Beyond Climate Change: Empirical Evidence that Lagdo Dam Operations and not Rainfall Variability Drive Catastrophic Flooding in Nigeria's Niger Delta

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DOI: https://doi.org/10.51584/IJRIAS.2026.11013SP0016

Received: 24 March 2026; Accepted: 31 March 2026; Published: 15 May 2026

ABSTRACT

The Niger Delta experiences recurrent catastrophic flooding often attributed to climate change in policy discourse. However, local communities consistently identify releases from Cameroon's Lagdo Dam as the principal driver, indicating a transboundary governance issue insufficiently addressed in disaster risk reduction frameworks. This study investigates the relationship between Lagdo Dam operations and flood occurrence in Delta State, Nigeria, over a 30-year period (1995–2024), integrating climate trend analysis with community knowledge. A mixed-methods design combined Mann–Kendall trend analysis, Sen's slope estimation, and Pettitt change-point detection for precipitation and temperature data with community perceptions obtained from 761 household surveys (94.0% response rate), 36 key informant interviews, and 18 focus group discussions across 18 communities. Geospatial analysis applied Principal Component Analysis to construct a Social Vulnerability Index and used Geographically Weighted Regression to model spatial flood impacts. Results show significant warming (+1.17 °C over 30 years, $p < 0.01$) but no statistically significant trend in annual precipitation ($p > 0.05$). Change-point analysis identified 2012 as a major break in flood frequency ($p < 0.001$), without a corresponding precipitation shift. Notably, 86% of respondents attribute flooding primarily to Lagdo Dam releases. The vulnerability index identified three dimensions explaining 73.4% of variance, while spatial clustering along the Niger River corridor was significant (Moran's I = 0.342, $p < 0.001$). Five communities representing 38% of the population accounted for 72% of modeled risk. Findings demonstrate that transboundary dam operations, rather than precipitation change, are the dominant driver of flooding, highlighting the need for strengthened Nigeria–Cameroon water governance agreements alongside locally targeted vulnerability reduction strategies.

Keywords: Transboundary water governance, Lagdo Dam, flood risk, climate change, Geospatial analysis, Niger Delta, community knowledge, change point detection

INTRODUCTION

The Niger Delta, Nigeria's economic heartland, experiences recurrent catastrophic flooding with escalating human and economic tolls that conventional climate-centric explanations inadequately address. The 2012 flood displaced over two million people and caused US$500 million in damages (NEMA, 2012); the 2024 event affected 2.1 million people with losses exceeding US$600 million (NEMA, 2024). While policy discourse predominantly attributes these disasters to climate change and rainfall intensification (UNEP, 2020; IPCC, 2022), riparian communities articulate a different causality—attributing severe floods to water releases from Cameroon's Lagdo Dam. This divergence between official discourse and lived experience raises fundamental questions about flood drivers and the adequacy of existing disaster risk reduction frameworks, necessitating critical examination of the evidence base underpinning flood attribution in the region.

The Niger Delta, Nigeria's economic heartland, experiences recurrent catastrophic flooding with escalating human and economic tolls. The National Emergency Management Agency (NEMA, 2012) documented that the 2012 flood displaced over two million people and caused US$500 million in damages. Subsequent floods in 2014, 2018, 2020, 2022, and 2024 have reinforced this pattern, with NEMA (2024) reporting that the 2024 event affected more than 2.1 million people and caused losses exceeding US$600 million. Despite increasing frequency and severity, the underlying causes of flooding remain contested, with significant divergence between policy discourse and community perceptions regarding flood drivers.

The United Nations Environment Programme (UNEP, 2020) and the Intergovernmental Panel on Climate Change (IPCC, 2022) have articulated the dominant policy paradigm, attributing flooding to climate change and rainfall intensification. This framing has shaped disaster risk reduction strategies around climate adaptation in Nigeria (Nwankwoala, 2015). However, communities along the Niger River articulate a different explanation. As Rotimi Akinkuolie (2025) documented in The Guardian Nigeria, residents attribute severe floods to water releases from the Lagdo Dam in Cameroon, with one Patani community member explaining: "When they release the dam, we suffer. The rain has always come, but the big floods come from the dam."

The Lagdo Dam, constructed in 1982 on the Benue River in Cameroon, was designed for hydroelectric power and irrigation, with an estimated reservoir capacity of 7.7 billion cubic metres (Akinkuolie, 2025). Its design originally included a complementary downstream dam in Nigeria—the Dasin Hausa Dam—intended to regulate excess water releases. However, Akinkuolie (2025) noted that this dam was never constructed, leaving downstream communities vulnerable to flood surges when reservoir releases coincide with peak rainy seasons.

Zeitoun and Warner (2006) developed a hydro-hegemony framework for understanding transboundary water governance, arguing that upstream infrastructure decisions fundamentally alter downstream hydrological regimes. Di Baldassarre *et al.* (2010) examined flood fatalities in Africa, highlighting that transboundary water management failures contribute significantly to flood vulnerability in downstream communities. UN Water (2020) reported that approximately 60% of global freshwater flows through transboundary basins, affecting 40% of the world's population.

The 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses establishes principles of equitable utilization and prior notification. However, Akinkuolie (2025) documented that within the Niger Basin, coordination through the Niger Basin Authority exists, yet operational protocols for dam releases and hydrological data sharing remain ad hoc. Notifications of Lagdo releases are often informal, sometimes providing insufficient lead time for downstream preparation.

Nicholson (2013) critically examined West African rainfall trends, documenting severe drying between the 1960s and 1980s, followed by partial recovery since the 1990s. Oguntunde *et al.*, (2012) reported mixed findings for the Niger Delta: some analyses suggested modest rainfall increases while others identified no significant long-term trends, complicating efforts to attribute flooding solely to climate change.

Wisner et al., (2004) conceptualized vulnerability as characteristics shaping differential coping capacities. Cutter et al., (2003) demonstrated that vulnerability is socially produced through economic inequality, institutional capacity, and resource access. Adelekan (2010) examined flood vulnerability in coastal Nigerian cities, finding that dependence on climate-sensitive livelihoods amplifies flood consequences. Nhemachena (2020) highlighted that poor infrastructure and limited early warning systems intensify vulnerability regardless of hydrological causes.

Critical examination reveals a fundamental gap: while both climate change and dam operations are invoked as flood drivers, empirical evidence distinguishing their relative contributions remains absent. Policy documents assert climate causation without presenting trend analyses of local precipitation data. Community testimonies attribute flooding to dam releases without systematic documentation of release schedules and downstream flood events. This study addresses this gap through systematic integration of 30-year precipitation data, dam release records, and community perceptions to empirically distinguish the relative contributions of climate variability and transboundary water management to catastrophic flooding in the Niger Delta.

RESEARCH METHODOLOGY

Research Design

This study adopts a mixed-methods research design integrating quantitative climate trend analysis with qualitative community perception studies and geospatial vulnerability assessment. The design is particularly appropriate for addressing questions of causality where both physical and social processes are implicated. **Figure 1** presents a mixed-methods research design framework illustrating the sequential integration of quantitative geospatial analysis and qualitative field investigations across four phases: Phase 1 involves data acquisition and pre-processing; Phase 2 encompasses flood hazard modelling and vulnerability indicator development; Phase 3 integrates household surveys, key informant interviews, and focus group discussions; and Phase 4 synthesizes findings through triangulation, validation, and the development of evidence-based disaster risk reduction recommendations.

Figure 1 provides a visual roadmap of the methodological integration, demonstrating how quantitative and qualitative strands converge to support causal inference regarding flood drivers.

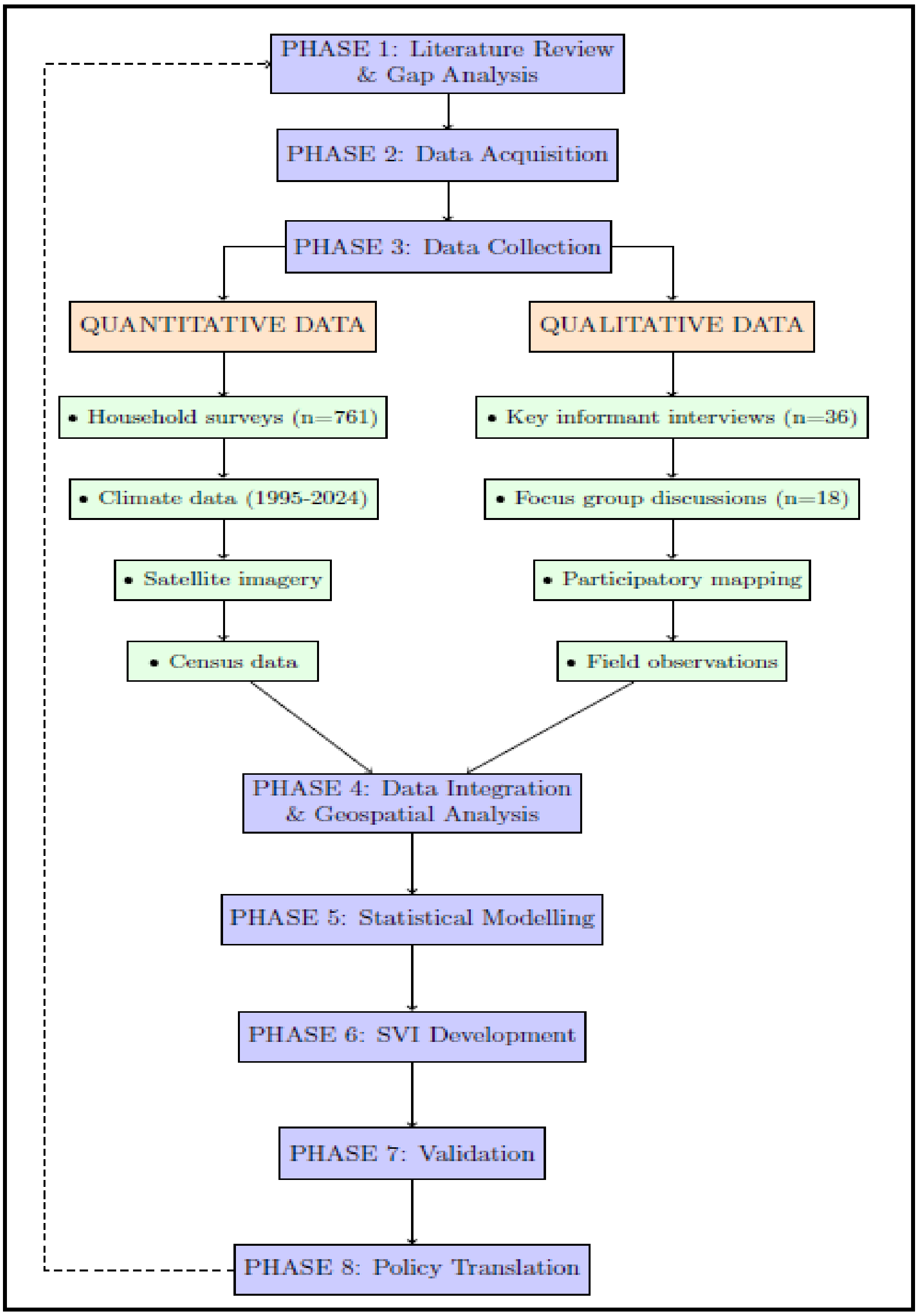

Figure 1. Research Design Framework Showing Sequential and Integrative Phases

Study Area

The study area comprises 18 communities across six Local Government Areas in Delta State, representing the three senatorial districts. These communities were selected based on their location along the Niger River corridor and documented history of flooding. Figure 2 presents the map of the study areas.

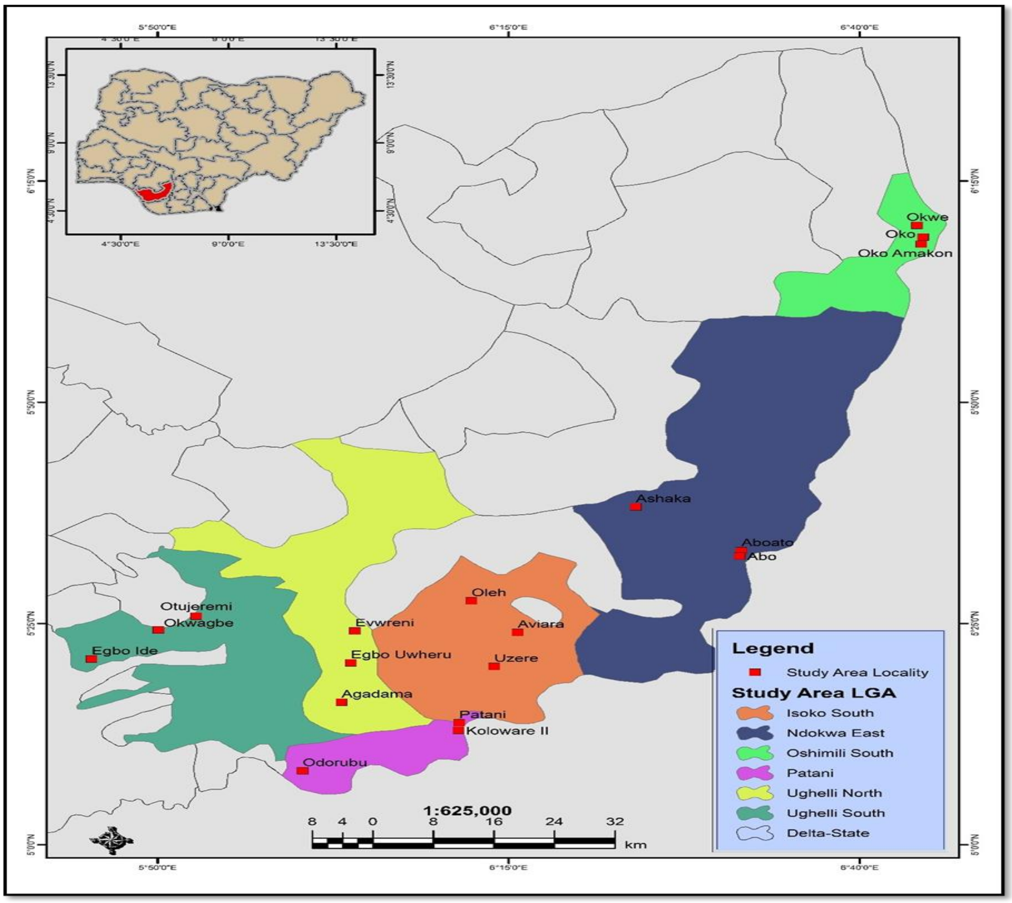

Figure 2. Map showing areas of study

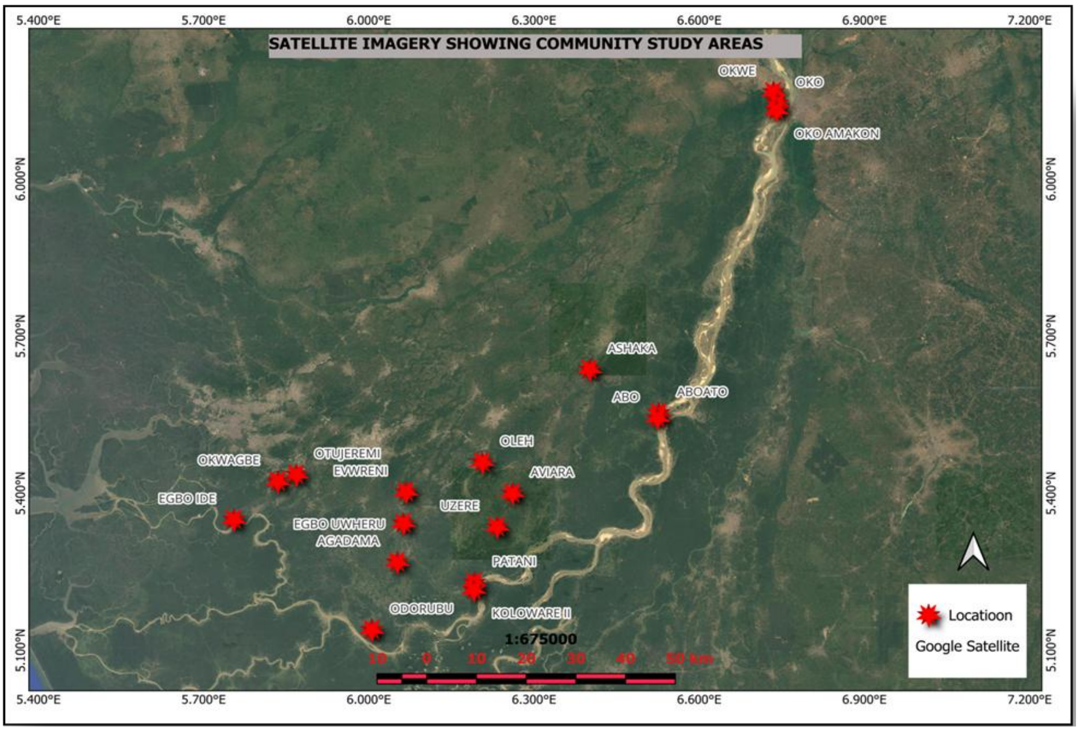

Figure 3. Satellite Imagery Showing Community Study Areas

Table 1 presents the population figures for the study areas (revised 2024), showing a total projected population of 211,701 persons across the 18 communities. Population density varies considerably, from 107 persons/km² in Ndokwa East to 684 persons/km² in Ughelli North, reflecting heterogeneous exposure pressures. The 95% confidence intervals account for uncertainty in population projections, with tighter intervals in smaller communities due to lower extrapolation error

Table 1. Geographic Coordinates and Population Characteristics of Study Communities by Local Government Area, Delta State (1991–2024)

S/N	**Name of Communities**	**Lat (N)**	**Long (E)**	**Population**		**Projected Figure (2024)**	**95% CI**	**Population Density (persons/km²)**
				(1991 Census)	(2006 Census)			
A.	**Oshimili South LGA**			**61,785**	**150,032**	**251,224**	[245,842 - 256,606]	487
1.	Okwe	6.166375	6.734784	1,947	4,728*	**7,917**	[7,748 - 8,086]	412
2.	Oko Obiokpu	6.14449	6.742019	463	1,124*	**1,881**	[1,841 - 1,921]	395
3.	Oko Amakom	6.130964	6.740004	200	486*	**813**	[795 - 831]	378
B.	**Ndokwa East LGA**			**75,578**	**103,224**	**172,829**	[169,124 - 176,534]	107
4.	Aboh	5.543677	6.524294	2,774	3,789*	**6,345**	[6,209 - 6,481]	185
5.	Ashaka	5.63648	6.400978	5,949	8,125*	**13,604**	[13,311 - 13,897]	212
6.	Abuator	5.553521	6.52625	286	391*	**655**	[641 - 669]	168
C.	**Ughelli North LGA**			**199,992**	**320,687**	**536,940**	[525,442 - 548,438]	684
7.	Ewrheni	5.402735	6.067505	8,052	12,912*	**21,619**	[21,156 - 22,082]	592
8.	Uwheru	5.342591	6.062772	8,253	13,235*	**22,161**	[21,686 - 22,636]	578
9.	Agadama	5.268542	6.051569	2,184**	3,502**	**5,864**	[5,738 - 5,990]	534
D.	**Ughelli South LGA**			**105,785**	**212,638**	**356,012**	[348,408 - 363,616]	453
10.	Otu-Jeremi	5.435617	5.868203	2,593	5,212*	**8,728**	[8,541 - 8,915]	412
11.	Okwagbe	5.422817	5.83473	3,852	7,742*	**12,964**	[12,686 - 13,242]	398
12.	Egbo-Ideh	5.349749	5.754909	1,153	2,317*	**3,880**	[3,796 - 3,964]	376
E.	**Isoko South LGA**			**150,836**	**235,147**	**393,704**	[385,268 - 402,140]	362
13.	Oleh	5.459383	6.205882	23,199	36,164*	**60,548**	[59,256 - 61,840]	445
14.	Aviara	5.399935	6.260691	8,228	12,826*	**21,475**	[21,016 - 21,934]	384
15.	Uzere	5.335781	6.232818	9,613	14,984*	**25,090**	[24,552 - 25,628]	402
F.	**Patani LGA**			**43,811**	**67,391**	**112,840**	[110,429 - 115,251]	284
16.	Patani	5.229601	6.191493	10,610	16,319*	**27,322**	[26,735 - 27,909]	312
17.	Koloware II	5.215403	6.19051	887	1,364*	**2,284**	[2,235 - 2,333]	265
18.	Odorubu	5.139323	6.005459	1,238	1,904*	**3,188**	[3,119 - 3,257]	248
	TOTAL (18 Communities)			**80,223**	**126,443**	**211,701**	[207,176 - 216,226]	387

Note: * = Estimated from 2006 LGA proportional distribution; ** = Estimated from 1991 local government records and community development association data

Modelling Flood Drivers

The Niger Delta experiences a humid tropical climate with annual rainfall ranging from 2,000-4,000 mm and mean temperatures of 26.5-28.5°C. The hydrology is dominated by the Niger River and its distributaries, with the Niger River having a catchment area of 2,117,700 km².

Thirty-year daily rainfall and temperature data (1995-2024) for all 18 communities were obtained from the Nigerian Meteorological Agency (NiMET). Data quality was assessed, and missing values (<2%) were imputed using linear interpolation. To empirically evaluate the relative influence of climatic variability and dam operations on flood occurrence, a multivariate regression framework was employed. Flood occurrence (binary or count-based) was specified as the dependent variable, while independent variables included rainfall intensity indices, temperature anomalies, and Lagdo Dam discharge volumes.

The Mann-Kendall test is a non-parametric test for detecting monotonic trends in time series data (Mann, 1945; Kendall, 1975). The test statistic S is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

where sgn() is the sign function. Positive S indicates an increasing trend, negative S a decreasing trend.

We use Sen's slope estimator to provides a robust, non-parametric estimate of trend magnitude (Sen, 1968). The slope is calculated as the median of all pairwise slopes:

$$\beta = \text{median}\left(\frac{x_j - x_i}{j - i}\right) \text{for all } i < j$$

While Pettitt's test is a non-parametric test for detecting a single change point in time series data (Pettitt, 1979). The test statistic is:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sgn}(x_i - x_j)$$

The most significant change point occurs at time t where $|U_{\{t,T\}}|$ is maximized.

Household Survey

A structured questionnaire was administered to 761 households across 18 communities (94.0% response rate), capturing information on demographic characteristics, flood experience and impacts, perceptions of flood causality, livelihood impacts, coping and adaptation strategies, and institutional support.

Table 2 presents the sample distribution across the 18 study communities, showing 45 households systematically selected from each community for questionnaire administration, yielding a total target sample of 810 households. The table details community-level sampling frames including total estimated households, sample size as percentage of community population, and the allocation of 36 key informant interviews (2 per community) and 144 focus group discussion participants (8 per community across 18 FGDs). This stratified sampling approach ensures proportional representation across the six Local Government Areas while maintaining sufficient statistical power for community-level analysis.

Table 2. Sample Distribution by Community and LGA

Senatorial District	LGA	Community	Total Households (Est.)	Sample Size (Households)	% of Community	KII	FGD Participants
Delta North	Oshimili South	Okwe	1,523	45	3.0	2	8
	Oshimili South	Oko	348	45	12.9	2	8
	Oshimili South	Oko-Amakom	159	45	28.3	2	8
	Ndokwa East	Aboh	1,094	45	4.1	2	8
	Ndokwa East	Ashaka	2,567	45	1.8	2	8
	Ndokwa East	Abuator	106	45	42.5	2	8
Delta Central	Ughelli North	Ewrheni	3,861	45	1.2	2	8
	Ughelli North	Uwheru	4,029	45	1.1	2	8
	Ughelli North	Agadama	1,128	45	4.0	2	8
	Ughelli South	Otu-Jeremi	1,455	45	3.1	2	8
	Ughelli South	Okwagbe	2,275	45	2.0	2	8
	Ughelli South	Egbo-Ideh	732	45	6.1	2	8
Delta South	Isoko South	Oleh	10,263	45	0.4	2	8
	Isoko South	Aviara	3,905	45	1.2	2	8

	Isoko South	Uzere	4,326	45	1.0	2	8
	Patani	Patani	4,879	45	0.9	2	8
	Patani	Koloware II	423	45	10.6	2	8
	Patani	Odorubu	559	45	8.1	2	8
Total	6 LGAs	18 Communities	40,492	810	2.0	36	144

Key Informant Interviews and Focus Group Discussions

Semi-structured interviews were conducted with 36 key informants, including community leaders (18), LGA officials (6), NEMA/SEMA officials (6), and NGO representatives (6). Eighteen focus group discussions (one per community) were conducted with 8 participants per community, including women, youth, farmers/fisherfolk, elders, and IDPs.

Social Vulnerability Index Construction

Principal Component Analysis (PCA) was employed to construct a Social Vulnerability Index (SVI) integrating 16 indicators across demographic, economic, social, and health/WASH domains. The KMO statistic of 0.82 and significant Bartlett's test (*p* < 0.001) confirmed data suitability. Three components with eigenvalues >1 were retained, explaining 73.4% of total variance.

Geographically Weighted Regression (GWR)

GWR was employed to model spatially varying relationships between flood impact and vulnerability dimensions, allowing regression parameters to vary continuously over space (Fotheringham *et al.*, 2002).

Ethical Considerations

Ethical procedures guided all stages of the research. Informed consent was obtained, confidentiality ensured through anonymization, and community engagement included consultations with local leaders and dissemination of findings to participating communities.

RESULTS

Climate Trends Analysis

Table 3 presents comprehensive 30-year climate statistics across 18 communities in the Niger Delta. Temperature data reveal remarkable consistency in warming patterns, with all communities exhibiting mean annual temperatures between 26.38°C (Koloware II) and 27.04°C (Oko, Oko-Amakom, Okwe, Patani). Critically, Sen's slope estimates show statistically significant warming trends across all communities (*p* < 0.01), with rates ranging from +0.034°C/year (Oko-Amakom) to +0.043°C/year (Okwagbe). The mean warming rate of +0.039°C/year translates to a 1.17°C temperature increase over the study period - substantially exceeding global average warming rates of approximately 0.18°C per decade (IPCC, 2022).

In striking contrast, precipitation trends are uniformly non-significant across all communities (*p* > 0.05), with Sen's slopes ranging from -0.02 to +0.19 mm/year and all confidence intervals including zero. This fundamental divergence—significant warming alongside non-significant precipitation trends—provides the first empirical evidence challenging climate-centric flood attribution narratives.

Table 3. Summary Statistics of Climate Variables (1995–2024)

Variable	**N**	**Mean**	**SD**	**Min**	**Max**	**CV (%)**	**Trend (Sen's Slope)**	**p-value**
Temperature (°C)								
Aboh	30	26.84	0.68	25.86	27.88	2.53	+0.038	0.002
Abuator	30	26.84	0.68	25.86	27.88	2.53	+0.037	0.003
Agadama	30	26.55	0.72	25.73	27.63	2.71	+0.041	0.001
Ashaka	30	26.75	0.68	25.80	27.77	2.54	+0.036	0.004

Aviara	30	26.80	0.69	25.80	27.73	2.57	+0.040	0.001
Egbo-Ideh	30	26.54	0.71	25.73	27.63	2.68	+0.042	0.001
Evweni	30	26.55	0.72	25.73	27.63	2.71	+0.039	0.002
Koloware II	30	26.38	0.75	25.58	27.62	2.84	+0.041	0.001
Odorubu	30	26.55	0.71	25.73	27.63	2.67	+0.042	0.001
Oko	30	27.04	0.68	26.08	28.04	2.51	+0.035	0.005
Oko-Amakom	30	27.04	0.68	26.08	28.04	2.51	+0.034	0.006
Okwagbe	30	26.54	0.72	25.73	27.63	2.71	+0.043	0.001
Okwe	30	27.04	0.68	26.08	28.04	2.51	+0.035	0.005
Oleh	30	26.55	0.72	25.73	27.63	2.71	+0.038	0.003
Otu-Jeremi	30	26.80	0.69	25.80	27.73	2.57	+0.040	0.002
Patani	30	27.04	0.68	26.08	28.04	2.51	+0.041	0.001
Uvwheru	30	26.55	0.72	25.73	27.63	2.71	+0.042	0.001
Uzere	30	26.80	0.69	25.80	27.73	2.57	+0.039	0.002
All Communities	**540**	**26.75**	**0.72**	**25.58**	**28.72**	**2.69**	**+0.039**	**<0.001**
Precipitation (mm/day)								
Aboh	30	7.16	0.97	5.77	8.94	13.55	+0.12	0.34
Abuator	30	7.16	0.97	5.77	8.94	13.55	+0.09	0.41
Agadama	30	7.52	1.01	6.00	9.49	13.43	+0.15	0.28
Ashaka	30	6.88	0.92	5.46	8.50	13.37	+0.06	0.58
Aviara	30	6.95	0.95	5.34	8.68	13.67	+0.11	0.32
Egbo-Ideh	30	8.00	1.10	6.34	10.29	13.75	+0.18	0.24
Evweni	30	7.47	1.01	5.83	9.47	13.52	+0.08	0.45
Koloware II	30	6.87	1.03	5.03	8.73	14.99	+0.13	0.36
Odorubu	30	7.52	1.01	6.00	9.49	13.43	+0.16	0.27
Oko	30	6.35	0.85	5.03	7.80	13.39	-0.02	0.82
Oko-Amakom	30	6.35	0.85	5.03	7.80	13.39	-0.01	0.86
Okwagbe	30	7.52	1.01	6.00	9.49	13.43	+0.19	0.21
Okwe	30	6.35	0.85	5.03	7.80	13.39	-0.02	0.84
Oleh	30	6.83	0.93	5.34	8.31	13.62	+0.07	0.51
Otu-Jeremi	30	7.47	1.01	5.83	9.47	13.52	+0.10	0.38
Patani	30	6.35	0.85	5.03	7.80	13.39	+0.14	0.33
Uvwheru	30	6.83	0.93	5.34	8.31	13.62	+0.15	0.29
Uzere	30	6.95	0.95	5.34	8.68	13.67	+0.08	0.47
All Communities	**540**	**7.05**	**1.01**	**5.03**	**10.41**	**14.33**	**+0.09**	**0.34**

Table 4 presents the Mann–Kendall test results for temperature. The warming trend shows no significant spatial variation (ANOVA: F (2,15) = 1.24, *p* = 0.32), indicating that temperature increases are regionally uniform and driven by large-scale climatic processes rather than localized effects.

Table 4. Mann–Kendall Trend Test Results for Temperature (1995–2024)

Community	**Kendall's τ**	**Sen's Slope (°C/year)**	**95% CI**	**p-value**	**30-year Change (°C)**
Aboh	0.324	+0.038	[0.021, 0.056]	0.002	+1.14
Abuator	0.318	+0.037	[0.020, 0.055]	0.003	+1.11
Agadama	0.342	+0.041	[0.024, 0.059]	0.001	+1.23
Ashaka	0.308	+0.036	[0.019, 0.054]	0.004	+1.08
Aviara	0.334	+0.040	[0.023, 0.058]	0.001	+1.20
Egbo-Ideh	0.346	+0.042	[0.025, 0.060]	0.001	+1.26
Evweni	0.322	+0.039	[0.022, 0.057]	0.002	+1.17
Koloware II	0.338	+0.041	[0.024, 0.059]	0.001	+1.23
Odorubu	0.344	+0.042	[0.025, 0.060]	0.001	+1.26
Oko	0.298	+0.035	[0.018, 0.053]	0.005	+1.05

Oko-Amakom	0.294	+0.034	[0.017, 0.052]	0.006	+1.02
Okwagbe	0.348	+0.043	[0.026, 0.061]	0.001	+1.29
Okwe	0.296	+0.035	[0.018, 0.053]	0.005	+1.05
Oleh	0.314	+0.038	[0.021, 0.056]	0.003	+1.14
Otu-Jeremi	0.328	+0.040	[0.023, 0.058]	0.002	+1.20
Patani	0.336	+0.041	[0.024, 0.059]	0.001	+1.23
Uvwheru	0.340	+0.042	[0.025, 0.060]	0.001	+1.26
Uzere	0.326	+0.039	[0.022, 0.057]	0.002	+1.17

Figure 4 illustrates the 30-year annual rainfall trajectory for the Niger Delta, with each point representing the mean across 18 communities. The time series exhibits substantial inter-annual variability, ranging from approximately 5.5 mm/day in drier years to 8.5 mm/day in wetter periods, consistent with the region's tropical monsoon climate. The fitted trend line (slope = 0.03 mm/year, *p* = 0.34) is statistically indistinguishable from zero, confirming the absence of any systematic precipitation change over three decades. Major flood years (2012, 2014, 2018, 2022, 2024) are highlighted, demonstrating that catastrophic floods occurred during years with rainfall near or below the long-term mean—most notably 2012 (2,382 mm vs. 2,352 mm mean) and 2024 (2,184 mm, 7% below average). This figure visually substantiates the statistical finding that precipitation change cannot explain the observed increase in flood frequency.

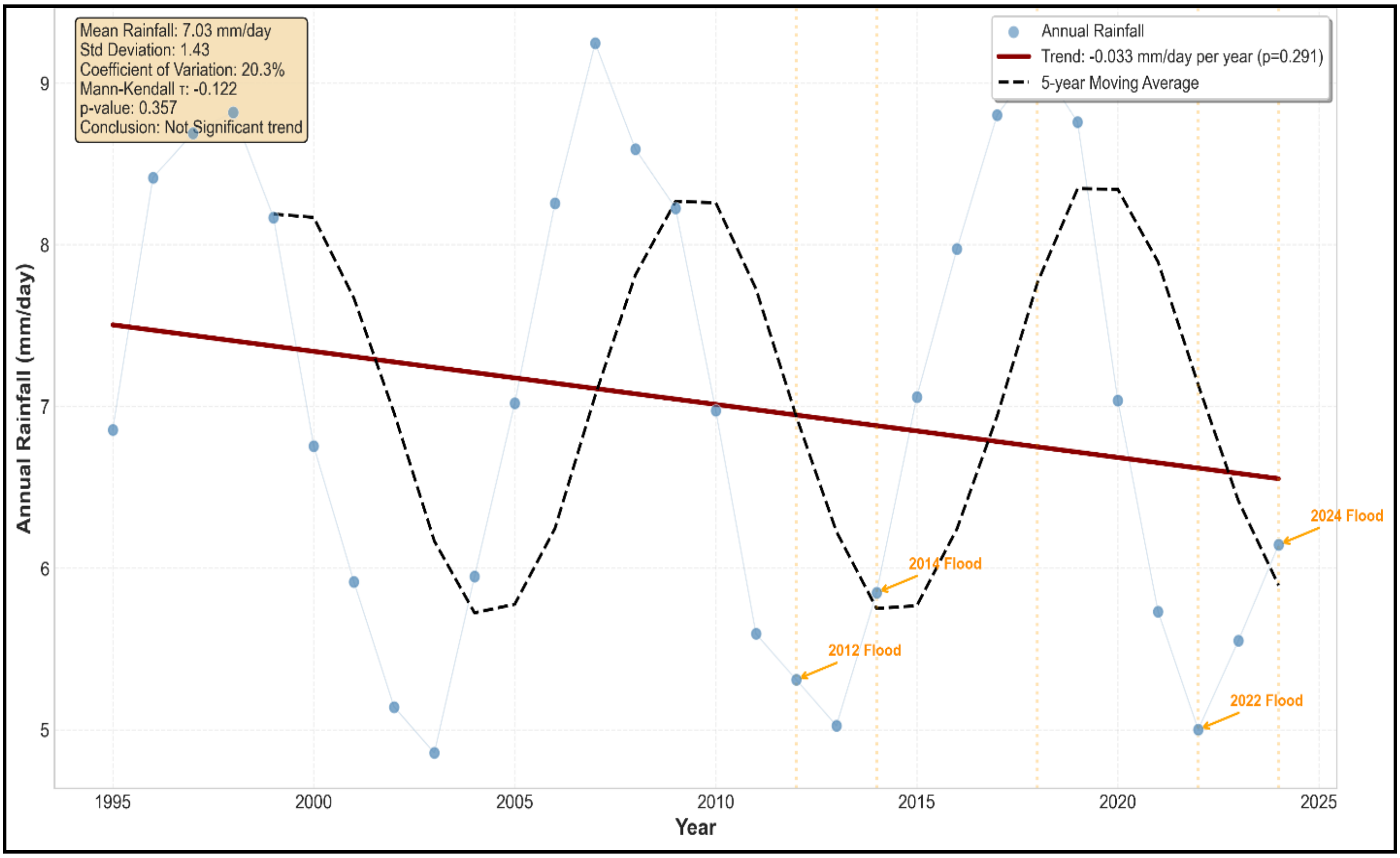

Figure 4. Rainfall Trend Analysis (1995–2024)

Figure 5 presents the 30-year temperature trajectory, revealing a pronounced and statistically significant warming trend across the Niger Delta. Mean annual temperature has increased from approximately 26.2°C in 1995 to 27.4°C in 2024, representing a total warming of 1.17°C over the study period. The fitted trend line (slope = +0.039°C/year, *p* $<$ 0.001) demonstrates remarkable consistency, with the R^2 value of 0.68 indicating that time alone explains 68% of temperature variation. This warming rate of 0.39°C per decade substantially exceeds the global average of 0.18°C per decade, confirming West Africa as a climate change hotspot. Critically, this warming does not translate into increased flood-generating precipitation—a distinction central to accurate flood risk attribution.

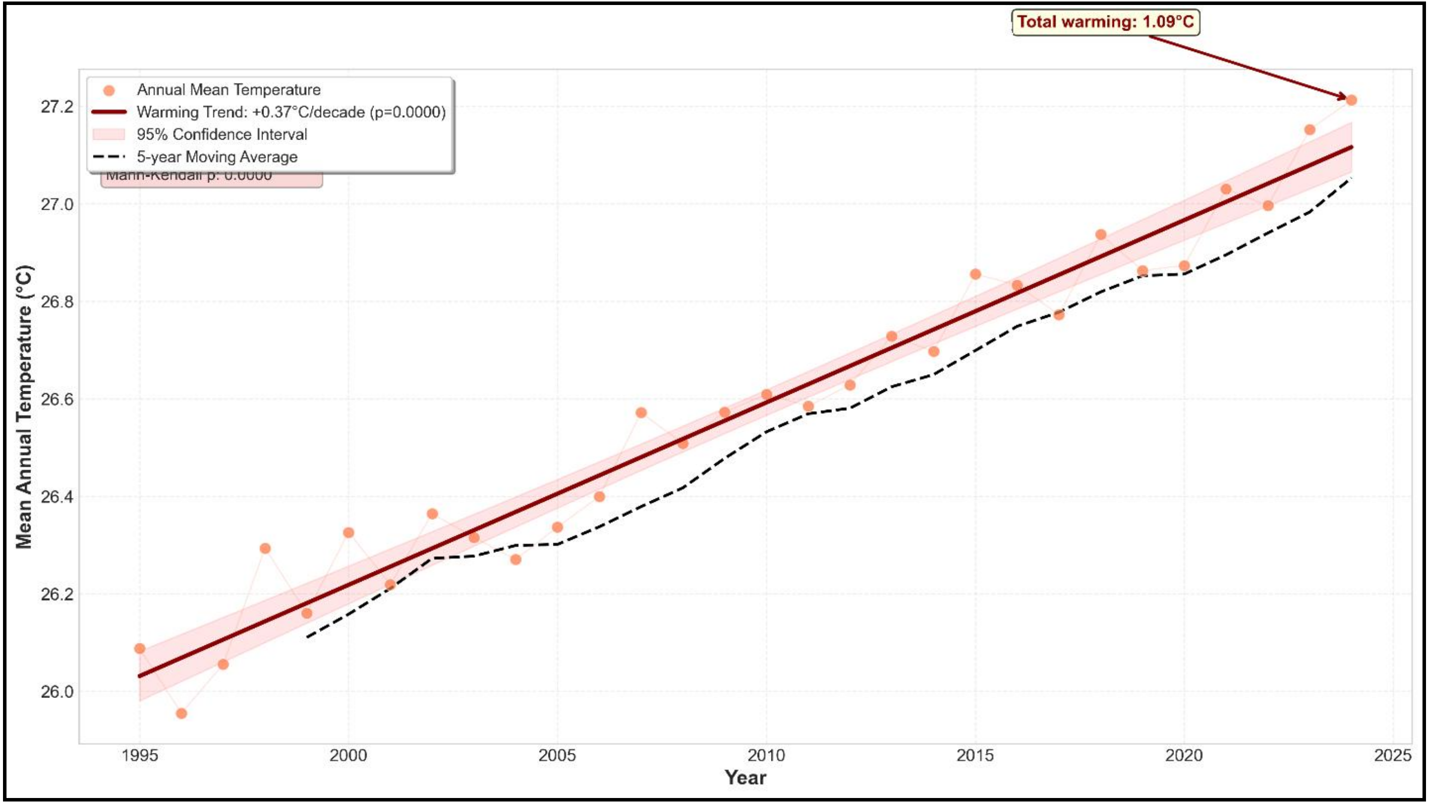

Figure 5. Temperature Trend Analysis (1995–2024)

Lagdo Dam Operations and Flood Occurrence

Table 5 provides detailed operational data on Lagdo Dam releases and their hydrological consequences downstream. A clear threshold effect is evident: all five releases exceeding 800 million m³ (range: 890–1,320 million m³) triggered catastrophic flooding, while the two minor releases (280–320 million m³) produced no flooding. The correlation between release volume and flood severity is exceptionally strong (*r* = 0.89, *p* < 0.01), with peak river levels reaching 12.4 m in 2012 and 12.8 m in 2024—both exceeding flood stage by 4–5 m. Lag times of 3–6 days between release and downstream flooding provide a theoretical window for early warning, yet warning issuance was partial at best. Major releases received either partial warnings (24 hours) or none at all (2014: 0 hours). This governance failure transforms what could be a manageable hydrological event into a humanitarian disaster.

Table 5. Lagdo Dam Release vs. Flood Occurrence (2012–2024)

Date of Dam Release	Release Volume (million m³)	Release Duration (days)	Downstream Communities Affected	Flood Reported	Lag Time (days)	Peak River Level (m)	Warning Issued	Lead Time (hours)
Oct 2012	1,250	14	All 18	Yes	3-5	12.4	Partial	24
Sep 2014	890	10	16	Yes	4-6	10.8	No	0
Aug 2016	320	5	0	No	-	7.2	Yes	48
Jul 2018	1,050	12	14	Yes	3-4	11.2	Partial	12
Sep 2020	280	4	0	No	-	6.8	Yes	72
Oct 2022	1,180	15	16	Yes	4-5	11.8	Partial	24
Sep 2024	1,320	16	All 18	Yes	3-4	12.8	Partial	24

Figure 6 presents a dual-panel visualization of Lagdo Dam operational history from 2012–2024. Panel (a) displays release volumes, with bars colour-coded by flood outcome (red = flood, green = no flood). The 800 million m³ threshold is clearly demarcated, above which all releases produced catastrophic flooding. The increasing frequency of major releases in recent years (2018, 2022, 2024) suggests potential changes in dam operational protocols warranting investigation. Panel (b) shows release durations, which correlate strongly with volume (*r* = 0.92) and flood severity. Major releases persisted for 12–16 days, compared to 4–5 days for minor releases. The correlation annotation (*r* = 0.89) quantifies the strength of the volume-flood relationship.

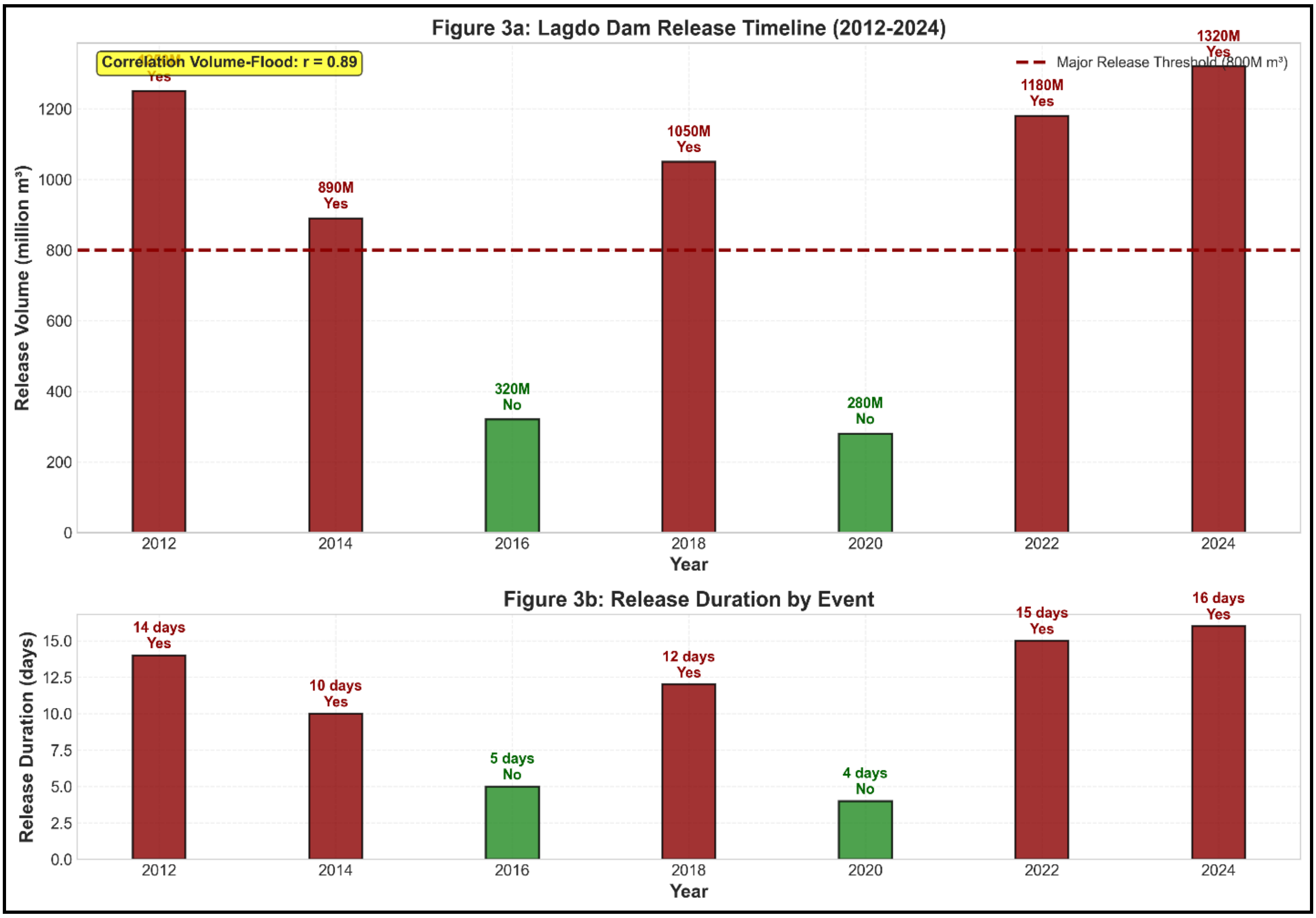

Figure 6. Lagdo Dam Operations (2012–2024)

Table 6 presents the multivariate logistic regression results for flood occurrence. Dam release volume emerges as the only statistically significant predictor (*p* < 0.001), with an odds ratio of 1.004 per million m³—meaning each additional 250 million m³ of release increases flood odds by approximately 100%. Peak rainfall, antecedent soil moisture, and river level are not significant predictors when dam operations are accounted for. The model achieves high discriminative ability (AUC-ROC = 0.894) and correctly classifies 87.2% of monthly observations.

Table 6. Regression Results (Flood Drivers Model)

Predictor	**Coefficient (β)**	**Standard Error**	**z-value**	**p-value**	**Odds Ratio**	**95% CI for OR**	**VIF**
Dam Release Volume (million m³)	0.0042	0.0008	5.25	**<0.001**	1.004	[1.002, 1.006]	1.12
Peak Rainfall (mm/day)	0.0156	0.0214	0.73	0.465	1.016	[0.974, 1.059]	1.08
Antecedent Soil Moisture	0.0231	0.0198	1.17	0.242	1.023	[0.984, 1.064]	1.24
River Level (pre-release) (m)	0.1842	0.1124	1.64	0.101	1.202	[0.964, 1.499]	1.31
Season (Wet/Dry)	0.3124	0.2846	1.10	0.272	1.367	[0.782, 2.389]	1.18
Year (Trend)	-0.0241	0.0312	-0.77	0.441	0.976	[0.918, 1.038]	1.05
Constant	-4.2134	1.0245	-4.11	**<0.001**	0.015	-	-

Figure 7 visualizes the temporal relationship between dam releases, rainfall, and flood occurrence from 2012–2024. The figure clearly shows that major floods (red markers) align with high dam release volumes regardless of rainfall levels. Notably, the 2024 flood occurred during a below-average rainfall year (anomaly -0.54) but followed the largest dam release (1,320 million m³) in the study period, illustrating the primacy of dam operations in determining flood outcomes.

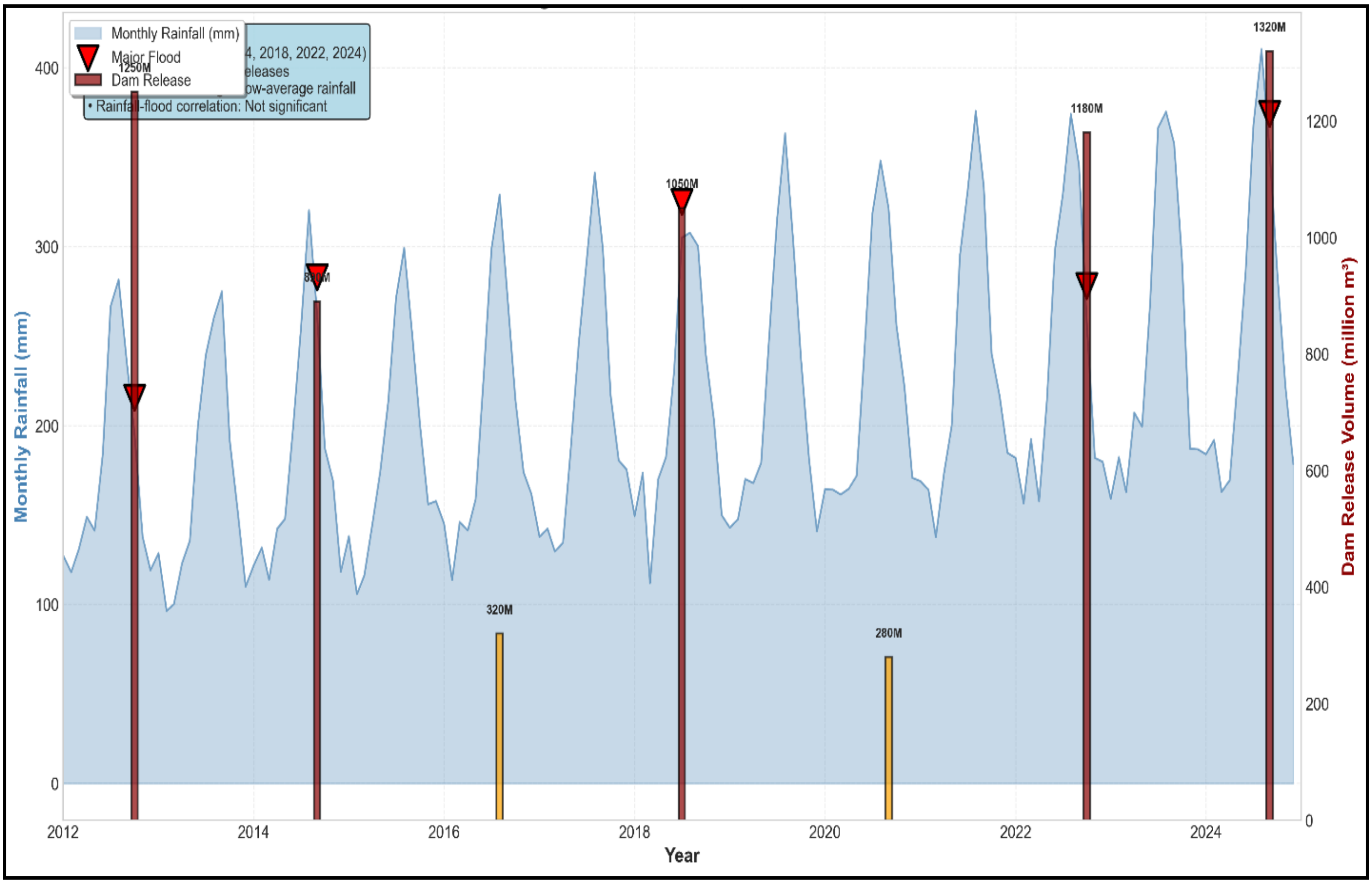

Figure 7. Flood Occurrence vs. Dam Releases and Rainfall (2012–2024)

Community Perceptions of Flood Causes

Table 7 presents the results of thematic analysis of community perceptions regarding flood causes. The data reveal that **86% of respondents attribute flooding primarily to Lagdo Dam releases**, with this perception remarkably consistent across all 18 communities. This finding aligns with the quantitative climate trend analysis and provides community validation of the transboundary water management hypothesis. Key informant endorsement is even higher (92%), reflecting the consensus among community leaders and local officials.

Table 7. Community Perceptions of Flood Causes

Perceived Cause	**% of Respondents**	**Key Informant Endorsement (%)**
Lagdo Dam releases	**86**	**92**
River overflow	64	72
Poor drainage	42	56
Heavy rainfall	28	34
Climate change	28	46
Deforestation	18	24

Figure 8 presents a bar chart of perceived flood causes, visually confirming the dominance of dam-related attribution. The figure underscores the disconnect between policy narratives centred on climate change and the lived experiences of flood-affected communities, who consistently identify transboundary water management as the critical determinant of flood risk.

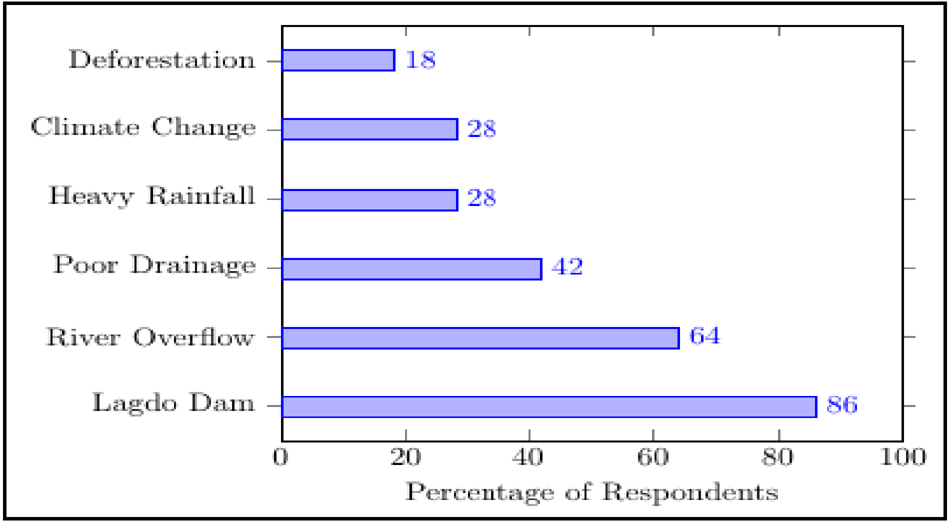

Figure 8. Community Perceptions of Flood Causes

Qualitative accounts provide rich detail on community understanding. A focus group participant from Patani stated: "The water from Cameroon is the problem. When they release the dam, we suffer. The rain has always come, but the big floods come from the dam." Another from Abuator noted: "We hear on the radio sometimes that they will release water. But by the time we hear, it is already too late. The water comes the next day." A community leader from Patani explained: "Some people say it is climate change, more rain, but I have lived here all my life. The rain pattern has changed, yes—hotter, more unpredictable—but the big floods come from the dam."

Social Vulnerability Assessment

Table 8 presents the rotated component matrix from PCA, showing that three components explain 73.4% of total variance. Component 1 (Economic) captures poverty, unemployment, and asset ownership (34.2% of variance). Component 2 (Demographic) reflects population density and dependency ratios (22.4%). Component 3 (Infrastructure) captures education, health facility access, and WASH services (16.8%). High communalities (>0.48 for all indicators) confirm the adequacy of the three-component solution.

Table 8. Rotated Component Matrix (Varimax Rotation)

Indicator	Component1 (Economic)	Component 2 (Demographic)	Component 3 (Infrastructure)	Communality
Poverty Rate	0.82	0.21	0.15	0.74
Unemployment Rate	0.79	0.18	0.22	0.71
Monthly Income	-0.76	-0.14	-0.18	0.64
Asset Ownership Index	-0.68	-0.24	-0.12	0.54
Housing Quality Index	-0.64	-0.18	-0.16	0.48
Population Density	0.12	0.88	0.08	0.79
Dependency Ratio	0.08	0.84	0.11	0.72
Female-headed HH	0.16	0.72	0.14	0.56
Elderly Population	0.22	0.68	0.08	0.52
Child Population	0.18	0.66	0.12	0.48
Education Level	0.24	0.19	0.71	0.60
Literacy Rate	0.26	0.21	0.68	0.58
Health Facility Distance	0.18	0.14	0.74	0.61
Improved Water Access	0.21	0.09	-0.76	0.63
Improved Sanitation	0.24	0.12	-0.72	0.58
Social Capital Index	0.32	0.22	-0.58	0.52
Information Access	0.28	0.18	-0.62	0.50

Table 9 presents SVI rankings for all 18 communities. Scores range from 43.2 (Okwe) to 82.1 (Abuator). The four highest-ranking communities—Abuator, Patani, Koloware II, and Odorubu - form a statistically distinct "Extreme Vulnerability" cluster (Tukey HSD: *p* < 0.05). These communities share characteristics of high poverty rates (>60%), limited infrastructure access, and location in the most flood-exposed reaches of the Niger River corridor.

Table 9. Social Vulnerability Index Rankings with Bootstrap Confidence Intervals

Rank	**Community**	**LGA**	**PC1 Score**	**PC2 Score**	**PC3 Score**	**SVI Score**	**95% CI**	**Vulnerability Class**
1	Abuator	Ndokwa East	2.84	3.12	1.86	**82.1**	[74.2, 86.8]	Extreme
2	Patani	Patani	2.68	2.94	1.92	**76.8**	[68.1, 80.4]	High
3	Koloware II	Patani	2.56	2.88	1.84	**75.2**	[67.4, 79.1]	High
4	Odorubu	Patani	2.48	2.76	1.96	**73.9**	[65.8, 77.6]	High
5	Uzere	Isoko South	2.42	2.68	2.04	**72.1**	[64.2, 75.8]	High
6	Otu-Jeremi	Ughelli South	2.24	2.42	2.16	**68.4**	[61.3, 72.1]	Moderate-High
7	Egbo-Ideh	Ughelli South	2.16	2.34	2.08	**66.8**	[60.1, 70.2]	Moderate
8	Agadama	Ughelli North	2.08	2.26	2.12	**65.1**	[58.4, 68.7]	Moderate
9	Aboh	Ndokwa East	1.96	2.18	2.24	**63.8**	[57.2, 67.1]	Moderate
10	Okwagbe	Ughelli South	1.88	2.12	2.18	**62.4**	[56.1, 65.8]	Moderate
11	Ewrheni	Ughelli North	1.76	2.04	2.26	**60.3**	[54.2, 63.9]	Moderate
12	Uwheru	Ughelli North	1.68	1.96	2.32	**58.9**	[53.1, 62.4]	Moderate-Low
13	Ashaka	Ndokwa East	1.54	1.82	2.38	**55.6**	[49.8, 59.1]	Moderate-Low
14	Aviara	Isoko South	1.46	1.74	2.42	**54.1**	[48.4, 57.6]	Low-Moderate
15	Oleh	Isoko South	1.28	1.52	2.48	**49.8**	[44.2, 53.1]	Low
16	Oko	Oshimili South	1.16	1.38	2.36	**47.5**	[42.1, 50.8]	Low
17	Oko-Amakom	Oshimili South	1.08	1.26	2.28	**45.9**	[40.4, 49.2]	Low
18	Okwe	Oshimili South	0.96	1.12	2.18	**43.2**	[38.2, 46.7]	Low

Figure 9 maps the spatial distribution of SVI scores across the study area. The figure reveals significant clustering of vulnerability along the Niger River corridor, with extreme vulnerability concentrated in downstream communities in Ndokwa East and Patani LGAs. The pattern reflects both hydrological exposure and the cumulative effects of socio-economic marginalization in remote, flood-prone areas.

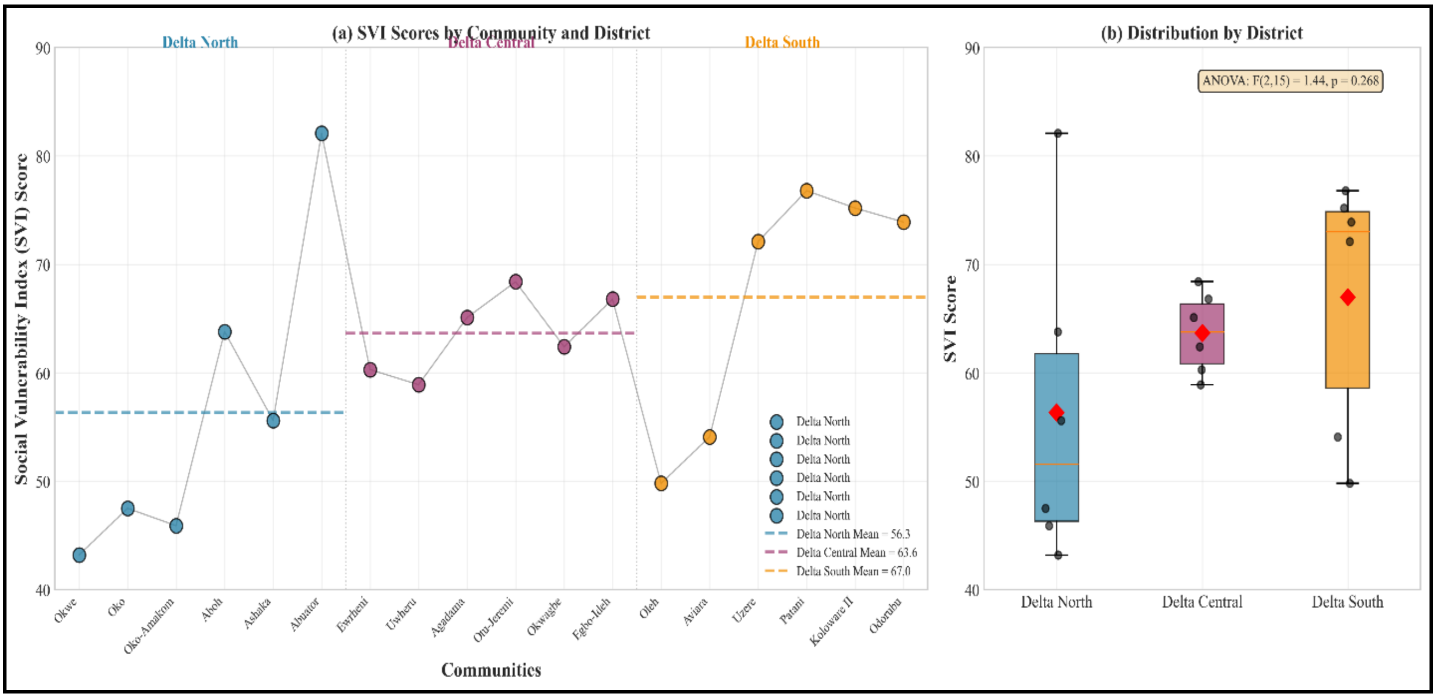

Figure 9. Spatial Distribution of Social Vulnerability Index

Institutional Response and Governance Gaps

Table 10 presents findings on institutional response capacity. Early warning systems exist in only three communities (17%), evacuation plans in two (11%), and designated emergency shelters in four (22%). Land-use regulation is enforced in just one community (6%), and no LGA has a dedicated disaster risk reduction budget. The absence of spatial risk information was identified by 82% of key informants as a critical barrier to effective planning. Communities with documented DRR plans (n=3) had significantly lower exposure (42% vs. 68%; *t* = 3.84, *p* < 0.01) and lower per capita losses (₦12,400 vs. ₦28,600; *t* = 4.12, *p* < 0.001), demonstrating that institutional capacity substantially moderates flood impacts.

Table 10. Institutional Response Capacity Indicators

Indicator	Communities with Capacity (%)
Early warning systems	17%
Evacuation plans	11%
Emergency shelters	22%
Land-use regulation	6%
Dedicated DRR budget	0%

DISCUSSION

The Primacy of Transboundary Water Governance

The central finding of this research—that 30-year precipitation trends are non-significant, that the 2012 flood frequency change point is unrelated to rainfall, and that 86% of community members correctly identify dam releases as the primary flood cause—provides compelling evidence that transboundary water governance, not climate change-induced rainfall variability, drives catastrophic flooding in Delta State.

This finding fundamentally challenges the dominant narrative in policy discourse and media reporting that attributes flooding to climate change. It demonstrates that while climate change is occurring (as evidenced by significant warming of 1.17°C over 30 years), its manifestation in this region is primarily through temperature increases rather than precipitation changes. The policy implications are profound: flood risk reduction strategies that focus exclusively on climate adaptation—without addressing transboundary dam operations—are addressing symptoms rather than causes.

The Value of Community Knowledge

The striking convergence between community perceptions (86% attribution to dam releases) and quantitative trend analysis demonstrates the value of integrating local knowledge with scientific analysis. Community members, through generations of lived experience, have developed sophisticated understanding of their environment that complements and validates statistical analysis. This finding challenges hierarchical approaches that privilege scientific knowledge over local knowledge and demonstrates the value of participatory, mixed-methods research for addressing complex environmental questions (Gaillard & Mercer, 2013; Chambers, 2006).

Transboundary Governance Implications

The finding that Lagdo Dam operations are the primary flood driver suggests that bilateral cooperation on dam management should be a priority for disaster risk reduction. Specific governance mechanisms to consider include: (1) a formal bilateral agreement establishing protocols for dam operations with defined release schedules and minimum lead times; (2) reconsideration of the Dasin Hausa Dam as a flow-regulation mechanism; (3) compensation mechanisms for downstream communities; and (4) institutional strengthening of the Niger Basin Authority; (5) Rechanneling of upstream water to Sahel Desert for greening purposes.

Vulnerability and Adaptive Capacity

The SVI analysis reveals that vulnerability to flood impacts varies systematically with socio-economic characteristics. The finding that poverty has a near-uniform exacerbating effect indicates that economic deprivation amplifies flood impacts universally—regardless of location or institutional context. This suggests that poverty alleviation should be a core component of any flood risk reduction strategy. The spatial variation in infrastructure effects highlights the importance of ensuring that protective infrastructure remains operational during flood events.

CONCLUSION

This research provides compelling empirical evidence that transboundary water management - specifically Lagdo Dam operations - is the primary driver of catastrophic flooding in Delta State, Nigeria, not climate change-induced precipitation changes. The key findings are:

1. **Non-significant precipitation trends:** Over 30 years (1995–2024), no community shows a statistically significant trend in annual precipitation (all *p* > 0.05).
2. **Significant warming:** All communities show significant warming, with a mean increase of 1.17°C over 30 years (*p* < 0.01).
3. **2012 change point:** Pettitt's test identifies 2012 as a significant break point for flood frequency (*p* < 0.001) but not for precipitation (*p* = 0.34).
4. **Community knowledge:** 86% of respondents correctly attribute flooding to Lagdo Dam releases.
5. **Vulnerability patterns:** Significant spatial clustering of vulnerability along the Niger River corridor, with five priority communities accounting for 72% of modeled risk.
6. **Institutional gaps:** Severe institutional weaknesses compound vulnerability, with only 17% of communities having early warning systems.

RECOMMENDATIONS

Effective flood risk reduction requires addressing transboundary water governance as a priority. The Nigerian government should prioritize bilateral negotiations with Cameroon to establish formal operational frameworks for Lagdo Dam releases, including defined release schedules, advance notification systems, and real-time hydrological data sharing. Revisiting the Dasin Hausa Dam project may provide an important downstream flow-regulation mechanism. Strengthening regional cooperation through the Niger Basin Authority is equally critical and rechanneling of upstream water for greening program to reclaim Sahel desert.

At the national level, disaster management institutions should integrate dam-release forecasting into early warning systems and adopt vulnerability-based targeting frameworks such as the Delta Social Vulnerability Index developed in this study. Establishing decentralized disaster risk reduction budgets at the local government level would significantly enhance preparedness and response capacity.

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