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SPECIAL ISSUE: CELEBRATING 20 YEARS OF GEOGRAPHY IN KADUNA STATE UNIVERSITY - ADVANCES AND FRONTIERS IN GEOGRAPHY

Resilience Pathways in the Flood-Prone Hadejia River Using a Relative Importance Index Approach for Targeted Mitigation Strategies

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ABSTRACT
Floods are among the most devastating consequences of global warming and can cause unprecedented disruptions in the operations of contemporary communities. Despite global efforts to increase flood resilience, the local pathways driving increasing flood risk in the Hadejia River remain poorly quantified, hindering the development of effective, targeted mitigation strategies. This study addresses this critical knowledge gap by identifying and prioritizing the key physical and socioeconomic drivers of flood risk in the Hadejia River, Jigawa State, Nigeria. The study employed a field reconnaissance survey, which utilized a structured questionnaire as the primary instrument, to collect baseline data from a sample of 400 households across flood-prone communities between August 2023 and January 2024. The collected data were analysed via the relative importance index (RII) technique to objectively rank the significance of the identified flood drivers. The results indicate that riverbed siltation (RII=0.87) is the most significant factor influencing flood risk, followed closely by steep side channels (RII=0.86) and prolonged periods of rainfall (RII=0.86). Other critical contributors include a high number of tributaries discharging into the main river (RII=0.84), urbanization (RII=0.82), and the presence of Typha grass and water weeds (RII=0.82). However, the analysis confirmed that socioeconomic factors, such as land use changes, river diversion, and urban expansion, significantly influence the flood vulnerability of the basin. These findings provide a clear, evidence-based prioritization of flood pathways, highlighting the urgent need for targeted interventions, specifically desilting and channel management, to increase flood resilience, improve infrastructure, and support community adaptation strategies in the Hadejia River Basin.

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1 Introduction

A flood is the overflow of water onto normally dry land, often resulting from excessive rainfall, river overflow, storm surges, or dam failures (Javadinejad, 2022). Floods can be categorized into different types, including riverine floods, flash floods, coastal floods, and urban floods (Sharma et al., 2019). In the Hadejia River Basin, the predominant cause of riverine flooding is overflow of the Hadejia River due to intense precipitation and upstream water release (Ologunorisa et al., 2022). Floods have both immediate and long-term consequences, such as loss of life, destruction of property, displacement of communities, and disruption of economic activities (IPCC, 2012).

The Hadejia River Basin in Nigeria is particularly susceptible to severe flooding, a natural catastrophe causing extensive environmental and socioeconomic harm (Kura et al., 2023). The increased incidence of flood disasters globally, exacerbated by the anthropogenic handling of hydrological infrastructures and the impact of climate change, poses a substantial challenge to sustainable development, especially in regions with proximal wetlands (Aderogba, 2012; Eli & Bariweni, 2020; Tudunwada & Abbas, 2022).

However, despite the recurring nature of flooding and the associated risks, there have been instances of governmental oversight and a lack of proactive measures to address early warning messages. Neglecting early warnings has led to devastating consequences and a reactive, rather than proactive, approach to flood disaster response. This was notably observed in 2012 when the release of water from Cameroon's Lagdo Dam, coupled with torrential rains and the climate change phenomenon, triggered widespread and relentless flooding across Nigeria (Danumah et al., 2016). The aftermath of this catastrophic event, as reported by NEMA in 2013, affected more than 32 states in Nigeria, with 24 states classified as severely impacted. An estimated 7.7 million people were affected, and over 2 million individuals were internally displaced. Subsequent years, such as 2017, also experienced substantial but less severe flooding (Ibrahim & Abdullahi, 2016; Awu et al., 2017).

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Despite these advancements, there are notable gaps in previous studies. Studies by Erena and Worku (2018) and Almouctar et al. (2024) presented practical flood risk assessments. More studies are needed to evaluate the effectiveness of these measures across different contexts. Shuaibu et al. (2022) and Shanono et al. (2023) highlighted the need for integrated water resource management, but gaps exist in understanding how reservoir utilization and anthropogenic activities interact with climate variability. This suggests that there is a need for more localized studies to address specific flood causes, emphasizing the importance of targeted research into urban planning, community engagement, and infrastructure development.

2 Materials and methods

2.1 Study area

The study focuses on the Hadejia River, which is situated in the Sudano--Sahelian zone of northern Nigeria, between latitudes 12°00' and 12°55' N and longitudes 8°59' and 10°40' E of the Greenwich Meridian (Figure 1). Located in eastern Jigawa State, the study area's population was estimated to be approximately 1,785,896 according to the 2006 population census (NPC, 2006). The study area comprises 11 LGAs within a 5 km buffer zone from the river, including Auyo, Guri, Hadejia, Jahun, Kafin Hausa, Kaugama, Kiri Kasamma, Malam Madori, Miga, Ringim, and Taura. It encompasses significant features such as two major dams and the Hadejia Valley Wetland.

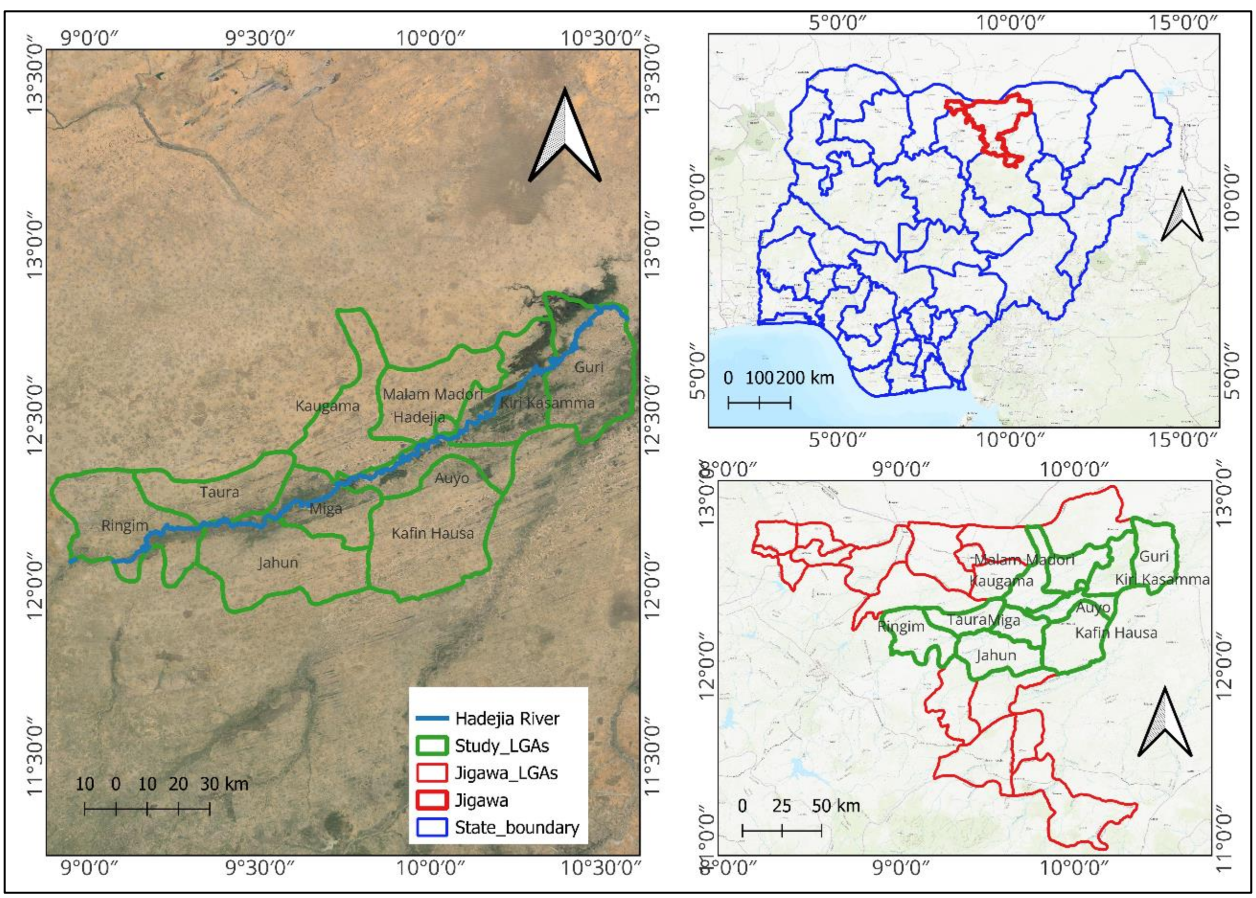

Figure 1: Study area map
Source: Adapted and modified from the administrative map of Nigeria

2.2 Sample size and sampling technique

The study area was estimated to have a population of 1,785,896 people on the basis of the 2006 Census (NPC, 2006). The projected population of the study area in 2023 is 2,923,906. The formula used for population projection is given in Eqn. (1):

$$P_{t+n} = P_t e^{rn} \quad (1)$$

where P_{t+n} = future population (2023), P_t = base year population (2006), r = growth rate, n = interval between the future population and base year population (2023–2006) = 17 years, and e = exponential.

$$P_{t+n} = 1{,}785{,}896e^{0.03*17}$$

Based on the projected population of the study area in 2023 (2,923,906), the Yamane (1967) formula (Eqn. 2) for sample size determination was used to obtain the number of respondents for questionnaire administration:

$$Sample\ Size = \frac{N}{1+N\,(e)^2} \quad (2)$$

where N = the number of populations under study.

e = proportion of population given as 0.05%

A total of 399.99, which was approximately 400 respondents, were selected for the administration of the questionnaire. The questionnaire was randomly administered to the selected households in the study area. However, the study was established through careful attention to the validity and reliability of the data collection instruments, which included a structured questionnaire, focus group discussions (FGDs), and key informant interviews (KIIs). Content validity was ensured by designing tools to align directly with the study's objective of capturing specific physical and socioeconomic flood drivers, a process further strengthened by expert validation from the Komadugu Yobe Basin (KYB) Working Group and academicians from Sule Lamido University. Facial validity was maintained by assessing the clarity and readability of the questions to minimize misinterpretation among community respondents, whereas construct validity was enhanced by employing the relative importance index (RII) to objectively convert Likert-scale responses into a standardized, quantitative ranking of flood drivers. Furthermore, the reliability and generalizability of the findings were structurally reinforced by the selection of a statistically adequate sample of 400 respondents via a proportional random sampling technique that allocated questionnaires to households on the basis of ward and LGA population size, thereby ensuring a non-biased, representative, and stable dataset for analysis. However, the sample size for each ward varied with population size through the use of Eqn. (3):

$$\frac{nQ}{N} \quad (3)$$

where N= total population of the study area; Q= total sample size; and n= population of LGA.

Table 1: Sample size by population of the selected LGAs

LGA Name	Population_2006	Projected Population_2023	Sample Size
Auyo	132,001	216,115	29
Guri	115,018	188,310	26
Hadejia	105,628	172,936	24
Jahun	229,094	375,077	51
Kafin Hausa	271,058	443,782	61
Kaugama	127,956	209,492	29
Kiri Kasamma	191,523	313,565	43
Malam Madori	161,413	264,269	36
Miga	128,424	210,258	29
Ringim	192,024	314,386	43
Taura	131,757	215,715	29
Total	1,785,896	2,923,906	400

Data collection was conducted via a systematic sampling technique to administer questionnaires to household heads within flood-prone areas, which were precisely delineated by a 5 km buffer zone along the Hadejia River. This method was chosen for its practical efficiency in the field and its ability to ensure a uniform spatial distribution of the 400 sampled households across the study area, thereby minimizing clustering bias. To ensure representation across varying flood risks, systematic sampling was implemented within each local government area (LGA) after preliminary stratification on the basis of the LGA's proximity and historical flood records, effectively ensuring that the sample captured a spectrum of flood severity zones. The questionnaire, which targeted household heads with a minimum of ten years of residency (both farmers and nonfarmers), was designed to measure physical flood drivers not by direct physical measurement but by capturing the local community's perceived relative importance and experiential knowledge of these drivers via a Likert scale, which was then quantified via the relative importance index (RII). This approach leverages long-term ground observations of the residents, providing a critical socio-experiential validation of the physical processes at play, with the final sample size and administration details for each LGA provided in Table 1.

2.3 Method of data analysis

The Relative Importance Index (RII) method was used to identify the causes of flooding in the study area. This analysis helps prioritize and identify the most critical factors contributing to flooding in the study area, aiding in targeted interventions and mitigation strategies (Ahmad et al., 2024). The Relative Importance Index (RII) is a quantitative method used to determine the relative significance or weight of various factors or criteria within a decision-making process. It's calculated by respondents' ratings or preferences for each criterion on a scale, often ranging from 1 to 5. The formula for RII is given in Eqn. (4):

$$RII = \frac{Weighted\ Score\ for\ each\ Criterion}{Highest\ Possible\ Score\ \times Number\ of\ Respondents} \tag{4}$$

The weighted score for each criterion is the sum of individual ratings for that criterion divided by the highest possible score achievable for that criterion. The RII ranges between 0 and 1, where a higher RII value indicates a greater relative. This analysis is critical as it transforms qualitative experiential data into a prioritized, objective ranking, which directly informs targeted interventions and mitigation strategies (Gunduz et al., 2013). The RII approach has been widely and successfully utilized in similar environmental and civil engineering contexts, such as identifying critical infrastructure resilience components in flood-prone areas and ranking the environmental impacts of construction activities (Ahmad et al., 2024; Gunduz et al., 2013).

To create a flood risk map for the study area, the Analytic Hierarchy Process (AHP) model of Multi-Criteria Decision Analysis (MCDA) was used. The factors influencing flood vulnerability were selected based on information from research tools along with the existing literature. These factors included rainfall, distance from river to settlement, elevation, slope, drainage density, soil moisture, topographic wetness index, population density, soil type, temperature, land use, evapotranspiration, NDVI, geology, lineament density, and literacy rate. The AHP technique involved pairwise comparisons and ranking of these factors to determine their relative importance. The responses were transferred to a pair-wise comparison matrix using Saaty's scale, and the weights of each criterion were computed from the normalized matrix. The overall priority vector was then determined by averaging the criteria weights across all respondents. A consistency ratio (CR) was calculated to ensure the judgments were consistent, with a $CR \leq 0.1$ indicating acceptable judgments. Finally, the flood risk map was created using the raster calculator in ArcGIS by combining the weighted criteria maps.

3 Results and Discussion

3.1 Major causes of flood in Hadejia River

Figures 2 and 3 present key findings from qualitative data collected through Key Informant Interviews (KII) and Focus Group Discussions (FGD), providing insights into local perceptions of floods ("*ambaliya*") and their major causes. Figure 2 illustrates what residents associate with the word "flood." The results revealed that floods are closely linked to significant losses, including the destruction of farmlands and homes, loss of life, and property damage. This suggests that floods are not viewed merely as natural events, but as devastating occurrences that severely threaten livelihoods and communities in the study area (Nasidi et al., 2023; Odewole et al., 2020).

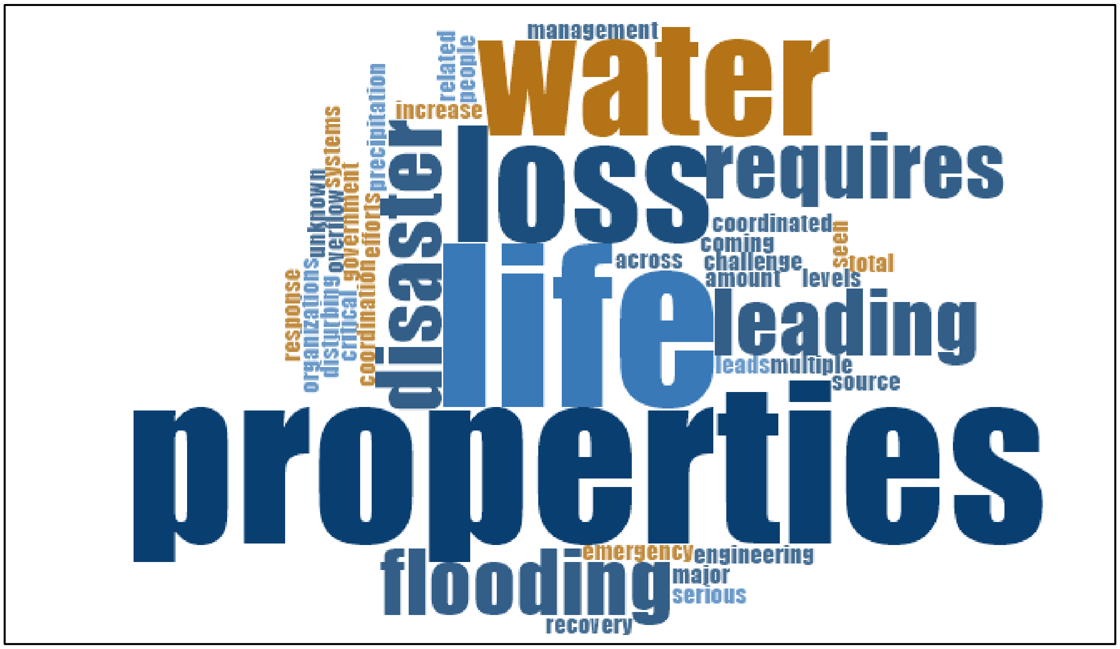

Figure 2: Concept of Flood

Figure 3 highlights the major perceived causes of flooding in the Local Government Areas (LGAs) along the Hadejia River in Jigawa State. The qualitative data indicate that residents have identified two primary causes: heavy rainfall and river diversion. Heavy rainfall increases flood risks due to the region's vulnerability to intense seasonal storms, which lead to the overflow of water bodies. In addition, river diversion, often resulting from human activities such as dam construction, irrigation projects, and poorly managed drainage systems, disrupts natural water flow patterns, heightening the risk of flooding. These findings emphasize the local understanding of flood dynamics, pointing to both natural and human-induced factors that contribute to flood risk in the area.

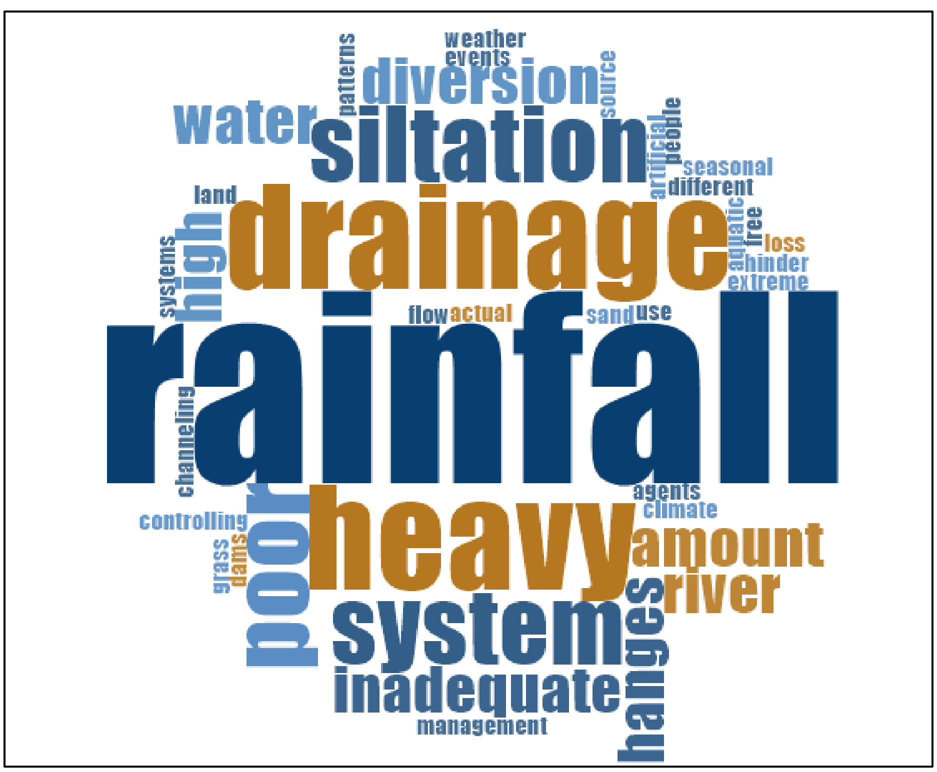

Figure 3: Causes of Flood along Hadejia River

This observation aligns with the findings of Tudunwada and Abbas (2022), who identify floods as some of the most economically and socially disruptive weather-related disasters globally. The recognition of floods as transformative events underscores the pressing need to address their underlying causes and mitigate their impacts effectively. A localized understanding of the factors contributing to flooding revealed that heavy rainfall emerged as a key natural driver, consistent with studies such as Babati et al. (2022), which document an increasing trend in flood frequency in the Hadejia-Jama'are River Basin due to heightened precipitation intensity. Additionally, river diversions, identified as another primary cause, reflect the role of human-induced changes in exacerbating flood risks. Activities such as dam construction, irrigation schemes, and poor drainage management disrupt the natural hydrological pattern. This aligns with the findings of Radwan et al. (2019) and Umar et al. (2019), who emphasizes on the significant influence of anthropogenic factors in altering river flows and heightening flood susceptibility.

Table 2: Relative Importance Index of the Perceived Factors Influencing Floods

Causative Factors	NI	SI	I	VI	EI	Total	Weight	RII	Rank
Poor town planning	38	82	186	436	752	400	1493	0.75	8
Improper/inadequate drainage channels/river diversion	33	104	226	467	613	400	1443	0.72	10
Poor solid waste management	36	112	321	349	571	400	1389	0.69	12
Deforestation	38	112	277	499	446	400	1372	0.69	14
Poor farming practices	34	123	268	478	481	400	1383	0.69	13
Urbanization	20	76	150	221	1181	400	1649	0.82	5
Poor management/dam failure	24	111	177	436	763	400	1511	0.76	7
Sand mining	47	142	291	270	591	400	1340	0.67	15
Recent Construction of a Dam	28	98	237	455	653	400	1470	0.74	9
Long periods of rainfall	21	43	101	237	1324	400	1726	0.86	3
Siltation of the riverbed	18	37	99	230	1366	400	1750	0.87	1
A high number of tributaries are discharging into the main	23	49	133	295	1171	400	1671	0.84	4
Steep side channels	11	63	122	212	1319	400	1727	0.86	2
The soils are sticky and impervious	45	100	189	422	686	400	1441	0.72	11
Presence of Typha grass and water weed	18	82	152	252	1137	400	1641	0.82	6

Note: *NI=Not Important; SI=Slightly Important; I= Important; VI= Very Important; EI=Extremely important*

The results in Table 2 revealed that riverbed siltation (RII=0.87) is the most critical factor contributing to flood risk, followed closely by steep side channels (RII=0.86) and extended periods of rainfall (RII=0.86). These findings are in line with previous studies by Sani et al. (2010) and Shuaibu et al. (2022), which identified siltation and steep topography as significant contributors to flood risks. Urbanization (RII=0.82), the presence of Typha grass and water weeds (RII=0.82), and a high number of tributaries discharging into the main river (RII=0.84) also play substantial roles, underscoring the impact of human activities and natural vegetation on flood dynamics, consistent with Mahmood et al. (2019).

In contrast, sand mining (RII=0.67) and deforestation (RII=0.69) are ranked lower, indicating their impact on flood risk is less significant compared to more immediate factors like drainage capacity and rainfall intensity. This is supported by Radwan et al. (2019) and Shanono et al. (2023), who found that while sand mining and deforestation are relevant, their effects are often overshadowed by more pressing factors. The table provides a detailed ranking of flood causative factors using the Relative Importance Index (RII). The top-ranked factor, riverbed siltation (RII = 0.87), underscores the critical role of sediment accumulation in obstructing water flow and reducing river channel capacity. This finding is consistent with the work of Shuaibu et al. (2022), which identifies sedimentation as a key contributor to river overflow and increased flood risks. Similarly, steep side channels (RII = 0.86) and prolonged periods of rainfall (RII = 0.86) further highlight the interplay between topography and climatic variability in shaping flood dynamics, as noted by Yahaya et al. (2010).

Urbanization (RII = 0.82) also emerged as a significant factor, emphasizing the impact of impervious surfaces in increasing runoff and reducing water infiltration. This observation aligns with Mahmood and Rani (2022), who demonstrate that urban expansion exacerbates flood risks by altering natural drainage patterns. Furthermore, the presence of Typha grass and water weeds (RII = 0.82) highlighted the ecological dimension of flooding, where invasive vegetation obstructs water flow and contributes to channel blockages. These findings are supported by Umar and Ankidawa (2016), who discussed the ecological disruptions caused by invasive species in wetlands and river basins. Interestingly, sand mining (RII = 0.67) and deforestation (RII = 0.69) ranked lower in importance, suggesting their relatively less immediate impact on flood risks compared to factors like rainfall and drainage capacity. Nevertheless, their long-term effects on soil stability and hydrology remain critical, as emphasized by Radwan et al. (2019). Climate variability further complicates these dynamics. Studies by Buontempo (2018) and Ojoye et al. (2016) documented long-term changes in rainfall and temperature patterns in the Sudano-Sahelian regions, highlighting how erratic rainfall, rising temperatures, and reduced river flow volumes exacerbate water resource challenges. The irregular inter-annual and inter-decadal variability in flood occurrences, including the absence of clear trends in maximum river discharge, as observed by Buma et al. (2016) and Ibrahim et al. (2022), reinforces the necessity for predictive models. Tools such as the SWAT model have proven effective in simulating streamflow and assessing flood risks under diverse climatic scenarios, as demonstrated by Ejieji and Akinsunmade (2020).

Socioeconomic factors further amplify flood risks. Poor urban planning (RII = 0.75), high population density, and low literacy rates limit community preparedness and adaptive capacity. These vulnerabilities are compounded by land use changes, particularly the conversion of vegetative cover to urban or agricultural use, which increases impervious surfaces and disrupts natural drainage systems. Sparse vegetation, reflected in low NDVI values, intensifies flood risks by reducing interception and soil infiltration, consistent with findings by Umar et al. (2019). The studies of Nasidi et al. (2023) and Wilby and Keenan (2012) emphasize the importance of community-based flood management frameworks to address these challenges.

The interplay between climatic, hydrological, and anthropogenic factors calls for a comprehensive and integrated approach to flood management. This approach should encompass both structural measures, such as improved drainage systems, and non-structural measures, including community education and sustainable land-use planning. Kundzewicz et al. (2018) highlighted the value of incorporating climate variability indices into flood risk assessments to enhance predictive accuracy and inform adaptive strategies. The findings on the causes of flooding in the Hadejia River Basin illustrate its multifaceted nature, shaped by the interactions among climatic variability, hydrological processes, and human activities. By integrating qualitative insights, quantitative analyses, and existing literature. This discussion underscores the critical need for adaptive and holistic flood management strategies. The measures will not only mitigate the impacts of floods but also enhance community resilience against future occurrences.

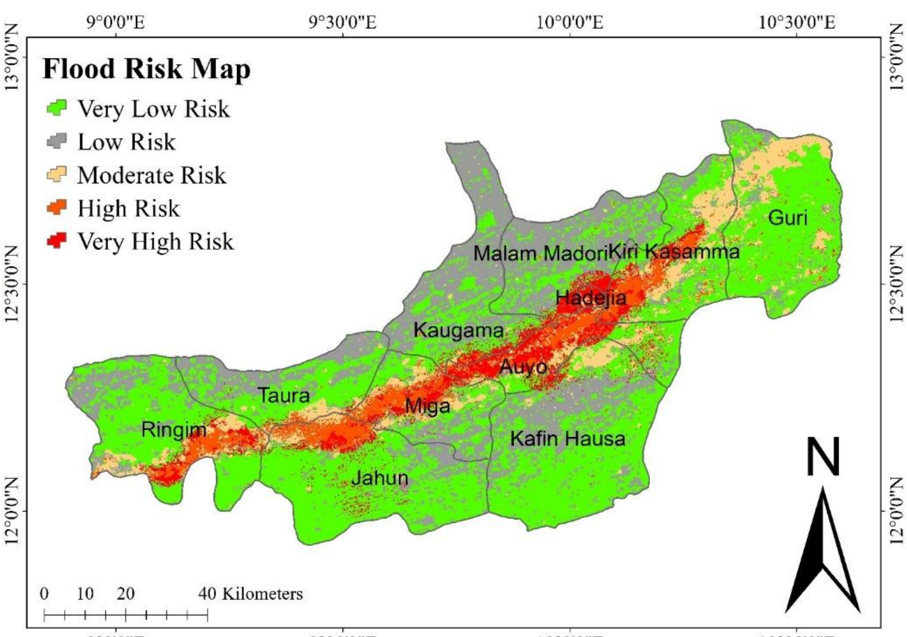

Figure 4: Flood Risk Map from MCDA (AHP)

The assessment of flood risk in the Hadejia River, using the Multi-Criteria Decision Evaluation (MCDE) and Analytic Hierarchy Process (AHP) techniques, reveals significant variations in risk levels across the region. The flood risk map statistics, as summarized in Table 3, categorize the area into five distinct risk levels: Very Low Risk, Low Risk, Moderate Risk, High Risk, and Very High Risk. Previous studies have demonstrated the effectiveness of these techniques in similar contexts. Jeb and Aggarwal (2008) applied remote sensing and GIS to model flood inundation hazards in the River Kaduna, revealing significant spatial variability in flood risk levels. Similarly, Yalcin and Akyurek (2004) used AHP for earthquake susceptibility mapping, which can be analogously applied to flood risk assessment.

Table 3: Statistics of Flood Risk Map

S/No	Flood Risk Level	Area	Percentage
1	Very Low Risk	4137.97	46.54
2	Low Risk	1765.86	19.86
3	Moderate	1653.59	18.60
4	High Risk	998.84	11.23
5	Very High Risk	334.38	3.76
Total		8890.63	100.00

The Hadejia River Basin flood risk analysis shows varied flood risk, with nearly half the area (46.54%) classified as Very Low-Risk, suggesting effective flood prevention. Low-risk areas (19.86%) require basic management, while Moderate-risk zones (18.60%) need enhanced planning. High-Risk regions (11.23%) are more prone to severe flooding, requiring significant intervention, and the Very High-Risk areas (3.76%) are critical for emergency response.

4 Conclusion

This study identified several factors contributing to increased flood risk in the Hadejia River Basin, including heightened heavy rainfall, river diversion, siltation from sand and aquatic grasses, artificial channeling by community members, and inadequate drainage systems. These findings offer a comprehensive understanding of flood risk dynamics in the Hadejia River Basin and provide crucial insights for policymakers and stakeholders in developing effective flood risk management strategies. Significant contributors to flood risk include heavy rainfall, river diversion from its natural course, and siltation caused by various agents such as aquatic grasses and sand, all of which obstruct the free flow of water. Human activities, often carried out without a full understanding of their consequences, alongside inadequate water management from dams and poor drainage systems, exacerbate the basin's vulnerability by disrupting natural drainage patterns and increasing runoff. These findings have been used by the Hadejia-Jama'are River Basin Development Authority (HJRBDA) to guide regional flood risk management into local and regional policy frameworks to address land use practices contributing to increased flood risk. This was proved during a stakeholder engagement focused on the development of a strategic catchment management plan for riparian and wetland zones in northern Nigeria, held in Kano state, Nigeria. These contributions have facilitated dialogues between government departments, research institutions, and local communities, fostering collaborative approaches to flood risk management and climate adaptation. The findings have also sparked scientific debates on integrating traditional knowledge with modern flood management techniques, influencing both policy and practice in the region.

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