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Multi-criteria Analysis and Mapping of the Vulnerable Flood Risk Areas of Jigawa State, Nigeria

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Abstract

This study evaluates flood risk factors and maps flood-prone areas in Jigawa State, Nigeria, using geospatial techniques. By integrating various flood-causing factors—such as rainfall distribution, elevation, slope, drainage network and density, land cover and use, flow accumulation, and soil type—through a multi-parametric approach, it employs the Analytical Hierarchy Process (AHP) to perform pairwise comparisons and assign priority weights to each factor. Spatial multi-criteria analysis (MCA) then ranks and identifies potential flood locations. Using ArcGIS's weighted overlay tool, these layers are combined to produce a final flood risk map, classifying areas into high, very high, moderate, low, and very low-risk categories. Elevation and slope were found to have the greatest impact on flooding, with normalized criterion weights of 30 and 22, respectively. The Consistency Ratio (CR) of 0.06 validated the strength of the judgment, and these AHP-derived factor weights were used to create the flood risk map showing areas with varying risk levels, highlighting eight local governments in the study area. —Auyo, Hadejia, Kirika-samma, Kafin-Hausa, Ringim, Miga, Jahun, and Dutse—compose areas of very high risk, while Guri, some portions of northern Kiri-kasamma, southern Jahun, northern Auyo, Birnin-Kudu, and northwestern Ringim local governments comprise high-risk areas. Areas of moderate risk comprise a small portion of northern Kirika-samma, larger portions of Gwaram, small portions of Jahun, Kafin-Hausa, Dutse and Birnin-kudu local governments respectively and areas of low to very low risks consist of many parts of Gwaram and some tiny portions of Birnin-kudu.

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Keywords: Flood, risk, mapping, slope, drainage density.

INTRODUCTION

The frequency and severity of extreme weather events and natural disasters have increased in the past decades worldwide (Kundzewicz, 2016). As a result of global warming, the climate in Africa is predicted to become more variable, and extreme weather events are expected to be more frequent and severe even with relatively small average temperature increases, with increasing risk to health and life (Few *et al.,* 2004). Many countries are already dealing with grave impacts resulting from irregular, unpredictable rainfall patterns, increased incidence of storms and prolonged droughts (Christensen *et al.,* 2007; United Nations International Strategy for Disaster Reduction [UNISDR], 2015). Flood hazard poses one of the greatest natural risks (Ayinde *et al.,* 2013). Flood has been defined by the UNISDR (2004) as a general temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or unusual and rapid accumulation or runoff of surface waters from any source. Floods are influenced by various factors, this includes the intensity, volume, timing, and type of precipitation (rain or snow), as well as the pre-existing conditions of rivers and their drainage basins. These conditions include the presence of snow and ice, soil characteristics and status (whether frozen, saturated, or unsaturated), wetness, the rate and timing of snow/ice melt, urbanization, and the presence of dykes, dams, and reservoirs. Globally, floods have caused significant damage to properties and lives, resulting in up to 50,000 deaths and negatively impacting around 75 million people annually. Heavy floods occurred in Australia during the austral summer (2010/11), in Pakistan, India and China in the summer of 2015, Colombia from October to December 2015 (Kundzewicz, 2016). In Africa, an estimated 1.5 million people were affected and another 300 were killed as a result of floods that swept through 22 countries, from the east to west coast of the continent in 2007, the worst hit being Uganda, Sudan, Kenya, Ethiopia, Ghana, and Congo (National Geographic News, 2007). In Nigeria, flood is a phenomenon of every rainy season in Lagos, Niger, Imo, Katsina, Maiduguri, Aba, Warri, Benin, and Ibadan and a constant occurrence in towns located on flat or low-lying terrain especially where little or no provision has been made for surface drainage or existing drainage has been blocked (Adedeji, Odufuwa and Adebayo, 2012; Ezemonye and Chukwudi, 2014; Ikusemoran, Kolawole and Adegoke, 2014; Emeribeole, 2015; Umar and Muazu, 2017).

In Jigawa State, the Hadejia River, which splits into three channels in the Hadejia-Nguru Wetland—the Marma channel flowing into Nguru Lake, the old Hadejia River joining the Jama’are River, and the smaller Burum Gana River—has a history of seasonal overflow. Flooding is influenced by rainfall and other factors. During the 2018 rainy season, floods, wind, and rainstorms resulted in the deaths of around thirty people and devastated several Local Government Areas (LGAs) within the river basin, destroying over sixty-eight thousand hectares of farmland. Approximately 421 communities in the Jahun, Miga, Auyo, Kafin Hausa, Guri, and Hadejia LGAs were reported to be severely affected. Despite government efforts to provide relief to the victims, the impact has been minimal. Worse still floods have been confirmed to continuously cause huge socio-economic and environmental losses as a result of over flow of River Hadejia (Sani, 2016; Aliyu 2018). This research work aim at improving the flood risk map of Jigawa State,Nigeria by delineating the flood risk zone of the State.

MATERIAL AND METHODS

Study area

Jigawa State is located in the northwestern region of Nigeria, between latitudes 11°00'00" N and 13°00'00" N, and longitudes 8°00'00" E and 10°30'00" E. Its administrative capital is Dutse, and the state comprises 27 Local Government Areas (LGAs). Covering an area of approximately 24,742 km², Jigawa State had a population of around 5,828,200 people in 2016 (NBS, 2016). Wetlands (Fadama) account for about 14% of the state's total landmass (Yusuf et al., 2021). The vegetation in Jigawa State consists of Sudan Savannah and Sahel Savannah types, and the area experiences a tropical wet and dry climate with seasonal rainfall from May to October. This semi-arid climate features a long dry season and a short wet season from June to September. The average annual temperature is around 25°C, with monthly temperatures ranging from 21°C in the coolest month to 31°C in the hottest month. Annual rainfall ranges from 600mm to 762mm, with significant variations that can lead to severe and prolonged droughts in some years (Ogunkoya and Dami, 2007; Kaugama and Ahmed, 2014). The soils are relatively recent, generally sandy at the top and compact at depth, often with hard pans, and substantial aeolian deposits from the Sahara Desert contribute to the soil composition (Abubakar et al., 2016).

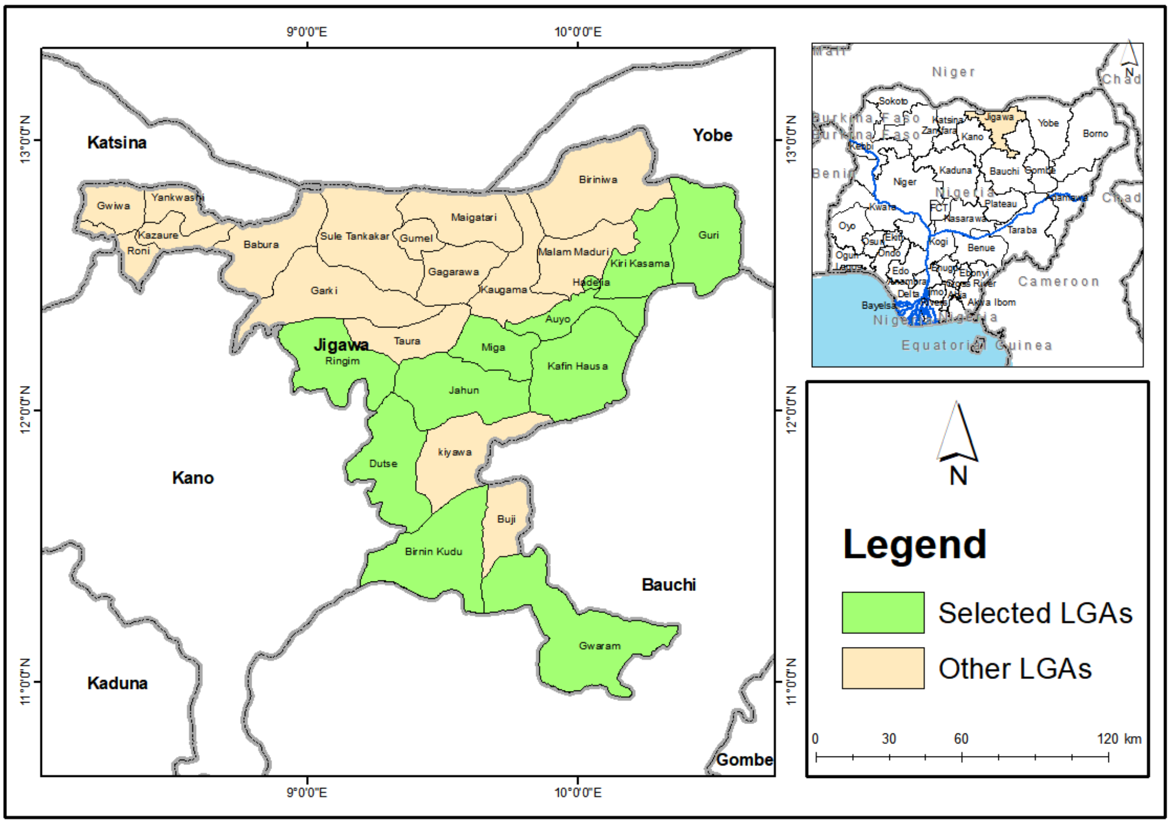


Fig 1: The Study Area
Source: Adapted from the Administrative Map of Jigawa State.

Data

Data are fundamental and essential for GIS analyses (Shuaibu,2022). Data are obtained from various sources such as government agencies(Nigerian Meteorological Agency), research institutions, or remote sensing data providers such as weather stations, stream gauges, radar systems, and remote sensing platforms(The National Space Research and Development Agency),(Nigeria Hydrological service agency) and (Nigeria Geological Survey Agency). Those variables considered topographic and land use and land cover as environmental change indicators, with Geospatial data processing and analysis from satellite imageries. Arcmap 10.8.2 was used in change detection analysis and also to detect the impact of flooding in the area under study.

Data Collection Procedure

a. Quantitative Data:

Geographic data: Geospatial data, including digital elevation models and land cover maps, as well as hydrological data, were acquired from reliable sources such as (The National Space Research and Development Agency, Nigeria Hydrological Service Agency, Nigeria Geological Service Agency and United State Geological Survey) and generated through remote sensing and GIS software.

Socio-economic data: Data related to population density, infrastructure, land use, agricultural practices, and socio-economic indicators were collected through surveys and secondary sources.

Data processing: ArcMap was used for data processing, image interpretation, and analysis.

Method of data analysis: The factors influencing flooding in the study were identified based on its hydrological, geological, and physio-geographical characteristics, which were measured and evaluated. These factors include land use/land cover, slope, elevation, drainage density, distance from the river, flow accumulation, soil, and rainfall. Each factor was weighted according to its estimated significance in contributing to flooding, using the Analytical Hierarchy Process (AHP) to determine the major factors influencing floods in the study area.

In the context of a decision-making process also referred to as the Analytical Hierarchy Process, is a decision-making procedure that prioritizes the criteria based on pairwise comparisons (Saaty, 1980). The criterion pairwise comparison matrix uses Pairwise comparisons are used as input to generate relative weights as output. The Analytical Hierarchy Process (AHP) then mathematically converts this matrix into a vector of relative weights for the criteria. The fundamental scale for the pairwise comparison is presented in Table 1.

Table 1 shows the Fundamental Scale for Pair-wise Comparison

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favour one element over another.
5	Strong importance	Experience and judgement strongly favour one element over another.
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation.
	2,4,6, and 8 are intermediate values	

Source: Adapted from Saaty (1980)

The thematic maps for factors like land use/land cover, slope, elevation, drainage density, proximity to rivers, flow accumulation, soil, and rainfall intensity were reclassified into appropriate classes based on their perceived contribution to flood occurrence using the Reclass tool in the Spatial Analysis tools of ArcGIS 10.8.2. A pairwise comparison matrix was then created using Saaty's nine-point importance based on the thematic layers used for delineating flood risk. The Analytical Hierarchy Process (AHP) incorporates the concept of uncertainty in judgments through the consistency index, as defined by Saaty (2004). The Consistency Ratio (CR) assesses the consistency of these judgments among the criteria.

(i) The general guideline is that the Consistency Ratio (CR) should be 0.1 or less; a value within the range of 0 to 0.1 is deemed acceptable.
(ii) (Higher values suggest that the judgments need to be re-evaluated.
(iii) The CR is calculated as follows: CR = CI / RI, where CI is the Consistency Index reflecting the consistency of one's judgment and is calculated as CI = (λmax - n) / (n - 1). λmax is obtained by averaging the values of the consistency vector, which are the computed factor weights. The Random Inconsistency Index (RI) varies depending on the sample size, as outlined in Table 2.

Table 2 shows the Random Inconsistency Index (RI), which varies according to the sample size. The Consistency Ratio (CR) is employed to check the consistency of the criteria comparisons Made by decision-makers. It assesses the reliability of the pairwise comparison matrix. A CR of 0.10 or less signifies an acceptable level of consistency in the matrix. If the CR is higher than 0.10, it implies inconsistencies in the comparison matrix and necessitates a review of the pairwise comparisons.

Table 2 displays the RI values based 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

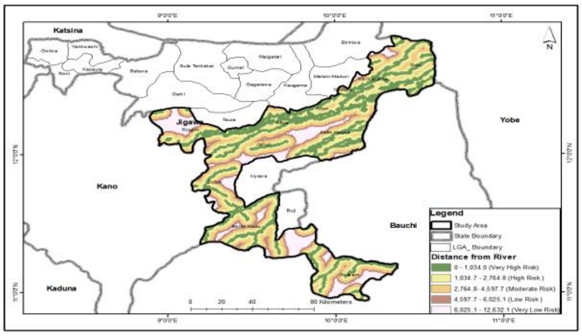
Source: Saaty (1980)

The weights derived from the flood causative analysis using AHP were applied using the weighted overlay tool in ArcGIS 10.8.2 spatial analysis tools. This method highlighted areas at risk, which were then classified into five categories: very low, low, moderate, high, and very high risk.

RESULTS AND DISCUSSION

Features of Flood Risk Factors in Jigawa State: figures a, b, c, d, e, f, j, h and i below illustrate the flood risk area ranges based on:

(a) Distance from Rivers
(b) Drainage Density
(c) Flow Accumulation
(d) Elevation
(e) Mean Annual Rainfall
(f) Land Use
(g) Slope
(h) Soil
(i) Flood Risk Map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11°0'0"N
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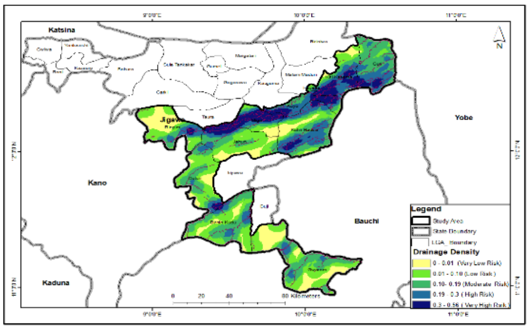
0 20 40 80 Kilometers
Legend
Study Area
State Boundary
LGA_ Boundary
Distance from River
0 - 1,034.0 (Very High Risk)
1,034.7 - 2,764.8 (High Risk)
2,764.8- 4,597.7 (Moderate Risk)
4,597.7 - 6,025.1 (Low Risk)
6,025.1 - 12,632.1 (Very Low Risk)

(a)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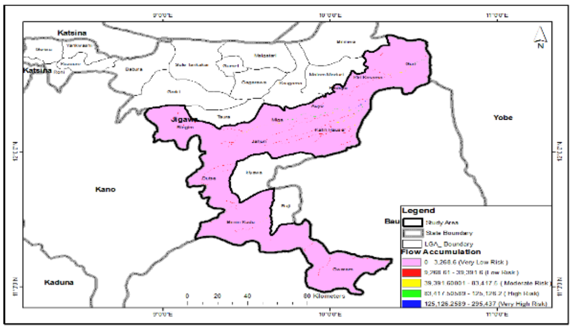
Legend
Study Area
State Boundary
LGA_ Boundary
Drainage Density
0 - 0.01 (Very Low Risk)
0.01 - 0.10 (Low Risk)
0.10- 0.19 (Moderate Risk)
0.19 - 0.3 (High Risk)
0.3 - 0.56 (Very High Risk)

(b)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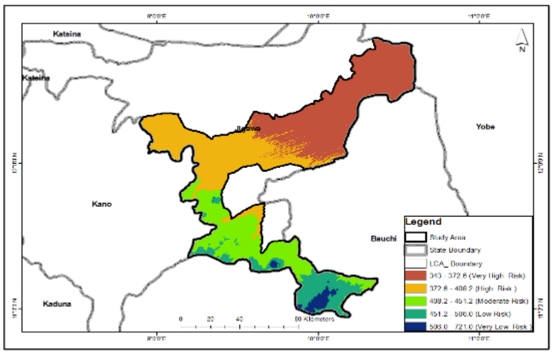
Legend
Study Area
State Boundary
LGA_ Boundary
Flow Accumulation
0 - 3,268.6 (Very Low Risk)
9,268.61 - 39,391.6 (Low Risk)
39,391.60001 - 83,417.5 (Moderate Risk)
83,417.50589 - 125,126.2 (High Risk)
125,126.2589 - 295,437 (Very High Risk)

(c)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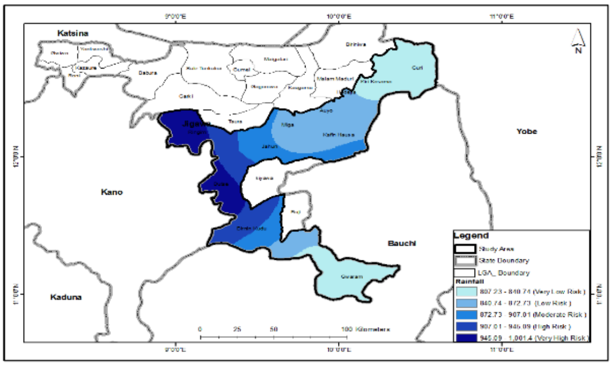
Legend
Study Area
State Boundary
LGA_ Boundary
343 - 372.6 (Very High Risk)
372.6 - 408.2 (High Risk)
408.2 - 451.2 (Moderate Risk)
451.2 - 506.0 (Low Risk)
506.0 - 721.0 (Very Low Risk)

(d)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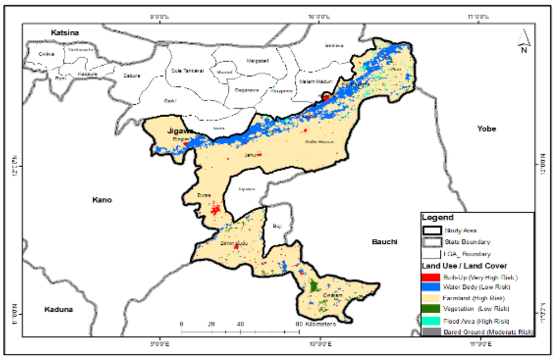
Legend
Study Area
State Boundary
LGA_ Boundary
Rainfall
807.23 - 840.74 (Very Low Risk)
840.74 - 872.73 (Low Risk)
872.73 - 907.01 (Moderate Risk)
907.01 - 945.09 (High Risk)
945.09 - 1,001.4 (Very High Risk)

(e)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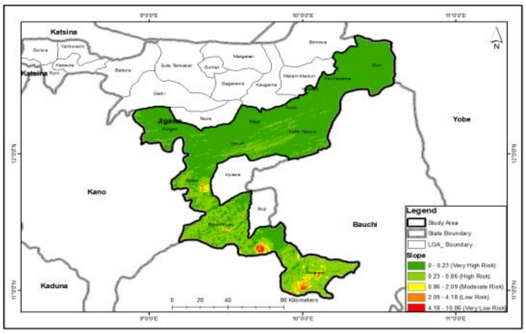
0 20 40 80 Kilometers
Legend
Study Area
State Boundary
LGA_ Boundary
Land Use / Land Cover
Built-Up (Very High Risk)
Water Body (Low Risk)
Farmland (High Risk)
Vegetation (Low Risk)
Flood Area (High Risk)
Bared Ground (Moderate Risk)

(f)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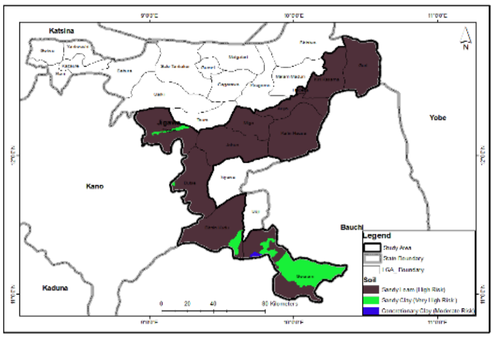
Legend
Study Area
State Boundary
LGA_ Boundary
Slope
0 - 0.23 (Very High Risk)
0.23 - 0.86 (High Risk)
0.86 - 2.09 (Moderate Risk)
2.09 - 4.18 (Low Risk)
4.18 - 10.06 (Very Low Risk)

(g)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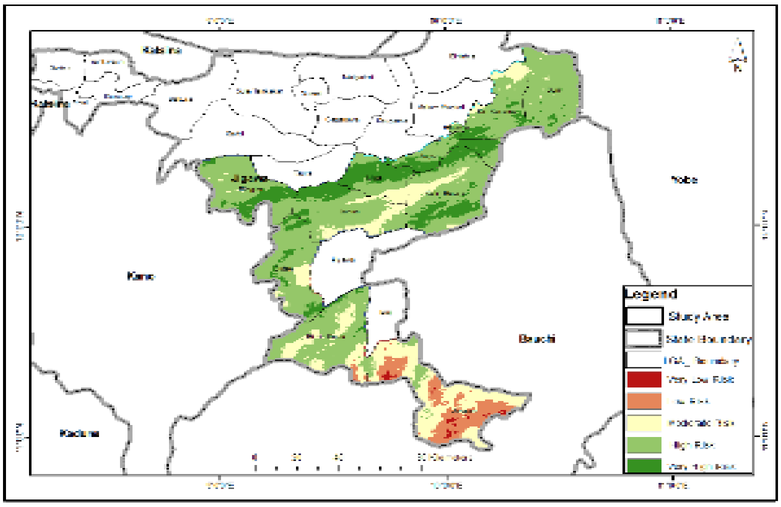
0 20 40 80 Kilometers
Legend
Study Area
State Boundary
LGA_ Boundary
Soil
Sandy Loam (High Risk)
Sandy Clay (Very High Risk)
Concretionary Clay (Moderate Risk)

(h)



(i)

(a) Distance from the river

The topography of Jigawa State is one of the major factors in determining flood risk. Proximity to a river is an important indicator of flood hazard because areas close to rivers experience more frequent flooding than areas further away from rivers (Mahmoud and Gan 2018). Figure a above shows the study area and their distance from the river. The most at-risk areas are concentrated around the rivers, which are very high-risk. Distance classified as very high risk falls within 0-1,034.0m including communities like Auyo, Hadejia, Kiri-kasamma, Guri Kafin Hausa, Miga, Gwaram and Jahun**.** Areas close to a river are likely to experience frequent and severe flooding. High-risk areas which fall between 1,034.7-2,764.8m include Birnin Kudu, some parts of Gwaram still pose a significant threat of flooding in those areas, but it may not be as frequent or severe as in the very high-risk zones areas. The distance of wards that lies between 2,764.8 and 4,597.7m involves communities like Dutse, some parts of Jahun, some portions of Birnin Kudu and Ringim are at moderate risk of experiencing flooding. The risk of flooding here is lower than in the previous categories but is still a concern. Low-risk areas that may be less likely to be affected by floods fall within 4,597.7-6,025.1 m. Flooding is less likely to occur in those areas, but it is still possible. In a very low-risk area, which have a distance from 6,025.1-12,632.1m (this involves some parts of the communities of Ringim, Kafin-Hausa and Dutse) from a river, the risk of flooding is uncommon.

(b) Drainage density

Drainage density is the measure of the length of streams or channels per unit area of a watershed and is a critical hydrological parameter that influences the propensity of landscapes to experience flooding, drainage density plays a significant role in shaping the spatial distribution and severity of inundation events, with implications for community resilience, infrastructure development, and disaster preparedness (Lyu et al 2018). In Jigawa State, where the landscape is crisscrossed by a network of watercourses, drainage density varies spatially, reflecting the natural hydrological characteristics of different regions. High drainage density signifies high surface runoff and thus high flooding likelihood (Mahmoud and Gan 2018). High drainage densities mean greater runoff rates and hence high flooding susceptibility (Radwan *et al.*,2019).

Figure b above reveals a comprehensive overview of the drainage density and their corresponding risk levels in the area under study. Areas with higher drainage density within the range of 0.3-0.5km including areas like Auyo, Miga, Kiri-kasamma, Hadejia, Kafin some parts of Guri,Kafin Hausa, Jahun, Ringim and Dutse respectively which are deemed to be at very high risk of experiencing flooding, while areas that fall within 0.19-0.3km include some parts of Guri, Auyo, Kafin hausa, and Ringim has a high risk of flood occurrence. Moderate risk area has a density of 0.10-0.19km and consists of some major parts of Guri, Gwaram and Birnin-kudu and are therefore prone to minute fluvial flood occurrence. The map also shows drainage density with low-risk and very low-risk areas with 0.1-0.10 and 0-0.1km respectively which include some areas Ringim, Gwaram, Kafin-hausa and Dutse. The drainage density details depicted on the map offer insights into the spatial distribution of drainage channels and their potential impact on flood occurrence in various locations within the area under study. Places with higher drainage density are generally less prone to flooding, while those with lower drainage density may face higher flood risk.

(c) Flow accumulation

Flow accumulation is considered a contributing indicator of flood risk in Jigawa State (Mahmoud and Gan 2018). A flow accumulation map was generated by analyzing the digital elevation model with the Spatial Analyst tool in ArcGIS.

Figure c above shows the flow accumulation of water during flood events. Flow accumulation is classified into five categories, each representing a different level of accumulation of water flow and associated flood risk. The areas are classified as very low risk and fall within 0-3268.6 pixels for flow accumulation which experience minimal accumulation of water flow. These regions typically have efficient drainage systems and are less prone to significant water accumulation even during heavy rainfall events. Low-risk areas located between 9268.61-39391.6pixels are categorized as low risk for flow accumulation which have a relatively low level of water flow accumulation. While some water accumulation may occur in these areas during rainfall events, it is generally manageable and does not pose significant flood risks. Moderate flow accumulation lies within 39,391.6001-83,417.5 pixels, flood events in these regions may occur periodically during intense rainfall, leading to moderate levels of flooding that may impact infrastructure and property. High-risk areas on 83417.50589-125,126.2 pixels exhibit a significant accumulation of water flow. Flood events in these areas are frequent and can cause substantial damage to infrastructure, and property, and sometimes pose risks to human lives. Effective flood risk mitigation measures are necessary in these regions. Other areas classified as very high risk with 125,126.2589-295,437 pixels for flow accumulation experience the highest levels of water flow accumulation. These regions are highly susceptible to flooding, with severe and frequent flood events that can result in extensive damage to lives, property, and infrastructure.

(d) Elevation

The elevation is an important factor that contributes to flood risk in a particular watershed (Lyu *et al*., 2018). Floods of minor magnitude typically affect low-lying areas. In the study area, elevations range from a maximum of 721.0 meters to a minimum of 343 meters above mean sea level. The lowest elevations are associated with a very high flood risk, while the highest elevations correspond to a very low flood risk.

Figure d presented above offers detailed information regarding the level of flood risk that is bound to occur due to the elevation of the area under study. Very high-risk areas which fall within the range of 343-372.6m comprised of communities like Hadejia, Miga, Guri, Auyo, Kiri-kasamma and some major parts of KafinHausa have a very high vulnerability to flood risk. They are situated at the lowest elevations and are most prone to frequent and severe flooding during heavy rainfall events. High-risk areas located between 372.6-408.2m include areas like Ringim and Jahun are also vulnerable to flood and can be affected by its devastating effect. They are located at lower elevations and are more prone or susceptible to flooding if

Precipitation occurs. Whereas moderate-risk areas are bound to experience flood and those are areas that are situated between 408.2-451.2m like Dutse and Birnin-kudu. They are situated at moderate elevations, which may experience occasional flooding. Additionally, locations that are situated on 451.2-506.0m like Gwaram have a low vulnerability to flood risk. While they are not as elevated as very low-risk areas, they still experience relatively infrequent flooding events. Very low-risk areas which bear the distance between 506.0-721.0m some small portions of Gwaram are considered to have very low vulnerability to flood risk. They are situated at higher elevations, which typically experience minimal flooding with little or no impact.

(e)Average annual rainfall

The average yearly rainfall in the basin varies between 807.23 and 1,001.4 mm. Rainfall occurs from the northwestern to northeastern parts of the study area. As rainfall increases, so does the risk of flooding. This is illustrated in Figure e which displays areas that are at various levels at risk of flood because of rainfall. The contribution of annual rainfall is a major factor in analysing flood vulnerability. The result reveals that areas like Gwaram, Guri and Kiri Kasama have a very low risk of flood due to small amounts of rainfall ranging from 807.23 - 840.74mm. In other areas like Birnin Kudu, Kafin Hausa, Miga and Auyo, there is a low risk of flood due to a minimal amount of rainfall between 840.74 and 872.73mm. Moderate-risk areas experience minimal rainfall of 872.73 - 907.01mm. Also, some parts of Jahun and Birnin Kudu are liable to experience a high risk of flooding as a result of higher rainfall amounts of 907.01 - 945.09mm. Areas under study that are at a very high risk of flood are mostly Ringim and Dutse with the amount of rainfall reaching 945.09 - 1001.04mm.

(f) Land use

Land use/land cover plays an important role in identifying zones vulnerable to flooding (Ghosh and Kar 2018). Impervious surfaces, like residential areas and roads, lead to increased storm runoff. Bare lands tend to increase the erosion of soils and high runoff flow downstream of the watershed, whereas areas with high vegetation density generally have low potential for flooding, as vegetation enhances infiltration and decreases runoff generation (Mishra and Sinha 2020).

Figure f reveals the land use/land cover features in the area under study and their level of vulnerability to flood occurrence. Built-up areas depicted in red color in Figure 4f above represent buildings, infrastructure, and other urban features, and are highly susceptible to flooding as a result of increased surface runoff and reduced infiltration capacity. Therefore, they are classified as very high risk in terms of flood vulnerability. Water bodies depicted in blue color such as rivers, lakes, and reservoirs are categorized as low risk in terms of flood vulnerability. While they may contribute to flooding in surrounding areas, they themselves are not at risk of flooding and are essential components of the natural landscape. Farmland areas depicted in wheat color in Figure f are classified as high risk in terms of flood vulnerability. Although they may have lower levels of surface runoff compared to built-up areas, farmlands are often located in floodplains or low-lying areas prone to inundation during heavy rainfall or river overflow. Vegetated areas, including forests, woodlands, and grasslands, are considered low risk in terms of flood vulnerability. Vegetation helps to absorb water, reduce surface runoff, and stabilize soil, mitigating the risk of flooding in these areas. Flooded areas, depicted in aqua color, are categorized as high risk in terms of flood vulnerability. These areas are frequently experiencing flooding and pose significant risks to nearby communities and infrastructure. Areas classified as bare ground depicted in bronze color are categorized as moderate risk regarding flood vulnerability. Although these areas might not have significant surface runoff like built-up areas, they lack vegetation cover and are prone to erosion, increasing their susceptibility to flooding.

(g) **Slope**

Flood inundation depends on the length and steepness of the slope in a particular area (Ghosh and Kar 2018). Relatively flat and moderate slopes suffer prolonged inundation, while steep and high slopes pass flood waters downstream (Mishra and Sinha 2020).

Figure g shows the spatial distribution of slope across the region, with different areas highlighted based on their slope characteristics. Areas where there are steeper slopes between 0-0.23degrees has a very high risk of flood occurrence it comprises areas like Miga, Auyo, Hadejia, Ringim, Guri, Kiri-kasamma, and Kafin-hausa. Less steep slopes ranging from 0.23-0.86degrees like Dutse, Birnin-kudu and Gwaram have a high risk of flooding. Moderate risk areas that are prone to flood have a slope of about 0.86-2.09degrees which consist of a small portion of Gwaram. Areas with flatter slopes experience low risk and very low risk of flood with a slope range of 2.09-4.18 and 4.18-10.06degrees respectively. Geographic areas with gentler slopes generally have better water retention capacity and are less susceptible to rapid runoff and flooding.

(h) Soil

The soil in Jigawa State, characterized by its predominantly sandy texture and low permeability, plays a dual role in exacerbating flood risk. On one hand, the limited capacity of sandy soils to absorb and retain moisture renders them prone to rapid runoff during heavy rainfall, exacerbating surface water buildup, and raising the risk of flash floods, especially in urbanized areas with impermeable surfaces. On the other hand, the seasonal variability in soil moisture content, exacerbated by agricultural practices and land use changes, further amplifies the susceptibility of the landscape to inundation, as saturated soils reach their saturation point more quickly, resulting in higher surface runoff and reduced infiltration capacity.

Moreover, the spread of impermeable surfaces, such as roads, buildings, and paved areas, further diminishes the ability of soils to naturally absorb and retain water, leading to heightened flood risk and exacerbating the impacts of extreme weather events.

Figure h shows the distinct distribution of different soil types across the region, with different areas highlighted based on their soil characteristics. Soil is regarded as a factor that can influence flood occurrence and the level of its magnitude in affected areas. Where there is sandy clay soil, such areas depicted in lime color in Figure h are classified as very high risk for flooding. Sandy clay has a higher proportion of clay particles than sandy loam, allowing for less infiltration and more runoff. This means that during rain events, water is more prone to flow over the surface instead of seeping into the soil, increasing the risk of floods. Sandy loam soil depicted in maroon in Figure h is classified as a high risk zone for flooding. Sandy loam consists of sand, silt, and clay particles in roughly equal proportions. This soil type allows for some infiltration, but also has a high rate of runoff, especially during heavy rainfall events. Locations that have concretionary clay soil depicted in blue are classified as a moderate risk zone for flooding. Concretionary clay contains lumps or masses of cemented material within the soil. This type of soil has a lower infiltration rate than sandy loam but higher than sandy clay. So, while there is some risk of runoff, it is less severe than the other two soil types.

Table 3 Weights for all the Causative Factors

Factors	Elevation	Slope	Drainage Density	Soil	Land use /land Cover	Average Annual Rainfall	Flow Accumulation	Distance from Rivers	Criteria weight (%)
Elevation	1	2	3	3	5	5	7	6	30
Slope	½	1	2	2	3	6	7	5	22
Drainage Density	1/3	½	1	2	3	3	6	4	16
Soil	1/3	½	½	1	2	3	4	3	11
Land use /land Cover	¼	1/3	1/3	½	1	2	3	4	8
Mean Annual Rainfall	1/5	1/6	1/3	1/3	1/2	1	2	5	6
Flow Accumulation	1/7	1/7	1/6	¼	1/3	½	1	3	4
Distance from Rivers	1/6	1/5	¼	1/3	2/7	1/5	1/3	1	3
Sum	**2.92**	**4.84**	**7.58**	**9.41**	**15.13**	**20.7**	**30.33**	**31**	**100**

Consistency ratio or index: 0.06
Source: Authors Analysis (2024).

The results indicate that elevation has the most significant effect or impact on flood occurrence in the study area, carrying a weight of 30%. Next is slope, with a weight of 22%, drainage density at 16%, soil at 11%, land use/land cover at 8%, mean annual rainfall at 6%, and flow accumulation and distance from the river at 4% and 3%, respectively. The findings demonstrated a Consistency Ratio (CR) of 0.06, significantly below the threshold value of 0.1, demonstrating a high level of consistency (refer to Saaty Table 2). The acceptable CR level further confirmed the robustness of the judgment, indicating that elevation and slope exert the most significant impact of geomorphology on and its role in contributing to flooding events in the area under study

(i) flood risk map

Flood risk encompasses a myriad of interconnected factors, each contributing to the overall risk of a given area. From topographical features such as elevation and slope to hydrological variables like river discharge and drainage capacity, the complex interplay of these elements shapes the propensity of a region to experience flooding and determines the severity of its impacts. Moreover, socioeconomic factors such as population density, infrastructure resilience, and access to early warning systems further compound or mitigate the risks posed by inundation events (Pathak et al 2020).

Figure i above highlights flood risk associated with various areas and their level of impact. Areas classified as very low-risk experience minimal vulnerability to flooding. These regions are typically situated at higher elevations or areas with efficient drainage systems, making them less prone to flooding. Locations falling within the low-risk category have a relatively low vulnerability to flooding. While flooding may occur occasionally in these areas, it is generally manageable and does not pose significant risks to lives or property. Moderate-risk areas are much more susceptible or prone to flooding in comparison with low-risk areas. Flood events in these regions may occur periodically during intense rainfall but are typically manageable with proper flood risk management measures in place. Areas categorized as high-risk are significantly vulnerable to flooding. Flood events in these areas are frequent and can cause substantial damage to infrastructure, and property, and sometimes pose risks to human lives. Effective flood risk mitigation measures are necessary in these areas. Very high-risk areas are much more susceptible to flooding. They experience severe and frequent flood events, leading to extensive damage and posing significant risks to lives, property, and infrastructure. The flood risk map shows that approximately eight local government areas under study are categorized as very high risk: Auyo, Hadejia, Kirika-samma, Kafin-Hausa, Ringim, Miga, Jahun and Dutse while high-risk areas consist of Guri, some parts of northern Kiri-kasamma, southern Jahun, northern Auyo, Birnin-Kudu and northwestern Ringim local governments and areas moderate risk constitute small portion of northern Kirika-samma, larger parts of Gwaram, small portions of Jahun, Kafin-Hausa, Dutse and Birnin-kudu local governments respectively and areas of low to very low risks consist of many parts of Gwaram and some tiny portions of Birnin-kudu. In the study area, places at high risk of flooding are located in the extreme northeast, due to low elevation; in the southwestern zone, where rainfall is abundant; and in low-lying areas near rivers or depressions.

Most properties in these high-risk zones include residential zones, commercial buildings, roads, and agricultural lands. Communities that are at very high risk include Auyo, Miga, Marwa, Fantum, Hadejia, Ringim, Sankara, Maizan, Balangu, Basirka, Gwaram, Harbo and Karnaya.

Consequently, Cultural elements like residential, commercial, educational, and healthcare facilities, along with the populations in these areas, face a significant risk of flooding. Floods can cause the spread of diseases transmitted through water, such as cholera by damaging sanitation and the immediate environment. Additionally, the lack of institutional capacity to put or implement risk reduction measures into action, such as public early warning systems, exacerbates the problem. The risk context of the area demonstrates how vulnerability is heightened by increased exposure to risks. Ignoring the flooding problem in Jigawa State will likely lead to greater risk exposure, resulting in more damage to properties, farmlands, crops, public infrastructure, and lives. Therefore, local councils and other stakeholders should utilize the flood risk map to prepare for possible floods and actively promote suitable land-use policies to reduce risks to lives. Comprehensive flood risk management strategies are crucial to mitigate the effects of flooding in these areas.

Table 4

Indicator	Relative Weight	Revised Indicator	Ranking	Risk
Elevation (m)	30%	507–721	1	Very low
		452–506	2	Low
		408–451	3	Moderate
		374–408	4	High
		343–373	5	Very high
Slope (°)	22%	10.06 - 4.18	1	Very low
		4.17- 2.09	2	Low
		0.86–2.08	3	Moderate
		0.85–0.23	4	High
		0.00–0.23	5	Very high
Drainage density(Km/Km^2)	16%	0.00–0.01	1	Very low
		0.01–0.10	2	Low
		0.10–0.19	3	Moderate
		0.19–0.30	4	High
		0.31–0.56	5	Very high
Soil type	11%	Concretionary Clay	3	Moderate
		Loamy loam	4	High
		Sandy clay	5	Very high

Average annual rainfall (mm)	6%	807–841	1	Very low
		842–873	2	Low
		874–907	3	Moderate
		908–945	4	High
		946–1001	5	Very high
Flow accumulation (px)	4%	0–3,267	1	Very low
		9,269–39,392	2	Low
		39,393–83,417	3	Moderate
		83,417–125,126	4	High
		125,126–295,437	5	Very high
Distance from Rivers (m)	3%	>6025	1	Very low
		4597–6025	2	Low
		2764–4598	3	Moderate
		1034–2763	4	High
		< 1034	5	Very High
Land use	8%	Water Bodies	1	Very low
		Vegetation	1	Very low
		Bared Ground	3	Moderate
		Farmland	2	High
		Flood Area	5	High
		Built-up	5	Very high

Source: Field Survey, 2024

Table 4 provides a comprehensive overview of various factors contributing to flood occurrence, highlighting their relative importance, classification, and associated risk levels. Areas with lower elevations (343-373 meters) are ranked as "very high" risk, while higher elevations (507-721 meters) are "very low" risk. As water flows downhill, lower areas are naturally more prone to accumulating floodwater with a priority weight of 30%. Steeper slopes (10.06-4.18 degrees) have a "very low" risk ranking due to faster water runoff. Conversely, flatter slopes (0.00-0.23 degrees) are rated "very high" risk as water accumulates more easily, with a criterion weight of 22%. Drainage density is the concentration of streams and channels in an area. Higher drainage density (0.31-0.56 km/km^2) indicates a greater capacity to remove water, resulting in a "very high" risk ranking. Conversely, lower drainage density (0.00-0.01 km/km^2) signifies poor drainage and a "very low" risk ranking with a 16% weight. The table considers three soil types. Concretionary clay has a "moderate" risk ranking (3) as it allows for some water infiltration. Loamy loam and sandy clay are ranked "high" (4) and "very high" (5) respectively, due to their reduced infiltration capacity, resulting in quicker surface runoff and increased potential for flooding ranking 11% of relative weight. Areas receiving higher amounts of rainfall (946-1001 mm) are ranked "very high" risk, while those with lower amounts of rainfall (807-841 mm) are "very low" risk. Higher rainfall translates to more water entering the system, increasing the flood risk by 6% weight. Closeness to the river can be a major factor responsible for flood events in an area. Areas further away from rivers (>6025 meters) have a "very low" risk ranking, while those closer to rivers (<1034 meters) are "very high" risk. Proximity to rivers means overflowing water or backflow can directly cause flooding relatively with a 3% weight. This category highlights human influence on flood risk. "Flood Area" and "Built-up" areas are ranked "high" (5) and "very high" (5) respectively, indicating a high risk of flooding due to factors like impermeable surfaces that prevent water infiltration. "Water Bodies" and "Vegetation" are ranked "very low" (1) due to their capacity to store and absorb water. Thus, this factor accounts for an 8% relative weight of flood occurrence in an area with unmonitored urban expansion.

CONCLUSION AND RECOMMENDATION

Findings from the study provide a comprehensive overview of various factors contributing to flood occurrence, highlighting their relative importance, classification, and associated risk levels. The analysis reveals that elevation, along with other critical factors including land use, soil type, and proximity to water bodies, significantly influences flood risk. Low-lying regions with inadequate drainage systems are particularly susceptible to flooding, exacerbating the impact on communities, infrastructure, and agricultural lands. The evaluation of flood risk underscores the importance of understanding the spatial distribution of flood hazards to implement effective mitigation strategies. The findings reveal that areas at lower elevations are more vulnerable to flooding, resulting in severe socio-economic impacts. These include displacement of populations, damage to property and infrastructure, disruption of economic activities, and adverse effects on public health.

Tackling these risks demands a thorough approach that integrates structural and non-structural measures. Structural measures involve the construction of flood defences, such as levees and drainage systems, while non-structural measures involve improved land use planning, early warning systems, and community awareness programs. Integrating scientific data with traditional knowledge and local practices can enhance the effectiveness of these strategies.

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