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Application of GIS and MCDA in flood susceptibility modeling in Jigawa State, Nigeria

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Abstract
Flood disaster is considered one of the devastating and destructive in the world. Due to its high concern, predicting areas with varying susceptibility is crucial. This study aims at identifying and mapping areas and the extent of varying flood susceptible areas in Jigawa State. Multi-criteria decision-making, Analytical Hierarchy Process (AHP), and geographic information science (GIS) were used. Distance to river, Elevation, Flow accumulation, Lineament density, Slope, Geology, Soil, and Land use were used as explanatory parameters to develop the model. The raster data parameters were analyzed using ArcGIS 10.1, and AHP was calculated. The model ranked distance to river high, followed by elevation, flow-accumulation, lineament, land use and land cover, slope, geology, and soil. Area covered by very high and high susceptibility was 27.68% and 29.20% respectively. The use of the analytical hierarchy process, a multi-criteria process, has modeled the susceptibility to flood in Jigawa state accurately. Among the 23 Local Government Areas in the study area, 12 fell within very high and high susceptibility areas covering 56.88%. The study recommends adopting early warning system strategies to prevent future flood disasters.

Keywords: Flood Assessment, MCDA; Disaster, Jigawa State, LULC

Article Type: Research Article

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1. Introduction

In tropical regions, floods remain the biggest natural disasters that harm people, agriculture, livelihoods, and infrastructure both in urban and rural areas around the world. (Zhao et al., 2020). Due to changes in rainfall patterns, an increase in catastrophic events, and changes in land use, flood risk is rising globally (Lappas & Kallioras, 2019). According to the World Bank, with an estimated $1 trillion in economic damage worldwide, flooding is the fourth deadliest calamity in 2011 (Khan et al., 2019). The most prevalent and ubiquitous environmental issue in the world today is flooding (Otokiti et al., 2022). As global temperatures rise, causing torrential rains and an increase in sea level that overflowed river banks and inundated nearby coastal areas, it is understood that floods will not diminish in the future. Instead, they will become more frequent and intense, posing a threat to many parts of the world (Alhamdu et al., 2022). The majority of rural communities in wetlands along rivers or on the coast of Africa are vulnerable to flooding (Douglas, 2017). Numerous people in densely populated urban areas are at risk of flooding because of frequent, brief, but intense thunderstorm showers (Satterthwaite, 2007).

In Nigeria, floods account for about 90% of all-natural disaster-related damages, behind only droughts (Akinbobola et al., 2015; Adeoye et al., 2009). Flooding in Nigeria is caused by excessive rainfall, drainage obstructions, and dam failures (Akinbobola et al., 2015). As a result, there is a greater need for the government to implement proper flood management to eliminate this threat and mitigate the damage that this phenomenon has already done. (Akinbobola et al., 2015). The number of deaths and losses brought on by this recurring tragedy, which affects more than 700,000 hectares of agricultural land and built-up regions, is worrying. The effect of floods in Nigeria has been on the rise, especially in the previous three decades (Njoku et al., 2020). More than half of Nigeria's 36 states have experienced flooding of some kind. (Jeb & Aggarwal, 2008); (Adeoye et al., 2009). Most of Nigeria appears to be experiencing this water overflow caused by climate change in coastal locations. (Premium Times, 2022). One of the greatest floods to ever be observed occurred in Nigeria in 2013 (Chukwuma et al., 2021).

Out of the 27 local government areas, 17 have been affected by the flood, and about 50,000 houses have been affected. It destroyed farmlands and damaged crops, affecting Hadejia, Buji, Ringim, Taura, Jahun, Miga, Malammadori, Auyo, Kafin hausa, Guri, Gwaram, Kiyawa, Kaugama, Birninkudu, Kirikasamma, Garki, Kazaure, and Babura (Oriola & Chibuike, 2016; Zakaria et al., 2022; Tudunwada & Abbas, 2022). Most of the flood-prone areas in the study area were characterized by low elevation, proximity to water bodies, and poor land use planning (Zakaria et al., 2022). The major causes of flood in Jigawa State of Nigeria were heavy downpour of rainfall, overflow of river bank, rainstorm, long duration of rainfall, and steep side channels Tudunwada & Abbas, 2022). Furthermore, Zakaria et. al. (2022). While (Tukur et al., 2018) revealed that the anthropogenic factors were discovered to include deforestation, poor flood embankment, poor waste disposal, poor drainage network, poor physical planning, and poor infrastructure.

To aid policymakers in taking measures to prevent future flood occurrences and to emphasize areas with high flood susceptibility of flood occurrence probabilities, this research mapped flood susceptibility zones in Jigawa State.

2. Materials and Methods

2.1 The Study Area

The study area, Jigawa State, was created in 1991 and it was carved from the former Kano State. It bordered the Republic of Niger to the north and Bauchi state and Yobe state to the east, to the south and west by Kano state and Katsina state (Figure 1). The latitudinal extent of the state is 11.00°N to 13.00°N and longitudes 8.00°E to 10°.15'E. It covers an estimated area of 23,154 km2 (8,940 sq. miles) with geology of basement complex in the northwestern part of Jigawa, while intrusions of younger granites are in the south; Chad Sedimentary Formation consists largely of unconsolidated porous sandy sediments covering greater parts of the area (Tukur et al., 2018). The area has a tropical wet-dry climate with high temperatures throughout the year (Mustapha et al., 2014). The elevation is as high as 772 meters in the southern part and as low as 309 meters in the north east. The main rivers draining Jigawa State are River Hadejia and River Kafin Hausa, traversing in the North East of the state and moving toward Lake Chad by the hydro-geological divide, which is composed of porous sandy sediments that host more abundant aquifers. The major economic activities are farming and trading (Nalami et al., 2019). This translates to the availability of the agricultural land. The indiscriminate clearing of land for agriculture is continuously creating four vegetation zones of Sudano Sahelian Savannah, Sudan Savannah, Open Guinea Savannah, and Protected Guinea Savannah (Mustapha et al., 2014). The state is the 8th most populous in Nigeria, with a figure of 4.3 million (National Population Commission, 2006).

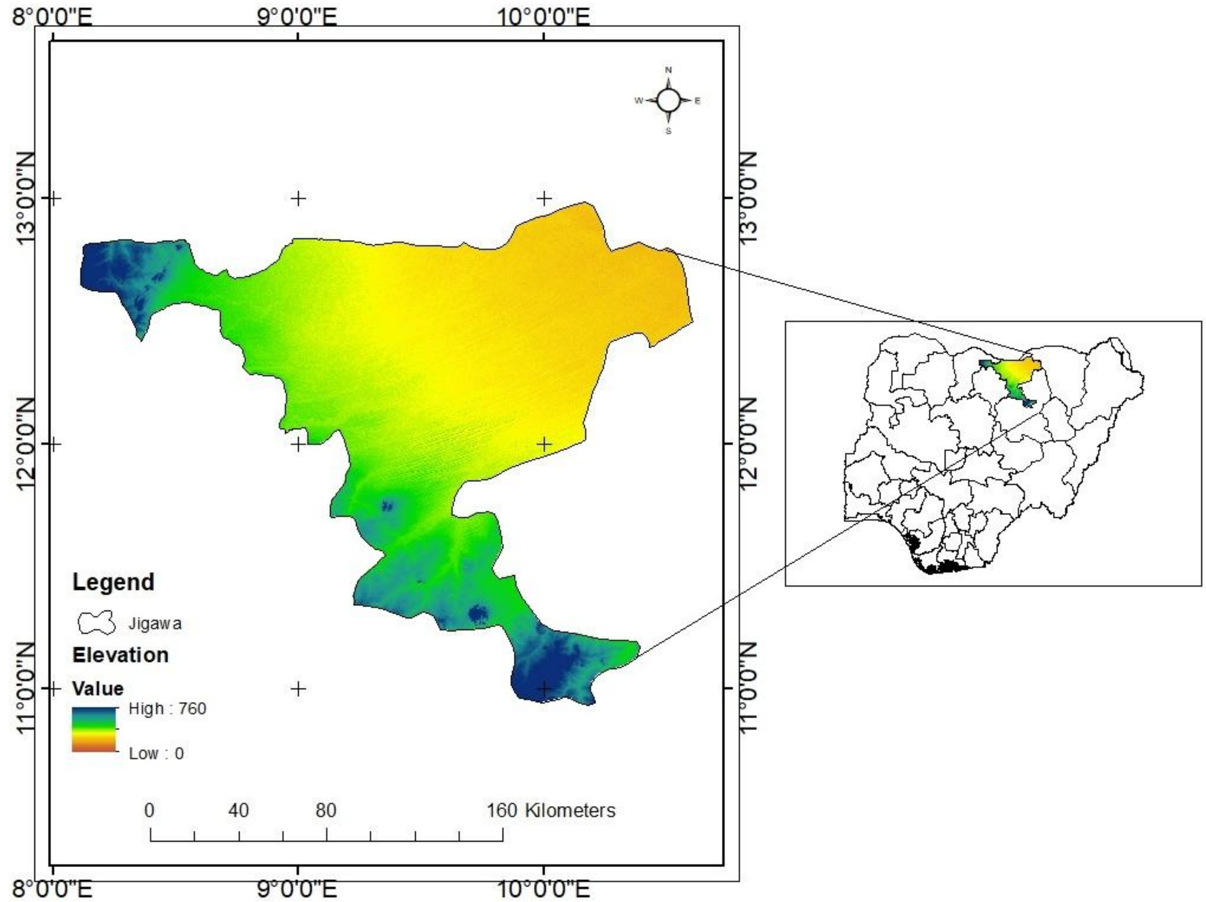

Figure 1. The location of the study area in Nigeria

2.2. Methodology

Based on other findings in the available literature, careful selection was done in order to come up with the parameters for the flood susceptibility modeling of Jigawa State. Distance from the river, elevation, slope, flow accumulation, soil, geology, and land use and land cover are the parameters used, as shown in Figure 2.

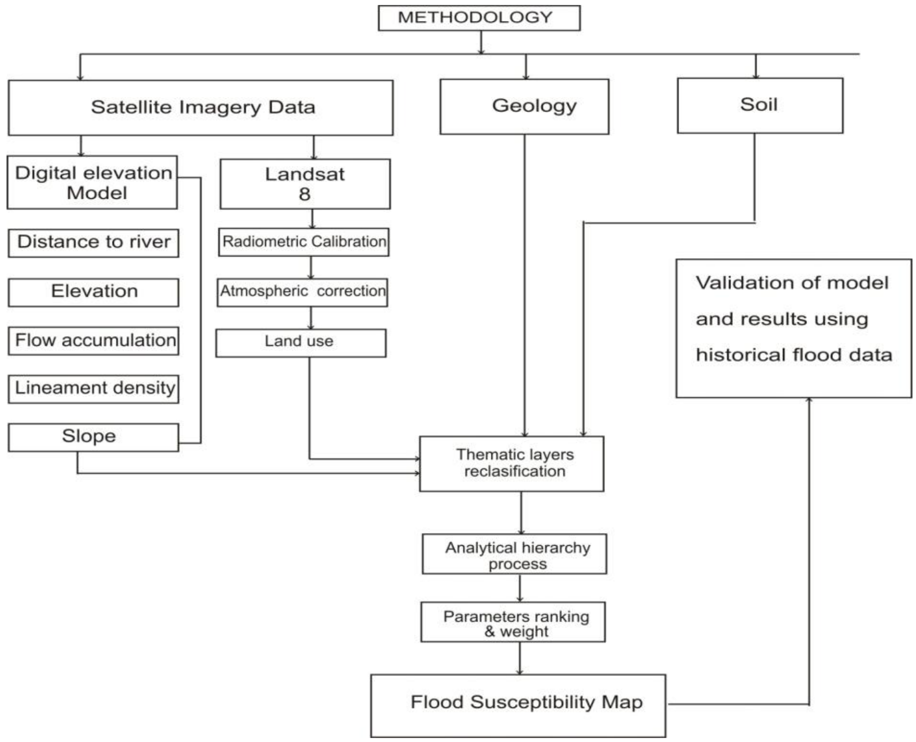

Figure 2: Methodological Flow chart

2.3. Data used and Data Source

The data used in the present study are presented in Table 1.

Table 1. Data source used in this study

Type of Data	Data Source	Period	Output
Landsat 8	http://earthexplorer.usgs.gov/	2021	Land Use map
DEM (Aster)	http://earthexplorer.usgs.gov/	2021	Slope, Elevation, Distance from river, Lineament density, Flow accumulation
Soil	https://www.fao.org/soils-portal/data-hub/	Accessed May 2022	Soil Map
Geology	http://earthexplorer.usgs.gov/	Accessed May 2022	Geology map

2.4. Analytical Hierarchy Process (AHP)

AHP is one of the widely used MCDA methods and is well known to be integrated with GIS for flood susceptibility, as it helps to integrate all thematic layers. Eight (8) criteria were carefully selected for this study. Saaty's scale (1–9) 1980) (Table 3) was used to assign the weight using the field knowledge and literature (Saaty, 1977).

Table 3: Saaty's 1–9 scale in the AHP weighting method

1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong plus
6	Strong importance
7	Very strong importance
8	Very very strong importance
9	Extreme importance

Pairwise comparison matrix in Excel was used to compare the thematic layers. For calculating the consistency ratio (CR), the following equations were used:

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

Where: n is the number of factors (8), λmax is the principal eigenvalue.

$$CR = \frac{CI}{RI} \quad (2)$$

RI is Random inconsistency provided in Saaty Scale (Table 4) which is 1.41

Table 4. The Random inconsistency values (Saaty, 1977).

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3. Results

3.1 Results of the parameters

3.1.1. Distance from River

The distance to the river map was classified into five in (m) as follows: 0-0.035, 0.035-0.89, 0.89-0.16, 0.16-0.24, and 0.24-0.38. Nearness to rivers poses more flood thereat [27; 28]. The class of 0-0.035 has high flood incidents, and it is the closest to the river. The distance to the river map was calculated using Euclidean distance in ArcGIS 10.1 (figure 4). The result shows that the distance from large water bodies influenced the flood. The class of 0-0.035 has high flood incidents, and it is the closest to the river.

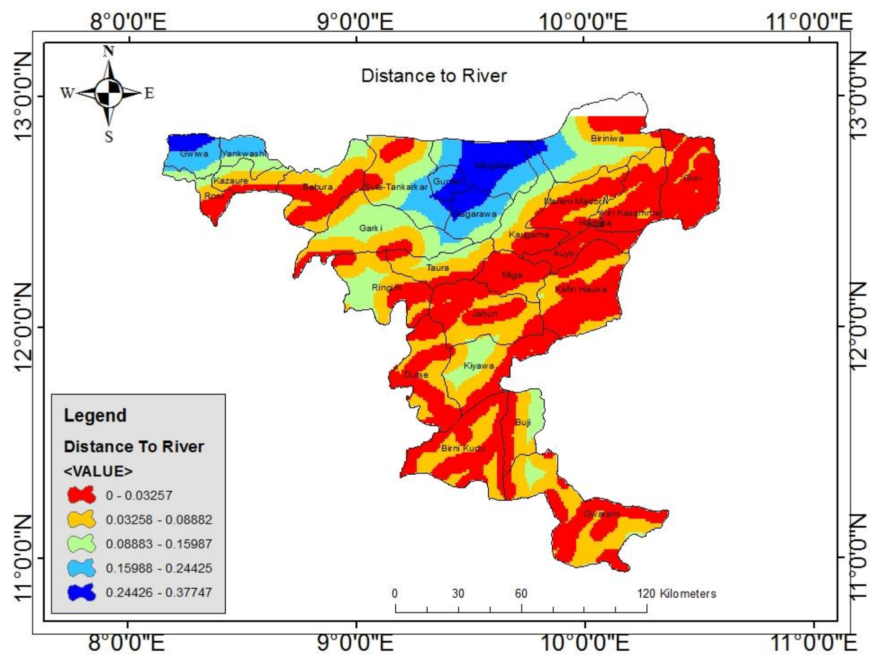

Figure 4: Distance to river map

3.1.2. Elevation

One of the important factors in flooding is elevation. High elevation accounts for low flood incidents because water drains quickly to lower elevation, while low elevation attracts inflow of surface run-off (Rahimy, 2012; Azua et al., 2019; Rahman et al., 2021). A higher slope attracts higher susceptibility to flood (Khosravi et al., 2019). That greater part of the study area falls within an elevation of 300- 370 meters on an extensive flat plain (Figure 5). South East and North West, the study area recorded higher elevation between 400- 772 meters.

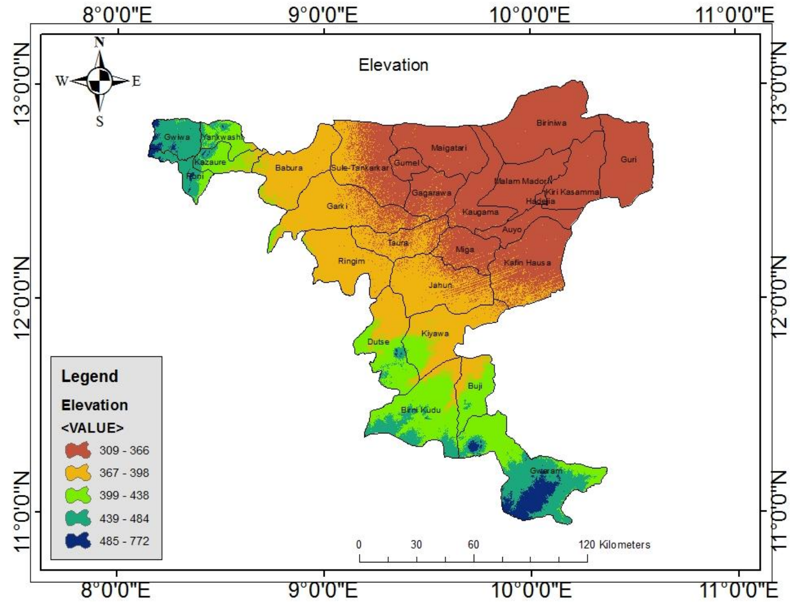

Figure 5: Elevation map

3.1.2. Flow Accumulation

The flow accumulation map (Figure 6) was computed for each cell by quantifying the number of upstream cells that contribute drainage to it.

Cells exhibiting elevated flow accumulation values are situated in regions of intensified flow and are classified as stream channels in accordance with the predetermined flow accumulation threshold (El Morjani et al., 2016). The outcomes of the flow accumulation analysis can be utilized to construct a stream network by implementing a threshold value to identify cells characterized by substantial accumulated flow.

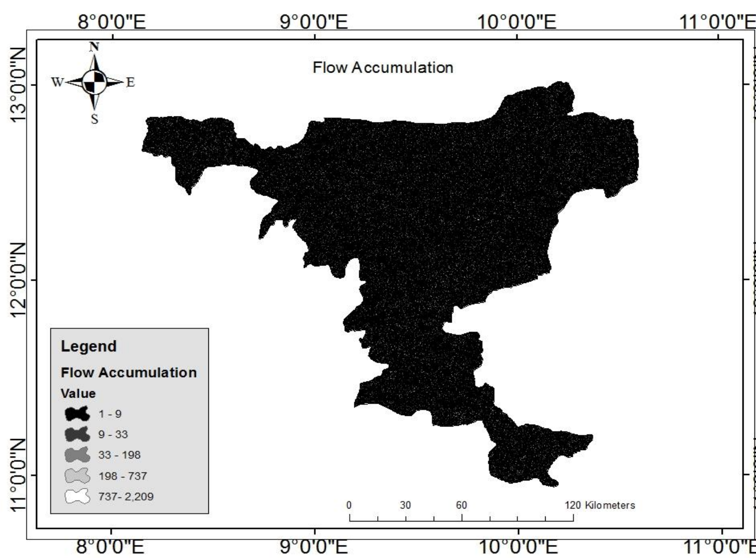

Figure 5: Flow Accumulation map

3.1.3. Lineaments

Lineaments delineate the regions characterized by faulting and fracturing, which subsequently contribute to an augmentation of secondary porosity and permeability (Chen et al., 2016). The lineament density map (Figure 6) was subsequently constructed utilizing line density methodologies. The analysis indicates that the risk of flooding escalates as the proximity to the lineaments diminishes.

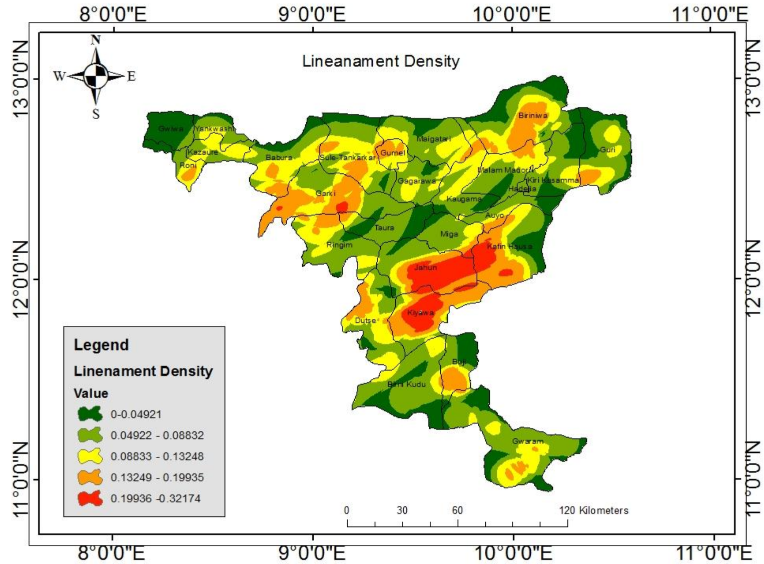

Figure 6: Lineament Density map

3.1.4. Slope

One of the important criteria in flood modelling is slope, as the danger of flooding increases as the slope decreases. It decides to some extent the runoff and stagnation of the surface water. The slope, as shown in Figure 7, is also very closely connected to the flow of runoff directly toward downstream (Khoirunisa et al., 2021).

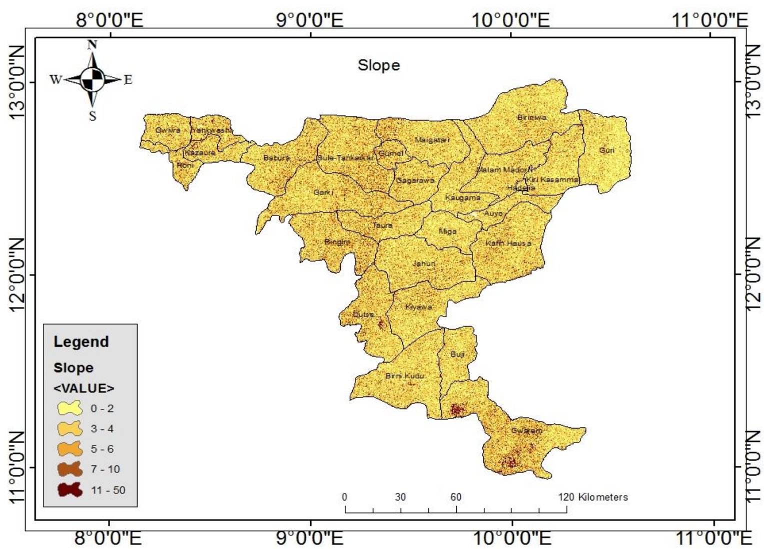

Figure 7: Slope map

3.1.5. Geology

The lithology of the area consists of the basement complex and the Chad formation, which largely allows different rates of movement of water. However, in a relatively flat terrain, water movement in rocky areas may be slow, allowing water to accumulate, which can result in flooding. The geology of the study area is shown in Figure 7. The result shows that the area is composed mainly of the Chad formation on a flat plain with a high volume of drainage density, which makes a high contribution to flooding.

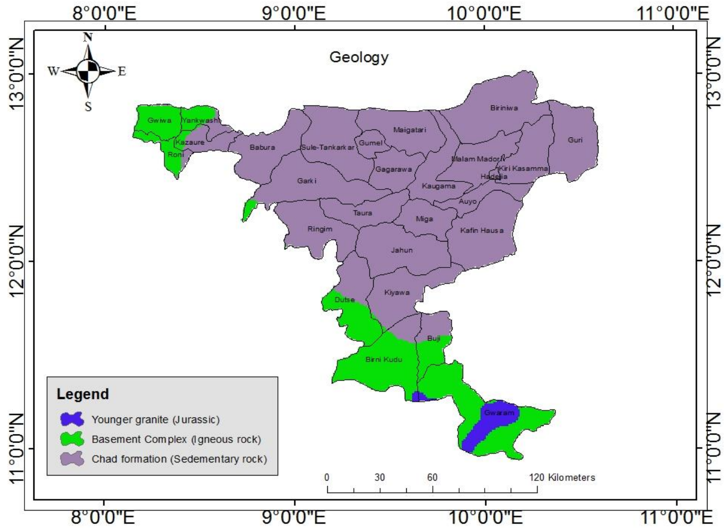

Figure 8: Geology map of the study area

3.1.6. Soil

Soil types of the area are playing a significant role in influencing floods in the area. Different types of soil have different water-holding capacity. The major soils found in the study area are Eutric fluvisols, Luvic Arenosols, Eutric regosols, plinthic luvisols, Weights are assigned subjectively to each soil unit after taking into consideration the type of soil and its water holding capacity. Map of soil type of the study area is shown in Figure 9.

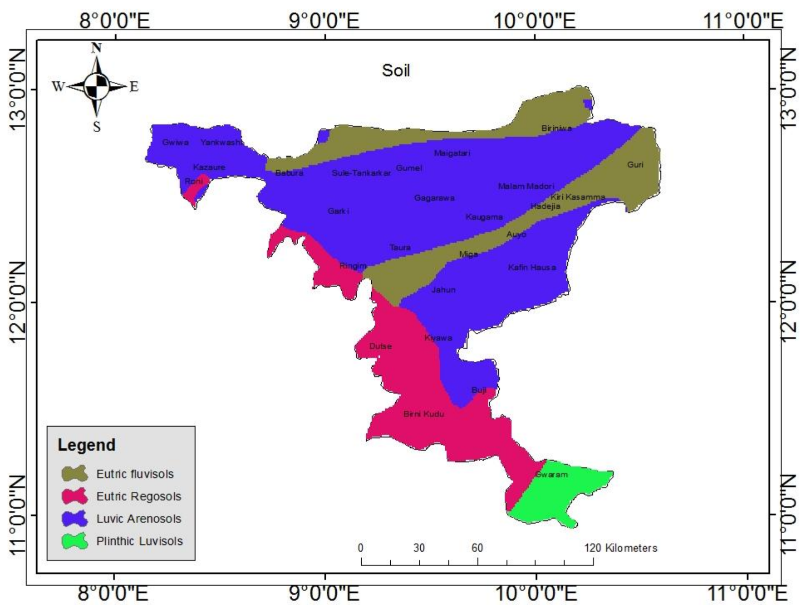

Figure 9: Soil map of the study area

3.1.7. Land Use

The occurrence of flood in areas with different land use shows different performance. For instance, the flooding mechanism is very different in urban areas, areas with vegetation, and areas with soil and rock texture. Therefore, each feature, as in Figure 10, will play a substantial role in flood study (Azua et al., 2019; Amede et al., 2020). The weight and rank assigned to each land use are according to the literature. Land-use/land-cover types that increase surface runoff are more likely to induce flooding than those that restrain surface runoff (Apollonio et al., 2016; Zhao et al., 2020; Rahimy, 2012).

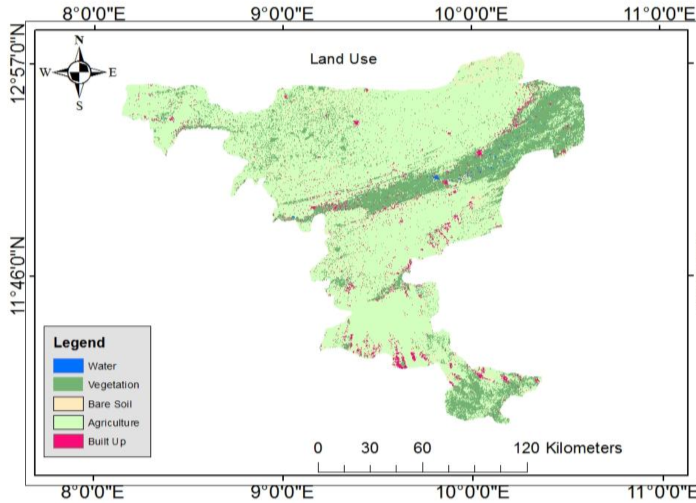

Figure 10: Land use map

3.2. AHP Flood Susceptibility Results

The Consistency Ratio calculated using equation 1 and 2 are and its value is 0.06. Also, the Random Inconsistency values provided by the Saaty Scale (table 3) are calculated, and their value is 0.04.

According to Lappas & Kallioras (2019), the acceptable value of CR should be equal to or less than 0.1. Therefore, the CR of 0.04 is acceptable.

Table 5: Pairwise comparison matrix of the 8 criteria

Parameters	DR	EL	FA	LD	SL	GL	SO	TWI
Drainage Density (DR)	**1**	2	2	4	7	8	7	5
Elevation (EL)	1/2	**1**	2	3	6	6	7	5
Flow Accumulation (FA)	1/2	1/2	**1**	1	5	8	6	4
Lineament Density (LD)	1/4	1/3	1	**1**	7	8	7	4
Geology (GL)	1/7	1/6	1/5	1/7	**1**	1	2	1/3
Slope (SL)	1/8	1/6	1/8	1/8	1	**1**	1	1/3
Soil (SO)	1/7	1/7	1/6	1/7	1/2	1	**1**	1/3
Land Use (TWI)	1/5	1/5	1/4	1/4	3	3	3	**1**

The calculation of the normalized weight of the layers (Table 5) revealed that drainage density had the greatest weight (30%), which is justified by the fact that the area is characterized by the presence of many drainages, which play an important role in flood occurrences. Elevation is next with (23%), and it is a fact that elevation plays a role in surface runoff, which is also a factor in flood susceptibility. The model ranked flow accumulation and lineament density equally with 16%. Geology, slope, and soil also ranked equal with (3%).

Table 6. Calculated the normalized pairwise matrix and the criteria weight

Parameters	DR	EL	FA	LD	SL	GL	SO	LU	Weight
Drainage Density (DR)	0.35	0.44	0.30	0.41	0.23	0.22	0.21	0.25	0.30
Elevation (EL)	0.18	0.22	0.30	0.31	0.20	0.17	0.21	0.25	0.23
Flow Accumulation (FA)	0.18	0.11	0.15	0.10	0.16	0.22	0.18	0.20	0.16
Lineament Density (LD)	0.09	0.07	0.15	0.10	0.23	0.22	0.21	0.20	0.16
Geology (GL)	0.05	0.04	0.03	0.01	0.03	0.03	0.06	0.02	0.03
Slope (SL)	0.04	0.04	0.02	0.01	0.03	0.03	0.03	0.02	0.03
Soil (SO)	0.05	0.03	0.03	0.01	0.02	0.03	0.03	0.02	0.03
Land Use (LU)	0.07	0.04	0.04	0.03	0.10	0.08	0.09	0.05	0.06
SUM	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Parameters' weights were calculated as to percentage to get the influence of each parameter for use in producing the flood susceptibility map, as shown in Table 7.

Table 7. Flood parameters were weighed and influence obtained from the Eigen Vector pair-wise comparison

Parameters	AHP Normalized weight	AHP Influence
Distance to River	0.30	30
Elevation	0.23	23
Flow Accumulation	0.16	16
Lineament Density	0.16	16
Slope	0.03	3
Geology	0.03	3
Soil	0.03	3
Land Use	0.06	6
Sum	1	100

As shown in Table 7, the area is classified into five flood risk zones; the classes are areas of Very low, Low, Moderate, High, and Very High flood risk Zones. Very Low flood risk zone occupied 1964.93km^2 (8.72%) in the North central and extreme North East of Jigawa State. Low flood risk areas that occupied 2995171km2 (13.11%) lie mostly in areas immediately below the Very Low Risk Zones and bordering the Moderate Risk Zones. Moderate Flood Risk Zones flanked between the high and low Flood Risk Zones occupying an area of 4789.48km2 (21.27%), High Flood Risk Zones occupied parts of areas in the South, Central West and North East with an area of 6574.31km2 (29.20%) with the last and very high flood risk zone occupying of 6232.46km2 (27.68%) stretching from the North West to the North Central part of the Jigawa State.

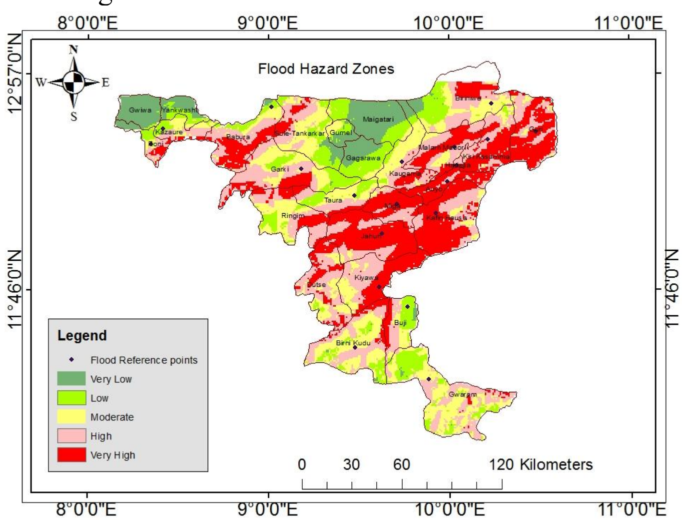

Figure 12: Flood Susceptibility map

Table 7: Result of the flood Susceptibility and area coverage in Km^2

Flood Magnitude	Area (KM^2)	Percentage
Very Low	1964.93	8.72
Low	2951.71	13.11
Moderate	4789.48	21.27
High	6574.31	29.20
Very High	6232.46	27.68
Sum	**22512.89**	**100**

3.3. Flood Susceptibility validation using reference flood data

The result of the flood susceptibility and historical flood data reveals good agreement. This proves that the parameters and method can be applied at the local government level on a smaller scale. Figure 10 shows that the high and very high flood susceptibility are located in areas that have historical flood records stretching from Birniwa down to the Ringim local governments, with Babura from the west and Dutse and Kiyawa from the south, while low and very low flood susceptibility areas are located in the north central and north west around Gwiwa and Yankwashi local governments. The findings of Tudunwada et al. (2022) & Zakaria et al. (2022), and Tukur et al. (2018) align with this study in Jigawa State.

4. Discussion

The selected parameters in assessing the flood susceptibility of Jigawa State gave the result that agreed with the historical flood incident data provided by Tudunwada et al. 2022 & Zakaria et al. (2022) and Tukur et al. (2018). The first arguable issue is the number of flood conditioning factors, as well as the question of which factors should be chosen in order to best characterize the physical characteristics that determine the propensity of the study area to flooding (Vojtek & Vojteková, 2019). The parameters used have modeled the flood susceptibility of the study region. According to (Mahmoud & Gan, 2018), for an accurate flood model, more than six parameters were recommended for the weights to have representative dominance, so one or two parameters will not be overrated, which could bring bias. The number of flood conditioning factors should also be adjusted with respect to the local geomorphologic and geologic conditions since flat areas may require other parameters than hilly (mountainous) areas (Mahmoud & Gan, 2018. This made it clear that, flood model of each study region should be independently carried out as the model of one region will not predict well in another region. Using the following factors (Shuaibu, 2020).

Elevation, Slope, Drainage Density, Soil Type, Mean Annual Rainfall, Flow Accumulation, and Distance to Rivers; his research included parts of Kano and Yobe States following the watershed, ignoring some parts of the state with or without a flood record. This will not only give guidance and help in predicting floods in different parts of the state. In this study, the Rainfall parameter was removed because, based on the literature and community engagement, one of the factors of flood disaster in the area is induced by overflow of rivers. Lineament and Geology were added to make the parameters eight (8). The parameters were compared, and the weight was determined using AHP.

5. Conclusion

A greater parts of the study area fall under the River Hadejia Basin. Because of the frequent flood incidents in Jigawa State that destroy farm lands and houses, mapping flood susceptible areas of the state at the state level was necessary; there is also a need to develop a model that fits in predicting areas that require high concern. Most of the high flood susceptible areas are within the Chad Formation, while parts of the low susceptible areas are under the Basement Complex (Figure Geology).

Application of the multi-criteria approach to flood susceptibility using the Analytical Hierarchy Process and GIS was found to be acceptable in the area. Due to its simplicity and data availability, the approach is recommended for further flood analysis in the state to try to predict the flood return period of different areas at the state level. Eight parameters were used to model flood susceptibility of the study area, and they are: Distance to river, Elevation, Flow Accumulation, Lineament density, Slope, Geology, Soil, and Land use.

Author Contributions:
Muttaka Idris: Conceptualization, methodology, GIS and remote sensing analysis and preparing of the original draft.
Adamu Mustapha: Methodology, supervision, and statistical analysis.
Akinola Adesuji Komolafe: Methodology, GIS and remote sensing analysis, vetting of the manuscript

Conflicts of interest

The authors declared no conflict of interest.

Data availability statement:

All the data used in this study are included in this published article and all relevant data are available on request.

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