



ASSESSMENT OF FLOOD RISK AND ADAPTATION STRATEGIES IN HADEJIA RIVER BASIN, NIGERIA

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ABSTRACT

This study evaluates the impact of land use and land cover changes on flood occurrences, highlighting the interplay between environmental modifications and flood dynamics. Additionally, the study employs Multi-Criteria Decision Analysis (MCDA) to predict and map flood risk scenarios, providing a robust framework for risk assessment. The research further examines the rural communities' responses and adaptation strategies, evaluating the effectiveness of local measures and overall community resilience. The study employed a three-phase field reconnaissance survey conducted between August 2023 and January 2024 to collect baseline data. Both primary and secondary data sources were utilized. Primary data included satellite imagery and GPS coordinates, while secondary data comprised topographic and soil maps, hydrological records, and historical rainfall data. Various data processing and analytical techniques, such as image pre-processing, classification, and MCDA, were employed to generate accurate flood risk maps and assess the impact of different contributing factors. The results revealed varying levels of susceptibility. Nearly half of the study area (46.54%) falls under the Very Low-Risk category, suggesting the effectiveness of current flood prevention measures. Low-risk zones account for 19.86%, requiring only basic management interventions, while Moderate-risk areas (18.60%) necessitate improved planning and mitigation strategies. High-Risk regions (11.23%) are highly vulnerable to severe flooding and demand significant intervention, whereas Very High-Risk areas (3.76%) require urgent emergency response measures. Further analysis shows that socio-economic factors, such as land use changes have significantly influenced flood risk in the basin. Over the decade from 2013 to 2023, land cover changes were characterized by a reduction in water bodies and dense vegetation, coupled with an increase in farmland and built-up areas, as well as a slight rise in bare land and shrubland. These transformations have heightened flood vulnerability by reducing natural absorption capacity and increasing surface runoff. MCDA-based flood risk mapping underscores the spatial variation in flood susceptibility across the basin, with high-risk areas requiring immediate intervention. The findings highlight the urgent need for targeted interventions to enhance flood resilience, improve infrastructure, and support community adaptation strategies.

Keywords: Flood-Risk, Adaptation, GIS and Multi-criteria Decision Analysis

INTRODUCTION

Disasters, often arising from natural phenomena and exacerbated by human interventions, exhibit diverse temporal characteristics, ranging from gradual manifestations to abrupt occurrences. Flood disasters, while generally considered sudden events, distinguish themselves through their potential for accurate prediction, anticipation, and partial control (Ghapar *et al.*, 2018). Despite their predictable nature, floods qualify as disasters only when they inflict damage or adverse effects on human lives, livelihoods, and properties. Floods, being among the most prevalent disaster events globally, cause significant mortality, with notable occurrences in various parts of the world, such as the Chiang Jiang River in China, the Mozambican floods, and the Mississippi river floods (Adams *et al.*, 2010).

Flood events in Nigeria, as emphasized by Shuaibu (2020), have accounted for the highest losses resulting from extreme hydrological events. Flood events in Nigeria reveal the severity of the issue, affecting over 1.9 million individuals across 12 states in Nigeria and displacing over half a million people (Kenyi, 2024). Flood occurrences in Nigeria surpass other natural hazards, causing substantial damage to lives and properties (Alfa *et al.*, 2018). These events, manifesting as

coastal floods, river floods, flash floods, and urban floods, are primarily attributed to the inability of river channels to accommodate floodwaters beyond their carrying capacity (Komolafe *et al.*, 2015).

Adaptation refers to the adjustments made in natural or human systems in response to actual or expected climate and environmental changes, aimed at minimizing negative impacts and maximizing potential benefits (IPCC, 2012). Adaptation can take various forms, including infrastructural, technological, behavioral, institutional, and ecosystem-based measures (Smit & Wandel, 2006). In the context of flood management, adaptation involves proactive measures such as constructing embankments, improving drainage systems, implementing land-use policies, and enhancing community preparedness through early warning systems and disaster response strategies (Birkmann *et al.*, 2025). An adaptation strategy is a systematic approach to planning and implementing measures that reduce vulnerability and enhance resilience to environmental risks, including floods (Adger *et al.*, 2013). It encompasses a combination of structural and non-structural measures designed to address current and future flood risks. Structural strategies include the construction of levees, retention basins, and flood barriers,

while non-structural strategies involve policy frameworks, capacity-building programs, insurance mechanisms, and community-based flood management initiatives (Few et al., 2013). In general, effective adaptation strategies should be informed by scientific assessments, traditional ecological knowledge, and stakeholder engagement to ensure sustainable flood risk management (Evers et al., 2016).

Jigawa State boasts a wealth of agricultural land, rivers, and flood plains suitable for crop cultivation, livestock rearing, and fish production. This agricultural abundance, with over 80% of the state's total land mass deemed arable, positions Jigawa as one of Nigeria's agriculturally endowed states. Approximately 90% of the state's 4.3 million residents are primarily engaged in agriculture, with the sector serving as a fundamental source of livelihood, food security, and poverty alleviation. The centrality of agriculture to the region's socioeconomic fabric underscores the importance of effective flood risk assessment and management (Jigawa State Emergency Management Agency, 2013).

This comprehensive overview emphasizes the importance of flood risk assessment and adaptation strategies in the Hadejia River Basin, Nigeria, demonstrating its nature, implications, and evolving methodologies. The study aims to address this recurring threat by employing a Multicriteria Decision Analysis (MCDA) approach to assess climate variability impacts on flood risk mapping, taking into account key demographic, socio-economic, and relevant variables to capture population heterogeneity and contextual information. The research not only holds academic significance but also contributes to mitigating the recurrent threat of floods in the region.

MATERIALS AND METHODS

The study focuses on the Hadejia River, 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 (Figure 1). 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. Flooding, exacerbated by climate change-induced rainfall

patterns, is a prevalent disaster in Nigeria, affecting the region annually during the rainy season due to inadequate infrastructure and urban planning. Addressing flood risk through effective Flood Risk Management strategies, including spatial planning and infrastructure development, is crucial for sustainable development in Nigeria (Babati et al., 2022). The Hadejia River system is heavily influenced by the Tiga Dam (operational since 1974) on the Kano River and the Challawa Gorge Dam (operational since 1992) on the Challawa River (Water Audit for KYB, 2019).

Methodology

Data Collection

The different datasets required include primary and secondary data which contain both spatial and non-spatial attributes.

The primary data: The primary data comprises medium-resolution satellite images, including NigeriaSat-2, NigeriaSat-X, Landsat, Sentinel-2, and ALOS PALSAR. These satellite datasets are integral to analyzing land use and land cover (LULC) changes over time, a key objective of this study. By detecting trends in vegetation cover, built-up areas, agricultural expansion, and bare lands, the data helps identify critical contributors to flood risk. Specifically, Sentinel-2 imagery, with a 10-meter resolution, and ALOS PALSAR Digital Elevation Models (DEM), with a 12.5-meter resolution are highly suitable for spatial analysis, floodplain delineation, and terrain modeling.

Additionally, field-collected GPS coordinates serve as essential ground-truthing data to validate the accuracy of remote sensing outputs, such as classified LULC maps, elevation models, and flood hazard maps. This integration enhances the reliability of the spatial datasets, making them effective tools for flood risk assessment and mitigation planning.

The secondary data: The secondary data includes topographic maps, soil maps, administrative maps, and population data. These foundational spatial layers provide critical information on the Hadejia River Basin. By contextualizing the study area and integrating diverse datasets, these maps are instrumental in supporting spatial analyses and linking environmental factors with flood risks. Table 1 describe the hydrological and climatic datasets type, sources, and purpose.

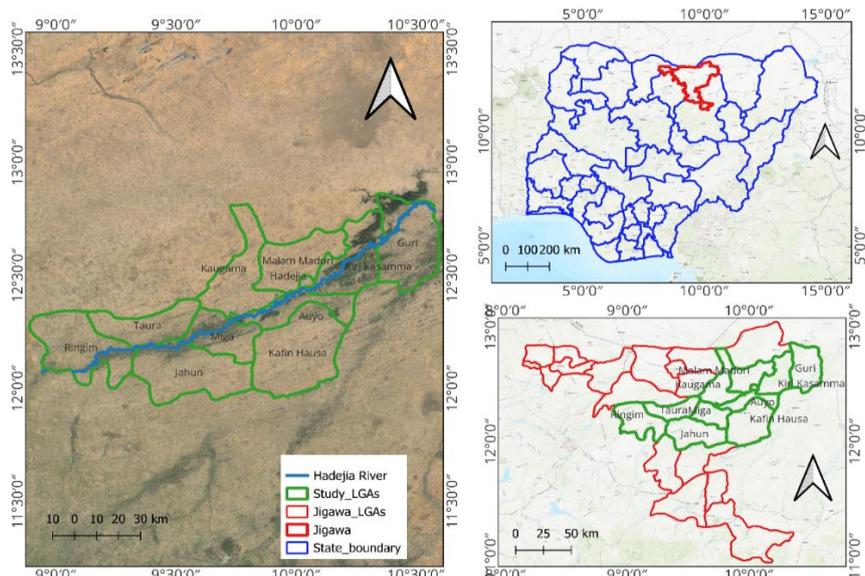


Figure 1: Study Area Map

Flood Causative Factors

Sixteen (16) assumed flood causative factors, derived from a comprehensive review of relevant literature, were utilized in this research to analyze and predict flood risk. These factors encompass a wide range of environmental, climatic, and anthropogenic variables that significantly influence flood occurrences. Each factor was carefully selected based on its relevance and contribution to flood susceptibility:

Data Processing

- i. Image acquisition (sentinel 2A)
- ii. Image preprocessing using sen2core in SNAP and Semi-Automatic Classification Plugin in QGIS.
- iii. Sub setting and mosaic using ENVI5.3 software
- iv. Image classification and ground truthing
- v. Accuracy assessment and final LULC map creation using ArcMap and ArcGIS Pro
- vi. Multicollinearity Check and Flood Risk Mapping Analysis Using Multi-criteria Decision Analysis (MCDA)

Table 1: Data Type and Sources

Type of Data	Source	Purpose
Hydrological Data: Flow Discharge Data	Hadejia Jama'are River Basin Development Authority	To understand the hydrological processes driving flood events and predicting future flood risks
Rainfall Data	CHIRPS (https://app.climateengine.org/climateEngine)	To assess long-term rainfall trends and their role in triggering flooding in the study area.
Sentinel-2A Imagery	USGS Earth Explorer (http://earthexplorer.usgs.gov)	To analyze current land use/land cover (LULC) conditions and identify flood-prone areas using high-resolution satellite imagery.
ALOS PALSAR DEM	Alaska Satellite Facility Vertex (https://vertex.daac.asf.alaska.edu/#)	To perform terrain analysis, map floodplains, and identify flood-vulnerable zones using elevation data.
Administrative Map	Humanitarian Data Exchange (HDX) https://data.humdata.org/dataset/cod-ab-nga?	To delineate the administrative boundaries of Jigawa State and the study area for spatial analysis.
Soil Map	https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v20/en/	To analyze soil characteristics for flood susceptibility and hydrological modeling.
Flood Inventory Data	Questionnaire responses, NIHSA, SEMA, NEMA, HJRBDA	To evaluate historical flood occurrences, damages, and losses for mapping flood risk scenarios.
Soil Moisture Data	Copernicus (https://land.copernicus.eu/en/products/soil-moisture)	To monitor soil moisture levels and assess their contribution to flood risks.
Evapotranspiration Data	NASA Earth Data (https://appears.earthdatacloud.nasa.gov/)	To evaluate water cycle processes affecting flood risk, such as evaporation and transpiration.
Literacy Rate Data	National Bureau of Statistics (NBS) (https://www.nigerianstat.gov.ng/pdfuploads/National%20Literacy%20Survey,%202010.pdf)	To assess literacy levels for evaluating community awareness and adaptation strategies to flooding.
Road Networks, Rivers, and Water Bodies	Satellite imagery, HDX https://data.humdata.org/dataset	To map and analyze critical infrastructure and natural features contributing to flood risk.
Temperature Data	WorldClim (https://www.worldclim.org/data/index.html)	To analyze temperature variability and its influence on flood risk through climatic modeling.

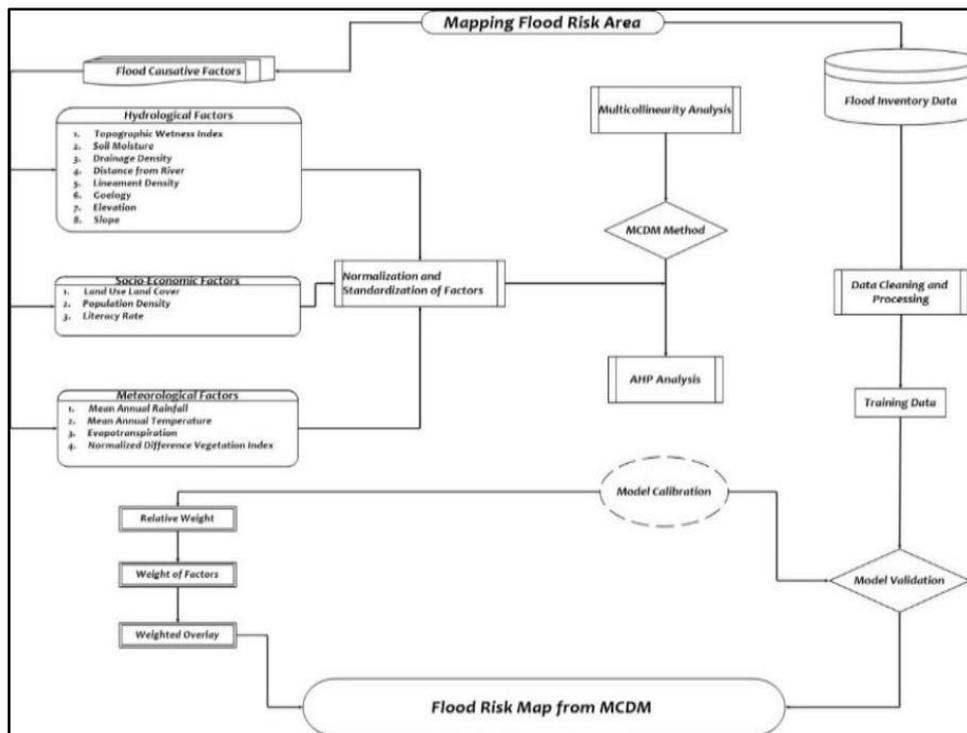


Figure 2: Methodology Flowchart

Analytical Hierarchy Process (AHP)

The methodology employed for rigorously evaluating flood risk areas within the study area (as in Figure 2) extensively utilizes ranking and pair-wise comparison techniques. This method investigates three primary criteria and thirteen subordinate criteria, subjecting them to meticulous pair-wise analyses to unveil their relative significance in determining flood risk areas within the study's domain. Within this framework, a comprehensive recalibration and hierarchical ranking of the subordinate criteria are conducted, contextualizing their perceived impact on flood risk areas within the study area. The assessment of the relative importance of flood causative factors involves translating respondent judgments into a Pair-wise Comparison matrix, adhering to the Saaty Scale (Table 2), a preference evaluation system facilitating comparative judgments among criteria (Saaty, 1977). Subsequently, a normalized matrix computation technique is employed to ascertain the weight attributed to each criterion. This process entails dividing each criterion within every column by the sum of that column, ultimately resulting in the computation of criterion weights through row averaging. The execution of the Analytical

Hierarchy Process (AHP), delineated by Equations 1 to 7, embodies a multicriteria decision analysis technique elucidated in the study by Singh *et al.* (2018) and employed in the study by Abubakar *et al.* (2025). Within this framework, the AHP-entropy technique harnesses data gathered from a questionnaire survey involving highly experienced specialist's adept at identifying flood risk areas. Moreover, the determination of criterion weights involves normalizing matrix values and their division by multiple criteria, ensuring a statistically robust assessment of judgment accuracy (Dolui and Sarkar, 2023).

The foundational steps in executing the AHP approach, as outlined by Zahedi (1986), involve a comparative assessment of factors. Utilizing a scale comprising nine levels of intensity, a pair-wise matrix is meticulously constructed following the specifications outlined in Table 3. Equation 1 is applied to derive the respective values within this comparison matrix, with C11 representing the values in the first row and first column of the matrix. This comprehensive and systematic methodology ensures a holistic evaluation of both criteria and sub-criteria in delineating flood risk areas within the study's scope.

Table 2: Weighting Scale Preference for Pair-wise Comparisons

Intensity of Importance	Description	Risk Class	Explanation
1	Equal importance	Low Risk	Two activities contribute equally to the objective
2	Equal to moderate importance	Very low Risk	
3	Moderate importance	Low Risk	Experience and judgment slightly to moderately favor one activity over another
4	Moderate to strong importance	Moderately low risk	
5	Strong importance	Moderately risk	Experience and judgment strongly or essentially favor one activity over another
6	Strong to very strong importance	Moderate high risk	

7	Very strong importance	High risk	An activity is strongly favored over another and its dominance is shown in practice
8	Very to extremely strong importance	Very high risk	
9	Extreme importance	Highest risk	The evidence of favoring one activity over another is of the highest degree possible of an affirmation
Reciprocals			
1/3,1/5,1/7,1/9	Opposites	Used for inverse comparison	

Source: Adapted and Modified from Saaty, 1977

$$\text{Comparison matrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \dots & C_{1n} \\ C_{21} & C_{22} & C_{23} & \dots & C_{2n} \\ C_{31} & C_{32} & C_{33} & \dots & C_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & C_{n3} & \dots & C_{nn} \end{bmatrix} \quad 1$$

Complete the matrix: Values within the matrix were summed individually for each column (Shunmugapriya *et al.*, 2021). Furthermore, the column totals of the pair-wise matrices are computed using equation (2):

$$C_{ij} = \sum_{i=1}^n C_{ij} \quad 2$$

Matrix normalization: The normalization for each column value could then be expressed using the following equations.

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^n C_{ij}} = \begin{bmatrix} X_{11} & X_{12} & X_{13} & \dots & X_{1n} \\ X_{21} & X_{22} & X_{23} & \dots & X_{2n} \\ X_{31} & X_{32} & X_{33} & \dots & X_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & X_{n3} & \dots & X_{nn} \end{bmatrix} \quad 3$$

Weight determination: After normalization, the row sum in the normalization matrix was divided by the total number of criteria (Majeed *et al.*, 2023). The following shows how the priority vector's criteria weights were calculated:

$$W_{ij} = \frac{\sum_{i=1}^n X_{ij}}{n} = \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \quad 4$$

Calculate the consistency ratio (C.R.): Only the consistency ratio (C.R.) value may be used to evaluate the judgment value's trustworthiness. As a result, when the C.R. value was less than 0.10 (10%), the comparison matrix was consistent, as indicated by (Saaty, 1987).

Lambda (λ) max: The average value of each consistency vector was used to calculate the principal eigenvector (λ max). The following is the equation that was used to obtain the principal eigenvalue (λ max) (Ajibade *et al.*, 2021).

$$\lambda_{max} = \sum_i^n XCV_{ij} \quad 5$$

The consistency index (CI): This was chosen to assess the degree of a matrix's departure from consistency. The value of λ max was highlighted as being necessary for the discussion of the consistency ratio calculation (Paul and Gosh, 2022). The consistency index (CI) was calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad 6$$

where λ max is the maximum eigenvalue and n represents the number of criteria.

Random index (R.I.): The only factor affecting the random index was how many elements were compared. Table 3 displays the random index values for the consistency index.

Consistency ratio (C.R.): Comparing the CI with the random index resulted in the development of the final consistency ratio (Saaty, 1987). To ensure the reliability of judgments, the next stage involves verifying consistency and drawing conclusions from the results. Since individual judgments may not perfectly align, the Consistency Ratio (CR) will be employed to measure the degree of consistency achieved in the ratings. A CR less than or equal to 0.1 is considered acceptable, indicating reliable judgments. A ratio exceeding 0.1 suggests the need for matrix revision. Revision involves identifying inconsistent judgments regarding the importance of criteria and reevaluating these judgments by re-examining pairs of criteria that were judged inconsistently (Yahaya *et al.*, 2010).

Formula for Calculating Consistency Ratio (CR)

$$C.R = \frac{CI}{CR} \quad 7$$

Where CI= Consistency Index and $\lambda_{max} = (\lambda_{max} - n) / (n - 1)$, RI= Random Consistency Index, n= number of criteria. λ_{max} = priority vector multiplied by each column total

Table 3: Random Consistency Index (Saaty, 1997)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

n = order of the matrix

The current study exhibits a Consistency Ratio (C.R) of 0.05, which falls below the established threshold of 0.10. Should the computed C.R exceed this threshold, any inconsistencies within the pair-wise comparison matrix would necessitate a reassessment and repetition of the process (Dolui and Sarkar, 2023). This outcome suggests that the assigned weights were fittingly allocated. Moreover, the model aptly mirrors the actual conditions prevailing within the research area, showcasing the methodology's effectiveness in identifying and mapping flood risk areas.

Sample Size and Sampling Technique

The study area was estimated to have a population of 1,785,896 people based on 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:

$$P_{t+n} = P_t e^{rn}$$

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

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

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

$$\text{Sample Size} = \frac{N}{1 + N(e)^2} \text{Number of respondents for Questionnaire Administration}$$

$$= \frac{N}{1 + N(e)^2}$$

Where N = number of populations under study

e = proportion of population given as 0.05%
 A total of 399.99 which was rounded up to 400 respondents were selected for administration of the questionnaire. The questionnaire was randomly administered to selected households in the study area (Table 4). However, the sample

size for each ward varied with its population size through the use of:

$$\frac{nQ}{N}$$

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

Table 4: 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

Source: Author's Compilation, 2023

Data collection was carried out using systematic sampling techniques, and administering questionnaires to household heads in flood-prone areas. The sample includes both farmers and non-farmers who have lived in the area for at least ten years. The process starts with randomly selecting the first household and then choosing subsequent households at predetermined intervals, ensuring each household has an equal chance of selection without repetition. Table 3.5 details the sample size and the number of questionnaires administered in each selected Local Government Area (LGA), aiming for a representative and comprehensive data collection across the identified LGAs.

Method of Data Analysis

Utilize Multicriteria Decision Analysis (MCDA) in predicting and mapping current and future flood risk scenarios in the study area. Multicriteria Decision Analysis (MCDA) was utilized to predict and map both current and future flood risk scenarios in the study area. Specifically, the Analytic Hierarchy Process (AHP) model, a subset of MCDA, was employed to create a flood risk map. The factors influencing flood vulnerability were selected based on questionnaire responses from staff at the Hadejia Jama'are Basin River Development Authority (HJRBDA) and a review of existing literature. These factors included rainfall, proximity to rivers, 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 pairwise comparison matrix using Saaty's scale, and the weights for each criterion were calculated from the normalized matrix. The overall priority vector was determined by averaging the criteria weights across all respondents. A consistency ratio (CR) was calculated to ensure the consistency of judgments, with a CR ≤ 0.1 indicating acceptable levels of consistency. Finally, the flood risk map was generated using the raster calculator in ArcGIS by combining the weighted criteria maps. Identify and assess the response capabilities and adaptation strategies employed by rural communities in the study area to address flooding

events. This objective was achieved by examining the mean scores, frequencies, and percentages related to flood risk perceptions and preparedness from the responses to the questionnaire.

RESULTS AND DISCUSSION

Land Use and Land Cover Change Impact on Flood Occurrences

Land use and land cover (LULC) changes play a vital role in flood dynamics. This section examines how alterations in LULC, driven by agricultural expansion, urbanization, and deforestation, have modified the hydrological response of the basin. Using satellite imagery and GIS analysis, we demonstrate the correlation between LULC changes and increased flood occurrences, emphasizing the need for sustainable land management practices. Figure 3 shows that the Hadejia River Basin has undergone significant land use and land cover changes between 2013 and 2023, impacting flood risk. Key changes include a reduction in water bodies by 10 km² and a decrease in dense vegetation by 6 km², both of which are critical for flood mitigation. There was a substantial increase in farmland by 94 km² and a smaller expansion in built-up areas by 8 km² (see Table 5). These changes, coupled with reduced shrubland, suggest increased vulnerability to flooding due to higher surface runoff and reduced natural absorption of rainwater. Effective land management and flood mitigation strategies are essential to address these changes and reduce flood risks in the region.

2013 and 2023 has had profound effects on the basin's hydrological dynamics, significantly heightening flood risks. Anthropogenic activities such as agricultural expansion, urbanization, and deforestation have fundamentally altered the natural landscape, diminishing its capacity to regulate floodwaters. These patterns mirror global trends, where human-induced LULC changes intensify hydrological challenges, particularly in regions prone to flooding. Previous studies, including those by Wheeler and Evans (2009) and Zope et al. (2016), highlight the critical influence of LULC changes on surface runoff, water infiltration, and flood behavior. In the Hadejia Basin, the reduction in water bodies and vegetation alongside expansions in farmland and built-up areas has disrupted the hydrological balance, exposing the

region to increased flood risks and environmental degradation.

A particularly alarming outcome of the LULC analysis is the loss of 10 km² of water bodies and 6 km² of dense vegetation within the basin. These features are crucial for flood mitigation, as they absorb and retain excess water. Their decline has compromised the basin's natural flood-buffering capacity. Idris (2020) notes that soils covered by vegetation contain higher levels of organic carbon and nitrogen, which enhance water infiltration and reduce surface runoff. Consequently, the reduction in vegetation across the Hadejia Basin undermines these protective mechanisms, making the region more susceptible to flooding. Furthermore, the loss of wetlands natural sponges that absorb floodwaters has worsened the situation. Similar findings by Bullock and Acreman (2003) illustrate how wetland degradation worldwide has increased flood vulnerability, a phenomenon now evident in the Hadejia River Basin.

During the study period, farmland expanded by 94 km², and built-up areas grew by 8 km², further disrupting the basin's hydrological equilibrium. Unsustainable agricultural

practices contribute to soil compaction and the reduction of vegetation cover, which in turn amplifies runoff volumes (Wheater & Evans, 2009). Urbanization introduces impervious surfaces such as roads and buildings, which hinder water infiltration and accelerate surface runoff. Zope et al. (2016) observed similar trends in Mumbai, where urban growth resulted in higher flood peaks and increased runoff volumes. In the Hadejia Basin, these LULC changes have intensified rapid-onset flooding, strained existing flood control systems and posing risks to both lives and infrastructure.

Figure 4 presents the predicted landuse and landcover pattern for the year 2050, revealing a landscape that is increasingly dominated by built-up and fam land with notable spatial variation in waterbody, vegetation and bareland. The predicted landuse and landcover suggests a future landscape shaped largely by settlement growth and agricultural expansion. These trends highlights the need for sustainable land use planing, and policies that balance development with environmental protection. Figure 5 presents the contributing factor used in predicting the LULC.

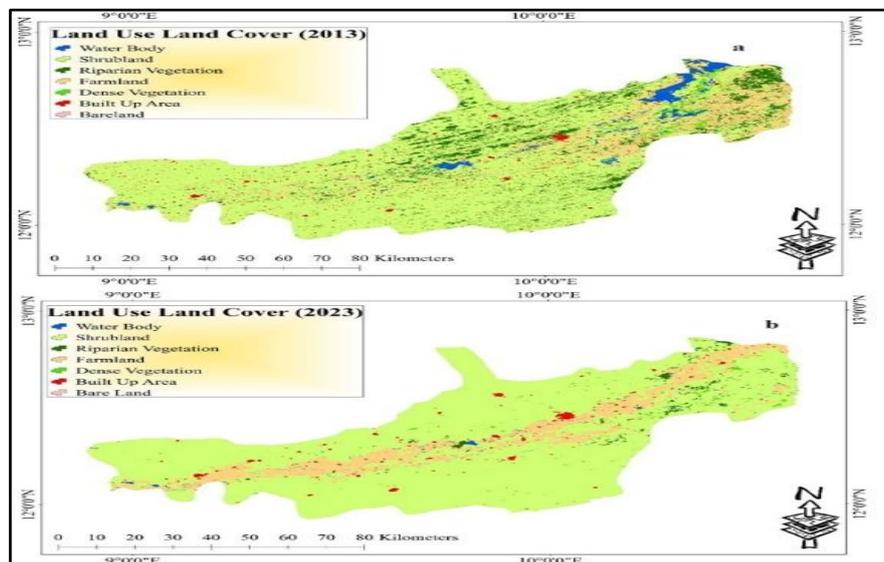


Figure 3: Spatio-temporal Analysis of Land Use Land Cover Changes

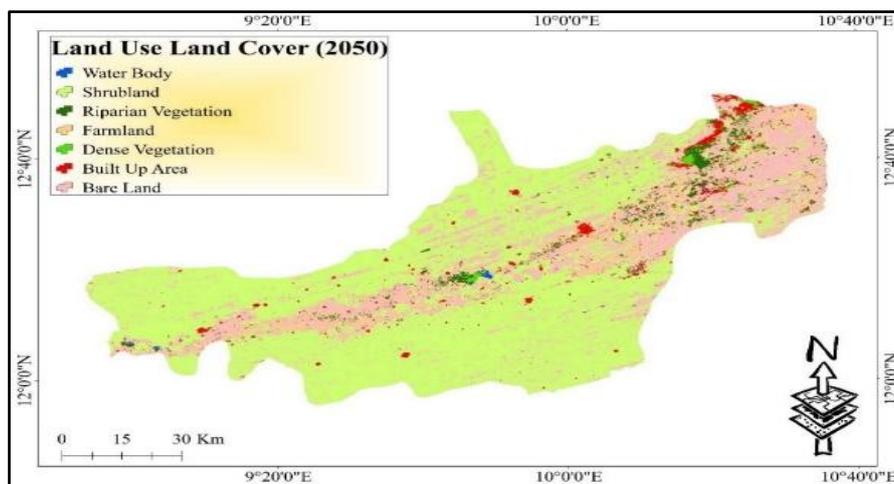


Figure 4: Spatio-Temporal Pattern of the Predicted Land Use Land Cover 2050

Table 5: Land Use Land Cover Change Statistics (2013 – 2023)

S/N	Class	Area in Square km (2013)	Percentage	Area in Square km (2023)	Percentage	Area Change	Percentage Cover Change	Annual Rate of Change (km ² /year)	Percentage of Annual Rate of Change (%/year)
1	Water Body	47.76	0.53	37.76	0.42	-10.00	-0.11	-1.00	-0.01
2	Dense Vegetation	48.43	0.54	42.43	0.47	-6.00	-0.07	-0.60	-0.01
3	Riparian Vegetation	98.00	1.09	97.00	1.08	-1.00	-0.01	-0.10	0.00
4	Farmland	1089.56	12.09	1183.56	13.13	94.00	1.04	9.40	0.10
5	Built-Up Area	89.90	1.00	97.90	1.09	8.00	0.09	0.80	0.01
6	Bare Land	0.75	0.01	0.91	0.01	0.17	0.00	0.02	0.00
7	Shrubland	7637.70	84.75	7552.53	83.80	-85.17	-0.95	-8.52	-0.09
	Total	9012.08	100.00	9012.08	100.00				

Source: Analysis, 2024

The transformation of land use and land cover (LULC) in the Hadejia River Basin between The combined effects of reduced vegetation, loss of water bodies, and increased impervious surfaces have far-reaching hydrological implications. These include elevated surface runoff, diminished water infiltration, and more frequent and intense flood events. Paul and Meyer (2001) emphasize that urbanization significantly reduces the lag time between rainfall and peak discharge, a trend that aligns with observations in the Hadejia Basin. Additionally, the loss of 85.17 km² of shrubland has further exacerbated these issues by removing critical transitional zones that aid water absorption. Brody et al. (2014) reported similar findings in New York's Croton River Basin, where impervious surfaces increased peak discharge by as much as 300%. These parallels underscore the urgency of addressing LULC changes in the Hadejia River Basin to mitigate their hydrological impacts.

The LULC transformations in the Hadejia Basin reflect global patterns observed in rapidly urbanizing and agriculturally expanding regions. Sugianto et al. (2022) identified moderate-to-high flood risks in Indonesia's Teunom Watershed due to comparable LULC changes. Similarly, Zope et al. (2016) documented how unregulated urbanization magnified flood risks in India's Oshiwara River Basin. These cases highlight the universal challenge of balancing developmental pressures with environmental sustainability. In the Hadejia Basin, these challenges are further compounded by climatic factors, such as increased rainfall variability and intensity, which exacerbate the effects of LULC changes and elevate flood risks. Addressing these interconnected issues requires integrated land management strategies that consider both natural and human drivers of flooding.

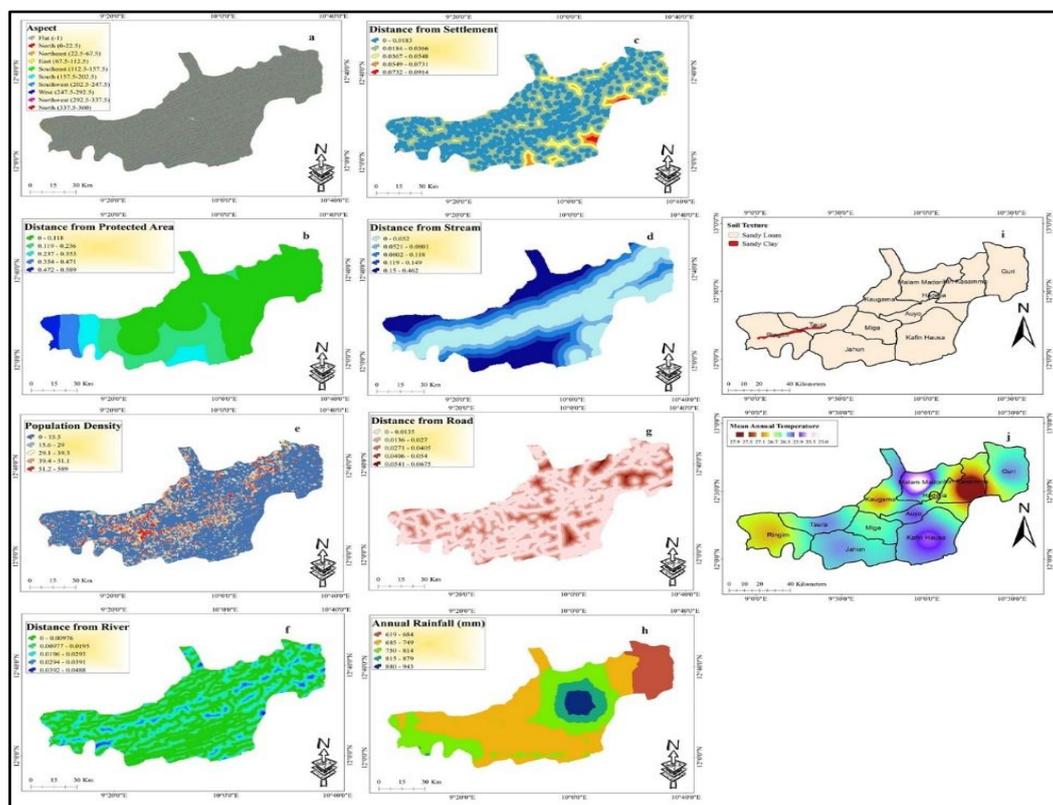


Figure 5: Contributing Factors Used to Predict Land Use Land Cover

To mitigate the adverse effects of LULC changes on flood dynamics, targeted interventions are imperative. Reforestation and vegetation restoration can enhance water infiltration and curb surface runoff, as McCulloch (2007) demonstrated in similar contexts. Wetlands must be preserved to maintain their role as natural flood buffers, while sustainable agricultural practices such as contour farming and agroforestry can reduce soil degradation and improve water retention. Urban planning should prioritize green infrastructure, including permeable pavements and stormwater management systems, to counteract the impact of impervious surfaces (Brody et al., 2014). Lastly, integrated land use policies are essential to balance agricultural expansion, urban growth, and environmental conservation. By adopting these measures, the Hadejia Basin can reduce flood risks and build resilience against future climate and environmental challenges.

Nature of Flood Risk Using Multicriteria Decision Analysis (MCDA)

Employing Multicriteria Decision Analysis (MCDA), this segment evaluates the multifaceted nature of flood risk in the Hadejia River Basin. MCDA allows for the integration of various criteria, including hydrological, socio-economic, and

environmental factors, to assess and prioritize flood-prone areas. The results provide a comprehensive risk profile, aiding in the development of targeted flood mitigation strategies. Table 6 depicts the weight for each of the factors contributing to the flooding in the study area.

Figure 6 outlines various factors contributing to flood risk in the study area. Key drivers include rainfall intensity and duration, with areas experiencing higher rainfall showing increased flood risk. High temperatures and evaporation rates can exacerbate flooding by contributing to more intense rainfall. Vegetation health, as indicated by NDVI, also plays a role, with sparse vegetation increasing flood susceptibility. Urbanization and deforestation, leading to more impervious surfaces, further heighten flood risk.

Literacy rates and population density influence flood preparedness and risk levels, with higher literacy contributing to lower risk and dense populations increasing it. Soil texture, slope steepness, and topographic wetness are also critical, affecting water infiltration and runoff. Areas with high soil moisture, proximity to rivers, and lower elevation are more prone to flooding. Geological factors, like rock type and lineament density, can also affect flood risk by influencing groundwater flow and surface runoff.

Table 6: Flood Causative Factors and their Weightage

C_Factor	Reclassified Index	Relative Weight	Ranking	Over all Weight	Flood Risk
Rainfall (mm)					
	462 - 526	30	1	30	Very Low
	527 - 582		2	60	Low
	583 - 625		3	90	Moderate
	626 - 662		4	120	High
	663 - 704		5	150	Very High
Distance From River (m)					
	0 - 1000	15	5	75	Very High
	1001 - 2000		4	60	High
	2001 - 3000		3	45	Moderate
	3001 - 4000		2	30	Low
	5000 and above		1	15	Very Low
Elevation (m)					
	Less than 354	10	5	50	Very High
	354 - 364		4	40	High
	364 - 375		3	30	Moderate
	375 - 386		2	20	Low
	387 and above		1	10	Very Low
Slope (degrees)					
	0 - 1.3	7	1	7	Very Low
	1.3 - 2.3		2	14	Low
	2.3 - 3.6		3	21	Moderate
	3.6 - 5.3		4	28	High
	5.4 and above		5	35	Very High
Drainage Density					
	Less the 77	6	1	6	Very Low
	78 - 110		2	12	Low
	111 - 130		3	18	Moderate
	131 - 140		4	24	High
	150 and above		5	30	Very High
Soil Moisture					
	Less than 79	5	1	5	Very Low
	80 - 85		2	10	Low
	86 - 94		3	15	Moderate
	95 - 110		4	20	High
	120 and above		5	25	Very High

C_Factor	Reclassified Index	Relative Weight	Ranking	Over all Weight	Flood Risk
Topographic Wetness Index (TWI)	-7.52 - -3.41	4	1	4	Very Low
	-3.4 - -1.11		2	8	Low
	-1.1 - -1.18		3	12	Moderate
	1.19 - 4.49		4	16	High
	4.48 - 14.4		5	20	Very High
Population density	Less than 350	4	5	20	Very High
	351 - 456		4	16	High
	457 - 612		3	12	Moderate
	613 - 844		2	8	Low
	845 and above		1	4	Very Low
Soil Type	Eutric Regosol	3	1	3	Very Low
	Orthic Luvisol		2	6	Low
	Eutric Fluvisol		3	9	Moderate
	Gleyic Cambisol		4	12	High
	Dystric Gleysol		5	15	Very High
Temperature	Less than 25.9	3	1	3	Very Low
	26. - 26.2		2	6	Low
	26.3 - 26.6		3	9	Moderate
	26.7 - 27.1		4	12	High
	27. 2 and above		5	15	Very High
Land Use Land Cover	Water body	3	5	15	Very High
	Vegetation		3	9	Moderate
	Shrubland		3	9	Moderate
	Riparian Vegetation		4	12	High
	Built Up Area		1	3	Very Low
	Bareland		2	6	Low
	Agricultural Land		3	9	Moderate
Evapotranspiration	5.96 - 6.45	2	5	10	Very High
	6.46 - 6.76		4	8	High
	6.77 - 7.01		3	6	Moderate
	7.02 - 7.35		2	4	Low
	7.36 - 7.81		1	2	Very Low
Normalized Difference Vegetation Index (NDVI)	-0.158 - 0.128	2	5	10	Very High
	0.129 - 0.299		4	8	High
	0.3 - 0.356		3	6	Moderate
	0.357 - 0.436		2	4	Low
	0.437 - 0.61		1	2	Very Low
Geology	Aeolian sands	2	2	4	Low
	Sand dunes over Sandstone and chad sediment and Basement Complex		4	8	High
	Undifferentiated Basement Complex		5	10	Very High
	Aeolian sand over alluvium		1	2	Very Low
	Recent Alluvium		3	6	Moderate
Lineament Density	Less than 0.225	2	1	2	Very Low
	0.226 - 0.64		2	4	Low
	0.641 - 1.00		3	6	Moderate
	1.01 - 1.36		4	8	High
	1.37 and above		5	10	Very High
Literacy Rate					

C_Factor	Reclassified Index	Relative Weight	Ranking	Over all Weight	Flood Risk
	Less than 10.6	2	5	10	Very High
	10.7 - 17.0		4	8	High
	17.01 - 20.0		3	6	Moderate
	20.01 - 28.4		2	4	Low
	28.5 and above		1	2	Very Low

Flood risk in the Hadejia River Basin is inherently multifaceted, driven by a combination of hydrological, geological, environmental, and socio-economic factors. Addressing these complexities requires advanced analytical approaches, and Multicriteria Decision Analysis (MCDA) has proven to be an invaluable tool in this regard (Figure 7). By integrating diverse datasets, MCDA allows for a comprehensive understanding of flood risks, enabling the precise identification of high-risk areas. Unlike conventional methods that often focus on isolated factors, this approach highlights the interconnected nature of flood drivers, providing actionable insights for implementing targeted mitigation and adaptation measures. Among hydrological factors, rainfall intensity emerged as the most critical contributor to flood risk. Areas receiving rainfall

above 663 mm were identified as "very high risk," aligning with the findings of Adeoye (2024) and underscoring the need for enhanced meteorological monitoring and early warning systems. Additionally, localized rainfall patterns influenced by evapotranspiration were found to play a secondary role, as corroborated by Sylla and Solecka, (2020). From a geological perspective, low-lying areas with gentle slopes were particularly vulnerable due to their propensity for water retention, echoing the conclusions of Youssef et al. (2016). Moreover, geological features such as undifferentiated basement complexes significantly impact surface runoff and groundwater dynamics, as similarly observed by Dutta and Deka (2024). These findings emphasize the need for geologically informed flood risk planning.

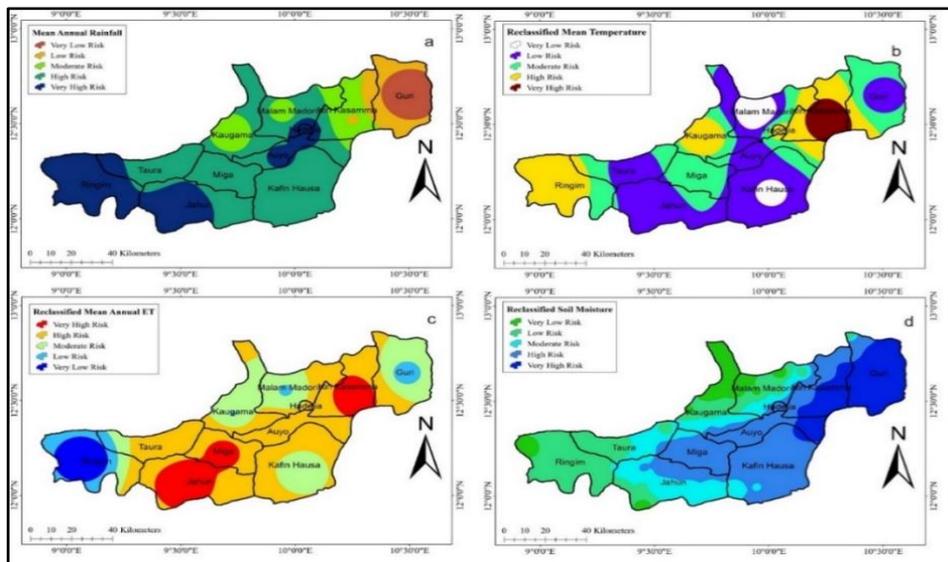


Figure 6: Reclassified Flood Causative Factors Used for MCDA AHP Flood Risk Mapping

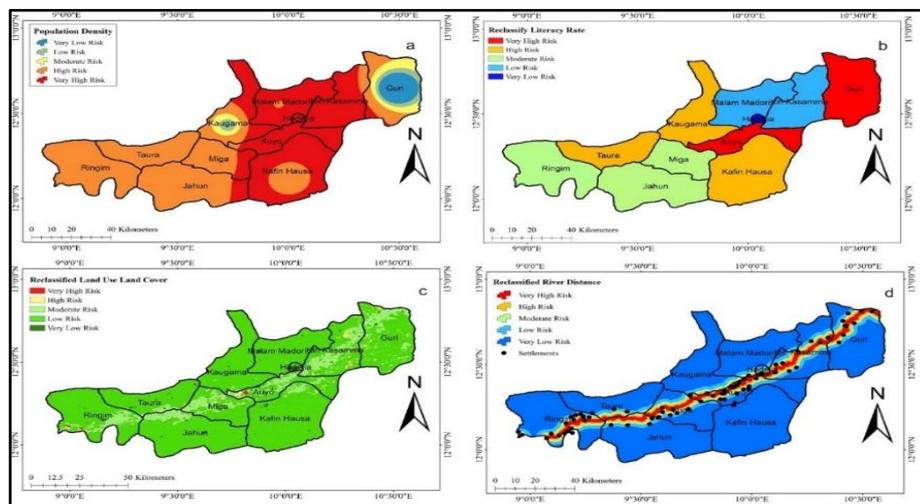


Figure 6: (Continued) Reclassified Flood Causative Factors Used for MCDA AHP Flood Risk Mapping

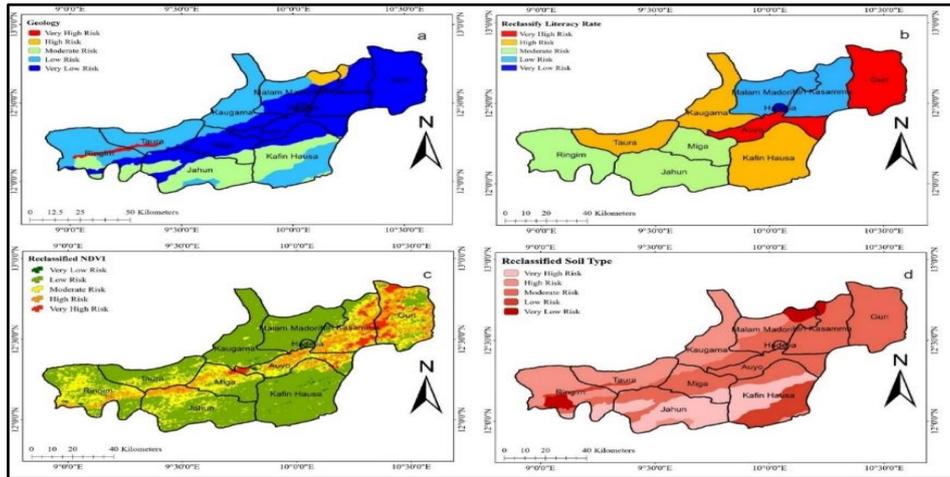


Figure 6: (Continued) Reclassified Flood Causative Factors Used for MCDA AHP Flood Risk Mapping

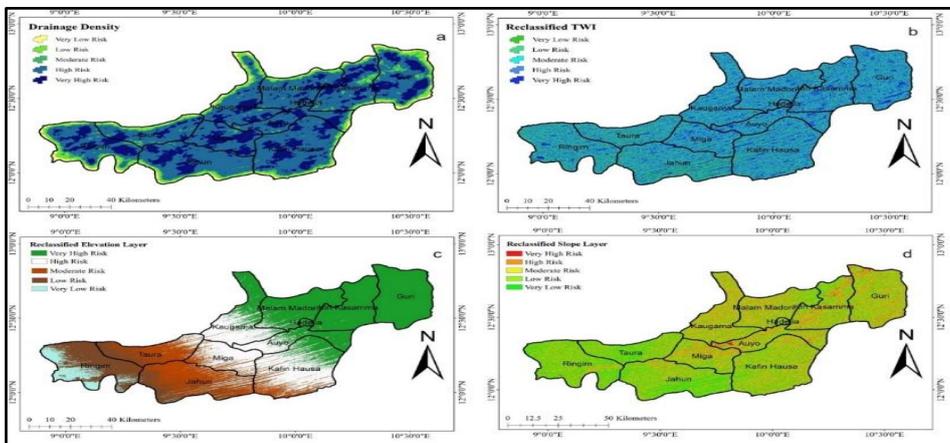


Figure 6: (Continued) Reclassified Flood Causative Factors Used for MCDA AHP Flood Risk Mapping

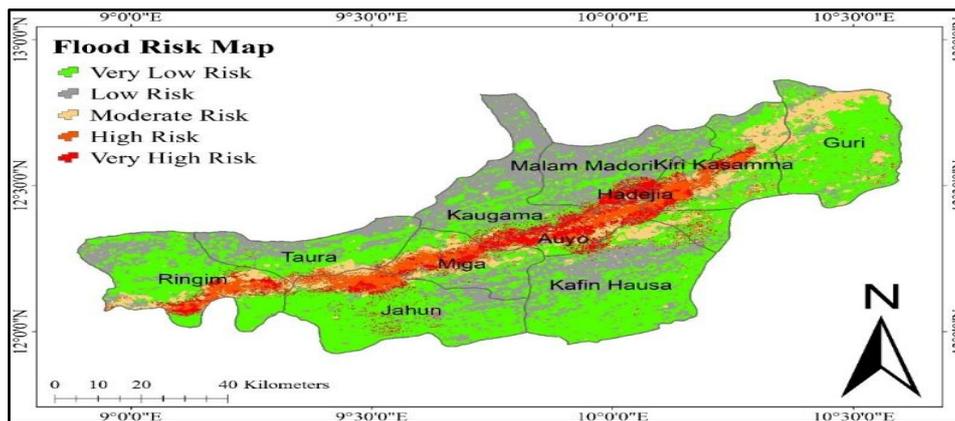


Figure 7: Flood Risk Map from MCDA (AHP)

Table 7 presents the Comparison Matrix for Flood Causative Factors. As shown on the table, rainfall had the highest relative weight of 29.58%, followed by distance of river from

settlement 14.79%, while the literacy rate factor had the lowest relative weight of 1.85%. this implies that rainfall and river are the drivers of flooding in the study area.

Table 7: Comparison Matrix for Flood Causative Factors

C_Factor	Rainfall	Distance from River Settlement	Elevation	Slope	Drainage Density	Soil Moisture	Topographic Wetness Index	Population Density	Soil Type	Temperature	Land Use	Evapotranspiration	NDVI	Geology	Lineament density	Literacy rate	Priority Weight	Relative Weight
Rainfall	16.00	15.00	14.00	13.00	12.00	11.00	10.00	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00	1.00	0.30	29.58
Distance from River to Settlement	8.00	7.50	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	3.00	2.50	2.00	1.50	1.00	0.50	0.15	14.79
Elevation	5.33	5.00	4.67	4.33	4.00	3.67	3.33	3.00	2.67	2.33	2.00	1.67	1.33	1.00	0.67	0.33	0.10	9.86
Slope	4.00	3.75	3.50	3.25	3.00	2.75	2.50	2.25	2.00	1.75	1.50	1.25	1.00	0.75	0.50	0.25	0.07	7.39
Drainage Density	3.20	3.00	2.80	2.60	2.40	2.20	2.00	1.80	1.60	1.40	1.20	1.00	0.80	0.60	0.40	0.20	0.06	5.92
Soil Moisture	2.67	2.50	2.33	2.17	2.00	1.83	1.67	1.50	1.33	1.17	1.00	0.83	0.67	0.50	0.33	0.17	0.05	4.93
Topographic Wetness Index	2.29	2.14	2.00	1.86	1.71	1.57	1.43	1.29	1.14	1.00	0.86	0.71	0.57	0.43	0.29	0.14	0.04	4.23
Population Density	2.00	1.88	1.75	1.63	1.50	1.38	1.25	1.13	1.00	0.88	0.75	0.63	0.50	0.38	0.25	0.13	0.04	3.70
Soil Type	1.78	1.67	1.56	1.44	1.33	1.22	1.11	1.00	0.89	0.78	0.67	0.56	0.44	0.33	0.22	0.11	0.03	3.29
Temperature	1.60	1.50	1.40	1.30	1.20	1.10	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.03	2.96
Land Use	1.45	1.36	1.27	1.18	1.09	1.00	0.91	0.82	0.73	0.64	0.55	0.45	0.36	0.27	0.18	0.09	0.03	2.69
Evapotranspiration	1.33	1.25	1.17	1.08	1.00	0.92	0.83	0.75	0.67	0.58	0.50	0.42	0.33	0.25	0.17	0.08	0.02	2.46
NDVI	1.23	1.15	1.08	1.00	0.92	0.85	0.77	0.69	0.62	0.54	0.46	0.38	0.31	0.23	0.15	0.08	0.02	2.28
Geology	1.14	1.07	1.00	0.93	0.86	0.79	0.71	0.64	0.57	0.50	0.43	0.36	0.29	0.21	0.14	0.07	0.02	2.11
Lineament density	1.07	1.00	0.93	0.87	0.80	0.73	0.67	0.60	0.53	0.47	0.40	0.33	0.27	0.20	0.13	0.07	0.02	1.97
Literacy rate	1.00	0.94	0.88	0.81	0.75	0.69	0.63	0.56	0.50	0.44	0.38	0.31	0.25	0.19	0.13	0.06	0.02	1.85
Total	54.09																1.00	100.00

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 8, 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. Aladejana et al., (2021) applied remote sensing and GIS to model flood inundation hazards in the River Kaduna, revealing significant spatial variability in flood risk levels. Similarly, Javan et al., (2011) used AHP for earthquake susceptibility mapping, which can be analogously applied to flood risk assessment. Environmental factors, including vegetation health (measured by NDVI) and land-use changes, also play pivotal roles in flood susceptibility. Deforestation and urbanization, in particular, exacerbate flood risks by reducing natural water absorption and increasing surface runoff. These results highlight the importance of afforestation and sustainable land-use planning as critical strategies for mitigating flood impacts.

Socio-economic factors further complicate flood vulnerability, with population density and literacy rates emerging as key determinants. Densely populated areas face higher risks due to limited space for water dispersal and increased exposure, consistent with the findings of Ologunorisa and Abawua (2005). Conversely, regions with higher literacy rates displayed lower flood susceptibility, likely reflecting better preparedness and adaptive capacity. This underscores the importance of community education, awareness campaigns, and participatory planning in flood risk

management. Integrating traditional ecological knowledge (TEK) with scientific approaches could further bolster the resilience of flood-prone communities by bridging gaps between local practices and technical expertise.

The study's findings align with global research while emphasizing local nuances. For instance, the prioritization of rainfall intensity and proximity to rivers mirrors similar studies conducted in the Niger Delta (Ibitoye et al., 2020). However, the inclusion of socio-economic variables, such as literacy and population density, introduces a unique dimension to this analysis. Similarly, geological parameters, often overlooked in flood studies, were shown to play a pivotal role, aligning with observations by van den Brink et al. (2014) in the Netherlands. Furthermore, the integration of MCDA, as advocated by Shahabi et al. (2020), show its effectiveness in synthesizing diverse datasets to develop holistic flood risk profiles, demonstrating the adaptability of this approach across different contexts.

This MCDA-based assessment offers valuable guidance for policymakers in managing flood risks. High-risk areas, such as those experiencing intense rainfall or located near rivers, should be prioritized for structural interventions, including levees, retention basins, and improved drainage systems. Climate-resilient urban planning must also focus on green infrastructure, reforestation, and sustainable agricultural practices to minimize flood impacts. Community-driven strategies, such as investments in literacy and public awareness campaigns, can further strengthen adaptive capacities. Incorporating TEK alongside scientific insights ensures culturally relevant and practical solutions for affected communities.

Table 8: 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

Source: Authors Analysis, 2024

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. The adaptive capacity of rural communities significantly influences their resilience to flooding events. This section investigates the existing response mechanisms and adaptation

strategies employed by local populations, using field surveys and interviews to assess the effectiveness of both traditional and contemporary practices. The evaluation focuses on several key metrics: the percentage of households implementing structural adaptations, the number and scope of community-based adaptation projects, and the implementation rate of local government policies and programs designed to enhance flood resilience. Additionally, it assesses the reduction in flood damage and loss over time that can be attributed to these adaptation strategies (Table 9).

Table 9: Response Capabilities

Response Capabilities	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
To what extent do you prepare for flood disaster	To a great extent	258	64.55	9	2.27
	Somewhat	104	25.91	4	1.09
	Neutral	10	2.64	2	0.55
	Not very much	7	1.82	1	0.18
	Not at all	5	1.18	0	0.00
		384	96.09	16	4.09

Response Capabilities	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
How well do community leaders understand the value of improving emergency preparedness and response in the events of a disaster?	Very well	251	62.73	13	3.18
	Well	100	24.91	6	1.55
	Neutral	13	3.36	4	1.00
	Poorly	9	2.27	1	0.36
	Not at all	3	0.64	0	0.00
		376	93.91	24	6.09
On Availability of Resources:	Excellent	232	58.09	5	1.36
	Good	127	31.82	1	0.18
	Average	21	5.27	0	0.00
	Poor	11	2.64	0	0.00
	Very Poor	3	0.64	0	0.00
		394	98.45	6	1.55
In your opinion, how accessible are emergency services like fire departments, paramedics, and search and rescue teams in the study area?	Highly accessible	232	57.91	0	0.09
	Moderately accessible	118	29.45	9	2.36
	Neutral	23	5.82	1	0.18
	Limited accessibility	12	2.91	0	0.00
	Not accessible at all	5	1.27	0	0.00
		389	97.36	11	2.64
On Access to Information	Highly defined and accepted processes	72	18.09	10	2.45
	Moderately defined and accepted processes	58	14.45	0	0.00
	Neutral	236	59.09	2	0.55
	Limited definition and acceptance	16	3.91	0	0.00
	No defined or accepted processes	6	1.45	0	0.00
		388	97.00	12	3.00
How important do you think social media platforms such as Facebook and Twitter are in propagating emergency information to disaster-affected communities?	Very important	39	9.64	2	0.45
	Important	39	9.73	4	1.09
	Neutral	54	13.55	2	0.45
	Not very important	24	6.09	0	0.00
	Not important at all	231	57.64	5	1.36
		387	96.64	13	3.36
How would you evaluate the contribution of social networks to flood risk?	Contributed significantly	85	21.36	2	0.45
	Contributed moderately	47	11.64	4	1.09
	Neutral	54	13.55	2	0.45
	Contributed minimally	24	6.09	0	0.00

Response Capabilities	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
To what extent do community members rely on social media for critical information related to disaster management?	No contribution at all	176	44.00	5	1.36
	Very much	387	96.64	13	3.36
		84	20.91	2	0.45
	Moderately	54	13.45	4	1.09
	Neutral	52	13.09	1	0.36
	Minimally	24	6.09	0	0.00
How would you rate the effectiveness of Institutional Support in managing flood risk?	Not at all	172	43.09	6	1.45
	Highly effective	387	96.64	13	3.36
		86	21.45	3	0.64
	Effective	209	52.36	14	3.45
	Neutral	21	5.27	4	1.00
	Ineffective	44	11.00	3	0.82
Highly ineffective	16	4.00	0	0.00	
To what extent are community members aware of the standards set by NEMA and other emergency management agencies?	Very aware	376	94.09	24	5.91
	Aware	43	10.64	5	1.27
		235	58.82	13	3.18
	Neutral	53	13.18	13	3.18
	Unaware	32	7.91	5	1.18
	Very unaware	3	0.64	0	0.00
In assessing the challenges of response capabilities in managing flood risk, how would you rate the degree to which these challenges hinder effective responses?	Very aware	365	91.18	35	8.82
	Significantly hinders	52	13.09	3	0.82
		273	68.18	5	1.36
	Moderately hinders	42	10.45	2	0.45
	Neutral	19	4.73	3	0.73
	Minimally hinders	1	0.18	0	0.00
In your opinion, how does the remote location of some areas in the study region affect the immediate or emergency help reaching them after a disaster?	Does not hinder at all	387	96.64	13	3.36
	Greatly affects	273	68.18	9	2.27
		53	13.36	3	0.64
	Somewhat affects	30	7.55	1	0.36
	Neutral	24	6.09	4	0.91
	Minimally affects	3	0.64	0	0.00
In evaluating the impact of low awareness on the flood risk, how would you rate its hindrance level?	Does not hinder at all	383	95.82	17	4.18
	Hugely hinders	285	71.36	8	2.09
	Moderately hinders	47	11.64	4	0.91
	Neutral	33	8.36	2	0.45

Response Capabilities	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
How can awareness be effectively increased in such locations to enhance response capabilities?	Minimally hinders	14	3.45	4	1.09
	Does not hinder at all	3	0.64	0	0.00
	Through community workshops	382	95.45	18	4.55
	Increased use of local media	108	27.09	4	1.09
	Involvement of community leaders	9	2.18	0	0.00
	Collaboration with educational institutions	23	5.73	0	0.00
		246	61.45	10	2.45
		386	96.45	14	3.55

Table 9 provides critical insights into flood preparedness, response capabilities, and the role of social media in disaster management across the Local Government Areas (LGAs) of the Hadejia River Basin. The data reveals significant disparities between flood victims and non-victims, with the former showing higher levels of preparedness and awareness due to their direct experiences with flooding. Flood victims rate their community leaders, resource availability, and emergency service accessibility more positively than non-victims. However, both groups express skepticism about the effectiveness of social media in emergency communication and the contribution of social networks to flood risk reduction. These findings underscore the need for improved community engagement, clearer communication strategies, and targeted interventions to enhance flood risk management in the region. Furthermore, it evaluates perceptions of the effectiveness of constructing buildings on raised platforms to keep structures above floodwaters. Responses are categorized into five levels: strongly agree, agree, neutral, disagree, and strongly disagree. This data is crucial for understanding community support for specific flood adaptation measures and for developing effective strategies for climate variability adaptation and flood risk management. The data highlights a significant difference in the perceptions of flood adaptation strategies between flood victims and non-victims in the Hadejia River Basin. Flood victims show strong support for various measures, such as constructing buildings on raised platforms, modifying river channels, establishing early warning systems, and developing emergency response plans. They also favor strategies like raising flood-resistant livestock, preserving natural vegetation, creating alternative channels, and supporting government-led initiatives like dam clearing and afforestation. In contrast, non-victims demonstrate minimal engagement with these strategies, indicating a lack of awareness and support. These findings emphasize the need for tailored flood risk management strategies that address the specific experiences of flood victims and broader public education to foster community-wide support.

The data reveals a significant disparity between flood victims and non-victims regarding flood preparedness across various Local Government Areas (LGAs) within the Hadejia River Basin. Victims of flooding show a much higher level of preparedness compared to non-victims. For instance, in Auyo LGA, 65% of flood victims prepare for flood disasters to a great extent, while only 5% of non-victims do the same. This trend is consistent across other LGAs like Guri, Hadejia, Jahun, Kafin Hausa, Kaugama, and Malam Madori,

suggesting that direct experience with flooding drives higher preparedness levels among victims. Previous studies in the Hadejia River Basin also highlight this phenomenon, indicating that those with firsthand flood experience tend to be more proactive in their preparedness measures (Salihu et al., 2022). This highlights the need for broader community engagement to elevate preparedness among non-victims.

Flood victims perceive community leaders as having a good understanding of emergency preparedness, with a significant percentage rating their understanding as very well or well. For example, in Auyo LGA, 72% of flood victims believe that community leaders understand emergency preparedness very well. In contrast, non-victims rate community leaders' understanding much lower, indicating a gap in perception between victims and non-victims. This underscores the need for community leaders to engage more with non-victims to enhance overall community preparedness. Studies have shown that effective community leadership is crucial for enhancing disaster preparedness and resilience (Ibrahim and Balzter, 2024). Flood victims generally rate the availability of resources for flood management as excellent or good. In Auyo LGA, 70% of victims rate resource availability as excellent, compared to only 2% of non-victims. This trend continues in other LGAs, such as Guri, Hadejia, and Jahun. Non-victims consistently show minimal awareness or perception of resource availability, indicating a need for better communication and community engagement to ensure all residents are aware of and can access available resources. Prior research in the region has similarly emphasized the importance of resource awareness in effective flood management (Umar and Gray, 2023).

Victims report higher accessibility to emergency services like fire departments, paramedics, and search and rescue teams. For example, in Auyo LGA, 65% of victims rate emergency services as highly accessible, compared to only 1% of non-victims. Similar trends are observed across other LGAs, emphasizing the necessity for infrastructure improvements and enhanced community engagement to ensure equitable access to emergency services. The disparity in access to emergency services highlights the need for targeted efforts to improve infrastructure and services in flood-prone areas (Nwilo et al., 2012). There is a significant discrepancy between flood victims and non-victims in access to information on flood management. For instance, in Auyo LGA, 65% of victims report neutral access to information, while non-victims show minimal access. This pattern is consistent across other LGAs, indicating a need for improved

communication strategies to ensure all community members are well-informed. Enhanced information dissemination can significantly improve community preparedness and response (Salihu et al., 2022).

Flood victims generally do not consider social media important for disseminating emergency information. In Auyo LGA, 52% of victims believe social media is not important at all, with similar sentiments in other LGAs. This highlights a general skepticism or lack of awareness regarding the efficacy of social media in emergency communication, suggesting the need for targeted efforts to educate communities about the potential benefits of using social media for emergency purposes. Studies have shown that social media can be an effective tool for disaster communication if appropriately utilized (Ibrahim and Balzter, 2024). There are mixed perceptions among flood victims about the contribution of social networks to flood risk management. For example, in Auyo LGA, 16% of victims believe social networks contribute significantly, while 42% feel there is no contribution. This variability indicates that while some victims recognize the value of social networks, many do not, pointing to the need for better integration and promotion of social networks in disaster risk management strategies. Social networks can play a critical role in community resilience and disaster response (Umar and Gray, 2023).

Reliance on social media for disaster information is low among flood victims. For example, in Auyo LGA, 42% of victims do not rely on social media at all. This trend is observed in other LGAs, highlighting a general distrust or lack of familiarity with using social media for obtaining critical disaster-related information. Efforts should be made to enhance the reliability and perceived usefulness of social media in this context. Effective use of social media can improve real-time information sharing and community engagement during disasters (Nwilo et al., 2012). Flood victims generally have a positive perception of institutional support for managing flood risk, with many rating it as effective or highly effective. For example, in Auyo LGA, 60% of victims rate institutional support as effective. However, non-victims rate institutional support significantly lower, indicating a need for institutions to engage more broadly with the entire community to improve perceptions and effectiveness. Strengthening institutional support and community trust is crucial for effective flood risk management (Salihu et al., 2022).

Flood victims show higher awareness of standards set by emergency management agencies like NEMA compared to non-victims. For instance, in Auyo LGA, 62% of victims are aware of these standards. This trend is consistent across other LGAs, suggesting that direct experience with floods enhances awareness. Efforts should focus on increasing awareness among non-victims to ensure comprehensive community preparedness. Awareness of emergency management standards can significantly enhance community resilience and response capabilities (Ibrahim et al., 2019). Flood victims perceive significant challenges in response capabilities, with many indicating that these capabilities moderately or significantly hinder effective responses. For example, in Auyo LGA, 24% of victims report significant hindrance. This pattern highlights the need for improvements in response strategies and capabilities to better manage flood risks. Enhancing response capabilities is essential for effective disaster management (Umar et al., 2019).

Victims believe that remote locations significantly affect the timeliness and effectiveness of emergency help. In Auyo LGA, 52% of victims report that remoteness greatly affects emergency help. This trend is observed in other LGAs, emphasizing the need for targeted logistical planning and infrastructure development to address challenges posed by remoteness in disaster response. Addressing logistical challenges in remote areas is critical for effective emergency response (Nwilo et al., 2012). Low awareness is perceived as a major hindrance to effective flood risk management among flood victims. For example, in Auyo LGA, 72% of victims believe that low awareness hugely hinders flood risk management. This indicates a critical need for comprehensive awareness programs to educate the community on flood risks and mitigation strategies. Increasing community awareness can significantly improve flood risk management (Salihu et al., 2022).

Flood victims favor collaboration with educational institutions and community workshops as effective methods to increase awareness. For instance, in Auyo LGA, 60% of victims believe collaboration with educational institutions is the most effective method. This suggests that leveraging educational institutions and community-based initiatives could significantly enhance awareness and response capabilities. Collaborative efforts with educational institutions and community organizations can enhance disaster preparedness and resilience (Ibrahim et al., 2019).

Table 10: Adaptation Strategies to Flood

Adaptation Strategies	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
Constructing buildings on raised platforms can effectively keep structures above floodwaters	Strongly Agree	303	75.64	5	1.36
	Agree	33	8.27	3	0.64
	Neutral	34	8.45	4	1.00
	Disagree	12	2.91	0	0.00
	Strongly Disagree	7	1.73	0	0.00
		388	97.00	12	3.00
Modifying and managing river channels is a viable strategy to control the flow of water and prevent flooding in vulnerable areas	Strongly Agree	273	68.18	3	0.82
	Agree	40	10.00	3	0.73
	Neutral	39	9.64	4	0.91
	Disagree	27	6.73	0	0.09
	Strongly Disagree	12	2.91	0	0.00
		390	97.45	10	2.55
Establishing effective early warning systems to alert communities about impending floods can provide	Strongly Agree	313	78.27	4	1.00
	Agree	38	9.45	4	0.91
	Neutral	28	7.00	5	1.36
	Disagree	5	1.36	3	0.64

Adaptation Strategies	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
sufficient time for evacuation and preparation	Strongly Disagree	0	0.00	0	0.00
		384	96.09	16	3.91
Developing and regularly practicing emergency response plans can efficiently manage flood related crises	Strongly Agree	292	72.91	3	0.82
	Agree	36	8.91	2	0.45
	Neutral	33	8.27	4	0.91
	Disagree	24	6.00	0	0.00
	Strongly Disagree	7	1.73	0	0.00
		391	97.82	9	2.18
Raising flood-resistant livestock breeds and implementing appropriate management practices can protect animals during floods	Strongly Agree	301	75.18	5	1.36
	Agree	40	9.91	0	0.00
	Neutral	33	8.27	4	1.00
	Disagree	12	3.00	1	0.18
	Strongly Disagree	4	1.09	0	0.00
		390	97.45	10	2.55
Natural vegetation can act as a buffer against floods by absorbing excess water and stabilizing soil	Strongly Agree	51	12.73	3	0.82
	Agree	273	68.18	5	1.36
	Neutral	42	10.45	2	0.45
	Disagree	19	4.73	3	0.73
	Strongly Disagree	2	0.45	0	0.09
		386	96.55	14	3.45
Creation of alternative channels is a feasible community adaptation strategy to floods	Strongly Agree	304	75.91	3	0.82
	Agree	40	10.00	0	0.00
	Neutral	31	7.64	4	0.91
	Disagree	16	4.09	0	0.00
	Strongly Disagree	3	0.64	0	0.00
		393	98.27	7	1.73
Clearing dams from siltation is an effective community adaptation strategy to floods	Strongly Agree	292	72.91	9	2.27
	Agree	47	11.64	3	0.82
	Neutral	27	6.64	2	0.45
	Disagree	16	3.91	5	1.18
	Strongly Disagree	1	0.18	0	0.00
		381	95.27	19	4.73
Early warning system (dredging station) is an effective government and agencies adaptation strategy to floods	Strongly Agree	320	80.09	0	0.00
	Agree	42	10.45	0	0.00
	Neutral	28	7.09	2	0.45
	Disagree	8	1.91	0	0.00
	Strongly Disagree	0	0.00	0	0.00
		398	99.55	2	0.45
Afforestation by the government is an effective adaptation strategy to floods	Strongly Agree	246	61.45	10	2.55
	Agree	108	27.09	4	1.09
	Neutral	9	2.18	0	0.00
	Disagree	23	5.64	0	0.00
	Strongly Disagree	0	0.00	0	0.00
		385	96.36	15	3.64
Building barriers and levees can be in preventing floodwaters from reaching critical areas and protecting communities and agricultural land	Very Effective	296	74.00	10	2.55
	Effective	83	20.73	4	1.00
	Moderately Effective	7	1.73	0	0.00
	Slightly Effective	0	0.00	0	0.00
	Not Effective	0	0.00	0	0.00
			386	96.45	14
Construction of reservoirs and dams in regulating water flow, storing excess water, and preventing downstream flooding	Very Effective	271	67.73	10	2.55
	Effective	89	22.18	4	1.09
	Moderately Effective	22	5.45	0	0.00
	Slightly Effective	4	1.00	0	0.00
	Not Effective	0	0.00	0	0.00
		385	96.36	15	3.64

Adaptation Strategies	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
Implementation of land-use policies that restrict construction in flood-prone areas and promote sustainable development practices is for flood adaptation	Very Effective	63	15.64	11	2.82
	Effective	282	70.55	10	2.55
	Moderately Effective	18	4.55	0	0.00
	Slightly Effective	16	3.91	0	0.00
	Not Effective	0	0.00	0	0.00
Choosing flood-resistant crop varieties and practicing crop rotation is in minimizing the impact of floods on agriculture in the Hadejia River basin?	Very Effective	379	94.64	21	5.36
	Effective	210	52.45	12	3.00
	Moderately Effective	149	37.27	5	1.36
	Slightly Effective	19	4.73	0	0.00
	Not Effective	5	1.18	0	0.00
Efficient water management practices, such as rainwater harvesting and soil conservation, in reducing soil erosion and the risk of flooding	Very Effective	0	0.00	0	0.00
	Effective	383	95.64	17	4.36
	Moderately Effective	42	10.55	0	0.00
	Slightly Effective	71	17.64	0	0.00
	Not Effective	239	59.82	3	0.82
Building materials (Retrofitting materials) is as a household adaptation strategy to floods	Very Effective	397	99.18	3	0.82
	Effective	99	24.82	3	0.82
	Moderately Effective	62	15.55	1	0.36
	Slightly Effective	124	30.91	0	0.00
	Not Effective	39	9.73	0	0.00
Building embankments using sandbags as a community adaptation strategy to floods	Very Effective	70	17.45	1	0.36
	Effective	394	98.45	6	1.55
	Moderately Effective	260	65.09	12	3.00
	Slightly Effective	107	26.82	8	1.91
	Not Effective	9	2.18	0	0.00
Clearing and construction of drainages is as a community adaptation strategy to floods	Very Effective	380	95.09	20	4.91
	Effective	299	74.82	8	2.09
	Moderately Effective	79	19.82	5	1.36
	Slightly Effective	6	1.55	0	0.00
	Not Effective	1	0.36	0	0.00
Cleaning of typer grasses as a government and agencies adaptation strategy to floods	Very Effective	0	0.00	0	0.00
	Effective	386	96.55	14	3.45
	Moderately Effective	320	80.00	9	2.27
	Slightly Effective	59	14.73	4	0.91
	Not Effective	8	2.09	0	0.00
Educating communities about flood risks, evacuation procedures, and the importance of preparedness is in enhancing resilience	Very Effective	0	0.00	0	0.00
	Effective	387	96.82	13	3.18
	Moderately Effective	314	78.55	8	2.09
	Slightly Effective	55	13.73	4	1.09
	Not Effective	17	4.18	0	0.00
Early maturing variety seeds as an adaptation strategy to floods	Very Crucial	1	0.36	0	0.00
	Crucial	0	0.00	0	0.00
	Moderately Crucial	387	96.82	13	3.18
	Slightly Crucial	313	78.27	9	2.27
	Not Crucial	65	16.18	4	0.91
	Very Crucial	8	1.91	0	0.00
	Crucial	2	0.45	0	0.00
	Moderately Crucial	0	0.00	0	0.00
	Slightly Crucial	0	0.00	0	0.00
	Not Crucial	0	0.00	0	0.00

Adaptation Strategies	Variables	Frequency of Victim	Percentage of Victim	Frequency of non-victim	Percentage of non-victim
Construction of bigger basins within farmlands as a household adaptation strategy to floods	Very Crucial	387	96.82	13	3.18
	Crucial	294	73.45	9	2.27
	Moderately Crucial	58	14.55	4	0.91
	Slightly Crucial	35	8.82	0	0.00
	Not Crucial	0	0.00	0	0.00
		387	96.82	13	3.18

The data from Table 10 provides a detailed analysis of flood adaptation strategies in the Hadejia River Basin, reflecting a range of community perceptions among flood victims. The high support for constructing buildings on raised platforms (65%-90%) across different LGAs indicates a strong consensus on its effectiveness in keeping structures above floodwaters. This aligns with previous studies in the Hadejia River Basin, which emphasize the importance of elevating structures to mitigate flood damage (Olusegun, 2023). The limited engagement from non-victims underscores the direct impact of flooding on those affected, reinforcing the need for prioritized risk management measures. Managing and modifying river channels also garners substantial support, with 60%-80% of flood victims viewing it as a viable flood control strategy. This reflects a recognition of the importance of river channel management in reducing flood risk, corroborating findings from earlier research that highlights river management as a critical component of flood risk mitigation in the region (Ibrahim et al., 2019). The lower engagement from non-victims suggests that those directly impacted by floods are more likely to advocate for such measures.

Early warning systems receive strong endorsement from flood victims, with 60%-93% agreeing on their effectiveness for timely evacuation and preparation. This broad consensus underscores the critical role of early warning systems in improving flood preparedness, which is consistent with previous studies that highlight their effectiveness in enhancing community resilience (Kamal et al., 2024). Emergency response plans also enjoy high support, with 65%-90% of victims recognizing their importance, reflecting a high level of trust and reliance on structured response frameworks. Raising flood-resistant livestock and implementing management practices are widely supported by 60%-93% of flood victims, illustrating a clear need for protecting animals during floods. This support is in line with studies that emphasize the role of resilient livestock practices in enhancing overall agricultural and community resilience (McShane and Yusuf, 2019). Preservation of natural vegetation and creating alternative channels show varied support (45%-93%), indicating a general belief in their benefits but with some inconsistency across LGAs.

However, clearing dams from siltation, using sandbag embankments, and constructing reservoirs and dams are all supported by significant portions of flood victims, with agreement levels ranging from 56% to 93%. This widespread endorsement highlights the perceived importance of these structural measures in flood management, aligning with earlier research that identifies similar strategies as effective in reducing flood impacts (Nabara et al., 2021). Overall, the data underscores the need for tailored adaptation strategies that reflect local conditions and community preferences to enhance resilience against flooding in the Hadejia River Basin. This study offers a comprehensive analysis of the response capabilities and adaptation strategies employed to manage flooding in the Hadejia River Basin. It emphasizes

the significance of adaptive capacity in fostering resilience among rural communities, particularly by identifying disparities in preparedness levels and perceptions of flood risk management between flood victims and non-victims. Through a comparison with recent literature, the findings provide actionable insights into enhancing disaster resilience in the region.

The data indicates that flood victims demonstrate significantly higher levels of preparedness and engagement in flood risk management practices compared to non-victims. This aligns with the "disaster experience hypothesis," which asserts that individuals or communities affected by prior disasters are more likely to adopt proactive measures to mitigate future risks (Salihu et al., 2022). For instance, in Auyo Local Government Area (LGA), 65% of flood victims reported taking preparatory actions against floods, compared to only 5% of non-victims. Similar trends were documented by Salihu et al., (2022) in the Niger Delta, where prior disaster exposure fostered greater preparedness. These findings suggest that disaster risk reduction (DRR) strategies should leverage the experiences of flood victims to drive broader community engagement in flood preparedness. Initiatives such as targeted education campaigns and participatory programs could bridge the preparedness gap between victims and non-victims. Recent studies reinforce the importance of incorporating local experiences into proactive disaster management to build community-wide resilience.

The role of community leadership in emergency preparedness reveals contrasting perceptions between flood victims and non-victims. Flood victims often regard local leaders as effective in understanding and addressing preparedness needs, reflecting the trust and confidence placed in leadership during crises. This finding aligns with Ibrahim et al. (2019), who highlighted the crucial role of trusted leaders in fostering community resilience to flooding. Conversely, non-victims expressed skepticism about their leaders' preparedness efforts, pointing to a potential engagement gap. Bridging this gap requires improved communication and collaboration between leaders and non-victimized groups, enabling more inclusive and cohesive preparedness strategies. Integrating local knowledge and community-driven approaches could strengthen adaptive capacities (Ibrahim et al., 2019). Resource availability and access to emergency services also emerged as key factors in shaping community resilience. Flood victims generally rated resource availability and emergency services more positively than non-victims. For example, in Auyo LGA, 70% of flood victims rated resource availability as excellent, compared to just 2% of non-victims. This aligns with Umar et al. (2019), who found that resource accessibility is critical to enhancing community resilience. However, the disparity underscores the need for improved infrastructure and equitable access to resources, particularly for non-victimized communities. Ensuring the availability of shelters, relief materials, and medical supplies, especially in remote areas, is essential for bolstering community preparedness (Umar et al., 2019).

A notable finding of the study is the skepticism among flood victims regarding the effectiveness of social media for disaster communication. While urban studies have demonstrated the potential of social media in real-time disaster management (Ibrahim et al., 2020), rural communities in the Hadejia River Basin perceive these tools as less effective. This disparity suggests that rural populations may require targeted education on leveraging digital tools during emergencies. Additionally, while some flood victims recognized the role of social networks in disaster management, others were less convinced of their utility. This highlights the need to formalize social networks as part of disaster risk management frameworks, as they could significantly enhance community engagement in preparedness and response efforts (Ibrahim et al., 2020). Support for flood adaptation strategies among victims was overwhelmingly high, with 60% to 93% endorsing measures such as building elevated structures, modifying river channels, and establishing early warning systems. These preferences align with findings by Ibrahim et al. (2019), who identified these interventions as critical for reducing flood risks. In particular, the strong advocacy for raised platforms reflects the practicality and effectiveness of this measure in mitigating flood impacts. Tailoring adaptation interventions to align with community preferences and perceived needs, such as prioritizing elevated structures and early warning systems, is essential for enhancing resilience. Despite this support, flood victims face significant challenges in implementing response strategies, including low awareness, geographical remoteness, and inadequate logistical support. Addressing these barriers requires a multifaceted approach that includes improving infrastructure, raising community awareness, and ensuring equitable access to resources. As Nwilo et al. (2012) emphasized, robust and coordinated response systems are crucial for delivering timely assistance, particularly in remote areas.

The study's findings echo patterns observed in other flood-prone regions. Research in the Niger Delta by Salihu et al., (2022) similarly revealed higher preparedness levels among flood victims compared to non-victims, underscoring the role of disaster experience in driving adaptive behaviors. Moreover, the strong support for elevated structures and river channel modifications aligns with the recommendations of Ibrahim et al. (2019). However, the skepticism surrounding social media's utility for disaster communication in the Hadejia River Basin contrasts with studies that have highlighted the potential of digital tools for disaster management, particularly in urban contexts (Ibrahim et al., 2020). This difference underscores the need for targeted efforts to educate rural communities and invest in digital infrastructure to integrate these tools effectively. This study sheds light on the adaptive capacities of rural communities in the Hadejia River Basin, highlighting the higher preparedness levels and stronger support for adaptation measures among flood victims compared to non-victims. However, the disparities in resource accessibility and engagement call for targeted interventions to address the specific needs of both groups. By integrating local knowledge, fostering effective leadership, and improving resource availability, the region can enhance its resilience to future floods. Tailored strategies, coupled with educational initiatives, are vital for building comprehensive and sustainable disaster resilience across the basin.

CONCLUSION

This study offers a comprehensive analysis of flood risk management in the Hadejia River Basin, focusing on flood

vulnerability mapping and adapting adaptation strategies. The key findings reveal that land use and land cover changes have significantly impacted flood occurrences. The emergence of Typha grass in areas such as Kaugama, Taura, Hadejia, and Miga, combined with the conversion of wetlands and forests into agricultural lands, has diminished the basin's natural flood mitigation capacity, leading to more frequent and intense floods. This assessment has influenced land management policies, particularly in the development of land use plans by environmental agencies, and has been incorporated into regional documents to guide sustainable development. The study highlights the effectiveness of Multicriteria Decision Analysis (MCDA) for predicting and mapping flood risk scenarios. It also reveals that, flood victims face significant challenges in implementing response strategies, including low awareness, geographical remoteness, and inadequate logistical support.

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