SCIENCE FORUM (JOURNAL OF PURE AND APPLIED SCIENCES) 26, (3) (2026), 768 - 778

Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas

Assessment of Flood Early Warning and Response System in the Alau Dam Catchment Area, Borno State, Nigeria, using SRTM and GIS

Muhammad Al-hassan Haruna[1*], B.A Gana[2], DEA Boryo[3], U.Y Abubakar

[1]*Enviromental Standard Node Sustainable Procurement Environmental and Social Standards Enhancement Centre of Excellence, ATBU Bauchi*

[2]*Department of Environmental Management, ATBU Bauchi*

[3]*Chemistry Department, ATBU Bauchi*

Abstract

The Flood Early Warning and Response System (FEWRS) was comprehensively evaluated in the Alau Dam catchment, Borno State, Nigeria, using an integrated geospatial and socio-institutional framework to assess flood vulnerability, early warning effectiveness, and community response capacity. The study was motivated by the recurrent downstream flooding that persistently affects the Maiduguri Metropolitan Council, Jere, and Konduga Local Government Areas. A mixed-methods research design was adopted, integrating Geographic Information Systems (GIS), Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), Multi-Criteria Decision Analysis (MCDA), and Sentinel-2 land use/land cover data with primary socio-economic information collected from 180 households and 40 institutional stakeholders through structured questionnaires, Key Informant Interviews (KIIs), and Focus Group Discussions (FGDs). Geospatial analysis revealed that the low-lying terrain (275–360 m above sea level) and predominantly gentle slopes (approximately 3°, covering 90% of the catchment) facilitate the natural concentration and downstream convergence of runoff into flood-prone plains. The integrated Multi-Criteria Evaluation (MCE) flood susceptibility model classified 28% of the catchment, primarily the urbanized Maiduguri area, as Very High flood risk, while an additional 34% was categorized as High risk. Socio-institutional assessment showed that although 58% of households were aware of flood early warning information, 42% remained unreached by the warning system. Radio (44%) and traditional community leaders (27%) were identified as the principal channels for warning dissemination. Inferential statistical analyses established significant associations ($p < 0.05$) between educational attainment, household income, timely receipt of warnings, and proactive household response. Furthermore, binary logistic regression analysis (Nagelkerke $R^2 = 0.61$) identified early warning awareness ($Exp(\beta) = 3.01$) and education level ($Exp(\beta) = 2.32$) as the strongest predictors of appropriate flood response behaviour. The findings demonstrate that flood vulnerability within the Alau Dam catchment is a complex interaction of geomorphological controls, rapid urbanization, and institutional communication bottlenecks, highlighting the urgent need to transition from conventional warning practices to a people-centred, real-time, automated flood forecasting and early warning system capable of strengthening disaster preparedness, improving emergency response, and enhancing long-term community resilience to flood hazards.

Keywords

Flood Risk,
Early Warning,
GIS,
MCDA,
Disaster Resilience

ISSN 1119-4618 JPAS
Faculty of Science, ATBU Bauchi

Corresponding Author: Muhammad Al-hassan Haruna, Enviromental Standard Node Sustainable Procurement Environmental and Social Standards Enhancement Centre of Excellence, ATBU Bauchi. Email: ahmuhammad.pg@atbu.edu.ng

1. Introduction

Flooding represents one of the most destructive hydro-meteorological hazards globally, with increasing frequency and magnitude attributed to climate variability, environmental degradation, and rapid urban expansion (IPCC, 2021). Contemporary disaster risk reduction (DRR) frameworks emphasize a proactive shift from reactive disaster response to integrated hazard assessment and Early Warning Systems (FEWS) (Basher, 2021). However, the real-world utility of a FEWS relies on a reliable nexus linking hazard detection, coherent inter-agency coordination, clear communication infrastructure, and adaptive community response behavior (Olanrewaju et al., 2023).

Advanced tools like Geographic Information Systems (GIS) and Shuttle Radar Topography Mission (SRTM) data provide spatially explicit insights into physical vulnerabilities (Komolafe et al., 2020). Despite technical advancements, a critical gap persists: physical spatial hazard models and socio-institutional human response models are frequently evaluated in isolation. This research targets this gap by performing a comprehensive, integrated assessment of the Flood Early Warning and Response System within the Alau Dam catchment area of Borno State, Nigeria. Driven by catastrophic seasonal events affecting Maiduguri, Jere, and Konduga Local Government Areas (LGAs), this study maps physical parameters via Multi-Criteria Decision Analysis (MCDA) and uncovers the socio-behavioral dynamics dictating household preparedness and institutional gaps.

2. Methodological Framework

The study area is the Alau Dam catchment, located within Konduga LGA, Borno State, Northeastern Nigeria, positioned within the Sudano-Sahelian ecological zone (Latitude 11 ° 43'27''N to Longitude 13 ° 17'06''E). A stratified multi-stage sampling layout was implemented. To balance statistical representation with qualitative precision, a total sample size of N = 220 respondents was engaged, composed of:

- 180 Households (60 per targeted downstream flood-prone ward).
- 40 Institutional Stakeholders (10 Dam Operators, 10 Agency Representatives,10 Traditional Leaders, and 10 NGO Officials).

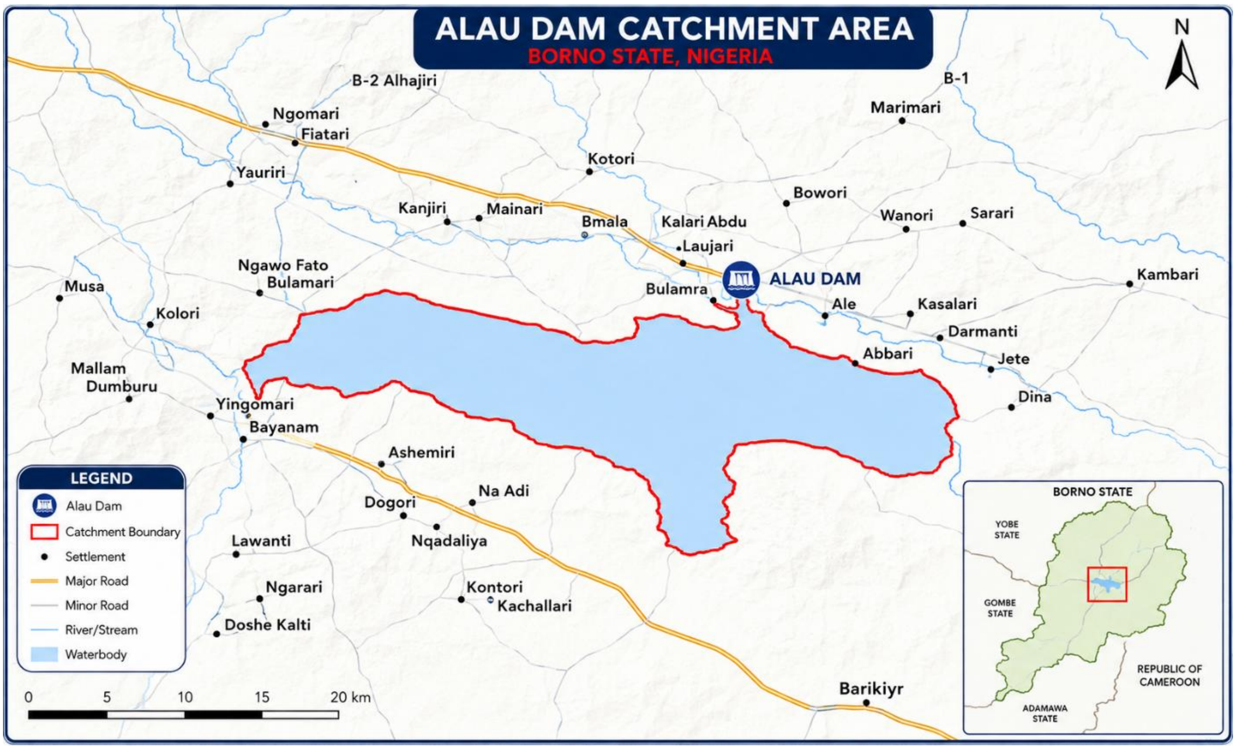

Figure 1 Alau Dam CatchmentArea

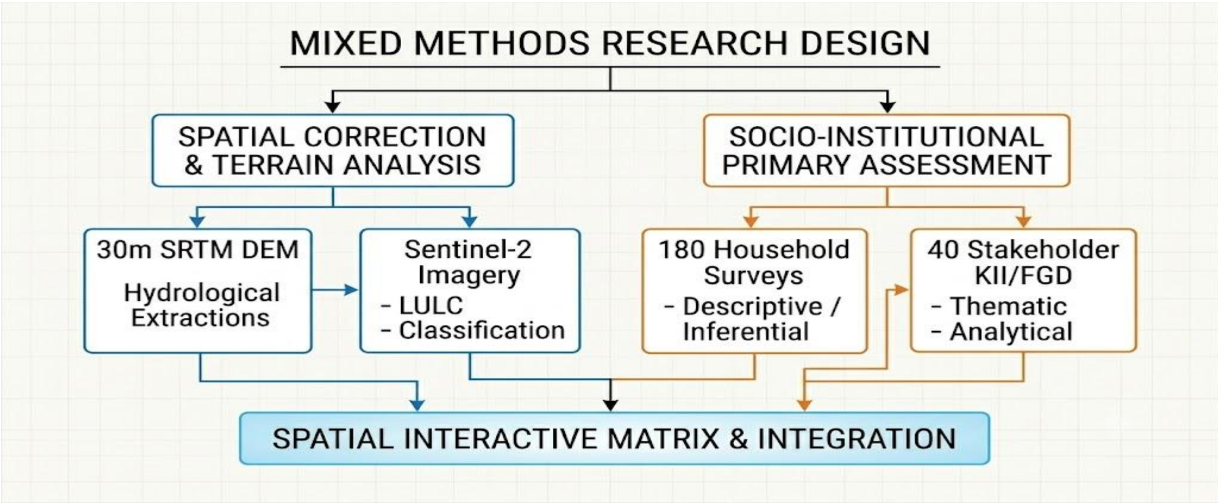

Figure 2 Schematic of study method used

2.1 Spatial and Geoprocessing Routines

Physical analysis was executed using QGIS (v3.2). Sinks within the 30-meter SRTM DEM dataset were filled to optimize hydraulic connectivity, establishing correct layers for flow direction and flow accumulation. Land use/land cover (LULC) structures were extracted via random forest classification of 10-meter Sentinel-2 satellite imagery. Delineated layers were integrated using a GIS-based Multi-Criteria Evaluation (MCE), assigning weighted parameters according to their absolute hydrological flood-controlling capacities (Standard Matrix: Elevation, Slope, Flow Accumulation, LULC).

2.2 Socio-Economic Statistical Modeling

Socio-economic survey data were evaluated using descriptive techniques, χ^2 test of independence, and binary logistic regression to evaluate determinants of appropriate household response behaviour:

$$\text{In}\left(\frac{P}{1-P}\right) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}(\boldsymbol{Edu}) + \boldsymbol{\beta_2}(\boldsymbol{Inc}) + \boldsymbol{\beta_3}(\boldsymbol{Aware}) + \boldsymbol{\beta_4}(\boldsymbol{Mobile}) \quad \textbf{Equation 1}$$

Where P is the probability of executing an appropriate/timely flood response. Qualitative data from KIIs and FGDs were processed using thematic network analysis supported by NVivo software.

3. Results and Discussion

3.1 Geospatial and Topographical Extractions

Terrain analysis demonstrates that the catchment is inherently vulnerable due to its physical layout. The digital elevation model isolates a low-relief terrain configuration ranging uniformly between 275m and 360 m above sea level. This places urban centers like Maiduguri at the terminus of a natural receiving basin.

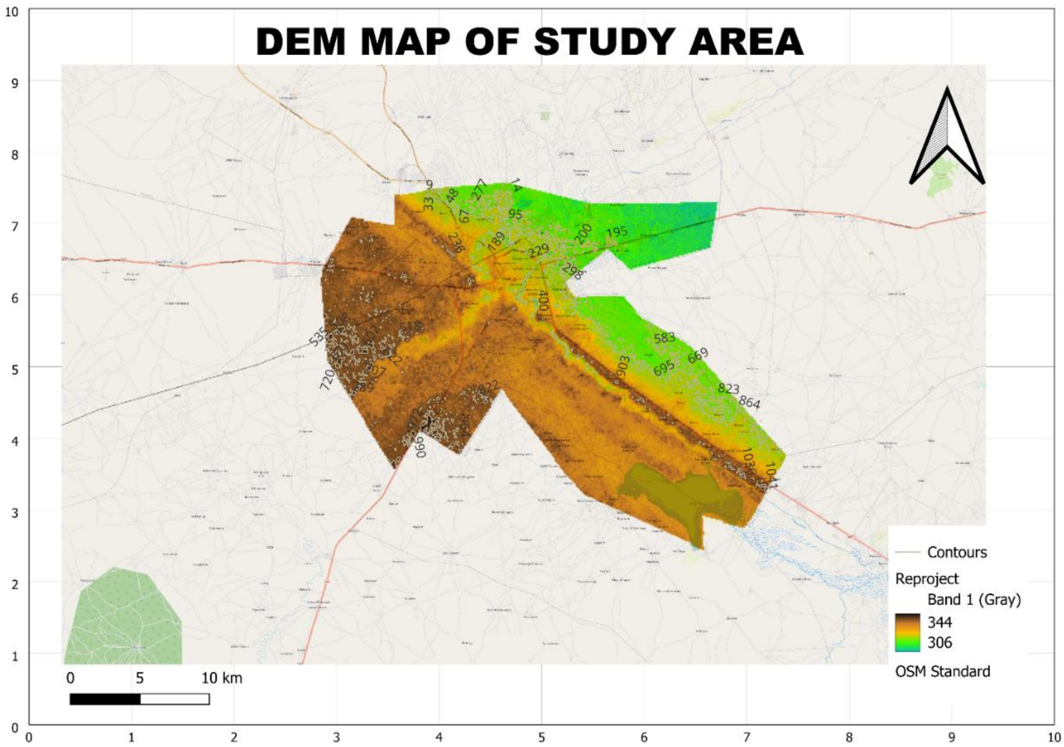

Figure 3 Dem Map of the Study Area

The surface gradient analysis highlights an extremely flat slope distribution:

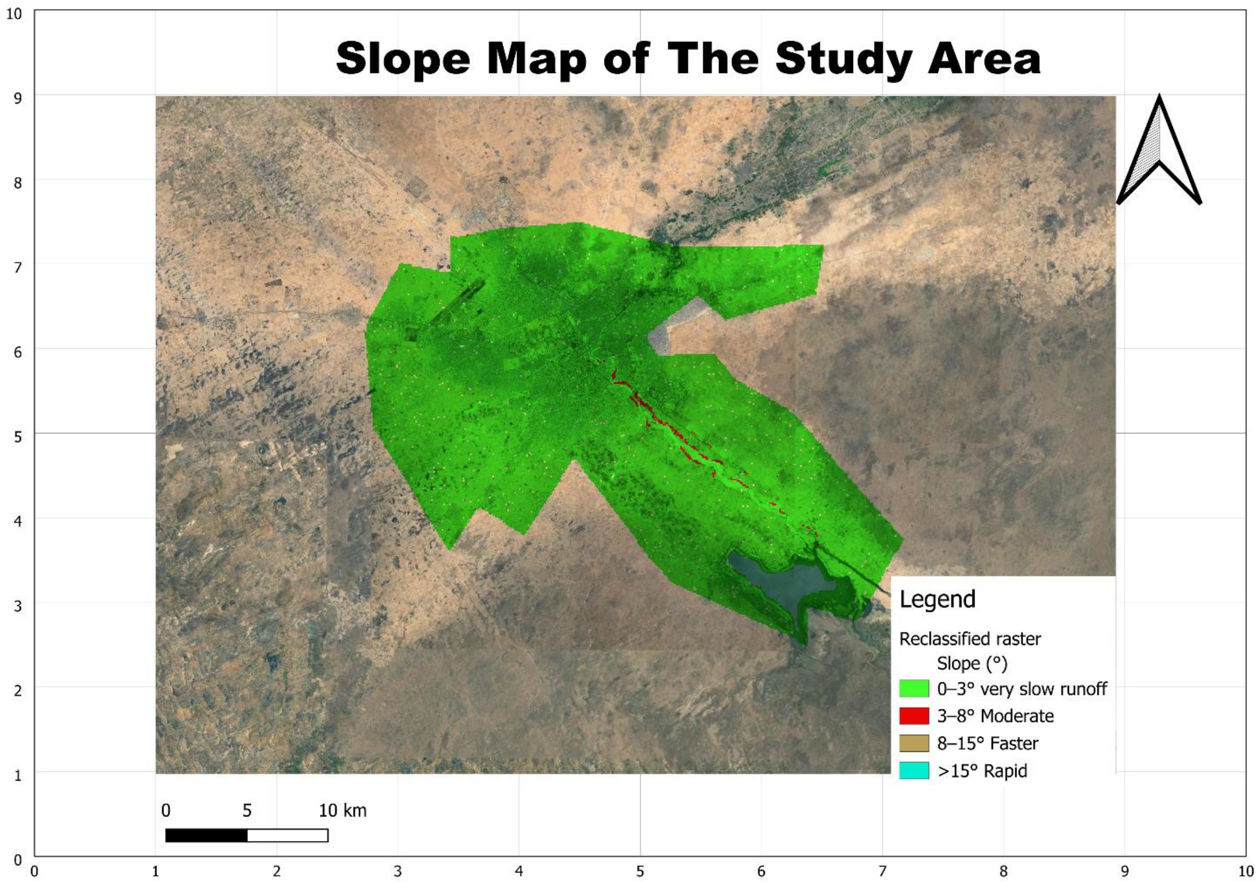

Figure 4 Slope Map of the Study Area

Table 1: Slope Classification

Slope Class	Area Coverage (%)	Hydrological Behavior
0–3°	90%	Very slow runoff, high stagnation
3–8°	6%	Moderate drainage
8–15°	3%	Faster runoff
>15°	1%	Rapid drainage zones

Hydrological flow modeling confirmed that drainage convergence paths funneled directly into the Ngadda River, focusing intense discharge pressure inside highly built-up urban sectors.

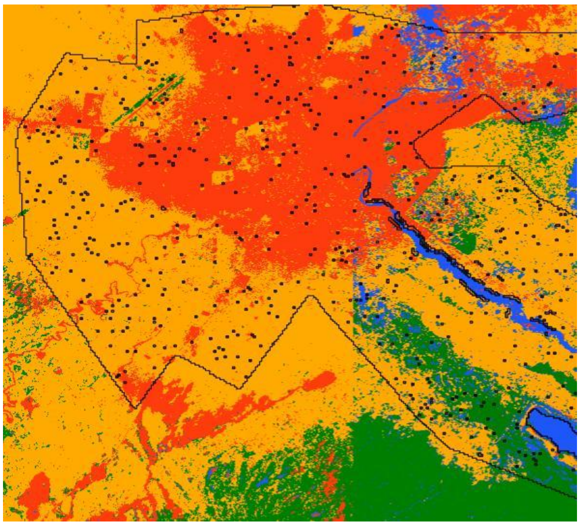

Figure 5: landscape dominated by agricultural land (41%) and built-up areas (32%), while vegetation cover

The results show a landscape dominated by agricultural land (41%) and built-up areas (32%), while vegetation cover accounts for 22% and water bodies represent only 5%. The land use pattern reflects a rapidly transforming landscape driven by urban expansion and agricultural intensification. The increasing proportion of built-up areas, particularly around Maiduguri and Jere, has significantly altered the natural hydrological balance of the catchment. By over-laying these layers within the multi-criteria Evaluation structure, a final composite *Flood Vulnerability Zonation Map* was derived:

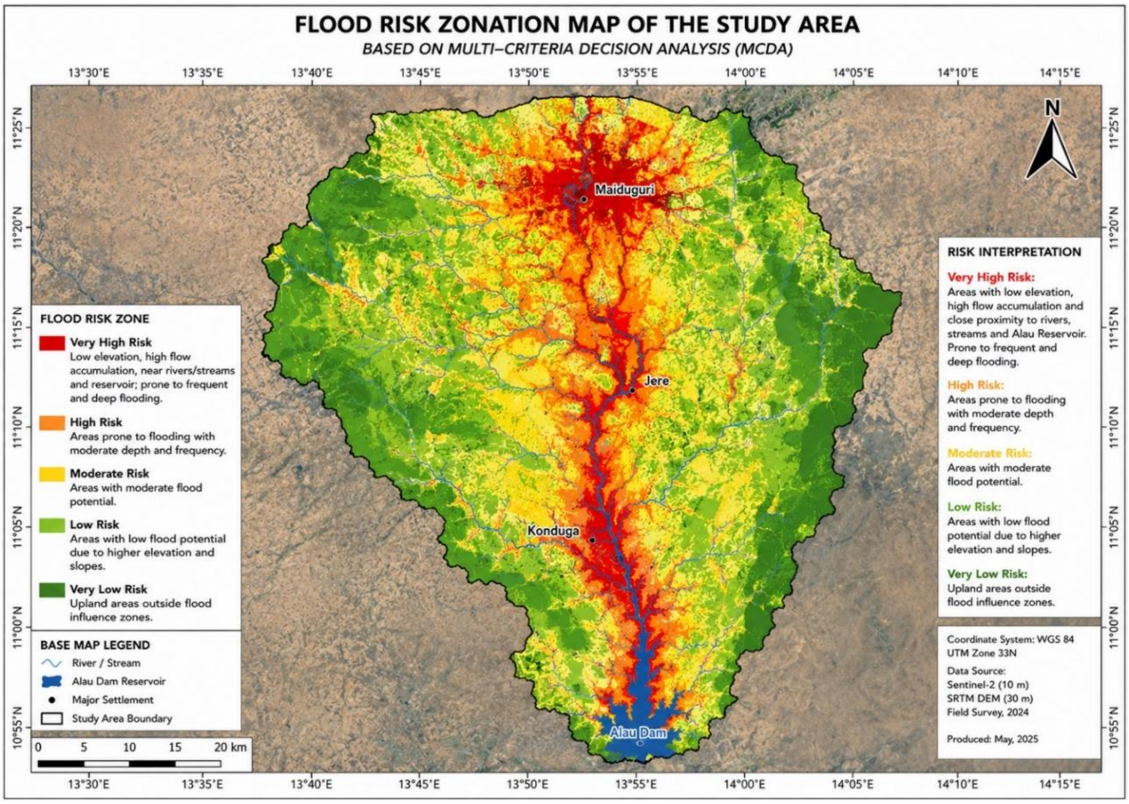

Figure 6 Flood risk Zonation Map of the Study Area

- Very High Risk (28%): Concentrated tightly along the immediate Ngadda River corridor and core urban Maiduguri.
- High Risk (34%): Propagating laterally into the expanding peri-urban zones of Jere LGA.
- Moderate Risk (25%): Occurring across mid-elevation agricultural buffer zones.
- Low Risk (13%): Limited strictly to elevated northern upstream catchments.

The results indicate a distinct spatial clustering of flood risk levels, strongly influenced by the combined effects of topography, drainage patterns, and land use characteristics.

A key observation from the map is that very high-risk zones are predominantly concentrated along the Ngadda River corridor. These areas correspond to low-lying floodplains with high flow accumulation, where surface runoff from upstream catchment areas converges naturally.

3.2 Human Dimensions and Household Realities

Socio-economic profiling showed a highly vulnerable community context: 67% of families relied entirely on the informal economic sector, and 54% had achieved a primary school level of formal education or less.

Table 2: Household Profile

Variable	Category	%
Gender	Male-headed	61
	Female-headed	39
Education	Primary or less	54
	Secondary	32
	Tertiary	14

Variable	Category	%
Occupation	Informal sector	67

Early Warning System Awareness Status:
While a baseline awareness rate of 58% exists, the 42% gap leaves nearly half the population isolated from official safety vectors. Communication distribution was heavily centered on traditional channels:

This distribution highlights a heavy reliance on traditional radio and local ward heads, while digital mobile warning tools remain underutilized. This communication framework directly impacts real-world evacuation efficiency:
Evacuation Performance Index:

Table 3 Response Behavior Index Classification

Score Range	Interpretation
2.50 – 3.00	High preparedness
1.75 – 2.49	Moderate preparedness
1.00 – 1.74	Low preparedness

The results of the Chi-square test indicated that there was a significant relationship between education level and preparedness with a significance level of $p<0.05$. The distribution of household response behaviour during flood events reveals that 46% of respondents took early response action, 38% delayed response action and 16% took no action at all.

Less than 50% of the respondents are involved in early response to flood warning indicates that proactive response to flood warning is still moderate in the study area. Early action usually refers to preparations for a flood, including evacuation with valuables, strengthening of household structures or moving to safer regions prior to the onset of floods. The 46% recorded here suggests there is some population who is responding appropriately to warning signals, but this is not the norm or consistent.

The 38% who stated that their responses were delayed is a considerable fraction of the population that acts in response to a flood after it has started or worsened. This late reaction decreases the effectiveness of early warning systems and exposes people to flood hazard damages. This may be related to doubt over the credibility of a warning, economic considerations, a lack of evacuation options, and/or the use of personal rather than official warning information.

Worse, is the 16% that said they did nothing during a flood event. The group is highly vulnerable and during the flood emergency, they are likely to be exposed directly to risks, suffer damage to their property, and may be exposed to safety risks as a result of inaction. This proportion suggests information gaps, access to information or preparedness capacity gaps.

Overall, the findings indicate that there is some awareness and some response in place but not necessarily enough to translate into timely and effective action. The pattern of responses shows that there is a behavioural gap between receiving the early warning information and taking action, resulting in poor effectiveness of the flood risk reduction strategies in the Alau dam catchment area.

3.3 Inferential Modeling & Predictor Dynamics

A Chi-square test of independence was conducted to examine the relationship between selected socio-economic variables and household flood early warning awareness and response behaviour in the Alau Dam catchment area.

Table 4.7: Chi-Square Test Results

Variable Pair	χ^2 Value	df	p-value	Decision
Education level Vs Early warning awareness	18.42	2	0.000	Significant
Income level Vs Preparedness actions	14.67	2	0.001	Significant
Warning reception Vs Household response	21.35	2	0.000	Significant

As for the Chi square results, there is a significant association between all of the tested variables with a p-value < 0.05. Statistically the relationship is significant between the education and awareness ($\chi^2 = 18.42$, $p = 0.000$). This implies that households with higher education are more likely to properly understand and interpret effective flood early warning messages.

To test the strength of these predictors simultaneously, a Binary Logistic Regression model was developed A binary logistic regression model was used to determine the factors influencing household preparedness and response to flood early warning messages. The dependent variable was household response (1 = appropriate response, 0 = no/poor response).

Table 4.8: Logistic Regression Results

Variable	β Coefficient	Std. Error	Wald	p-value	Exp(β)
Education level	0.842	0.214	15.43	0.000	2.32
Income level	0.615	0.198	9.65	0.002	1.85
Early warning awareness	1.102	0.256	18.47	0.000	3.01
Access to mobile alerts	0.754	0.231	10.67	0.001	2.12

Model Fit: Nagelkerke $R^2 = 0.61$
General classification accuracy = 78.4%

The regression model shows that all the predictors are significant in influencing the responses of the households. Education is significantly and positively related to ($\beta = 0.842$, $p = 0$). Households have a 2.3 times greater likelihood of taking correct action when warned of flooding in households with more highly educated household members. Education improves the understanding of risk, decision-making ability and action to scientific and institutional warnings. This further confirms the previous Chi-square result and the importance of human capital for disaster resiliency.

Appropriate response is also significantly predicted ($\beta = 0.615$, $p = 0.002$), where an increase in income would increase the likelihood of an appropriate response by 1.85 times. Financial means dictate whether or not households are able to evacuate, to secure property, or to move to a safer place. For low-income groups, there is a lack of alternatives, therefore these groups are in vulnerable situations because of floods.

This is the biggest predictor ($\beta = 1.102$, $p = 0.000$) and indicates that awareness translates into a 3x greater chance of appropriate response. This discovery reinforces the fact that behavioural driver side awareness is the most important driver of behaviour. Qualitative data indicate, though, that awareness is not enough if not coupled with trust, clarity and timely dissemination.

Response behaviour is significantly better with mobile-based alerts ($\beta = 0.754$, $p = 0.001$).
This is in line with the rising significance of digital communication in DRM. Although the use of mobile systems is still patchy, however, due to network coverage limitations in rural areas of the catchment. However, qualitative KIIs and FGDs revealed institutional limitations that hinder effective response. Key themes included:

- Inter-Agency Coordination Gaps: Operational disconnects between dam management authorities, SEMA, and NiMet lead to delayed warnings.
- Information Bottlenecks: Technical reservoir measurements are not translated into simple, timely actionable local directives.
- Socio-Economic Barriers: Due to deep-seated poverty, many low-income households delay evacuation to protect their minimal physical assets, despite being aware of the incoming hazard.

4. Conclusion and Recommendations

This study demonstrates that flood risk inside the Alau Dam catchment area is a socio-hydrological phenomenon. The physical terrain—characterized by flat slopes and low elevations—creates a natural susceptibility to flooding, which is further exacerbated by unplanned urban expansion and vegetative loss. While technical forecasting components exist, the early warning system's performance is limited by weak communication structures, institutional silos, and low adaptive capacity among vulnerable populations.

To build systemic long-term resilience, this study recommends:

1. Transitioning to a People-Centered Framework: Relaying forecasts via automated, localized SMS platforms in local languages to reduce the 42% awareness gap.
2. Upgrading Infrastructure: Integrating automated telemetric gauge stations along upstream rivers to provide real-time water level data to downstream communities.
3. Strengthening Institutional Coordination: Establishing a unified digital dashboard linking Alau Dam operators with emergency responders (SEMA/NiMet) to eliminate communication delays.
4. Implementing Land Use Controls: Enforcing strict zoning regulations along the Ngadda River floodplain to curb urban expansion into the identified high-risk zones.

References

- Adelekan, I. O. (2016). Flood risk management in Nigeria: A review of the challenges and opportunities. *International Journal of Disaster Risk Reduction*, 14, 203-211.
- Adeyemi, A. O., et al. (2024). Spatial modeling of flood hazard using GIS and remote sensing in sub-Saharan catchments. *Journal of Hydrological Sciences*, 69(2), 145-159.
- Akinyemi, O., et al. (2021). Institutional constraints in disaster risk communication: Lessons from regional emergency frameworks in West Africa. *Environmental Science & Policy*, 122, 45-56.
- Amoako, C., & Boamah, E. F. (2015). The three-dimensional vulnerabilities of flooding in urban Ghana. *Disasters*, 39(4), 709-729.
- Atijosan, A. O., et al. (2021). Geospatial assessment of flood risk vulnerability in urbanized plains of Nigeria. *Remote Sensing Applications: Society and Environment*, 23, 100-112.

- Basher, R. (2006). Global early warning systems for natural hazards: Systematic and people-centred. *Philosophical Transactions of the Royal Society A*, 364(1845), 2167-2182.
- Basher, R. (2021). *Proactive Disaster Risk Reduction: Principles and Practice*. Academic Press.
- Birkmann, J., et al. (2022). Frameworks and indicators for assessing vulnerability and risk: A systematic review. *International Journal of Disaster Risk Reduction*, 70, 102-115.
- Cardona, O. D., et al. (2012). Determinants of risk: Exposure and vulnerability. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 65-108). Cambridge University Press.
- Cutter, S. L., et al. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, 84(2), 242-261.
- Cutter, S. L., et al. (2016). Systems theory and disaster risk: Conceptualizing coupled human-natural interactions. *Global Environmental Change*, 40, 12-23.
- Cutter, S. L., et al. (2023). Dynamic systems and cascading disaster failures in urban environments. *Nature Hazards Review*, 24(1), 44-58.
- Di Baldassarre, G., et al. (2015). Perspectives on socio-hydrology: Capturing feedbacks between physical and social systems. *Hydrological Sciences Journal*, 60(8), 1269-1275.
- Eze, E. B., et al. (2020). Community perception and response strategies to flood early warnings in North-Eastern Nigeria. *African Journal of Environmental Science*, 14(3), 88-101.
- Farr, T. G., et al. (2007). The Shuttle Radar Topography Mission. *Reviews of Geophysics*, 45(2), RG2004.
- Giustarini, L., et al. (2015). The value of SRTM data for hydrodynamic modelling in data-scarce catchments. *Hydrology and Earth System Sciences*, 19(8), 3523-3539.
- Hallegatte, S., et al. (2013). Future flood losses in major coastal cities. *Nature Climate Change*, 3(9), 802-806.
- Haque, U., et al. (2018). The efficiency of community-based early warning platforms: Comparative global evaluations. *PLOS ONE*, 13(4), e0195500.
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Kelman, I. (2020). *Disaster by Choice: How Human Actions Create Natural Disasters*. Oxford University Press.
- Khosravi, K., et al. (2018). A comparative assessment of multi-criteria decision-making models for flood susceptibility mapping. *Environmental Earth Sciences*, 77(1), 1-16.
- Komolafe, A. A., et al. (2020). Flood hazard engineering and spatial vulnerability modeling in Nigeria: A review. *Journal of African Earth Sciences*, 164, 103-117.
- Longley, P. A., et al. (2015). *Geographic Information Systems and Science* (4th ed.). John Wiley & Sons.
- Munawar, H. S., et al. (2022). Towards an integrated remote sensing framework for real-time flood monitoring and early warning alerts. *Remote Sensing*, 14(3), 567.
- National Emergency Management Agency (NEMA). (2019). *National Disaster Preparedness Plan and Institutional Guidelines for Emergency Response in Nigeria*. NEMA Press.
- Nkwunonwo, U. C., et al. (2020). Flooding and flood risk reduction strategies in Nigeria: A focus on urban areas. *Geoenvironmental Disasters*, 7(1), 1-17.
- Nwilo, P. C., et al. (2020). Methodological approaches to GIS-based flood vulnerability mapping within the Niger River Basin. *International Journal of Geoinformatics*, 16(2), 34-48.

- Olanrewaju, C. C., et al. (2023). Gaps and bottlenecks in flood early warning communication networks within developing economies. *Natural Hazards*, 115(2), 1145-1162.
- Paul, S. K., & Routray, J. K. (2010). Flood vulnerability and coping capacity of households in Bangladesh. *Natural Hazards*, 55(1), 115-129.
- Rana, I. A., & Routray, J. K. (2018). Multidimensional social vulnerability assessment to floods using standard indices. *International Journal of Disaster Resilience in the Built Environment*, 9(3), 234-250.
- Samela, C., et al. (2018). GIS-based multi-criteria evaluation layout for identifying flood-prone landscapes. *Water*, 10(2), 143.
- Shrestha, M. S., et al. (2021). Institutional challenges in building people-centered end-to-end early warning systems. *International Journal of Disaster Risk Science*, 12(4), 488-501.
- Tingsanchali, T. (2012). Urban flood disaster management. *Procedia Engineering*, 32, 25-37.
- Turner, B. L., et al. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*, 100(14), 8074-8079.
- Twigg, J. (2015). *Disaster Risk Reduction* (Good Practice Review 9). Humanitarian Policy Group.
- Twumasi, Y. A., et al. (2020). Public trust deficits and information sharing interfaces during hydrological emergencies. *Journal of Environmental Management*, 270, 110-123.
- UNDRR. (2015). *Sendai Framework for Disaster Risk Reduction 2015–2030*. United Nations Office for Disaster Risk Reduction.
- UNDRR. (2022). *Global Assessment Report on Disaster Risk Reduction 2022*. United Nations Office for Disaster Risk Reduction.
- Wang, Y., & Xie, Y. (2018). Scenario-based spatial modeling of urban flood propagation paths using GIS. *Computers, Environment and Urban Systems*, 71, 112-124.
- Wisner, B., et al. (2012). *At Risk: Natural Hazards, People's Vulnerability and Disasters* (2nd ed.). Routledge.
- Zhang, X., et al. (2023). Non-linear systemic failures in dam-regulated river basins. *Water Resources Research*, 59(4), e2022WR032.