© JAN 2026 | IRE Journals | Volume 9 Issue 7 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I7-1713860

From Reservoir to Resilience: Enhancing the Sustainable Utilization of Nigeria's Dam Infrastructure under Climate and Security Constraints

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Abstract *- Nigeria's extensive network of dams constitutes a vital pillar of its socio-economic and environmental development strategy, serving as the foundation for water supply, irrigation, flood control, and hydropower generation. Yet these assets face a dual threat from intensifying climate variability and deepening security crises that have disrupted their management and undermined their contribution to national resilience. This article explores the sustainable utilization of Nigeria's dam infrastructure, focusing on the Gurara Water Transfer Project (GWTP), to examine how climate change, security disruptions, and governance weaknesses affect its operational efficiency and resilience. The study adopts a case study methodology, analyzing the Gurara Water Transfer Project as a representative example of Nigeria's broader dam infrastructure. Data was collected through mixed methods, including water supply, hydropower generation, and agricultural performance record. In addition, qualitative interviews and focus group discussion were employed to understand the local socio-economic impacts. The study finds that, despite the Gurara dam augmenting the raw water supply into Usuma dam for the delivery of potable water to the Federal Capital territory, it's potential to contribute to hydropower, and irrigation and achieve the overall objectives of the project are constrained by the noncompletion of the retrofitting works in the power plant and the transmission lines, seasonal fluctuation of inflow into the reservoir, increased sedimentation, deteriorating water quality, and security disruptions. Additionally, fragmented governance structures and inadequate coordination between stakeholders have hindered effective management and utilization. The article concludes that transitioning from "reservoir reliance" to "resilience" requires addressing climate resilience, security-sensitive planning, and improved governance. Implementing these reforms is essential for maximizing the sustainable utilization of Nigeria's dam infrastructure, ensuring long-term benefits for water, energy, and agricultural sectors.*

Keywords: *Gurara Water Transfer Project; Nigeria's dam infrastructure; Climate change; Security disruptions; Water supply; Hydropower generation; Governance and resilience*

I. INTRODUCTION

Dams have long been recognized as critical infrastructure for advancing global development, particularly in regions where water scarcity and energy shortages pose significant challenges (World Bank, 2018; UNEP, 2020). The role of multipurpose dams extends beyond water storage to encompass essential services such as irrigation, hydropower generation, flood control, and even ecosystem management (FAO, 2016). These water infrastructure support food security, improve living standards, and contribute to economic growth by harnessing water resources for a variety of uses (Grey & Sadoff, 2007). According to the International Commission on Large Dams (ICOLD, 2021), dams provide a sustainable solution to meeting the increasing demand for water, food, and energy, especially in developing countries. In sub-Saharan Africa, where agriculture remains a central pillar of the economy, large dams have played a crucial role in supporting both small-scale and industrial farming, helping to mitigate the impact of erratic rainfall patterns while also contributing to regional energy grids (African Development Bank, 2019; Nicol et al., 2020).

In Nigeria, the state of dam infrastructure is pivotal to addressing the country's multifaceted development challenges. With a rapidly growing population and the need for consistent access to water and electricity, Nigeria's dams, such as the Kainji, Shiroro, and Gurara dams have been central to national development plans (Adeniran et al., 2021; Bello et al., 2024). These multipurpose dams are designed to provide water for irrigation, power generation, and domestic consumption, playing a vital role in enhancing food security, boosting hydropower production, and driving regional development (Oladipo & Oladokun, 2020). Despite their immense potential, however, the sustainable utilization of these water resources remains hampered by various

challenges, including climate variability, sedimentation, and governance gaps that undermine their effectiveness (Ogunbode et al., 2019; Bello et al., 2024).

Climate change has exacerbated the challenges facing Nigeria's dam infrastructure, with shifts in rainfall patterns, increasing temperatures, and changing hydrology threatening the long-term viability of water storage and management (Adeniran et al., 2021). In many parts of the country, particularly in the northern region, rainfall variability and prolonged dry spells have put significant pressure on water resources (Ogunbode et al., 2019). This has been further complicated by the escalating issue of water quality degradation, including increased sedimentation rates, which reduce reservoir capacity and efficiency (Bello et al., 2024). Additionally, water contamination due to poor management practices has made water resources less viable for agricultural and industrial use (Oladipo & Oladokun, 2020). These climate-induced stresses, combined with the looming threat of insecurity, present a complex challenge for the sustainable management of dam infrastructure in the country (Okoye et al., 2022). The rise of banditry, insurgency, and communal conflicts in northern Nigeria has led to the disruption of dam operations, including delays in maintenance, hindrances to water flow, and the abandonment of projects (Aliyu & Shehu, 2021). Furthermore, insecurity has hindered access to key infrastructure and resulted in the displacement of communities that depend on the dams for their livelihoods, contributing to a reduced capacity for local development and economic resilience (Nwankwo et al., 2023).

The Gurara Water Transfer Project (GWTP) provides an insightful case study to explore these intertwined challenges. The project, designed to transfer water from the Gurara dam to the Lower Usuma dam and the Federal Capital Territory (FCT), is a critical infrastructure project that highlights the complex relationship between climate, security, and governance in managing dam infrastructure (Ogunbode et al., 2019). The Gurara dam, despite its potential to support both water supply and hydropower generation, has faced setbacks due to inadequate infrastructure development, security threats, and inefficient governance frameworks (Bello et al., 2024). These challenges reveal the broader issue of underutilization of Nigeria's dam infrastructure, where projects often fail to meet their intended capacity or benefits due to a lack of coordination between government agencies, inadequate funding, and lack of community engagement in decision-making processes (Oladipo & Oladokun, 2020).

This article seeks to examine the sustainable utilization of Nigeria's dam infrastructure, with a focus on how climate change and security dynamics affect the potential of dams like Gurara. It addresses critical questions regarding how these stressors hinder the long-term sustainability of dams, and the governance gaps that create a "resilience gap" between infrastructure potential and realized benefits. Specifically, it explores how climate-induced changes in water availability and quality, combined with the increasing security risks, affect the performance of Nigeria's dams. Furthermore, the article examines the governance and institutional barriers that limit the effectiveness of these dams, including fragmented policy frameworks, inadequate inter-agency collaboration, and a lack of robust monitoring and maintenance practices. Ultimately, this paper will argue that shifting Nigeria's dam portfolio from a reliance on large reservoirs to a resilience-focused model requires targeted reforms in both governance and infrastructure management. By framing these challenges within the broader context of Nigeria's development agenda and climate security concerns, this study aims to contribute to a deeper understanding of how multi-sectoral collaboration, climate adaptation, and security-sensitive planning can enhance the sustainable utilization of dam infrastructure in Nigeria.

II. LITERATURE REVIEW

2.1 Impounded Reservoirs, Sustainable Development, and the Water-Energy-Food (WEF) nexus

Impounded reservoirs, created by the construction of dams, are essential infrastructures that support a range of socio-economic activities. These artificial bodies of water are designed primarily for water storage, but their roles extend far beyond this function, with significant implications for sustainable development. The reservoirs help provide water for irrigation, hydropower, industrial use, and domestic consumption, contributing to agricultural productivity, energy generation, and economic growth (Biggs, Bruce, Boruff, & Imanari, 2015). In

many developing countries, including Nigeria, the development of large dams has been critical to improving food security and enhancing water availability in regions prone to drought (Rasul & Sharma, 2015).

Beyond water supply, impounded reservoirs play an important role in enhancing livelihoods through fish farming, recreational activities, and tourism. These multi-functional benefits make them vital to achieving several Sustainable Development Goals (SDGs), particularly Clean Water and Sanitation (SDG 6), Affordable and Clean Energy (SDG 7), and Zero Hunger (SDG 2) (Wang et al., 2023). The effective management and sustainability of these reservoirs are central to fostering long-term economic stability and addressing the needs of vulnerable populations.

The water–energy–food (WEF) nexus concept highlights the interconnectedness between water, energy, and food systems, emphasizing that actions taken in one sector can significantly impact the others. Dams, as key infrastructure, sit at the heart of this nexus. Dam Reservoirs are instrumental in managing water resources, which are crucial for irrigation and hydropower generation, both of which contribute to agricultural and energy production. Additionally, reservoirs contribute to ecosystem services by supporting biodiversity, regulating water quality, and maintaining environmental flows (Healy & Tang, 2021).

However, the sustainable utilization of these reservoirs faces challenges, such as water availability, water pollution, sedimentation, and climate variability (Paulos et al., n.d.). Water scarcity, fluctuating rainfall patterns, and unpredictable weather events are increasingly threatening the viability of reservoirs, limiting their capacity to serve multiple functions (Winton et al., 2019). As a result, the need to manage the WEF nexus effectively has become more urgent, especially in regions like Nigeria, where the interaction between these sectors is crucial to economic and social development (Biggs et al., 2015).

2.2 Climate-Resilient Infrastructure and "Compound Risk"

The Resilience theory has gained prominence in the context of infrastructure planning, particularly in understanding how systems can withstand and adapt to various stressors over time. Resilience refers to the ability of systems to absorb shocks, adapt to changes, and continue functioning under adverse conditions. Climate-resilient infrastructure, such as dams, requires more than just the ability to handle environmental stresses. It also needs to be designed and managed to accommodate the evolving risks associated with climate change, including rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events (Paulos et al., n.d.). This concept is vital when assessing the role of dams in Nigeria, where water management systems are vulnerable to the combined impact of climate variability and other stressors such as security issues and political instability (Rasul & Sharma, 2015).

The concept of "compound risk" refers to the interaction between climate-related risks and non-climate stresses, such as insecurity, governance failure, and socioeconomic inequality, all of which compound the challenges of maintaining dam infrastructure and achieving resilience. In Nigeria, the impact of compound risk is particularly pronounced in northern regions, where ongoing insecurity exacerbates the effects of climate change on dam infrastructure (Winton et al., 2019). This multi-layered risk environment makes it difficult to ensure that dams continue to serve their intended purposes, including water supply, energy generation, and agricultural support (Healy & Tang, 2021).

The relationship between climate change and security is increasingly recognized as a critical challenge for infrastructure development and sustainability. In regions such as northern Nigeria, where violent conflict and displacement are prevalent, the ability of communities and governments to manage infrastructure is severely compromised (Biggs et al., 2015). Insecurity not only disrupts maintenance activities but also hinders the equitable distribution of resources from dams.

Moreover, the compounded effects of climate-induced droughts and floods, alongside conflict, lead to delays in the completion and operation of dams, which undermine their potential to support regional economic development (Wang et al., 2023). Addressing compound risks requires a holistic approach that incorporates both climate adaptation strategies and measures to enhance security and governance. Building resilience into Nigeria's dam

infrastructure, therefore, demands not only addressing environmental stresses but also mitigating the social and political factors that exacerbate vulnerability to these risks (Healy & Tang, 2021).

2.3 Security, Governance, and Large Dams in Nigeria

In Nigeria, the governance of large dams is often challenged by weak institutional frameworks, inadequate regulation, and insufficient coordination between various stakeholders, leading to inefficiencies and underutilization of available water resources. The socio-economic impacts of large dams, such as Gurara, Kainji, Tiga, Shiroro and Dadin Kowa, have been widely discussed in literature, particularly regarding their contribution to regional economic development and poverty alleviation (Zhang et al., 2020). These dams, which have been essential to Nigeria's energy and agricultural sectors, often face challenges in terms of management and operation, resulting in missed opportunities for sustainable development.

The socio-economic benefits of these dams, such as water for irrigation, power generation, and domestic consumption, are often not fully realized due to inconsistent maintenance, political interference, and a lack of long-term planning (Singh & Sharma, 2021). Furthermore, the governance of these dams is further complicated by issues of accountability and transparency, where overlapping roles of Federal, State, and Local Governments create confusion and inefficiencies (Chambers & Dunlap, 2022).

One of the most pressing concerns is the governance of these dams under conditions of insecurity, particularly in northern Nigeria. The issue of insecurity, driven by conflict and insurgency, remains an underexplored determinant of dam outcomes. For instance, in regions affected by Boko Haram and banditry, the safety of infrastructure and personnel involved in dam management is compromised, leading to delayed projects, vandalization, and decreased dam performance (Bello & Ogar, 2021).

In addition, insecurity disrupts access to vital dam infrastructure and affects the local populations who rely on these resources for their livelihoods (Kofi & Adeyemi, 2023). The inability to secure these areas undermines the full potential of dams and limits their contribution to regional development, especially in rural areas where access to water, energy, and agricultural support is crucial for economic survival. The impacts of insecurity thus exacerbate the challenges faced by the governance of large dams, highlighting the need for more integrated, secure, and resilient infrastructure management approaches (Olugbenga et al., 2021).

2.4 Water Law, Policy, and Institutional Architecture

Nigeria's water law and policy framework, which includes the National Water Resources Act (2004), the River Basin Development Authorities (RBDAs) Act (2004), and the regulatory oversight of bodies such as the National Electricity Regulatory Commission (NERC) for hydropower generating dams, National Water Resources Policy & Strategy (2016), National Irrigation & Drainage Policy & Strategy (2016), National Water Supply & Sanitation Policy (2000) and the Infrastructure Concession Regulatory Commission (ICRC) Act (2005), are integral to the management and utilization of dam reservoirs. These policies aim to ensure sustainable water management, water conservation, efficient allocation, and equitable distribution of resources (Chambers & Dunlap, 2022). However, despite these institutional structures, the management of water resources and large dams often faces challenges related to ineffective coordination, lack of funding, and unclear roles and responsibilities, which hinder efficient utilization (Singh & Sharma, 2021).

The National Water Resource Act provides a broad legal framework for the sustainable management of water resources, but its implementation has been inconsistent. The RBDAs, which are tasked with overseeing the development of dams and water infrastructure in specific hydrological areas, often face capacity constraints, limiting their effectiveness in managing water resources (Rasul & Sharma, 2015). Furthermore, the reliance on Public-Private Partnerships (PPPs) for financing and managing dams has raised concerns regarding accountability, transparency, and equitable benefit distribution. Although PPPs offer potential for increased investment in dam infrastructure, they can also result in misalignment of priorities, where private sector interests may not fully align with the public good (Zhang et al., 2020).

The governance of water resources in Nigeria also suffers from gaps in policy implementation and

regulatory enforcement. While laws and policies exist to promote sustainable water management, the lack of effective enforcement and the politicization of water management have led to inconsistent practices and outcomes (Healy & Tang, 2021). The ICRC, which regulates infrastructure concessions, plays a role in facilitating PPPs for the development of dams, but there is often a lack of clarity regarding the roles of different actors, particularly at the local level. This fragmented institutional landscape undermines the ability to manage dams effectively, especially in regions affected by security threats and insecurity, further complicating the governance framework (Bello & Ogar, 2021). As Nigeria continues to grapple with these institutional challenges, there is a clear need for a more cohesive and transparent framework that ensures the efficient and equitable utilization of water resources and improves the sustainability of large dam infrastructure (Kofi & Adeyemi, 2023).

2.5 Research gap and article positioning

Despite the growing recognition of the importance of sustainable dam management, there remains a significant gap in the literature on the comprehensive assessment of dam performance in the Nigerian context. While several studies have addressed the technical and socio-economic aspects of dam development, there is limited research on the sustainability of these projects, particularly in relation to the interaction between climate change, security, and governance. Existing studies often overlook the compound risks posed by these factors and their impact on the long-term viability of dams. This article seeks to fill this gap by providing a detailed analysis of the Gurara Water Transfer Project, using it as a case study to explore how climate and security stressors affect the sustainable utilization of Nigeria's dams. The paper will examine the governance structures in place and the institutional gaps that hinder the effective management of dam infrastructure, focusing on the interplay between climate, security, and institutional weaknesses. By doing so, this article aims to extend existing knowledge on dam governance and resilience, offering new insights into the challenges and opportunities for enhancing the sustainability of Nigeria's dam infrastructure.

III. METHODOLOGY

The research adopted a mixed-methods approach, using a case study design to analyze the sustainable utilization of the Gurara Water Transfer Project (GWTP). Data was collected through household surveys, key informant interviews (KIIs), and focus group discussions (FGDs), which provided a comprehensive understanding of community experiences and perceptions. Additionally, project documents and water quality data from the National Water Quality Research Laboratory (NWQRL) in Minna were used, covering four key sites: the Gurara reservoir, Lower Usuma, River Gurara at Izom, and Gwagwalada. These data sources allowed for a holistic assessment of the project's impact on water supply, irrigated agriculture, hydropower generation, and socio-economic outcomes. The study also explored governance challenges and the role of security concerns in the operation of the infrastructure, capturing both quantitative and qualitative dimensions.

The study area, centered on the Gurara dam and its associated infrastructure, was selected for its significance in Nigeria's water management system. The dam, located in central Nigeria, was designed to serve multiple functions, including water supply for the Federal Capital Territory (FCT) and surrounding areas, hydropower generation, and irrigation for agriculture. The analytical framework combines Sustainable Development Theory, addressing economic, social, and environmental dimensions, with resilience thinking to capture the impact of compound climate-security risks. The analysis involved examining socio-economic indicators through descriptive statistics, evaluating water quality trends from 2019 to 2023, and analyzing qualitative data to identify recurring themes related to security, governance, and community resilience. This comprehensive approach was used to assess the gaps between the dam's potential and actual performance, positioning the study within the broader context of climate resilience and sustainable infrastructure management.

IV. RESULTS

The Gurara Water Transfer Project (GWTP), designed to provide water supply to the Federal Capital Territory (FCT), support hydropower generation, and facilitate agricultural irrigation, faces significant challenges in fully realizing its potential. Despite its design to meet multiple developmental

goals, the project's effectiveness has been compromised by a combination of factors including security disruptions and institutional fragmentation. This results section outlines the key findings regarding the dam's multi-sector utilization, environmental stressors, security-related impacts, and governance challenges.

4.1 Security Crisis and Its Impact on the Gurara Water Transfer Project

The security challenges in northern Nigeria which became pronounced in the 2010s escalated to Kaduna State, including Kachia, Kagarko, and regions around the Gurara Dam and Jere Irrigation Project. The attacks by bandits, kidnappers and other criminal elements began to significantly affect the southern parts of Kaduna state, including Kachia and Kagarko. These areas have been targeted due to their strategic importance and vulnerabilities, such as the presence of critical infrastructure like the Gurara Dam and Jere Irrigation Project. Bandits and other armed groups exploited gaps in security to carry out kidnappings, attacks on communities, and other criminal activities. The escalation of insecurity around the Gurara Dam and its surrounding communities marked a critical turning point in the utilization and management of the project. Violent attacks and persistent threats from armed groups led to widespread fear and forced displacement of local residents. Entire communities abandoned their homes, farmlands, and livelihoods, seeking refuge in safer areas, thereby disrupting the socio-economic activities integral to the dam's operational environment. As a result of the deteriorating security situation, all official activities at the dam site including operation, maintenance and irrigation were suspended. Contractors and government personnel vacated the area due to safety concerns, leaving critical infrastructure

The suspension of activities also created a ripple effect on the surrounding ecosystem and local economy. Agricultural productivity declined sharply and the absence of human oversight increased the risk of resource mismanagement.

Efforts to address these challenges have included the deployment of the Nigeria Civil Defence and Security Corps (NCDSC) as well as the Special Mobile Police Force from 2020 to 2021. The Special Mobile Police Force disengaged in 2021 following the loss of their men to the crisis.

Despite the efforts by security agencies to restore order, the situation underscored the fragility of infrastructure development in conflict prone regions and highlighted the urgent need for integrated security and community engagement strategies in the management of critical national assets like the Gurara Water Transfer Project.

In 2024, a military base was established in the project area to secure the dam and environs. At this time, the communities had fled having lost many of their members to the bandits and criminal elements. The situation was very complex, with socio-economic factors and weak governance contributing to the persistence of the insecurity.

The interruption of dam operations, coupled with increased costs of security and the displacement of farmworkers, resulted in economic losses for both the local population and national agricultural outputs. The socio-economic impacts on displaced communities are severe, with reduced income from farming, fishing, and other livelihood activities.

Presently security in the dam and environs is provided by the Military and Nigeria Civil Defence and Security Corps (NCDSC). The Military have been allocated 1000 hectares of land for agricultural purpose. Peace is gradually being restored. Communities who fled are returning and there seems to be light at the end of the tunnel.

Peace, Justice and Strong Institutions (SDG 16) play a crucial role in the sustainable development of any nation. Peace is absolutely necessary for the long-term utilisation of the Gurara dam reservoir for the sustainable socio-economic development of Nigeria. Without peace, access to the Gurara dam water resources, hydropower and land resources cannot be guaranteed. Peace is a foundational pillar for the sustainable utilisation of the Gurara dam reservoir for water supply, food security, hydropower generation and other economic benefits.

4.2 Multi-Sector Utilization Performance

4.2.1 Examination of the Contribution of the Gurara Water Transfer Project (GWTP) to Water Supply in the Federal Capital Territory

Water transfer from Gurara dam to Lower Usuma Dam (LUD) is carried out during the dry season when the reservoir level has drawn-down and can no longer

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DOI: https://doi.org/10.64388/IREV9I7-1713860

supply enough raw water to the treatment plants. For optimal release of water from LUD to the treatment plants, the Highest Flood Level (HFL) of the reservoir should be at 574m. Table 1 shows the data on the history of water from Gurara dam reservoir from November, 2007 to March 2025.

Table 1: Water Transfer from Gurara Dam Reservoir to Lower Usuma Dam from November, 2007 to March 2025

S/N	DATE OF OPENING (PUMPING)	RAW WATER LEVEL AT OPENING R.W.L	DATE OF CLOSE AT RAW WATER LEVEL	R.W.L INCREASE AT CLOSER
1	19 November 2007	573.92	27 November 2007	573.858
2	28 November 2007	573.82	9 December 2007	574.1
3	19 November 2008	573.25	26 November 2008	573.95
4	22 January 2009	572.61	23 January 2009	572.73
5	28 January 2009	572.59	11 February 2009	574.0
6	25 March 2009	572.97	7 April 2009	573.97
7	12 February 2010	572.31	9 March 2010	574.2
8	19 June 2010	568.42	20 June 2011	569.40
9	11 July 2011	568.70	17 August 2011	573.8
10	4 April 2012	572.33	12 May 2012	573.4
11	28 February 2013	572.34	27 March 2013	574.2
12	3rd April 2014	569.10	8 March 2014	573.4
13	19 February 2015	569.7	2 April 2015	573.9
15	20 February 2017	571.35	10 April 2017	574.1
16	7 February 2018	571.10	29 March 2018	574.6
17	6 February 2019	572.41	15 March 2019	574.0
18	22 January 2020	571.91	18 February 2020	574.0
19	15 March 2020	572.93	10 April 2020	573.9
20	3 February 2021	572.6	16 March 2021	574.0
21	23 January 2022	571.8	28 February 2022	573.9
22	2 March 2023	572.7	4 April 2023	574.2
23	21 February 2024	571.6	26 March 2024	574.1
24	10 May 2024	572.2	2 June 2024	574.4

Source: Data for 2016 was not available at the FCT Water Board

Depicted in Fig.1 is the relative water level at LUD and the frequency of release since the inception of the water transfer. The breakdown of Fig. 1 is presented in fig. 2 and Fig. 3

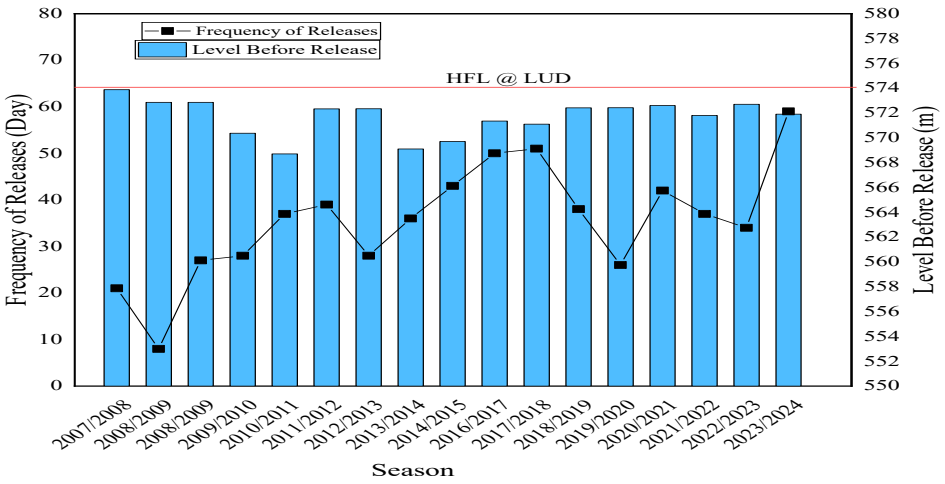

Fig.1: Seasonal Level of Water Before Release and the Frequency of Release from Gurara Dam

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DOI: https://doi.org/10.64388/IREV9I7-1713860

Fig. 2 shows that in 2023/2024 season, water was released in 60 days while in 2008/2009 season, water was released in 8 days. These depict more than 200% increase of raw water demand and release to Lower Usuman Dam (LUD) over the period in view. This also points toward a geometrical increase of raw water demand of the LUD Water Treatment Plant and rapid drawdown of Lower Usuma reservoir during the dry season.

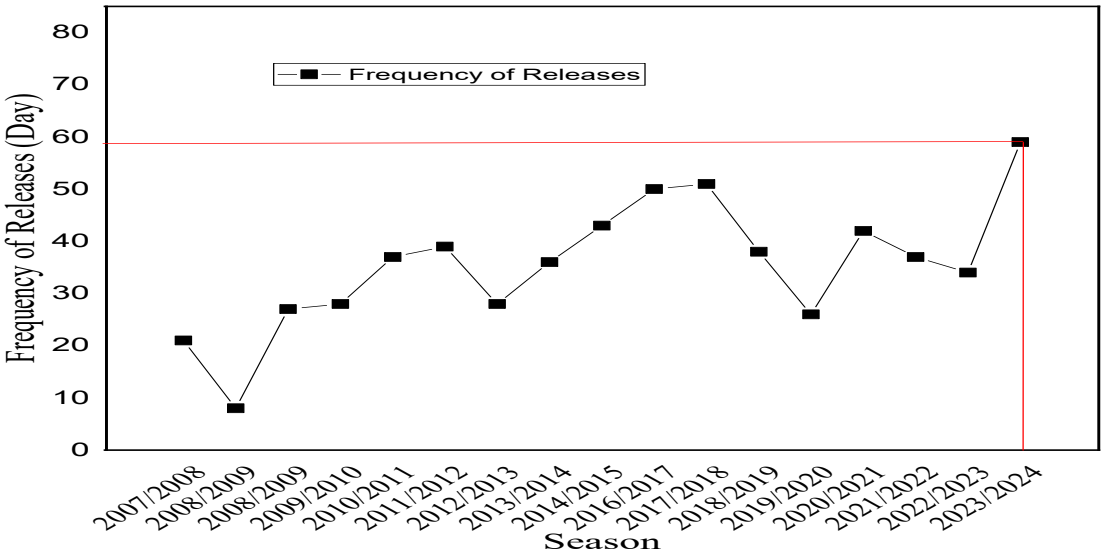

Fig. 2: Frequency of Release from Gurara Dam since commencement

Fig. 3 shows seasonal water level from 2007 to 2024. As shown in the figure, the HFL for optimal operation of the LUD Water Treatment Plant is 574m.

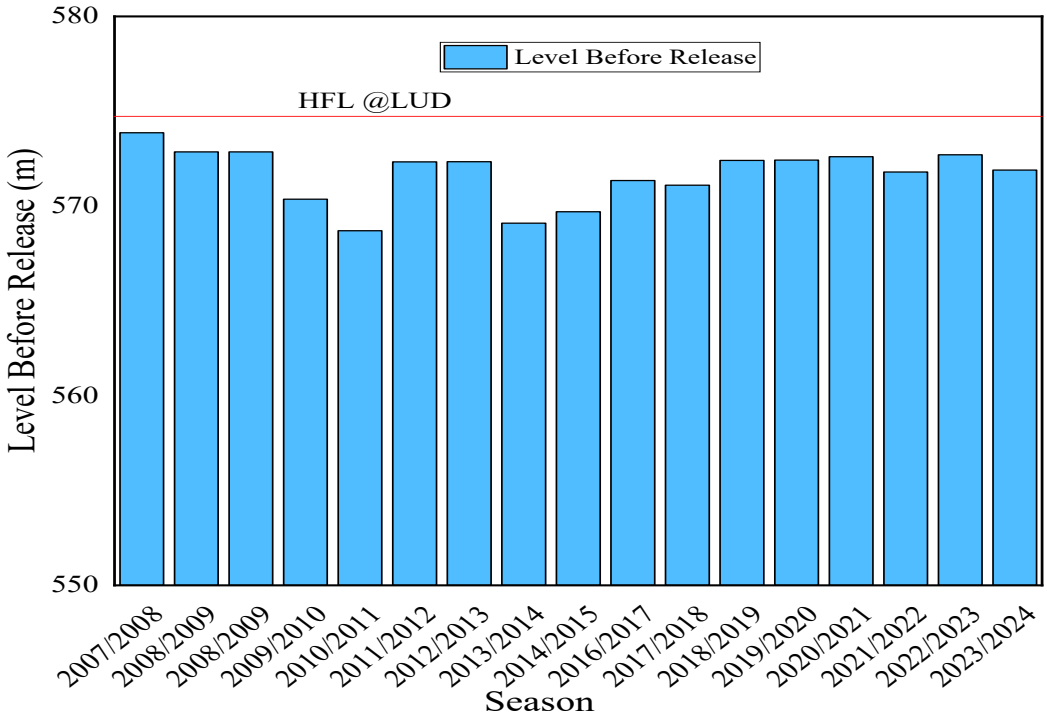

Fig 3: Seasonal Level of Water Before Release

The Abuja Water Supply Master Plan is designed to produce 60,000m^3/hr for a population of three million people at the design horizon. The existing water treatment plant capacity of 30,000m^3/hr. is currently serving the city. Treatment plants 1 and 2 are of 5,000m^3/hr. capacity each while treatment plants 3 and 4 are of 10,000 m^3/hr. capacity each. The treated water is distributed to the residents across the city by

gravity except for higher elevated locations like the Ministers Hill and Maitama that require pumping.

The areas of the FCT that are presently being served by the Water Board are Asokoro, Garki 1 & 2, Wuse 1 & 2, Gudu, Gwarinpa, Jabi, Karu, Nyanya, Maitama, Utako, Wuye, Kubwa 1 & 2, Bwari and Gwagwalada.The current population of the FCT is estimated at about Five million. The available water supply infrastructure in the FCT can serve less than 1.5 million people. Water supply development in the FCT has a huge infrastructural gap, requiring urgent investments to bridge the gap. The Management of the FCT Water Board has development a five years Strategic Plan (Road Map) to revitalize the FCT Water Board for effective and efficient delivery of clean water to the residents.

When the Gurara Water Transfer Project was at the study and design stage, the FCT Water Board had only one treatment plant of 5,000m^3/hr. Presently the water treatment plant capacity is 30,000m^3/hr. This has been made possible by the augmentation of raw water from the Gurara dam reservoir via the 75 km pipeline. Despite the success achieved in water supply to the FCT, challenges remain. Rising urbanization in the FCT continues to expand demand, requiring ongoing upgrades in treatment and distribution networks.

4.2.2 Examination of the Contribution of the Gurara Water Transfer Project (GWTP) to Power Supply

Federal Ministry of Water Resources completed the construction of the Gurara dam 30MW hydropower plant in 2014. The power plant has a configuration of three units of 10MW each. The power generated is to be wheeled through the transmission network to Mando sub-station in Kaduna. The hydropower plant has the potential to contribute significantly to Nigeria achieving the Sustainable Development Goals (SDGs) by enhancing public health, food security, industrialization and poverty reduction. In 2020, the Federal Government completed the concession of the 30MW hydropower plant to North South Power Company Limited under a Public Private Partnership arrangement in line with the Public Procurement Act, 2007 and the Infrastructure Concession Regulatory Commission (ICRC) Act, 2005. The Concessionaire has the responsibility to operate and maintain the power plant.

The transmission line from Gurara dam to Kudenda in Kaduna State was also completed by Federal Ministry of Water Resources. The Transmission Company of Nigeria (TCN) is undertaking the 25km, 132KV transmission line from Kudenda to Mando, Kaduna State.

The operations of the power plant have been delayed because of the following factors:

i. The Concessionaire, North South Power Ltd. is presently undertaking a general maintenance/retrofitting to enhance the plants performance, efficiency and sustainability. This is scheduled to be completed in June, 2025.
ii. The short line of 25km, 132KV transmission line from Kudenda to Mando, Kaduna State is yet to be completed by the Transmission Company of Nigeria.
iii. The security challenge at Gurara dam and environs halted all activities at the dam site for some time until recently following the deployment of the Military to provide security in the area.

The power plant is expected to become operational by the last quarter of 2025. This will bring transformation to all the components of the project. Electricity will be supplied to the facilities at the dam, camp as well as the communities. The production of power at the plant will transform the Gurara dam and environs. Electricity will also be available to power the irrigation infrastructure (center pivots etc). In addition, the power generated will be supplied to the moribund factories in Kaduna, creating employment and reviving the economy.

Global and local records show that multipurpose dams can be powerful levers for sustainable socio-economic development that support energy access, food security, employment and industrialization, thereby supporting many SDGs simultaneously. The Gurara Water Transfer Project when fully operational will showcase the value of multi-functional dam infrastructure for water supply, irrigated agriculture and power generation, demonstrating optimal resource use from a single reservoir system.

When all the project components (water supply, irrigated agriculture, hydropower and environmental flow) become fully operational, the operation of the reservoir must be data driven, taking into consideration the annual rainfall prediction by

Nigerian Meteorological Agency (NIMET) and annual flood outlook of the Nigerian Hydrological Services Agency (NIHSA). Water stress in the dry season may necessitate the shutting down of one or two units of the hydropower plant. This will depend on the water inflow into the reservoir, release of raw water into Usuma reservoir and the extent of the development and cultivation of 6000 Ha irrigation farms.

4.2.3 Examination of the Contribution of the Gurara Water Transfer Project (GWTP) to Irrigated Agriculture and Aquaculture.

The Gurara Water Transfer Project represents a significant investment with the potential to substantially support irrigated agriculture through the provision of reliable water resources and the implementation of modern irrigation technologies. The project's contribution to irrigated agriculture is multifaceted. The regulated release of water from the dam to downstream users has paved the way for the development of modern irrigation schemes. A notable achievement is the establishment of the irrigation pilot scheme at the dam site utilizing surface, sprinkler, and center pivot irrigation systems. At the Azare-Jere irrigation scheme, farm lands were allocated to the local communities.

However, with the security challenge in the area, the irrigation infrastructure was seriously vandalised and the farms abandoned. Consequently, in 2017, Federal Ministry of Water Resources revoked the previous allocation of farm lands and initiated the process of acquiring a Facility Manager to undertake the operations and maintenance of the dam and irrigation infrastructure and in 2019 the Ministry also leased some of the farms to commercial farmers.

The Gurara dam's reservoir and the consistent water supply it ensures also hold considerable promise for aquaculture. The creation of a large water body provides an environment suitable for traditional fishing and aquaculture, potentially boosting local economies and contributing to the nation's fish production. The local fishermen undertake their fishing activities in the reservoir. There are about 50 fishermen but some of them leave during the lean periods. The fishermen observed the introduction of new species of fish from the Izom area after the impoundment of the dam, The fishermen sell their products in the fish market. Some of the fish are processed dry before they are sold in the local market.

Realizing the full potential in irrigated agriculture and aquaculture requires sustained investment, effective management of water resources and continuous monitoring of environmental impacts to ensure long-term sustainability and benefits.

4.3 Environmental and Climate-Related Stressors

Environmental pressures, particularly climate-induced variability and sedimentation, have exacerbated challenges to the dam's functionality. The water quality assessment of the dam revealed a significant decline in water quality across key monitoring sites; Gurara reservoir, Lower Usuma Dam, River Gurara at Izom, and Gwagwalada. Over the past few years, key water quality indicators such as turbidity, dissolved oxygen (DO), and E. coli levels have shown consistent deterioration. This suggests that the dam's water supply capability is increasingly compromised, threatening its utility for both agricultural irrigation and potable water production.

The increased sedimentation rates have also severely affected the dam's storage capacity, reducing its ability to provide consistent water supply. This environmental stress has been exacerbated by changing rainfall patterns and poor land management practices in the catchment area, which contribute to the sedimentation problem.

Table 2: Water Quality Trends (2019-2023)

Year	Turbidity (NTU)	Dissolved Oxygen (mg/L)	E. coli (CFU/100mL)	Notes
2019	~5.4 NTU	~4.8 mg/L	~120 CFU/100mL	Generally, within WHO limits, but microbial contamination evident in rural sites
2020	~5.9 NTU	~4.6 mg/L	~135 CFU/100mL	Slight increase in turbidity and E. coli linked to flooding and runoff

2021	~6.2 NTU	~4.5 mg/L	~150 CFU/100mL	DO decline observed; turbidity exceeded WHO guideline (5 NTU)
2022	~6.4 NTU	~4.2 mg/L	~160 CFU/100mL	Seasonal variation significant; wet season contamination spikes
2023	~6.5 NTU	~4.0 mg/L	~170 CFU/100mL	Persistent microbial contamination; classified as "medium quality, unfit for drinking without treatment"

4.4 Governance, Institutions, and Operational Fragmentation

The governance structure surrounding the Gurara dam has been marked by significant fragmentation. The roles of key stakeholders, such as the Federal Ministry of Water Resources (FMWS), the affected River Basin Development Authorities, Generating Companies of Nigeria GENCOs), Facility Managers, Water Boards etc. are often unclear, leading to inefficiencies in dam management and operations. This lack of clear responsibility and coordination has been exacerbated by political interference and a lack of sustained technical capacity.

4.5 Synthesis: Underutilization and the Resilience Gap

The combination of climate-induced pressures, security threats, and governance failures created a substantial resilience gap in the utilization of the Gurara dam. Despite its significant potential to provide water supply, hydropower, and agricultural benefits, the dam's operational effectiveness remains well below design expectations. The compounded effects of sedimentation, security disruptions, delay in the completion of power transmission lines and institutional fragmentation have led to underutilization amid abundance. The dam's role in regional economic development, energy production, and water supply is severely hampered by these barriers, preventing it from reaching its full potential.

To address these challenges and enhance the resilience of Nigeria's dam infrastructure, it is crucial to implement systemic reforms. These reforms should include climate adaptation strategies, improved governance and coordination between stakeholders, and better management of security risks. Only through these integrated efforts can Nigeria's dams evolve from a state of reservoir reliance to one of true resilience, capable of withstanding both environmental and socio-political challenges.

V. DISCUSSION AND CONCLUSION

The experience of the Gurara Water Transfer Project (GWTP) offers valuable lessons when viewed in comparison with other major dams in Nigeria and across Africa, such as Kainji, Shiroro, Tiga, Dadin Kowa, and Akosombo. Like these dams, Gurara was designed with ambitious goals, including providing water to the Federal Capital Territory (FCT), supporting agricultural irrigation, and generating hydropower. However, common patterns of underperformance are evident across all these projects. Delays in completing complementary infrastructure, such as power transmission networks, hindered their ability to deliver full benefits. Additionally, weak benefit-sharing mechanisms, particularly in terms of local community engagement, have led to underutilization of the dams' potential. This theme of delayed development and limited local development is consistent across Nigeria's major dams and points to systemic issues in how dam projects are conceived, managed, and executed.

The complex interplay between climate change, security, and governance has created a nexus of vulnerability for the Gurara dam. This case supports and extends theories on security-sensitive infrastructure planning, particularly in regions affected by instability. As evidenced by the challenges at Gurara, without a peaceful environment and functional institutions, efforts to adapt to climate change or ensure the sustained benefits of infrastructure like dams are inevitably undermined. The security disruptions experienced in northern Nigeria, such as banditry and insurgency, have led to significant delays in maintenance, reduced agricultural output, and loss of livelihoods for communities dependent on the dam. Furthermore, the governance challenges fragmented institutional roles and poor inter-agency coordination have compounded these issues, making it difficult to implement effective climate adaptation measures or ensure that dam benefits are fully realized. These findings resonate with SDG 16, which emphasizes peace, justice, and strong institutions as foundational

to achieving sustainable development goals, particularly in the context of infrastructure.

The shift from traditional utilization metrics (such as installed capacity or water volumes) to resilience-based metrics is essential in addressing the long-term sustainability of Nigeria's dam infrastructure. While installed capacity and water volumes have been conventional indicators of success, they do not account for the ability of these systems to function under climate stress or security threats. The resilience of dams should be measured by their ability to continue providing services during extreme weather events, their contribution to equitable benefits for local populations, their environmental health (in terms of water quality and ecosystem maintenance), and their robustness in the face of security risks. This shift is not only aligned with the SDGs, particularly those related to climate action (SDG 13) and sustainable infrastructure (SDG 9), but also reflects the critical need to recognize insecurity as an overlooked determinant in infrastructure planning. Without addressing these underlying vulnerabilities, the full potential of dams like Gurara will remain unrealized.

The policy and practice implications of this study underscore the need for comprehensive reforms in governance, climate adaptation, and community engagement. Inter-agency coordination must be improved among the Federal Ministry of Water Resources & Sanitation, River Basin Development Authorities (RBDAs), Hydropower Generating Companies, Facility Managers, State Water Boards, and other stakeholders to ensure cohesive management and long-term sustainability. A national policy or framework specifically focused on dam and reservoir management would provide clear guidelines and responsibilities for each stakeholder, preventing the fragmentation observed in Gurara's governance. Additionally, climate adaptation measures such as watershed management, sediment control, and continuous water quality monitoring are essential to mitigating the environmental stressors on dams. With climate change exacerbating these challenges, dams must be equipped with adaptive management strategies that prioritize environmental flows and climate-informed operations.

Security-sensitive planning is another key aspect that needs urgent attention. Dams like Gurara should integrate security risk assessments into their design and operation to safeguard against vandalism, theft, and sabotage. Additionally, there must be stronger benefit-sharing mechanisms, such as corporate social responsibility (CSR) initiatives, to support displaced communities and those affected by the dam's operations. Providing long-term support to these communities, through livelihood restoration and infrastructure development, can ensure that the benefits of the dam are equitably shared and lead to more resilient communities.

Finally, the need for data collection, monitoring, and research cannot be overstated. Building long-term monitoring frameworks is crucial for assessing the performance of dams, particularly in the face of evolving climate and security challenges. Collaborations with the Nigerian Hydrological Services Agency (NIHSA), Nigerian Meteorological Agency NIMET) and research institutions should be expanded to incorporate more sophisticated technologies such as remote sensing and geospatial analysis to better understand the impacts of these stressors on dam infrastructure and local communities.

In conclusion, the Gurara Water Transfer Project illustrates how climate, security, and governance challenges, when compounded, severely limit the sustainable utilization of dam infrastructure. Moving from "reservoir reliance" to "resilience" requires integrated reforms that address these challenges through effective governance, climate adaptation, improved security planning, and community engagement. The findings from this case study offer valuable lessons for Nigeria's broader dam portfolio, emphasizing the need for a holistic approach to infrastructure management that balances environmental, social, and economic factors. Future research should focus on developing more robust models for resilience measurement and examining the long-term impacts of security and climate change on dam infrastructure across Nigeria.

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