Flood Hazard Assessment and Mapping in River-Rima Floodplain, Birnin Kebbi-Nigeria

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ABSTRACT: Floods pose a significant threat to people and their properties, primarily due to the limited attention given to flood hazard analysis and area assessment. The River Rima floodplain in Birnin Kebbi is particularly prone to severe and frequent flooding, which has destroyed homes, farmland, and caused loss of lives. This floodplain is of critical importance due to its agricultural productivity, supporting rice cultivation and other farming activities that are vital for local livelihoods and food security. This study focuses on assessing and mapping the flood hazard zones of the Rima River floodplain by utilizing an integrated approach combining the Analytic Hierarchy Process (AHP) and Geographical Information System (GIS). The flood hazard indicators for the area were identified through an extensive review of literature, field surveys, and consultations with experts. The study pinpointed six critical indicators for flood hazard assessment: rainfall (19%), elevation (22%), slope (38%), drainage network density (6%), soil type (4%), and land use (11%). Among these, slope, elevation, and rainfall were the most significant factors in flood hazard mapping. The analysis revealed that high to moderate flood hazard zones account for 27.6% (285.99 km²) and 22.8% (236.25 km²) of the area, affecting regions such as Jawo, Anguwar Sani, Anguwar Kayi, Anguwar Gero, Makerah, Maurida Wuro Maliki, and Kola. The flood hazard map indicates that approximately 50.4% (522.24 km²) of the area is at risk of flooding. This research is vital for developing new policies and strategic plans to help the government and aid organizations mitigate the adverse effects of flooding in the region.

KEYWORDS**:** GIS**;** Flood Hazard Map; Multi-criterion Analysis; Analytical Hierarchical Process (AHP)

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I. INTRODUCTION

The growing challenges associated with hydrological risks, particularly floods, have become a significant global concern. These hydrological changes are largely attributed to global warming and climate change, driven by human activities (NHSA, 2015). Riverine flooding occurs when intense rainfall over a short period causes rivers to overflow, inundating nearby land. This happens when water cannot follow its usual path and breaches riverbanks (Christopher, *et al.,* 2013). Flooding is a widespread environmental issue, occurring at global, regional, and national levels, and it manifests in various forms and scales, from large-scale events to urban flooding. Broadly, atmospheric changes, rainfall variability, and continental shifts can influence flood occurrences. In Nigeria, the Federal Emergency Management Agency (FEMA, 2020) has observed that floods are common during the rainy season, particularly in floodplains along major rivers and their tributaries, as predicted by the Nigeria Meteorological Agency (NIMET). For instance, in 2020, NIMET forecasted that heavy rainfall could lead to floods, potentially disrupting transportation, delaying construction activities, and damaging infrastructure such as roads, tunnels, and bridges. Riverine flooding generally affects low-lying areas near rivers (Risi, 2020). The Nigeria Hydrological Services Agency (NIHSA) estimated in 2019 that 12 Local Government Areas (LGAs) in Kebbi State, including Birnin Kebbi, Dandi, Kalgo, Koko/Bese, Suru, Aliero, Argungu, Augie, Bagudo, Bunza, Ngaski, and Shanga, would be impacted by floods. The contributing rivers include Rivers Sokoto, Gagare, Bunsuru, Maradi, and Zamfara. Additionally, water released from the Bakolori and Goronyo dams often contributes to flooding during the rainy season as it flows through the River Rima.

Collecting baseline data for flood risk management strategies through field surveys is challenging, time-consuming, and costly. However, this process is increasingly being replaced by more efficient, timely, and cost-effective remote sensing techniques. In the context of the River Rima floodplain, traditional survey tools and local authority terrain data are largely unavailable. Moreover, the extreme terrain of the region makes physical surveys highly challenging, costly, and time-consuming. In this regard, Geographic Information Systems (GIS) and Remote Sensing Imagery (RSI) offer practical alternatives for collecting and analysing spatial data. These technologies enable the efficient assessment of flood hazards in inaccessible areas, providing timely and reliable data for planning and mitigation efforts. The ability of GIS to integrate various layers of spatial information and RSI to capture real-time imagery are particularly beneficial in a region where traditional data sources are scarce or absent. Geographic Information Systems (GIS) and Remote Sensed Imagery (RSI)

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are particularly valuable for understanding the spatial aspects of flood control. They help quantify and monitor the extent of flooded areas and provide estimates of the land and infrastructure affected by floods and erosion (Izinyon, *et al.,* 2011). GIS has been widely used to create flood hazard maps that show vulnerability to floods in different regions around the world (Manandhar, 2010). Bello, *et al.* (2022) conducted a study on the geospatial mapping of flood-prone areas along the Sokoto-Rima River basin in Sokoto. In developing the flood hazard zone map, natural factors contributing to flooding, such as elevation, precipitation, land use, slope, and drainage density, were considered. Geographic information systems, remote sensing, and multi-criteria decision analysis (MCDA) methods have been employed to delineate flood-prone areas (Samela *et al.,* 2018). Multi-criteria analysis (MCA) techniques have been applied in numerous flood hazard assessment studies. Researchers have performed multi-criteria GIS-based evaluations of flood susceptibility in Ethiopia and Slovakia (Vojtek and Vojteková, 2019; Desalegn and Mulu, 2020; Hussain *et al.,* 2021), and conducted flood risk assessments in Malaysia and Côte d'Ivoire (Elsheikh *et al*., 2015; Danumah *et al.,* 2016). Arya and Singh (2021) and Ogato *et al*. (2020) applied GIS-based multi-criteria flood hazard assessments in different regions, while Sadiq *et al.* (2022) used remote sensing and techniques to model floods in Beledweyne town. Several key environmental factors influence flood hazard susceptibility. Elevation significantly impacts the direction of water flow and the depth of floodwaters, playing a crucial role in flood distribution since water naturally moves from higher to lower elevations (Gigović et al., 2017). Slope percentage is another critical factor, as it affects the estimation of surface runoff velocity and vertical percolation, both of which are crucial in assessing flood vulnerability (Rahmati et al., 2016). Flooding in river basins is primarily triggered by heavy rainfall, with increased rainfall heightening flood risk (Rincón et al., 2018). Studies have shown that as rainfall amounts increase, so does the likelihood of flooding (Radwan et al., 2018; Ghosh & Kar, 2018).

Additionally, drainage density plays a vital role in flood susceptibility. High drainage density increases the runoff rate, which can elevate flood risks (Mitra et al., 2022). There is a direct correlation between flood risk and drainage density; greater drainage density leads to higher surface water flow, thereby increasing vulnerability to flooding (Subbarayan & Sivaranjani, 2020). While high drainage density results in increased surface runoff and a higher risk of flooding, lower drainage density is associated with reduced runoff and flood risk (Mahmoud & Gan, 2018; Danumah et al., 2016). Furthermore, land use and land cover (LULC) significantly influence flood frequency and severity. Naturally vegetated areas, such as forests and grasslands, help reduce runoff and increase infiltration, thus mitigating flood impacts (Ahmadi et al., 2021). The runoff characteristics of a river and its catchment area are also influenced by the land use and land cover within the watershed (Mishra & Sinha, 2020). Similarly, the type of soil in an area affects its rainfall infiltration rate and, consequently, its potential for runoff and flood risk (Ntajal et al., 2017).

Flood hazard mapping and analysis, which identifies the most vulnerable areas based on physical factors that indicate flood susceptibility, is a crucial component of early warning systems and strategies for preventing and mitigating future flood disasters. Flood hazard mapping is crucial for land use planning in areas prone to flooding and for creating effective mitigation strategies (Bhatt *et al.,* 2014). These maps provide easily interpretable information that allows planners to identify high-risk areas and prioritize mitigation efforts (Wang *et al.,* 2011).

Several researchers have explored flood-prone areas in Birnin Kebbi, particularly Muktar *et al.* (2020). They used a Digital Elevation Model (DEM) generated from The Shuttle Radar Topography Mission (SRTM) and applied the GIS Map Overlay approach to estimate the flood susceptibility of villages within the River Rima floodplain in Birnin Kebbi. Additionally, a study by Yerima et al. in 2014 used two sets of questionnaires: one to identify flood-prone areas and another to gather information from agencies responsible for flood control. The authors recommended relocating settlements to higher ground for safety and integrating flood control measures into physical development plans. They also suggested adopting a planning matrix for flood-prone areas and implementing urban renewal strategies for settlements in these regions. While past studies have explored flood-prone areas in Birnin Kebbi, this research introduces a novel methodology by integrating GIS with the Analytic Hierarchy Process (AHP). Unlike previous works that relied solely on GIS or conventional methods, this study uses AHP to systematically prioritize and weight flood hazard indicators based on expert input. The AHP assists decision-makers in finding optimal solutions by decomposing complex issues into simpler pairwise comparisons of competing attributes (Shahin *et al.,* 2007; Saaty, 2008). This method streamlines the decision-making process, particularly in complex multi-attribute situations, by providing a structured way to assess relative importance (Greco *et al.,* 2016).

This approach provides a more refined and evidence-based hazard assessment. Additionally, the unique geographical and socio-economic characteristics of the River Rima floodplain, such as its reliance on agriculture and vulnerability to extreme weather events, distinguish it from other flood-prone areas studied globally. These distinctions contribute valuable insights for further research and policy development.

Although studies have extensively documented GIS applications in flood hazard mapping, there is limited research on the application of AHP in this domain. AHP offers several advantages, such as its structured approach to decision-making and ability to incorporate qualitative and quantitative data. Compared to other methods, such as flood simulation models like HEC-RAS or machine learning approaches, AHP is less resource-intensive and allows for incorporating expert judgment in the absence of extensive datasets. This makes it particularly suitable for regions like the River Rima floodplain, where data availability is limited. This paper builds on prior research by combining GIS and AHP for flood hazard assessment, providing a replicable framework for similar studies in other regions. The findings of this research are expected to aid policymakers, urban planners, and disaster management agencies in effectively addressing flood risks and improving resilience in vulnerable

areas. The study aims to develop a GIS-based framework for mapping and assessing flood hazards in the River Rima floodplain. The approach used readily available data and less time-consuming GIS analysis for flood hazard assessment.

II. MATERIALS AND METHOD

A. Description of the Study Area

Birnin Kebbi is one of the local government areas of Kebbi State in Nigeria where the activities of River Rima are influenced. The elevation of the region is between 150 and 300 meters Above Sea Level (ASL). About 90% of the region lies below the altitude of 250 meters (ASL) and is relatively flat. These physical properties of the land make it excellent for rice growing. Thus, the local community in the area engages in both rainy and dry-season agriculture. The study area is geographically located between Latitudes 12° 20' to 12° 39' North of the Equator and Longitudes 04° 04' to 04° 28' East of the Greenwich Meridian.

B. Climate

According to Eberibe *et al.* (2017), the region falls within a semi-arid climatic zone characterized by low average annual rainfall, ranging from 300 to 700 mm, primarily occurring between May and October (a six-month rainy season). The remaining months make up the dry season, which is exerted by a hot continental air mass blowing from the northwest across the Sahara Desert. The region's daily maximum temperatures range between 34°C and 40°C, while during the Harmattan season, daily low temperatures range from 21°C to 24°C. The peak heat period, from February to April, sees temperatures reaching up to 40°C.

C. Soil

According to (Augie, 2021), The region typically consists of the following soil types: Sandy, gravel, loam, silt, and clay soils found in the upland locations of the North, North West and Central parts of the State; These soils are found on the floodplains of the Rima Basin and provide an ideal foundation for agriculture in the floodplains of the major rivers and enclosed depressions (Fadama areas).

D. Vegetation

The vegetation of the area is called Sudano-Sahelian which is characterized by vast grassland with scattered woody plants found along the flood-plains. Small plants, mainly grasses, shrubs, and small trees dominate the landscape of semi-arid areas. Certain plants in semi-arid environments may have some of the same adaptations as desert plants, such as thorny branches or waxy cuticles to decrease evaporation and water loss through their leaves (Moll, 2020).

III. DATA DESCRIPTION

This study utilized remote sensing data, meteorological stations, and field surveys. The Nigerian Meteorological Agency (NIMET) and the Sokoto Rima River Basin Development Authority (SRRBDA) provided daily rainfall data from four locations over 40 years. Additionally, focus groups involving stakeholders, policymakers, and residents, along with reconnaissance surveys, were conducted to collect further insights on public perceptions of flood events, contributing factors, sources of flooding in the study area, and the historical record of previous floods (Shuaibu *et al*., 2022). Soil data for the basin was sourced from the Food and Agriculture Organization (FAO) website, while the USGS supplied SRTM DEM (30 x 30) and Sentinel-2 satellite imagery. GPS technology was used to collect coordinates of flood-damaged areas. The methodological framework for the development of flood Hazard map and their assessment is shown in Figure 2.

A. Selection of Flood Hazard Indicators

To assess flood hazards, it is essential to analyse the various factors that contribute to flooding and their interactions with flood occurrences (Sahana and Patel 2019). Previous studies on flood hazard mapping have utilized different flood-regulating parameters (Das 2018; Dou *et al.* 2018; Samanta *et al*. 2018). Researchers typically select these parameters based on the physical and natural characteristics of the study area, though there is no standardized method for selecting these factors or determining their relative importance. In this study, after a comprehensive review of relevant literature, we identified six key factors contributing to flooding: Rainfall, Slope, Elevation, Drainage, Soil, and Land use/cover.

B. Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was employed to identify the key natural factors influencing flooding in the study area, including rainfall, slope, elevation, drainage, soil, and land use/cover. These factors were weighted according to their perceived impact on flooding. The thematic maps of these factors were analysed using the AHP technique, which applied normalized weights to develop a flood hazard map for the study area. Implementing AHP requires scientific expertise, robust evidence, and an evaluation of matrix consistency (Awawdeh *et al.,* 2014; Saaty, 2014). The factors influencing flood occurrence were weighted using the AHP, following Saaty's methods. A pairwise comparison was conducted for each map using a 1–9-point significance scale (as detailed in Table 1). According to Saaty (1980), AHP is a multi-criteria decision-making technique that provides a systematic approach to measuring and integrating the effects of various factors by connecting different levels of qualitative and quantitative information, thereby solving complex decision-making problems by prioritizing criteria. AHP has been widely used for multi-criteria decisions in urban flooding hazard and risk analysis (Yahaya *et al.,* 2010; Chowdary *et al.,* 2013; Li *et al.,* 2013; Rimba *et al.,* 2017).

Several studies have demonstrated the superiority of AHP over other methods. For example, Mishra and Sinha (2020) highlighted that AHP's ability to integrate expert judgment makes it more adaptable for regions with limited quantitative data, unlike machine learning techniques, which require extensive datasets. Rincón *et al.,* (2018) emphasized that AHP's structured framework allows for the clear prioritization of factors, making it more transparent and easier to implement than simulation models like HEC-RAS. Furthermore, Shale *et al.,*

(2020) found that AHP performs better in identifying spatial variations in flood hazards compared to other multi-criteria methods due to its emphasis on pairwise comparisons. These studies reinforce the advantage of AHP in flood hazard assessment, particularly in resource-constrained settings.

Table 1: Fundamental Scale for Pair-wise Comparison

Strength of importance	Explanation
1	Equal significance
3	Medium significance
5	Strong significance
7	Very strong significance
9	Maximum significance
2, 4, 6, and 8	Intermediate between two adjacent values

C. Assessing Matrix Consistency

A consistency check was performed by calculating the consistency ratio (CR), which indicated the reliability of the pairwise comparisons. This is important because, in reality, the decision-maker's judgments may include some uncertainty, potentially leading to inconsistencies in the matrix (Mishra & Sinha, 2020). The guidelines for measuring consistency, as provided by Saaty (1980), are as follows:

i. The rule of thumb states that the consistency ratio (CR) should be less than or equal to 0.1. Thus, a value of 0 to 0.1 is acceptable in practice.
ii. Higher values indicate that the judgment needs to be re-visited.
iii. It is evaluated as follows: CR=CI/RI (1)

Where the consistency index reflects the consistency of one's judgment.

RI- denotes the Random Inconsistency index that is dependent on the sample size **(**Table 2)

CR- denotes the consistency ratio

$$\text{And CI} = \frac{\lambda - n}{n-1} \quad (2)$$

λ is calculated by averaging the value of the consistency vector (calculated factor weight) and n is the number of factors.

Table 2: Random Inconsistency (RI) Index that is Dependent on the Sample Size

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

A. Derivation of Flood Hazard Index

The Flood Hazard Index (FHI) was derived by aggregating the weights and corresponding hazard and vulnerability classes at each level of hierarchy using Equation 3

$$\text{FHI} = \sum_{i=1}^{n} W_i \times r_i \quad (3)$$

Where, FHI = flood hazard index, w_i = weight of each indicator, r_i = rating of the indicator in each point, and n = the number of the criteria.

$$\text{FHI} = W_i \times (\text{Slope}) + W_i \times (\text{Elevation}) + W_i \times (\text{Rainfall}) + W_i \times (\text{LULC}) + W_i \times (\text{DD}) + W_i \times (\text{Soil type}) \quad (4)$$

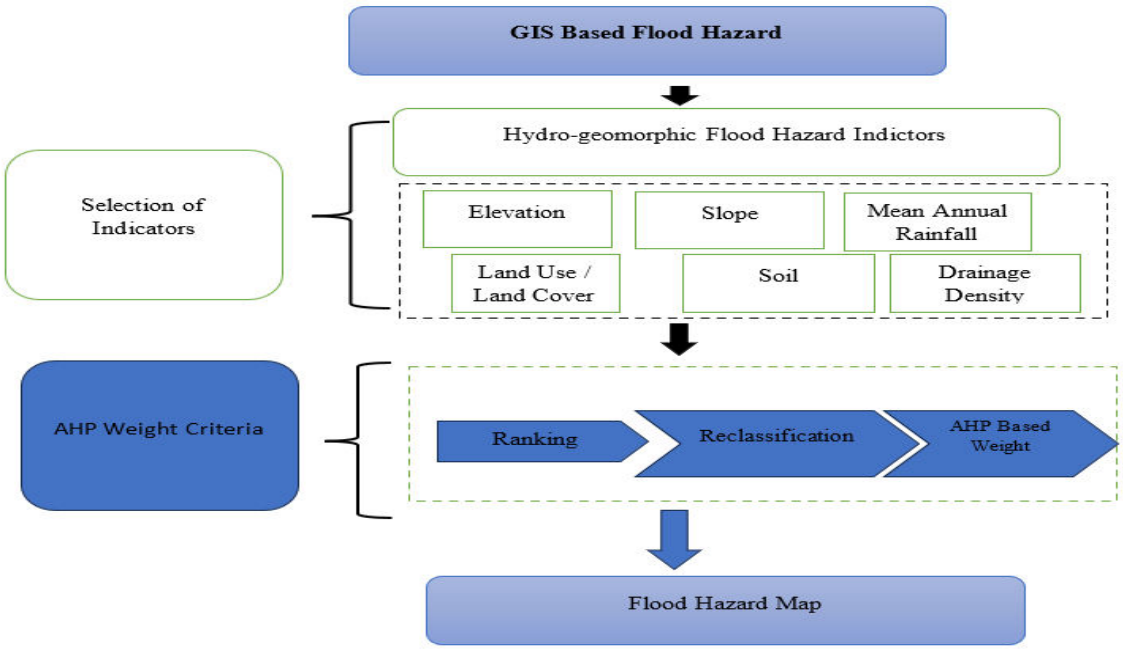

Figure 1: Methodological Flowchart of the study

IV. RESULTS AND DISCUSSION

A. Flood Hazard Indicator

The flood hazard indicators chosen for this study were based on geomorphological and hydrological factors, including slope, elevation, rainfall, land use/land cover, drainage density, and soil type. The selection of these indicators involved consultations with various stakeholders, including representatives from the Nigerian Meteorological Agency (NIMET), the Sokoto Rima River Basin Development Authority (SRRBDA), local government officials, agricultural extension workers, and community leaders. A total of 45 respondents participated in the consultation process, providing valuable insights into public perceptions of flood events, contributing factors, and the historical record of previous floods. These respondents were selected to ensure a diverse representation of expertise and local knowledge, thereby enriching the study's findings and ensuring the reliability of the indicators used. Table 3 shows the Pairwise Comparison of Six Criterion Matrix.

Table 3: Pairwise Comparison of Six Criterion Matrix Source: (Based on Experts' and local residents' interview, 2022 and literature review, 2022)

Flood factors	Slope	Elevation	Rainfall	LULC	Drainage	Soil type
Slope	1	3	3	3	5	7
Elevation	1/3	1	2	3	5	3
Rainfall	1/3	1/2	1	3	5	5
LULC	1/3	1/3	1/3	1	3	3
Drainage	1/5	1/5	1/5	1/3	1	3
Soil type	1/7	1/3	1/5	1/3	1/3	1

1. Elevation

In the study area, elevation was categorized into three groups based on its impact on flood hazard: High (188 - 225m), moderate (226 – 237m), low (238 - 259m), The lowest elevation category was designated as a

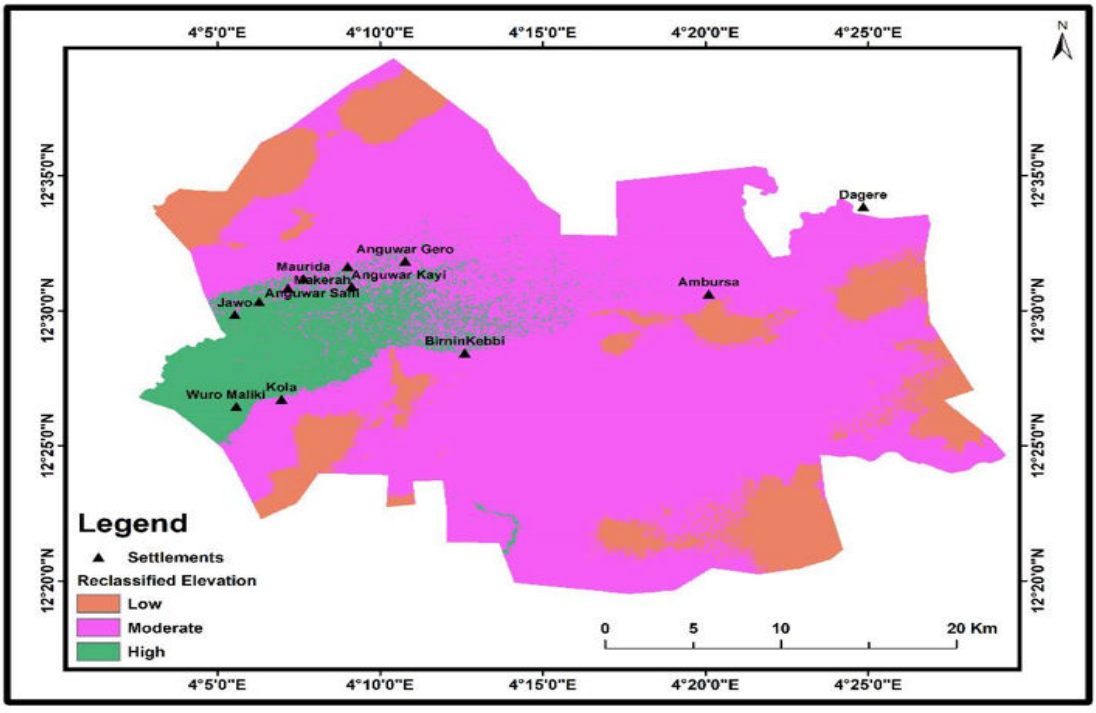

Figure 2: Elevation Map of the Study Area

very high flood hazard zone, whereas the highest elevation was categorized as having a very low flood hazard level, this is shown in Figure 2. Rahman *et al*. (2019) found that low-lying areas are particularly vulnerable to flooding, as even minor floods can submerge these regions. Consequently, the western parts of the study area, which have the lowest elevations, are the most prone to flooding.

2. Slope

As shown in Figure 3, the slope of the study area varies from 0 to 28.8 degrees. Slopes ranging from 0 to 3.4 degrees are classified as low, 3.5 to 6.3 degrees as moderate, and 6.5 to 28.8 degrees as high. Areas with flatter slopes are more prone to flooding, whereas steeper areas with higher slopes are less likely to experience flooding.

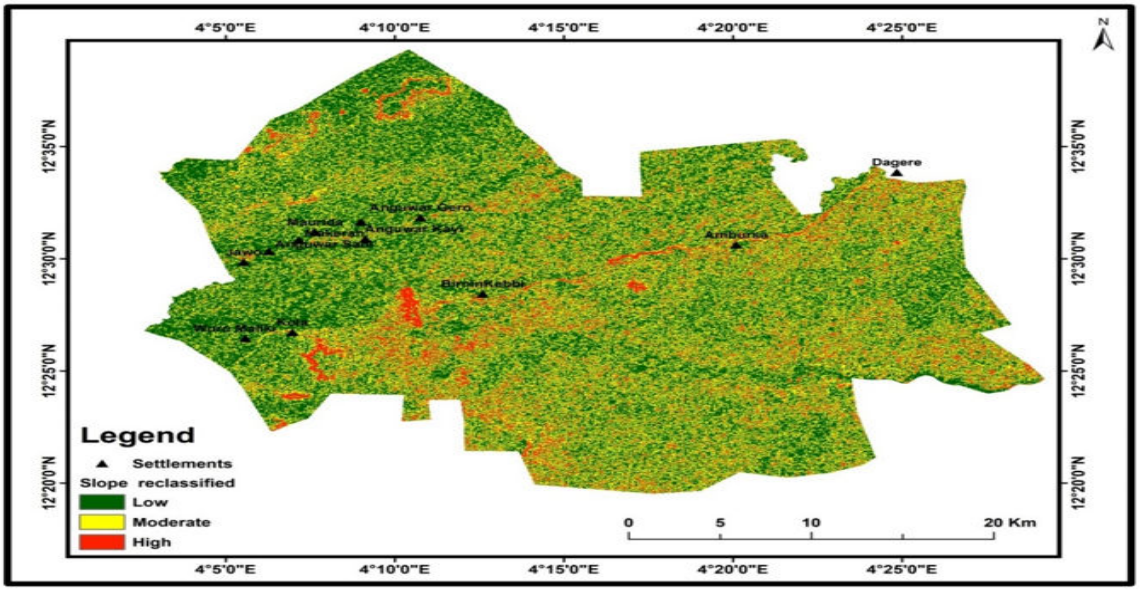

Figure 3: Slope Map of the Study Area

3. Rainfall

The mean annual rainfall of the study area ranges from 41.75 mm to 415.21 mm. Figure 4 illustrates that the rainfall amounts in the area are categorized into three ranges, to better understand how rainfall contributes to flooding, these ranges were further classified as low (41.75–178.67 mm), moderate (178.68–253.93 mm), and high (253.94–414.21 mm). Notably, rainfall decreases as you move northward and increases southward, reflecting the typical rainfall distribution pattern in Nigeria.

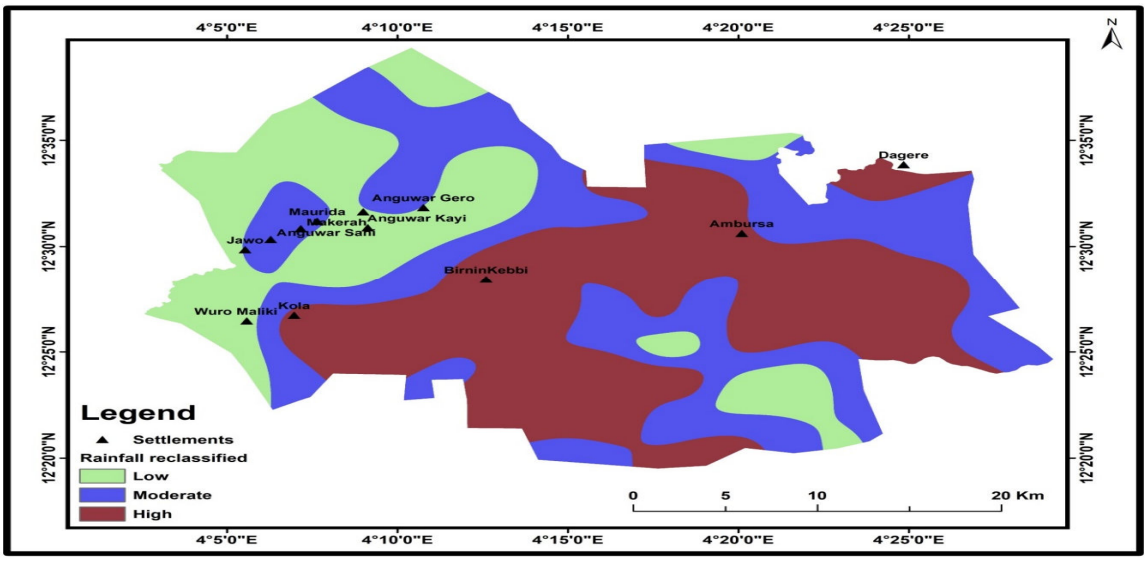

Figure 4: Mean Annual Rainfall Map of the Study Area

4. Drainage Density

As shown in Figure 5, drainage densities in the study area range from 0 to 264.83 km². To assess drainage density's impact on flooding, the values were categorized into three classes: low (0–60.24 km²), moderate (60.25–126.7 km²), and high (126.71–264.83 km²). According to Pallard *et al.* (2009), high drainage densities generally indicate a greater risk of flooding, whereas lower drainage densities usually correspond to reduced flood volumes.

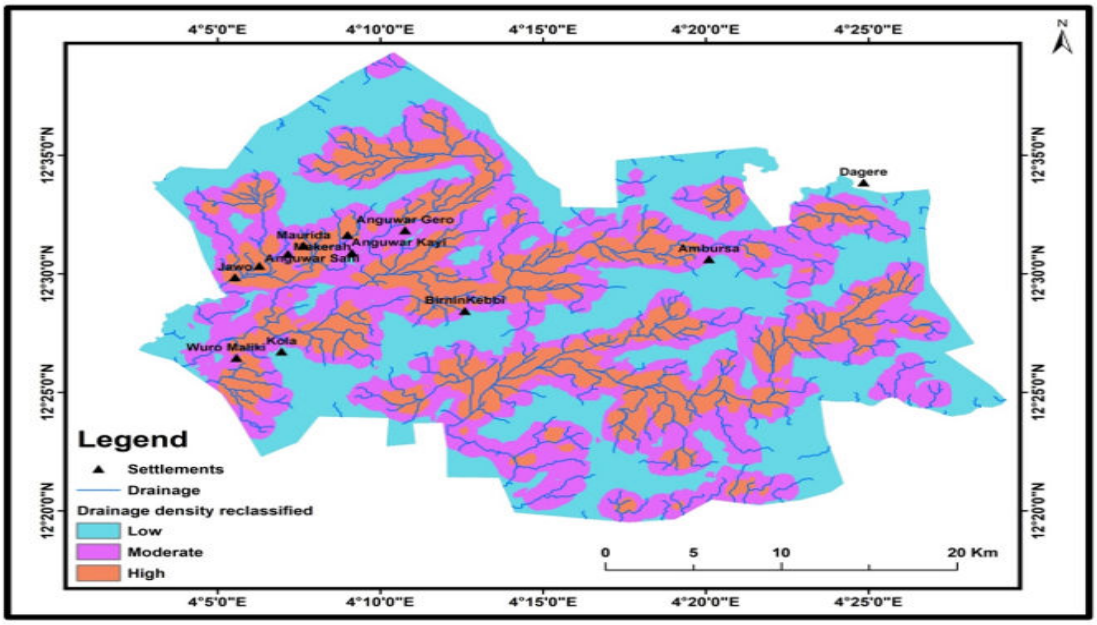

Figure 5: Drainage Density Map of the Study Area

5. Land use land cover (LULC)

According to Figure 6a, the land cover includes water bodies (4.23 km², 0.41%), vegetation (804.38 km², 77.63%), farmland (174.89 km², 16.88%), built-up areas (51.17 km², 4.94%), and bare land (1.56 km², 0.15%). Areas with dense vegetation typically have a lower flood potential because vegetation helps increase infiltration and reduce runoff (Mishra & Sinha, 2020). Also, Figure 6b shows the land use and land cover classification in bar chart.

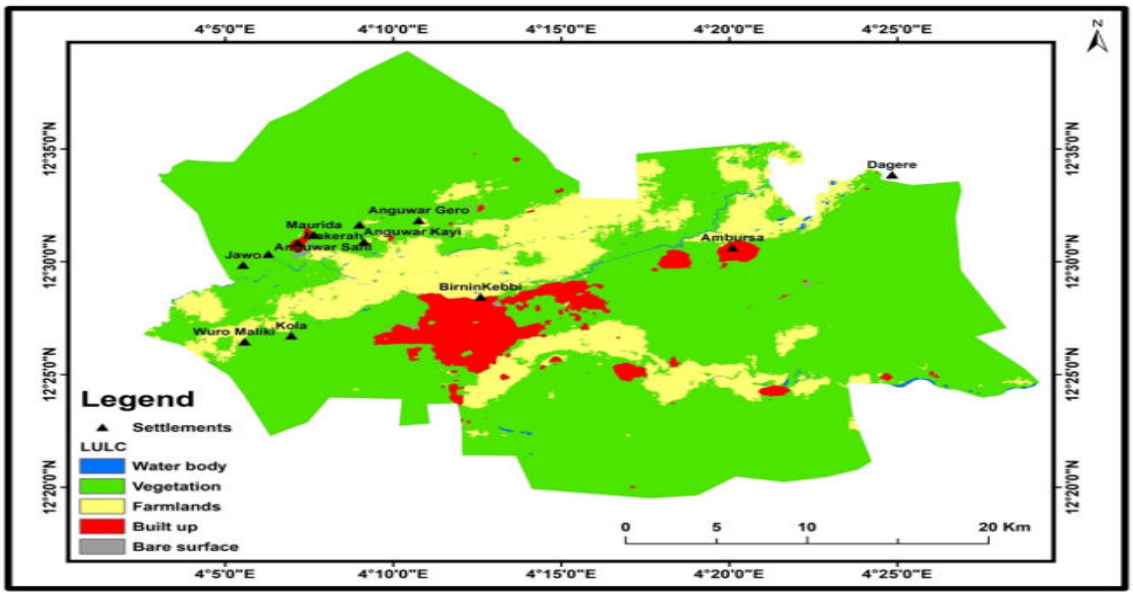

Figure 6a: Land-Use and Land-Cover Map of the Study Area

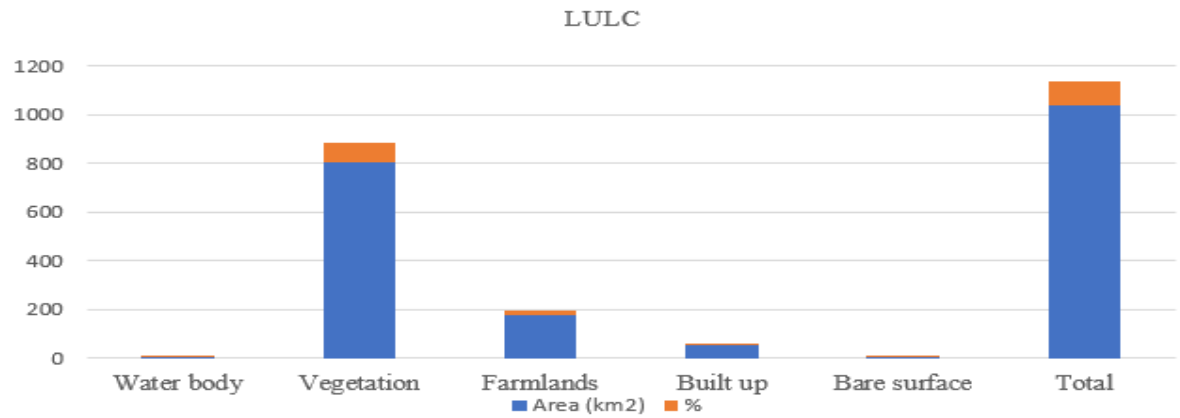

Figure 6b: Land use and land cover classification

6. Soil Type

Figure 7a and Figure 7b displays the soil map of the study area and soil type in bar chart respectively, which reveals two primary soil types. Sandy soil, covering 83.10% of the area, has high permeability and a high infiltration rate, making it a low flood hazard. In contrast, clay-loam soil, covering 16.9% of the area, has low permeability and a low infiltration rate, resulting in a higher flood hazard. The map shows that sandy soils are predominant in the study area, contributing to high infiltration rates and low flood susceptibility, indicating the lowest flood hazard.

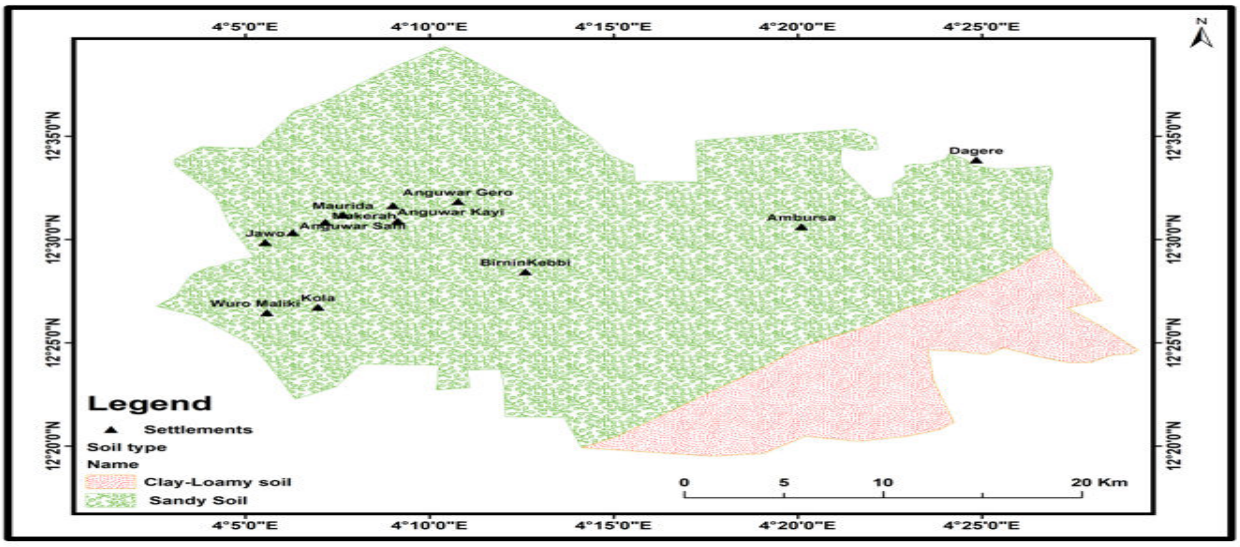

Figure 7a: Soil Map of the Study Area

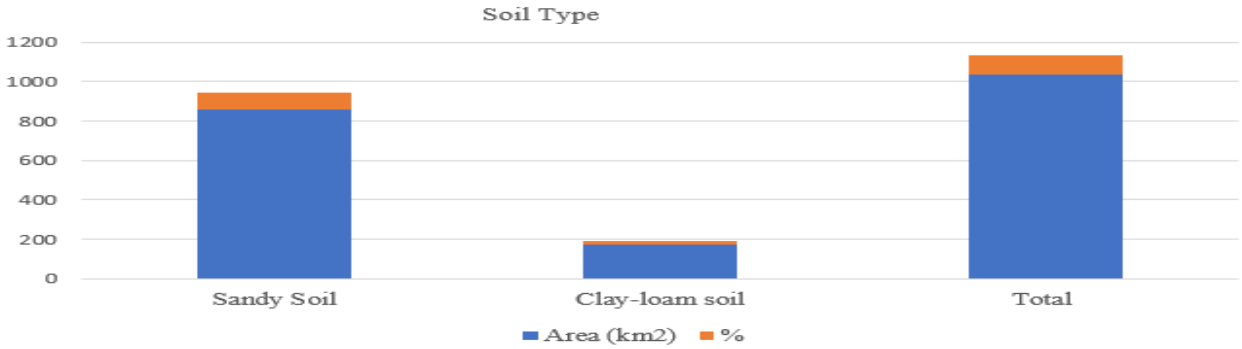

Figure 7b: Soil type

B. Pairwise Comparison Matrix

In this study, Multi-Criteria Evaluation (MCE) was used to identify vulnerable locations, while the Analytic Hierarchy Process (AHP) was employed to assign weights to various parameters. In this case, The Pairwise Comparison Method was employed to assign weights to the criteria. Experts were given a questionnaire to assess the relative importance of six flood-related factors—rainfall, drainage density, land use/land cover (LULC), slope, soil, and elevation. Each expert compared these factors two at a time, using Saaty's 1–9 scale to rate their importance, with the results being recorded in a table. Table 4 to 8 shows the Pairwise Comparison calculations.

C. Assessing Matrix Consistency

The Consistency Index (CI), which signifies the departure from consistency, was estimated with equation (1) Where n is the number of factors (6) and λ is the average value of the consistency vector estimated as 6.4495 and CI is 0.0899. Consequently, a consistency ratio (CR) of 0.073, which is less than 0.1, indicates an acceptable level of consistency in the pairwise comparisons. Typically, a CR of 0.1 or below is deemed satisfactory. If the CR exceeds this threshold, it suggests that the judgments should be reassessed to address any inconsistencies (Yonas *et al.,* 2022).

Table 4: Determined consistency ratios (CR)

Flood factors	**Slope (0.381)**	**Elevation (0.216)**	**Rainfall (0.191)**	**LULC (0.105)**	**Drainage (0.061)**	**Soil (0.040)**	**Weight sum Value (W.S)**	**Criteria weight (C.W)**	**W.S/C. W**
Slope	0.381	0.648	0.573	0.315	0.305	0.040	2.502	0.381	6.566
Elevation	0.125	0.216	0.382	0.315	0.305	0.280	1.463	0.216	6.768
Rainfall	0.125	0.108	0.191	0.315	0.305	0.120	1.244	0.191	6.513
LULC	0.125	0.071	0.063	0.105	0.105	0.200	0.667	0.105	6.352
Drainage	0.076	0.043	0.038	0.034	0.034	0.120	0.372	0.061	6.098
Soil type	0.053	0.071	0.038	0.034	0.034	0.040	0.256	0.040	6.400

Table 5: Pairwise Comparison of Six Criterion Matrix

Flood factors	**Slope**	**Elevation**	**Rainfall**	**LULC**	**Drainage**	**Soil type**
Slope	1	3	3	3	5	7
Elevation	1/3	1	2	3	5	3
Rainfall	1/3	1/2	1	3	5	5
LULC	1/3	1/3	1/3	1	3	3
Drainage	1/5	1/5	1/5	1/3	1	3
Soil type	1/7	1/3	1/5	1/3	1/3	1

Table 6: Pair-Wise Comparison Decimal Matrices

Flood factors	**slope**	**Elevation**	**Rainfall**	**LULC**	**Drainage**	**Soil type**
slope	1.00	3.00	3.00	3.00	5.00	7.00
Elevation	0.33	1.00	2.00	3.00	5.00	3.00
Rainfall	0.33	0.50	1.00	3.00	5.00	5.00
LULC	0.33	0.33	0.33	1.00	3.00	3.00
Drainage	0.20	0.20	0.20	0.33	1.00	3.00
Soil type	0.14	0.33	0.20	0.33	0.33	1.00
Sum	2.33	5.36	6.73	10.66	19.33	22.00

Table 7: Normalized Pairwise Matrix Calculated.

Flood factors	Slope	Elevation	Rainfall	LULC	Drainage	Soil type	Criteria weight
Slope	0.429	0.559	0.445	0.281	0.258	0.318	0.381
Elevation	0.141	0.186	0.0297	0.281	0.258	0.136	0.216
Rainfall	0.141	0.093	0.148	0.281	0.258	0.227	0.191
LULC	0.141	0.061	0.049	0.093	0.155	0.136	0.105
Drainage	0.085	0.037	0.029	0.030	0.051	0.136	0.061
Soil type	0.060	0.061	0.029	0.030	0.017	0.045	0.040

Table 8: The Eigen Vector weights of each flood factor obtained after the pairwise comparison

Flood Factors	Normalized Weighted	Influence (%)
Slope	0.381	38.0
Elevation	0.216	22.0
Rainfall	0.191	19.0
LULC	0.105	11.0
Drainage	0.061	6.0
Soil type	0.040	4.0
Total	1.00	100%

D. GIS Integration of Data Layers and The Generation of Flood Hazard Map

The AHP was used to establish the ranks and weights of the sub-factors and map layers, a multi-criteria decision-making method, based on their impact on the results. These layers were then analyzed through a weighted overlay. The flood hazard map for the study area was created by combining six thematic layers: slope, elevation, rainfall, land use/land cover, drainage density, and soil type using the AHP to calculate the flood hazard index (FHI) according to their relative weights. Following the creation of the decision matrix and computation of relative importance weights (RIWs), the consistency index (C.I.) and consistency ratio (C.R.) were calculated and found to be satisfactory (C.R. $\leq$ 0.10 or $\leq$ 10%). The FHI was then derived by performing an arithmetic overlay of all decision factors based on the RIW values (Table 8).

Table 9: Classes of Flood Hazard Indicators, their Weight and Ranking

Indicators	Relative Weight	Reclassified Indicators	Ranking	Hazard
Slope (degree)	38%	6.4 –28.28	1	Low
		3.5 – 6.3	2	Moderate
		0 -3.4	3	High
Elevation (m)	22%	238 - 259	1	Low
		226 – 237	2	Moderate
		188 - 225	3	High
Rainfall (mm)	19%	41.47 – 178.67	1	Low
		178.68 – 255.93	2	Moderate
		253.94 – 415.21	3	High
LULC	11%	Built-up	1	Low
		Farmland	2	Moderate
		Vegetation	3	High
Drainage density(km/km^2)	6%	0 – 60.24	1	Low
		60.25 – 126.7	2	Moderate
		126.71 – 264.83	3	High
Soil type	4%	Clay- loamy soil	1	Low
		Sandy soil	3	High

E. Flood Hazard Map

Figure 8 shows the flood hazard map of the area, identifying regions at risk of flooding. The map categorizes the hazard into three classes: low, moderate, and high. High to moderate hazard areas make up 27.6% (285.99 km²) and 22.8% (236.25 km²) of the area, including regions such as Jawo, Anguwar Sani, Anguwar Kayi, Anguwar Gero, Makerah, Maurida Wuro Maliki, and Kola. These areas are characterized by relatively flat slopes, low elevation, and lower rainfall. The map also indicates that high-hazard levels are prevalent in agricultural lands and areas with dense vegetation. Additionally, high drainage density contributes to the increased flood hazard, further elevating the flood risk. In essence, a high flood hazard corresponds to a high flood risk (Hu *et al.,* 2017). Additionally, the low hazard class encompasses approximately 49.6% (513.96 km²) of the area, including regions such as Birnin Kebbi, Ambursa, and Dagere. These areas are distinguished by their high elevation, steep slopes, sandy soils, and moderate drainage density. This observation aligns with findings by Chakraborty *et al.* (2019), Desalegn *et al.* (2020), and Shuaibu *et al.* (2022), which indicate that regions with high elevation, steep slopes, and sandy soils are less susceptible to flooding. Furthermore, farmland is identified as the most flood-prone area when comparing land use and land cover categories against flood hazard zones. In contrast, built-up areas, located in low flood hazard zones, are less at risk of flooding.

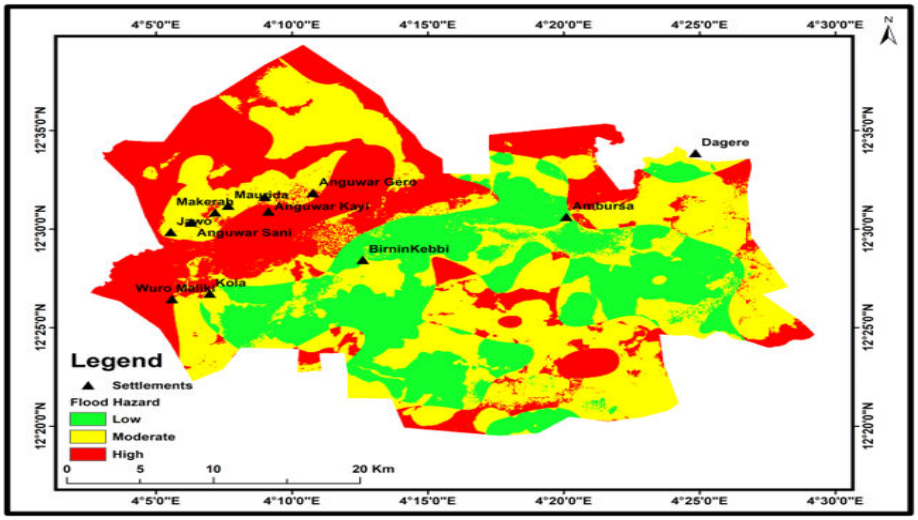

Figure 8: Flood Hazard Map of Birnin Kebbi

F. Validation of Flood Hazard Map

Figure 9 shows the Validated Flood Hazard Map which entails systematically comparing model outputs with independent real-world observations to evaluate their accuracy and consistency with reality, both in quantitative and qualitative terms. Currently, there is no dedicated quantitative method for validating flood hazard maps. However, some research has attempted to verify these maps using historical flood data from specific areas (Shuaibu *et al.,* 2022; Wu *et al.,* 2015). Earlier studies employed qualitative validation methods to assess spatial hazard maps. To validate the flood hazard map results, historical flood locations were documented through field visits, where GPS coordinates of past flood sites, including inundated towns and farmlands, were collected. The field visits also involved detailed observations and discussions with residents, professionals, and policymakers to gather their insights. These coordinates were then overlaid on the flood hazard map of the area to compare field data with the map. All historical flood coordinates were located within high and moderate flood susceptibility zones, demonstrating the reliability of the flood vulnerability model employed. For example, a flood event in September 2020 affected over 450,000 hectares of rice fields and damaged houses, resulting in an estimated 30 fatalities. The validation results showed a strong correlation between the flood hazard map and past flood records (Muis *et al.,* 2015).

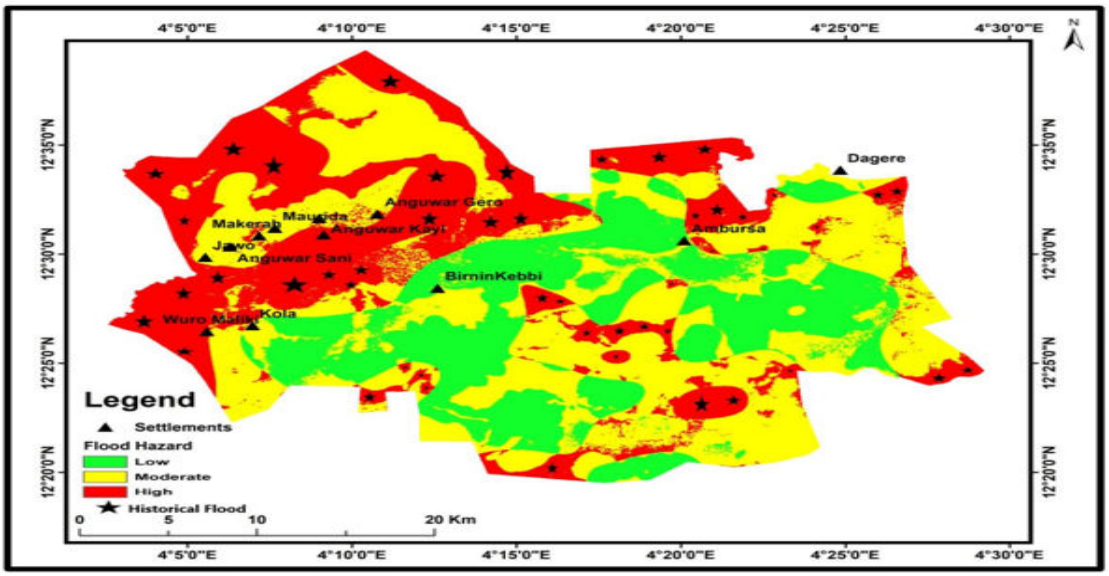

Figure 9: Validated Flood Hazard Map of Birnin Kebbi

V. DISCUSSION OF FINDINGS

The integration of Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP) in this study provides a robust framework for assessing flood hazards in the River Rima floodplain, Birnin Kebbi, Nigeria. This methodological approach is especially critical given the area's vulnerability to frequent and severe flooding, which has profound implications for agriculture, infrastructure, and local livelihoods. The results not only align with findings from other studies but also offer novel insights into the unique socio-environmental dynamics of the study area.

The identification of slope, elevation, and rainfall as the most significant flood hazard indicators emphasizes the geomorphological and hydrological characteristics that predispose certain areas to flooding. The weights assigned through AHP underscore slope (38%), elevation (22%), and rainfall (19%) as primary determinants, which is consistent with findings from Rahman *et al*. (2019) and Gigović *et al.* (2017). Low slopes and elevations facilitate water stagnation and hinder runoff, while heavy rainfall directly exacerbates flood risks. This relationship is evident in high-hazard zones identified in the study, such as Jawo and Anguwar Sani, characterized by low elevations and flat terrains.

The contributions of land use/land cover (LULC), drainage density, and soil type to flood hazards further highlight the interplay between anthropogenic activities and natural processes. High vegetation cover, which dominates the region, mitigates runoff, yet agricultural expansion into vulnerable zones increases susceptibility. Similar observations have been made by Mishra and Sinha (2020) regarding the influence of land use on flood vulnerability. Furthermore, areas with clay-loam soils, which have low permeability, are more prone to waterlogging compared to sandy soils, as corroborated by Ntajal *et al.* (2017).

The flood hazard map produced in this study delineates the flood-prone zones into low, moderate, and high hazard categories, effectively representing 49.6%, 22.8%, and 27.6% of the study area, respectively. The spatial distribution of these zones reflects the combined influence of the analysed indicators, showcasing the utility of GIS in spatial decision-making. High-hazard zones—primarily located in low-elevation areas-correspond to regions with historical flooding events, such as the September 2020 floods that affected over 450,000 hectares of rice fields. The validation of the flood hazard map using field data and historical records demonstrated a strong correlation between the model outputs and real-world observations, reinforcing the reliability of this approach.

The results of this study are critical for developing effective flood management strategies. Identifying high-hazard zones enables targeted interventions, such as the construction of drainage systems, additionally, there is a need for long-term flood reduction and mitigation measures tailored to the floodplain zone. Structural and non-structural approaches are being considered, including restoring the river's natural state through dredging the riverbed and implementing land use planning and building zoning practices. The State Government, in collaboration with the Sokoto Rima River Basin Development Authority (SRRBDA), should also address agricultural encroachments near rivers. Furthermore, the findings highlight the necessity of incorporating flood hazard assessments into regional development plans, as emphasized by Yerima and Bello (2014). Moreover, Future studies should explore integrating real-time data, machine learning techniques, and hydrodynamic models to enhance the accuracy and predictive capabilities of flood hazard maps. Socio-

economic factors, such as population density and infrastructure vulnerability, could be incorporated to provide a more holistic risk assessment. Also, new studies on the impacts of climate change on flooding could be done in order to address complex environmental challenges.

VI. CONCLUSION

The current study created a GIS-based spatial flood hazard map by combining the Analytic Hierarchy Process (AHP) with Geographic Information Systems (GIS) to mitigate flood risk and susceptibility. This method was successful in mapping flood hazard zones within the study area and was the first research in the region to incorporate a hydro-geomorphic hazard analysis. The identification of flood risk factors was informed by a literature review, direct observations, and consultations with residents and experts. Key flood hazard elements in the area were assessed, considering factors such as land use/cover, elevation, slope, drainage density, soil, and rainfall. The findings indicate that areas with low elevation, high drainage density, and gentle slopes are particularly vulnerable to flooding. According to the flood hazard map, approximately 50.4% (522.24 km²) of the area is at risk of flooding. These results are crucial for improving flood mitigation and vulnerability management strategies.

AUTHOR CONTRIBUTIONS

M.Aliyu: Conceptualization, Methodology, Software, Validation, Writing -original draft, review & editing, Revision. **A. A Dandajeh:** Supervision, Writing – review & editing, Revision. **S. B Igboro:** Supervision, writing – review & editing, Revision. **N. I. Abdullahi:** Writing – review & editing, Revision.

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