



Assessing the Adaptive Capacity of Informal Settlements in Bauchi Metropolis to Urban Flooding: A Vulnerability Analysis

¹Hauwa Saleh Abdullahi, ²I. Y Chindo, ³Haruna Adamu, ⁴Mudathir Qossim

^{1&4}Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi

^{2&3}Department of Chemistry, Faculty of Sciences, Abubakar Tafawa Balewa University Bauchi

⁴Department of Medical Microbiology, Faculty of Basic Clinical Science, Abubakar Tafawa Balewa University Bauchi

ABSTRACT

Urban flooding is a major challenge in informal settlements in sub-Saharan Africa, driven by climate variability, rapid urbanisation, and inadequate infrastructure. This study assessed the adaptive capacity of four flood-prone informal settlements in Bauchi Metropolis, Nigeria, using a mixed-method approach involving 384 household surveys, 22 Key Informant Interviews, 10 Focus Group Discussions, and GIS-based spatial analysis. Results showed that 58.9%–74.6% of built-up areas lie within flood hazard zones, while the overall Adaptive Capacity Index (ACI) was low (mean = 0.31), indicating high vulnerability. Social capital was the strongest adaptive asset due to strong community support networks, whereas institutional capacity was the weakest because of limited government engagement and poor dissemination of flood warnings. Household adaptation was largely reactive and constrained by low income, insecure land tenure, and limited knowledge, with household income emerging as the strongest predictor of adaptive capacity ($\beta = 0.61$, $p < 0.001$). The study concludes that vulnerability is primarily structural rather than behavioural and recommends strengthening institutional support through an Integrated Flood Resilience Framework, improved land tenure formalisation, and dedicated funding for urban resilience.

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INTRODUCTION

Urban flooding is an escalating environmental challenge in informal settlements across sub-Saharan Africa, particularly in Nigeria, driven by climate variability, rapid unplanned urbanisation, and inadequate infrastructure (Akindejoye et al., 2025; Fanama & Bang, 2026; Akatah et al., 2025; Sani & Wibowo, 2026). In Bauchi Metropolis, recurrent flooding has become increasingly severe due to the expansion of informal settlements into low-lying, flood-prone areas, poor drainage systems, ineffective solid waste management, and inadequate access to essential urban services (Mottelson et al., 2026; Ajibade et al., 2013; Ilesanmi et al., 2025; Okunola et al., 2026). Rapid population growth and environmental degradation, including the loss of vegetation and natural drainage buffers, have

further increased surface runoff and flood intensity (Aladejana et al., 2026).

The vulnerability of these communities is shaped by the interaction of exposure, sensitivity, and adaptive capacity, with adaptive capacity serving as a critical determinant of long-term resilience (Nkwunonwo et al., 2024; Msongole et al., 2026). However, adaptive capacity remains constrained by poverty, insecure land tenure, weak institutional support, limited access to financial and technical resources, and the exclusion of informal settlements from formal urban planning and disaster risk reduction programmes (Amaechina et al., 2022; Mohammed & Favretto, 2025; Effiong, 2025; Okunola & Werners, 2024).

Although residents adopt a range of household- and community-based coping

Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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strategies, including structural modifications to buildings and collective self-help initiatives, these responses are largely reactive, resource-constrained, and insufficient to address increasing flood risks without stronger institutional support (Yusuf et al., 2021; Okunola & Olawuni, 2022). Consequently, strengthening adaptive capacity through improved infrastructure, inclusive urban planning, effective disaster risk governance, and community-centred resilience initiatives is essential for developing sustainable and locally appropriate flood risk reduction strategies in Bauchi Metropolis.

PROBLEM STATEMENT

Urban flooding is becoming increasingly severe in secondary Nigerian cities such as Bauchi, research has largely focused on major coastal cities, including Lagos and Port Harcourt, leaving significant knowledge gaps for rapidly growing inland urban centres (Ajibade et al., 2013; Akindejoye et al., 2025). Existing studies have primarily emphasized flood hazard mapping and physical risk assessment, with limited attention to the social, economic, and institutional dimensions of vulnerability and adaptive capacity (Gambo et al., 2024; Okoli et al., 2026). There is limited context-specific evidence on how households in Bauchi's informal settlements perceive flood risks and how factors such as income, education, access to finance, and institutional support influence their adaptive capacity (Enete et al., 2016; Yusuf et al., 2021). Current adaptation strategies are predominantly household-based, reactive, and resource-constrained, relying on measures such as raising building foundations and constructing temporary flood barriers, whose long-term effectiveness remains uncertain under increasing climate and urbanisation pressures (Ameh & Lamond, 2023; Okunola & Olawuni, 2022; Sani & Wibowo, 2026).

The exclusion of informal settlements from urban planning and disaster risk reduction frameworks has created a persistent disconnect between institutions and vulnerable communities, limiting access to early warning systems, financial assistance, and critical infrastructure investments required for resilience (Effiong, 2025; Okunola et

al., 2026; Ben-Enukora et al., 2025; Fanama & Bang, 2026). Consequently, there is an urgent need for an integrated vulnerability assessment that combines physical flood exposure with socioeconomic, institutional, and community resilience factors to provide evidence for inclusive and effective flood risk management in Bauchi's informal settlements (Okunola et al., 2026; Msongole et al., 2026).

Aim and Objectives

The primary aim of this study is to assess the adaptive capacity of informal settlements in Bauchi Metropolis to urban flooding using a vulnerability analysis framework, with the goal of identifying barriers to adaptation and opportunities for strengthening community resilience. The specific objectives were to:

1. To characterize flood-vulnerable informal settlements in the Bauchi metropolis by documenting hazard exposure and articulating their physical and socioeconomic profiles.
2. To construct and implement a household-level Adaptive Capacity Index (ACI) to quantify current resilience levels and analyze variations across diverse settlements and demographic cohorts.
3. To evaluate the efficacy of existing household and community-level adaptation mechanisms while identifying the underlying constraints that limit their success.
4. To examine the multi-dimensional drivers including governmental roles, community organizational structures, and social networks that serve as enablers or barriers to adaptive capacity.
5. To formulate a framework of targeted policy recommendations and community-centered interventions designed to bolster long-term flood resilience and adaptive governance.

MATERIALS AND METHODS

Location and Geographical Setting

Bauchi Metropolis, the capital of Bauchi State in northeastern Nigeria, lies between latitudes 10°17'N–10°20'N and longitudes

Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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9°45'E–10°00'E. As the state's administrative and commercial centre, it has experienced rapid urban expansion. The landscape consists of uplands, low-lying plains, and scattered inselbergs (rocky outcrops), with many informal settlements located in poorly drained low-lying areas that are highly susceptible to flooding. Bauchi has a tropical continental climate with distinct wet (May–October) and dry seasons, while August records the highest rainfall (Abdulkadir et al., 2020). The metropolis lies within the Gongola River tributary drainage basin. Rapid urbanisation has encroached on natural floodplains and reduced green space from 24% in 1976 to 14% in 2018, decreasing infiltration and increasing surface runoff, thereby intensifying flood risk.

Population growth driven by natural increase, migration, and regional insecurity has accelerated the expansion of informal settlements. These communities are characterized by low household incomes, high dependency ratios, and livelihoods centred on informal economic activities such as petty trading and urban agriculture (Yusuf et al., 2021). Housing is generally substandard, often constructed with mud bricks and lacking secure land tenure, which limits access to government compensation, disaster relief, and infrastructure investment. Land use in Bauchi Metropolis is predominantly residential but is increasingly characterized by unplanned development and poor compliance with urban planning regulations. Informal settlements have expanded into floodplains, ecological buffer zones, and areas adjacent to seasonal streams (fadamas), where inadequate drainage and high building density significantly increase flood risk. These locations have experienced repeated flooding, particularly during recent high-intensity rainfall events (Ajayi et al., 2023), making them priority areas for flood vulnerability and resilience assessment.

Study Design and Population

A mixed-methods cross-sectional study was conducted among household heads residing in flood-prone informal settlements in Bauchi metropolis, Nigeria. Household heads were selected because they are the primary decision-

makers regarding flood preparedness and recovery. Key stakeholders from the Bauchi State Emergency Management Agency (BASEMA), Bauchi State Environmental Protection Agency (BASEPA), and community-based organizations also participated in the qualitative component.

Sample Size and Sampling

The sample size of 384 households was determined using Cochran's formula at a 95% confidence level and a 5% margin of error. A multistage sampling technique was employed. Initially, flood-prone settlements were purposively selected based on historical flood records and BASEPA risk classifications. The settlements were subsequently stratified according to proximity to drainage channels, after which households were selected using systematic random sampling. Key informants were purposively selected based on their expertise and community leadership roles.

Data Collection

Primary data were collected using structured questionnaires, semi-structured key informant interviews, focus group discussions, and direct field observations. Secondary data were obtained from the Nigerian Meteorological Agency (NiMet), satellite imagery (Landsat and Sentinel), official reports from disaster management agencies, and relevant scientific literature.

Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 27. Descriptive statistics were used to summarize respondents' characteristics, while Principal Component Analysis (PCA) was applied to construct the Adaptive Capacity Index (ACI). Correlation analysis was performed to examine relationships between socioeconomic variables and resilience. Qualitative data from interviews and focus group discussions were transcribed and analyzed using thematic analysis.

Corresponding author: Hauwa Saleh Abdullahi

✉ hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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RESULTS

Sociodemographic Characteristics of Respondents

A total of 384 questionnaires were successfully completed and analyzed, representing a 100% response rate. The respondents were predominantly male (67.7%), while females constituted 32.3% of the sample. The largest proportion of respondents (34.1%) were aged 31–40 years, followed by those aged 41–50 years (28.4%), indicating that most respondents were within the economically active age group. Educational attainment was generally low, with 42.2% having primary education or less, 35.4% completing secondary education, 14.3%

attaining post-secondary education, and 8.1% having no formal education. Monthly household income was similarly low, as 71.9% of respondents earned less than ₦50,000 per month, while only 2.3% earned more than ₦100,000. The mean household size was 6.8 ± 2.1 persons, indicating relatively large households with potentially higher dependency burdens.

The findings indicate that residents of the selected informal settlements are predominantly low-income households with limited educational attainment, characteristics that may reduce their capacity to prepare for, respond to, and recover from flood events.

Table 1: Sociodemographic Characteristics of Survey Respondents (n = 384)

Variable	Category	Frequency	Percentage (%)
Sex	Male	260	67.7
	Female	124	32.3
Age Group	18–30 years	105	27.3
	31–40 years	131	34.1
	41–50 years	109	28.4
	51–60 years	6	1.6
	Above 60 years	33	8.6
	No formal education	31	8.1
Education	Primary	131	34.1
	Secondary	136	35.4
	Post-secondary	55	14.3
	Tertiary	31	8.1
Monthly Income	Below ₦50,000	276	71.9
	₦50,001–₦100,000	98	25.5
	Above ₦100,000	10	2.6
Household Size	1–4 persons	67	17.4
	5–7 persons	195	50.8
	8–10 persons	98	25.5
	Above 10 persons	24	6.3

Kitchen waste exhibited high carbohydrate content, averaging approximately 62.77%, confirming its suitability as a substrate for bioethanol production. The elevated volatile solids fraction indicated high biodegradability and substantial organic matter availability for microbial conversion.

The dominant fermentable sugars detected in raw waste were maltose (11.52 ± 0.14

g/L), glucose (3.45 ± 0.05 g/L), fructose (0.42 ± 0.21 g/L), and sucrose (0.13 ± 0.11 g/L). These sugars provide readily available substrates for yeast metabolism and ethanol production.

Physical Exposure Characteristics

Most respondents (78.4%) lived within 200 m of seasonal streams or drainage channels, with 39.1% residing less than 50 m away,

Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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indicating a high level of physical exposure to flooding. Flooding was highly recurrent, as 91.7% of households reported experiencing at least one flood event during the previous five years, while 63.5% had experienced flooding more than three times.

The mean perceived severity of the most recent flood event was 3.8 ± 0.94 on a five-point Likert scale, reflecting moderate-to-severe impacts. The average reported flood depth was 0.62 ± 0.34 m, sufficient to inundate ground-floor

living areas and damage household property. Housing conditions further increased flood vulnerability. Approximately 61.2% of dwellings were constructed using mud-brick (adobe) or mixed mud and corrugated iron materials, whereas only 11.4% had reinforced concrete foundations with adequate damp-proofing. These findings indicate high physical exposure and structural susceptibility of households to flood hazards.

Table 2: Flood Exposure Indicators Across Study Settlements

Exposure Indicator	Yelwa (%)	Makama (%)	Wunti (%)	Dan Kano (%)	Overall (%)
< 50m from Fadama channel	51.3	42.7	35.1	27.8	39.1
50–200m from Fadama channel	35.9	40.3	42.6	37.0	39.3
Flooded 3+ times (2019–2024)	74.4	68.2	60.1	54.7	63.5
Mud/adobe housing structure	69.2	65.1	58.3	52.7	61.2
No access to drainage system	88.5	82.7	76.4	69.3	79.2
Mean flood depth (metres)	0.78	0.67	0.55	0.49	0.62

The data in Table 2 reveal a clear spatial gradient of exposure, with Yelwa presenting the most severe exposure profile across all indicators and Dan Kano representing comparatively lower but still substantial risk levels. The absence of formal drainage infrastructure, reported by 79.2% of respondents overall, is a defining characteristic of physical vulnerability across all four settlements.

Construction of the Adaptive Capacity Index (ACI)

The Adaptive Capacity Index (ACI) was developed using the IPCC Vulnerability Framework and Sustainable Livelihoods Framework, incorporating indicators adapted from Brooks et al. (2005) and Cutter et al. (2008). Five dimensions of adaptive capacity were assessed: human capital (education, health, disaster knowledge, and technical skills), social capital (social networks, community participation, and institutional trust), financial capital (income,

savings, credit, and productive assets), physical capital (housing quality, drainage, water and sanitation, and household assets), and institutional capital (early warning awareness, access to disaster services, and participation in community planning).

Following Principal Component Analysis (PCA), 28 indicators were retained for index construction. Indicator values were normalized using the Min–Max method to a 0–1 scale, after which dimension scores were calculated as the mean of their constituent indicators. The overall ACI was computed as the equally weighted average of the five-dimension scores, yielding a composite index ranging from 0 (lowest adaptive capacity) to 1 (highest adaptive capacity). Adaptive capacity was classified as low (0.00–0.33), moderate (0.34–0.66), or high (0.67–1.00).

Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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Adaptive Capacity Index (ACI) by Settlement and Respondent Characteristics

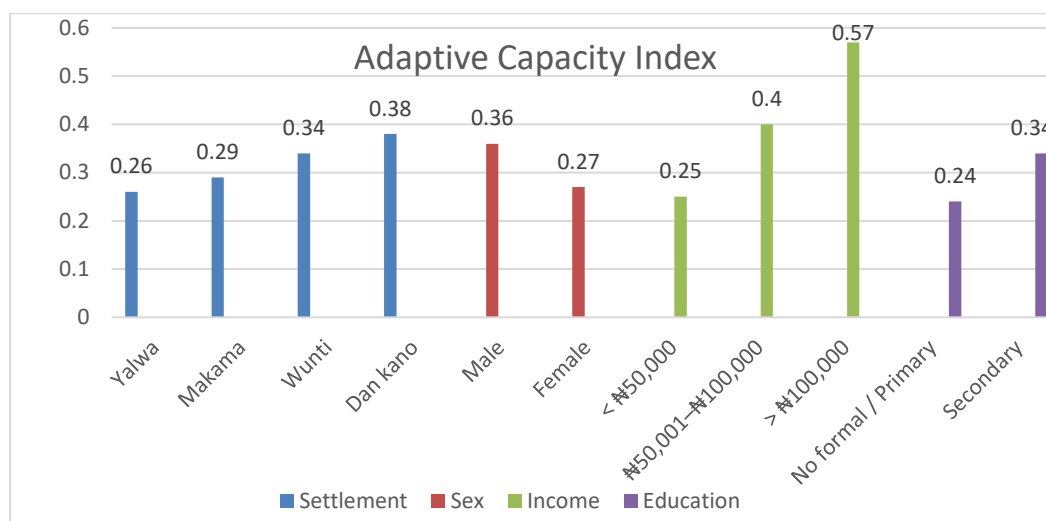


Figure 1: presents the mean Adaptive Capacity Index (ACI) scores by settlement and selected sociodemographic characteristics.

The findings reveal marked variations in adaptive capacity across settlements, sex, income groups, and educational levels, indicating substantial heterogeneity in households' capacity to prepare for, respond to, and recover from flood events. The overall mean Adaptive Capacity Index (ACI) was 0.31 ± 0.11 , indicating that most households had low adaptive capacity to flooding. Adaptive capacity varied across settlements, with Yelwa recording the lowest mean ACI (0.26), while Dan Kano had the highest (0.38), reflecting moderate adaptive capacity.

Significant gender differences were observed ($p < 0.001$), with male-headed households exhibiting a higher mean ACI (0.36) than female-headed households (0.27). The greatest disparity occurred in the financial capital dimension, where female-headed households recorded substantially lower scores than their male counterparts.

Household income and educational attainment were positively associated with adaptive capacity. Overall ACI showed a strong positive correlation with monthly household income ($r = 0.68$, $p < 0.001$) and educational level ($r = 0.61$, $p < 0.001$). Households earning more

than ₦100,000 per month achieved a mean ACI of 0.57, compared with 0.25 among households earning less than ₦50,000, demonstrating that higher socioeconomic status is associated with greater capacity to prepare for, respond to, and recover from flood events.

Dimensional Analysis of the Adaptive Capacity Index

Analysis of the five dimensions of the Adaptive Capacity Index (ACI) revealed notable differences in household adaptive capacity. Social capital recorded the highest mean scores across settlements and respondent groups, indicating the important role of community support networks and collective action in enhancing resilience to flooding. In contrast, institutional capital was the weakest dimension, with an overall mean score of 0.26. Only 18.2% of respondents reported receiving flood preparedness information from government agencies within the preceding 24 months, while 9.4% were aware of official emergency contacts or response procedures. These findings suggest limited institutional engagement with flood-prone communities and identify institutional capacity as a major constraint to effective flood adaptation.

Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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Household and Community-Level Adaptation Strategies

Adaptation Strategy Typology

Respondents identified the flood adaptation measures they had adopted during the

two years preceding the survey. As presented in table3, these measures were categorized into structural, behavioral, and institutional adaptation strategies to reflect the range of household- and community-level responses to recurrent flooding.

Table 3: Flood Adaptation Measures

Strategy Type	Specific Strategy	Frequency	Percentage (%)
Structural	Raising floor level / building plinth	218	56.8
	Constructing earthen or sand-bag barrier at entrance	187	48.7
	Reinforcing walls with cement plastering	142	37.0
	Installing raised storage platforms for valuables	201	52.3
	Relocating main sleeping area to upper floor	89	23.2
Behavioural	Early evacuation to relatives' homes	224	58.3
	Relocating valuables before expected flood	261	68.0
	Monitoring weather patterns / cloud formations	198	51.6
	Restricting movement of children during rains	274	71.4
	Diversifying income to non-flood-dependent sources	84	21.9
Institutional	Participation in community flood committee	72	18.8
	Membership in savings/credit cooperative (Adashi)	145	37.8
	Receiving early warning from ward head (Mai Angwa)	167	43.5
	Accessing government relief after flooding	61	15.9
	Attending government flood preparedness training	29	7.6

Household and Community-Level Adaptation Strategies

Behavioral adaptation strategies were the most commonly adopted measures (Table 4.4). The most frequently reported practices were restricting children's movement during periods of heavy rainfall (71.4%) and relocating valuables before anticipated flooding (68.0%), indicating a reliance on low-cost, reactive coping strategies. Structural adaptation measures were less common and were significantly associated with higher household income ($\chi^2 = 47.3$, $df = 4$, $p < 0.001$). Raising the floor level was the most frequently reported structural measure (56.8%), although qualitative findings indicated that these modifications were generally insufficient to withstand typical flood depths experienced in the study area.

Institutional adaptation was the least adopted category. Only 7.6% of respondents had participated in government flood preparedness training, while 43.5% relied on early warning

information provided by ward heads (Mai Anguwa), highlighting the important role of community leadership in disseminating flood-related information.

Constraints to Effective Adaptation

Thematic analysis of data from 22 key informant interviews and 10 focus group discussions (98 participants) identified five major constraints to effective flood adaptation. Financial constraints emerged as the most frequently reported barrier, limiting households' ability to undertake structural flood-proofing measures. Tenure insecurity was also prominent, with 64.3% of key informants indicating that the absence of secure land tenure discouraged investment in permanent housing improvements.

An information deficit was evident, as only 18.2% of respondents reported receiving formal flood preparedness information from disaster management agencies, leaving most households dependent on informal warning

Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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systems. Participants also highlighted institutional exclusion, describing limited government support for informal settlements in urban planning, drainage development, and disaster management interventions. Finally, social fragmentation, particularly in settlements experiencing rapid in-migration, weakened community support networks and reduced participation in collective flood mitigation activities.

Institutional, Social, and Economic Determinants of Adaptive Capacity

Government Institutions

Key informant interviews with representatives of BASEMA, BASEPA, and the Bauchi Local Government Area revealed that flood risk management is constrained by limited resources, overlapping institutional mandates, and a greater emphasis on post-disaster response than on preparedness and mitigation. Environmental regulations and drainage standards were reported to be weakly enforced in informal settlements, while ward heads (Mai Anguwa) served as the primary community-level coordinators for flood response despite limited institutional support.

Social Capital

Social capital emerged as the strongest dimension of the Adaptive Capacity Index. Community-based support mechanisms, including *Adashi* (rotating savings groups) and *Gandu* (cooperative labour), played important roles in providing financial assistance, organising drainage maintenance, and supporting collective flood response. However, participants noted that rapid urbanisation and population mobility have weakened these traditional support networks in some settlements.

Economic Determinants

Regression analysis identified monthly household income ($\beta = 0.61, p < 0.001$), education level ($\beta = 0.47, p < 0.001$), and access to credit ($\beta = 0.38, p < 0.001$) as significant predictors of adaptive capacity. Access to formal credit was limited, with only 14.1% of respondents reporting

use of formal financial institutions, whereas 37.8% participated in informal *Adashi* savings groups. In addition, only 21.9% of households had diversified livelihood sources, while 62.4% depended on a single income source, increasing their vulnerability to flood-related economic disruption.

Synthesis and Theoretical Implications

The findings demonstrate the presence of a vulnerability trap in the flood-prone informal settlements of Bauchi metropolis, where high flood exposure, socioeconomic disadvantage, and limited adaptive capacity reinforce one another. Settlements with the greatest flood exposure, particularly Yelwa and Makama, also recorded the lowest household incomes, weakest institutional support, and lowest Adaptive Capacity Index (ACI) scores, indicating a close relationship between poverty and flood vulnerability. Viewed through the IPCC Exposure Sensitivity Adaptive Capacity framework, the results show that households experience high exposure to recurrent flooding, elevated sensitivity due to poor housing conditions and inadequate drainage infrastructure, and generally low adaptive capacity. Together, these interacting factors increase the likelihood of repeated flood losses and constrain the ability of households to prepare for, respond to, and recover from flood events.

Institutional Community Disconnect and the Role of Social Capital

A major finding of this study is the weak linkage between formal institutions and flood-prone communities. The low mean Institutional Capital score (0.26) indicates limited engagement of households with formal disaster management systems, reflecting inadequate access to preparedness information, early warning services, and institutional support. Consequently, community leaders (Mai Anguwa) have assumed a central role in coordinating local flood response and disseminating risk information.

Although social capital was the strongest dimension of the Adaptive Capacity Index, qualitative findings indicate that its contribution to resilience is increasingly fragile. Community-based initiatives such as *Adashi*

Corresponding author: Hauwa Saleh Abdullahi

✉ hasaleh.pg@atbu.edu.ng

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(rotating savings groups) and *Gandu* (cooperative labour) continue to support flood preparedness and recovery, but participants reported that rapid urbanisation, population mobility, and weakening social cohesion are reducing their effectiveness. Overall, the findings suggest that while strong community networks enhance households' ability to cope with flood events, they are insufficient to achieve long-term resilience without sustained institutional support and investment.

CONCLUSION

This study assessed flood vulnerability and household adaptive capacity in selected informal settlements of Bauchi metropolis using a mixed-methods approach. The findings indicate that households are characterized by high physical exposure to flooding, low socioeconomic status, and limited adaptive capacity, with an overall Adaptive Capacity Index (ACI) of **0.31**, indicating generally low resilience. Adaptive capacity varied across settlements and demographic groups, with lower scores observed among households with lower income, lower educational attainment, and female-headed households.

Households relied primarily on low-cost behavioural adaptation measures, while structural and institutional adaptation strategies were less common due to financial constraints, insecure land tenure, inadequate access to credit, and limited government support. Although community-based social networks such as *Adashi* and *Gandu* contributed positively to household resilience, weak institutional engagement and limited access to disaster preparedness services constrained their effectiveness.

The study further demonstrated that household income, education, and access to credit were significant determinants of adaptive capacity, while institutional capital represented the weakest dimension of resilience. These findings suggest that strengthening flood resilience in Bauchi's informal settlements requires integrated interventions that combine improved urban planning, investment in drainage infrastructure, strengthened institutional engagement, secure land tenure, and expanded access to livelihood

opportunities and climate-sensitive financial services. The study provides empirical evidence on flood vulnerability and adaptive capacity in a secondary city of Northern Nigeria and offers a methodological framework that can support flood resilience assessments and policy development in similar rapidly urbanising cities.

RECOMMENDATIONS

Based on the findings, the following recommendations are proposed:

1. Strengthen institutional capacity: The Bauchi State Government should establish a dedicated unit within the Bauchi State Emergency Management Agency (BASEMA) to coordinate flood risk reduction in informal settlements through community-based early warning systems, preparedness campaigns, and regular vulnerability assessments.
2. Improve land tenure and urban planning: The Ministry of Lands, Survey and Country Planning should implement progressive land tenure regularization and integrate flood risk information into urban planning to discourage settlement expansion into high-risk flood zones.
3. Enhance investment in flood resilience: The state government should increase investment in drainage infrastructure, flood-resilient housing, and community-based adaptation programmes. Financial support, including affordable credit and climate adaptation funds, should be made available to low-income households to facilitate structural flood mitigation measures.
4. Support community-based adaptation: Local governments should strengthen Community Flood Management Committees and collaborate with traditional leaders (Mai Anguwa) to improve early warning dissemination, drainage maintenance, and emergency preparedness.
5. Promote financial inclusion and climate services: Development partners and non-governmental organizations should expand access to adaptation-focused microfinance, strengthen community savings groups (*Adashi*), and support the provision of

Corresponding author: Hauwa Saleh Abdullahi

✉ hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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localized weather forecasts and climate information to vulnerable communities.

6. Strengthen research and monitoring: Future studies should validate the Adaptive Capacity Index (ACI) in other flood-prone cities of Northern Nigeria and employ longitudinal designs to monitor changes in household adaptive capacity and evaluate the effectiveness of resilience interventions over time.

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Conflict of Interest

The authors declare no conflict of interest.

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Corresponding author: Hauwa Saleh Abdullahi

✉ hasaleh.pg@atbu.edu.ng

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Corresponding author: Hauwa Saleh Abdullahi

✉ hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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Corresponding author: Hauwa Saleh Abdullahi

hasaleh.pg@atbu.edu.ng

Department of Environmental Standard Faculty of SPESSECE, Abubakar Tafawa Balewa University Bauchi.

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