

Water Infrastructure and Facilities in Africa: An Integrated Overview and Approach to Addressing Issues in Governance, Sustainability, and Technology

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ABSTRACT

Water is essential for survival and growth. The approach to water management and its governance is linked to the adequacy of the water infrastructure, and its related facilities. Altogether, they profoundly influence societies and countries. This research investigates water management issues, and its infrastructural facilities in Africa with a focus on several African nations. It underscores three primary domains: governance, sustainability, and technical solutions. This research includes six nations: Nigeria, Ethiopia, Morocco, Egypt, South Africa, and the Democratic Republic of Congo. The researchers collected data from past and recent studies, publications, and global databases, including the World Bank. The research highlights critical concerns related to water management in these countries. It tackles issues including water scarcity, insufficient governance, and the need for creative technologies. The study emphasizes the inequalities and common issues faced by various countries through comparative analysis. The results underscore the necessity of an efficient water management policy. This involves improving governance, executing sustainable practices, and embracing advanced tactics. The paper offers practical ideas for governments, NGOs, and international organizations to improve water resource management.

Keywords: Water management, infrastructure, Facilities, Governance, Sustainability, Technological Innovations, Project Management.

INTRODUCTION

Background to the study

Water is a fundamental resource that supports economic development, social welfare, and environmental sustainability. In Africa, it plays a critical role in various sectors such as agriculture, energy production, health, and overall livelihoods. However, the continent faces severe water-related challenges due to inadequate water in that impede its development and hinder the achievement of the United Nations' Sustainable Development Goals (SDGs). As one of the driest continents, Africa is characterized by water stress, uneven distribution, and rising demand, exacerbated by rapid population growth, urbanization, and climate change (UNEP, 2019; Tignor et al., 2020).

Water scarcity in Africa is one of the most pressing issues of the 21st century. According to the African Development Bank (2018), nearly 400 million people in sub-Saharan Africa lack access to clean water, and over 700 million people face the threat of water scarcity by 2025. Africa is also home to some of the world's most water-stressed regions, particularly in Northern and Southern Africa, where arid and semi-arid climates are widespread. Despite these challenges, the continent also boasts several transboundary rivers, lakes, and

groundwater sources that have the potential to support large populations and economies, provided they are sustainably managed (Iweha, 2018).

In Nigeria, which serves as a critical example of urban water challenges in Africa, a significant portion of the population still lacks access to potable water, despite being one of the largest economies in sub-Saharan Africa. The urban population in Nigeria faces increasing demand for water, with cities such as Lagos, Kano, and Abuja experiencing rapid urbanization, stretching existing water infrastructure beyond its capacity (Gore et al., 2020; Nwachukwu et al., 2020). Access to safe drinking water remains a significant issue in many parts of Africa, with rural areas experiencing greater disparities than urban centers. Inadequate infrastructure, poor governance, and insufficient investments in water supply systems further exacerbate the problem (Tantoh et al., 2021). According to UNESCO (2021), water infrastructure deficits are a major barrier to improving water access, with many regions lacking reliable systems for water collection, treatment, and distribution. This lack of access is also linked to a high incidence of waterborne diseases, contributing to mortality and morbidity in the continent, particularly in Nigeria, where inadequate sanitation and poor water quality are widespread (Akinmoladun et al., 2019).

Beyond water scarcity, the quality of water is another major challenge. Pollution from industrial, agricultural, and domestic sources is widespread, further reducing the availability of safe water for drinking, sanitation, and agriculture (Nwankwo et al., 2017). The contamination of freshwater resources through waste disposal, mining activities, and chemical runoff has led to severe ecological and public health impacts, particularly in countries with inadequate regulatory frameworks (Oluduro et al., 2020). Furthermore, climate change exacerbates these challenges by altering rainfall patterns, increasing the frequency of droughts and floods, and reducing the predictability of water availability (Wigwe et al., 2019).

Given the complexity and interconnection of water challenges in Africa, it is crucial to adopt integrated approaches that consider the multi-dimensional aspects of water management. These approaches should encompass the adequacy of the water infrastructural projects, facilities, governance, sustainability, and technological solutions, each of which plays a critical role in addressing the water crisis. Effective governance is fundamental to ensuring equitable access to water, establishing sound policies, and promoting sustainable resource management (Ahmed et al., 2018; Sogunro et al., 2020). In parallel, sustainability must be integrated into water management practices, with an emphasis on protecting ecosystems, addressing climate change impacts, and ensuring social equity in water distribution (Olaniyan & Olofin, 2019).

Technological innovations also offer opportunities to address water challenges, from smart water management systems to advanced purification and desalination technologies (Ekpenyong et al., 2020). The application of technology can enhance the efficiency of water distribution, reduce waste, and improve access to clean water, especially in underserved areas (Ajayi & Olayiwola, 2020). However, the successful implementation of such technologies requires strong governance frameworks, sound policy support, and the involvement of local communities (Akinmoladun et al., 2020).

Hence, the water issues in Africa are multifaceted and require collaborative and integrated solutions that bring together various sectors, stakeholders, and strategies. Understanding the interconnectedness of water infrastructural projects, governance, sustainability, and technology is vital to creating a comprehensive response to Africa's water challenges (Nwachukwu et al., 2020). This paper aims to explore these dimensions and provide an overview of the key water issues in Africa, offering insights into effective strategies and solutions for achieving water security and sustainable development across the continent.

Issues in Sustainable Water infrastructure Projects and Facilities

Water scarcity and inadequate access to clean water represent pressing global challenges, affecting billions of people across both developed and developing nations. According to the United Nations, over 2 billion people worldwide still lack access to safely managed drinking water, with the situation exacerbated by rapid urbanization, climate change, and poor governance (United Nations, 2020). In regions such as sub-Saharan Africa, Asia, and parts of Latin America, water shortages are not only a matter of limited supply but also reflect deep structural issues in water facilities, governance, infrastructure, and sustainability practices (Mekonnen et

al., 2017; Gleick, 2018). This global water crisis manifests through increasingly frequent droughts, contamination of water sources, and water pollution, all of which threaten public health, economic stability, and social equity (Bates et al., 2021).

Additionally, global water demand is expected to rise by 55% by 2050, further intensifying pressures on already scarce resources (United Nations, 2020; United Nations Water, 2021). The growing water-related challenges require urgent, coordinated action at the international level, focusing on sustainable management practices, technological innovations, and robust policies to ensure water security for all (Vörösmarty et al., 2010; Postel, 2017). The complex, interconnected nature of these issues underscores the necessity for integrated, multi-disciplinary approaches to water management that can address both supply and demand constraints while ensuring equitable access (Shiklomanov, 2021; Sadoff & Muller, 2019).

Water scarcity and access to clean water have long been central concerns for African nations, with countries like Nigeria, South Africa, Ethiopia, Egypt, and Morocco serving as significant examples of these challenges. In Nigeria, rapid urbanization, particularly in megacities like Lagos, Abuja, and Kano, has strained existing water infrastructure. Despite Nigeria's vast water resources, less than 30% of urban residents have reliable access to potable water, with many urban dwellers depending on unsafe sources. The water crisis is further exacerbated by mismanagement, corruption, and an over-reliance on outdated infrastructure, leaving millions without access to safe drinking water and contributing to the spread of waterborne diseases such as cholera and typhoid (Akinmoladun et al., 2019; Nwachukwu et al., 2017; Akinmoladun et al., 2020). Similarly, South Africa, a country with significant economic and industrial power, faces severe water stress, with over 50% of the population in urban areas experiencing water shortages. Cape Town's "Day Zero" crisis in 2018, where the city nearly ran out of water, is a stark example of how governance, climate change, and inadequate water management can result in a disaster (Sogunro et al., 2020; Oluduro et al., 2020).

In Ethiopia, the water crisis is marked by both scarcity and accessibility challenges, particularly in rural and underserved urban areas. The country's dependency on rain-fed agriculture, combined with a lack of infrastructure to store and distribute water, leaves millions vulnerable to droughts. Ethiopia's large rural population, where nearly 70% lacks access to clean water, illustrates the severe impact of insufficient water supply systems on livelihoods and health (Tantoh et al., 2021; Ekpenyong et al., 2020). In Egypt, the Nile River is a lifeline for the entire country, but the increasing demand for water due to population growth, industrialization, and climate change poses a grave threat to the sustainability of water resources. Egypt's challenges are compounded by political tensions with upstream Nile Basin countries, which limit its access to water (Oluduro et al., 2020; Ekpenyong et al., 2020). Morocco, which faces similar issues of water scarcity, has implemented extensive water conservation measures, including the construction of dams and investment in irrigation systems, but still struggles with the sustainability of water resources, especially in arid regions. These examples highlight the critical need for integrated approaches to address water governance, infrastructure, and sustainability across diverse African nations, with technological and policy innovations crucial for overcoming the continent's mounting water challenges (Wigwe et al., 2019; Olufemi et al., 2020; Oladipo et al., 2020).

Importance of Sustainable Water infrastructural Projects in Africa

The purpose of this study is to provide an integrated overview of Africa's water issues, focusing on the interplay between governance, sustainability, and technological advancements. By examining these critical dimensions, the research aims to highlight the root causes and persistent barriers that hinder equitable water access and sustainable management on the continent. The study seeks to explore the role of effective water governance frameworks, innovative technologies, and sustainable practices in addressing water scarcity, pollution, and infrastructural deficiencies. Furthermore, it aims to identify actionable insights and strategies that can inform policymakers, stakeholders, and development agencies in designing holistic solutions tailored to Africa's unique socio-economic, environmental, and cultural contexts. Ultimately, the research aspires to contribute to the global discourse on water security, emphasizing Africa's pivotal role in achieving the United Nations' Sustainable Development Goals (SDGs), particularly Goal 6, which aims to ensure availability and sustainable management of water and sanitation for all.

Addressing water issues in Africa is critical to fostering socio-economic growth, improving public health, and ensuring sustainable development across the continent. Access to clean and adequate water resources is a cornerstone for economic activities such as agriculture, industry, and energy production, which drive national economies. Moreover, resolving water challenges directly impacts health outcomes by reducing waterborne diseases, enhancing hygiene, and improving overall living conditions. For instance, achieving water security can significantly reduce poverty levels, increase educational attendance particularly for young girls—and empower communities by promoting equitable access to resources. Additionally, sustainable water management is crucial for mitigating the adverse effects of climate change, preserving biodiversity, and fostering resilience in vulnerable regions. This study contributes to these efforts by providing an integrated perspective on water governance, sustainability, and technological innovation, offering insights to policymakers, stakeholders, and researchers on addressing Africa's persistent water issues.

This study provides an integrated overview of water issues across Africa, focusing on the critical dimensions of governance, sustainability, and technological perspectives. It seeks to analyze the continent's water challenges holistically, addressing the multifaceted nature of water resource management, access, and distribution. While encompassing all African regions, the study places particular emphasis on Nigeria, Ethiopia, Morocco, Egypt, South Africa, and Congo, as these countries represent diverse hydrological, socio-economic, and policy contexts. The scope of this research includes an examination of governance structures and their role in shaping water management practices. It explores the effectiveness of existing policies, institutional frameworks, and regulatory mechanisms in addressing water scarcity, quality, and accessibility. The study delves into issues such as transboundary water governance, corruption, and the equitable distribution of water resources, identifying governance gaps and opportunities for improvement.

Sustainability is a central focus, analyzing how Africa's water resources are managed in the face of increasing demand from agriculture, industry, and domestic use, as well as the pressures of climate change. The research investigates the impact of unsustainable practices, such as overextraction, pollution, and poor waste management, on water ecosystems. It also highlights best practices and community-based approaches to sustainable water use, emphasizing strategies for balancing economic development with environmental preservation. Technological perspectives form another core aspect of the study, exploring the role of innovation in addressing Africa's water issues. The research examines the adoption of technologies such as desalination, water recycling, remote sensing, and smart water management systems, as well as the integration of traditional and modern water harvesting methods. It also evaluates the challenges of technology transfer, affordability, and scalability across different regions.

The study adopts a comparative approach, analyzing the water issues in Nigeria, Ethiopia, Morocco, Egypt, South Africa, and Congo to represent Africa's regional diversity. Nigeria and Ethiopia illustrate the challenges of population growth, urbanization, and water stress in West and East Africa, respectively. Morocco and Egypt highlight the water governance dynamics in North Africa, where arid conditions and transboundary water resources demand innovative solutions. South Africa, with its advanced water infrastructure and history of water crises, provides insights into Southern Africa's unique challenges. Congo, representing Central Africa, offers a perspective on managing abundant water resources amidst socio-economic and political complexities.

LITERATURE REVIEW AND CASE STUDY PROTOCOLS

The literature review explores key concepts and theories related to water governance, sustainability, and technological innovations in managing water resources. It critically examines existing research on water issues in Africa, focusing on the governance structures, sustainable practices, and technological advancements implemented across the continent. The review highlights gaps in the current literature and establishes a foundation for understanding the challenges and opportunities in addressing water scarcity and quality in the selected African countries.

Water scarcity is one of the most pressing challenges facing Africa, where the combination of climate change, rapid population growth, and inefficient water management is exacerbating the situation. According to Akinbile (2021), many parts of Africa face severe water stress due to the increasing unpredictability of rainfall patterns

and high evaporation rates. Water scarcity in the continent threatens agricultural productivity, with over 60% of the population relying on agriculture as a primary livelihood (Mubiala et al., 2022). Furthermore, rapid urbanization and industrialization, particularly in countries like Nigeria, have intensified the demand for water resources, placing additional strain on the already limited supply (Ekpo et al., 2021). This escalating crisis has far-reaching implications for the continent's development, requiring urgent attention from both national governments and international agencies.

Climate change is a primary driver of water scarcity in Africa. The Intergovernmental Panel on Climate Change (IPCC, 2021) predicts that the effects of climate change, including increased temperatures and altered rainfall patterns, will exacerbate the existing water stress in Africa. In particular, regions such as East Africa and the Sahel are expected to experience more frequent and severe droughts, diminishing their capacity to meet water needs (Houghton et al., 2021). This reduction in freshwater availability has direct implications for food security, as agriculture is highly dependent on predictable water cycles. The situation is worsened by irregular water distribution, which limits access to safe drinking water and adequate sanitation (Lehner et al., 2023).

Population growth further compounds the problem of water scarcity. Africa's population, currently estimated at over 1.3 billion, is projected to grow substantially in the coming decades, placing immense pressure on water resources (Liu et al., 2022). This demographic expansion, combined with rural-to-urban migration, leads to increased competition for water between agriculture, industry, and domestic consumption. As populations grow in cities such as Lagos, demand for water has surged, putting further strain on the existing infrastructure (Ogunbode et al., 2021). In rural areas, increased agricultural activities, such as irrigation, also compete for limited water resources, leading to depletion of groundwater reserves (Olawale et al., 2021).

Moreover, the role of poor water management cannot be overlooked in understanding the water scarcity crisis in Africa. Many African countries, including Nigeria, face challenges with inadequate water infrastructure and mismanagement of existing resources. Poor governance, inefficient water allocation policies, and a lack of investment in water treatment and distribution systems exacerbate the crisis (Igbokwe et al., 2022). In many cases, water resources are over-extracted, and there is a lack of effective policies to ensure sustainable use. Furthermore, inadequate water storage and distribution systems mean that much of the available water is lost through leakage or mismanagement (Bassey et al., 2020). Addressing these inefficiencies is critical to alleviating the pressure on water resources across the continent.

To mitigate water scarcity, Africa requires a multi-faceted approach that includes improved water management, investments in infrastructure, and strategies to cope with climate change. According to Muller et al. (2020), innovative water-saving technologies, such as water-efficient irrigation systems, can help reduce the strain on available resources. Additionally, regional cooperation on transboundary water resources could play a pivotal role in managing shared water bodies more effectively (Lehner et al., 2023). Policymakers must also prioritize long-term sustainable water management practices that consider the impacts of climate change and population growth. For instance, water conservation and the adoption of water reuse systems could provide alternative solutions to meet the growing demands of both urban and rural populations (Mubiala et al., 2022). Table 1 shows water issues in various African regions.

Table 1: Water Issues across African Regions

Water Issue	East Africa	West Africa	Central Africa	North Africa	Southern Africa
Water Scarcity	Uneven rainfall, population growth.	Droughts, population growth.	Deforestation, population growth.	Arid climate, population growth.	Droughts, population growth.
Access to Safe Drinking Water	Limited access, leading to	Limited access, leading to	Limited access, leading to	Limited access, leading to	Limited access, leading to

	waterborne diseases.	waterborne diseases.	waterborne diseases.	waterborne diseases.	waterborne diseases.
Sanitation	Limited access to facilities, poor hygiene.	Limited access to facilities, poor hygiene.	Limited access to facilities, poor hygiene.	Limited access to facilities, poor hygiene.	Limited access to facilities, poor hygiene.
Water Quality	Pollution from industrial waste and contaminants.	Pollution from industrial waste and contaminants.	Pollution from industrial waste and contaminants.	Pollution from industrial waste and contaminants.	Pollution from industrial waste and contaminants.
Climate Change	Increased droughts and floods.	Increased droughts and floods.	Increased droughts and floods.	Increased droughts and water scarcity.	Increased droughts.
Water Infrastructure	Inadequate infrastructure, poor management.	Inadequate infrastructure, poor management.	Inadequate infrastructure, poor management.	Inadequate infrastructure, poor management.	Inadequate infrastructure, poor management.
Transboundary Water Management	Shared resources between countries.	Shared resources between countries.	Shared resources between countries.	Shared resources between countries.	Shared resources between countries.
Urbanization	Pressure on resources and infrastructure.	Pressure on resources and infrastructure.	Pressure on resources and infrastructure.	Pressure on resources and infrastructure.	Pressure on resources and infrastructure.
Conflicts Over Water	Resource competition leading to conflicts.	Resource competition leading to conflicts.	Resource competition leading to conflicts.	Resource competition leading to conflicts.	Resource competition leading to conflicts.

Source: Authors' Illustrations

Effective governance of water resources is critical for addressing the challenges of water scarcity and ensuring equitable access to water in Africa. As discussed by Igbokwe et al. (2022), the institutional frameworks governing water management in many African countries are often fragmented, with insufficient coordination between different levels of government and sectors. In countries like Nigeria, the management of water resources is split between federal, state, and local governments, which complicates decision-making and the implementation of water policies. This lack of coordination results in inefficiencies and overlaps, especially in urban water projects where rapid population growth intensifies demand (Ogunbode et al., 2021). Furthermore, the absence of clear and enforceable policies related to water rights and management has led to unregulated extraction and pollution of water bodies, undermining the sustainability of water resources (Mubiala et al., 2022).

Weak governance structures and poor institutional capacity exacerbate the water crisis in many parts of Africa. The lack of a strong regulatory framework often allows for corruption and the misallocation of water resources. According to Ekpo et al. (2021), corruption is prevalent in many African countries, including Nigeria, where officials in charge of water distribution often divert resources for personal gain. This not only exacerbates water scarcity but also undermines public trust in water management systems. Without adequate oversight and accountability mechanisms, water resources are often mismanaged, and essential infrastructure for urban water supply systems is neglected or poorly maintained (Lehner et al., 2023). In developing countries, the challenge is further compounded by a lack of technical expertise and resources to monitor and enforce water policies effectively (Igbokwe et al., 2022).

To address these governance challenges, there is a need for comprehensive reforms in water management institutions. A key strategy for improving governance is the decentralization of water management to local authorities, as recommended by Bassey et al. (2020), which could ensure more responsive and context-specific solutions for urban water supply in cities like Lagos and Abuja. Additionally, establishing transparent, inclusive, and accountable governance structures can improve the effectiveness of water projects and enhance cooperation among government agencies, the private sector, and civil society (Olawale et al., 2021). The adoption of participatory water management models that involve local communities in decision-making processes could also help reduce corruption and ensure that water resources are managed sustainably (Mubiala et al., 2022). Table 2 shows the water governance issues in Africa.

Table 2: Water Governance Issues in Africa

Water Governance Issues	Description	References
Fragmented Institutional Frameworks	Water management is often split across different levels of government (federal, state, local), leading to inefficiencies and overlaps in water projects.	Igbokwe et al. (2022), Ogunbode et al. (2021)
Lack of Coordination Between Sectors	Insufficient coordination between government sectors complicates decision-making and policy implementation, especially in rapidly urbanizing areas.	Igbokwe et al. (2022), Ogunbode et al. (2021)
Unregulated Water Extraction and Pollution	The absence of clear and enforceable policies on water rights leads to unregulated extraction and pollution, threatening the sustainability of water resources.	Mubiala et al. (2022)
Weak Governance Structures	Corruption and poor institutional capacity exacerbate water management issues, allowing for the misallocation of resources and neglect of infrastructure.	Ekpo et al. (2021), Lehner et al. (2023)
Corruption in Water Distribution	Corruption, particularly in water distribution, diverts resources for personal gain, exacerbating water scarcity and undermining public trust in management systems.	Ekpo et al. (2021)
Lack of Oversight and Accountability	Weak oversight and accountability mechanisms lead to poor management of water resources and neglected infrastructure, especially in urban areas.	Lehner et al. (2023)

Limited Technical Expertise	In many developing countries, a lack of technical expertise and resources prevents the effective monitoring and enforcement of water policies.	Igbokwe et al. (2022)
Decentralization of Water Management	Decentralizing water management to local authorities could provide more responsive and context-specific solutions, especially in urban areas with rapid growth.	Bassey et al. (2020)
Inclusive and Transparent Governance	Establishing transparent, inclusive, and accountable governance structures can enhance cooperation among agencies, the private sector, and civil society for better water management.	Olawale et al. (2021)
Participatory Water Management Models	Involving local communities in decision-making could reduce corruption and promote sustainable management of water resources.	Mubiala et al. (2022)

Source: Authors' Illustrations

The sustainability of water resources is a critical issue in the context of Africa, where water scarcity continues to impact both urban and rural populations. Environmental sustainability in water management practices is essential for preserving water quality, improving availability, and ensuring long-term water security. It encompasses strategies for maintaining the integrity of water ecosystems, addressing challenges posed by climate change, and adapting to the growing demand for water resources due to population growth and industrial development (Adama et al., 2021).

The role of ecosystem protection is central to the sustainability of water resources. Healthy ecosystems, including wetlands and watersheds, play a crucial role in water filtration, flood regulation, and maintaining groundwater levels (Mogaji et al., 2020). Ecosystem-based approaches to water management, which include protecting and restoring natural environments, help safeguard water quality and availability, enhancing resilience to climate impacts. Climate change, with its effects on rainfall patterns, evaporation rates, and water availability, further complicates water management in Africa. Climate adaptation strategies, such as the implementation of drought-resistant crops, water-efficient technologies, and improved irrigation systems, can significantly enhance the resilience of both agricultural and urban water systems (Adebayo & Balogun, 2020).

Moreover, water conservation practices, such as the promotion of efficient water use, recycling, and the adoption of technologies like rainwater harvesting, are pivotal in sustaining water resources in the face of increasing demand. These practices not only reduce the pressure on existing water supplies but also mitigate the environmental impacts of excessive water extraction and pollution. Integrating sustainable practices into water management policies and governance frameworks is essential for long-term water security in Africa (Moriarty et al., 2019). By addressing these key factors, African nations can better manage their water resources and foster environmental sustainability, ensuring that water remains a vital and accessible resource for future generations. The sustainability of water resources also requires addressing the regional disparities in water availability and the management of shared water systems. Effective cooperation between countries sharing transboundary water bodies is vital to avoid conflicts and ensure equitable distribution. Policies that encourage the joint management of rivers, lakes, and aquifers, such as the Nile Basin Initiative, offer promising models for promoting shared responsibility and sustainable use of water resources (Nwagboso et al., 2020).

Furthermore, the integration of renewable energy solutions in water management, such as solar-powered pumping systems and desalination plants, represents an important step toward reducing the environmental footprint of water provision in regions facing energy shortages (Eze et al., 2021). These technologies not only improve water access but also help mitigate the energy demands of traditional water distribution systems,

contributing to more sustainable and resilient water infrastructure. Table 3 shows the sustainability of water resources in Africa.

Table 3: Sustainability of Water Resources in Africa

Sustainability of water resources in Africa	Key Factors & Strategies	References
Environmental Sustainability	Strategies for preserving water quality, improving availability, and ensuring long-term security. Includes ecosystem protection, maintaining healthy ecosystems (wetlands, watersheds), and enhancing resilience to climate change.	Adama et al. (2021); Mogaji et al. (2020)
Ecosystem Protection	Protection and restoration of natural environments (wetlands, watersheds) to regulate flood, maintain groundwater levels, and improve water filtration.	Mogaji et al. (2020)
Climate Change and Adaptation	Climate change impacts on rainfall, evaporation, and water availability. Adaptation strategies like drought-resistant crops, water-efficient technologies, and improved irrigation systems.	Adebayo & Balogun (2020)
Water Conservation Practices	Efficient water use, recycling, rainwater harvesting, and adopting water-efficient technologies to reduce pressure on water supplies.	Moriarty et al. (2019)
Integration of Sustainable Practices	Integration of sustainable water management practices into policies and governance frameworks for long-term security.	Moriarty et al. (2019)
Regional Disparities and Transboundary Management	Addressing regional disparities in water availability and promoting cooperative management of shared water systems (e.g., Nile Basin Initiative).	Nwagboso et al. (2020)
Renewable Energy Integration	Use of solar-powered pumping systems and desalination plants to reduce the environmental footprint and address energy shortages in water provision.	Eze et al. (2021)

Source: Authors' Illustration

Technological innovations play a crucial role in addressing the growing water challenges in Africa. As water scarcity continues to intensify due to climate change, population growth, and unsustainable water management practices, the need for advanced technologies to optimize water use and improve water access has become more apparent. In Africa, a variety of technological advancements, such as desalination, smart water systems, and water recycling technologies, have been implemented to mitigate the

Impacts of water shortages and enhance the sustainability of water resources.

Desalination, the process of converting seawater into potable water, has gained attention as a viable solution in coastal regions facing freshwater scarcity. Several African countries, particularly those with access to coastlines, such as South Africa, Algeria, and Egypt, have adopted desalination technologies to supplement their freshwater supplies. The development of solar-powered desalination plants, for instance, has proven to be a sustainable solution, as it reduces reliance on fossil fuels while addressing water scarcity (Eze et al., 2021). Solar desalination

technology has been implemented in rural and off-grid communities where electricity supply is limited, enabling access to clean drinking water in previously underserved areas (Akinmoladun et al., 2019).

Smart water systems, which involve the use of sensors, data analytics, and automation, have also emerged as important tools in improving water management across the continent. These systems help monitor and optimize water distribution, reduce leakage, and enhance water conservation. Smart meters, for example, are increasingly being deployed in urban areas to monitor water usage patterns and detect leaks in real-time, ensuring more efficient water distribution and reducing water waste (Mogaji et al., 2020). In addition to smart meters, Internet of Things (IoT)-enabled water management systems are being used in agriculture to optimize irrigation practices, ensuring that water is used more efficiently in crop production (Bamigboye et al., 2020).

Case studies from across Africa highlight the success of these technological interventions in addressing water challenges. In Cape Town, South Africa, a smart water system was implemented to monitor and control the city's water supply network, reducing the impact of drought and improving water management during the severe water crisis in 2017 (Adebayo & Balogun, 2020). Similarly, in Egypt, the integration of desalination technology has provided a consistent water supply to communities in the coastal regions, significantly improving water access in the face of increasing water demand and salinity intrusion (Moriarty et al., 2019). In Kenya, innovative water harvesting technologies, including rainwater harvesting systems and water recycling plants, have helped provide water to rural communities, where infrastructure is often inadequate (Ibrahim & Okereke, 2021).

Technological innovations in water management also extend to the agricultural sector, where efficient irrigation systems and water-saving technologies, such as drip irrigation and moisture sensors, are being adopted to increase crop yields while minimizing water usage. This is particularly important in countries like Nigeria, where agriculture is heavily reliant on water resources. These technologies ensure that water is used optimally, enhancing agricultural productivity and supporting food security (Nwagboso et al., 2020). While these technological innovations hold great promise, their widespread adoption across Africa remains hindered by factors such as high initial costs, lack of technical expertise, and insufficient infrastructure. To fully realize the potential of these technologies, it is essential for governments, development partners, and private stakeholders to collaborate on providing financial and technical support, ensuring that these innovations are accessible to communities across the continent. Table 4 shows the Technological Innovations in Water Management.

Table 4: Technological Innovations in Water Management

Technological Innovations in Water Management	Description	References
Desalination	Desalination is the process of converting seawater into potable water, particularly useful in coastal regions facing freshwater scarcity. Solar-powered desalination plants have been implemented as a sustainable solution in areas with limited electricity.	Eze et al., 2021; Akinmoladun et al., 2019
Smart Water Systems	Smart water systems use sensors, data analytics, and automation to monitor and optimize water distribution, detect leaks in real-time, and conserve water. These systems also include IoT-enabled systems for optimizing agricultural irrigation.	Mogaji et al., 2020; Bamigboye et al., 2020
Water Recycling	Water recycling technologies, including rainwater harvesting systems and water recycling plants, have been introduced to address water shortages, particularly in rural areas with inadequate infrastructure.	Ibrahim & Okereke, 2021

Drip Irrigation and Moisture Sensors	In the agricultural sector, drip irrigation and moisture sensors are used to increase crop yields while minimizing water usage, helping to improve water efficiency in countries reliant on agriculture.	Nwagboso et al., 2020
Innovative Water Harvesting	Rainwater harvesting systems have been implemented in regions with limited access to water infrastructure to ensure access to clean drinking water, especially in rural communities.	Ibrahim & Okereke, 2021
Integrated Desalination in Coastal Regions	Desalination technology in Egypt has provided a consistent water supply to coastal communities, addressing water demand and salinity intrusion.	Moriarty et al., 2019
Smart Water System in Cities & Town	Some African Cities like Cape Town implemented a smart water system to monitor and control its water supply network, helping to mitigate the impact of drought and improve water management during the 2017 water crisis.	Adebayo & Balogun, 2020
IoT-enabled Agricultural Water Management	IoT-enabled water management systems are used to optimize irrigation practices in agriculture, ensuring efficient water use in crop production, particularly in water-scarce regions.	Bamigboye et al., 2020

Source: Authors' Illustrations

RESEARCH METHODOLOGY

This study adopts a desk research methodology to provide an integrated overview of water issues in Africa, focusing on governance, sustainability, and technological perspectives. Desk research, also known as secondary research, involves collecting, analyzing, and synthesizing existing data from credible sources. As recommended by Saunders et al. (2019) and Cooper and Schindler (2014), this approach is particularly suited to studies seeking to leverage diverse datasets and literature to address complex, multi-dimensional challenges such as water management in Africa. The methodology is systematic and iterative, following three key phases: data identification, data evaluation, and data synthesis. These steps align with Creswell's (2014) framework for conducting comprehensive literature-based studies. By synthesizing existing knowledge, the study aims to capture a holistic understanding of the governance, sustainability, and technological dimensions of water issues in Africa.

The data for this research will be sourced from three main categories. First, academic literature, including peer-reviewed journal articles, conference proceedings, and books from databases such as Scopus, Web of Science, and Google Scholar, will serve as primary sources. Foundational works from key scholars, including Bryman (2016) and Yin (2018), will provide theoretical underpinnings for governance, sustainability, and technological frameworks. Second, policy and institutional reports from reputable organizations such as the United Nations (e.g., UN-Water), the African Union, the African Development Bank, and the World Bank will offer critical insights into governance and sustainability practices in Africa. Additionally, national water policies and strategic plans from countries such as Nigeria, Ethiopia, Morocco, Egypt, South Africa, and Congo will be reviewed to capture region-specific challenges and strategies. Finally, quantitative data will be drawn from reliable databases, including AFDIB, AQUASTAT (FAO), World Bank Open Data, and the International Water Management Institute (IWMI), to provide metrics on water availability, use, and management. Regional datasets, such as those from the African Development Bank, will support contextual analysis specific to the selected countries.

The data collection process follows an iterative approach. First, key search terms such as "water governance," "sustainable water management," and "water technology in Africa" will guide the search strategy. Boolean

operators will refine searches in academic databases, as suggested by Creswell (2014). Next, sources will be critically appraised for credibility, relevance, and timeliness using evaluation criteria outlined by Flick (2018). Priority will be given to sources published within the last ten years, except for foundational or theoretical works. Finally, relevant information will be synthesized into thematic categories addressing governance, sustainability, and technological perspectives. This systematic organization of complex datasets follows Yin's (2018) recommendations.

The data will be analyzed using thematic and comparative methods. Thematic analysis will identify recurring patterns and gaps in the literature on water issues in Africa. NVivo software will be utilized for coding and organizing qualitative data, as suggested by Maxwell (2013). A comparative analysis of governance and sustainability practices across the selected countries will highlight similarities and differences, ensuring context-specific insights while drawing generalizable conclusions, as recommended by Patton (2015).

The study adheres to ethical guidelines by ensuring proper attribution of all secondary sources and maintaining transparency in data collection and interpretation, as emphasized by Bryman (2016) and Saunders et al. (2019). By employing a desk research methodology, this study integrates insights from diverse and credible sources, addressing critical gaps in the understanding of water governance, sustainability, and technological perspectives in Africa. Leveraging foundational works such as Creswell (2014), Yin (2018), Saunders et al. (2019), and Bryman (2016) ensures robust and actionable outcomes. Figure 1 shows and describe the methodological steps for this study.

Figure 1: Methodological Steps



Source: Authors' Illustrations

The desk research methodology employed in this study follows a systematic, structured approach to address the governance, sustainability, and technological aspects of water issues in Africa. Initially, the research focus was clearly defined by outlining the study's objectives and selecting six focus countries: Nigeria, Ethiopia, Morocco, Egypt, South Africa, and DR Congo. A robust search strategy was developed using relevant keywords like "water governance in Africa," "sustainable water management," and "technological solutions for water challenges,"

with Boolean operators to refine database searches. Secondary data was gathered from credible academic sources, policy documents, and reports from organizations such as UN-Water, the African Union, and the World Bank, complemented by quantitative datasets from platforms like STATISRA, WORLDOMETER, AFDIB, AQUASTAT and the World Bank Open Data.

Data evaluation involved applying critical appraisal criteria to ensure the relevance and credibility of sources, with a focus on recent publications while integrating foundational works for theoretical depth. The data was organized thematically into governance, sustainability, and technology areas. Thematic and comparative analysis was conducted to identify recurring patterns and contextual differences across the selected countries. The findings were synthesized into a cohesive understanding of the issues, while ensuring ethical standards were maintained throughout. Finally, the results were documented in a structured format, contributing actionable insights and recommendations to advance knowledge of water resource management in Africa.

CASE STUDY

The selection of Nigeria, Ethiopia, Congo (DRC), South Africa, Egypt, and Morocco for this case study is based on their geographical location, GDP, infrastructure, and relevance in research works. These countries are strategically located across Africa's five regions—Northern, Western, Eastern, Central, and Southern Africa ensuring a comprehensive representation of the continent's diverse socio-economic and geographical dynamics. Nigeria represents Western Africa as the continent's most populous nation, while Egypt and Morocco showcase Northern Africa's socio-economic vibrancy. South Africa exemplifies advanced infrastructure in Southern Africa, Ethiopia highlights Eastern Africa's emerging economy, and DR Congo reflects the challenges of Central Africa. This geographic diversity allows for a balanced assessment of regional variations in economic performance, infrastructure development, and policy implementation.

Economic significance, as measured by GDP, is another critical selection criterion. Countries like Nigeria, South Africa, and Egypt are among Africa's largest economies, demonstrating diverse industrial bases and strategic global relevance. Morocco and Ethiopia are selected for their growing economies, reflecting progressive developmental policies and investments in critical sectors. Infrastructure development further justifies the inclusion of these nations. While South Africa and Egypt boast advanced infrastructure systems, Nigeria and Ethiopia illustrate the rapid evolution of transport, energy, and urban development, offering insights into overcoming infrastructural deficits. Additionally, research on these countries in areas such as sustainable development, economic growth, and regional integration highlights their importance as case studies. This multifaceted approach ensures that the selected nations provide a rich and nuanced perspective for analyzing population, economic trends, and infrastructure within Africa.

This Section explored the water management issues, challenges and opportunities faced by the six African countries, examining their unique contexts and strategies for addressing water scarcity and stress. By exploring governance frameworks, sustainability efforts, and technological innovations, this section aims to provide a holistic view of the water management landscape across these nations.

Nigeria

Nigeria experiences moderate to high water stress, particularly in the northern regions, due to low rainfall, overextraction, and pollution, exacerbated by rapid urbanization and population growth. Governance is fragmented among federal, state, and local agencies, leading to poor coordination and weak enforcement of water laws and policies. The sustainability of water resources is under threat from overextraction of groundwater and contamination from industrial and agricultural activities, compounded by limited investment in sustainable infrastructure. Technological advancements, such as rainwater harvesting and community-based water monitoring, have shown localized success, but the adoption of large-scale innovations like smart irrigation remains slow. Challenges include climate change, pollution, and insufficient funding, while opportunities lie in strengthening governance, adopting water-saving technologies, and fostering public-private partnerships to address infrastructure deficits.

Ethiopia

Ethiopia faces severe water scarcity, especially in arid and semi-arid regions, as recurrent droughts and reliance on rain-fed agriculture amplify vulnerability. Governance is centralized under the Ministry of Water, Irrigation, and Energy but struggles with limited capacity and resources. Transboundary disputes over the Nile River add complexity to water governance. Sustainability is strained by seasonal variability, overreliance on the Nile, and poor watershed management practices, such as deforestation that accelerates soil erosion. While low-cost technologies like solar-powered pumps and community-managed schemes have been implemented, resource limitations impede widespread adoption of advanced water management innovations. Key challenges include droughts, insufficient infrastructure, and regional conflicts, but opportunities exist in enhancing community-based management programs and fostering regional cooperation through initiatives like the Nile Basin Initiative.

Democratic Republic of Congo (DR Congo)

Despite abundant water resources, the Democratic Republic of Congo struggles with limited access due to infrastructure deficits and weak governance. Urban areas experience localized water stress as rapid population growth outpaces infrastructure development. Governance is undermined by corruption and a lack of institutional capacity to implement and enforce water policies effectively. Sustainability is threatened by poor waste management, mining activities that contaminate water sources, and deforestation in the Congo Basin, which disrupts the hydrological cycle. Technological innovations in water management are limited, with international aid supporting small-scale projects like boreholes and water purification systems. Challenges include weak governance, pollution, and inadequate infrastructure, while opportunities lie in leveraging the country's vast water resources through regional initiatives and increased investment in water infrastructure.

Morocco

Morocco experiences high water stress due to arid conditions, declining rainfall, and overextraction, with agricultural demands accounting for over 80% of water usage. Governance is relatively robust, with strategies like the National Water Strategy aimed at improving water management; however, decentralized governance faces challenges in agency coordination. Sustainability is hindered by aquifer overuse, pollution from agricultural runoff, and inadequate water-saving measures, though the country is making strides through investments in desalination and wastewater reuse. Morocco has embraced technological innovations such as drip irrigation, advanced water monitoring systems, and renewable energy-powered desalination plants. Despite challenges like climate change, pollution, and increasing water demands, opportunities exist in scaling up renewable energy projects for water management and enhancing public-private partnerships to address water scarcity sustainably.

Egypt

Egypt is heavily reliant on the Nile River, making it highly vulnerable to upstream developments, climate change, and increasing water demands from agriculture and urbanization. Governance is centralized, with a focus on controlling Nile water resources, but transboundary disputes, particularly with Ethiopia over the GERD, complicate management. Sustainability is undermined by inefficient irrigation practices, water salinization, and pollution, but efforts to improve water-use efficiency and promote recycling are underway. Egypt is investing in technological advancements, such as modern irrigation systems, wastewater treatment facilities, and digital water distribution monitoring. Key challenges include transboundary water conflicts, inefficient water use, and rising sea levels, while opportunities lie in advancing regional cooperation within the Nile Basin and expanding the adoption of water-saving technologies to ensure long-term resource sustainability.

South Africa

South Africa faces severe water stress due to overextraction, pollution, and climate variability, with urban centers like Cape Town experiencing "Day Zero" scenarios. While the country has progressive water laws prioritizing equitable access, implementation is hampered by maintenance challenges, aging infrastructure, and funding gaps. Sustainability is further hindered by pollution, non-revenue water losses, and outdated infrastructure,

though integrated water resource management is being promoted. The country is adopting technological innovations such as water reuse, desalination, and smart water meters, alongside public awareness campaigns to encourage conservation. Challenges include aging infrastructure, inequitable access, and recurrent droughts, but opportunities exist in expanding water reuse programs, fostering private sector involvement, and leveraging renewable energy for sustainable water management solutions.

Comparative Summary of Water Resource Management in the Six Selected Countries in Africa

This section offers a comparative analysis of water resource management in the six selected African countries, highlighting the distinct challenges and strategies each country faces in managing its water resources. This analysis aims to identify common themes, differences, and potential lessons that can inform more effective water management policies and practices across the region. Table 5 shows the Comparative Summary and Description of Water Resource Management in the Six Selected African Countries.

Table 5: Comparative Summary and Description of Water Resource Management in the Six Selected African Countries

Case Study by Country	Water Scarcity and Stress	Governance of Water Resources	Sustainability of Water Resources	Technological Innovations in Water Management	Challenges	Opportunities
Nigeria	Moderate to high stress, especially in northern regions.	Fragmented governance among federal, state, and local agencies, leading to poor coordination and enforcement of water laws.	Threatened by overextraction, pollution, and lack of sustainable infrastructure investments.	Rainwater harvesting, community-based monitoring; slow adoption of smart irrigation.	Climate change, pollution, insufficient funding, and weak infrastructure.	Strengthening governance, adopting water-saving technologies, fostering public-private partnerships.
Ethiopia	Severe scarcity in arid regions due to droughts and reliance on rain-fed agriculture.	Centralized governance under the Ministry of Water, Irrigation, and Energy; limited capacity and regional transboundary disputes over Nile resources.	Seasonal variability, overreliance on Nile waters, deforestation, and poor watershed management threaten sustainability.	Solar-powered pumps, community-managed schemes; resource limitations hinder broader adoption.	Droughts, insufficient infrastructure, regional conflicts over water resources.	Enhancing community-based management, fostering regional cooperation through initiatives like the Nile Basin Initiative.
DR Congo	Abundant water resources, but limited access due to infrastructure deficits.	Weak governance, corruption, and lack of institutional capacity to enforce water policies.	Threatened by pollution from mining, poor waste management, and deforestation affecting hydrological cycles.	Limited to small-scale international aid projects like boreholes and water purification systems.	Corruption, pollution, inadequate infrastructure, and weak governance.	Leveraging vast water resources through regional initiatives and investments in infrastructure.

Morocco	High stress due to arid conditions, declining rainfall, and overextraction.	Relatively robust governance under the National Water Strategy; coordination challenges in decentralized systems.	Threatened by aquifer overuse, agricultural runoff pollution, and inadequate water-saving measures.	Advanced irrigation systems, desalination, wastewater reuse, and renewable energy projects.	Climate change, pollution, increasing water demands.	Scaling up renewable energy projects, enhancing public-private partnerships.
Egypt	High stress due to reliance on the Nile River and increasing demands from agriculture and urbanization.	Centralized governance; transboundary disputes, especially over GERD with Ethiopia.	Inefficient irrigation, salinization, and pollution pose sustainability challenges, though recycling efforts are underway.	Modern irrigation, wastewater treatment, and digital water distribution monitoring.	Transboundary water conflicts, inefficient water use, and rising sea levels.	Advancing Nile Basin cooperation, expanding water-saving technologies.
South Africa	Severe stress due to overextraction, pollution, and climate variability; urban areas experience "Day Zero" scenarios.	Progressive water laws; implementation hampered by aging infrastructure, maintenance challenges, and funding gaps.	Non-revenue water losses, pollution, and outdated infrastructure hinder sustainability, though integrated water management is promoted.	Desalination, water reuse, smart water meters, and public awareness campaigns.	Aging infrastructure, inequitable access, recurrent droughts.	Expanding water reuse programs, leveraging renewable energy, fostering private sector involvement.

Source: Authors' Illustrations of the comparative summary

ANALYSES AND DISCUSSIONS

This section provides a comprehensive analysis and discussion of the key findings from the study, focusing on the critical aspects, issues and factors influencing water management in the selected African countries. It also synthesizes the data, highlights the main challenges, and explores opportunities for improving water governance, sustainability, and technological innovations in the region.

The table highlights the pervasive water challenges faced by various regions of Africa, with key issues such as water scarcity, access to safe drinking water, sanitation, and climate change impacts being common across all areas. East, West, and Central Africa experience water scarcity due to factors like population growth, uneven rainfall distribution, and deforestation. Meanwhile, North Africa struggles with its naturally arid climate, and Southern Africa faces recurring droughts. These environmental pressures are compounded by rapid population growth, which increases demand for already limited resources, further exacerbating the crisis. The lack of proper sanitation and poor water quality are universal issues across the continent, leading to significant health risks, including waterborne diseases. Inadequate infrastructure prevents effective water management, contributing to these problems.

Additionally, the impact of climate change is felt throughout Africa, with increased occurrences of floods and droughts disrupting water access and agricultural production. Urbanization also places pressure on water resources, especially in growing cities, where demand outstrips supply and infrastructure struggles to keep pace with population increases. Transboundary water management and conflicts over water resources are further complicating the situation. Shared rivers and lakes often lead to tensions between neighboring countries, making effective management and equitable distribution of resources a challenge. Inadequate infrastructure and a lack of cooperation between nations hinder the development of sustainable water solutions. To address these multifaceted challenges, Africa needs to prioritize infrastructure development, climate adaptation, and collaborative water management practices that account for both environmental and population pressures.

The key issues in the governance of water resources across Africa, highlighting the systemic problems and their implications for sustainable water management. A central issue is the fragmented institutional frameworks across different levels of government, such as the federal, state, and local levels, which complicates decision-making and policy implementation. This fragmentation leads to inefficiencies in managing urban water supply projects, particularly in cities like Cairo, Addis Ababa, Lagos and Abuja, where rapid population growth intensifies water demand. The lack of coordination among various sectors further exacerbates these challenges, as the roles and responsibilities of different actors often overlap, hindering effective water governance. The solution to these issues lies in decentralization, allowing for more responsive, localized management of water resources.

The absence of clear and enforceable policies around water rights, extraction, and pollution is another critical issue. In many African countries, weak legal frameworks enable unregulated water extraction, exacerbating water scarcity and compromising the sustainability of water resources. Moreover, poor governance structures, including corruption, undermine the effectiveness of water management systems. In many countries, officials responsible for water distribution engage in corrupt practices, diverting resources for personal gain and resulting in inadequate infrastructure development or maintenance. Without robust oversight and accountability mechanisms, these issues are likely to persist, leading to inefficient water management, neglected infrastructure, and eroded public trust.

To address these governance challenges, adopting inclusive, transparent, and accountable governance structures is crucial. Involving local communities in decision-making through participatory water management models can help mitigate corruption and improve water resource management. Decentralization, as recommended by Bassey et al. (2020), is a key strategy for enabling more context-specific solutions to water challenges, particularly in rapidly growing urban areas. By allowing local authorities to take charge of water management, governance becomes more responsive to local needs, thereby improving the effectiveness of water supply systems and policies (Olawale et al., 2021). These reforms, however, require adequate resources, technical expertise, and political will to implement effectively, making institutional capacity building a key priority for improving water governance across Africa.

The table outlines the critical issues and strategies for the sustainability of water resources in Africa, emphasizing the multifaceted approach needed to address water scarcity and ensure long-term water security. One key aspect is environmental sustainability, which involves strategies such as ecosystem protection, including the restoration of wetlands and watersheds, to regulate flood patterns and maintain groundwater levels. Protecting these ecosystems not only helps to preserve water quality but also enhances resilience to the impacts of climate change. Furthermore, adapting to the changing climate is crucial, with strategies like drought-resistant crops, efficient irrigation systems, and water-efficient technologies contributing to the resilience of both agricultural and urban water systems. By

integrating these practices into governance frameworks, African nations can promote sustainable water management while addressing the growing demand for water due to population growth and industrial development.

In addition to ecosystem-based solutions, the table highlights the importance of water conservation practices and the integration of renewable energy in water management systems. Efficient water use, recycling, and rainwater harvesting help alleviate pressure on existing water supplies and reduce the environmental impacts of over-

extraction. Furthermore, the regional disparities in water availability across Africa call for cooperative management of shared water bodies, such as the Nile Basin Initiative, to ensure equitable distribution and avoid conflicts. Lastly, incorporating renewable energy solutions, such as solar-powered pumping systems and desalination plants, is a promising step toward reducing the environmental footprint of water provision, especially in regions facing energy shortages. These strategies together provide a comprehensive approach to ensuring that Africa's water resources are managed sustainably, both in the short and long term.

Technological innovations in water management are playing a critical role in addressing water scarcity and improving water access in Africa. Desalination, particularly solar-powered desalination, has emerged as a viable solution in coastal regions facing freshwater shortages. Countries such as South Africa, Egypt, and Algeria have adopted desalination technologies to supplement their water supplies, especially in areas with limited freshwater resources. Solar desalination, in particular, is viewed as a sustainable approach because it reduces reliance on fossil fuels, which aligns with Africa's increasing demand for eco-friendly solutions. The widespread adoption of such technologies is still constrained by the high initial costs and infrastructure limitations, making it essential for greater investment and support from governments and international stakeholders.

Smart water systems, which include sensors, data analytics, and IoT-enabled platforms, are another key innovation improving water management in Africa. These systems monitor water distribution in real-time, helping to reduce leakage, optimize consumption, and ensure efficient water management. In urban areas, smart meters have been deployed to track water usage patterns and identify leaks immediately, enhancing water conservation efforts. Additionally, IoT-enabled water management systems are being integrated into agricultural irrigation systems to ensure efficient use of water, which is particularly important in water-scarce regions like sub-Saharan Africa, where agriculture is heavily dependent on water resources. The ability to monitor and optimize water usage in agriculture is crucial for improving food security and sustainable farming practices, particularly in countries such as Nigeria.

While these technological innovations present promising solutions, their adoption faces significant challenges. High initial costs, technical expertise shortages, and insufficient infrastructure remain major barriers to their widespread implementation. Governments, development partners, and private stakeholders must collaborate to provide financial support and build local technical capacity to scale these solutions across the continent. However, as evidenced by case studies from cities like Cape Town, where smart water systems have mitigated the impacts of drought, and rural communities in Kenya, where rainwater harvesting systems have provided critical water access, these technologies have the potential to significantly improve water security. To maximize the effectiveness of these innovations, African nations must focus on policy reforms, infrastructure development, and capacity building to ensure that technological advancements are accessible and sustainable.

The comparative analysis of water management across the six selected African countries Nigeria, Ethiopia, DR Congo, Morocco, Egypt, and South Africa, reveals significant regional variations in the governance, sustainability, and technological management of water resources. Each country faces unique challenges linked to water scarcity, the management of water resources, and infrastructure, driven by both natural and socio-economic factors. For instance, countries like Morocco and Egypt, which are geographically arid, have implemented sophisticated water management strategies, including extensive irrigation systems and desalination plants. In contrast, countries like Nigeria and DR Congo, with abundant water resources, struggle with poor governance, inadequate infrastructure, and political instability, which hinder the effective management of water resources.

Water scarcity and stress are prevalent issues across many of the countries analyzed, though the causes and severity differ. Morocco, Egypt, and South Africa experience significant water scarcity, compounded by high population growth and climate change, which intensifies water stress. In Morocco and Egypt, the adoption of water-efficient technologies, such as drip irrigation and wastewater recycling, is critical to overcoming scarcity. On the other hand, nations like DR Congo and Nigeria, despite their abundant water resources, suffer from a mismanagement of these resources, where inefficiencies in infrastructure and governance exacerbate the problem. The disparity between water abundance and scarcity management highlights the importance of not only the availability of water but also the effectiveness of water governance frameworks.

The governance of water resources across these countries exhibits notable contrasts in terms of institutional capacity, policy frameworks, and enforcement. While Morocco and Egypt have established robust water management systems with clear regulations and centralized control, other countries such as Nigeria and DR Congo face challenges related to weak institutions, corruption, and inconsistent policy enforcement. This disparity in governance structures directly impacts the sustainability of water resources. Effective governance is crucial in ensuring equitable distribution, proper infrastructure maintenance, and safeguarding against water-related conflicts, particularly in regions with uneven access to water resources. A lack of effective governance has led to inefficiencies and inequities in water distribution, hindering economic and social development in some countries.

Technological innovations in water management are also a critical factor in addressing water challenges. South Africa and Morocco stand out as leaders in utilizing cutting-edge technology, including wastewater recycling, water-saving irrigation, and desalination. These innovations are essential in mitigating water scarcity in urban areas and improving agricultural productivity in water-scarce regions. However, while these countries are taking steps toward technological advancement, other nations like DR Congo and Nigeria still struggle with outdated infrastructure and limited access to modern technologies. The adoption of appropriate technological solutions could provide significant opportunities for improving water use efficiency and sustaining water resources in these countries, but this requires both political will and financial investment.

Several key lessons emerge from the comparative analysis of these countries which is multifold: First, the importance of governance cannot be overstated, as it directly influences the sustainability and equitable distribution of water resources. Effective management relies on robust institutions, transparent policies, and active public participation. Secondly, technological innovation plays a critical role in mitigating water scarcity, especially in arid regions, but requires a strong institutional framework to ensure successful implementation. Third, there is a need for integrated water management approaches that account for both demand and supply-side solutions, including conservation, efficiency measures, and sustainable infrastructure. Finally, the experiences of countries like Morocco and Egypt demonstrate that proactive planning and long-term investments in water infrastructure, coupled with political stability, are key to successfully managing water resources in the face of growing population pressures and climate change.

CONCLUSIONS AND RECOMMENDATIONS

The literature review, analysis, and case studies reveal several key insights into the challenges and opportunities surrounding water management in Africa. Water scarcity and stress remain significant concerns across the continent, with countries such as Egypt, Morocco, and South Africa facing critical shortages due to climate change, population growth, and inefficient water usage. While governance frameworks in these countries vary, it is clear that weak institutional structures, inadequate policy implementation, and fragmented management systems have hindered progress in addressing water issues. In contrast, countries like Ethiopia and Nigeria have made notable strides by embracing decentralized water management models and increased community involvement in decision-making.

Technological innovations, such as water conservation technologies and the use of satellite data for water resource monitoring, have shown promise in improving efficiency and monitoring in countries like South Africa and Morocco. However, these innovations remain underutilized in many regions, primarily due to lack of investment and technical expertise. Sustainability of water resources has also emerged as a common concern, as current practices often fail to incorporate long-term strategies for maintaining water availability.

From the case study analysis, it is evident that countries like South Africa and Morocco have incorporated integrated water resource management (IWRM) strategies, which emphasize collaboration between various stakeholders, including government bodies, local communities, and private sector players. However, these initiatives have encountered obstacles such as inadequate funding, lack of political will, and social inequities. Meanwhile, nations like the Democratic Republic of Congo and Nigeria face immense challenges due to political instability, resource mismanagement, and lack of infrastructure, which hinders effective water distribution and access to safe water. Despite these challenges, these countries present opportunities for intervention through improved governance and the adoption of more resilient water management frameworks.

This study critically evaluates water resource management across six African countries, shedding light on the multifaceted challenges and opportunities in managing water resources. While countries like Egypt and Morocco have made notable advances in water management through technology and robust policy frameworks, others like Nigeria and DR Congo still grapple with severe water scarcity, governance inefficiencies, and infrastructure challenges. The findings suggest that addressing water scarcity in Africa requires a well-coordinated approach, including improved governance, advanced technologies, and regional cooperation for effective water management.

In conclusion, this study highlights the urgent need for Africa to adopt integrated, sustainable water management practices to cope with the growing pressures of water scarcity, climate change, and population growth. The critical role of both governmental and non-governmental organizations in strengthening water management infrastructure, enforcing policies, and investing in technological innovations is clear. Future efforts should prioritize cross-border water governance, the implementation of water-saving technologies, and the enhancement of policies to ensure long-term water security and sustainability in Africa.

This study presents several key contributions to the field of water resource management in Africa, offering new insights into governance, technological innovations, and sustainable practices across six selected countries.

- (1). The study provides a comparative analysis of water management across six African countries, highlighting country-specific governance, technological innovations, and sustainability practices. It offers valuable insights into the effectiveness of various strategies in addressing water scarcity and stress across the continent.
- (2). The research explores the role of emerging technologies such as AI, remote sensing, and IoT in enhancing water management, especially in countries like South Africa and Morocco. It emphasizes how technology can improve water resource efficiency and sustainability across Africa.
- (3). The study underscores the importance of decentralized water management models, particularly in Ethiopia and Nigeria, where local communities play a key role. It highlights the benefits of community involvement in improving water governance and resource sustainability.
- (4). The study provides actionable recommendations for improving water governance in Africa, including strengthening institutions, promoting regional collaborations, adopting efficient technologies, and revising water pricing systems to ensure sustainability and equity.
- (5). The study suggests future research areas focused on integrating new technologies, exploring decentralized governance models, and developing sustainability models, offering a roadmap for advancing water management practices in Africa.

To improve water management across Africa, governments, NGOs, and international organizations must adopt a multifaceted approach. This will entail a combined focus on the operationalization of the integrated framework, as its practical implementation is constrained by significant challenges, including a lack of cross-sectoral collaboration, insufficient long-term funding, and a deficit in local technical capacity. To address these limitations, there is a need to examine how to embed capacity-building initiatives and foster genuine community involvement from the outset. Additionally, stakeholders should stress the development of transparent and accountable governance models and evaluate diversified financial strategies that blend public, private, and donor funding. Ultimately, there is a need to study, examine, and learn from scalable pilot projects initiated in stable regions that utilize locally maintainable technology to provide empirical evidence of the framework's viability and to demonstrate its enduring benefits.

Strengthening the institutional frameworks is crucial for ensuring effective governance of water resources. This can be achieved by establishing clear roles and responsibilities, promoting transparency, and ensuring that water management policies are adequately implemented at both national and local levels. Decentralized governance models, where local communities are actively involved in water management decisions, should be scaled up, particularly in rural and underserved areas. Additionally, there should be a concerted effort to address the

political and economic factors that exacerbate water scarcity, such as corruption and the prioritization of short-term gains over long-term sustainability.

Another key recommendation is the investment in technological innovations that can enhance water use efficiency and monitoring. Governments should work with the private sector to integrate new technologies such as remote sensing, artificial intelligence, and data analytics to improve water management strategies and predict future water stress. Furthermore, water conservation technologies, such as efficient irrigation systems, rainwater harvesting, and wastewater treatment, should be prioritized and incentivized. International organizations and NGOs can play a role by providing technical expertise, facilitating knowledge exchange, and promoting the adoption of best practices. Additionally, creating cross-border collaborations to address transboundary water issues in countries like Egypt, Ethiopia, and the DR Congo will ensure that regional challenges are addressed collectively. In addition, water pricing policies should be re-examined to reflect the true cost of water. A tiered pricing system that discourages overuse while ensuring access to the poorest communities could help address inefficiencies in water distribution. Governments must also consider the economic, social, and environmental implications of water policies, making sure that the needs of vulnerable populations are prioritized in decision-making processes.

Future research should focus on other several key areas to improve water management in Africa. One critical area is the integration of new and emerging technologies in water management. Research could explore how artificial intelligence, machine learning, and Internet of Things (IoT) technologies can be used to enhance water monitoring, forecasting, and distribution. Further studies are needed to investigate how these technologies can be adapted to local conditions and integrated into existing water management systems in Africa. Additionally, the potential for mobile applications in improving water access and management, particularly in remote and underserved areas, should be explored.

Another key area for future research is the governance of water resources, especially in contexts marked by political instability, corruption, and weak institutions. Comparative studies that examine the impact of decentralized versus centralized water management systems could offer valuable insights into the effectiveness of different governance models across African countries. Research on stakeholder engagement and community-based water management initiatives would also provide insights into how local participation can improve water access and sustainability.

Finally, sustainable water management practices should remain a central focus of future research. Researchers should investigate how integrated water resource management (IWRM) can be scaled across the continent, addressing challenges related to land use, water conservation, and climate change adaptation. Long-term sustainability models that incorporate environmental, social, and economic considerations must be developed and tested across different African contexts to ensure water security for future generations.

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APPENDIX

African Countries by population (2025)

Click on each country to view current estimates (live population clock), historical data, list of countries, and projected figures.

Search:

#	Country (or dependency)	Population (2024)	Yearly Change	Net Change	Density (P/Km ²)	Land Area (Km ²)	Migrants (net)	Fert. Rate	Med. Age	Urban Pop %	World Share
1	Nigeria	232,679,478	2.10 %	4,796,533	255	910,770	-35,202	4.4	18	54 %	2.85 %
2	Ethiopia	132,059,767	2.62 %	3,368,075	132	1,000,000	30,069	3.9	19	22 %	1.62 %
3	Egypt	116,538,258	1.75 %	2,002,486	117	995,450	123,884	2.7	24	41 %	1.43 %
4	DR Congo	109,276,265	3.30 %	3,486,534	48	2,267,050	-26,968	6.0	16	44 %	1.34 %
5	Tanzania	68,560,157	2.92 %	1,942,551	77	885,800	-29,865	4.5	17	39 %	0.84 %
6	South Africa	64,007,187	1.26 %	794,803	53	1,213,090	166,972	2.2	28	66 %	0.78 %
7	Kenya	56,432,944	1.98 %	1,093,941	99	569,140	-19,781	3.2	20	31 %	0.69 %
8	Sudan	50,448,963	0.81 %	406,172	29	1,765,048	-544,257	4.3	18	35 %	0.62 %
9	Uganda	50,015,092	2.79 %	1,358,491	250	199,810	-117,924	4.2	17	29 %	0.61 %
10	Algeria	46,814,308	1.41 %	650,089	20	2,381,740	-31,240	2.7	28	74 %	0.57 %
11	Morocco	38,081,173	0.98 %	368,668	85	446,300	-46,802	2.2	30	67 %	0.47 %
12	Angola	37,885,849	3.09 %	1,135,943	30	1,246,700	-2,629	5.0	17	68 %	0.46 %
13	Mozambique	34,631,766	2.96 %	996,606	44	786,380	-38,940	4.7	16	41 %	0.42 %
14	Ghana	34,427,414	1.89 %	639,500	151	227,540	-13,114	3.3	21	58 %	0.42 %
15	Madagascar	31,964,956	2.47 %	769,024	55	581,795	-1,795	3.9	19	40 %	0.39 %
16	Côte d'Ivoire	31,934,230	2.47 %	768,576	100	318,000	7,838	4.2	18	49 %	0.39 %
17	Cameroon	29,123,744	2.65 %	751,057	62	472,710	-13,892	4.3	18	59 %	0.36 %
18	Niger	27,032,412	3.34 %	872,545	21	1,266,700	-4,041	5.9	15	18 %	0.33 %
19	Mali	24,478,595	2.98 %	709,468	20	1,220,190	-46,880	5.5	16	44 %	0.30 %
20	Burkina Faso	23,548,781	2.27 %	523,005	86	273,600	-25,807	4.1	17	33 %	0.29 %

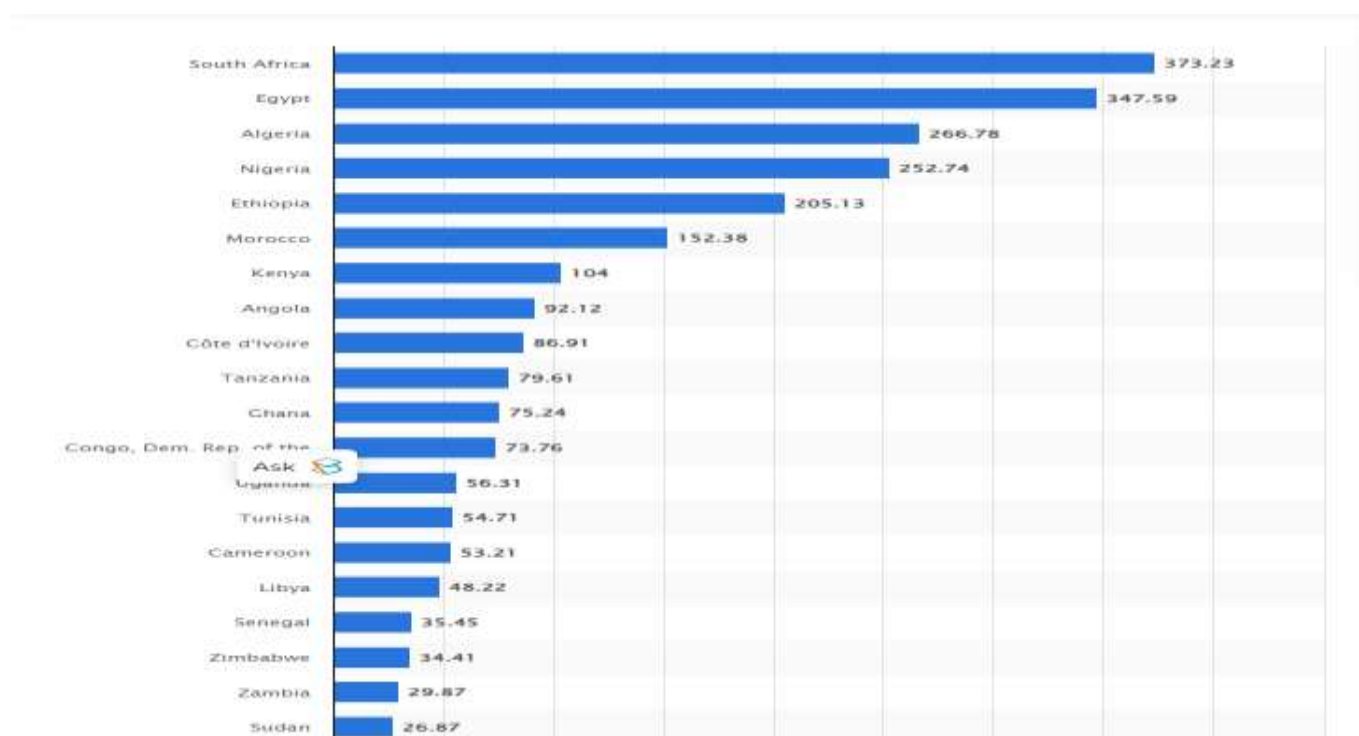
Source: Worldometer at <https://www.worldometers.info/population/countries-in-africa-by-population/>
Accessed 3rd January 2025

African countries with the highest Gross Domestic Product (GDP) in 2023-24(in billion U.S. dollars)

TRADING ECONOMICS				
Calendar News Markets Indicators				
GDP Africa				
World Europe America Asia Africa Australia G20 Export				
Country	Last	Previous	Reference	Unit
Egypt	396	477	Dec/23	USD Billion
South Africa	378	405	Dec/23	USD Billion
Nigeria	363	473	Dec/23	USD Billion
Algeria	240	226	Dec/23	USD Billion
Ethiopia	164	127	Dec/23	USD Billion
Morocco	141	131	Dec/23	USD Billion
Sudan	109	51.67	Dec/23	USD Billion
Kenya	107	113	Dec/23	USD Billion
Angola	84.72	104	Dec/23	USD Billion
Tanzania	79.16	75.77	Dec/23	USD Billion
Ivory Coast	78.79	70.17	Dec/23	USD Billion
Ghana	76.37	74.26	Dec/23	USD Billion
Congo	66.38	65.8	Dec/23	USD Billion

Source: Trading Economics at <https://tradingeconomics.com/country-list/gdp?continent=africa> Accessed 3rd January 2025

African countries with the highest Gross Domestic Product (GDP) in 2024(in billion U.S. dollars)



Source: <https://www.statista.com/statistics/1120999/gdp-of-african-countries-by-country/> Accessed 3rd January 2025

Map Of Africa



Map of Africa from <https://www.worldatlas.com/webimage/countrys/af.htm>. Accessed 3rd January 2025