the AHP revealed that rainfall (ranked 1^{st}) is the most dominant causative factor of flood in the study area, and this aligns with hydrological logic, which states that without rainfall, there's no flood. Its direct influence on surface runoff makes it naturally the most dominant factor. TWI ranked 2^{nd} (19.32%), which strongly influences flood-prone zones via slope and flow accumulation. The 3^{rd} factor observed is elevation (11.03%), which affects the general terrain height and determines the location and direction of water pools. Other factors include drainage density (4th with 10.56%), slope (5th with 7.95%), LULC (6th with 5.17%), and distance from rivers (7th with 4.21%), respectively (Table 9 and Figure 8).

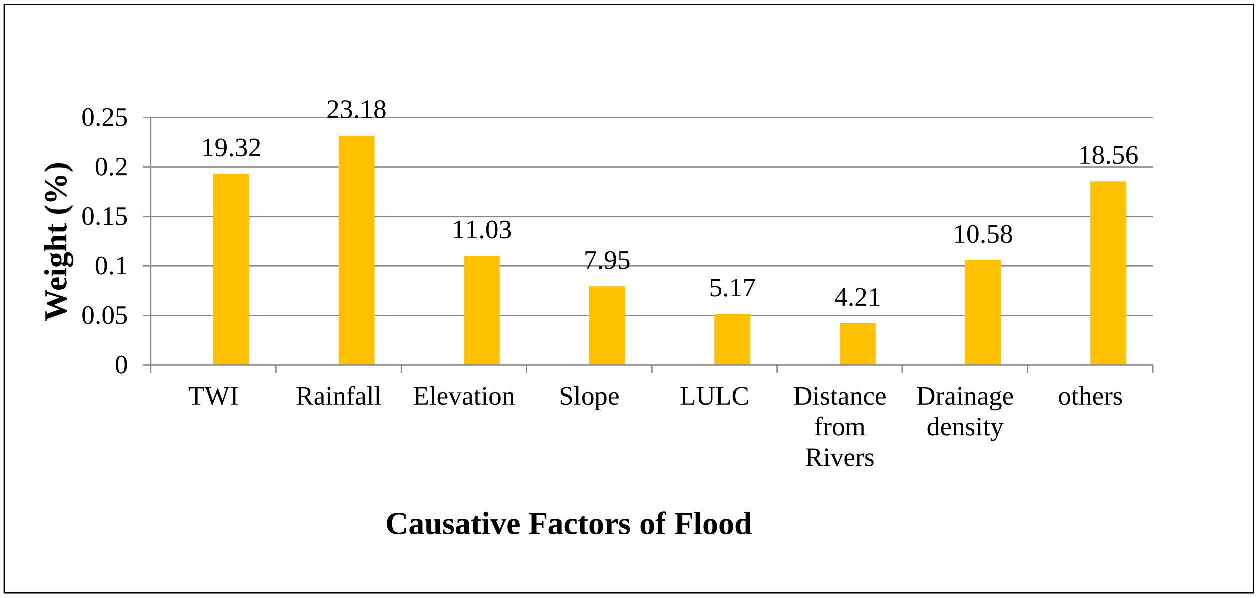

Fig. 8: Ranked Causative Factors of Flood in Maiduguri Metropolis

Flood Susceptibility Map and Implications

Table 11 presents the flood susceptibility scales in the study area and Figure 9 presents the spatial flood susceptibility zones in the study area.

Table 11: Flood Susceptibility Scales

	Scale	Area (km^2)	%
Risk Areas	Low	45.2	29.2
	Moderate	64.7	41.9
	High	44.7	28.9
	-	**154.6**	**100**

The findings revealed that moderate susceptibility dominates the landscape (41.9%), accounting for 64.7 km^2 of the total land area, 28.9% of the city lies in high flood susceptibility, and low-susceptible areas occupy 29.2%. The moderate-susceptibility dominance (41.9%) indicates escalation potential**.** These zones are precarious and any small changes in rainfall intensity, land use, or drainage alteration can push them into high- susceptible status. Overall, with more than 70% of Maiduguri Metropolis lying within moderate to high flood risk zones, this indicates a greater significant potential of flood occurrences in the area; hence, calling for the urgent need for flood risk interventions such as improved drainage infrastructure, early warning systems, and public sensitization and relocation planning where necessary.

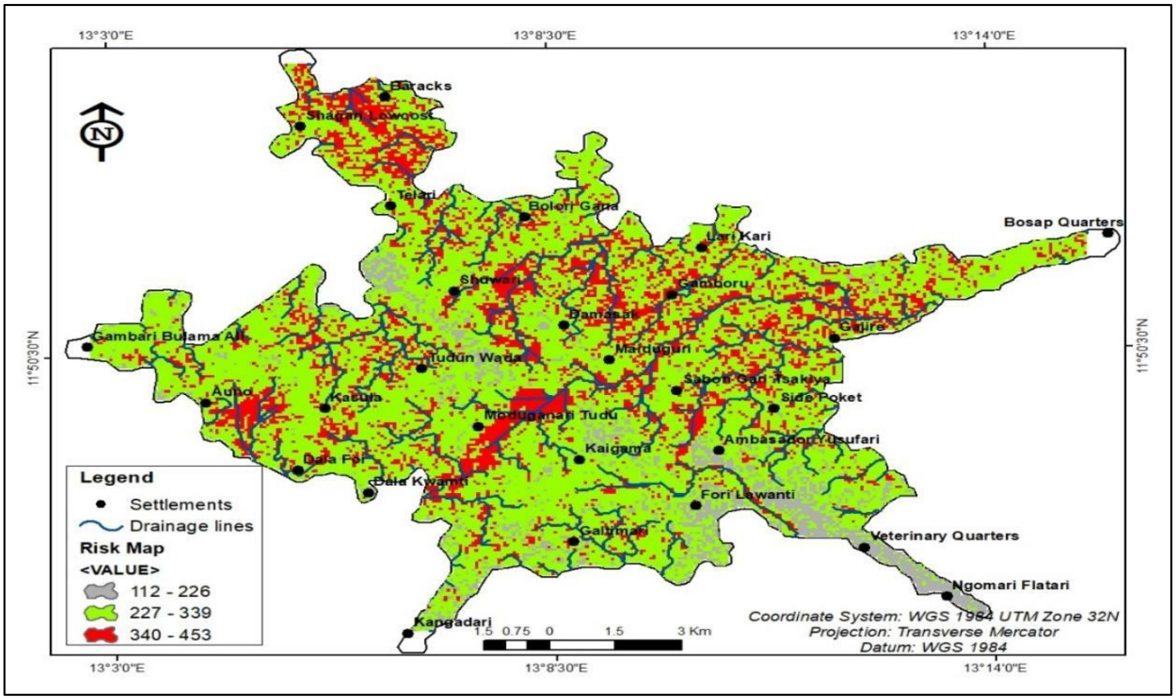

Fig. 9: Flood Susceptibility Map of Maiduguri Metropolis

Relationship between Urban Land Use Changes and Flood Vulnerability

The results of the land use land cover (LULC) across the study period showed major transformations, particularly highlighting the effects of urban expansion and land conversion in the study area. Urban land use (built-up) significantly increased from 21.7% (33.7 km²) in 2004 to 61.3% (94.8 km²) in 2024 (see Table 12). The built-up area increased almost threefold between 2004 and 2024. This significant growth (an increase of 61.1 km² for 20 years) shows rapid urbanization, likely due to population growth, economic development, and infrastructure expansion. Urban sprawl replacing other land uses, especially agricultural and bare lands in the area, increases flood risk, reduces green cover, and causes environmental degradation.

Adelekan (2010) highlighted LULC changes as key drivers of floods in Lagos due to loss of vegetative cover. Agricultural land has decreased by 40.1 km² over 20 years (a 54% decline). The steep drop from 2004 to 2014 reflects the early phases of land conversion to urban use. A steady but gradual decline of 3.0 km² of vegetation cover over two decades in the study area was observed. This indicates loss of natural or semi-natural vegetation due to urban encroachment. This may contribute to increased surface runoff and higher flood susceptibility. Moreover, bare land was reduced by 18 km², with the most significant change between 2014 and 2024. This reflects the intensification of land use and the decline in unused open spaces in the study area, possibly converted into built-up areas or used for temporary agriculture. A negligible decrease in water bodies, which were very small to begin with, was observed. Minimal water bodies make the area potentially more sensitive to stormwater runoff due to a lack of natural retention areas.

Table 12: LULC Changes between 2004 and 2024

	2004		2014		2024	
LULC	**Km²**	**%**	**Km²**	**%**	**Km²**	**%**
Built-up	33.70	21.70	66.50	43.00	94.80	61.31
Vegetation	8.30	5.40	7.30	4.72	5.30	3.43
Water Bodies	0.10	0.10	0.03	0.01	0.02	0.01
Bare Land	38.30	24.80	35.40	22.90	20.30	13.13
Agricultural Land	74.30	48.00	45.40	29.37	34.20	22.12
Total	**154.6**	**100**	**154.6**	**100**	**154.6**	**100**

The result of the extent of urban land use on flood high-susceptible areas showed a clear increase in risk areas over the 20-year period. The urban land use in susceptible areas increased by 17 km²**,** rising from 7.6% in 2004 to 18.6% in 2024 (Table 13).

Table 13: Extent of Urban Land Use in Flood High-susceptible Areas (2004-2024)

Year	**2004**		**2014**		**2024**	
	Km²	**%**	**Km²**	**%**	**Km²**	**%**
Susceptible Areas	11.7	7.6	20.9	13.5	28.7	18.6
Total Land Area	154.6	-	154.6	-	154.6	-

The substantial increase in built-up areas from 21.7% (33.7 km²) to 61.3% (94.8 km²) has a direct correlation with the growth in risk areas**,** which increased from 11.7 km² to 28.7 km². This expansion often involves development on marginal lands such as floodplains or steep slopes, which are naturally prone to environmental hazards like flooding or erosion**.** The 40.1 km² loss of agricultural land and a 3.0 km² decrease in vegetation cover reduces the land's ability to absorb rainfall, increasing surface runoff and potentially contributing to the expansion of risk areas. As vegetation and farmland shrink, the landscape becomes less resilient to extreme weather, supporting the observed increase in areas at risk. Figure 10 shows the relationship between urban land use changes and flood vulnerability.

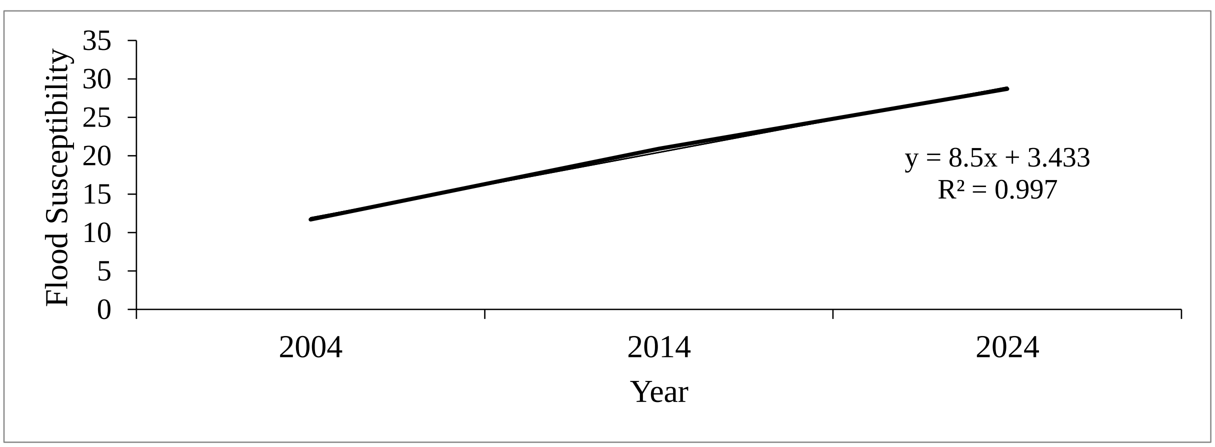

Fig. 10: Relationship between urban land use changes and flood vulnerability

The R^2 value of 0.997 indicates an extremely strong positive linear relationship between the urban land use change (x) and flood events or flood risk (y) over the period 2004 to 2024. This means that 99.7% of the variability in flood events can be explained by changes in urban land use in the study area. In other words, as urbanization increases, flood occurrences or severity are also increasing in a highly predictable manner. Zhou et al. (2017) demonstrated high R^2 values (>0.90) in Shanghai, linking urban sprawl to increased flood frequency.

CONCLUSION

In conclusion, the study demonstrates the importance of geospatial analysis in identifying flood-prone areas and informing policy decisions. The results revealed that a significant area of the Maiduguri Metropolis (over 70%) lies within high to very high flood risk zones. The primary causative factors of flooding were identified as rainfall, topographic wetness index (TWI), and elevation, while urban expansion emerged as a critical contributor to increased flood vulnerability. The strong correlation ($R^2 = 0.997$) between land use change and flood occurrences emphasizes the profound impact of rapid and unregulated urbanization in transforming the hydrological dynamics of the city. Additionally, the dominance of built-up areas, proximity to rivers, and inadequate drainage further compound the flood risk. The moderate to high flood susceptibility of over two-thirds of the metropolis underscores the pressing need for proactive and integrated flood management strategies. These include the development of sustainable urban planning policies, investment in drainage infrastructure, implementation of early warning systems, and public awareness campaigns.

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