FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 11, November, 2025, pp 129 – 141
DOI: https://doi.org/10.33003/fjs-2025-0911-4036

ASSESSING FLOOD RISK AND COMMUNITY VULNERABILITY TO A HYPOTHETICAL TIGA DAM FAILURE ON THE KANO RIVER, NIGERIA

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ABSTRACT
Flooding remains one of the most destructive natural disasters, particularly for communities located downstream of large dams. A dam failure can lead to severe socio-economic and environmental impacts, especially in regions with weak flood preparedness. This study evaluates the flood risk and vulnerability of downstream communities along the Kano River under a hypothetical failure of the Tiga Dam, using hydrological modeling, geospatial analysis, and socio-economic assessments. The Hydrologic Engineering Center's River Analysis System (HEC-RAS) was applied to simulate flood extent, depth, and velocity, while Geographic Information Systems (GIS) combined with Multi-Criteria Decision Analysis (MCDA) integrated topographic, land use, and socio-economic factors to assess vulnerability. Simulation results show that floodwaters could reach depths of up to 21.89 meters, posing catastrophic risks to low-lying, densely populated areas. Vulnerability analysis reveals that poverty, inadequate infrastructure, and environmental degradation significantly increase flood susceptibility. The study emphasizes the urgent need for enhanced flood management policies, strategic land-use planning, afforestation of floodplains, and the development of effective early warning systems. Additionally, strengthening community-based disaster preparedness and reinforcing critical infrastructure are essential to mitigating the potential impacts of dam failure. These findings provide actionable insights for policymakers, engineers, and disaster risk managers in designing proactive flood risk reduction strategies for the region.

Keywords: Flood risk, Vulnerability assessment, Tiga Dam, Hydrological modeling, GIS

INTRODUCTION
Flooding is one of the most common and destructive natural disasters worldwide, with devastating consequences for human lives, infrastructure, and economic activities. It occurs when water overflows onto land that is usually dry due to excessive rainfall, dam failures, storm surges, or other hydrological phenomena. Floods can be categorized into various types, including riverine floods, flash floods, and dam break floods, each with unique causes and impacts (Food and Agriculture Organization of the United Nations, 2020). While floods are often triggered by natural climatic events such as extreme precipitation, poor drainage, or melting snow, human activities such as deforestation, unregulated urban expansion, and improper dam management have significantly increased flood risks in many regions (Umar & Gray, 2023). These factors highlight the urgent need for comprehensive flood management strategies to protect vulnerable communities.

In recent decades, climate change has contributed to the increasing frequency and intensity of floods. Rising global temperatures have led to more intense rainfall, higher sea levels, and unpredictable weather patterns, further amplifying flood risks (Kundzewicz et al., 2013). Additionally, rapid urbanization and poor land-use planning have increased impervious surfaces, reduced natural drainage and increased flood susceptibility (Wilk, 2018; Panahi et al., 2021). The interplay between hydrological, climatic, and socio-economic factors has made flood risk management a complex challenge requiring multidisciplinary approaches. Understanding the relationship between flood hazards, exposure, and vulnerability is essential in identifying at-risk communities and designing targeted mitigation strategies to minimize flood damage and loss (Birkmann, 2023).

Economic losses from flooding are particularly severe in agriculture-dependent regions. Flooding can destroy farmlands, wash away topsoil, contaminate water sources, and disrupt food supply chains, leading to food shortages and increased prices. The Nigerian agricultural sector, which employs a significant portion of the population, is highly vulnerable to flooding, with repeated disasters threatening food security and rural livelihoods (Agada & Nirupama, 2015). The destruction of transportation networks and power infrastructure further compounds the economic burden, making it difficult for businesses and industries to recover after major flood events.

Beyond economic impacts, floods pose severe public health risks. Stagnant floodwaters create breeding grounds for mosquito-borne diseases such as malaria and dengue fever, while contaminated water sources increase the spread of cholera, typhoid, and dysentery (Few et al., 2004). Additionally, the destruction of healthcare facilities during floods limits access to medical treatment, exacerbating health crises in affected communities. The psychological trauma of losing homes, loved ones, and livelihoods can have long-lasting mental health consequences, making post-flood recovery a complex and multifaceted challenge.

Dams are essential for water storage, irrigation, hydroelectric power generation, and flood regulation. By controlling water flow, dams reduce the risk of seasonal flooding and provide a reliable water supply for agricultural and domestic use. However, despite their benefits, dams pose significant hazards to downstream communities, particularly in cases of structural failure. A dam break can result in the sudden, uncontrolled release of water, causing massive flooding, extensive damage, and loss of life (Wang et al., 2021).

The Tiga Dam, located in Kano State, Nigeria, is one of the country's most critical water management infrastructures, supporting agriculture, water supply, and flood control in the Kano River Basin. However, if the dam were to fail, it could lead to catastrophic flooding in the densely populated downstream areas. A dam break simulation is essential to understanding the potential flood extent, depth, and velocity, enabling policymakers and disaster management agencies to implement mitigation strategies.

MATERIALS AND METHODS

Study Area

The study area is situated between Latitude: 11°20′N to 12°00′N; Longitude: 8°10′E to 8°58′E encompassing a segment of the Kano River Basin downstream of the Tiga Dam. The entire basin comprises twenty-four (24) delineated sub-basins, out of which five (5) were selected for detailed analysis due to their proximity to potential flood pathways from the dam. These sub-basins 18 (Bebeji), 10 (Madobi), 9 (Dawakin Kudu), 8 (Warawa), and 7 (Wudil) represent the critical downstream locations most vulnerable to inundation in the event of dam failure or extreme discharge events (Ibrahim et al., 2022; Umar et al., 2023).

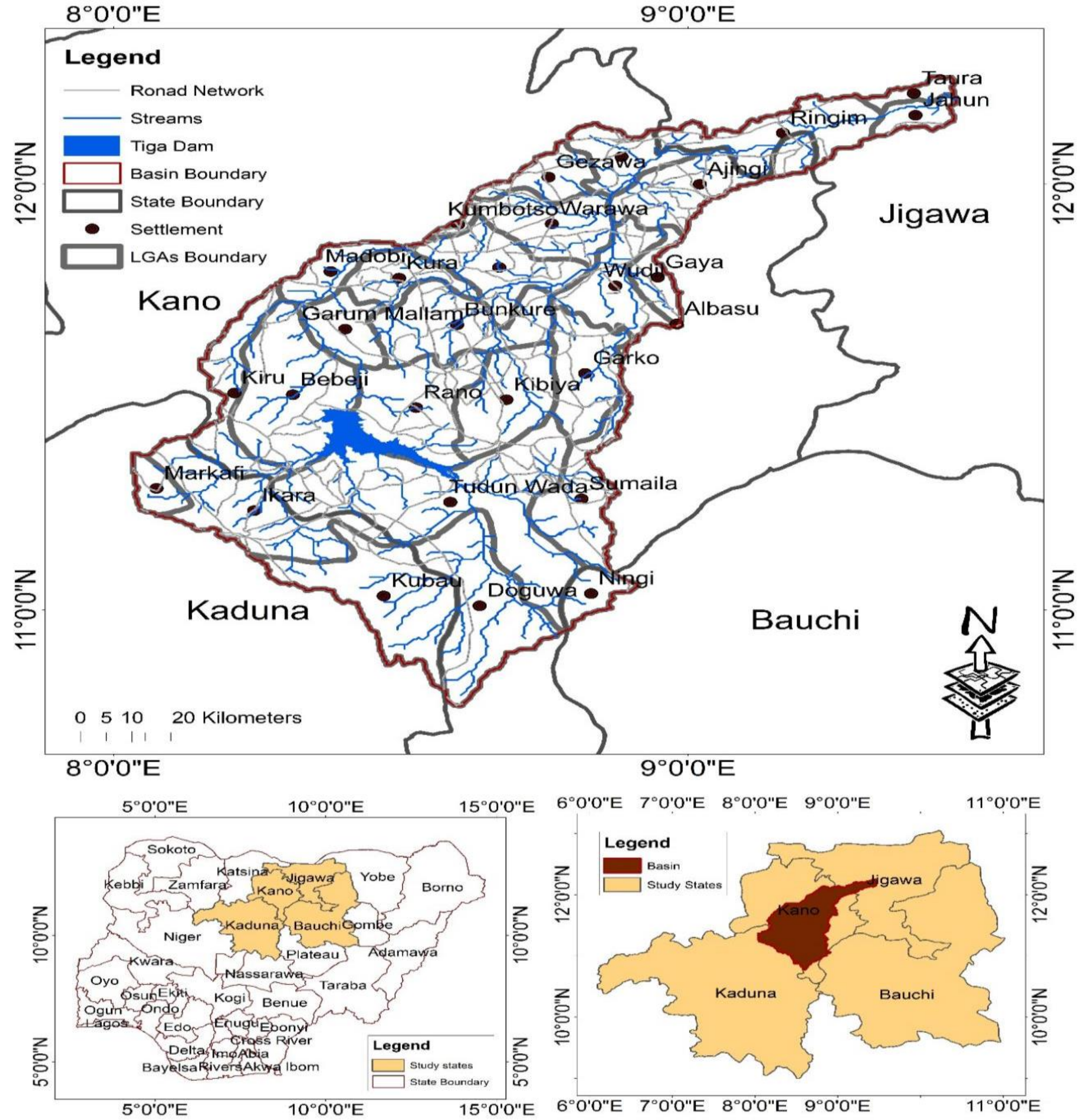


Figure 1: Map of the Study Area
Source: Adapted and Modified from the Administrative and Base Maps of Nigeria

Weather and Climate

The Kano Region falls under the tropical wet and dry climate (Aw) classification according to Köppen, with distinct seasonal variations in temperature, precipitation, and wind patterns. Mean monthly temperatures range from 21°C in the cooler months of December and January to peaks above 40°C in March and April (Bello & Ahmed, 2023). These thermal variations are closely associated with the latitudinal oscillation of the Intertropical Discontinuity (ITD), a major climatic boundary influencing moisture availability and rainfall intensity across the region (Yusuf et al., 2021).

Rainfall is highly seasonal, with over 90% of the annual precipitation occurring between June and September, especially in July and August when the ITD reaches its northernmost extent (Rahman et al., 2023). During these months, rainfall intensities frequently surpass 50 mm/day, with isolated events exceeding 90 mm in a single day, contributing to flash flooding and rapid surface runoff (Chukwuma & Nwankwo, 2022). Regional rainfall distribution varies: northern areas receive 110–130 rainy days annually, the central region 120–130 days, and the south up to 150 days (Aliyu et al., 2021).

These rainfall characteristics influence flood frequency and severity in the study area. Intense rainstorms during short durations overwhelm drainage systems, particularly in the hot and wet season (June–September), when runoff and stream discharge are highest (Umar et al., 2024). During the hot and dry season (March–May), high evaporation rates and false rainfall starts challenge agricultural activities. Conversely, the Harmattan-dominated cool and dry season (December–February) reduces moisture availability, affecting soil-water balance and surface hydrology.

Drainage Basin

The Kano River is a critical tributary of the Hadejia River and plays a central role in floodplain hydrology within northern Nigeria. Draining a semi-arid catchment, it supports irrigation, domestic water use, and ecosystem services, while posing flood hazards—especially during the rainy season when inflows into the Tiga Dam surge (Okonkwo et al., 2020). The operation of the Tiga Dam regulates water flow but also introduces risks: dam overtopping, structural breaches, or emergency releases can lead to abrupt flooding downstream (Umar et al., 2024).

Vulnerability in the basin is elevated by anthropogenic and climatic factors. Many communities downstream of the Tiga Dam lack effective flood defenses, with poor drainage infrastructure and limited emergency preparedness (Bello & Ahmed, 2023). Moreover, unsustainable land use in flood-prone areas exacerbates the impacts of river overflows. To support proactive risk management, technologies like GIS and remote sensing are increasingly being used for mapping flood risk zones and modeling dam breach impacts (Aliyu et al., 2021; Rahman et al., 2023).

Flood mitigation in this context must integrate structural and non-structural strategies. Predictive modeling, early warning systems, infrastructure upgrades, and stakeholder engagement are essential components for building flood resilience. Cross-sectoral collaboration, especially between environmental agencies and community groups, is vital for implementing sustainable mitigation frameworks (Ibrahim et al., 2022; Yusuf et al., 2021).

Geology, Soils and Vegetation

The geology of Kano State is primarily composed of Basement Complex rocks quartzites, meta-sediments, and granites formed during the Precambrian and Cambrian eras. These rock types are deeply weathered and lateritized, forming regolith and lateritic crusts that influence surface runoff, erosion, and infiltration dynamics (Yusuf et al., 2021). Elevation ranges from approximately 100 meters in the plains to over 500 meters in upland regions, with landforms such as hills and alluvial plains affecting drainage and flood behavior (Chukwuma & Nwankwo, 2022).

Soil types in the area include ferruginous tropical soils, reddish-brown loamy sands, and hydromorphic clays. In the southern region, ferruginous soils are well-drained but often contribute to runoff during intense rains due to limited infiltration. The north has semi-arid latosols with low organic matter, enhancing flood susceptibility. Hydromorphic soils in the northeastern areas retain water poorly and are prone to prolonged flooding and waterlogging (Aliyu et al., 2021; Bello & Ahmed, 2023).

Vegetation is predominantly Sudan Savanna, featuring scattered trees and grasses. Drought-resistant species such as Parkia biglobosa, Vitex doniana, and Khaya senegalensis dominate. These plants help regulate local hydrology by reducing erosion and improving soil structure. However, deforestation, overgrazing, and land conversion for agriculture have diminished this natural cover, increased surface runoff and lowering the land's natural flood-buffering capacity (Ibrahim et al., 2022). These environmental changes heighten flood risks, especially downstream of major hydraulic structures like the Tiga Dam.

Data Collection

The study utilized hydrological data, including river discharge, rainfall patterns, and dam storage capacity; geospatial data, such as Digital Elevation Model (DEM), land use/land cover (LULC) maps, and flood-prone areas; and socio-economic data, comprising household surveys, focus group discussions, and census reports on population vulnerability.

Hydrological and GIS-Based Flood Modeling

To simulate the potential flood extent and depth, the study employs HEC-RAS for flood wave propagation and breach modeling, and ArcGIS for spatial vulnerability analysis using Multi-Criteria Decision Analysis (MCDA), which incorporates factors such as topography and elevation, land use changes, infrastructure quality, and socio-economic resilience.

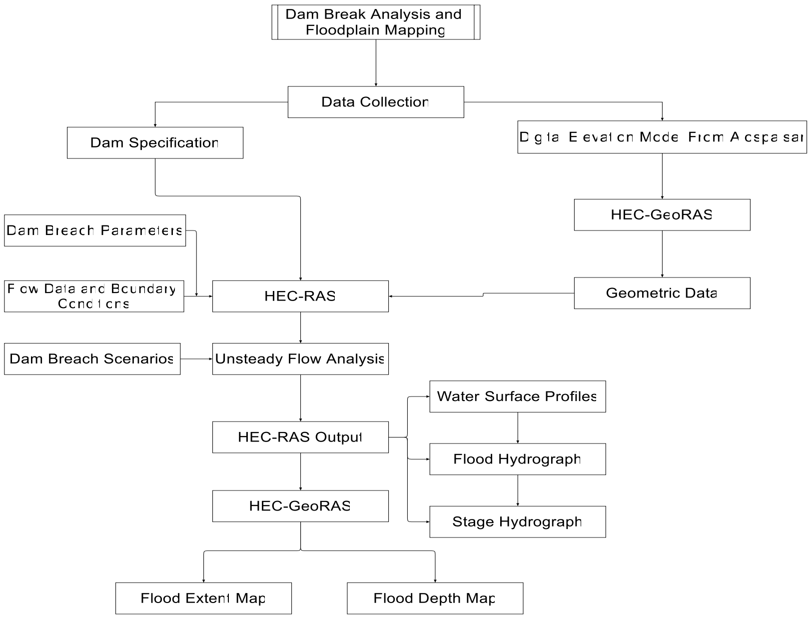


Figure 2: Methodological Framework

RESULTS AND DISCUSSION

Flood Extent and Inundation Depths

Modeling results reveal that flood depths could reach 21.89 meters in worst-case scenarios, with floodwaters spreading rapidly across settlements along the Kano River. Low-lying floodplain communities are at extreme risk, with potential inundation extending up to 40 kilometers downstream.

The analysis of flood risk and vulnerability associated with a hypothetical breach of the Tiga Dam provides valuable insights into the extent of flood inundation and its effects on various land use and land cover (LULC) categories. The findings presented in Tables 1 and 2 highlight key patterns in flood severity, spatial distribution, and their implications across different sectors.

Table 1 displays the results of modeled water levels for flood events with return periods of 5, 10, 20, 50, and 100 years at Tiga Dam. The water levels are measured at different elevations above sea level. As shown in Table 3.1, the extent of flood inundation progressively increases with the return period. A 5-year flood event results in an inundation of 689.82 km², while a 100-year flood event covers 690.92 km². It is noteworthy that beyond the 20-year return period, the increase in the inundated area becomes marginal, suggesting that floodwaters saturate the floodplain at a certain threshold, leading to increased flood depths rather than further lateral expansion. This observation has significant implications for flood risk mitigation strategies, as structural defenses may need to focus more on managing depth-related hazards rather than solely addressing surface area expansion.

Table 1: Return Periods (m) of Different Flood Stages

Return Period	Stage Level (m)	Area (m)
5 Years	368.5	689.82
10 Years	390.2	690.20
20 Years	425.8	690.57
50 Years	450.5	690.88
100 Years	495.7	690.92

Source: Authors Analysis, 2024

Flood frequency, as analyzed in this context, is multidimensional and crucial for assessing water resource potential, as well as the integration of both hydrologic and hydraulic measures in the engineering of structures designed to manage water bodies.

Table 2 reveals that shrubland consistently experiences the highest flood inundation, reaching a peak of 302.32 km² during the 10-year return period before slightly decreasing in higher return periods. This indicates that shrubland is the dominant land cover type on the floodplain, making it particularly susceptible to flooding. The reduction in inundation during later flood events could be attributed to increased water depth and channelization, which redirect excess floodwaters to other land use/land cover (LULC) categories, such as farmlands and built-up areas. This highlights the urgent need for ecological conservation measures to prevent the long-term degradation of natural flood buffers.

Table 2: Inundation Extent (km2) and Flood Frequency

Land Use Land Cover (LULC)	5 Years (km²)	10 Years (km²)	20 Years (km²)	50 Years (km²)	100 Years (km²)
Shrubland	290.6	302.32	228.9	232.59	224.37
Water Body	35.3	28.1	40.89	35.28	33.39
Dense Vegetation	70.5	56.3	56.29	74.33	86.28
Riparian Vegetation	40.2	35.8	70.37	77.65	72.65

Farmland	135.2	141.5	159.87	145.38	150.98
Built-Up Area	72.2	85.8	98.86	82.76	85.97
Bare Land	45.8	40.41	35.39	42.89	37.28
Total Area (km²)	**689.8**	**690.23**	**690.57**	**690.88**	**690.92**

Source: Authors Analysis, 2024

Agricultural land, on the other hand, experiences a gradual increase in inundation, from 135.2 km² in a 5-year flood event to 150.98 km² in a 100-year flood event. Peak inundation occurs during the 20-year return period (159.87 km²), indicating that medium-term flood events pose the greatest risk to agriculture. This increasing inundation is likely due to water accumulation and poor drainage in cultivated areas, which can have significant impacts on food security, economic stability, and soil degradation. Therefore, adopting climate-smart agricultural practices and resilient crop varieties is crucial to mitigating these risks.

In urban areas, flood exposure increases from 72.2 km² during a 5-year event to 85.97 km² during a 100-year event. The highest inundation occurs during the 10-year (85.8 km²) and 20-year (98.86 km²) return periods, underscoring the growing vulnerability of urban settlements due to expansion into flood-prone areas. This trend emphasizes the need for improved urban planning, resilient infrastructure, and enhanced flood risk management strategies to mitigate potential disaster impacts.

Riparian vegetation experiences a steady increase in inundation, from 40.2 km² during a 5-year flood to 72.65 km² during a 100-year flood. This progressive rise suggests that floodplains are expanding, threatening biodiversity and vital ecosystem services such as water filtration and erosion control. The impact on riparian zones highlights the importance of conservation efforts, including reforestation, buffer zones, and effective floodplain management to maintain ecological integrity.

Dense vegetation initially faces moderate inundation (70.5 km² during a 5-year flood), but exposure increases significantly during extreme events, reaching 86.28 km² during a 100-year flood. This suggests that natural vegetation buffers are being overwhelmed, resulting in habitat degradation, loss of soil stability, and reduced carbon sequestration capacity. Consequently, sustainable land management strategies are essential to mitigate the ecological impacts of prolonged and severe flooding.

Unlike other LULC categories, bare land shows a decreasing trend in flood exposure, from 45.8 km² in a 5-year flood to 37.28 km² in a 100-year flood. This pattern suggests that floodwaters are being redistributed to urban, agricultural, and riparian areas. Furthermore, sedimentation and erosion processes may be altering the floodplain, requiring targeted restoration efforts to control siltation and preserve hydrological stability.

Downstream communities face significant risks due to widespread inundation affecting key land use categories. The 50-year and 100-year floods highlight the potential for catastrophic impacts, particularly in urban and agricultural areas. This underscores the need for robust early warning systems, adaptive infrastructure, and community-based flood preparedness initiatives to reduce socio-economic losses.

Given the extensive farmland inundation, agricultural livelihoods are at considerable risk. Prolonged flooding can lead to soil nutrient depletion, increased salinity, and reduced productivity. As such, promoting flood-resistant crops, sustainable irrigation practices, and alternative livelihood options is crucial to enhancing resilience.

The increasing flood exposure of built-up areas indicates rapid urban expansion into vulnerable zones. Poor land-use planning and inadequate drainage infrastructure exacerbate flood risks. To reduce urban flood vulnerability, it is vital to implement stringent zoning regulations, invest in flood-adapted urban designs, and improve drainage networks.

Flooding of dense vegetation and riparian zones threatens biodiversity, habitat stability, and natural flood regulation mechanisms. Changes in shrubland and bare land coverage suggest shifts in sediment transport and erosion patterns. Therefore, sustainable land management practices, such as afforestation and sediment control measures, are crucial to mitigating long-term ecological degradation.

The analysis of flood stage levels and LULC-based inundation extents offers valuable insights into the spatial distribution of flood risks downstream of Tiga Dam. The findings indicate that shrub land, farmlands, and built-up areas are the most vulnerable, with flood exposure increasing as return periods lengthen. These results emphasize the urgent need for flood risk management strategies, climate adaptation measures, and sustainable land-use planning to protect downstream communities. This research supports the objective of determining flood inundation extents downstream of Tiga Dam and provides a foundation for future flood mitigation efforts and policy recommendations.

The findings of this study align with those of Isham (2014), who assessed the risk of urban flash floods using an inundation model in Indiana. The study found that the increase in developed areas led to a rise in flash flood risk. Similarly, Ademola (2023) examined flood vulnerability in communities downstream of Galma Dam in Zaria, revealing rising flood return periods and widespread inundation of settlements downstream. Likewise, Musa (2023) analyzed flood vulnerability in communities downstream of Kubanni Dam in Zaria, highlighting land uses prone to flooding that significantly affects downstream areas. Additionally, Minywach et al. (2024) conducted an inundation mapping and flood frequency analysis using the HEC-RAS hydraulic model and EasyFit software. Their study revealed flood inundation areas under different land use changes for 25-, 50-, and 100-year return periods as follows: 446.2 km² (annual crop cover), 404.4 km² (built area cover), 323.3 km² (flooded vegetation), and 93.58 km² (forest area). The study also reported varying inundation depths, ranging from 0–2.6 m upstream to 0–3.2 m downstream. These findings emphasize the need to reduce both temporal and permanent flood risks.

Community Vulnerability Analysis

The vulnerability assessment categorized communities into three groups: very high vulnerability, which includes poor communities with no flood defenses, high population density, and weak infrastructure; high vulnerability, comprising moderately developed areas with some resilience but still prone to significant damage; and moderate to low vulnerability, representing elevated zones with better flood resilience and preparedness measures.

Key Socio-Economic Findings

Poverty increases vulnerability, with 65% of the population in high-risk areas living below the poverty line; women, children, and elderly people are disproportionately affected; and the lack of early warning systems contributes to delayed evacuations and increased casualties.

Vulnerability assessment is essential for understanding how communities are affected by flood hazards. This section analyzes the social, economic, and infrastructural factors that contribute to the vulnerability of downstream communities. Using vulnerability indices and spatial analysis, the study identifies the most at-risk populations and areas, offering recommendations for targeted interventions to enhance community resilience.

Table 3: Level of Flood Vulnerability Statistics

Vulnerability Level	Area in SKM	Percentage (%)
Very Highly Vulnerable	1691.10	17.75
Highly Vulnerable	2116.22	22.21
Moderate Vulnerable	1575.47	16.54
Low Vulnerable	3214.54	33.74
Very Low Vulnerable	928.78	9.75
Total	**9526.11**	**100.00**

Source: Authors Analysis, 2024

Table 3.3, the total study area spans 9526.11 km², which is categorized into different levels of flood vulnerability. The Very Highly Vulnerable areas account for 17.75% (1691.10 km²), Highly Vulnerable areas make up 22.21% (2116.22 km²), and Moderate Vulnerable areas represent 16.54% (1575.47 km²). The Low Vulnerable areas cover 33.74% (3214.54 km²), while the Very Low Vulnerable areas, at 9.75% (928.78 km²), and are the least at risk of flooding.

The Highly Vulnerable zone, which encompasses 22.21% of the area, is expected to face severe flooding with substantial impacts on essential infrastructure, agricultural land, and human settlements. The Very Highly Vulnerable areas, comprising 17.75% of the total area, are the most at risk, with communities likely to experience extreme flood depths and prolonged durations. These high-risk areas are prone to significant disruptions and damages, requiring urgent flood risk management interventions. Key measures, such as reinforcing flood defenses, developing effective evacuation plans, and implementing early warning systems, are essential to mitigate the potential impacts in these areas.

The Moderate Vulnerable areas, which represent 16.54% of the area, will likely experience moderate flooding. Although the impacts in these regions will not be as catastrophic as those in the high-risk zones, they are still vulnerable to disruptions, including crop loss, temporary displacement, and infrastructure damage. These areas will require targeted preparedness strategies, such as enhancing flood resilience in infrastructure, fostering community-based adaptation plans, and launching public awareness campaigns to minimize flood risk exposure.

Conversely, the Low Vulnerable areas, accounting for the largest portion at 33.74%, are less prone to flooding due to favorable conditions, such as higher elevations and better drainage systems. While localized flooding may still occur, ongoing flood risk management efforts must ensure that these areas remain resilient. Ensuring the maintenance of existing flood mitigation infrastructure, improving drainage systems, and strengthening early warning systems are vital for managing flood risks in these regions. Although these areas are at lower risk, proactive flood management strategies should still be employed, particularly during extreme rainfall events.

Finally, the Very Low Vulnerable areas, which cover 9.75% of the total area, are the least likely to experience significant flooding due to favorable topographic features and natural flood management mechanisms, such as wetlands and dense vegetation. While these areas will require minimal intervention for flood management, they should still be included in the broader flood risk planning framework. The results highlight the importance of tailoring flood risk management strategies to the specific vulnerabilities of each region. A comprehensive approach, considering both physical and socio-economic factors, is critical to ensuring that all communities are adequately prepared for flood events.

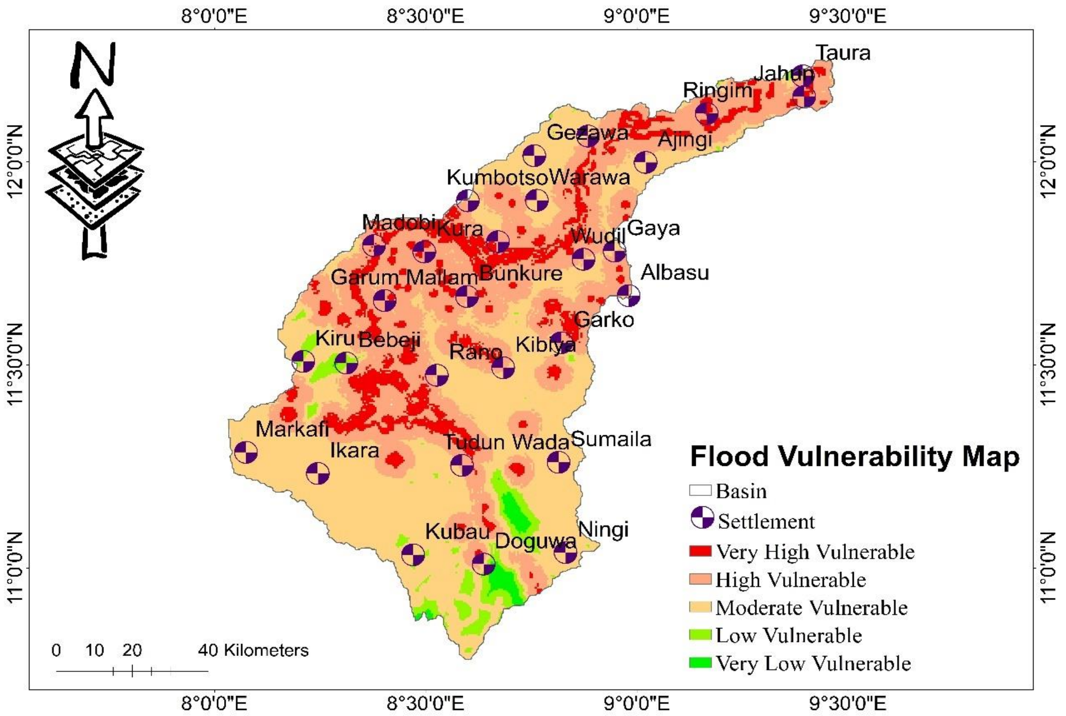


Figure 3: Flood Vulnerability Map
Source: Authors Analysis, 2024

This study reveals that areas with higher population densities, particularly those with vulnerable groups, coupled with proximity to rivers and insufficient infrastructure, are more prone to severe flood impacts. These findings not only identify the most at-risk areas but also provide a foundation for targeted flood risk management and mitigation strategies.

The findings highlight the significant role of population density and urban growth in increasing vulnerability to floods, particularly in areas downstream of the Tiga Dam. As illustrated in Figure 3, locations such as Wudil, Kura, and Warawa fall into the very high vulnerability category due to multiple contributing factors. These include high population density, especially among vulnerable groups like children and women, as well as significant socioeconomic challenges such as poverty, low literacy rates, and limited access to essential infrastructure. Additionally, the proximity of these areas to the Kano River exacerbates flood risk, making them highly susceptible to river overflow during extreme weather events, leading to severe damage and hampered recovery efforts.

In terms of vulnerability classification, the study identified five distinct vulnerability levels across the affected regions. Communities classified as having very high vulnerability, such as Wudil, Kura, and Warawa, exhibit densely packed populations with high concentrations of children and women, who are particularly at-risk during flood events due to their limited mobility and caregiving responsibilities. Poverty and low literacy rates compound the problem, as these communities lack resources for flood mitigation and preparedness, making them more susceptible to flood damage and slower recovery times (Figure 4).

Similarly, the communities of Ajingi and Kura fall into the high vulnerability category (Figure 3). These areas share characteristics with the very high vulnerability zones, including significant populations, proximity to water sources, poverty, and low literacy rates (Figure 4). While they are slightly less vulnerable than Wudil, Kura, and Warawa, they remain at considerable risk due to the same underlying factors, particularly the combination of high population density and geographic location near flood-prone areas.

Communities such as Garun Malam and Bunkura exhibit moderate vulnerability to flooding (Figure 3). These areas have moderate population densities, which, while still a risk factor, are less severe compared to the more densely populated regions. Their relative distance from key infrastructure like roads and healthcare facilities helps slightly reduce vulnerability, though they remain susceptible to flood hazards, especially during extreme weather events (Figure 4).

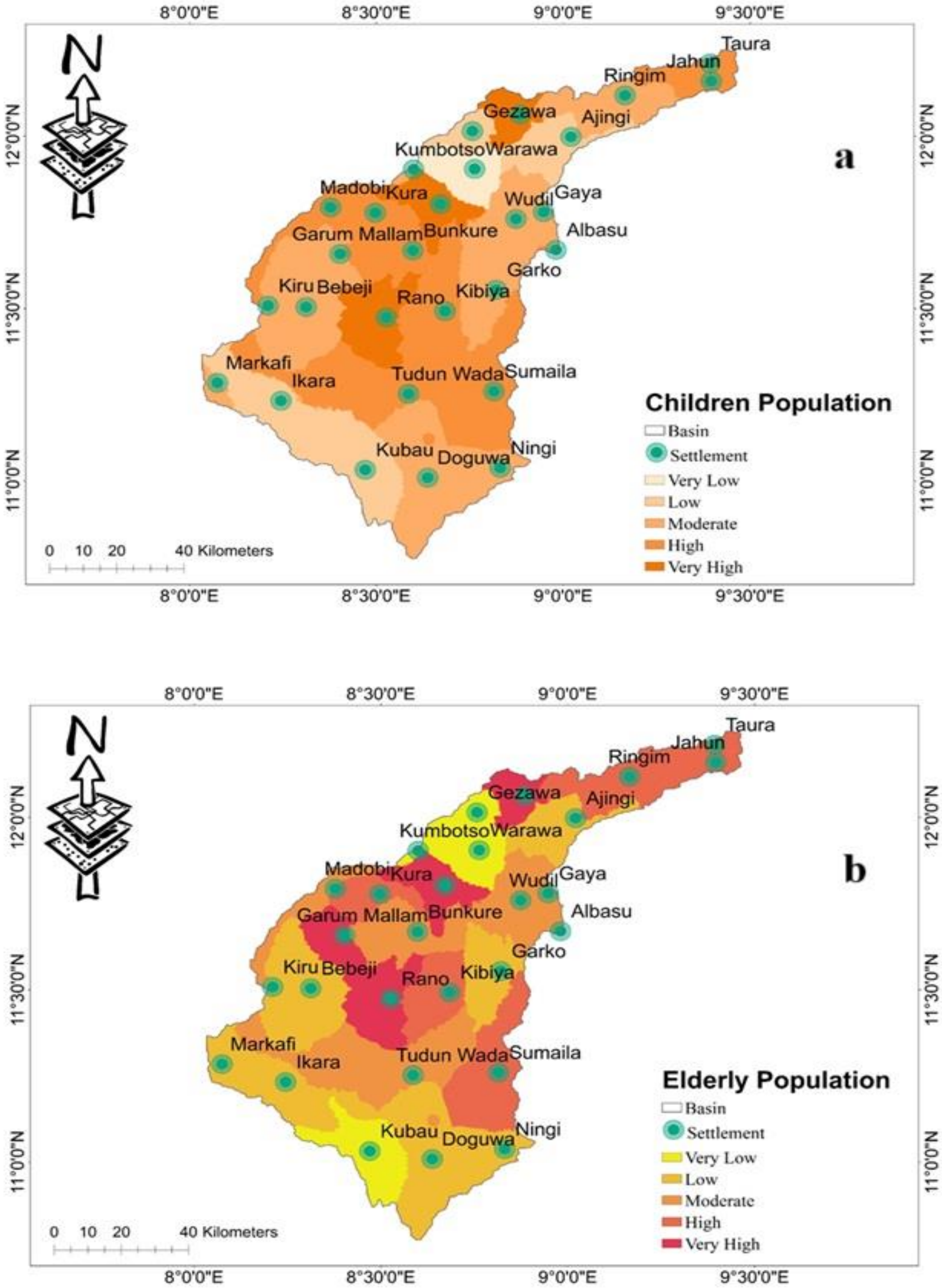


Figure 4: Flood Vulnerability Causative Factors: a) Children Population, b) Elderly Population

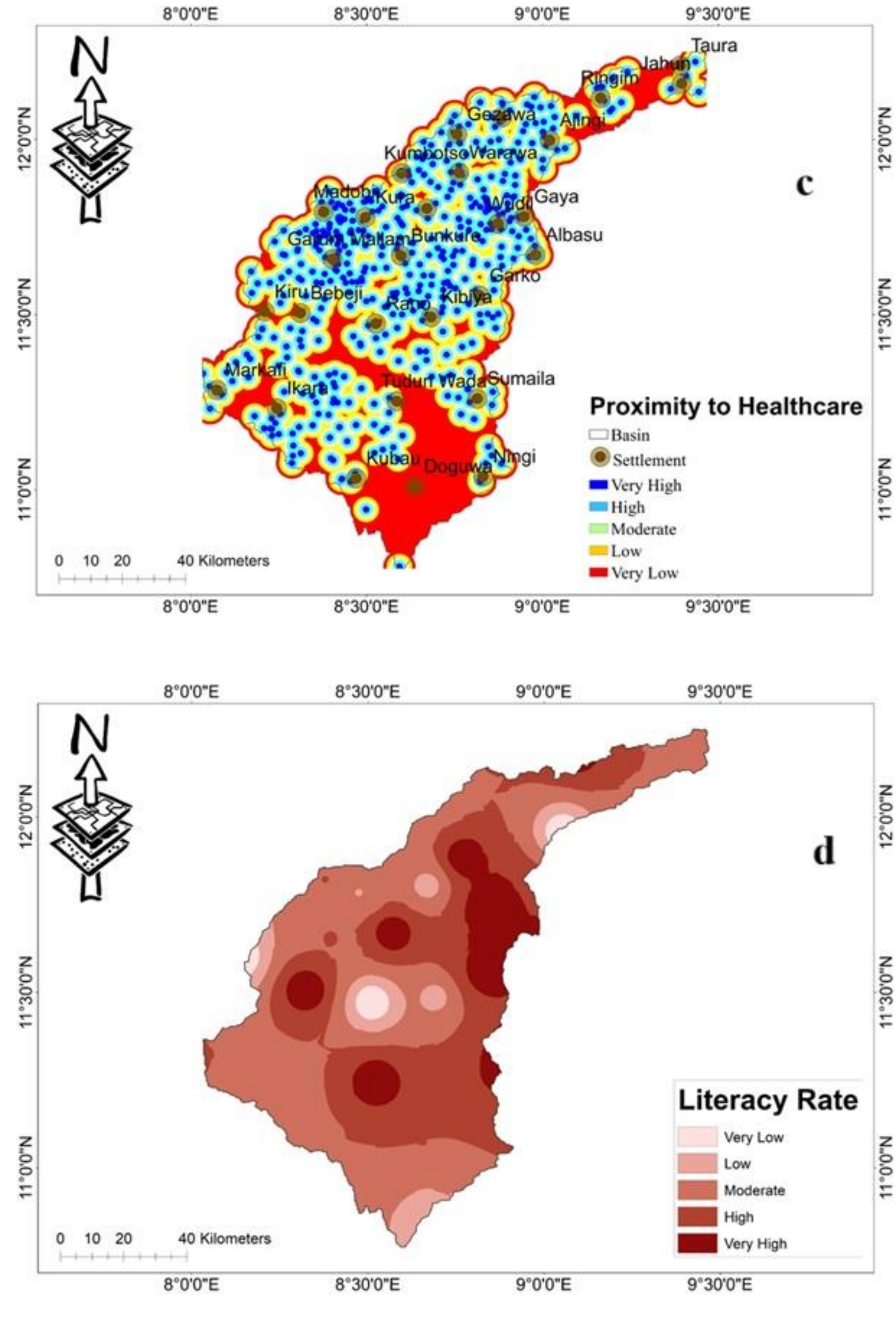
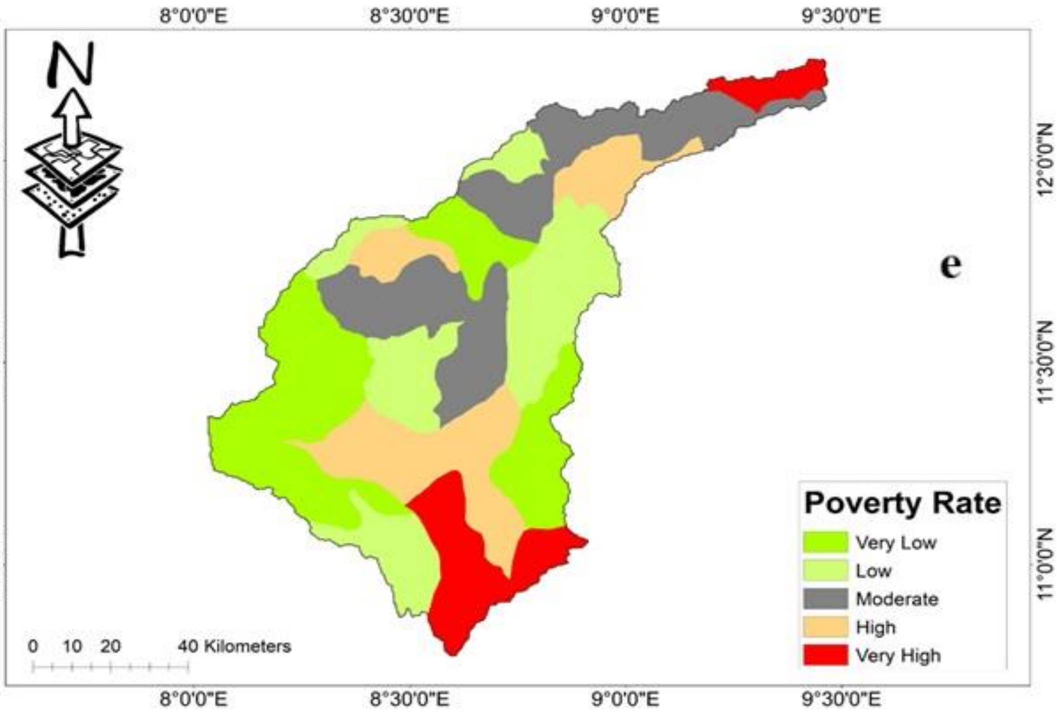


Figure 5: Continue: c) Proximity to Health Care, d) Literacy Rate



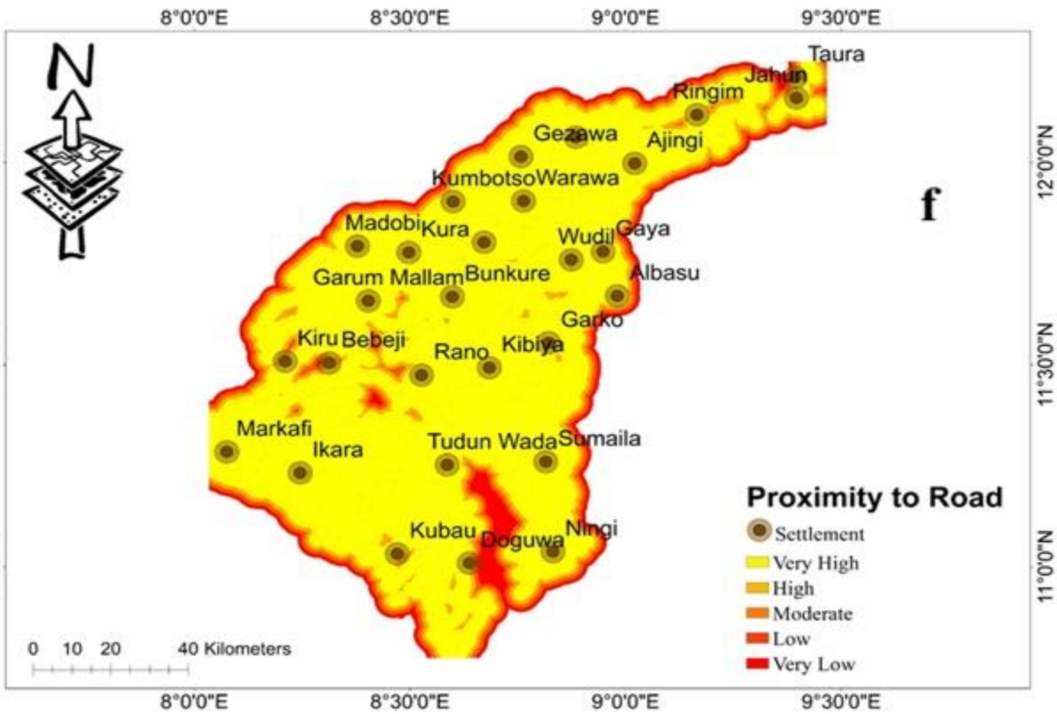


Figure 6: Continue: e) Poverty Rate, f) Road Proximity

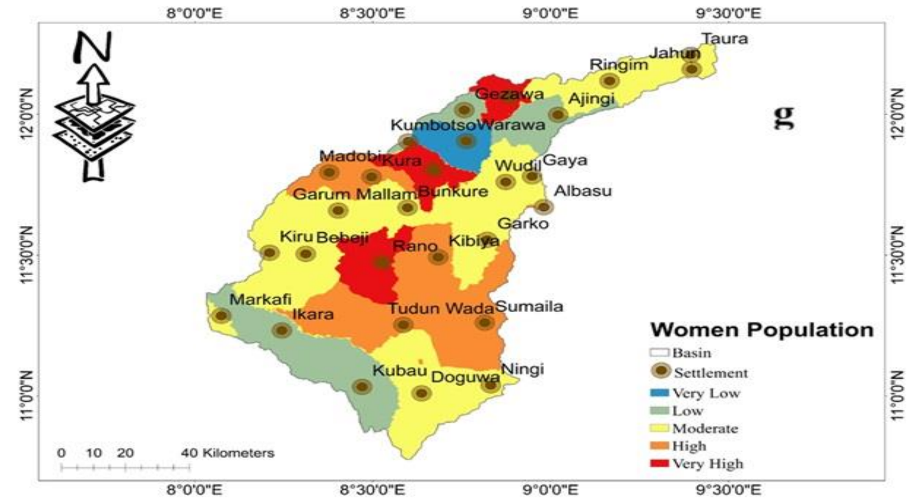


Figure 7: Continue: g) Women Population

On the other hand, communities like Sumaila and Ikara are classified as low vulnerability zones (Figure 3). These areas benefit from lower population densities, better access to infrastructure, and other mitigating factors that help reduce their exposure to flood hazards. Although they are still at risk, these communities are better equipped to handle flood events compared to their more vulnerable counterparts due to better preparedness and access to resources.

Kiru and Doguwa exhibit very low vulnerability to flooding (Figure 3). This lower vulnerability can be attributed to several factors, including higher elevation, lower population densities, and better access to critical resources such as roads and healthcare facilities. These geographic and socioeconomic advantages reduce both the likelihood and severity of flood impacts, allowing these communities to recover more quickly from potential flood events.

The study further identifies key factors influencing flood vulnerability levels across different communities. These include population density (especially among children, the elderly, and women), poverty and literacy rates, proximity to rivers and roads, and urbanization. Areas with high concentrations of vulnerable groups are particularly at risk due to their limited mobility and caregiving responsibilities. Additionally, communities with high poverty rates and low literacy levels, such as Dabi, Bunkure, and Kura, are more vulnerable to flood impacts as they lack the resources and knowledge to effectively mitigate flood risks (Figure 4). Furthermore, proximity to rivers and roads plays a crucial role; areas near water sources are more likely to be directly affected by flooding, while those farther from roads and healthcare facilities face additional challenges in responding to and recovering from flood events.

Urban areas generally exhibit lower vulnerability due to better infrastructure, higher literacy levels, and greater accessibility to healthcare and emergency services. For example, communities like Kubau and Doguwa, which have higher literacy rates and better access to flood protection infrastructure, show very low vulnerability to floods. In contrast, rural areas, particularly those with higher poverty rates and limited access to essential services, require more targeted interventions to improve their resilience to flood hazards.

The implications for flood risk management are clear. High vulnerability areas, such as Wudil, Kura, and Warawa, require targeted flood management interventions, including the construction of flood defenses such as embankments, the establishment of early warning systems, and comprehensive evacuation planning. Additionally, improving access to infrastructure such as roads, healthcare facilities, and drainage systems will significantly reduce flood vulnerability, particularly in moderate and low vulnerability zones like Madobi, Kiru, and Gezawa. Raising awareness about flood risks and improving literacy, especially in high-vulnerability areas, will help empower communities to take proactive measures to reduce their exposure to flood hazards.

To address the specific needs of flood-prone communities, flood planning efforts must focus on land-use planning and proximity to water bodies. Communities located near rivers, such as Dabi, Bunkure, and Kura, should implement stricter land-use regulations to limit development in flood-prone areas. Additionally, poverty alleviation and literacy programs should be prioritized to enhance the capacity of vulnerable populations to prepare for and recover from flood events. Government policies, non-governmental organizations (NGOs), and local communities should work together to provide socioeconomic support and educational initiatives to reduce vulnerability and enhance resilience.

Discussion of Findings

The hydrodynamic modeling results from this study provide critical insights into the spatial and temporal dimensions of flood risk downstream of the Tiga Dam. The simulations revealed maximum flood depths of up to 21.89 m, with inundation extending across nearly 690 km² in extreme scenarios. These results are consistent with previous dam break and flood hazard studies in Sub-Saharan Africa that highlight the catastrophic nature of extreme flood events on densely populated floodplains (Aliyu et al., 2021; Yusuf et al., 2021). The near-saturation of the floodplain after the 20-year return period indicates a threshold effect, where additional flood volume translates more into depth than lateral spread. This has serious implications for infrastructure planning, as depth-related hazards such as building collapse and drowning risks become more pronounced (Rahman et al., 2023).

The LULC-based analysis demonstrated that shrubland is the most inundated land cover, peaking at over 302 km² during moderate floods. This dominance reflects the floodplain's natural vegetation cover, which acts as the first receptor of floodwaters. However, the decline in shrubland inundation during higher return periods suggests displacement of floodwaters toward agricultural and built-up areas. Similar findings have been reported in the Hadejia River Basin, where land-use change redirected floodwaters, amplifying impacts on farmlands and urban settlements (Bello & Ahmed, 2023). This highlights the ecological trade-offs of vegetation loss and emphasizes the importance of conserving natural flood buffers (Ndubuisi et al., 2022).

Agricultural lands also showed significant flood exposure, increasing from 135.2 km² at a 5-year event to nearly 160 km² at a 20-year event. This is particularly alarming given the centrality of agriculture to livelihoods in the Kano River Basin. Flood-induced crop loss, soil degradation, and erosion threaten food security and economic stability (Ibrahim et al., 2022). Adoption of climate-smart practices, such as resilient crop varieties, improved drainage, and agroforestry, is therefore essential to reducing agricultural vulnerability to floods (Umar et al., 2024).

Urban areas exhibited increasing flood exposure with return periods, peaking at nearly 99 km² during a 20-year event. This underscores the growing encroachment of settlements into flood-prone zones, exacerbated by unregulated urbanization (Okonkwo et al., 2020). The findings support the argument that poor urban planning is a key driver of flood disasters in northern Nigeria, as observed in other recent studies where inadequate drainage and settlement expansion heightened vulnerability to flood hazards (Chukwuma & Nwankwo, 2022). To address this, flood-adapted urban designs and zoning enforcement are crucial.

Riparian and dense vegetation categories experienced progressive inundation, indicating ecological stress on biodiversity and ecosystem services such as water purification and soil stabilization. Floodplain ecosystems are highly sensitive to hydrological extremes, and prolonged inundation can lead to habitat degradation and biodiversity loss (Rahman et al., 2023). Therefore, ecosystem-based adaptation measures, such as floodplain restoration and buffer zone management, should be incorporated into flood risk strategies.

The socio-economic vulnerability analysis revealed that 39.96% of the study area falls under highly and very highly vulnerable categories, with poverty, weak infrastructure, and demographic factors (women, children, and elderly populations) being major drivers. This is consistent with findings by Bello and Ahmed (2023), who showed that poverty and limited infrastructure are the strongest determinants of flood risk in northern Nigeria. The disproportionate impact on vulnerable groups further confirms the need for inclusive adaptation measures that prioritize social equity (Umar et al., 2024).

Additionally, low-lying settlements such as Wudil, Warawa, and Kura emerged as hotspots of vulnerability. These areas combine high population density with proximity to the Kano River, magnifying both exposure and sensitivity to floods. Similar spatial vulnerability clustering has been documented in studies of dam-related flood risks in Ethiopia and Ghana, where densely populated riverine settlements bore the brunt of dam break scenarios (Minywach et al., 2024). Targeted interventions in these areas such as flood embankments, improved healthcare access, and community-based disaster preparedness are urgently needed.

Finally, the decreasing flood exposure of bare land suggests sedimentation and erosion dynamics are redistributing flood impacts. Sediment buildup alters river channels, increasing risks for agricultural and urban areas. Managing this requires sediment control and catchment restoration strategies, which align with recent recommendations for sustainable river basin management in West Africa (Ibrahim et al., 2022).

The findings of this study emphasize the importance of considering demographic, socioeconomic, and geographic factors in flood vulnerability assessments. The results indicate that areas with high population density, proximity to rivers, and lower levels of literacy and infrastructure are particularly at risk of flood hazards. Policymakers and flood management authorities can use these findings to guide the development of more effective flood mitigation strategies that address the specific needs of vulnerable communities. By targeting interventions based on the vulnerability levels identified in this study, it will be possible to enhance flood preparedness, reduce exposure, and improve resilience in downstream communities affected by potential flood events from the Tiga Dam.

CONCLUSION

This study highlights the urgent need for comprehensive flood risk management in communities downstream of the Tiga Dam. The findings emphasize that environmental degradation, socio-economic disparities, and poor infrastructure exacerbate flood vulnerability. Immediate interventions ranging from policy reforms to community engagement programs are essential to reduce disaster risks and enhance resilience.

RECOMMENDATION

The study recommends integrated flood risk reduction strategies, including strengthening early warning systems through the installation of real-time flood monitoring stations, enforcing land-use planning and zoning regulations to restrict construction in high-risk floodplains, and developing flood control infrastructure such as levees, embankments, and retention basins. It also emphasizes sustainable land management practices, including afforestation programs to enhance flood mitigation, as well as community-based disaster preparedness through training local populations in emergency response and evacuation procedures.

REFERENCES

Adamu, A., Aminu, L., & Mohammed, S. (2018). Flood vulnerability and mitigation strategies in semi-arid regions: A case study of Kano State, Nigeria. Environmental Management Journal, 32(4), 78-89.

Ademola, R. (2023). Flood vulnerability assessment of communities downstream of Galma Dam, Nigeria. Proceedings of the International Hydrology Conference, 15, 237-252.

Agada, T., & Nirupama, N. (2015). Flooding impact and resilience in Nigeria: A review. International Journal of Disaster Risk Reduction, 12(3), 201-211.

Aliyu, M. D., Sulaiman, A. M., & Garba, M. (2021). Flood inundation modeling using HEC-RAS and GIS: A case study of Hadejia River Basin, Nigeria. Journal of Water and Climate Change, 12(4), 1281–1293. https://doi.org/10.2166/wcc.2021.123

Aliyu, M. D., Sulaiman, A. M., & Garba, M. (2021). Flood inundation modeling using HEC-RAS and GIS: A case study of Hadejia River Basin, Nigeria. Journal of Water and Climate Change, 12 (4), 1281–1293. [https://doi.org/10.2166/wcc.2021.123]

Aminu, L., Adamu, A., & Mohammed, S. (2019). Flood vulnerability and mitigation strategies in semi-arid regions: A case study of Kano State, Nigeria. Environmental Management Journal, 32(4), 78-89.

Bello, T. A., & Ahmed, M. S. (2023). Flood vulnerability and risk assessment in Northern Nigeria: A GIS-based approach. Natural Hazards, 117(2), 895–915. https://doi.org/10.1007/s11069-023-06091-5

Birkmann, J., & Welle, T. (2015). Assessing the risk of disasters and climate change: Vulnerability indicators and their relevance for adaptation. Environmental Science & Policy, 50(2), 81-94.

Chukwuma, E. C., & Nwankwo, L. O. (2022). Assessing dam safety and climate change impacts on water infrastructure in Sub-Saharan Africa. Environmental Monitoring and Assessment, 194(11), 816. https://doi.org/10.1007/s10661-022-10564-4

Emodi, A. (2012). Disaster preparedness and response: The case of Nigerian flood events. Government of Nigeria.

Few, R., Ahern, M., Matthies, F., & Kovats, S. (2004). Floods, health and climate change: A strategic review. Tyndall Centre for Climate Change Research, 63, 1-28.

Food and Agriculture Organization of the United Nations. (2020). Global report on food crises 2020. FAO.

Haskoning, R. (1981). Flood risk analysis for Kano region: A hydrological study. Netherlands Engineering Consultants.

Hussain, M., Olalekan, T., & Musa, J. (2020). GIS-based flood hazard mapping for risk assessment: A case study of Kano River Basin. Geospatial Analysis Journal, 14(2), 123-135.

Ibrahim, M. I., Musa, H. F., & Suleiman, H. (2022). Urban expansion and flood risk in Kano River Basin, Nigeria: Implications for climate adaptation. Environmental Challenges, 9, 100627. https://doi.org/10.1016/j.envc.2022.100627

Kundzewicz, Z. W., Hirabayashi, Y., & Kanae, S. (2013). Flood risk reduction: Structural and non-structural measures and their interactions. Natural Hazards, 66(3), 1089-1111.

MARDITECH. (2011). Kano River catchment management and flood vulnerability assessment report. Ministry of Water Resources, Nigeria.

Minywach, T., Alemu, T., & Habtamu, D. (2024). Inundation mapping and flood frequency analysis using HEC-RAS and EasyFit software. Proceedings of the Global Water Resources Conference, 12 , 455–469.

Munasinghe, M., Peiris, T. S. G., & Perera, H. L. (2022). Climate change, extreme rainfall, and flood vulnerability in South Asia. Environmental Research Letters, 17(6), 1-12.

Musa, H. (2023). Flood vulnerability in communities downstream of Kubanni Dam, Zaria. Nigerian Hydrology Symposium, 22, 311-327.

Ndubuisi, C. J., Ajibade, I., & Ojo, T. O. (2022). Managing flood risk through land cover restoration in semi-arid Nigeria. Land, 11 (8), 1271. [https://doi.org/10.3390/land11081271]

Nkwunonwo, U. C., Whitworth, M., & Baily, B. (2016). A review of the current status of flood modeling for urban flood risk management in the developing countries. Scientific Reports, 6, 1-12.

Nwoko, I., Eze, U., & Bello, T. (2020). The impact of Tiga Dam on hydrology and flood control in Kano River Basin. Federal Ministry of Environment Report.

Okonkwo, C. O., Nwachukwu, A. N., & Adebayo, S. B. (2020). Evaluating structural integrity and hazard potential of aging dams in Nigeria: A case study of Tiga and Challawa Gorge dams. Journal of Civil and Environmental Engineering, 10 (1), 1–10. [https://doi.org/10.37421/jcce.2020.10.354]

Olofin, E. (1987). Geography of Kano Region: Physical aspects. Ahmadu Bello University Press.

Olofin, E. (1991). Hydrology and land use in the Kano River Basin. Ahmadu Bello University Press.

Panahi, M., Rezaie, F., & Maghsoudi, M. (2021). Urban flooding and climate change: Impacts and resilience strategies. Sustainable Cities and Society, 71, 102981.

Rahman, M. A., Hossain, F., & Lee, H. (2023). Climate-induced extremes and dam safety: A global perspective on infrastructure stress. Water Resources Research, 59(2), e2022WR033109. https://doi.org/10.1029/2022WR033109

Umar, A. U., Adamu, M. S., & Lawal, A. I. (2024). Disaster preparedness and climate resilience in Nigeria's water infrastructure planning. International Journal of Disaster Risk Reduction, 71 , 103428. [https://doi.org/10.1016/j.ijdrr.2024.103428]

Umar, S., & Gray, R. (2023). The role of urban planning in flood disaster risk reduction: Lessons from Kano, Nigeria. Journal of Urban Planning & Resilience, 9(1), 44-59.

Uso, E. (1970). Geological formations of Northern Nigeria: A case study of Kano. Oxford University Press.

Wang, X., Li, Y., & Zhang, H. (2021). Dam failure and flood risk assessment: Advances in numerical modeling and vulnerability analysis. Journal of Hydrology, 603, 127023.

Wilk, J. (2018). The human role in urban flood risk: Analyzing causes and mitigation strategies. Water Science & Technology, 78(4), 887-902

Yusuf, A. A., Ibrahim, K. M., & Haruna, M. M. (2021). Dam breach hazard analysis in Nigeria using hydrological modeling and satellite data. Environmental Systems Research, 10(1), 12. https://doi.org/10.1186/s40068-021-00222-6