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The River Niger and Sustainable Development in Nigeria's Built Environment: Risks, Resilience, And Pathways Forward

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Abstract **Original Research**

Millions of people in Nigeria's Lower Niger Basin are at risk of repeated flood losses due to urbanisation in floodplain zones, while hydropower production is hindered by sedimentation in reservoirs. The Lower Niger Basin, including the states of Lokoja, Delta, Bayelsa, and Rivers, was studied using a mixed-method methodology from 2010 to 2020. Using a stratified sample method that takes flood risk into account, three reservoirs and six cities were selected for further examination. Data collection involved a combination of quantitative field measurements, geographical analysis using remote sensing and GIS, and secondary data from government agencies. Descriptive statistics, Pearson correlation and linear regression were used to investigate associations between variables using statistical analysis. There is a substantial association between urban built-up change and house flood risk (r = 0.994). The 2012 floods displaced 2.3 million and destroyed 152,000 dwellings. Sedimentation has decreased reservoir storage capacity by 16%, 16%, and 18% in Jebba, Kainji, and Shiroro. Storage capacity accounted for 69% of variance in hydropower production. Water quality deteriorated below the World Health Organization limits with the turbidity at Onitsha reaching 88 NTU. The study's empirical approach addresses both natural disasters and the vulnerability of the built environment in the context of integrated basin governance. Policy proposals include enforced floodplain zoning, catchment afforestation, hydropower restoration and tougher water-quality enforcement related to Sustainable Development Goals 6, 7, 9 and 11.

Keywords: River Niger, flood risk, reservoir sedimentation, hydropower resilience, basin management.

1. Introduction

In Nigeria, the 2012 flooding of the River Niger produced a very high level of displacement, since well over two million individuals were impacted and more than 600,000 dwellings were damaged (Wizor & Week, 2014; Ologunorisa et al., 2022). The event exposed a persistent difficulty for the planners. The River Niger is a vital source of water supply, electricity, transport and agriculture and continues to be a cause of devastation and deadly calamities.

Adamou et al. (2021) point out that the infrastructure and the populations surrounding it are threatened by unfettered urban growth, sedimentation and decreasing water quality. Lokoja has undergone remarkable expansion from 34 km² in 2000 to 92 km² in 2020, with most of this increase intruding into high flood risk regions (NASRDA, 2020). Recurrent and predictable losses have been the result of interactions between urbanisation and natural catastrophes. Research on the Niger River frequently fragments critical topics, viz., hydrology, flood forecasting, human health hazards owing to the rising pollutants (Raimi et al. 2022; Egbueri et al. 2024) and urban decrease in power-generating decline. Such a study is vital but often lacks a robust integrative framework including physical environmental spatial and socio-economic elements. These constraints prevent planners from understanding the inter-relationship between discharge sediments, pollution, urbanisation and human vulnerability. The absence of integrated data has led to evaluations of urban expansion that disregard biological limits and assessments of hydropower that disregard sediment consequences on dam storage.

This research intends to solve this gap by linking data on hydrological, environmental, geographical and socio-economic aspects from 2010-2020. It combines discharge data, flood damage assessments, water quality monitoring, sediment surveys, urban expansion maps, hydropower production data and household relocation data into one evidence base. The study is based on successful international practices of integrated basin management, for example, the Mekong and Nile rivers (Sridhar et al., 2021; Jia et al., 2024), and calls for a systematic uptake of such strategies in Nigeria, which has been largely reactive in its responses with emphasis on relief measures over strategic planning. Every year the cost of delay becomes worse, with urban populations anticipated to make up over half of Nigeria's total by 2050, particularly in places sited near floodplains.

The major purpose of the project is to evaluate the effect of the River Niger on the vulnerability and resilience of Nigeria's built environment and to suggest means of attaining sustainable development. The work is motivated by three objectives: (1) to investigate the relationship between river discharge, flood damage and settlement exposure along the Lower Niger Basin between 2010 and 2020; (2) to assess the impact of reservoir sedimentation on storage capacity and hydropower generation at Kainji, Jebba and Shiroro; and (3) to analyse the consequences of river water quality and urban sprawl into floodplains on household flood exposure in selected cities. The research examines two null hypotheses. $H0_1$: The growth of built-up areas does not significantly relate to household flood risk in the Lower Niger Basin. There is no statistically significant relationship between the storage capacity of reservoirs and the hydroelectric output at the stations that were considered ($H0_2$).

The research encompasses the Lower Niger Basin from Lokoja to Anambra, Delta, Bayelsa and Rivers states. It only takes into account the years 2010–2020, which are critical for the severe floods of 2012, 2018 and 2020. Reasons for conducting this investigation stem from the following important issues: the yearly depletion of Kainji Dam's capacity due to sedimentation poses a threat to hydroelectricity and irrigation (Musa, 2024); the worsening of water quality heightens health risks in urban areas; and the fact that urbanisation into flood-prone areas is a recurrence of the displacements witnessed in 2012. The study aims to empirically examine the relationships between urban growth, environmental management, and resilience using empirical data and official records, while also contributing to the Sustainable Development Goals related to clean water and sanitation, affordable and clean energy, industry and infrastructure, and sustainable cities and communities.

2. Theoretical Framework

The Socio-Ecological Systems (SES) hypothesis conceptualises the relationship between human activities and ecological processes (Biggs et al., 2021). The River Niger is a complex SES connecting natural resources with the urban and rural livelihood infrastructure and policies. The sustainable development of the built environment requires management of hazards such as floods, pollution and resource exploitation that impact upon human and ecological resilience. The SES theory considers the river a common pool where interdependent actors manage a limited resource under shifting demand. A key challenge in applying the theory to the Niger is the inadequate integration of urban-development studies with river-basin governance. SES theory requires a systemic perspective linking flood regimes, land use types, infrastructure design and governance institutions (Zhou et al. 2024). The SES theory is applicable to the River Niger via the linkages between ecological, social and institutional processes (Figure 1).

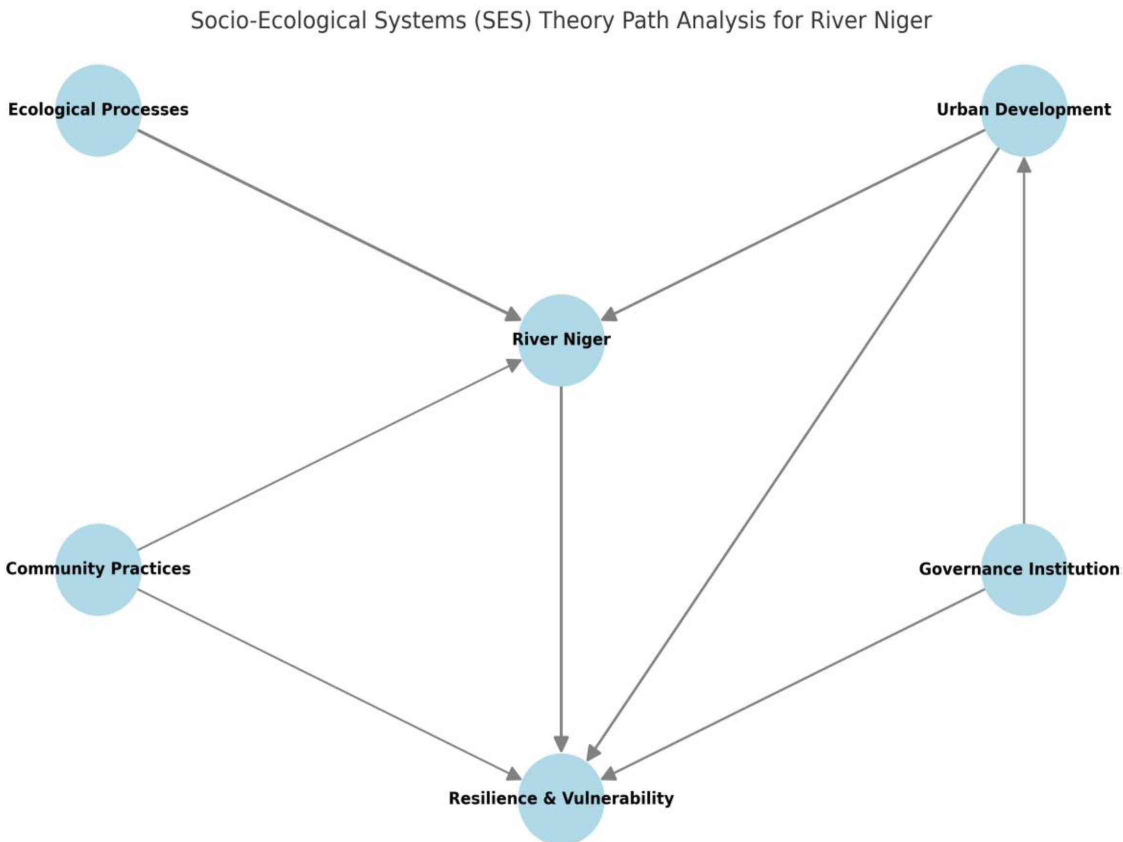

Figure 1: Socio-Ecological Systems (SES) theory applied to the River Niger

While Nigerian planning literature tends to gloss over these discrepancies, SES theory promotes a more pointed attention to who resilience methods protect and who they leave behind (Dickey et al., 2023). It also has methodological restrictions; it needs integrated modelling of ecological, social and institutional factors. Many Nigerian research projects are based on descriptive surveys or hydrological models employed in isolation. Despite these caveats, SES theory provides a clear road forward, recognising systemic risk at the nexus of urban development and ecological decline and anchoring the current study in feedbacks among decision-making in the built environment, ecological thresholds, and governance response.

The conceptual framework operationalises the SES theory into testable correlations of quantifiable variables (Figure 2). It structures the research around four driving factors, one moderating variable and four outcome variables, all leading to one goal: a resilient and sustainable built environment. The framework characterises each construct with a well-defined scope, enabling fuzzy concepts such as "vulnerability" to derive operational meaning from field and remote-sensing data. The driving factors include river flow and flood regime, sedimentation in reservoirs, water quality of rivers and urbanisation of floodplains. Each is a physical or geographical mechanism that exerts pressure on settlements. Water quality is a function of the net load of home and industrial waste; urban expansion evaluates how much built-up land encroaches on danger zones. These designs are based on integrated basin-management thinking, which sees hydrology, energy and settlement as a linked system (Sridhar et al., 2021; Zhou et al., 2024). Governance, planning and institutional capability are the moderating variables. The approach below implies that one and the same physical pressure might have diverse impacts depending on legislation, enforcement and community structure. Strong floodplain zoning and pollution controls to mitigate the threat of loss. Weak institutions mean that the same danger quickly leads to damage and displacement. This mediating function is in line with the SES focus on adaptive governance and institutional learning (Constantino et al., 2021; Biggs et al., 2021) and explains why identical basins present varying amounts of harm.

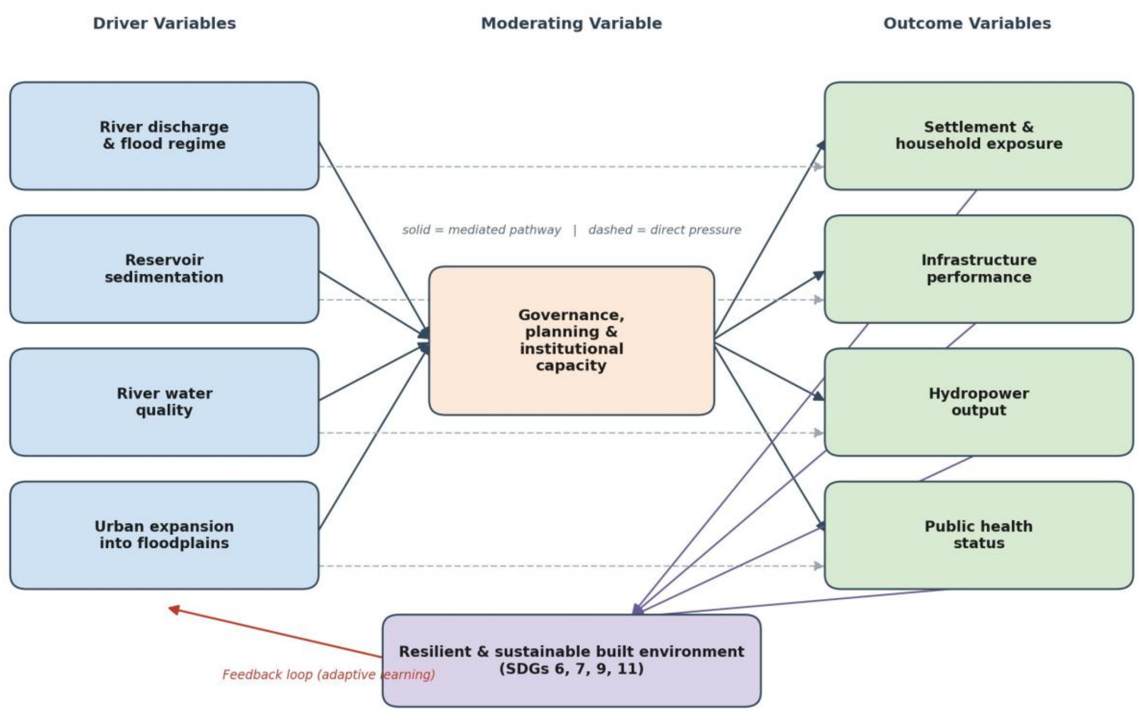

Figure 2: Conceptual framework linking river drivers, governance, and built-environment outcomes

Source: Authors' construct (2025), adapted from socio-ecological systems theory.

The outcome variables are settlement and household exposure, infrastructure performance, hydropower output, and public-health status. They capture how driver pressure, filtered through governance, lands on people and assets. The framework specifies two relationships for empirical testing. The link between built-up expansion and household exposure tests how spatial growth raises risk (Objective 3, H01). The link between storage capacity and hydropower output tests how sedimentation erodes energy supply (Objective 2, H02). A feedback loop closes the system: outcomes feed back into governance and driver behaviour through adaptive learning, so that recorded losses can reshape planning. The framework acknowledges its own limits. It does not capture rainfall variability upstream of the gauged reach, and it treats governance as a single construct rather than a layered set of agencies. Even so, it provides a logical structure that connects established theory with the variables measured in this study and supports the hypotheses tested in the results.

3. Materials and Methods

The study covered the Lower Niger Basin, stretching from Lokoja in Kogi State through Anambra, Delta, Bayelsa, and Rivers States (Figure 2). The area was selected for its frequent floods, dense urban settlements, and concentration of hydropower and transport infrastructure. Lokoja sits at the confluence of the Niger and Benue rivers (7.8021°N, 6.7333°E) and serves as the main hydrological monitoring point. Onitsha (6.1500°N, 6.7833°E), Asaba (6.2000°N, 6.7333°E), and Yenagoa (4.9267°N, 6.2676°E) represent large urban settlements with growing floodplain development. Idah (7.1100°N, 6.7300°E) and Patani (5.2167°N, 6.1833°E) reflect smaller communities facing flood vulnerability. Kainji, Jebba, and Shiroro reservoirs were included for their role in regulating water, trapping sediment, and producing energy.

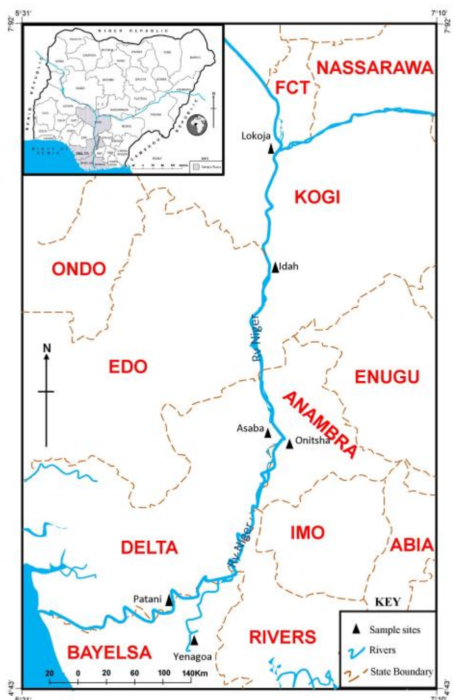

Figure 2: Map of the study area showing the River Niger and sample sites

Source: Department of Urban and Regional Planning Cartographic Unit, Dennis Osadebay University, Asaba

The basin lies within the tropical wet-and-dry climate zone, with a rainy season from April to October and a dry season from November to March. Mean annual rainfall ranges from about 1,100 mm in the north of the reach near Lokoja to over 2,500 mm in the southern delta near Yenagoa, which drives the seasonal flood pulse. Vegetation grades from Guinea savanna in the upper reach to freshwater swamp forest and mangrove in the delta. Economic activities along the corridor include farming, fishing, sand mining, river transport, trade, and hydropower generation. The geology spans Cretaceous sedimentary formations of the Anambra and Niger Delta basins, with alluvial deposits along the active floodplain that store fertile soils and also raise flood sensitivity. These conditions tie directly to the study title, since the same river that supports livelihoods also concentrates hydrological, sedimentary, and pollution risks on the built environment.

A mixed-method design integrated hydrological measurement, spatial analysis, and documentary evidence. The design suited the research problem because no single method captures the coupled physical and social processes the study addressed. Quantitative methods produced discharge records, sedimentation surveys, water-quality tests, and hydropower data. Spatial analysis applied remote sensing and GIS to map urban expansion and flood-prone zones. Documentary data came from government archives on disaster impact, household relocation, and energy production, which allowed triangulation between field data and institutional records. The mixed design strengthened internal validity by letting one data source check another, consistent with integrated basin-management practice (Sridhar et al., 2021).

The study used three data types. Primary field data covered river discharge, water quality, and reservoir sedimentation. Spatial data covered land cover and built-up change from satellite imagery. Secondary data covered flood damage, household relocation, hydropower output, and infrastructure loss from official agencies. The study population comprised the human settlements, infrastructure, and hydrological systems affected by the river. The human population covered households in low-lying flood zones across six states. The infrastructural population covered roads, bridges, schools, and housing exposed to recurrent floods. The hydrological population covered the main Niger channel, its reservoirs, and floodplains. The temporal scope of 2010 to 2020 captured the major flood years. Stratified sampling divided settlements into high, medium, and low flood-risk categories using elevation, historical flood records, and proximity to the river. Lokoja, Onitsha, Asaba, Idah, Yenagoa, and Patani were then purposively selected for their exposure and concentration of people and infrastructure. Kainji, Jebba, and Shiroro were purposively included as the major water-regulation and energy nodes. The stratified approach controlled for risk level, while the purposive step targeted sites where the study constructs were strongest, which improved the relevance of the sampled data. Table 1 presents the sampling distribution across strata.

Table 1: Sample population and sampling distribution across flood-risk strata

Flood-risk stratum	Settlements sampled	Sampling method	Field stations / units
High	Lokoja, Onitsha, Patani	Purposive	6 gauging and quality points
Medium	Asaba, Yenagoa	Purposive	4 gauging and quality points
Low	Idah	Purposive	2 gauging and quality points
Reservoir nodes	Kainji, Jebba, Shiroro	Purposive	3 bathymetric survey points

Total	**6 cities, 3 reservoirs**	**15 field units**

Source: Authors' fieldwork design (2021)

Data collection combined field instruments and secondary datasets. Flow gauges from the Nigeria Hydrological Services Agency (NIHSA) supplied discharge data. Turbidity meters, dissolved-oxygen probes, and pH meters supplied water-quality readings at the sampled reaches. Depth-sounding instruments measured reservoir sedimentation through bathymetric survey. Remote sensing applied Landsat 7 and 8 imageries analysed in ArcGIS to map built-up change. Damage and relocation figures came from the Federal Ministry of Works and Housing, the National Population Commission, and the National Emergency Management Agency (NEMA). Hydropower output came from the Nigerian Electricity Regulatory Commission (NERC). Field data answered what the river does physically, spatial data answered where growth and hazard meet, and documentary data answered who and what the hazard affects. Raw readings were stored in a structured spreadsheet database, backed up on two drives, and processed in SPSS version 27 and ArcGIS, which kept the data secure and auditable.

Statistical analysis matched the objectives. Water-quality data were summarised with descriptive statistics and benchmarked against World Health Organization standards. Sedimentation surveys calculated capacity loss and inflow rates. Land-cover classification quantified urban growth and exposure. Pearson correlation tested the relationship between built-up change and household exposure (H_{01}), and linear regression tested the effect of reservoir storage capacity on hydropower output (H_{02}), both at the 0.05 significance level. Descriptive statistics established spatial and temporal patterns of risk and resilience. These tools fit the data structure and the hypotheses, since correlation and regression measure the strength and direction of the relationships the conceptual framework specified.

Reliability and validity received deliberate attention. Instrument validity was secured through calibration against National Water Resources Institute (NWRI) standards. Flow-gauge data were cross-checked with manual records during peak floods. Satellite classifications were validated through field checks in Lokoja, Onitsha, and Asaba. Reliability rested on repeated measurement, seasonal consistency, and multi-analyst image processing to reduce classification error. The study observed standard ethical practice. It used official, non-personal records, anonymised settlement-level relocation data, and sought permission from relevant agencies before accessing archives, so that no individual household could be identified. The combined procedures produced a multi-dimensional view of flood impact, settlement exposure, and the role of hydropower in sustaining the built environment.

4. Results and Discussion

Discharge for the River Niger at Lokoja is shown in Table 2. Mean annual discharge for the River Niger between 2010 and '15 averaged from 4,890 m^3/s (2015) to 6,430 m^3/s (2012), fluctuating with no monotonic trend observed. Peak flood discharge targets have substantively more variation. The peak discharge in 2012 was recorded at 31,670 m^3/s, more than double the mean flood, and occurred with extreme flooding conditions. Later peaks in 2018 and 2020 records show a decrease in peak pressure (25,910 m^3/s and 24,120 m^3/s, respectively), with the 2012 peak remaining the most severe. Extreme flood conditions do not directly correlate with high annual discharge records, with highest flood peaks recorded in 2010, 2012, and 2015, with the latter recording the lowest mean discharge of the period. The 2015 mean discharge was much lower, though the peak still exceeded flood pressures seen in 2010. This general trend shows how short-term point rainfall and watershed response stimulate flood intensities (Wang et al. 2021; Ojoh et al. 2024). Greater flood prediction for Lokoja for extreme events must be incorporated into the monitoring network, as flood events with top years beyond mean conditions will always form the highest percentiles.

Table 2: Annual River Niger Discharge at Lokoja (2010–2020)

Year	Mean Discharge (m^3/s)	Peak Flood Discharge (m^3/s)
2010	5,120	11,240
2012	6,430	31,670
2015	4,890	12,150
2018	6,220	25,910
2020	5,970	24,120

Source: NIHSA (2021)

Table 3 documents flood damage in the Lower Niger Basin. The mega event of 2012 was proved by the process we apply as the dominant impact. It washed away 152,000 houses, returned 569,000 hectares of farmland and displaced 2.3 million people. The subsequent floods had a lesser scope but a greater extension. In 2018, 46,700 houses fell, 165,000 hectares of farmland were washed away and 600,000 people were displaced. The impact in 2020 included 39,200 houses, 148,000 hectares and 520,000 people displaced. The lesser impact of 2018 and 2020, relative to 2012, reflects a combination of more effective early warning and emergency response. Two features strike us strongly. First, the impact varies according to the training of rainfall and flood intensity/hazards. Second, despite the variability, the extent of displacement and farmland washed away is enormous even in lesser flood years, with 569,000 hectares of land lost in 2012, which posed a disaster for food output and aligns with our earlier findings on the climate hazards of the Niger Basin (Effiong et al., 2024). The evidence invites us to promote aggressive mitigation strategies involving the distillation of flood plain zoning, more contained regulation of dam management and enhanced community transition to become more resilient to the threats.

Table 3: Recorded Flood Damage along the Lower Niger Basin (2010–2020)

Year	Houses Destroyed	Farmland Lost (ha)	Population Displaced
2012	152,000	569,000	2.3 million
2018	46,700	165,000	600,000
2020	39,200	148,000	520,000

Source: NEMA (2021)

Table 4 presents result of on-site measurements of sediment and bank erosion at five monitored reaches. Onitsha had the largest suspended sediment load (498 mg/L), the biggest bed inflow (1.12 million tonnes per year) and the highest rate of bank retreat (2.4 m/yr). The Lokoja confluence also followed with 412 mg/L and 0.98 million tonnes, representing combined Niger and Benue contributions. The lowest concentrations were seen in Patani, in the delta, with 389 mg/L and 0.52 million tonnes of bank-retreat-monitored sediment load at all reaches, tying active erosion to channel sediment supply. Field observations reveal considerable sediment flow along the urbanised sections between Onitsha and Asaba, where land removal and sand mining boost supplies. These observations provide the physical foundation for reservoir-storage loss downstream and are consistent with catchment-erosion results for the Niger system (Ogunkoya, 2023). Direct measurement increases the dependability of the sedimentation.

Table 4: Field-measured sediment inflow and riverbank erosion at monitored reaches (2018–2020)

Monitored reach	**Suspended sediment (mg/L)**	**Bed sediment inflow (t/yr ×10³)**	**Bank retreat (m/yr)**
Lokoja confluence	412	980	1.8
Idah reach	356	640	1.3
Onitsha reach	498	1,120	2.4
Asaba reach	447	870	2
Patani delta reach	389	520	1.1

Source: Field measurement (2020); NIHSA sediment gauging (2021)

Table 5. Capacity reduction in the three major reservoirs. The Kanji capacity was reduced by 16%, from 15,000 cm³ to 12,600 cm³. Jebba's capacity was reduced by 16%, from 3,800 cm³ to 3,200 cm³ and from 6,000 cm³ to 4,900 cm³, representing an 8% reduction. Capacity diminished in all sites within the investigation period; denigrated initial design capacity was compared to surveyed 2020 volume, which is a typical sediment study practice. Similar levels of denigration rates were observed at Kainji and Jebba, with a slight transition in rates at Shiroro, which can be explained by differences in dam inflow and catchment health. Ogunkoya (2023) attributed capacity loss at Kainji and Jebba to upstream erosion and poor catchment management; the present results concur and confirm sedimentation as a significant driver of the dwindling storage efficiency. Such deteriorations could adversely affect water supply, hydropower production and flood control and require consistent monitoring and conservation measures such as afforestation and soil erosion management to prevent further deteriorations.

Table 5: Sedimentation Loss in Reservoir Capacity (2010–2020)

Reservoir	Initial Capacity (MCM)	2020 Capacity (MCM)	% Loss
Kainji	15,000	12,600	16
Jebba	3,800	3,200	16
Shiroro	6,000	4,900	18

Source: NWRI (2020)

Table 6 shows a progressive decrease in the hydroelectric production of Kainji, Jebba and Shiroro (520MW to 450MW). Jebba's capacity was increased from 300MW to 360MW. Jebba 300MW to 360MW. Shiroro decreased from 460MW to 410MW. All three indicate a constant drop, which shows that the issue is systemic and not just one of isolated plant failures. This pattern is consistent with previous studies that associate low generation in Nigerian plants to ageing infrastructure, poor maintenance and sedimentation (Ibegbulam et al., 2023). The decline matters because hydropower was the backbone of the national grid supply throughout the study period. Lower production destabilises supply and increases dependence on thermal plants. The consistent pattern supports the performance comparison method over time. Although Ibegbulam et al. (2023) discovered similar efficiency losses due to technical limits and flow changes, the data indicates that there is an urgent need for hydropower rehabilitation. This is because further degradation would put energy growth at risk and lead to a larger dependence on sources that are less sustainable.

Table 6: Hydropower Output Trends (2010–2020)

Year	Kainji (MW)	Jebba (MW)	Shiroro (MW)
2010	520	360	460
2015	480	320	430
2020	450	300	410

Source: NERC (2021)

According to Table 7, the water quality in Lokoja and Onitsha is higher than the safe level set by the World Health Organization. In contrast to the range of 6.5–8.5, the pH value at both sites was 6.0. The lower pH value indicates acidification of the water body, which affects aquatic creatures. Additionally, DO surpasses the minimal value of 5 mg/L, indicating that there is a depletion of oxygen and a reduction in the number of supports for aquatic life. The turbidity levels of suspended solids surpassed the maximum permitted limit of 5 NTU. In Onitsha, sediments, solid nutrients, organic matter and other solid pollutants were identified, most likely owing to the impacts of industry and high-density population. Lokoja was 56 NTU instead of 88 NTU. The turbidity reduces the productivity of water due to decreased light penetration and balance in aquatic habitats. The result also confirms that the number of pollutants and sediments in the Okrika and Onitsha rivers exceeds the permissible limit for water quality, confirming that pollution is alarming in these two study locations. It also confirms the depleting of the world's water quality due to erratic discharge of untreated domestic and industrial effluents, as well as erosion in the catchment area. The consistency with the present findings justifies the nature of the field data and urges the need to continuously monitor water quality and regulate protection under strict pollution control.

Table 7: Water Quality Indicators at Lokoja and Onitsha (2010–2020 averages)

Location	pH	DO (mg/L)	Turbidity (NTU)	WHO Limit	Coordinates (Lat, Long)
Lokoja	6	4.2	56	pH 6.5–8.5, DO ≥ 5, Turbidity ≤ 5	7.8021°N, 6.7333°E
Onitsha	6	3.7	88	pH 6.5–8.5, DO ≥ 5, Turbidity ≤ 5	6.1500°N, 6.7833°E

Source: Field measurement (2020)

Table 8 shows the evolution of built-up areas into floodplains in Onitsha, Asaba and Yenagoa. Studies of urban development have shown that several cities in Nigeria have grown rapidly. Onitsha saw a 70% increase in area (from 54 km² to 92 km²), Asaba a 57% increase (from 42 km² to 66 km²) and Yenagoa a 61% increase (from 38 km² to 61 km²). Kasim et al. (2022) revealed that continuous urban expansion over flood-prone regions using Landsat and ArcGIS leads to substantial flood hazards owing to population increase and land use change. Onitsha, being a significant commercial centre in south-eastern Nigeria, grew faster than the smaller towns. The unplanned urban growth of other cities like Port Harcourt and Lagos supports these results. The probability of flooding is growing as recorded by Echendu (2021) and Lawanson et al. (2023). The combination of growth data with satellite data offers a strong indication of land use change for flood risk management.

Table 8: Urban Expansion into Floodplains (2010–2020)

City	Built-up Area 2010 (km²)	Built-up Area 2020 (km²)	% Increase
Onitsha	54	92	70
Asaba	42	66	57
Yenagoa	38	61	61

Source: Landsat, ArcGIS (2021)

As shown in table 9, the water affected countless homes. In Kogi State, the number of displaced households has fallen the most, from 45,000 in 2012 to 14,200 in 2020. Households hit by floods in

Anambra and Delta saw severe decline. It is probable that this drop is due to either less severe floods or greater flood control in the years between. Areas remaining susceptible in the flood include Lokoja, Onitsha and Asaba. This pattern is consistent with other research that found the impact of floods was significantly larger in 2012 than in subsequent years. The greater government participation and community preparation after 2012 (Ndimele et al., 2024) correlates with the decreased data in 2018 and 2020. The findings are suggestive for planners of the limited effectiveness of post-2012 actions. Continued displacement points to continued flood danger and requires further investment in flood control in riverine areas where susceptibility is high.

Table 9: Household Relocations due to Floods (2010–2020)

State	2012 Relocations	2018 Relocations	2020 Relocations	Key Coordinates (Lat, Long)
Kogi	45,000	16,800	14,200	Lokoja: 7.8021°N, 6.7333°E
Anambra	28,400	11,200	9,600	Onitsha: 6.1500°N, 6.7833°E
Delta	18,200	7,900	6,800	Asaba: 6.2000°N, 6.7333°E

Source: NEMA (2021)

Table 10 illustrates a clear correlation between urban growth and home flood vulnerability. Onitsha has the greatest built-up growth of 70%, with an 82% increase in exposure. Asaba and Yenagoa rose at 57% and 61%, respectively, with exposure growth at 60% and 68%, respectively. Idah and Patani saw modest growth with 9% built-up and 11% exposed for Idah and 12% and 14% for Patani, respectively. Lok, respectively, showed an intermediate increase of 22% in built-up areas and 28% in exposure. Delta-Urban has 34% built-up and 38% exposed the proportionate increase between expansion and exposure lends support to previous studies that reveal urbanisation as a cause of flood hazard in Nigerian floodplains (Kasim et al., 2022). The higher exposure in Onitsha and Yenagoa is consistent with the population density and uncontrolled settlement, as suggested by Idowu and Zhou (2023). The evidence supports the argument for tight planning and floodplain enforcement.

Table 10: Built-up Area Growth and Household Exposure due to Floods (2010–2020)

City	Built-up Change (%)	Household Exposure Change (%)
Onitsha	70	82
Asaba	57	60

Yenagoa	61	68
Lokoja	22	28
Onicha-Ugwu	18	15
Patani	12	14
Idah	9	11
Delta-Urban	34	38

Source: NEMA (2021); NIHSA (2021)

Table 11 shows the fluctuation of flood-induced damage to infrastructure. The 2012 floods devastated 356 schools, 1,480 km of roads and 14 bridges. The damage was to 128 schools, 720 km of roads and 6 bridges in 2018 and again in 2020 – to 114 schools, 650 km of roads and 5 bridges. The 2018 and 2020 decreases suggest either decreased flood severity, more management or better preparedness. It is based on actual physical damage reports and provides unambiguous year-to-year comparison. The findings complement previous studies associating policy response and structural measures to decreasing flood loss. Since 2012, efforts such as early warning and better preparation have aimed to reduce vulnerability (Nehren et al., 2023). These efforts are shown in the decrease in the damage to roads and bridges from 2012 to 2020. The persistence of exposed schools suggests low structural resilience and poor siting, in line with Pal et al. (2023).

Table 11: Infrastructure Damage from Floods (2012, 2018, 2020)

Year	**Schools Affected**	**Roads Damaged (km)**	**Bridges Damaged**
2012	356	1,480	14
2018	128	720	6
2020	114	650	5

Source: FMW&H (2020)

Table 12 Comparison of resilience metrics for the three watersheds. The Mekong employs flood zoning and polders to restrict development in sensitive areas and protect low-lying ones. With such preparations, cities like Can Tho had less damage, as reported by the Mekong River Commission (Long et al., 2022). Repeated use of structural and regulatory procedures mitigates the losses. Drought: The Nile relies on re-operating the reservoir. To balance irrigation, power production, and environmental concerns, the Aswan High Dam and reservoirs upstream are operated in tandem. The method resulted in increased water availability during drought years (ENTRO 2019). The Niger relies on early warning and relocation, which reduce acute exposure but have relatively limited adaptive capacities. Reactive actions may provide some alleviation, but they don’t create long-term resilience. The comparison brings forth three approaches: Mekong regulates land use to reduce flood damage, the Nile cultivates drought resilience via partnership, and the Niger manages risks through short-term response. Design and institutional support promote effectiveness.

Table 12: Comparative Basin Planning Strategies

Basin	Resilience Measure	Outcome
Niger	Early warning, relocation	Limited long-term adaptation
Mekong	Flood zoning, polders	Reduced urban flood losses
Nile	Reservoir re-operation	Improved drought resilience

Source: NEMA (2021); MRC (2020); ENTRO (2019)

Table 13 links risk, the resilience plan, and the Sustainable Development Goals. Exposure to flooding causes the danger of relocation. Zoning of floodplains is related to risk and Sustainable Development Goal 11 (sustainable cities). According to Der Sarkissian et al. (2022), land-use planning is an important part of the process of reducing the risk of flooding in urban regions. Sedimentation affects the reservoir capacity and efficiency of energy production. The threat may be alleviated by a combination of dredging and watershed irrigation. They also relate to SDG 7 and SDG 9. Dredging has been proposed as a realistic alternative for store recovery, although the long-term effects are associated with upstream watershed management (Yan & Li, 2023; Xiang et al., 2024). The table provides a summary of short- and long-term actions to promote the sustainability of energy and infrastructure. Water quality issues are public health concerns. Enforcement of standards mitigates the risk and is consistent with SDG 6, which is more governance-dependent than infrastructure-dependent. The comparison illustrates that resilience depends on the type of danger.

Table 13: Framework Linking Risks, Resilience, and SDGs

Indicator	Link to Risk	Resilience Strategy	SDG Alignment
Flood exposure	Displacement	Floodplain zoning	SDG 11
Sedimentation	Reduced capacity	Dredging, watershed control	SDG 7, 9
Water quality	Public health risk	Standards enforcement	SDG 6

Source: UNDP (2021); NWRI (2020); WHO (2020)

Table 14 presents a summary of the central tendency and distribution of the main variables examined in SPSS output. The difference between the eight cities is clear in the average built-up change, which was 35.38% (SD = 23.48). Idah grew more slowly than Onitsha. The study indicates that the average change in house exposure is 39.50%, which is consistent with built-up trends. More so, the average reservoir storage for the 6 years was 7,583.33 MCM with a high fluctuation. The very high figures for Kainji substantially impacted this average. The descriptive profile indicates high dispersion in growth and exposure, supporting the use of correlation and regression as appropriate tests. The high averages for turbidity and built-up change quantify the pressure the conceptual framework anticipates.

Table 14: Descriptive statistics of key study variables

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Built-up change (%)	8	9	70	35.38	23.48
Household exposure change (%)	8	11	82	39.5	27.36
Reservoir storage (MCM)	6	3,200	15,000	7,583.33	4,564.10
Hydropower output (MW)	6	300	520	416.67	78.15
Turbidity (NTU)	2	56	88	72	22.63

Source: SPSS Computation Output

Table 15 shows the Pearson connection between the built-up change and the change in household exposure. The correlation is virtually perfectly positive, with a coefficient of 0.994 significant at the 0.01 level with eight observations. This conclusion is in agreement with the covariance values of 578.268 and 653.500. The two-tailed significance of 0.000 rejects the null hypothesis (H01) and affirms a strong association between built-up expansion and household exposure. A correlation this strong (>0.99) is rare in social and environmental studies, where values are usually below 0.90. The data suggest that spatial expansion is the predominant exposure in the area analysed. This is in line with the findings of Li et al. (2022) and Angel et al. (2021), who observed greater sensitivity to climate and flood risk during fast urban expansion in Asia and Africa. Physical expansion continues to be a key driver of exposure change. Household risk assessment becomes crucial in monitoring built-up development, and regulating expansion provides a clear method to reduce exposure.

Table 15: Pearson correlation between Built-up Change and Household Exposure Change (H_{01})

Correlations		
	Built-up Change (%)	Household Exposure Change (%)

Built-up Change (%)	Pearson Correlation	1	.994**
	Sig. (2-tailed)		0
	Sum of Squares & Cross-products	4047.875	4574.5
	Covariance	578.268	653.5
	N	8	8
Household Exposure Change (%)	Pearson Correlation	.994**	1
	Sig. (2-tailed)	0	
	Sum of Squares & Cross-products	4574.5	5236
	Covariance	653.5	748
	N	8	8
**. Correlation is significant at the 0.01 level (2-tailed).			

Source: SPSS Computation Output

Table 16 displays the regression of hydropower output on reservoir storage capacity. At R^2 of 0.687, the model is significant. Hydropower production is sensitive to storage capacity and contributes around 69% of the fluctuation. The findings of the ANOVA reveal significance at 0.041 ($p < 0.05$). There is a strong correlation between storage and hydro production. The non-standardised coefficient of 0.013 (Beta=0.829, t=2.961, p=0.041) demonstrates that output increases with storage, supporting sedimentation-induced capacity loss as a pathway to lower production. The conclusion concurred with Ibegbulam et al. (2023) and Musa (2024), who related silt buildup and capacity reduction to low generation in Nigerian dams. Thus, catchment management and dredging protect both storage and energy supply.

Table 16: Regression of Hydropower Output on Reservoir Storage Capacity (H_{02})

Model Summary					
R	R Square	Adjusted R Square	Std. Error of the Estimate		
0.829	0.687	0.608	48.897		
ANOVA					
Model	Sum of Squares	df	Mean Square	F	Sig.

Regression	20969.479	1	20969.479		8.77	0.041
Residual	9563.854	4	2390.964			
Total	30533.333	5				
Coefficients						
Model	B		Std. Error	Beta	t	Sig.
(Constant)	317.816		38.893		8.172	0
Storage (MCM)	0.013		0.004	0.829	2.961	0.04

Source: SPSS v27 output (2021). Dependent variable: Hydropower output (MW)

Discussion of Findings

The findings show a substantial hydrologic variability in the Niger Basin between 2010 and 2020 and an increasingly exposed developed environment to its swings. The worst consequences were not from normal flow, but from excessive discharge. A high flow of 31,670 m³/s in 2012 destroyed 569,000 hectares of crops and evacuated 2.3 million people. Even the lesser peaks in 2018 and 2020 displaced roughly half a million people every year. It's a fundamental vulnerability, not a disappearing threat. Reservoir sedimentation was 16% to 18%, reducing storage and hydropower generation. This has degraded grid stability and increased dependence on thermal plants. Water quality was below WHO guidelines, with turbidity reaching 88 NTU at Onitsha. This situation is indicative of the industrial and household demand on the urbanised reach. The near-perfect association between built-up development and exposure (r = 0.994) verifies the conceptual framework: spatial expansion into floodplains transforms danger into loss. The use of zoning and coordinated reservoir management in the Mekong and Nile basins results in poorer long-term adaptability compared to the Niger, which operates reactive relief. The results contribute to the concept of integrated basin management by evaluating the chain from river driver to government to human exposure in one dataset in Nigeria (Zhou et al., 2024; Effiong et al., 2024). The findings imply that planners should focus on floodplain zoning, watershed restoration, pollution enforcement and hydropower rehabilitation as linked and mutually reinforcing methods for practice.

The research has limitations worth addressing. The time period 2010–2020 has three big flood years but not the catastrophic 2022 flood; hence, the most recent extreme event is not included in the research. The statistical tests were based on small samples (eight cities for correlation and six reservoir-year observations for regression), which limited statistical power and scope of conclusion. Some secondary records from disaster agencies have missing entries during peak situations. Water-quality sampling encompassed two reaches, not the whole corridor. These limits affect the robustness of the results, although triangulation across field, geographical, and documentary sources has lessened their influence. Future research should extend the time series, include more sample ranges, and apply panel models to other cities.

5. Conclusion and Recommendations

Social-ecological systems linked via the River Niger affect risk and resilience in Nigeria's built environment. Floods displace settlements, sedimentation eats into reservoir storage and hydropower, declining water quality poses a risk to public health, and floodplain expansion increases household exposure. The near-perfect relationship between built-up growth and exposure, and the significant association between storage capacity and energy output, indicate that the current system has offered limited flexibility via reactive relief. Policy must move toward adaptive governance. Examples of practical measures include enforceable floodplain zoning with satellite monitoring, afforestation of catchments and dredging of reservoirs to restore storage capacity, tighter discharge standards for industrial and domestic effluents, and a costed hydropower rehabilitation programme for Kainji, Jebba and Shiroro. "Use flood-risk data on development permits to prevent new vulnerability. It is suggested that future research should use panel models in other cities, increase the number of water quality monitoring stations, and prolong the time series until 2020. This study offers an empirical basis for resilient development integrating socio-ecological aspects, as indicated by SDGs 6, 7, 9 and 11, by linking human exposure to sedimentation, outflow, water quality and urbanisation.

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