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A Systematic Review of Sedimentation and Water Quality in Kiri Dam, Adamawa State, Northeastern Nigeria

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Abstract: The Kiri Dam Reservoir, located on the River Gongola in Northeastern Nigeria, is experiencing rapid sedimentation and declining water quality, which threaten its long-term operation. This study offers a comprehensive review of scientific literature, analyzing 32 peer-reviewed articles published between 2015 and 2025 to assess the extent, causes, and effects of these environmental issues. Using a PRISMA-based approach and thematic analysis, the review identifies key sedimentation patterns, water contaminants, and management gaps. Results show a 15% decrease in storage capacity from 2002 to 2022, mainly due to upstream deforestation, erosion, and agricultural runoff. Water tests reveal high levels of heavy metals—especially lead and cadmium—that surpass WHO safety standards, particularly during dry seasons. Sediment resuspension worsens contamination risks. Predictive models, such as SWAT, RUSLE, and the Rouse method, have proven effective in estimating sediment loads and identifying areas prone to erosion. Comparative case studies support an integrated approach, including sediment control structures, real-time monitoring, and participatory governance. The study recommends strategies such as dredging, automated monitoring, better institutional coordination, and community-driven watershed management. These findings provide a practical framework for restoring the ecological health of Kiri Dam and promoting sustainable water resource management, applicable to similar tropical reservoirs facing environmental stress.

Keywords: *Sedimentation, Water Quality, Sustainable Management, Kiri Dam Reservoir, Nigeria*.

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I. INTRODUCTION

Dam reservoirs are vital for water management, offering hydropower, storage, irrigation, and flood control (Kariuki and Obiero, 2021). They support socio-economic growth and industry by ensuring reliable water for domestic, agricultural and commercial use. However, many reservoirs face threats from sedimentation and declining water quality (Wang *et al*., 2022).

Sedimentation involves the accumulation of silt, organic matter, and particles, including heavy metals, in reservoirs. Yao *et al*. (2023) state that this reduces storage and hydraulic capacity while increasing flood risk. Franchi *et al.* (2024) note it alters reservoir shape and efficiency. Hale *et al.* (2023) warn that without management, global capacity may drop significantly by century's end.

Sedimentation results from natural factors, such as soil erosion, landslides, and fluvial deposition, as well as human activities like deforestation, agriculture, and infrastructure development, which increase sediment loads by destabilizing catchments (Attulley *et al*., 2022). Vegetation removal boosts surface runoff, carrying more sediments into reservoirs.

The decline in water quality worsens sustainability concerns, influenced by upstream activities like agricultural runoff, untreated wastewater, and industrial effluents that introduce harmful substances such as nitrates, heavy metals, and pathogens (Panigrahi *et al*., 2024). Ikeda *et al.* (2021) highlight ecological and health risks like eutrophication, algal blooms, and biodiversity loss resulting from poor water quality.

The Kiri Dam Reservoir, built in 1982 on Nigeria's Gongola River, supports irrigation, hydropower, fisheries, and domestic water. Edward and Adamu (2023) highlight its socio-economic importance to nearby communities. However, recent studies report seasonal spikes in heavy metals like lead (Pb) and cadmium (Cd) during the dry season, often exceeding WHO thresholds.

Gadiga and Garandi (2018) documented observable reductions in both the surface area and depth of the reservoir, attributing these changes to sedimentation; however, the precise factors driving this trend warrant further investigation. These alterations present potential risks to water security, ecological integrity, and community resilience. This study aims to evaluate the challenges of sedimentation and water quality at Kiri Dam through a thorough synthesis of peer-reviewed literature published between 2015 and 2025. Its objectives are threefold: (i) to identify the causes and impacts of sediment build-up; (ii) to examine the primary pollutants affecting water quality and the efficacy of monitoring methods; and (iii) to propose evidence-based strategies for sustainable dam management, inspired by global best practices.

This manuscript advances research on sustainable reservoir management by synthesizing current literature and insights from Kiri Dam. It highlights the need for interdisciplinary methods, including sediment monitoring, water quality assessment, and capacity building. The document is organized as follows: Section 2 covers review methods; Section 3 discusses the findings; Section 4 offers conclusions and recommendations for improved governance and sustainability.

II. METHODOLOGY

This methodology section details the materials, review design, and analytical methods of this desktop systematic review. No field or lab tools were used. Data came from peer-reviewed journals via online databases, managed with Excel and Mendeley. The PRISMA framework guided the review for transparency and rigor.

- *Context of Review Focus*

The Kiri Dam Reservoir, established in 1982 in Adamawa State, Nigeria, is vital water infrastructure managed by the Upper Benue River Basin Development Authority. It supports irrigation for the Savannah Sugar Company, now Dangote Sugar Refinery, along with domestic water supply and potential hydroelectric power. The dam measures 1,250 meters long and 20 meters high, with a capacity of 6.5 million cubic meters, a catchment area of about 25,000 km², a max water level of 170.5 meters, and a reservoir surface of 19.7 km².

Plate 1: Showing Downstream of Kiri Dam

Plate 2: Showing Upstream with Domestic use and Fishing Activities

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Plate 3: Showing Environmental Hazard by Kiri Dam Flow

➢ *Review Design and Methodological Approach*

A systematic, thematic review examined sedimentation, water quality decline, and management of the Kiri Dam Reservoir. The PRISMA framework ensured transparency and reproducibility through clear article criteria, multi-reviewer screening, and organizing findings into predefined and emerging themes.

➢ *Search Strategy and Literature Sources*

- *Databases Consulted*

Four reputable academic databases—ScienceDirect, SpringerLink, Wiley Online Library, and Google Scholar—were selected for their extensive environmental engineering and water resource literature coverage. This multi-source approach reduced bias and ensured access to diverse, peer-reviewed studies.

- *Search Terms and Timeframe*

Search strings used keywords like “sedimentation,” “water quality,” “reservoir management,” and “Kiri Dam” with Boolean operators, e.g., "Sedimentation AND Water Quality AND Reservoir Management AND ‘Kiri Dam’." The timeframe was limited to 2015–2025 for recent issues, and only English publications were included for consistency.

➢ *Inclusion and Exclusion Criteria*

The review's literature was selected based on strict criteria to ensure relevance, quality, and applicability. Only peer-reviewed articles from 2015 to 2025 on sedimentation, water quality, and reservoir management in the Kiri Dam or similar reservoirs were included. Studies had to report empirical data or use scientific models, address relevant topics, include explicit methods, and be in English. Preference was given to studies on hydrological modelling, heavy metals, or community impacts. Articles lacking geographic relevance, empirical validation, or clear methods, as well as opinion pieces, duplicates, and grey literature, were excluded. This process ensured the inclusion of only methodologically sound and relevant studies.

➢ *Screening, Selection, and Bias Management*

The screening and selection process followed a systematic protocol. Out of 62 articles from databases, 17 were excluded after title and abstract screening for irrelevance or lack of rigour. Forty-five articles were reviewed in full to assess their relevance, leading to the exclusion of eight due to insufficient transparency, relevance, or thematic fit. Ultimately, 32 articles were included in the final synthesis.

Two independent reviewers conducted the screening, resolving discrepancies through consensus. A structured data extraction and quality assessment ensured reliability. This process guaranteed that only high-quality, relevant, and rigorous studies informed the final analysis. Table 1 summarizes the screening stages and retained studies.

Table 1 Overview of Screening, Selection, and Bias Control Process

Review Phase	**Number of Studies**
Records Identified through Databases	62
After Title and Abstract Screening	45
Full-text Articles Assessed for Eligibility	37
Final Articles Included in the Review	32

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➢ *Data Extraction and Software Tools*

Data were extracted using Microsoft Excel, cataloguing author(s), year, objectives, region, models, and findings. A thematic matrix enabled article comparison. Mendeley managed references, citations, and duplicates.

➢ *Thematic Grouping and Synthesis*

The literature synthesis used a hybrid thematic analysis with both deductive and inductive reasoning. Predefined themes came from research aims and scholarly literature, with sub-themes emerging through literature reviews. The analysis covered three main domains: (i) sedimentation drivers and dynamics, (ii) water quality and risks, and (iii) reservoir management and policies. Sub-themes included heavy metal contamination, community adaptation, and sediment modeling tools like RUSLE and SWAT. Coding was manual using matrices for comparison, helping identify patterns, strengths, and gaps. This systematic approach linked findings to reservoir sustainability and guided recommendations. The final structure aimed to improve clarity, coherence, and relevance to research goals.

➢ *Quality Assessment of Included Studies*

All studies underwent a rigorous quality assessment to ensure methodological soundness and relevance. A checklist focused on research design, data source credibility, thematic alignment, and data clarity. Only studies meeting the quality threshold were included. Articles with weaknesses, such as unclear design or insufficient focus on key topics, were excluded. This process ensured that only credible, relevant studies contributed to the review, enhancing its reliability and integrity.

➢ *Limitations of the Methodology*

Despite the structured approach, this review has limitations. Potential publication bias exists, as the search was limited to peer-reviewed literature, which favors studies with positive results. Relevant studies with null or inconclusive findings may have been missed. The search strategy relied on specific keywords, Boolean logic, and selected databases, possibly excluding important publications outside these parameters. Variability in study designs made data synthesis and comparison difficult. The review was also limited to English-language literature, likely missing relevant research in other languages or grey literature. To address these issues, reference lists were manually checked for additional studies, and a dual-reviewer protocol was used to reduce bias. These efforts improved the review's comprehensiveness and balance.

➢ *Data Synthesis and Reporting*

The synthesis categorized 32 studies into four themes: (i) sedimentation and modelling tools, (ii) water quality risks, (iii) management practices, and (iv) policy recommendations for sustainable reservoir governance. Sedimentation studies focused on dynamics, erosion, and models like RUSLE and SWAT. Water quality research examined parameters, contamination pathways, and health risks. Management explored governance and stakeholder engagement. Policy findings aimed to improve regulation, monitoring, and water resource management. Table 2 shows each study's contribution, highlighting patterns, gaps, and future research needs.

Table 2 Research Articles used for Analysis

	Research Articles and Reports	**Author(s) (Year)**
1	*Surface water fluctuations in Kiri Dam*: Documented seasonal changes in surface water levels at Kiri Dam.	Frichi *et al.*, 2023
2	*Spatio-temporal changes of Kiri Dam*: Surface area and depth reduction of Kiri Lake: Observed reductions in reservoir surface area and depth over time.	Gadiga & Garandi, 2018
3	*Geospatial assessment of river channel changes in River Gongola post-impoundment*: Evaluated channel morphological changes following dam impoundment.	Ikusemoran *et al.*, 2024
4	*Assessment of trends of surface water in Kiri Dam, Adamawa State, Nigeria:* Identified a declining trend in surface water area.	Bilham et al., 2023
5	*Hydrological changes in the upper Yellow River under the impact of upstream cascade reservoirs over the past 70 years*: Quantified impacts of cascade reservoirs on runoff and sediment load.	Hu *et al.*, 2025
6	*Spatiotemporal sediment yield variability in the upper Blue Nile Basin, Ethiopia*: Showed significant variability in sediment yield.	Bihonegn & Awoke, 2025
7	*Scoping potential dams: Utilizing remote sensing products to analyze topographic characteristics, runoff-to-storage ratio, and sedimentation—A Port Sudan case study*: Developed a framework for evaluating sedimentation potential.	Delaney *et al.*, 2025
8	*Assessment of the sediment load in the Pearl River Estuary based on land use and land cover changes*: Linked LULC changes to sediment load variations.	Ji *et al.*, 2025
9	*Quantification and potential erosion model in the Chichaoua Watershed and Boulaouane Dam, High Atlas, Morocco*: Quantified annual soil loss and identified erosion-prone areas.	Baiddah *et al.*, 2025
10	*Evaluating optimal relationships for estimating suspended sediment discharge in the Balaroud River*: Determined the most reliable model (Rouse method with 80% accuracy) for sediment discharge estimation.	Lashkar-Ara & Kiani, 2025
11	*Seasonal levels of heavy metals in Kiri Reservoir: Water, fish (*Brycinus leuciscus*), and sediments*: Higher heavy metal concentrations in the dry season, with Pb and Cd exceeding WHO limits.	Edward & Adamu, 2023

12	*Assessment of environmental and health problems caused by Kiri Dam:* Highlighted environmental issues such as flooding, erosion, and water contamination affecting human health.	Ibrahim *et al.*, 2021
13	*Public health implications of water quality of the Kiri Reservoir, Adamawa State, Nigeria*: Reported potential public health risks from waterborne contaminants.	Ikusemoran *et al.*, 2021
14	*Health risk assessment of water quality in Kiri Reservoir*: Identified significant correlations between contaminants (e.g., nitrates, coliform) and health risks.	Kwari, 2023
15	*An assessment of heavy metal contents impact on fish species obtained from Kiri Dam, Adamawa State, Nigeria*: Showed bioaccumulation of heavy metals in fish tissues, indicating potential risks for consumers.	Milam *et al.*, 2020a
16	*Determination of selected heavy metals and human health risk assessment in fishes from Kiri Dam and River Gongola*: Detected heavy metals in fish with potential health risks indicated through THQ values.	Orosun *et al.*, 2016
17	*Public health implications of water quality of the Kiri Reservoir, Adamawa State, Northeastern Nigeria:* Discussed water contamination and its associated public health concerns.	Soro, 2016
18	*Appraising water quality, health risk and correlation of water quality parameters of Kiri Dam Reservoir – Shelleng LGA*: Found significant correlations among key water quality parameters and health risks.	Williams, 2023
19	*Assessment of water quality at the Kiri Dam, Adamawa State, Nigeria:* Reported moderate water quality for irrigation but unsuitability for domestic use.	Zamdayu, 2021
20	*Water and wastewater treatment in Nigeria: Advancements, challenges, climate change, and socioeconomic impacts:* Reviewed water treatment advances and challenges, emphasizing socio-economic impacts.	Amaefule *et al.* (2023)
21	*Analysis of environmental and economic effects of Kiri Dam, Adamawa State, Nigeria*: Demonstrated environmental changes and economic impacts resulting from the dam's operation.	Adebayo *et al.* (2016)
22	*Livelihood diversification and income: A case study of communities' resident along the Kiri Dam, Adamawa State, Nigeria*: Examined socio-economic benefits and challenges faced by communities, highlighting reliance on dam resources.	Amurtiya *et al.* (2016)
23	*Assessment of community resilience to flood disaster in Kiri Dam's catchment:* Evaluated community resilience and adaptive capacity to flooding.	Ikusemoran *et al.* (2023)
24	*Assessment of water resources development and exploitation in Nigeria: A review of integrated water resources management approach:* Highlighted challenges in water governance and IWRM implementation in Nigeria	Ngene *et al.* (2021)
25	*Federalism and water management in Nigeria:* Examining overlapping responsibilities and fragmentation in water management.	Pillah *et al.* (2024)
26	*Effects of Kiri Dam construction on the economy of Lower Gongola Basin of Shelleng LGA:* Documented economic losses and shifts in agricultural practices post-dam construction	Shalangw *et al* (2023)
27	*Innovative approaches to water resource management in achieving sustainable development goals:* Proposed new strategies incorporating technology and policy for sustainable water use	Takhumova & Goncharova (2025)
28	*Environmental changes in Kiri Dam's watershed: Impacts on water resource sustainability:* Explored watershed changes and their implications on water sustainability	Zemba *et al.* (2016)
29	*Community resilience to flood disasters in Kiri Dam's catchment*: Assessed community adaptation and resilience to recurring flood events.	Mayomi *et al..* (2023)
30	*Water resource allocation management and dam catchment performance evaluation using the WEAP model: A case study of Iran's Bakhtegan Catchment:* Demonstrated benefits of coordinated dam operations and water allocation using WEAP.	Karimi & Khorshidi (2025)
31	*Optimizing integrated water supply management for multi-purpose reservoirs: A policy tree approach:* Developed an optimization model for reservoir operations that enhances storage and flood control	Erfani & Goharian (2025)
32	*Sedimentation management in reservoirs with particular reference to a medium-height Indian dam (Maithon*: Discussed sediment management challenges and potential mitigation techniques applicable to medium-height dams.	Jain (2025)

III. RESULTS AND THEMATIC DISCUSSION

This section presents the main findings of the review, organized by themes. Each subsection explores sedimentation, water quality issues, and reservoir sustainability at Kiri Dam, drawing lessons from international cases, with relevant figures and literature supporting the results.

➤ *Extent and Impact of Sedimentation at Kiri Dam*

- *Historical Trends and Measured Depth Loss*

Evidence of prolonged sediment accumulation at Kiri Dam shows seasonal water level changes, reductions in reservoir depth and surface area, and a 15% capacity decline from 2002 to 2022, as reported by Frichi *et al.* (2023), Gadiga and Garandi (2018), and Bilham *et al.* (2023).

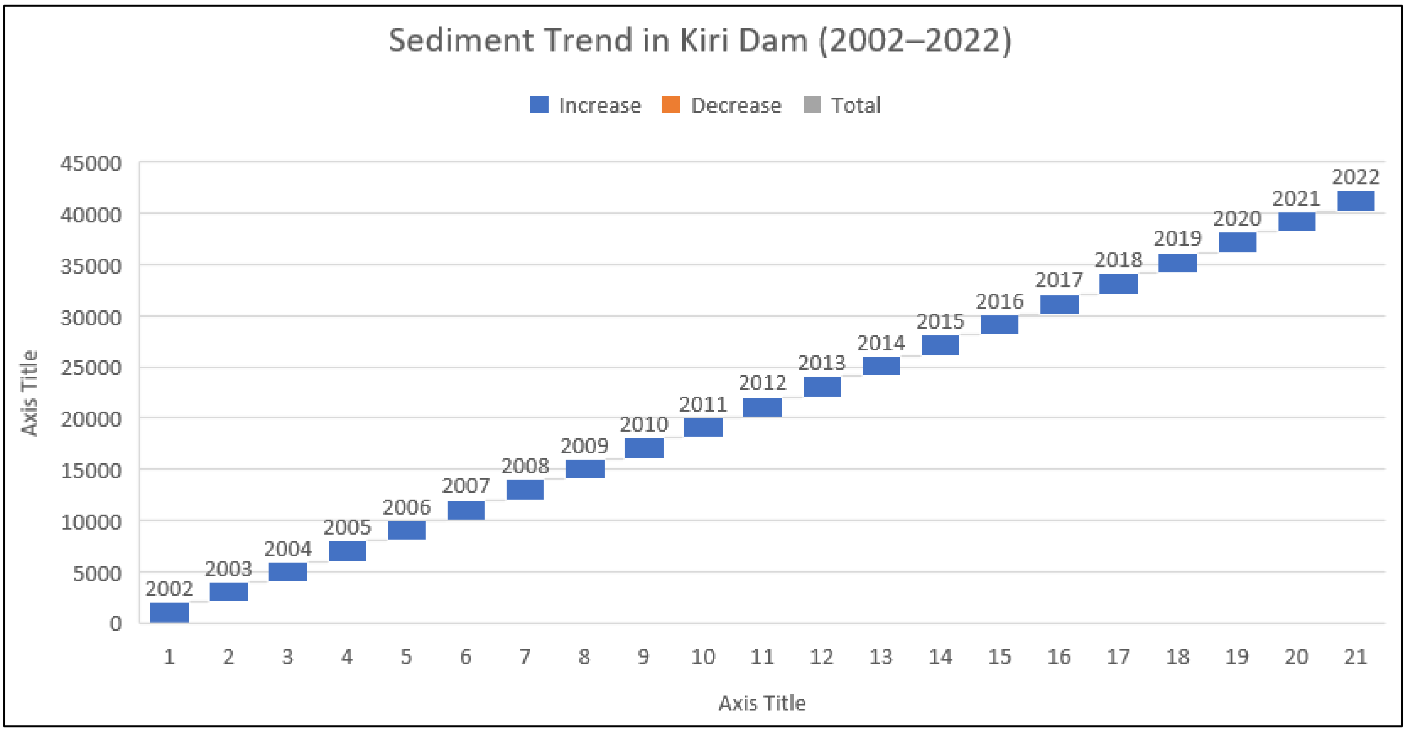

Fig 1 Sediment Trend in Kiri Dam (2002–2022) (Adapted from Frichi *et al.*, 2023)

This graph illustrates a steady decline in reservoir depth and capacity over a 20-year period, reflecting ongoing sediment accumulation.

- *Impacts on Hydraulic Performance*

Limited depth hampers irrigation, hydropower, and water resource reliability. Lashkar-Ara and Kiani (2025) showed the Rouse method predicts suspended sediment with around 80% accuracy. In Kiri, it may aid early sediment detection, dredging, and extending reservoir life.

➤ *Water Quality Status and Contamination Patterns*

- *Key Contaminants and Health Risks*

Dry season analyses show water samples exceed WHO safety thresholds for lead and cadmium (Edward & Adamu, 2023). Ibrahim *et al.* (2021) and Ikusemoran *et al.* (2021) link these contaminants to health risks. Kwari (2023) correlates nitrates, turbidity, coliform bacteria, with gastrointestinal diseases.

- *Seasonal Fluctuations*

Water quality varies seasonally. Williams (2023) noted turbidity was 70% higher in the dry season due to sediment resuspension and less dilution. These findings highlight the need for adaptive, seasonally adjusted monitoring strategies.

➤ *Sediment-Bound Pollutants and Remobilization*

Sediment transports pollutants that can be re-mobilized during low water flow or turbulence, increasing ecological risks. Installing vegetative buffers and sediment traps is recommended to mitigate these effects.

➤ *Predictive and Monitoring Tools*

- *Sediment Transport Modelling*

Tools like SWAT and RUSLE effectively estimate sediment yield in tropical regions. Baiddah et al. (2025) used RUSLE to assess erosion in Morocco, estimating up to 27.5 tonnes per hectare annually. These models can be calibrated for the Kiri watershed using local topography, rainfall, and land use data.

- *Accuracy and Practical Application*

The Rouse method is best suited for data-scarce environments like Kiri, achieving 80% accuracy with historical records and remote sensing, offering a cost-effective monitoring solution.

➤ *Comparative Lessons from Other Reservoirs*

Hu *et al.* (2025) documented upstream cascade dams' impact on Yellow River sediment, while Bihonegn and Awoke (2025) linked Ethiopia's Blue Nile sediment yield to

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land cover and rainfall. These suggest that watershed interventions like afforestation and conservation agriculture could be relevant to Kiri dam.

- *Integrated Strategies for Sustainable Management*

- *Structural Controls*

Engineering options like desilting, sediment bypass tunnels, and vegetative barriers, suggested by Jain (2025) and Delaney et al. (2025), suit medium-height dams and may apply in the Kiri basin.

- *Institutional and Policy Solutions*

The water governance fragmentation in Nigeria hampers dam operation. Ngene *et al*. (2021) and Pillah *et al*. (2024) support integrated frameworks. Models by Erfani and Goharian (2025), combining decision-support tools for reservoir management, could enhance water allocation in Kiri.

- *Key Insights*

Sediment buildup in Kiri Dam mainly results from human activities like deforestation and poor land management. Water quality is worsened by remobilized contaminants on sediments. To enhance sustainability, structural solutions, predictive models, policies, and community involvement are needed. Future studies should use high-resolution remote sensing (e.g., Sentinel-2, Landsat), participatory monitoring, and climate forecasting.

IV. CONCLUSION AND RECOMMENDATIONS

- *Summary of Findings*

This study finds sedimentation and water quality decline harm the Kiri Dam Reservoir's sustainability and ecology. Data show reduced surface area and capacity due to sediment build-up and hydrological issues. Contaminants like lead and cadmium often exceed WHO safety limits, risking health. Socioeconomic impacts include changing agriculture, losing vegetation, and disrupting livelihoods. The study highlights the importance of models like RUSLE, SWAT, and Rouse for monitoring sedimentation, erosion hotspots, and improving water management, especially with limited data.

- *Relevance and Contributions*

This review enhances understanding of reservoir sustainability in Nigeria's semi-arid regions by examining environmental degradation, public health, and socio-economic resilience. Using predictive models, GIS, and policy ideas, it offers a framework for similar reservoirs. The findings benefit policymakers, environmental planners, and researchers focused on sediment and water quality management.

- *Recommendations*

- *Technical Recommendations*

✓ Implement regular dredging and install sediment traps at key inflow points.
✓ Deploy and calibrate sedimentation models such as SWAT, RUSLE, and the Rouse method using local data.
✓ Integrate GIS and remote sensing tools for real-time sediment and water quality monitoring.
✓ Introduce automated water quality monitoring systems to track seasonal variations in contamination levels.

- *Governance and Monitoring*

✓ Strengthen coordination among River Basin Authorities and other stakeholders via enforceable, unified policies.
✓ Promote data sharing and joint planning mechanisms among relevant agencies.
✓ Institutionalize periodic environmental audits for dam reservoirs to assess sediment and water quality.
✓ Establish dedicated funding streams, including public-private partnerships, for monitoring infrastructure and research.

- *Community-Based Actions*

✓ Involve local communities in participatory monitoring programmes for sedimentation and water quality.
✓ Promote climate-smart agriculture and livelihood diversification as adaptive strategies.
✓ Ensure community initiatives are supported with technical training, institutional recognition, and access to funding.

- *Areas for Further Research*

- Conduct multi-seasonal sedimentation and contaminant studies across varying hydrological conditions.
- Field-validate the predictive models with in-situ sediment and water quality measurements.
- Investigate socio-ecological interactions, especially gendered impacts related to access and use of water resources.
- Develop integrated reservoir planning tools that merge environmental, institutional, and economic variables.
- Adapt and replicate these frameworks in other sediment-challenged dams, such as Dadin Kowa, Tiga, and Jibiya.

- *Final Remarks*

Kiri Dam highlights the link between sediment dynamics, water quality decline, and socio-environmental pressures. Sustainable management requires a shift from reactive to proactive, science-based strategies. Incorporating predictive models, policy reform, and community engagement offers a framework to safeguard water infrastructure amid environmental challenges. The review's insights are relevant to other tropical reservoirs facing similar issues.

- *Author Contributions*

- **Gambo, A.T.**: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Visualization
- **Dr. O. S. Olaniyan:** Supervision, Validation, Writing – review & editing

- **Prof. A. A. Adegbola:** Supervision, Writing – review & editing

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