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RESEARCH ARTICLE

Wastewater Infrastructure in Africa: Opportunities and Challenges in the Context of Urban Planning

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ABSTRACT

Wastewater infrastructure systems throughout Africa face major challenges, as urban population growth creates increasingly severe environmental and public health problems. The continent has extensive evidence of wastewater issues. However, existing studies primarily focus on treatment technologies, management methods, and health impacts and do not address infrastructure planning requirements for urban areas with complex systems. The research gap is addressed in this paper through a systematic literature review that investigates technical, economic, institutional, environmental, and social factors affecting African wastewater infrastructure development from an urban planning perspective. The research shows that six main elements cause system performance and sustainability to decline: fragmented planning methods; outdated technologies; lacking essential maintenance; insufficient institutional partnerships; financial limitations; and decreased community involvement. The review shows that existing wastewater treatment systems do not meet essential sustainability criteria, which include environmental protection, social inclusion, and economic efficiency. The paper creates new opportunities to support Sustainable Development Goal 6 by focusing on wastewater resource recovery and circular economy principles, cost-effective new technologies, and flexible infrastructure design. The study recommends using multi-criteria decision analysis, together with stakeholder participation, to develop wastewater infrastructure solutions that enhance local community resilience in specific areas. The study proposes a strategic planning framework that enables African nations to create sustainable urban spaces and build infrastructure systems that address future challenges and treat wastewater as a resource.

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1.0 Introduction

Infrastructure systems throughout the world experience difficulties because various hazards combine to produce destructive situations. In particular, wastewater management presents an ongoing environmental issue for the world because it endangers public health and damages natural ecosystems. To be sure, the environment suffers major harm because 80% of wastewater gets discharged into the environment without treatment, thus creating dangerous health threats. As some of the research shows (see Allison et al., 2024 and

Mbugua et al., 2025), developing countries face a more severe problem because only 4.2% of their wastewater gets treated properly.

Over the past 25 years, the population in African countries has almost doubled. However, the situation of water and sanitation services on the continent has not improved significantly, leaving millions of people without access to these essential services. The United Nations General Assembly passed resolution A/RES/64/292 on July 28, 2010, to establish the human right to safe and clean drinking water and sanitation (Mustapha et al., 2024). The 2022 WHO/UNICEF Joint Programme Monitoring Report on Water, Sanitation, and Hygiene (WASH) in Africa identified approximately 779 million people who still lack basic sanitation facilities. The study found that around 30% of the schools studied lacked basic water and sanitation facilities, while only 22% of healthcare facilities had essential sanitation capabilities. In light of the United Nations Sustainable Development Goals 6.1 and 6.2, which aim to ensure universal and equitable access to drinking water and sanitation by 2030, it is necessary to conduct a comprehensive wastewater infrastructure evaluation in the bid to achieve these objectives, as most African regions still lack well-developed wastewater systems.

The world is experiencing an upward trend in urbanization, which is presently affecting all regions. Urban areas are becoming more complex to plan because they need to achieve the sustainable development goals, build climate resilience, and manage their space resources (Bilic, 2025; Silva, 2023). The size and complexity of infrastructure projects have increased, resulting in simultaneous effects across multiple sectors. Consequently, urban systems face extreme stress because their essential components, including outdated infrastructure and the growing impact of climate change, are at risk of a complete breakdown. Today's sustainable city planning requires experts to address three main challenges: available land, environmental problems, and public wastewater treatment needs. When planners design infrastructure systems separately from other elements, they create two main problems: (i) operational inefficiencies and physical conflicts and (ii) environmental dangers that arise when systems overlap in both aboveground and underground spaces (Bilic, 2025). Infrastructure providers face operational challenges because they must manage system development amid unpredictable circumstances while maintaining financial control and preventing excess costs arising from premature or delayed system modifications (Allison et al., 2024).

Narrowing down to wastewater infrastructure specifically in Africa, population growth and industrial expansion have created significant wastewater problems, leading to water contamination across the continent (Omohwovo, 2024). The existing wastewater treatment systems in Africa provide only basic functions, leading to severe environmental damage and health risks, as well as failure to deliver safe drinking water and vital sanitation services. Multiple African nations face serious health consequences due to inadequate management of their wastewater systems. More often in Africa, these infrastructure projects were developed by engineers who designed them from an engineering perspective. Engineers follow two main criteria in their design work, including calculations and personal experience, even as they assess all available design options. The solutions provided do not always produce the best results because current procedures need to assess all possible options (Bhave & Rahate, 2018).

Wastewater infrastructure planning requires a multidisciplinary approach involving various professionals. First, the technical expertise of engineers is needed during its development. Two, planning knowledge is needed in incorporating wastewater systems into the other city systems and land uses, as well as how they will function alongside land development patterns, population growth, social equity, and future system sustainability. Four, sociological expertise is needed in mobilizing and educating the community about the entire wastewater system, especially on informing their perspective on wastewater reuse. Notably, urban planning places greater emphasis on building stakeholder relationships and designing infrastructure to meet future community needs, while managing wastewater systems that link to residential areas, transit networks and park spaces.

As a discipline, urban planning addresses environmental challenges by creating solutions that

achieve environmental protection goals, economic progress, equitable service distribution and spatial development across its service area. A complete waste management system requires a technical solution that meets environmental standards while creating safe, sustainable urban living spaces for all. Such a waste management system needs to address both technical aspects and environmental concerns during the design and development of public spaces that foster healthy living conditions for all citizens. The operation of built infrastructure, including reservoirs, pipes, and treatment plants, requires skilled personnel to maintain the system effectively and create conditions that benefit both public life and economic development. The process of 'service delivery' extends beyond the establishment of infrastructure, including activities such as installing underground pipes. The facility's opening is not the main point of focus. 'Delivery' requires the collection of wastewater, which must undergo treatment before either safe reuse or proper environmental discharge occurs. The process of infrastructure maintenance directly impacts system performance because neglected maintenance leads to system breakdown, causing economic damage and public disruption and, in some cases, violating citizens' rights.

Planning involves preparing for an expected future and guiding the use of available resources to meet the needs of both current and future generations without risking depletion. A 2021 study by Chrispim on resource recovery implementation in Macrometropolis found that only 26 percent of wastewater treatment plants incorporated at least one wastewater resource recovery method, with internal water reuse being the most common. Resource recovery efforts were mainly focused on larger plants and urban areas. Since only a few plants reuse water for external purposes, the production and sale of reclaimed water from treated effluent remain relatively low. The study also found that sewage sludge was disposed of in landfills, except at three plants that compost it for agricultural use. Importantly, none of the surveyed plants recovered energy.

In addition to analyzing the pressing needs of wastewater infrastructure, this study offers a guide to achieving the anticipated future as per SDG 6, ensuring that all have access to safe drinking water and sanitation services through well-planned, implemented and managed wastewater infrastructure.

Objectives of the study

This study has the following objectives:

1. to evaluate the challenges faced by existing wastewater infrastructure in Africa from a planning perspective;
2. to assess the available opportunities in wastewater management in Africa; and
3. to recommend criteria to be considered when planning wastewater infrastructure for sustainable development.

The study answers the following research questions:

1. What challenges are faced by existing wastewater infrastructure in Africa from a planning perspective?
2. What opportunities are available in wastewater management in Africa?
3. What criteria ought to be considered when planning wastewater infrastructure for sustainable development?

1.1 Attributes of Wastewater Infrastructure

Delanka-Pedige et al. (2021) reported that wastewater systems contain multiple elements that impact environmental, social, and economic sustainability. The first attribute of environmentally secure infrastructure systems is that they should handle wastewater from collection through safe treatment and disposal or reuse, thus reducing environmental damage and protecting aquatic habitats. The second attribute considered in the provision of wastewater infrastructure is social. The design of wastewater systems ought to be guided by these two goals: protecting public health and providing the community with access to clean water and proper sanitation facilities. The third attribute is that economic sustainability holds that wastewater infrastructure development ought to provide economic benefits by enabling organizations to recover and reuse resources, reduce operational expenses, and create revenue streams.

The reality is that although some countries in Africa, e.g., South Africa, Morocco and Egypt, have made serious efforts in wastewater management, most of the existing wastewater infrastructure in Africa does

not meet these sustainability criteria. Yet, developing African countries can learn to build sustainable wastewater infrastructure. This paper assesses the challenges faced by existing wastewater infrastructure in African countries and highlights the potential of future infrastructure possessing these sustainability attributes.

Sustainable wastewater infrastructure can adapt and maintain operations across different environmental conditions, enabling cities to address emerging needs and environmental challenges. The system can use a flexible design, together with real-time monitoring and automation, to manage a growing population, increasing urbanization, and the effects of climate change. The development of wastewater infrastructure is a fundamental component of the United Nations Sustainable Development Goals, as it enables responsible water resource management for present and future needs.

1.2 Socio-Ecological-Technological Systems (SETS) Theory

The Socio-Ecological-Technological Systems (SETS) theory provides a comprehensive framework for studying wastewater infrastructure problems by integrating social, ecological, and technological elements. The sociology of technology serves as the foundation for this system, explaining how societies develop technological systems at specific times and locations (Bijekar et al., 2022). The theory's main element establishes a system that connects social and technical elements through feedback loops, which support both adaptation and learning processes (Geels, 2004). The SETS framework demonstrates how governance systems, technological design systems, and ecological capacity systems work together to produce system results (Markolf et al., 2018). The situation requires special attention in Africa because wastewater management problems stem from governance breakdowns, social inequities and environmental challenges rather than technical difficulties. The theory shows how resilience connects to sustainability, as it requires solutions that follow adaptive, inclusive and ecologically responsible approaches (Sharifi, 2023). The study uses SETS as its foundation for comprehensive research, enabling the evaluation of economic and institutional elements in the development of sustainable wastewater management.

1.3 Case studies of wastewater infrastructure in the Global North

Research from the Global North demonstrates a fundamental transformation in wastewater management, with wastewater now seen as an urban water resource that supports water security rather than as waste disposal. Case studies from the Appalachian Mountains (USA), Limassol, Cyprus, Orange County, and California, as well as projects across Europe, demonstrate how reuse and aquifer recharge systems extend water supply and protect groundwater (Papaiacovou, 2001; De Feo & Ferrara, 2017; Paul & Blunt, 2012). In technical and economic terms, Johnson (1971) described wastewater recycling as a practical solution to water scarcity. However, he failed to consider the complications related to governance and planning. Papaiacovou (2001) established a connection between wastewater reuse and urban policy, demonstrating how combined sewer systems reduce environmental problems and help in the management of water scarcity. However, the study failed to address the social and political aspects of urban management. In a largely technical study, Paul and Blunt (2012) demonstrated the implementation of efficient recharge systems at scale. The studies demonstrate important technical progress, yet they also reveal deficiencies in governance systems, public participation practices, and urban planning collaboration.

2.0 Methods

This study was based on a systematic review of literature sourced from Google Scholar and Web of Science (66,500). The majority of the reviewed articles were published in journals on platforms such as ScienceDirect, Springer, Emerald, and Elsevier, hence their inclusion for this systematic review. Of the 66,500 articles on wastewater globally, only 1710 were focused on wastewater infrastructure in Africa. For this study, Africa was divided into five regions: West Africa, North Africa, Central Africa, East Africa, and Southern Africa. This study sampled two countries from each part and examined their wastewater infrastructure. From the sampled countries, only 67 articles focused on wastewater infrastructure planning. Further, the

study reviewed a few articles that conducted comparative analyses of wastewater infrastructure across African countries and globally. In total, 42 works were reviewed and are referenced in this paper; 9 were eliminated after the title and abstract screening, while 31 journal articles and book chapters were thoroughly reviewed, of which 23 were from African studies and 8 from other regions.

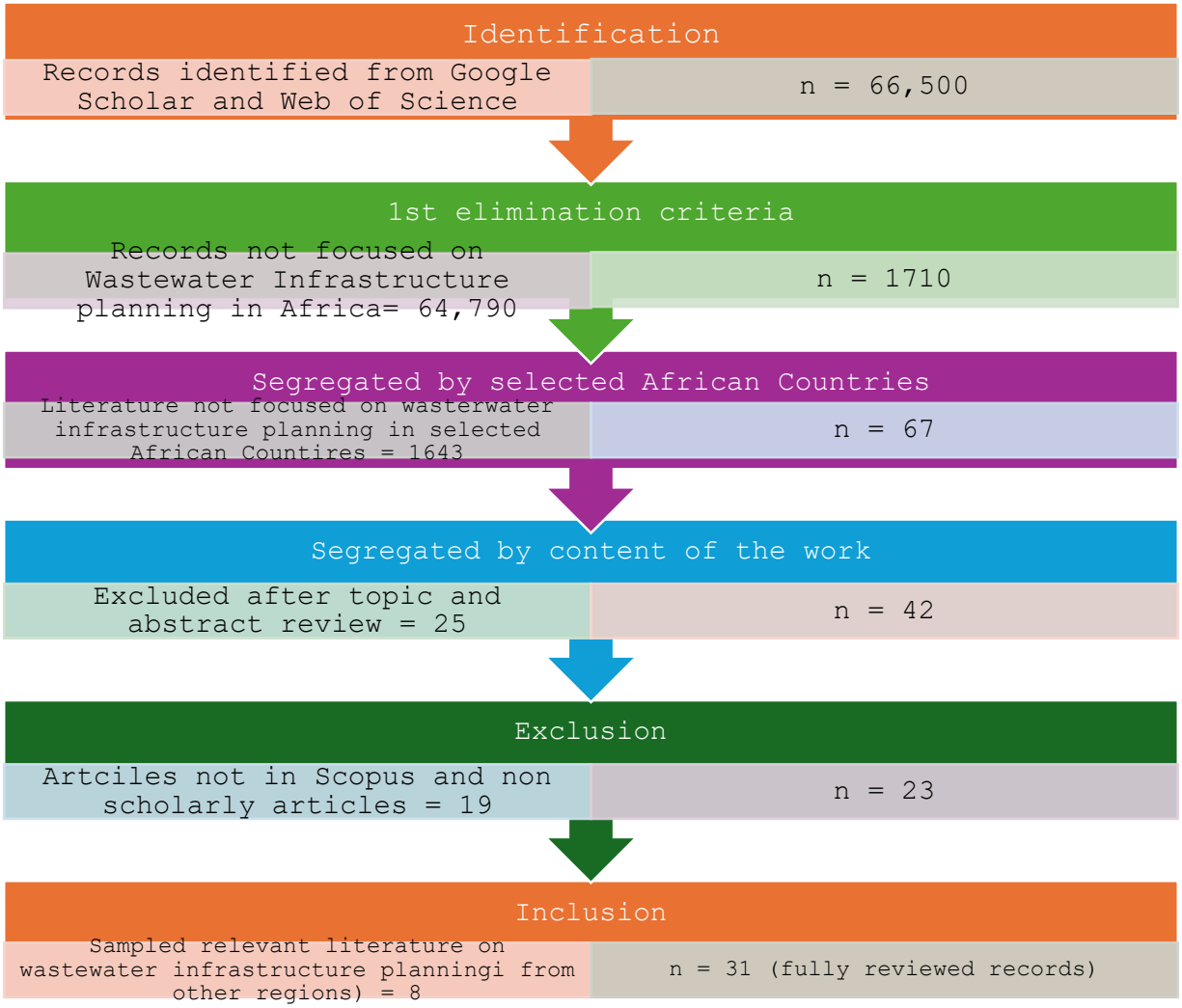


Figure 1: Systematic review of literature for the study
Source: Author's construct, 2026

Table 1: List of reviewed works

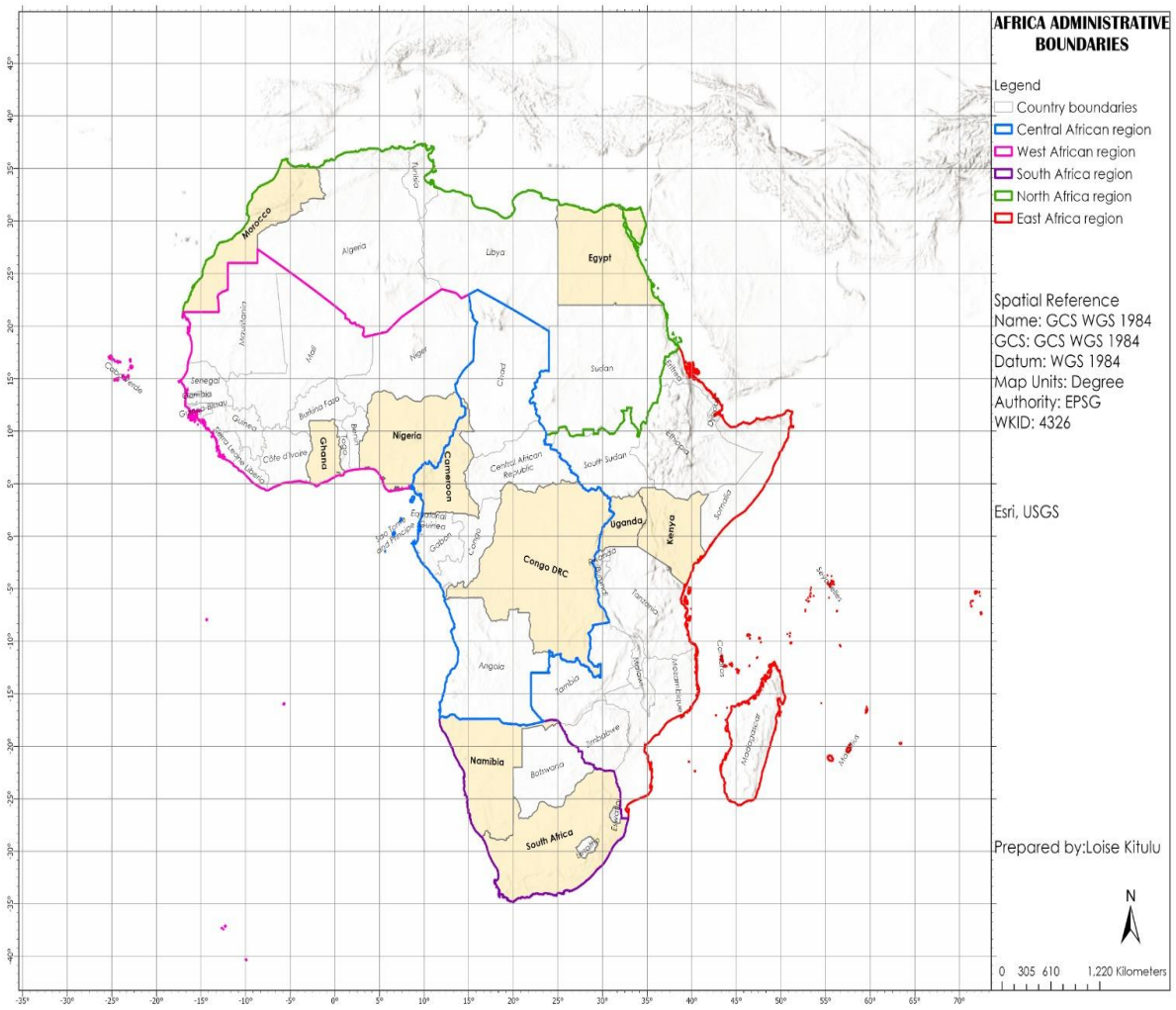
Region	Number of citations	Citations
Global	3	Mashala et al., 2023; Silva, 2023; Zechman Berglund et al., 2021
North America	2	Allaire et al., 2024; Johnson, 1971
South America	1	Chrispim, 2021
New Zealand	1	Allison et al., 2024
Mumbai, India	1	Bhave & Rahate, 2018
Africa in general	2	Mustapha et al., 2024; Omohwovo, 2024
Southern Africa	4	Montwedi et al., 2021; Wall, 2021; Müller et al., 2016; Frick-Trzebitzky et al., 2022

East Africa	5	Lema, 2025; Mbugua et al., 2025; Kilingo et al., 2021; Nsawotebba et al., 2026; McConville et al., 2019
Central Africa	4	Kamegne Kamtoh et al., 2021; Visiy et al., 2026; Mayeko, 2012 Kishota et al., 2025
West Africa	4	Adewumi & Oguntuase, 2016; Amaefule et al., 2023; Murray & Chris, 2009; Murray & Drechsel, 2011
North Africa	4	Wahaab et al., 2020; Reymond et al., 2018; Dahchour & El Hajjaji, 2023; Lemfarrak et al., 2025
Total	31	

Source: Author's construct, 2026

In West Africa, Ghana and Nigeria were picked. Ghana has made efforts on wastewater reuse for agricultural purposes and sludge management. While Nigeria – Lagos city in particular – offers studies on water, especially in a megacity context, it continues to grapple with issues of industrial wastewater treatment and water scarcity. In North Africa, Egypt was selected because it has made commendable efforts to develop wastewater infrastructure, with approximately 45,000 km of sewage networks. The second selected North African country was Morocco, which is currently developing intensive wastewater infrastructure, with particular focus on wastewater treatment and reuse for agricultural and industrial uses, as well as the irrigation of golf courses. In Central Africa, although the region generally lags behind North Africa, Cameroon and the Republic of Congo were selected for this study. The Republic of Congo was selected because of ongoing efforts to develop large-scale sanitation infrastructure in its major cities, while Cameroon was chosen because of its efforts at rehabilitating ageing infrastructure and working towards achieving 60 percent sanitation coverage by 2035.

In East Africa, Kenya was chosen because it has one of the largest wastewater treatment works in Africa, the Dandora Wastewater Treatment Plant, which is still under expansion. Uganda was also chosen for its efforts in wastewater management within the transboundary lake region. Lastly, in the southern part of the continent, South Africa was selected for its investment in engineering solutions to address water scarcity and wastewater treatment. The last country picked for this study was Namibia, which has been able to recycle municipal wastewater into potable water for urban use, including drinking. For each of these ten countries, two studies were sampled for this systematic review.



Map 1: African map showing the selected countries
Source: Author's construct, 2026

After the selected documents were downloaded, they were systematically analyzed. A spreadsheet was prepared in Excel, containing the year of publication, author, title, scope, objectives, methods, and findings. The findings were further analyzed in light of this study's objectives. Based on the first objective on the challenges facing wastewater infrastructure in Africa, the findings were thematically classified into technical, economic, institutional, environmental and social challenges in accordance with SETs theory as discussed in the theoretical review section. Table 1 in this report presents this data. In line with the second objective, a descriptive report was prepared and included in this paper.

Further, Vosviewer was used to analyze the four keywords emerging from the reviewed literature, viz: water source, water infrastructure, availability, and relevance. These key terms are central in this paper. Wastewater is a product of waste from water sources, water infrastructure and water systems. The majority of the articles also sought to assess the availability of wastewater infrastructure and its relevance to sustainable urban development. Thus, these keywords centrally informed this work. Other repetitive words around wastewater infrastructure planning were *water asset management, societal, quality, resilient solution, affordability, water infrastructure sustainability, sustainable development, challenge, practice, concept, significant change, planning*, and *access*.

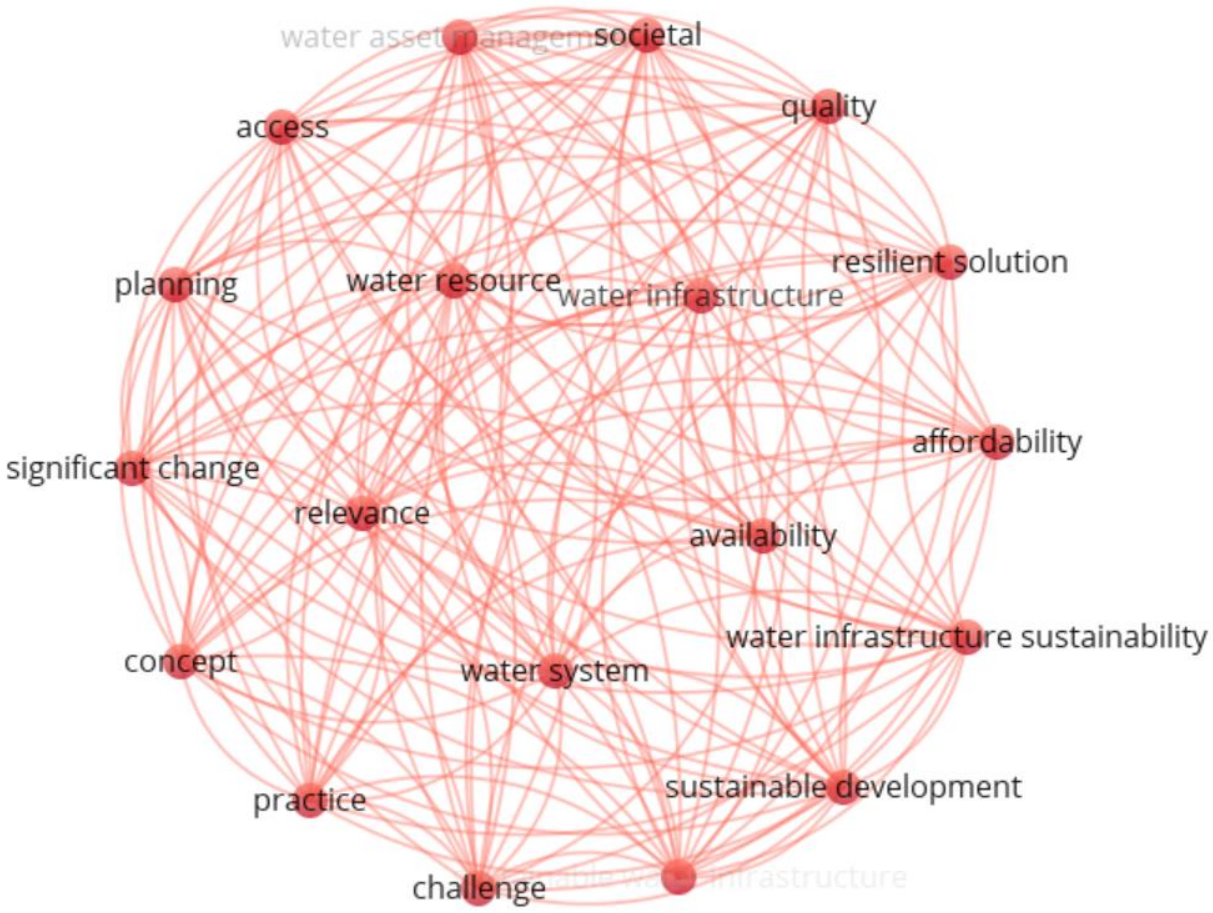


Figure 2: Keywords from reviewed articles
Source: Author's construct, 2026

3.0 Findings

3.1 West Africa

The research conducted by Murray and Drechsel in 2009 and 2011 showed that the successful operation of wastewater facilities in Ghana requires three essential elements: adequate financial resources, proper maintenance procedures, and effective operational methods, which together form a base system that supports the whole operation. Nigerian urban areas lack adequate wastewater treatment systems, resulting in sewage being dumped directly into nearby water bodies, according to Adewumi and Oguntuase (2016). International funding, together with local capacity building and stakeholder involvement, serves as the solution to existing financial problems and institutional deficiencies, according to Amaefule et al. (2023). Existing research primarily focuses on technical aspects and fails to investigate complete urban development frameworks. Sustainable wastewater management requires infrastructure planning that leverages multi-sectoral collaboration and participatory approaches.

3.2 North Africa

North Africa continues to confront ongoing difficulties with its wastewater management systems, according to recent research studies from the region. Egypt faces problems with environmental regulation enforcement, resulting in improper sludge disposal, while the country lacks comprehensive infrastructure to support sustainable methods such as anaerobic digestion (Wahaab et al., 2020). Government institutional barriers undermine small-scale treatment initiatives, showing that technical solutions alone are insufficient without governance and stakeholder engagement (Reymond et al., 2018). Morocco's

wastewater reuse ambitions have been hindered by insufficient treatment capacity, weak regulatory enforcement and low public trust, resulting in only 0.3% of treated water being reused (Dahchour & El Hajjaji, 2023; Lemfarrak et al., 2025).

3.3 Central Africa

Studies conducted in Central Africa have demonstrated that wastewater management systems face ongoing challenges and that their existing infrastructure lacks proper planning. In Cameroon, brewery operations produce wastewater that exceeds both national levels and World Health Organization thresholds (Kamegne Kamtoh et al., 2021). The implementation of bacterial bed technology faces challenges, including design issues, institutional limitations, financial constraints and maintenance requirements (Visiy et al., 2026). Decentralized sanitation systems show potential through the use of constructed wetlands. The Democratic Republic of Congo uses wastewater for irrigation, with implications for public health (Mayeko, 2012). Fecal sludge disposal occurs mainly through pit, canal and river dumping (Kishota et al., 2025). The studies illustrated focus on technical solutions and public awareness but they do not provide cohesive planning methods.

3.4 East Africa

The deficiencies in infrastructure development in East Africa wastewater management systems cause treatment facilities to fail because only 55% of the population has access to sewage systems, including 30% of Tanzania, 40% of Uganda, 50% of Kenya, 40% of Rwanda, 20% of Burundi, 30% of Ethiopia, 50% of Sudan and 15% of Somalia (Lema, 2025). The case studies show that Kenya faces a need for affordable decentralized solutions due to problems with government enforcement and treatment plant limitations (Mbugua et al., 2025), and that constructed wetlands deliver viable waste management systems for slum areas and residential waste disposal (Kilingo et al., 2021). The public health potential of wastewater monitoring in Uganda begins before clinical positivity (Nsawotebba et al., 2026). Sewage systems incur higher costs per person than fecal sludge systems because the two systems require different funding levels (McConville et al., 2019). The development of decentralized systems, resource recovery and advanced technologies creates new opportunities that require planning, stakeholder engagement and capacity building to achieve sustainable results (Lema, 2025).

3.5 Southern Africa

The reviewed research conducted in South Africa and Namibia showed multiple interconnected issues through their examination of water pollution, declining nutrient levels and water scarcity, thus exposing deficiencies in both infrastructure development and capacity planning (Montwedi et al., 2021). The sanitation problems in South Africa stem from fundamental systemic failures, leading to economic decline and human rights violations (Wall, 2021). Research conducted in Namibia found that facility planning depends on both utilization rates and wastewater parameters (Müller et al., 2016). Municipal governance systems experience capacity constraints but informal partnerships create opportunities for enhanced learning and monitoring activities (Frick-Trzebitzky et al., 2022). Successful sustainable development requires three essential elements: integrated technical solutions, participatory governance methods and strong institutional backing.

4.0 Comparison of Challenges of Wastewater Management in Africa

Wastewater management in Africa faces multiple challenges that require technical solutions, economic assessments, institutional evaluations, environmental protection and social impact mitigation, all of which become more difficult amid rapid urban growth and existing planning restrictions. The literature demonstrates that these challenges exist in a network of interdependent elements that together limit the ability to operate and sustain wastewater systems.

4.1 Technical Challenges

African wastewater treatment systems encounter technical difficulties because they rely on outdated systems, with their personnel lacking the proper skills and failing to update their knowledge (Omohwovo, 2024; Allison et al., 2024; Wall, 2021; Amarachi et al., 2023). The difficulties that both major and minor cities face worsen due to divided management systems, urban planning deficiencies and inefficient system operations (Zechman Berglund et al., 2021; Chrispim, 2021). The system lacks integrated components, thereby preventing both automated processes and monitoring systems from working properly (Mashala et al., 2023; Mustapha et al., 2024; Delanka-Pedige et

al., 2021). The combination of comprehensive strategies, technology expenditures and strong governance systems will produce sustainable development (Montwedi et al., 2021; Bhave & Rahate, 2018).

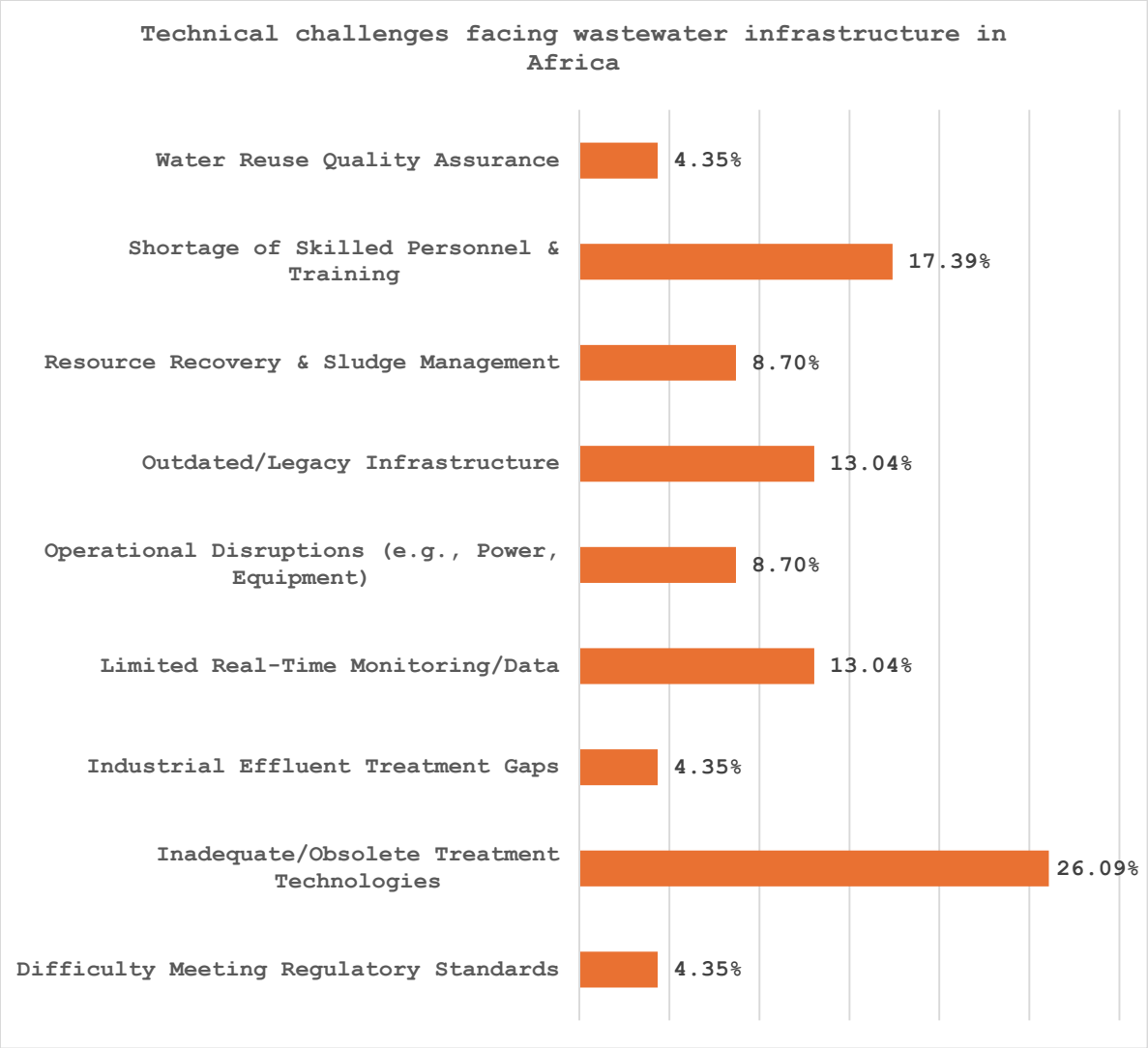


Figure 3: Technical challenges facing wastewater infrastructure in Africa
Source: Author's construct, 2026

4.2 Economic Challenges

The economic problems that African wastewater facilities face exist because of three main factors, which are insufficient funding, excessive operational expenses, and the inability to implement new technologies and develop advanced skills (Omohwovo, 2024; Allison et al., 2024; Wall, 2021; Amarachi et al., 2023; Mbugua et al., 2025; Chrispim, 2021; Mustapha et al., 2024). The financial obstacles that cities face during their development process lead to operational problems that undermine their ability to sustain their functions. The study proposes integrating urban planning with wastewater management systems to enhance resource distribution and increase regulatory compliance, while creating resilient infrastructure systems that connect investment choices to urban expansion and environmental protection.

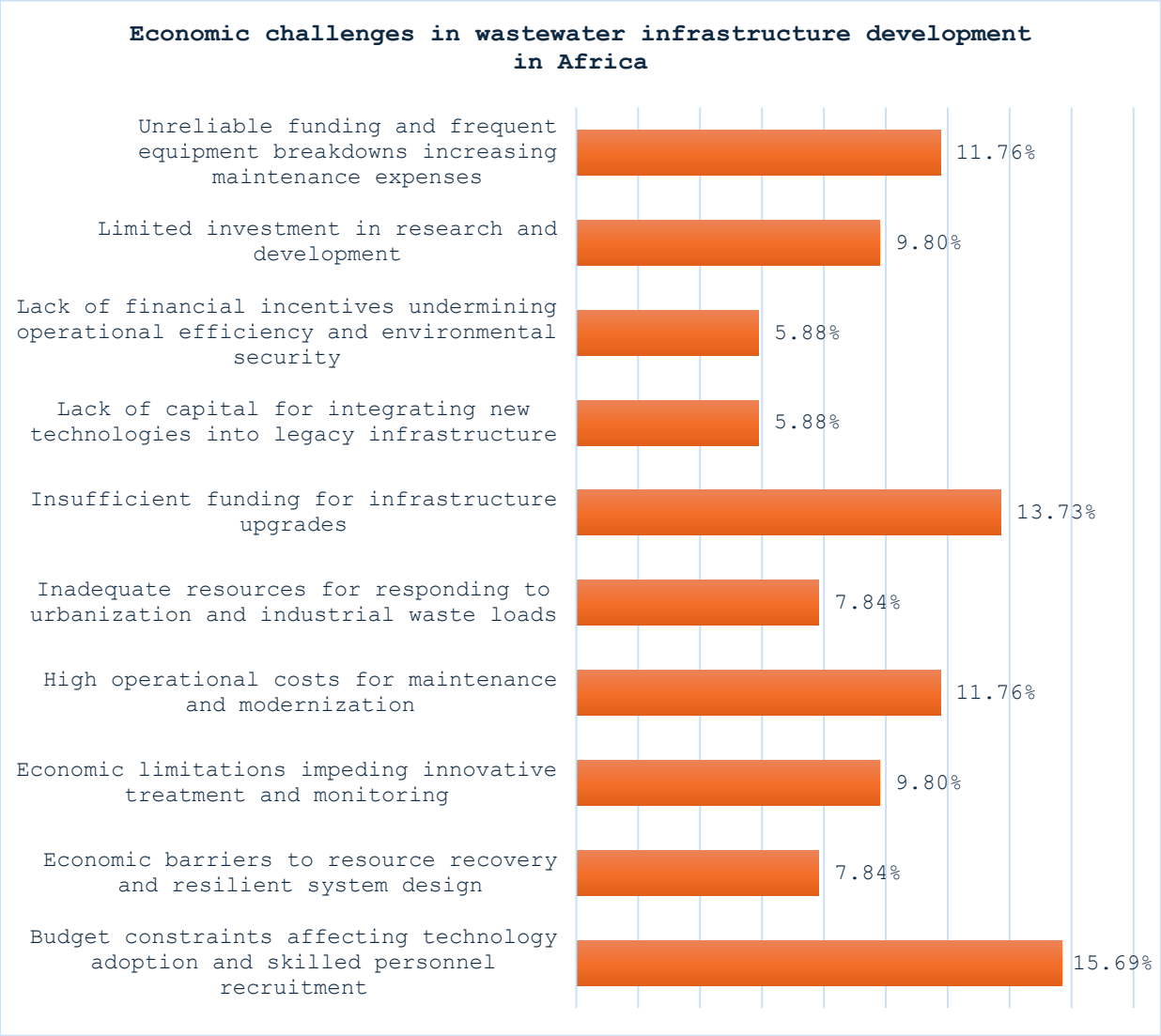


Figure 4: Economic challenges in wastewater infrastructure development in Africa
Source: Author's construct, 2026

4
.3 Institutional Challenges

The management of wastewater systems faces institutional challenges stemming from its fragmented governance and unpredictable regulatory frameworks, which create difficulties for both policy development and sector management (Omohwovo, 2024; Allison et al., 2024). The lack of clear responsibility assignments, together with ineffective partnership networks, stops the development of integrated plans (Wall, 2021; Amarachi et al., 2023). Cities fail to improve their infrastructure because they lack available, established improvement methods (Zechman Berglund et al., 2021; Montwedi et al., 2021). Infrastructure development faces limitations due to a shortage of skilled workers and available knowledge (Bhave & Rahate, 2018), while weak stakeholder involvement and insufficient accountability systems place sustainability at risk (Mbugua et al., 2025; Chrispim, 2021; Mustapha et al., 2024). The research connects institutional obstacles to urban development by recommending enhanced role definitions, improvements in teamwork, and leadership capacity building for sustainable urban wastewater management systems.

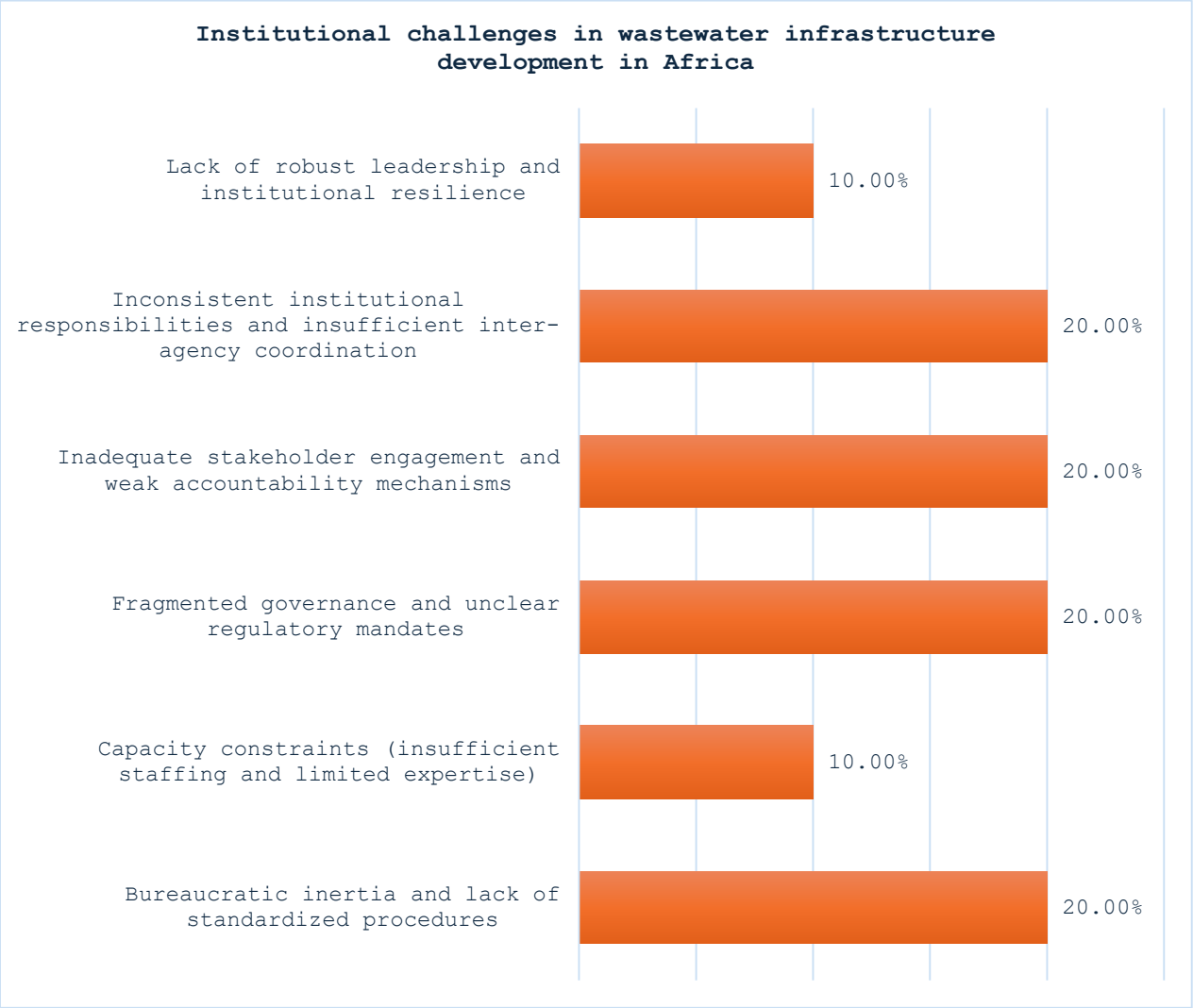


Figure 5: Institutional challenges in wastewater infrastructure development in Africa
Source: Author's construct, 2026

4.4 Environmental Challenges

The environment faces ongoing challenges because wastewater systems fail to treat wastewater completely and only treat some of its contents, resulting in water pollution, which endangers aquatic life and human safety through the release of heavy metals, pathogens and persistent organic pollutants (Omohwovo, 2024; Allison et al., 2024; Wall, 2021). Insufficient monitoring efforts, together with ineffective protective systems, create discharge problems that result in excessive nutrient accumulation and lead to ecosystem destruction (Amarachi et al., 2023; Zechman Berglund et al., 2021; Montwedi et al., 2021). The combined effects of climate change and urban growth create fresh challenges for establishing effective regulatory frameworks (Bhave & Rahate, 2018; Mbugua et al., 2025). The research demonstrates integrated environmental systems by focusing on resource recovery and pollution prevention, while also establishing a connection between environmental solutions and urban planning to create sustainable infrastructure.

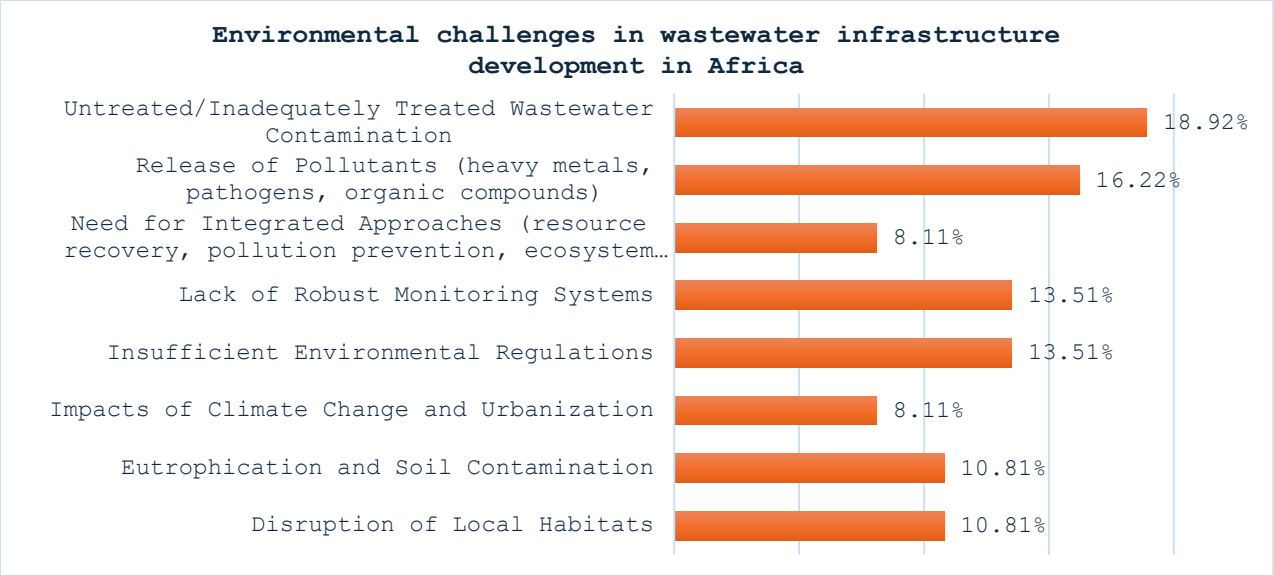


Figure 6: Environmental Challenges in Wastewater Infrastructure Development in Africa
Source: Author's construct, 2026

4.5 Social Challenges

Current research shows that social barriers impede wastewater management, as it depends on major urban planning elements. Omohwovo (2024) and Allison et al. (2024) reported that weak public participation and limited education lead to insufficient infrastructure support, resulting in deficiencies in participatory planning. Wall (2021) linked community resistance to inadequate stakeholder communication, which damages public trust in urban service delivery systems. Amarachi et al. (2023) and Zechman Berglund et al. (2021) demonstrated that spatial planning failures create inequitable access, which particularly harms marginalized communities. Montwedi et al. (2021) and Bhave and Rahate (2018) argued for inclusive governance, while Mbugua et al. (2025), Chrispim (2021) and Mustapha et al. (2024) observed that sustainable urban systems require outreach and social acceptance and capacity-building activities.

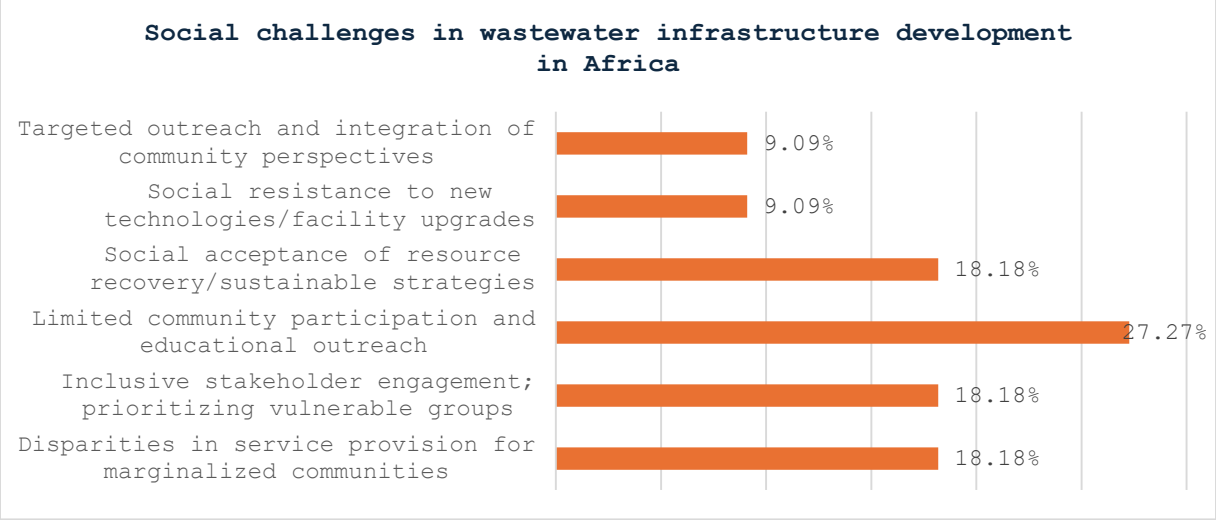


Figure 6: Environmental Challenges in Wastewater Infrastructure Development in Africa
Source: Author's construct, 2026

Table 2: Summary of challenges

Year of publication						
2024	Ejovwokeoghene Joseph Omohwovo	Inadequate wastewater treatment methods; lack of indigenous innovative technologies; poor operation and maintenance practices; inadequate training of treatment facility workers	Inadequate international financial support; lack of funding for wastewater treatment infrastructure	Poor government policies; lack of institutions; weak government participation and support; inadequate water resource distribution	Poor environmental outcomes; water-based pollution; aquatic ecosystem damage	Severe health risks for humans and animals; inadequate provision of safe water and sanitation; lack of public involvement
2024	Allison et al	Challenges in quantifying adaptation thresholds, triggers and indicators; implementation of DAPP plans			Climate adaptation challenges for wastewater systems	
2021	Kevin Wall	Infrastructure failure due to a lack of maintenance and care		Lack of political will; insufficiently skilled municipal leadership; ineffective municipal boards		Deprivation of citizen rights; inconvenience to citizens
2023	Amarachi et al.	Improper planning; insufficiently trained professionals; poor execution and monitoring	Inadequate funding; financing challenges	Weak regulatory frameworks; insufficient governance structures		
2021	Montwedi et al.	Malfunctioning sanitation and wastewater treatment systems	Market potential depends on regional volumes and recovery yields		Water-based pollution, declining nutrients and water shortage	Lack of access to dignified and safe sanitation facilities
2021	Zechman Berglund et al.	Challenges in drinking water infrastructure; sustainable reuse of wastewater			Effects on natural water bodies	Unequal access to WASH services; pandemic impacts on water demands
2018	Bhave & Rahate	Outdated hydraulic designing methods; network inefficiency (42% with FSI change); sewers overflowing; inadequate planning and design methodologies				Unhygienic conditions; disease outbreaks

2025	Mbugua et al.	Variability in biochar quality; limited local production infrastructure; insufficient treatment capacity; lack of decentralized alternatives	High production costs; budget constraints; lack of investment in wastewater reuse	Gaps in regulatory enforcement; lack of supportive policies, low institutional awareness, gap between policy and implementation	Treated water is discharged into water bodies instead of being recycled	Low public awareness
2021	Cardoso Chrispim	Low implementation of resource recovery practices; local conditions affecting implementation				
2024	Mustapha et al	Need for capacity building; local production of WASH equipment	Need for more investment in WASH programmes	Need for institutional strengthening; policy review required; data and information transfer challenges		Need for stakeholder collaboration; community involvement in design and implementation
2023	Mashala et al.				LULC changes impact on water quality and quantity	
2024	Allaire et al.			Uneven access shaped by local governance; unincorporated status affecting infrastructure access		Inequities associated with poverty rates, lower sewer coverage in unincorporated communities
2021	Delanka-Pedige et al.	Energy use in wastewater treatment: pathogen reduction challenges			Emission reduction in wastewater treatment	
2023	Jorge Alejandro Silva	Diseases and pathogens management; excessive energy consumption; inadequate skills; difficulties in managing sludge	Budgetary constraints		Pressure on natural water sources	

Source: Author's construct, 2026

5.0 Future Prospects and Opportunities for Wastewater Infrastructure in Africa

The prospects and opportunities for wastewater infrastructure planning in Africa are guided by five key attributes that support the achievement of SDG 6. As suggested by Delanka-Pedige et al. (2021), these five attributes are as follows: reuse-quality water recovery, safe pathogen reduction, energy use and recovery in wastewater treatment, biofertilizer recovery from wastewater, and emission reduction in wastewater treatment. The five attributes need to be addressed to develop sustainable solutions for wastewater management practices.

The present research builds on previous studies by presenting a unified approach to urban planning that addresses challenges in wastewater infrastructure. The work demonstrates planning failures by linking them to existing problems in real-time monitoring, as noted in Bhave and Rahate (2018) and Omohwovo (2023). The work also expands upon Silva's 2023 financial analysis by situating Public-Private Partnership funding models within governance frameworks and spatial planning systems to demonstrate how these models enable balanced service distribution.

In line with prior research on stakeholder collaboration, e.g. Omohwovo (2024), this paper demonstrates that various planning levels require public participation, institutional backing and policy implementation. The research connects satellite observation data from Mashala et al. (2023) with spatial tools to support active land-use planning and infrastructure site-selection processes.

Furthermore, the study presents a complete framework that connects the five elements of technical innovation, financial strategies, environmental visibility, social acceptance, and governance mechanisms with a view to demonstrating their combined effect on urban planning, resulting in waste infrastructure systems that operate efficiently and provide sustainable wastewater management solutions.

5.1 Resource Recovery

The worldwide study of wastewater treatment systems is changing how people perceive wastewater, demonstrating its value as a crucial resource. Wastewater reclamation and reuse systems have become essential for cities worldwide as they seek to improve their water supply systems amid climate emergencies and existing water shortages, especially as populations grow. Silva (2023) established that the worldwide water crisis stems from humans extracting more water than nature can replenish. However, wastewater treatment plants (WWTPs) have the capacity to deliver vital water recovery services, with its proper management creating two main advantages: reducing health risks and protecting natural environments.

Addressing the energy supply problem at wastewater treatment facilities, this research supports Omohwovo (2024) by recommending the conversion of wastewater or sludge into energy, with efforts already being made to develop treatment plants across African urban areas. It is suggested that urban resource reuse be implemented alongside proper infrastructure monitoring and management to meet increasing urban demands without additional resources or environmental harm.

African countries can learn from developed nations when it comes to implementing effective local solutions. The growing population problem, together with declining water supplies and existing energy shortages in Africa, should prompt countries to build sustainable wastewater treatment facilities. These facilities should operate with reduced resource requirements while achieving higher operational effectiveness, complete waste recycling, resource recovery, and financial benefits through technological systems and business processes that align with their regional social, economic and environmental requirements. Wastewater contains three essential resources: agricultural, industrial, and urban water for consumption and production; green, renewable biogas energy; and fertilizers derived from sludge. The three resources of wastewater treatment processes that can be recovered are shown in Figure 7.

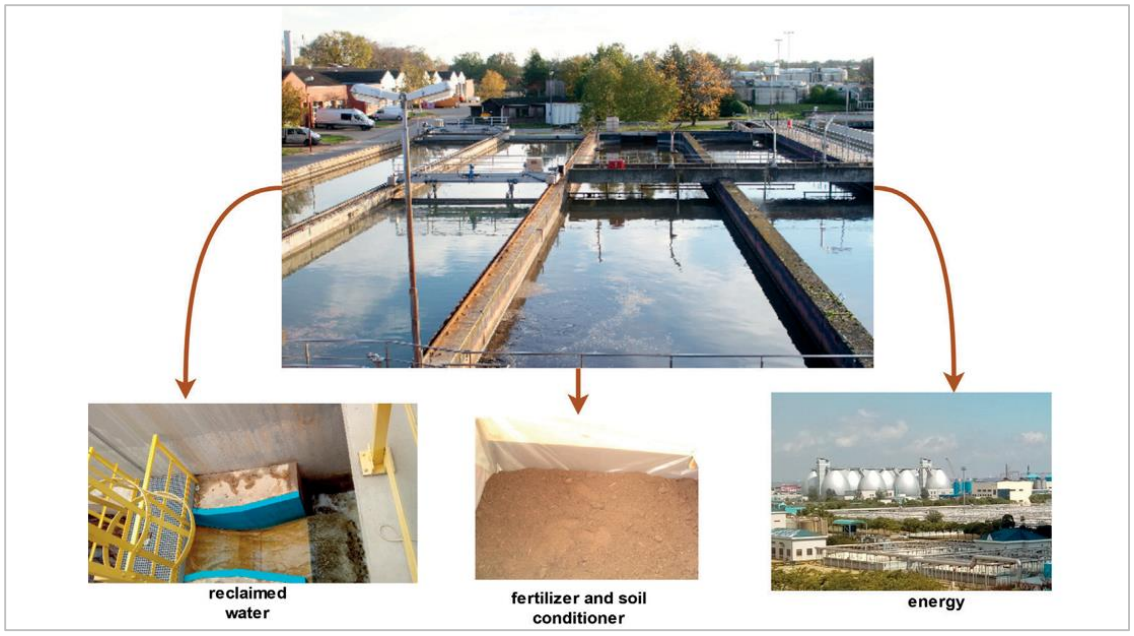


Figure 7: A sustainable water resource recovery facility showing some of the recovered resources.
Source: Chrispim, 2021

Resource recovery has the potential to provide environmental, social and economic benefits to local communities through reducing water stress, improving well-being and producing an alternative fertilizer source (Chrispim, 2021). A study by Vanhamäki et al. (2020) found that wastewater treatment facilities face difficulties implementing resource recovery systems as part of their circular economy transformation. The complete implementation of these sustainable strategies requires all African governments to meet their obligations in effecting the necessary systemic transformations.

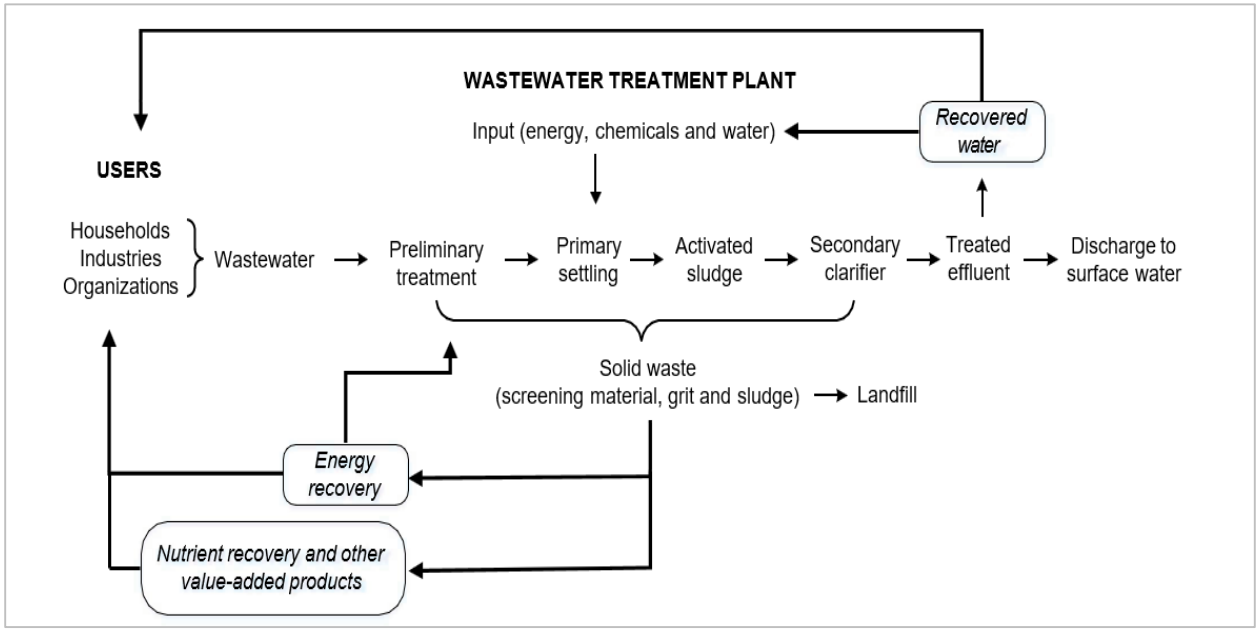


Figure 8: Illustration of the resource recovery process
Source: Chrispim, 2021

The development and enhancement of wastewater systems have been hampered by insufficient funding, given the economic status of most African countries. This study suggests that cities should implement local, affordable wastewater treatment systems that they can easily obtain. For example, biochar, a carbon-rich material, serves as an affordable treatment solution. As Mbugua et al. (2025) found in a Kenyan context, biochar application offers advantages, including resource recovery and complete waste treatment since it prevents untreated wastewater from being discharged into the environment due to financial constraints affecting wastewater treatment system acquisition. Moreover, the study also found that the use of biomass residues from local sources to produce biochar offers a cost-effective solution for treating wastewater in decentralized systems.

Accordingly, research should focus on three aspects to improve biochar adoption in Africa: optimizing the production process, improving contaminant removal efficiency, and assessing biochar's environmental effects in wastewater treatment applications. Research has shown that standardized testing methods are essential for evaluating biochar effectiveness across different wastewater treatment systems, and these systems must account for both feedstock type and pyrolysis process conditions. The surface functionalization process used to modify biochar enables the development of advanced absorption methods that specifically target heavy metals and organic compounds, according to Mbugua et al. (2025).

Thus, this study proposes that biochar technology should be combined with constructed wetlands and anaerobic digestion systems to enhance the operational performance of wastewater treatment facilities. Amarachi et al. (2023) observed that sustainable water and wastewater management requires site-specific solutions that adapt to the sociocultural and environmental conditions at each location. It is therefore necessary for researchers to collaborate with industry partners across nations in identifying suitable wastewater treatment methods that align with local economic conditions and the specific characteristics of the wastewater to be treated. Some cities can use bubble-less oxygen transfer technology, which operates without energy consumption, to solve their energy problems. The bubble-less oxygen transfer system works like human breathing, allowing it to remove nitrogen through simultaneous nitrification and denitrification (Silva, 2023).

5.2 Multi-Criteria Decision Analysis (MCDA) for Wastewater Infrastructure Planning

Today's wastewater infrastructure systems need a complete redesign based on SETS theory, as it establishes fundamental principles for designing integrated systems that build urban resilience and enable sustainable development. This study recommends using Multi-Criteria Decision Analysis (MCDA) for wastewater infrastructure planning because it can help address the multiple technical, economic, institutional, environmental and social challenges being faced across Africa. The current problems arise because people view wastewater systems as separate components that require input from only engineers for design and from chemical analysts to determine wastewater quality. The current system requires a full transformation that includes all concerned parties, starting with local residents who possess essential indigenous knowledge of wastewater treatment systems. The entire process requires input from all stakeholders, including engineers who provide technical design knowledge urban planners who can assess water use and the resulting wastewater volume from different land development types, economists who can perform financial assessments, environmental specialists who can conduct environmental assessments, and the national and local government bodies and private-sector investors who can determine the best funding strategies. The design process requires all stakeholders to gather and exchange information while establishing their contribution to the value of wastewater infrastructure design, development and management.

The MCDA model requires identifying all important decision-makers and their specific decision criteria. This study presents criteria for planning wastewater management research, as shown in Table 2.

Table 3: Criteria for planning wastewater infrastructure

s/no	Category	Criteria
1	Technical and environmental	Technological advancement Resource recovery potential Number of skilled labour needed Environmental effects Quality of final products
2	Economic	Investment costs Operational and maintenance costs Revenue from recovered resources.
3	Social	Acceptance by the community
4	Institutional	Alignment to local, national, and international standards, policies, and legal requirements
5	Political	Goodwill Approval of policies and legal frameworks for wastewater management

Source: Author's construct, 2026

These criteria align with those presented in Amarachi et al. (2023), who noted that for efficient and sustainable wastewater infrastructure, the following must be considered: thorough assessments of local conditions, identification of potential challenges and development of comprehensive plans to address them. Governments and other stakeholders must allocate sufficient funding to these projects to ensure their success. They must also formulate and implement regulations and policies for efficient wastewater management, develop adequate wastewater infrastructure across both urban and rural areas, provide adequate education and awareness to the public on the need to reuse wastewater, and involve all relevant stakeholders in the entire process.

This decision model can be complemented by the contribution of Allison et al. (2024), who described a seven-step approach to support infrastructure decision-making, viz: scoping workshops, systems mapping, Dynamic Adaptive Pathways Planning (DAPP), exploratory modeling, robust decision-making, real options analysis, and validation workshops. African countries can adopt this approach for infrastructure planning and stress testing to improve robustness and give decision-makers greater confidence.

Wastewater management methods require the development of tailored solutions for each individual site. The social, cultural, environmental and economic characteristics of the target area need to be defined in the design of the waste management solution. The technology employed should be cost-effective, environmentally sustainable and culturally accepted, as also noted by Amarachi et al. (2023). The present study calls for different sectors to work together, including government agencies, non-governmental organizations and community-based organizations involved in wastewater management.

No doubt, the future offers significant opportunities for sustainable wastewater infrastructure planning and management across Africa. Accomplishing this goal will require collaboration involving academic institutions, governmental bodies, non-profit organizations and business enterprises. The project will maintain climate resilience through its implementation of circular economy practices, which directly support the Sustainable Development Goal 6 of achieving clean water and sanitation. These recommendations an economical yet practical solution to the wastewater management problems faced by Africa while guaranteeing sustainable results.

6.0 Conclusion

The review indicates that Africa's wastewater systems encounter multiple challenges, which include technical problems, financial difficulties, institutional obstacles, environmental issues and social problems. The main challenges to this system stem from five factors: outdated equipment and insufficient ability to monitor operations; the system's financial shortcomings; the divided responsibilities of different

organizations; environmental pollution; and the lack of public support.

The study identifies three areas needing immediate intervention, as general suggestions do not solve the problem. The first requirement for municipal governments and utilities to complete within the first three years is to establish real-time monitoring systems, enhance workforce training and create structured programmes for public involvement. The second requirement (3-7 years) for national governments is to change their financing systems by implementing Public-Private Partnerships and specialized infrastructure funding, which they need to develop. The third requirement (8-15 years) for planners requires them to use spatial tools to integrate wastewater systems into land-use planning while establishing governance systems that require stakeholder participation in all decision-making processes.

In conclusion, the implementation of circular economy methods, together with wastewater reuse systems, offers potential benefits; nevertheless, potable water reuse requires careful evaluation because it depends on expensive advanced treatment technologies that remain unavailable for widespread use. The solution should focus on non-potable water reuse and decentralized systems, as these methods will improve both sustainability and public acceptance.

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