

Water infrastructure sustainability in Nigeria: a systematic review of challenges and sustainable solutions

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ABSTRACT

Using the PRISMA method, this systematic literature review synthesized findings from 15 studies to elucidate the key factors contributing to water infrastructure failure in Nigeria and propose evidence-based sustainable solutions. The study identified technical, financial, environmental, social, political, and institutional factors as predominant challenges in achieving water infrastructure sustainability. In response to these challenges, the researcher proposes a comprehensive 'Sustainability Framework for Water Infrastructure'. This framework is designed to guide every stage of water infrastructure development, starting from pre-construction with an emphasis on inclusive project planning, followed by the construction phase where suitable techniques are utilized, and extending to the post-construction stage, focusing on efficient monitoring and management mechanisms. The study highlights the complexity of water infrastructure sustainability in Nigeria and underscores the urgent need for a structured and comprehensive approach to address this pressing issue.

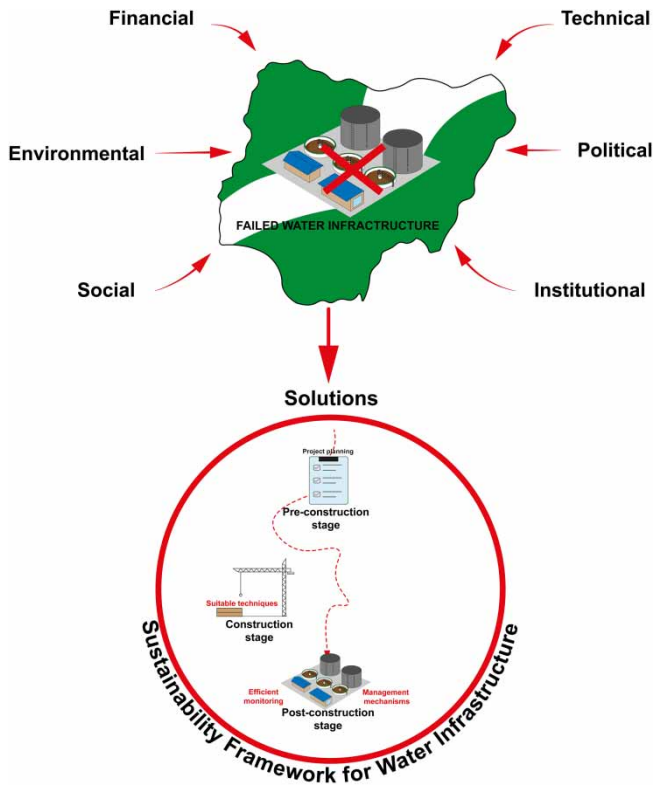
Key words: Nigeria, Sustainable Water Solutions, UN SDG 6.1, Water infrastructure, Water infrastructure failure, Water sustainability challenges

HIGHLIGHTS

- Analysis of causes of Nigeria's water infrastructure failure.
- Reviews existing research on Nigeria's water sector and identifies sustainable solutions.
- Novel Sustainability Framework for Water Infrastructure to guide future water infrastructure development.
- Evidence-based recommendations for policy, practice, and future research.
- Review of clean water access for UN SDG 6.1 in Nigeria.

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GRAPHICAL ABSTRACT



1. INTRODUCTION

Access to safe and affordable drinking water is a fundamental human right and a cornerstone of sustainable development (Bain *et al.*, 2014). The United Nations Sustainable Development Goal 6.1 (SDG 6.1) specifically aims to ‘achieve universal and equitable access to safe and affordable drinking water for all by 2030’ (United Nations, 2015). This target is critical, as it improves public health and well-being and has significant implications for other Sustainable Development Goals (SDGs), such as poverty alleviation, gender equality, and economic growth (UN-Water, 2016; Satterthwaite *et al.*, 2020, Aly *et al.*, 2022).

Achieving SDG 6.1 is crucial due to its far-reaching impact on the SDGs. Access to clean water reduces water-borne diseases, supports food production, energy generation, and industrial development, and alleviates the burden on women and girls who are disproportionately responsible for fetching water in developing countries (Ray, 2007; Sorenson *et al.*, 2011; WHO, 2017; Prüss-Ustün *et al.*, 2019). Despite progress made in recent decades, significant disparities in access to safe drinking water persist between and within countries, particularly in rural and disadvantaged areas (WHO, 2017, 2019). Tackling these challenges and filling the knowledge gaps in water infrastructure research calls for a joint effort from governments, communities, and international organizations. Moreover, it requires a systematic literature review of this kind to synthesize the existing literature on the subject to better understand the issues and identify effective solutions (Adeniran *et al.*, 2021; Adeniran, 2022).

Globally, significant progress has been made in expanding access to clean water, with over 90% of the world's population now enjoying improved water sources (WHO, 2019). However, approximately 785 million people still lack basic water services, and disparities persist between urban and rural areas and among different socioeconomic groups (Bain *et al.*, 2014; WHO, 2019). Additionally, the high rate of failed water infrastructure in developing countries remains a pressing challenge, with many projects failing due to inadequate planning, financing, and maintenance (Bonsor *et al.*, 2015; Whaley & Cleaver, 2017).

In developing countries, especially in sub-Saharan Africa, access to safe drinking water is hindered by numerous challenges, including rapid urbanization, population growth, climate change, and weak governance (Onda *et al.*, 2012; Dos Santos *et al.*, 2017). High rates of failed water infrastructure further exacerbate these issues, with estimates suggesting that as many as 40% of water points in the region have failed (Network, 2010; Foster & Hope, 2017). The failure of water projects can have severe consequences for local communities, contributing to water scarcity, poor health outcomes, and persistent poverty (Whaley & Cleaver, 2017; Prüss-Ustün *et al.*, 2019).

Nigeria, the most populous country in Africa, faces significant challenges in achieving the targets set by SDG 6.1. A thorough comprehension of the country's water infrastructure necessitates an in-depth analysis of its water demands, available water resources, and existing infrastructure. Geographically, Nigeria exhibits substantial variations, impacting both its economic conditions and water management. Borehole water and other groundwater sources play a crucial role in meeting the water needs of Nigerian communities. However, a concerning trend of borehole failures and non-operational water supply infrastructure persists (Andres *et al.*, 2018b), impeding Nigeria's progress towards SDG 6.1 and hindering the achievement of interconnected SDGs.

Despite significant investments in water infrastructure, only 67% of the Nigerian population has access to basic water services, leaving a stark 33% underserved and emphasizing the significant unmet demand for sustainable access to clean drinking water. Additionally, about 47% of water points are non-operational (Andres *et al.*, 2018b; NPC & ICF, 2019; UNICEF Nigeria, 2020). This crisis arises from a combination of technical, financial, environmental, social, political, and institutional challenges that exacerbate water infrastructure failures (Andres *et al.*, 2018a; Adeniran *et al.*, 2021). For a detailed understanding of the spatial distribution of these infrastructure failures, refer to Figures S1, S2, and S3 (see SI), illustrating water infrastructure failures across 1,696 communities in three distinct Nigerian states and visually presenting the challenges (Adeoti *et al.*, 2023). Addressing this complex scenario is crucial for improving Nigeria's water supply and advancing towards the goals outlined in the 2030 Agenda for Sustainable Development.

Despite the growing research on Nigeria's water infrastructure, there is a lack of in-depth studies focusing on the challenges and long-term viability of this infrastructure. A significant study by Adeniran (2022) underscores the importance of a deeper understanding of the terms 'sustainability' and 'infrastructure' in this context. These emphasize the significance of comprehensive reviews like the present one, aiming to unravel the complexities of Nigeria's water infrastructure sustainability and highlighting actionable sustainable solutions. This systematic literature review endeavors to shed light on the principal impediments leading to water infrastructure failures in Nigeria and to unearth sustainable solutions proposed in the existing literature. The specific objectives of this review include:

- Systematically identify and analyze the key technical, financial, environmental, social, political, and institutional factors contributing to water infrastructure failure in Nigeria.
- Critically review and synthesize the existing literature on water infrastructure challenges and sustainability in Nigeria, examining the employed theoretical frameworks, methodologies, and empirical findings, and understanding how the current research addresses the factors contributing to failure.
- Identify evidence-based sustainable solutions that have been proposed or implemented to address the challenges contributing to water infrastructure failure and promote sustainable development in Nigeria's water sector.

- Discuss the implications of the findings for policy, practice, and future research, highlighting the areas where further research is needed to advance the understanding of water infrastructure sustainability in Nigeria.
- Propose actionable recommendations for policymakers, practitioners, and researchers to address the identified challenges and contribute to achieving SDG 6.1 in Nigeria and other developing countries.

In addressing these objectives, this review focuses on studies conducted within the Nigerian context and published in English. The review primarily covers the period from 2000 to 2023. The year 2000 was chosen as the starting point because it marks the establishment of the Millennium Development Goals, which have now been replaced by the SDGs. By including articles from 2000 onwards, the review ensures that research articles on water supply infrastructure sustainability as a global goal are considered for potential inclusion. While this review aims to provide a comprehensive synthesis of the literature on water infrastructure sustainability in Nigeria, it is important to acknowledge that the findings may be limited by the availability and quality of the included studies, as well as the specific focus on Nigeria as a case study.

This systematic literature review represents the first comprehensive effort to address the research objectives and questions related to the sustainability of water infrastructure in Nigeria. By offering valuable insights, it holds significant value for stakeholders engaged in water infrastructure and sustainability, including policymakers, practitioners, and researchers. Through a systematic examination and synthesis of existing literature on the factors contributing to water infrastructure failure in Nigeria, this review serves as a crucial resource for evidence-based decision-making and interventions. By identifying sustainable solutions and proposing actionable recommendations, the study actively contributes to the global efforts aimed at achieving SDG 6.1 and ensuring universal access to safe and affordable drinking water, with a specific emphasis on Nigeria and other developing countries.

The findings and recommendations provided in this review have the potential to guide future research, shape policy development, and facilitate the implementation of sustainable solutions to address water infrastructure challenges in Nigeria. As such, this study makes a substantial contribution to the ongoing discourse surrounding water infrastructure sustainability and the pursuit of global SDGs.

2. METHODOLOGY

The methodology adopted for this systematic literature review is summarized below, with full details provided in the Supplementary Information (SI) section.

2.1. Search strategy

The study adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, ensuring a transparent, rigorous, and replicable review process (Moher *et al.*, 2009; Page *et al.*, 2021). The primary electronic database used for the search was Scopus, selected for its extensive collection of publications, large peer-reviewed library (Burnham, 2006; Falagas *et al.*, 2008), and ability to capture publications from various developing countries, including Nigeria (Mongeon & Paul-Hus, 2016; Zhu & Liu, 2020). Details of the search strategy are available in SI. Table S1 provides details of the search strings used across the search databases. Full-text review for eligibility was conducted on the selected articles. In addition to the electronic database search, hand-searching of relevant article references and grey literature was also performed. This comprehensive search strategy ensured the inclusion of a diverse range of literature and minimized bias in the review.

2.2. Inclusion and exclusion criteria

To ensure relevance and consistency, a set of predefined inclusion and exclusion criteria was established for the selection of studies. These criteria were designed to determine which studies should be included and which ones

should be excluded from the systematic review. The incorporation of mandatory and additional criteria provided a robust and adaptable framework for article selection. Detailed information on the inclusion and exclusion criteria can be found in Table S2 (see SI). Additional details regarding the criteria are also available in SI.

2.3. Data extraction and synthesis

Systematic data extraction was carried out using a custom-made Microsoft Excel form, focusing on significant details from each study related to the factors contributing to water infrastructure failure in Nigeria. An integrated approach combining thematic analysis, narrative synthesis, and content analysis was employed to synthesize the extracted data. This approach facilitated the identification of common themes, exploration of relationships and findings across studies, and quantification of the frequency of certain responses or factors. Further details on data extraction and synthesis are available in SI.

2.4. Quality assessment

The quality of each selected study was assessed using a customized checklist based on key criteria essential for evaluating the validity and reliability of research findings. This quality assessment tool was developed with reference to sources such as the Critical Appraisal Skills Programme (CASP) tools and literature on research methodology (e.g., Long *et al.*, 2020; Mengist *et al.*, 2020). More details about the quality assessment are provided in SI. However, it is important to note that this quality assessment method, while robust, has some limitations. It may not capture all aspects of a study's quality, and the binary 'yes/no' responses may oversimplify complex issues. Therefore, the quality assessment should be interpreted in conjunction with other considerations, such as the relevance of the study to the research questions and its overall contribution to the knowledge of water infrastructure sustainability in Nigeria.

2.5. Overview of the selected studies

The procedure used to select studies for inclusion in the review is comprehensively outlined in the flow chart Figure S4 (see SI). Based on this process, a total of 15 studies were chosen for data extraction and synthesis. Specific details of these studies can be found in Table S3.

The search period for this systematic literature review encompassed the years 2000–2023, providing a comprehensive understanding of the topic's evolution over two decades. The earliest article included in this review was published in 2008 by Adeoti, Adetola I., while the most recent publication was in 2022 by Ugwu, Paschaline Nkeiruka, and colleagues. Notably, a significant portion of the articles (7 of 15, 47%) were published in the last five years, between 2018 and 2023, indicating a growing interest and increased research activity on the subject during this period. A detailed year-wise distribution of the included articles is presented in Figure S5.

3. RESULT

3.1. Overview of analyzed water infrastructures from selected studies

The diverse landscape of Nigeria's water infrastructure is thoroughly examined in the 15 studies included in this review. Boreholes are a dominant focus consistently discussed across all 15 studies, underscoring their paramount significance in Nigeria's water supply framework. Wells, a primary water source for many households, are featured in over half of the studies, specifically 8 out of the 15. Pipe distribution systems, crucial for a seamless water supply across urban and rural areas, were highlighted in six studies. Dams, playing a pivotal role in bulk water supply and reservoir creation, were mentioned in three studies. Other sources such as standpipes and rainwater collection were discussed in two studies. Streams and protected springs, though less common, were touched upon in individual studies.

Adeniran *et al.* (2021) conducted a comprehensive analysis encompassing various dams and reservoirs, providing valuable insights based on data spanning from 1923 to 2007. On a more micro-level, Andres *et al.* (2018b) focused on 43,443 water points, primarily wells and boreholes, to comprehend their crucial role in community water supply. The significance of groundwater, especially in areas adjacent to landfill sites, was emphasized by Shiru *et al.* (2020), indicating potential environmental and health concerns.

Active stakeholder participation is fundamental to water projects. An integral component of the selected literature was the extensive use of questionnaires to understand the perspectives of local communities, a strategy predominantly employed by Popoola *et al.* (2021) and Olajuyigbe (2016). These grassroots insights, gathered from a wide spectrum of respondents, provide a detailed understanding of localized water challenges and underscore the pivotal role community engagement plays in the success of water projects. On a broader scale, Andres *et al.* (2018a) utilized the 2015 Nigeria National Water and Sanitation Survey to identify patterns in the failure of water initiatives across Nigeria.

Following this overview, we delve deeper into the myriad factors influencing the functionality and sustainability of these diverse water infrastructures.

3.2. Factors contributing to water infrastructure failure in Nigeria

This systematic literature review provides a comprehensive understanding of the multitude of factors contributing to water infrastructure failure in Nigeria. Based on the analysis of the 15 selected studies, these influential factors are methodically divided into technical, financial, environmental, social, political, institutional factors, and 'other'. The factors are further categorized into 52 distinct themes.

As highlighted in Figure S6, we identified 265 issues influencing the sustainability of water infrastructure in Nigeria. Among the identified issues, the technical factor holds the highest proportion with 59 issues (22.3%) spread across 11 themes. Institutional factors account for 56 issues (21.1%) categorized under nine themes. Social factors contain 48 issues (18.1%) falling under nine themes, while financial factors contribute 37 issues (14%) distributed among six themes (Figure S6).

Political factors, representing five themes, account for 32 issues (12.1%). Environmental factors, allocated into seven themes, encompass 22 issues (8.3%). Lastly, the category labeled 'Other' captures 11 issues (4.2%) that could not be neatly placed within the six principal categories and is separated into five unique themes (Figure S6).

In the subsequent sections, each factor will be explored in detail, providing a comprehensive understanding of the complex challenges confronting water infrastructure functionality and sustainability in Nigeria.

3.3. Technical factors

The review identifies a total of 59 issues under the technical factors contributing to water infrastructure functionality in Nigeria. These factors are grouped into 11 categories. The categorization and count of the technical issues are shown in Figure S7.

The most frequently occurring category, with 10 instances (17%), is related to the '*Deterioration of Infrastructure*'. It encompasses aspects like systemic malfunctioning (Adeniran *et al.*, 2021), aging water schemes, and poor infrastructure development and management (Otun *et al.*, 2011; Adeniran *et al.*, 2021), among others.

'*Poor Material and Construction Practices*', occurring four times (7%), involve instances of poor workmanship (Oyekale & Ogunsanya, 2012), poor construction materials (Popoola *et al.*, 2021), and design failures (Oloruntade *et al.*, 2014).

Nine instances (15%) pertain to '*Poor Operation and Maintenance*'. This category includes issues such as lack of preventive maintenance knowledge (Khan *et al.*, 2018), poor maintenance of water sources (Popoola *et al.*, 2021), and technical issues related to management (Andres *et al.*, 2018a).

Six instances (10%) were identified related to the ‘*Choice of Technology and Equipment*’, emphasizing the importance of the technological dimension (Adeoti, 2008; Andres *et al.*, 2018b), equipment failure (Andres *et al.*, 2018a), and the wrong choice of pump types (Khan *et al.*, 2018).

‘*Water Supply Issues*’ were identified five times (8%), covering topics like groundwater overdraft (Shiru *et al.*, 2020), uneven water distribution (Shiru *et al.*, 2020), and shallow wells that cannot provide an all-year-round water supply (Oloruntade *et al.*, 2014).

‘*Spare Parts Availability and Quality*’ were raised seven times (12%), focusing on the availability and quality of spare parts and supplies (Otun *et al.*, 2011; Andres *et al.*, 2018a; Khan *et al.*, 2018).

The ‘*Impact of External Factors*’, like vandalism impacting water infrastructure, leading to technical challenges, contamination, and lack of electricity, was reported five times (8%) (Andres *et al.*, 2018a; Khan *et al.*, 2018; Shiru *et al.*, 2020).

Three instances (5%) related to ‘*Overuse and Lack of Proper Planning*’ were identified, including exceeding the intended use of the infrastructure (Andres *et al.*, 2018a) and wear and tear due to aging (Oloruntade *et al.*, 2014).

‘*Inadequate Knowledge and Resources*’, such as poor knowledge of the Nigerian geological terrain and non-existent literature on water infrastructure functionality (Andres *et al.*, 2018a), and large maintenance backlogs (Otun *et al.*, 2011), were highlighted six times (10%).

‘*Specific Technology Issues*’, like the functionality of manual pumps versus hand pumps and pump failures (Oloruntade *et al.*, 2014), were reported three times (5%).

Lastly, there was one instance (2%) of ‘*Infrastructure Collapse*’ due to poor drilling (Popoola *et al.*, 2021).

Technical factors constitute a substantial proportion of the identified challenges, highlighting the need for technical capacity building, improved practices, and better management of water infrastructure in Nigeria.

3.4. Financial factors

The analysis identifies 37 issues pertaining to the financial factors affecting water infrastructure functionality in Nigeria, classified into 6 main groups (Figure S8).

The most frequently mentioned category, with eight instances (22%), accounts for issues related to the ‘*Cost of Infrastructure and Maintenance*’. This category captures increased costs of water production and distribution due to power supply issues (Shiru *et al.*, 2020), the high cost of laying pipes to rural communities (Adeoti, 2008), the cost of maintenance (Andres *et al.*, 2018a), and the substantial cost of solar panels, making it difficult for communities to afford repairs (Oloruntade *et al.*, 2014).

The second category, ‘*Insufficient Funding/Budget Allocation*’, identified in seven instances (19%), discusses challenges around infrastructure financing, dwindling finances, and deprioritizing Water Supply (Adeniran *et al.*, 2021), as well as insufficient funding (Oyegoke *et al.*, 2012) and decrease in the total budgetary allocation for water supply (Adeoti, 2008).

‘*User Fees and Willingness to Pay*’ is the third category with seven instances (19%), addressing issues such as the absence of user fee collection (Andres *et al.*, 2018b), inability to pay for water (Popoola *et al.*, 2021), and users’ unwillingness to pay charges (Khan *et al.*, 2018).

The fourth category is ‘*Government Funding and Allocation*’, highlighted in five instances (14%). This category includes issues such as the type of funding organization, the absence of fund allocations from the state or local government (Khan *et al.*, 2018), and unsustainable public sector spending (Ugwu *et al.*, 2022).

‘*Household Income and Poverty*’ has been listed six times (16%), focusing on issues such as increased household expenses in purchasing potable water (Popoola *et al.*, 2021), community members’ inability to meet full financial responsibility (Olajuyigbe, 2016), and the lack of financial means to connect to government water services (Oyekale & Ogunsanya, 2012).

Finally, ‘*External Funding*’ was discussed in four instances (11%), including points such as lack of infrastructure facilities due to funding (Andres *et al.*, 2018b), dependence on communities for financial responsibility (Emmanuel & Bamidele, 2013), and inefficient use of over 3 billion dollars in funds (Otun *et al.*, 2011).

The financial aspects of maintaining functional water infrastructure are multifaceted, involving a complex mix of user fees, government spending, external funding, and the socioeconomic status of the households that ultimately depend on these services.

3.5. Environmental factor

This review identifies 21 environmental issues that influence the functionality of water infrastructure in Nigeria, which are organized into seven key categories (Figure S9).

The most frequently discussed issue, featured in five instances (23%), pertains to ‘*Hydrogeology*’. It includes factors like sparse geographical locations of villages, morphological issues such as clay soil or rocky terrain (Popoola *et al.*, 2021), and the importance of hydrogeology to the functionality of water points (Andres *et al.*, 2018b).

‘*Water Scarcity*’ and ‘*Climate Change Impacts*’ were the next two prominent categories, each raised in four instances (18%) and addressing global water scarcity due to poor water management, increasing urbanization (Popoola *et al.*, 2021), climate change impacts on water resources (Shiru *et al.*, 2020), and variability by climate zone (Cronk & Bartram, 2017).

Three issues (14%) fell under the ‘*Pollution*’ category, exploring problems like environmental pollution and deforestation (Adeniran *et al.*, 2021).

‘*Population Growth*’ was raised in two instances (9%), addressing the strain on water infrastructure due to population growth and internal migration (Oyegoke *et al.*, 2012; Ugwu *et al.*, 2022).

‘*Insufficient Ground Water*’ featured in two instances (9%), pertaining to decline in groundwater storage (Shiru *et al.*, 2020) and insufficiency of the groundwater in the aquifer serving specific boreholes (Oloruntade *et al.*, 2014).

Lastly, the category ‘*Drought*’ was highlighted by two (9%) authors, emphasizing issues related to drought’s impact on water infrastructure (Oyekale & Ogunsanya, 2012; Adeniran *et al.*, 2021).

Environmental factors affecting water infrastructure in Nigeria are complicated, underscoring the need for comprehensive environmental management and protection measures in the planning and operation of water supply systems.

3.6. Social factor

The social factors influencing the functionality and sustainability of water infrastructure in Nigeria, as identified by the selected articles, are diverse and interconnected. Forty-eight issues were identified in the studies, grouped into eight categories (Figure S10).

The most frequently cited category is ‘*Community Involvement*’, with 13 instances (27%). This category includes issues like the neglect of rural water supply (Adeniran *et al.*, 2021), low functionality with local management (Andres *et al.*, 2018b), poor community cooperation (Popoola *et al.*, 2021), and lack of public participation in water infrastructure management (Adeoti, 2008). It is apparent from these data that the level and quality of community involvement significantly impact the performance and sustainability of water infrastructures.

Another prevalent category is ‘*Population and Migration*’, with eight mentions (17%). This category concerns the strain on water infrastructure due to population growth and internal migration, with a particular emphasis on issues in Lagos where the population continues to grow rapidly, causing an insurmountable water and environmental crisis (Andres *et al.*, 2018a; Shiru *et al.*, 2020; Adeniran *et al.*, 2021).

'*Socio-Economic Factors*' also emerged as a significant category with 10 instances (21%), encapsulating issues such as the influence of the household head's sex, education, and age on water access (Oyekale & Ogunsanya, 2012), as well as how socio-economic characteristics can affect the maintenance and sustainability of water schemes (Emmanuel & Bamidele, 2013).

The '*Ownership and Management*' category, highlighted in nine instances (19%), includes issues like the advantages of private sector management, the benefits of women in water committees (Andres *et al.*, 2018b), and the importance of community organization for system improvements (Cronk & Bartram, 2017).

Other categories with fewer instances include '*Rural-Urban Inequality*', '*Water Conflict*', '*Access to Water Sources*', '*Attitude and Corruption*', and '*Environmental Considerations*'. Despite their lower frequency, these factors still play a critical role in the overall picture of social determinants affecting water infrastructure functionality and sustainability. *Rural-Urban Inequality* describes the unequal water access in rural and urban areas. *Water Conflict* refers to disputes over water use and management. *Access to Water Sources* highlights the idea that social factors like community needs, usage patterns, and logistical constraints (like distance to the source and availability of water systems) can significantly influence water system functionality (Oyekale & Ogunsanya, 2012; Cronk & Bartram, 2017). The *Attitude and Corruption* category refers to behavioral and socio-political issues like corruptive attitudes and tendencies (Otun *et al.*, 2011) and theft of infrastructure parts. These issues highlight the importance of social engagement and attitudes in maintaining water infrastructure sustainability. *Environmental Considerations* involve the influence of environmental factors on social dynamics around water infrastructure.

Taken together, these results demonstrate the importance of considering a wide range of social factors in the planning, implementation, and management of water infrastructure projects in Nigeria.

3.7. Political factors

The political factors contributing to the failure of water infrastructure in Nigeria are complex and multifaceted, ranging from the politicization of infrastructure projects to the lack of effective regulation and corruption. This review has identified a total of 32 issues related to the political factors, categorized into five broad themes (Figure S11).

The '*Government Commitment*' category emerged as the most frequent, with eight instances, contributing 25% to the overall political factors. Key issues in this category include the lack of government commitment to water infrastructure (Popoola *et al.*, 2021), poor government attitude towards project continuity (Olajuyigbe, 2016), and the lack of political will to fix prevalent issues (Oyegoke *et al.*, 2012).

'*Geographical Politics*', with eight mentions (25%), ties in frequency with the '*Government Commitment*' category. Issues under this category entail how geographical location, whether strategic or based on local government policies, impacts the access, availability, and functionality of water infrastructure (Cronk & Bartram, 2017; Andres *et al.*, 2018a; Popoola *et al.*, 2021).

'*Policy Misalignment*' and '*Political Instability*' were observed with six (19%) and five (16%) instances, respectively, indicating their notable influence. They cover issues like functional misfits at policy implementation levels and the instability arising from complex political structures (Adeniran *et al.*, 2021).

Lastly, the '*Corruption and Noncompliance*' category, with five instances (16%), covers issues such as substantial increases in executive corruption and lack of accountability (Oyekale & Ogunsanya, 2012), and policy non-compliance (Ugwu *et al.*, 2022). Despite its fewer instances, its role in shaping water infrastructure functionality should not be underestimated.

3.8. Institutional factors

The review identified a total of 56 issues falling under the umbrella of institutional factors contributing to the functionality of water infrastructure in Nigeria, which are categorized into seven categories (Figure S12).

The most prevalent category, with 10 instances (18%), pertains to '*Infrastructure Planning and Management*'. This category covers various concerns such as decentralization of infrastructure types (Adeniran *et al.*, 2021), lack of thorough planning (Oyekale & Ogunsanya, 2012), infrastructural challenges due to ad hoc and unsustainable initiatives (Oyegoke *et al.*, 2012), and poor service delivery coverage and performance (Otun *et al.*, 2011).

The '*Policy and Regulation*' category, mentioned in six instances (11%), highlights the incomplete or unsustainable water infrastructure projects (Popoola *et al.*, 2021) and the lack of clear policies and guidelines on operation and maintenance (Khan *et al.*, 2018).

The '*Institutional Capacity*' category, found in eight instances (14%), emphasizes issues such as disjointed responsibility (Ugwu *et al.*, 2022), low institutional capacity (Otun *et al.*, 2011), and the lack of availability of trained mechanics (Khan *et al.*, 2018).

The '*Monitoring and Quality Control*' category, mentioned seven times (13%), addresses inadequate monitoring of water-related projects, poor quality control (Oyegoke *et al.*, 2012), and inefficient monitoring systems (Andres *et al.*, 2018a).

'*Community Engagement and Transparency*' is another significant category, highlighted in six instances (11%), stressing community participation in water programs (Olajuyigbe, 2016) and poor government motivation (Oloruntade *et al.*, 2014).

The '*Corruption and mismanagement*' category, with seven instances (13%), includes issues such as substantial increases in executive corruption (Ugwu *et al.*, 2022) and lack of accountability (Andres *et al.*, 2018a).

The '*Resource Allocation*' and '*Definition and Research*' categories, appearing in six (11%) and two (4%) instances, respectively, encapsulate issues ranging from state spatial inequalities due to investment (Adeniran *et al.*, 2021) to the lack of a widely agreed-upon definition for water infrastructure and sustainability (Andres *et al.*, 2018b).

Lastly, the '*Overarching Problems*' category, with four instances (7%), underlines broad issues like modernization and urbanization leading to the neglect of rural areas (Popoola *et al.*, 2021).

These findings underscore the multifaceted nature of institutional factors impacting water infrastructure functionality in Nigeria, necessitating comprehensive institutional reforms to address these challenges.

3.9. Other factors

The review categorizes 11 issues as 'Other Factors' that affect the functionality of Nigeria's water infrastructure. These factors, which do not fit neatly into the conventional categories of technical, financial, environmental, social, institutional, or political, are grouped into four distinct themes. Geographical factors, accounting for 5 out of 11 instances (45%), concern distance challenges, such as proximity to administrative centers and water sources (Adeoti, 2008; Cronk & Bartram, 2017; Andres *et al.*, 2018b; Popoola *et al.*, 2021). Vandalism/Theft, making up 3 out of 11 (27%), denotes concerns like damage and theft of infrastructure (Oloruntade *et al.*, 2014). Demographic and Age Factors, both at 1 out of 11 (9%), touch on the influence of population growth and household head age on financial contributions (Adeoti, 2008). Lastly, methodological factors, at 1 out of 11 (9%), reflect on the approaches used by certain developers and a deficiency in thorough feasibility studies (Olajuyigbe, 2016). Collectively, these highlight the intricate challenges facing Nigeria's water infrastructure, underscoring the need for multifaceted solutions.

3.10. Theoretical frameworks, methodology, and empirical findings of selected studies

3.10.1. Theoretical frameworks of selected studies

In the evaluation of 15 selected articles on water infrastructure sustainability in Nigeria, varied theoretical approaches are evident. Only one article provides a clear theoretical framework, necessitating an inference on

the rest based on content and methodology. Adeniran *et al.* (2021) and others gravitate towards the Integrated Water Resources Management (IWRM) framework, stressing the interplay of several factors affecting water resources. Andres *et al.* (2018b) utilize data-driven analyses, though the underpinning theoretical model is not explicitly mentioned. Popoola *et al.* (2021) and Olajuyigbe (2016) lean towards socio-ecological methods, with the latter specifying the community management model. Oyegoke *et al.* (2012) adopt a systems theory perspective, understanding the many interconnected issues in water supply. Both Ugwu *et al.* (2022) and Adeoti (2008) weave economic and socio-economic considerations into their works. Andres *et al.* (2018a) and Cronk & Bartram (2017) use advanced econometrics, inferred from their methodologies. Perspectives of community participation, decentralized management, and asset management emerge from Emmanuel & Bamidele (2013), Khan *et al.* (2018), and Otun *et al.* (2011). In summary, although most articles do not explicitly declare their theoretical approaches, the diverse methods deduced underscore the complexity of understanding water infrastructure sustainability in Nigeria.

3.10.2. Methodology of selected studies

Various methodologies were employed across the analyzed articles, encompassing qualitative, quantitative, and mixed methods designs. Quantitative methodologies were used in seven articles (47%), utilizing statistical techniques to analyze data. Four studies adopted mixed methods (27%), combining quantitative and qualitative techniques to offer a comprehensive perspective. Additionally, two articles employed a qualitative approach (13%), providing in-depth insights into the subject matter. However, in two articles (13%), namely Oyegoke *et al.* (2012) and Khan *et al.* (2018), the methodology was not explicitly stated. Nevertheless, Khan *et al.* (2018) provided a detailed account of their approach implementation. This diverse array of methodologies, often aligned with the article's theoretical framework, enriches our understanding of Nigeria's water infrastructure sustainability.

3.10.3. Empirical findings of selected studies

The empirical findings from the reviewed articles on water infrastructure sustainability in Nigeria are presented, shedding light on the complexities of the issues surrounding water infrastructure. These findings include aspects related to access to safe water, factors influencing infrastructure functionality, and the challenges of maintaining the sustainability of these systems. To facilitate ease of reference, the summarized results are presented in Table S4.

Collectively, these findings highlight the complex challenges of ensuring water infrastructure sustainability in Nigeria. Future research will need to continue to explore these complexities and devise effective interventions.

3.11. Evidence-based sustainable solutions for water infrastructure in Nigeria

In this systematic literature review, the reviewed articles propose a wide array of solutions to address the complex issue of water infrastructure sustainability in Nigeria. These solutions encompass improvements in the design, implementation, and maintenance of water points, as well as increased community and government involvement. Additionally, better monitoring, funding, and strategic planning are identified as vital components for enhancing water infrastructure sustainability. Table S5 (see SI) presents a summary of the proposed and implemented solutions discussed in each article.

The proposed solutions from the selected studies were systematically analyzed and categorized under appropriate themes for quantitative assessment. The frequency of proposed solutions varied across the themes, indicating the research intensity within each topic.

‘Technological Innovations and Infrastructure Optimization’ (15% of solutions): This theme proposes strategies such as appropriate extraction technology choice and the use of various modeling techniques to optimize water infrastructure utilization (Otun *et al.*, 2011; Andres *et al.*, 2018b; Adeniran *et al.*, 2021).

‘Financial Mechanisms, Monitoring, Funding, and Partnerships’ (11% of solutions): This theme advocates for increased private sector involvement, robust financial planning within the Village Level Operation and Maintenance (VLOM) strategy, and proper monitoring of WASH projects (Oyegoke *et al.*, 2012; Khan *et al.*, 2018).

‘Environmental Management Strategies, Regulation and Policy Improvement’ (11% of solutions): This theme underscores the implementation of stricter regulations, integrated water resource management, and infrastructural development (Oyegoke *et al.*, 2012; Shiru *et al.*, 2020).

‘Social Inclusiveness Approaches, Community Involvement and Education’ (22% of solutions): This theme focuses on community involvement in water resource management, awareness programs for rural households, and adult education (Adeoti, 2008; Oyekale & Ogunsanya, 2012; Olajuyigbe, 2016).

‘Institutional Reforms, Governance, Political Considerations, and Capacity Building’ (22% of solutions): This theme suggests governmental intervention, understanding the political dimensions of water infrastructure, and implementing the VLOM strategy (Khan *et al.*, 2018; Adeniran *et al.*, 2021).

‘Project Management Strategies’ (11% of solutions): This theme calls for better project management, prioritizing design, implementation, and operational stages (Andres *et al.*, 2018a; Popoola *et al.*, 2021).

‘Strategic Planning and Flexibility’ (7% of solutions): This theme emphasizes flexible infrastructure development and data-driven decision-making (Cronk & Bartram, 2017; Adeniran *et al.*, 2021).

Figure 1 is a Treemap chart that visually presents the various solutions for Nigeria’s water infrastructure challenges, organized by theme. The size of each section indicates the solution count per theme, making it easy to compare research intensity and identify potential gaps.

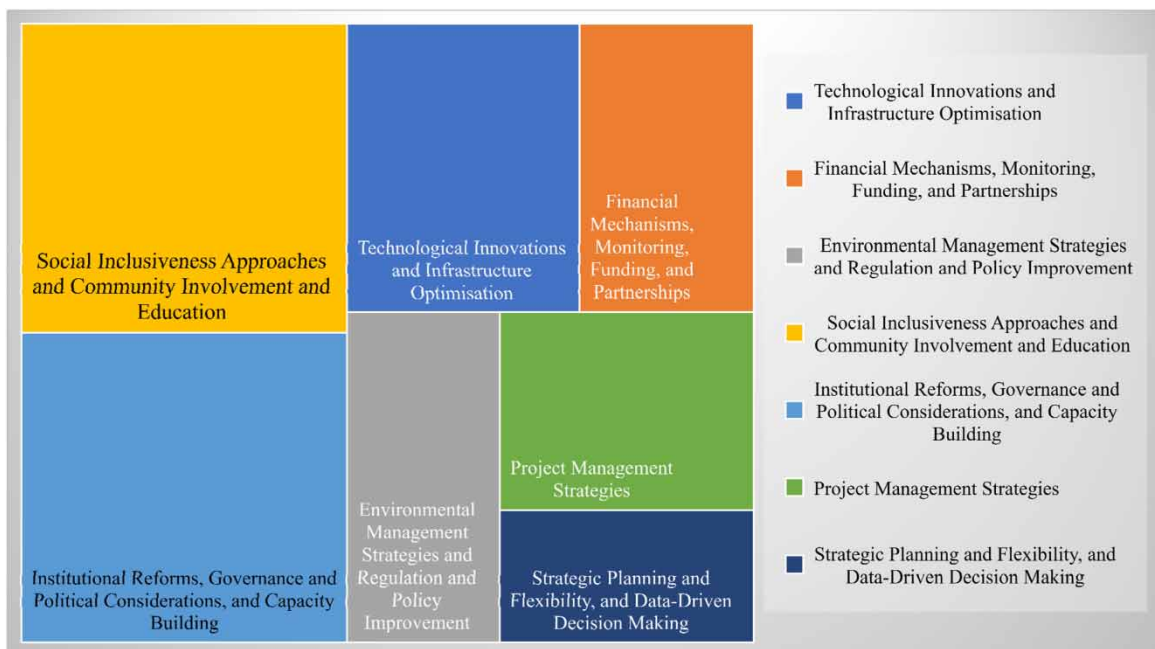


Fig. 1 | Distribution of proposed solutions for water infrastructure challenges in Nigeria.

4. DISCUSSION

This section aims to interpret the research findings in line with the primary objectives and research questions of the study.

4.1. Factors influencing water infrastructure sustainability in Nigeria

The complexities of determining water infrastructure sustainability in Nigeria unveil an intricate network of interdependent factors that present both challenges and enlightening prospects.

Technical factors, often regarded as the backbone of any infrastructural project, emphasize the critical importance of sound design, meticulous construction, and regular maintenance. A robust technical foundation is essential for sustainability. However, achieving the full potential of technically proficient projects is often hindered by financial factors. While the availability of funds is one part of the equation, the efficient utilization of these resources is equally vital. The best technical designs might remain unrealized without appropriate financial backing, and improper financial handling can diminish the efficacy of even the most proficient plans.

Environmental vulnerabilities, exacerbated by the looming threat of climate change, exert additional pressure on Nigeria's water infrastructure. Environmental factors underscore the acute need to construct and maintain infrastructure that can withstand climate-induced stressors such as droughts or excessive rainfall. Intertwined with these are the social factors that underscore the role of communities. Societal dynamics, community awareness, and involvement can play pivotal roles in how environmental challenges are perceived, managed, and adapted to. A well-informed and engaged community can be the linchpin for the effective implementation and upkeep of sustainable water projects.

The realm of political factors showcases the overarching influence of governance and policy-making. The political landscape often shapes the direction, prioritization, and allocation of resources for water infrastructure projects. This political will and direction must find resonance in institutional factors. Robust institutions can translate political intentions into actionable strategies, ensuring that projects are not only initiated but seen through their entire lifecycle with efficiency and efficacy.

Beyond the more evident categories, nuanced factors such as geographical considerations, demographic dynamics, or unforeseen challenges like vandalism come into play. These underscore the multifaceted nature of the challenges at hand.

In light of this, the 'Sustainability Framework for Water Infrastructure' emerges as a necessity. This framework is poised to serve as an invaluable instrument, adeptly navigating the myriad of challenges across the entire project lifecycle, from pre-construction to post-construction phases. By diligently addressing each factor and strategically interlacing solutions tailored to their unique challenges, this framework underscores the potential for a holistic, integrated trajectory towards reinforcing water infrastructure sustainability in Nigeria. Furthermore, the design of the Sustainability Framework for Water Infrastructure should emphasize flexibility, allowing for adjustments and adaptations based on specific circumstances. This inherent adaptability means it possesses the potential to address similar challenges not only in the context of Nigeria but also in varied situations and regions.

4.2. Existing literature on water infrastructure sustainability in Nigeria

The systematic review of literature on water infrastructure sustainability in Nigeria offers insightful patterns. A majority of studies hint at theoretical frameworks like IWRM and community-based approaches, underscoring the multifaceted nature of water challenges, and the need for integrated solutions.

Methodologically, the review reveals a dominance of quantitative methodologies. Despite this trend, the few qualitative studies included illuminated the socio-political intricacies of Nigeria's water challenges. It suggests that employing more qualitative research could offer a deeper understanding of these complexities.

Empirically, findings converge on challenges such as deteriorating infrastructure, influenced by factors ranging from political instability to population growth. These concerns, intertwined with the significance of location, technology, community engagement, and governance, suggest a pressing need for systemic, holistic interventions. Overall, the review underscores the importance of clearer theoretical anchoring, diverse methodological engagements, and comprehensive empirical explorations in shaping Nigeria's water sustainability narrative.

4.3. Evidence-based sustainable solutions for water infrastructure sustainability in Nigeria

The analysis in this review illuminates a spectrum of sustainable solutions aimed at bolstering water infrastructure sustainability in Nigeria. These solutions, categorized into seven themes, outline a comprehensive strategy to address the multifaceted challenges faced by Nigeria's water infrastructure.

'Technological Innovations and Infrastructure Optimization', accounting for 15% of the proposed solutions, advocates for the pivotal role of modern tools and technology. However, a pertinent question arises: How can these technological solutions be sustainably funded, particularly in regions where 'Household Income and Poverty' pose significant challenges?

'Financial Mechanisms, Monitoring, Funding, and Partnerships', comprising 11% of the solutions, underscores the critical importance of financial sustainability. Nevertheless, there is a need to ensure that these financial mechanisms effectively address and align with local economic disparities and challenges. What mechanisms can guarantee equitable distribution of these funds?

The emphasis on 'Environmental Management Strategies, Regulation, and Policy Improvement' (11%) provides a sustainable approach to environmental challenges but prompts questions regarding its intersection with local political dynamics. How can environmental regulations be effectively implemented amidst political instability or bureaucratic challenges?

The focus on 'Social Inclusiveness Approaches, Community Involvement, and Education' (22%) and 'Institutional Reforms, Governance, Political Considerations, and Capacity Building' (22%) underscores the symbiotic relationship between communities and institutions. How can community involvement be enhanced to ensure that these institutional reforms are not only top-down but also bottom-up?

'Project Management Strategies' (11%) are paramount for effective execution. However, how can these strategies remain flexible and adaptive to the unique challenges encountered in various regions of Nigeria? Similarly, 'Strategic Planning and Flexibility' (7%) emphasizes adaptability but raises questions about how these strategies will evolve with Nigeria's rapidly changing socio-political and economic landscape.

In essence, these proposed solutions, though foundational, raise numerous queries warranting further investigation. Real-life pilot projects, coupled with rigorous post-implementation reviews, will be pivotal in assessing the efficacy of these solutions. Merging findings from literature with expert knowledge, in conjunction with transdisciplinary stakeholder engagement, might provide a more holistic understanding and approach. The challenges faced by water infrastructure in Nigeria are complex, requiring not only comprehensive solutions but also a continuous, iterative evaluation process that keeps pace with changing dynamics.

5. IMPLICATIONS AND RECOMMENDATIONS FOR POLICY, PRACTICE, AND FUTURE RESEARCH

The systematic literature review has uncovered an array of challenges and sustainable solutions pivotal to water infrastructure sustainability in Nigeria. These findings call for a comprehensive approach to inform policy recommendations, guide practical applications, and provide directions for future research.

At the core of our proposition lies the ‘Water Infrastructure Sustainability Framework’ – an integrated roadmap specifically designed for the Nigerian context, guaranteeing the sustainable development, implementation, and management of water infrastructure projects. This encompassing framework, informed by the identified multifaceted challenges, should incorporate a multitude of influential factors, ranging from technical intricacies to political and financial considerations, significantly shaping the success of water projects.

To ensure optimal utility, the framework should be dynamic, covering the entire life cycle of water infrastructure projects. This initiates with a grassroots approach, involving local communities in site selection during the pre-construction phase and extends to the utilization of cutting-edge innovations, such as IoT and AI, for real-time monitoring, predictive maintenance, and adaptive responses in the post-construction phase.

From a policy standpoint, there is an urgent need to prioritize the often-neglected rural areas. Policies should emphasize not only the development but also the robust maintenance of water infrastructure. A shift towards standardized protocols for infrastructure development, encompassing global best practices contextualized to Nigerian realities, is imperative.

On the practical front, the focus should be multi-dimensional: mobilizing and empowering local communities to take ownership, enhancing management efficacy through capacity building, and leveraging technological innovations to strengthen infrastructure robustness.

The additional questions, particularly concerning the integration of sustainable solutions like ‘Financial Mechanisms, Monitoring, Funding, and Partnerships’ and challenges such as ‘Household Income and Poverty’, introduce a new avenue of exploration. Future research can delve into how these solutions, when integrated into the proposed framework, can address the nuanced socio-economic challenges inherent to the Nigerian context.

Thus, future research endeavors are urged to not only validate but also refine the proposed framework, ensuring its adaptability and responsiveness. By accomplishing this, Nigeria can set a formidable benchmark, aligning its efforts with global standards and progressively moving closer to the realization of SDG 6.1 – ensuring access to safe and affordable drinking water for all.

6. LIMITATIONS

This study is not without limitations. Firstly, the review excluded unpublished reports and theses due to their dissimilar structure and large volume, potentially leading to the omission of pertinent insights. Additionally, the findings presented in this review are limited to the issues, challenges, and solutions outlined in the selected studies, which may not encompass the entire scope of potential concerns related to water infrastructure sustainability in Nigeria. Moreover, the review was limited to sources published in the English language, which could potentially exclude relevant research conducted in neighboring French-speaking countries or those published in other languages. Therefore, these limitations might impact the comprehensiveness of the review’s results. Future research could seek to overcome these limitations by incorporating a broader range of sources and languages.

7. CONCLUSION

This systematic literature review offers a comprehensive synthesis of the factors contributing to water infrastructure failure in Nigeria based on a rigorous analysis of 15 research articles. The challenges identified across technical, financial, environmental, social, political, and institutional spheres demonstrate the complexity of achieving water infrastructure sustainability. To navigate this complexity, the authors have proposed the ‘Sustainability Framework for Water Infrastructure’, encompassing all stages of water infrastructure development. By providing a structured approach to address the multifaceted challenges, this study significantly contributes to

understanding and achieving sustainable water infrastructure in line with SDG 6.1. The study's valuable insights are relevant for policymakers, practitioners, and future research in Nigeria and other developing countries.

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PROTOCOL REGISTRATION

The protocol for conducting this systematic literature review is available on the Open Science Framework platform and can be accessed via the following DOI link: <https://doi.org/10.17605/OSF.IO/XZF24>.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories at <https://osf.io/g7nsf>.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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