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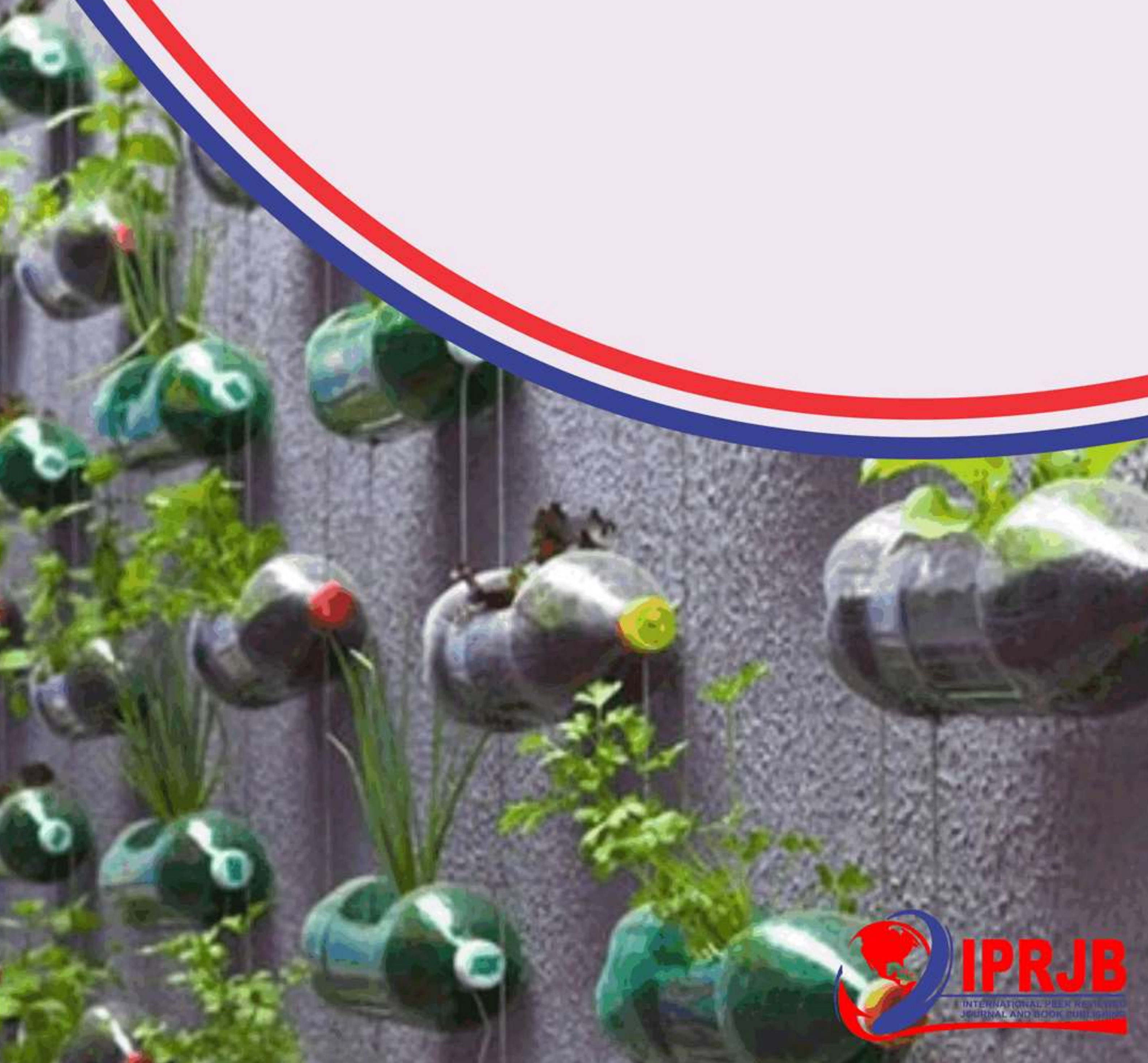

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On-Site Water Reuse Systems: A Sustainable Approach for Urban Water Management in Nigeria

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Abstract

Purpose: This study examines the potential of on-site water reuse (OSWR) systems as sustainable solutions to Nigeria's growing urban water challenges, assessing technological, socio-cultural, economic, and regulatory dimensions to determine their role in improving resilience and equity.

Methodology: A Systematic Literature Review (SLR) was conducted using Scopus, Web of Science, and Google Scholar databases, covering studies from 2015 to 2025. From over 400 initially identified publications, 100 were retained after applying the inclusion criteria. Thematic analysis was employed to evaluate the technological options, financial models, socio-cultural perceptions, and governance structures that influence OSWR adoption.

Findings: Evidence suggests that low-cost technologies, such as biosand and ceramic filtration, ultraviolet disinfection, and modular greywater systems, are technically feasible and locally adaptable. Economic assessments highlight long-term cost savings; however, the upfront capital intensity requires innovative financing mechanisms. Socio-cultural barriers—including mistrust, hygiene concerns, and low awareness—remain significant, while regulatory frameworks are fragmented and lack explicit guidelines for decentralized reuse. Case studies in Lagos and Abuja confirm feasibility but reveal gaps in policy enforcement and sustained investment.

Unique Contribution to Theory, Practice and Policy: OSWR systems are a viable pathway to strengthen urban water security, reduce reliance on centralized supply, and enhance resilience in Nigeria. Success requires governance reforms, participatory community engagement, targeted subsidies, and innovative financing (e.g., climate funds, PPPs). Embedding OSWR into national policy and urban planning frameworks is essential for long-term sustainability.

Keywords: *Water Reuse, Urban Infrastructure, Environmental Policy, Public–Private Partnerships, Sustainable Development*

JEL Codes: *Q25, H54, Q58, H42, O13*

INTRODUCTION

The provision of clean and potable water stands not merely as an essential service to humanity; it represents a fundamental, multifaceted challenge that significantly influences not only the efficient functioning but also the sustainable development of human society worldwide today (Howard et al., 2020). In light of ongoing economic advancements, the rapid pace of technological progress, and significant population expansion, the supply of clean and potable water is being placed under increasing pressure, particularly in the context of swiftly urbanizing areas found in many developing countries around the world (Beker & Kansal). Conventional sources of clean and potable water, which primarily encompass vital resources such as groundwater aquifers and surface water bodies, are becoming progressively depleted due to rampant overexploitation and widespread contamination resulting from various industrial, agricultural, and domestic activities (Mishra, 2023). Moreover, the ongoing scenario is likely to deteriorate even further due to the adverse impacts of climate change, which adds another intricate layer of complexity to an already critical and urgent issue that societies face (Don et al., 2024).

Climate change has led to an alarming increase in the frequency and heightened severity of extreme weather events, such as torrential floods and prolonged drought conditions, which have disastrous impacts on socio-economic activities, natural ecosystems, and the broader environment as a whole (Van et al.2023). These pressing challenges have evolved into a serious global concern, currently affecting approximately 3 billion people worldwide, making this matter one of utmost urgency and critical importance (Shemer et al., 2023). The World Economic Forum identified water crises as the second most significant global risk in its 2015 analysis, underscoring the pressing need to address this critical issue effectively and promptly (Wu et al., 2023).In numerous developing countries, water crises continue to be grossly underestimated, despite the alarming reality that these challenges present and their profound implications for the environment, food security, public health, and the overall quality of life for individuals residing in those affected regions (Uttah et al.). Effectively addressing these interconnected issues is crucial for ensuring a sustainable future where equitable access to clean, safe, and uncontaminated water becomes a realistic and attainable reality for all individuals, transcending the boundaries of privilege and geography. (Naroth, 2016)

METHODOLOGY

This study utilized a Systematic Literature Review (SLR) methodology to comprehensively examine on-site water reuse systems and their potential to address urban water challenges in Nigeria. The SLR approach provided a structured and unbiased synthesis of high-quality, peer-reviewed research, ensuring a thorough analysis of existing knowledge. The research process began with clearly defined objectives and a carefully developed search strategy, followed by the application of strict inclusion and exclusion criteria to identify relevant studies. The primary aim was to explore the role of decentralized water reuse systems in mitigating Nigeria’s urban water issues by investigating technological innovations, socio-cultural barriers, economic feasibility, and regulatory frameworks.

To gather pertinent literature, a systematic search was conducted across three major academic databases—Scopus, Web of Science, and Google Scholar—selected for their extensive coverage of peer-reviewed studies. The search employed targeted keywords, including "water reuse," "Nigeria," "decentralized systems," "greywater," and "urban water management," which initially yielded over 400 articles. These were then rigorously screened for relevance, quality, and alignment with the research focus. Inclusion criteria limited the selection to peer-reviewed articles published between 2015 and 2025 that addressed water reuse technologies, socio-cultural challenges, regulatory policies, or economic evaluations. Empirical studies, case reports, and theoretical analyses related to on-site water reuse systems were prioritized, while non-peer-reviewed works, studies outside the scope of water reuse, and publications preceding 2015 were excluded. After removing duplicates and irrelevant records, 108 articles remained for detailed examination. The selected studies underwent thematic analysis to identify key patterns and insights. This analysis highlighted significant technological advancements in water reuse systems, including innovations such as ceramic filtration, biosand filtration, and ultraviolet purification, which were evaluated for their efficiency, cost-effectiveness, and suitability within Nigerian contexts. Additionally, socio-cultural factors emerged as critical barriers to adoption, with research revealing concerns related to hygiene, religious beliefs, and general lack of public awareness that impede acceptance of water reuse practices. Economic assessments in the literature have focused on cost-benefit analyses, funding mechanisms, and the financial sustainability of decentralized water reuse, underscoring its potential to offer cost savings and enhance resilience against drought and water scarcity. Finally, the review emphasized the importance of robust regulatory frameworks, drawing attention to the necessity for policy development aligned with international standards to support the successful implementation and governance of water reuse initiatives in Nigeria.

Ethical Consideration

As a systematic literature review, this study utilized existing peer-reviewed publications, adhering to the standards of academic integrity. Proper citation practices were maintained, and all sourced data were synthesized without misrepresentation. No primary human subjects were involved, eliminating needs for participant consent or confidentiality measures.

Limitation

The study's reliance on peer-reviewed literature may introduce selection bias, overlook local grey literature, and limit the generalizability of its findings beyond Nigeria. Temporal constraints (2015-2025 data) and database restrictions (Scopus/Web of Science) could exclude emerging innovations or regional nuances.

Urban Water Challenges in Nigeria

Nigeria is currently facing a complex array of critical water challenges, driven by rapid population growth and rising urbanization rates (Irene et al., 2025). These factors have led to significant water scarcity and stress nationwide, which has been exacerbated by inadequate regulatory and governance frameworks essential for managing vital water resources (Shemer et al., 2023). The situation is further compounded by an underdeveloped infrastructure that fails to meet the urgent demands of a growing population (Morante-Carballo et al., 2022). Low investment levels in the water sector deepen this problem, perpetuating a cycle of scarcity and limited access to safe, clean water. This combination of shortcomings creates a dire predicament for citizens who rely on consistent water access for their health and well-being (Shemer et al., 2023). Additionally, widespread pollution from diverse sources and improper wastewater management practices exacerbate the water crisis (du, 2023). These interconnected problems threaten community health and safety, highlighting the urgent need for comprehensive, coordinated actions that address both the symptoms and root causes of the crisis (Musie & Gonfa, 2023). The continuous exploitation of water resources jeopardizes both economic growth and long-term community development across Nigeria. Failure to address these issues risks perpetuating cycles of poverty and health crises for future generations (Ingrao et al., 2023). Progress was made in 2018 when Nigeria published its National Water Resources Bill, establishing a strategic framework and minimum requirements for adequate water supply and sanitation services nationwide (Egbueri et al., 2024). The Bill emphasizes access to clean water as an inherent right, not a commodity (Wilson et al., 2021). It mandates that federal and state water agencies provide unwavering support and resources for implementation and enforcement (Hastie et al., 2022). Such support is crucial for the national water regulatory body to function efficiently and deliver timely water services across the country.

Nigeria's water resources and sanitation policies are strategically designed to promote sustainable development and optimal resource management. These policies prioritize protecting water resources from pollution caused by industrial and residential activities, emphasizing the urgent need to combat unsustainable water abstraction and usage (Ibeme et al., 2023; Ukpai, 2022). Effective enforcement of these policies and related legislation is expected to significantly improve water accessibility, thereby transforming the national water landscape. Implementing these measures will enable efficient planning, allocation, and sustainable management of water resources with consideration for future generations (Olujobi et al., 2024; Amaefule et al., 2023). Ultimately, this comprehensive approach could enhance equity and sustainability across Nigeria's urban centers, towns, and cities, ensuring a more equitable distribution of water and improving citizens' quality of life nationwide (Adewoyin et al., 2025; Unegbua et al., 2024; Okonkwo et al., 2025). If executed consistently and properly, these initiatives are vital for Nigeria's resilience in navigating water governance complexities amid growing population demands and environmental challenges, preserving this essential resource sustainably for years to come (E. Akpan et al., 2020).

RESULT AND DISCUSSION

Pollution and Contamination

Water contamination in Nigeria occurs through multiple pathways, including the discharge of polluted effluents into drinking water sources and infiltration into aquifers (Jahan & Singh, 2023). Harmful microorganisms such as Escherichia coli, Salmonella, and Pseudomonas aeruginosa cause waterborne diseases like cholera and typhoid fever, severely impacting public health (Obahiagbon & Ogwu, 2024; Seymour & McLellan, 2025). Chemical contaminants, including heavy metals like lead, mercury, and cadmium, pose serious health risks, even at low concentrations (Lawal et al., 2021). Other hazardous substances, such as pesticides, nitrates, phosphates, oils, detergents, and radioactive materials, further threaten human health (Samuel et al., 2023; Edo et al., 2024). Nigeria faces a critical shortage of sewage and wastewater treatment facilities, leading to contamination of local water systems, particularly in rural areas reliant on pit latrines (Amaefule et al., 2023; Ugwu et al., 2022). Untreated human waste introduces pathogens into drinking water, resulting in severe health and economic consequences (Nwadike et al., 2024). Infrastructure improvements and public health initiatives are urgently needed to ensure safe drinking water and protect communities from waterborne diseases, fostering a cleaner and healthier environment for future generations (Benjamin, 2023; Olugbami et al., 2025).

Significant Infrastructure Deficiencies and Challenges

Urban water delivery systems in Nigerian cities face critical challenges due to aging infrastructure and poor maintenance practices that have persisted over time (Adeoti et al., 2023; Adeoti et al., 2024; Adeniran et al., 2021). These issues cause significant leakages and contamination during water transport and distribution, resulting in reduced water quantity and declining water quality for consumers across various neighbourhoods, with serious public health implications (Nwadike et al., 2024; Ahmed et al., 2022). Sewage disposal in urban centers is further hindered by systemic inefficiencies in collection and treatment infrastructure, allowing human waste to leak into water bodies that would otherwise remain clean (Ebekozien et al., 2024). This leads to severe contamination of surface and groundwater resources, adversely affecting many communities' access to safe potable water and posing grave public health risks (Adeloju et al., 2021).

Many urban areas lack proper centralized wastewater collection systems, worsening the situation (Izah et al., 2024). Municipal wastewater and abattoir effluents are often discharged illegally into surface waters without treatment, compounding environmental and health threats (Das, 2025). The absence of comprehensive national policies on wastewater reuse and treatment further complicates effective waste management, necessitating a robust, multifaceted response (Amaefule et al., 2023; Ogunbode et al., 2023). Low investment in wastewater treatment technologies and the ongoing release of untreated effluents into waterways used for drinking and sanitation remain urgent concerns (Omohwovo, 2024; Obiuto et al., 2024). This careless practice deteriorates fragile ecosystems and poses long-term risks to ecological systems and public health (Folorunso & Folorunso, 2022).

Statistical evidence highlights the severity of these deficiencies. Nationally, less than 10% of wastewater in Nigeria receives any form of treatment before discharge, compared to over 70% in South Africa (World Bank, 2022). In Lagos, groundwater samples near unlined dumpsites and informal settlements have recorded Escherichia coli concentrations exceeding 1,000 CFU/100 mL, far above the WHO standard of 0 CFU/100 mL for potable water (Akinbile et al., 2021). Kano has similarly reported nitrate contamination in shallow wells, with concentrations averaging 52 mg/L, surpassing the WHO limit of 50 mg/L and raising risks of methemoglobinemia in children (Usman et al., 2020). Epidemiological data reveal that diarrheal diseases linked to contaminated water account for nearly 10% of under-five mortality in Nigeria, with urban hotspots like Lagos, Kano, and Port Harcourt recording recurrent cholera outbreaks during rainy seasons (UNICEF, 2023). Addressing these complex challenges requires urgent, sustained intervention from authorities and the public to protect health, safety, and quality of life for those reliant on these critical water resources (Shemer et al., 2023).

Concept of Water Reuse

Water reuse is a sustainable practice that involves recycling water from various sources, including precipitation and wastewater from domestic and industrial activities, to address global water scarcity (O'Donnell et al., 2021; Silva, 2023). Greywater, sourced from household uses like showers and sinks, and blackwater, derived from sewage systems requiring rigorous treatment, are key components of water recycling (Shahangian et al., 2022; Kumar, 2021). Rainwater harvesting further contributes by collecting water from roofs and catchment surfaces (Raimondi et al., 2023). This approach supports a circular economy by providing reliable water supplies, reducing dependence on freshwater sources, and protecting resources from depletion and pollution (Karim et al., 2025; Borowski, 2024). Recycled water is utilized for irrigation, industrial processes, groundwater recharge, landscaping, and toilet flushing. Challenges include public concerns over health risks, negative perceptions, and the need for advanced treatment technologies to ensure safety (Chen et al., 2024). Strict quality standards, effective communication, education, and outreach are essential to foster acceptance and trust (Olatunji et al., 2024). Globally, water reuse aids climate adaptation by reducing groundwater extraction and mitigating soil salinization, with applications in direct, indirect, and non-potable reuse (Mwafy et al., 2025; Agbasi et al., 2025).

In Nigeria, however, water reuse concepts face contextual barriers tied to urban informality, affordability, and governance gaps. Urban slums in Lagos and Port Harcourt often rely on unsafe surface water or shallow wells, where reuse practices could improve resilience but remain underutilized due to weak infrastructure and fragmented service delivery (Akinyele et al., 2023). Rural-urban differences are also stark: while rural communities often practice informal rainwater harvesting and small-scale reuse out of necessity, urban populations face higher demand pressures with limited formalized reuse systems. Affordability is another constraint, as households in low-income areas are unable to invest in advanced treatment units without subsidies or community-driven schemes (Akpan et al., 2020). Thus, while global models emphasize technological sophistication, the Nigerian context calls for low-cost, decentralized, and culturally acceptable reuse systems integrated into broader water governance reforms.

Benefits of Water Reuse

Water reuse offers significant advantages that support sustainability by conserving resources and improving water supply management (Obiuto et al., 2024). Advanced wastewater treatment increases water availability, enhancing resilience against droughts, especially in water-scarce regions (Zhang, 2025; Shemer et al., 2023). It supplements water supplies, helping municipalities adapt to seasonal variations, population growth, and climate change (Portman et al., 2022). In agriculture, water reuse provides an innovative alternative for irrigation, addressing global water demands while preserving freshwater resources, bolstering food security, and ensuring agricultural productivity despite climate challenges and population growth (Oiganji et al., 2025; Alengebawy et al., 2024). Urban areas benefit from reclaimed water for non-potable uses such as toilet flushing, park irrigation, landscaping, vehicle washing, and industrial cooling, reducing pressure on drinking water supplies strained by urbanization (Borah, 2025; Tella et al., 2025). Water reuse technologies offer cost savings by providing economical and sustainable alternatives to sourcing new freshwater, which is increasingly rare and environmentally taxing (Silva, 2023). Additionally, it reduces environmental pollution by decreasing untreated sewage discharge into water bodies, protecting aquatic ecosystems and biodiversity (Salim et al., 2021; Scanlon et al., 2023; Tella et al., 2025). Broad adoption of water reuse promotes sustainable water management, environmental protection, and resource conservation for present and future generations (Shahangian et al., 2022). Forward-thinking initiatives and community engagement foster resilient ecosystems, align with global sustainability goals, and ensure responsible water use for continued prosperity and well-being (E. Akpan et al., 2020).

On-Site Water Reuse Systems

Irrigation accounts for approximately 70% of global freshwater consumption, leading to significant water stress in water-scarce regions and raising sustainability concerns due to increasing climate variability and population growth (Kahn et al., 2025). Traditional irrigation methods exacerbate freshwater depletion, prompting the development of innovative on-site water reuse systems designed to mitigate freshwater withdrawal and enhance efficiency (Kahn et al., 2025). These systems emphasize reusing domestic wastewater for non-potable purposes, such as irrigation and toilet flushing, significantly reducing community water demand (Qadir et al., 2024). On-site water reuse systems bypass the complex infrastructure and multiple treatment stages required by centralized systems, making them particularly suitable for areas with acute water shortages (Moll, 2023). Technologies like constructed wetlands and advanced filtration processes lower operational costs and alleviate municipalities' economic burden associated with traditional water supply and treatment systems (Han et al., 2023). Treating wastewater generated from routine household activities, such as washing and bathing, provides multifaceted benefits, including reduced reliance on freshwater and improved wastewater management that minimizes environmental pollution (Hutagalung & Matsumoto, 2020). Countries like Israel, with a 99% wastewater reuse rate, showcase the potential for maximizing domestic wastewater resources (Qadir et al., 2024). Low-strength wastewater can be treated for non-potable applications, while water-efficient fixtures further enhance the efficacy of reuse systems by reducing overall water consumption (Wang et al., 2025). On-site water reuse systems address water scarcity, improve climate resilience, and reduce effluent discharge, positively impacting local ecosystems (Dare et al., 2017). These systems offer a sustainable alternative to conventional water management practices by addressing economic and ecological challenges holistically, while tailoring solutions to local needs and conditions for maximum effectiveness.

Technologies and Methods

Wastewater contains chemically stored energy that can be harnessed through innovative technologies, enhancing recovery potentials and supporting sustainable water reuse practices amid growing resource constraints (Maiga et al., 2024). An urban sanitation framework has been proposed to guide stakeholders in selecting efficient water reuse technologies, maximizing environmental, economic, and societal benefits (Santos et al., 2024). Five domestic water reuse technologies are commercially available: Reverse Osmosis, Ultrafiltration, Ultra-Violet Purification, Biosand Filtration, and Ceramic Filtration, each with unique features and applications (Meese et al., 2021). Technology selection depends on factors such as process complexity, energy consumption, treatment efficiency, water quality challenges, and financial costs, summarized by the acronym WETFDC—Water quality, Energy consumption, Technology availability, Financial costs, Design simplicity, and Client's confidence. In Nigeria, Biosand Filtration, Ultra-Violet Purification, and Ceramic Filtration have been identified as practical options for local conditions (Obijole, 2021). Ceramic Filtration stands out due to its durability, ease of maintenance, and environmentally friendly materials, offering a long lifespan and reduced environmental footprint (Ndebele et al., 2021; Fukushima & Ohji, 2023). Implementing Ceramic Water Reuse Systems supports a sustainable and water-secure future, addressing water scarcity while promoting responsible resource use and conservation (Adigun et al., 2025). This approach fosters resilience and sustainability, balancing human needs with environmental integrity (van et al., 2021).

Table 1: Classification of Water Reuse Technology based on Developing Country Context as expressed by Previous Researches

Technology	Order of preference	Rationale	Key References
Reverse Osmosis (RO)	Conditional	High efficacy for desalination/arsenic removal but energy-intensive and costly. Limited to urban/industrial use.	Adeloju et al. (2021), Agbasi et al. (2025),
Ultrafiltration (UF)	Moderate	Effective for pathogen removal but requires membrane maintenance. Less viable in rural Nigeria.	Ahmed et al. (2022), Meese et al. (2021), Silva (2023)
UV Purification	Low	Electricity dependency and the need for pre-filtration limit practicality in off-grid areas.	Nwadike et al. (2024). (2022), Han et al. (2023)
Biosand Filtration	Highly Preferred	Low-tech, community-managed, proven in peri-urban Nigeria. Reduces turbidity and pathogens effectively.	Emenike et al. (2017), Maiga et al. (2024)
Ceramic Filtration	Most Preferred	Validated for Nigeria (e.g., silver-impregnated filters). Low-cost, scalable, and culturally accepted.	ADEWOYIN et al. (2025), Ndebele et al. (2021), Obijole (2021), Tella et al. (2025), Nwadike et al. (2024)

Design Considerations

Water reuse technology plays a pivotal role in creating sustainable water-retention societies and mitigating shortages caused by unpredictable meteorological phenomena linked to climate change and other environmental challenges (E. Akpan et al., 2020). Effective design must integrate considerations of local water quality, energy demands, technology availability, costs, simplicity, and user confidence to ensure successful implementation and long-term sustainability. On-site water reuse systems offer a practical, economical, and environmentally sound solution to the pressing issue of water scarcity, especially in agriculture and urban settings. By leveraging advanced technologies like Ceramic Filtration and adhering to comprehensive design principles, communities can significantly reduce freshwater withdrawals, improve wastewater management, and enhance resilience against climate variability. This holistic approach supports sustainable development goals and ensures water security for present and future generations.

Case Studies

Untreated greywater significantly contributes to urban pollution in Nigeria, posing severe environmental challenges, particularly in rapidly expanding cities (Nelson et al., 2025; Amaefule et al., 2023). With a growing population facing water scarcity and unreliable access to running water, greywater from household activities such as bathing and cleaning is becoming an increasingly valuable resource (Saquib et al., 2022). This scarcity, combined with challenging climates and diverse housing structures, highlights the urgent need for effective on-site water reuse systems in urban areas (Matchawe et al., 2022). Two innovative water reuse strategies have been extensively studied. The first is a gravity-driven membrane-aerated biofilm reactor system, utilizing a locally sourced granular activated carbon unit with a three-hour hydraulic retention time (HRT). This system effectively treats greywater, significantly reducing bacterial, chemical, and nutrient concentrations (Zisopoulou & Panagoulia, 2021). The second is a hybrid photobioreactor-ultraviolet (PBR-UV) system, designed for compact wastewater treatment. Its configuration, where the PBR outlet feeds directly into the UV reactor, maximizes efficiency while maintaining a minimal footprint, making it ideal for urban conditions (Senna, 2021). Pilot programs in cities such as Lagos, Abuja, and Kano have demonstrated the feasibility of wastewater reuse for agriculture. Notably, Lagos has operated a wastewater reclamation plant since 1996, supplying recycled water for irrigation (Adewumi & Oguntuase, 2016). However, regulatory gaps remain, as the 2007 NESREA Act lacks clear provisions on wastewater reuse (NESREA, 2007). Community-government collaborations, such as rural water programs in Anambra State, emphasize the benefits of decentralizing wastewater reuse responsibilities to local governments and involving communities. This approach provides a sustainable model for addressing urban pollution and water scarcity, while promoting resource conservation and enhanced management (E. Akpan et al., 2020).

Critical Evaluation. The Lagos wastewater reclamation plant, commissioned in 1996, was initially considered a pioneering project for Nigeria; however, operational performance was limited due to insufficient maintenance, inadequate funding, and weak institutional support (Adewumi & Oguntuase, 2016; Nwankwoala, 2011). While it succeeded in demonstrating technical feasibility, the plant ultimately failed to achieve long-term sustainability, underscoring the importance of continuous financing and robust institutional frameworks. Lessons learned include the necessity of capacity building, proper tariff structures to recover operation and maintenance costs, and integration of wastewater reuse into urban water master plans (Ogbonna et al., 2018). Regarding governance, although the 2007 NESREA Act did not explicitly regulate wastewater reuse, it strengthened environmental compliance by mandating standards for effluent discharge and pollution control, thereby indirectly supporting reuse initiatives by promoting water quality management (NESREA, 2007; Oluduro, 2012). Going forward, amending the Act to cover wastewater recycling and reuse explicitly could provide the regulatory clarity needed to scale decentralized treatment systems in both urban and peri-urban Nigeria.

Regulatory Framework

The successful implementation of on-site water reuse (OSWR) systems in the public domain requires robust regulatory frameworks that establish water quality and safety standards (E. Akpan et al., 2020). Nigeria currently lacks guidelines for the design and operation of decentralized water reuse systems (Ukpai, 2022) (Omokaro et al.2024). Regulations promulgated by agencies such as the Nigeria Sanitation Regulatory Commission (NSRC) and the Standard Organization of Nigeria (SON) have yet to address OSWR (Ajagunna and Gbadegesin, 2023). Given the intricate challenges related to the discharge of treated effluent into water supplies that are meant for potable use, it is essential that the Nigerian National Agency for Food and Drug Administration and Control (NAFDAC) plays a significant role in overseeing and guiding the regulatory process involved in this matter. (Awele, 2021) (Oni et al.2025) (Ojeih et al.2024). Comprehensive guidelines should incorporate criteria impacting health, the environment, and society, as well as design and operation criteria suited to small-scale OSWR units. Existing standards from the WHO, European Union, United States

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Environmental Protection Agency, and California State Water Resources Control Board can inform development of a national regulatory framework governing OSWR application in Nigeria.

Current Policies in Nigeria

According to (E. Akpan et al., 2020), water management policies are currently inadequate, leading to the pollution of water bodies and the pollution of aquifers. Releases of untreated effluents and indiscriminate solid waste disposal further aggravate the contaminants, and a combination of domestic and industrial discharges is a significant contributor to deteriorating water quality. Although the Nigerian government has enacted several policies to regulate water quality across various uses, and standards for drinking water and effluent discharge limits are enforceable, there is little enforcement of these guidelines.

Economic Analysis

Despite the well-documented advantages and opportunities associated with on-site water reuse (previously discussed), the analysis indicates that designing effective water reuse systems requires a comprehensive understanding of the economics and appropriateness of the different types of distributed water reuse systems suitable for specific sites. Economic analyses must encompass water savings, energy savings, additional operation, and maintenance (O&M) costs (E. Akpan et al., 2020). The majority of on-site reuse configurations are economically viable under current utility and equipment costs. Although widespread application of emerging decentralized treatment technologies remains limited, evidence suggests that properly selected on-site reuse systems can provide affordable, reliable, and safe water supply solutions (Kolawole & Kan, 2016).

Cost-Benefit Analysis

The implementation of on-site water reuse holds the potential to substantially alleviate potable water demand and curtail wastewater generation, driven by economic considerations (Kolawole & Kan, 2016). Pursuing approval for such initiatives necessitates a comprehensive assessment of the associated benefits and costs across individual, community, and environmental dimensions. The benefits encompass reductions in urban water demand, waste discharge, carbon footprint and energy consumption, wastewater disposal expenditures, groundwater contamination risks and related health costs, along with enhanced availability of alternative water sources during drought and water stress conditions (Arena et al., 2020). Parallelly, the costs encompass capital and operational expenses, potential health hazards linked to improper wastewater applications, environmental impacts related to the discharge of untreated wastewater, increased irrigation expenses in scenarios involving deficient salt balances, and the effects of excessive nutrients in wastewater (E. Akpan et al., 2020). A preliminary comparison undertaken in this study indicates that the anticipated advantages of on-site water reuse are likely to surpass the expenditures involved, suggesting a favorable economic proposition for its adoption in urban contexts such as the Federal Capital Territory (FCT). Further in-depth analysis is imperative to quantify these factors with greater precision and to delineate the prevailing parameter conditions conducive to optimal water reuse practices.

Funding and Financial Models

Financing can be achieved through a single or mixed cost-recovery strategy that combines revenue generation, full cost recovery, and enabling subsidies. The economic constraints and uncertainty surrounding water supply, particularly the low willingness to pay for reuse, highlight the necessity of donor assistance during implementation phases (Kolawole & Kan, 2016). Agencies such as the World Bank, the African Development Bank, the Nigerian Economic Summit Group, and the Nigerian Government can provide funding support. Private sector bond investment also offers substantial resources for water-reuse development (E. Akpan et al., 2020). Ongoing costs encompass operation and maintenance, costs of chemicals and energy, and depreciation. The level of recoverable costs depends on charges related to the adopted reuse scenarios. Funding models should distinguish between urban and rural financing mechanisms, as rural communities often rely on community-based financing and microcredit schemes (Whittington et al., 2012), whereas urban systems may utilize tariff reforms, blended finance, and infrastructure bonds (Marin, 2009). Incorporating performance-based subsidies and risk-sharing mechanisms can further enhance sustainability, particularly in contexts with low cost-recovery potential (Banerjee & Morella, 2011).

Public Perception & Social Acceptance

Public perception is pivotal to the acceptance of wastewater reuse (Akpan et al;2020). The attitudes of urban populations in both developed and developing countries towards the recycling and reuse of wastewater depend on various factors crucial to successful implementation (Drechsler et al, 2015). Different responses have been reported in numerous studies, with some expressing concern about health risks while others remain indifferent (Chen et al, 2015). Public appraisal of treated wastewater depends heavily on the social trust given to the water source or water provider, and the perception of risk imposed by the recycled water, which affects the acceptance of water from recycled sources (Ormerod, 2016). At least sixteen different types of uses for recycled water have been objectified, with irrigation and toilet flushing remaining the most popular (Gul, 2023). Policy makers and stakeholders can only accept the implementation of wastewater reuse if the level of confidence given to recycled water, its source, and the public authority in charge are appropriate. Achieving this confidence level is the major issue for wider social acceptance, and two different approaches have been proposed (E. Akpan et al., 2020).

Water reuse and recycling has long been recognized as a key strategy to ensuring sustainable water use and the delivery of municipal services. However, the development of reuse schemes requires consideration not only of institutional and technical factors, but also the opinion of the public (Smith et al; 2018). Social acceptance remains a barrier toward the successful development of reuse schemes and other wastewater treatment projects (Duong et al; 2015). The successful implementation of reuse schemes requires catching the drivers in favor, accommodating or managing those opposed, and clearly understanding the narratives underlying acceptance or resistance (Egan, 2015). The importance of social acceptance has received limited attention in the water and wastewater industry, and consequently, research is needed to fully communicate the benefits of reuse schemes (Salgot & Folch, 2018). Investigating and understanding social acceptance is crucial. (E. Akpan et al., 2020) Noted that "while water shortage is a major challenge to several developed and developing nations, water reuse remains a sustainable alternative to water supply and a strategic underpinning of water security and independence." (E. Akpan et al., 2020) Also, reported that there is limited acceptance of water reuse schemes for potable use, as shown by the limited number of such schemes globally.

Challenges and Barriers

More often than not, water service companies in Emerging Economies (EEs) face difficulty in meeting the requirements of the World Health Organization (WHO) because NRW rates are usually very high due to illegal connections, metering inaccuracies and incorrect estimation of meter consumption. The Nigerian Water and Sanitation Sector in NaWSSIP estimates the NRW in most Nigerian cities to be greater than 50% (E. Akpan et al., 2020). Even though utility managers fully understand the importance of reducing NRW within the sector, most of the tools available for reducing NRW are adapted to the needs of the European cities and thus cannot be directly integrated to the tools used by water utilities in EEs. Besides, these water utilities possess limited resources and tools, which further limit their ability to explore potential NRW reduction.

Technical Challenges

Most current on-site water reuse systems recycle graywater, due to its higher availability than blackwater. Graywater is usually stored in a settling tank for clarification, followed by filtration, disinfection and sometimes advanced treatment to remove pollutants and kill pathogens (Baykal, 2019). Blackwater is generally treated by sterilization or disinfected using chlorine or ultraviolet (UV) irradiation, to improve microbial quality. When the system is connected to both blackwater and graywater sources, such as a washbasin and a closet, a combining tank is frequently used to collect both of them periodically and the influent or effluent is treated accordingly (Talekar et al,2018). Despite the technical challenges, sustaining the qualitative and quantitative reliability of water use and supply for commerce, industry, and daily life is critical. For the vital water needs in food preparation, sanitation, and hygiene, source water may be direct through municipal potable supply or collected as rainwater or groundwater (Butler et al, 2017). Collection and storage systems are usually not designed for long-term retention, to avoid over-reliance on a single water source. The same water may be disinfected and re-used in various ways, depending on need, volume, and constitution, to provide for high quality needs, such as potable supply. Water can be re-used by uniting and pre-mixing: this allows buffering; a coarse settling base may be used to reduce total components and improve quality. Advanced treatment of collected and pre-mixed water can be used to obtain specified water quality requirements. Water quality and sanitation services will continue to be significant issues, given the rapid growth of mega-cities in the coming decades. Due to population, socioeconomic, and environmental issues, there is great interest at all levels in diversification and better management of water sources and wastewater collection and re-use systems. On-site water systems have been used in Nigeria, to support water management and sanitation. Compared to centralized conventional water systems, they are comparatively simple, require less energy, can exploit multiple sources, provide continuous supply, and reduce dependency on a single source (E. Akpan et al., 2020).

Socio-Cultural Barriers

Communities in Nigeria have always battled with access to safe potable water, with the reasons as varied as they are complex. Many people turn to alternative sources to sustain their water needs, including surface water, rainwater, and groundwater (Emenike et al, 2017). Ensuring this water is of acceptable quality for reuse purposes, however, remains a formidable challenge. The necessity of recycling and reusing wastewater is well established, whether in agriculture, industrial processes, or general water service. However, for developing nations, particularly in Sub-Saharan Africa, there are many barriers to overcome before wastewater reuse can become a viable practice. These include technical (regulatory and scientific uncertainties) and socio-cultural (customers' attitudes, trust, and regulations) issues (E. Akpan et al., 2020). There is also an information barrier, i.e. a lack of awareness about the feasibility of treated wastewater use. Recycling on a building scale can offer a bigger scope than other methods since it provides a supply of high-quality water if designed correctly, thus overcoming the quality and regulation barriers. Whether the water can be extracted from any source, the socio-cultural barriers will tend to remain. (Behailu et al; 2017) At a very early stage in the planning process, there must be consultation with the users regarding the acceptability of existing sources and alternative ones. Selection of a source for water supply that is in direct contradiction to the wishes of the users may condemn any scheme to failure. Failure of water sources, or indeed the services that are being supplied, then often results in abandonment of the existing arrangements and resorting to less acceptable, or even unsafe, methods.

Ranking of Barriers

Among the barriers constraining effective water reuse and non-revenue water (NRW) reduction in emerging economies, technical challenges remain the most severe. These include the limited applicability of European-designed NRW reduction tools (Akpan et al., 2020), the complexities of treating graywater and blackwater (Baykal, 2019; Talekar et al., 2018), and inadequacies in system design for long-term storage (Butler et al., 2017). Addressing these requires context-specific solutions, modular low-energy reuse systems, cost-effective disinfection technologies, and capacity building for utility engineers. Financial barriers are also significant, as constrained resources hinder infrastructure investment, operation, and maintenance (Akpan et al., 2020). The capital intensity of reuse infrastructure further deters adoption. Mitigation strategies include developing public–private partnerships (PPPs), implementing performance-based financing models, and leveraging climate finance to support the water–energy nexus (Behailu et al., 2017). Socio-cultural barriers, although less technically complex, persist due to negative perceptions of reused water, limited awareness, and mistrust in service institutions (Emenike et al., 2017; Behailu et al., 2017). Overcoming these challenges requires well-designed awareness campaigns, participatory planning processes that engage users early in the decision-making process, and community-based monitoring frameworks to build long-term trust.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The provision of clean and potable water remains a critical challenge in Nigeria, exacerbated by rapid urbanization, population growth, inadequate infrastructure, and climate change. On-site water reuse systems (OSWR) offer a sustainable solution to address water scarcity, pollution, and inefficient water management. Technologies such as ceramic filtration, biosand filtration, and ultraviolet purification demonstrate cost-effectiveness and suitability for Nigeria's context. However, socio-cultural barriers, regulatory gaps, and limited public awareness hinder widespread adoption. Economic analyses highlight the financial viability of OSWR systems, while pilot programs in urban areas showcase their feasibility for agricultural and non-potable applications. Addressing these challenges requires cohesive policies, robust governance, and community engagement. Scaling OSWR systems can significantly reduce dependence on freshwater sources, improve wastewater management, and foster resilience against climate variability, ultimately ensuring equitable access to clean water and sustainable resource management for future generations.

Recommendations

To ensure the successful adoption of on-site water reuse systems in Nigeria, the government should establish comprehensive regulatory frameworks aligned with international standards, addressing design, operation, and safety criteria. Public awareness campaigns must be prioritized to overcome socio-cultural barriers and foster acceptance of water reuse technologies. Collaborative efforts among communities, government agencies, and private sector stakeholders are crucial for driving implementation while leveraging donor funding from organizations such as the World Bank and the African Development Bank. Pilot programs should be expanded nationwide to demonstrate the economic and environmental benefits of OSWR systems. Furthermore, integrating advanced technologies, such as ceramic filtration, with policy cohesion and sustainable funding models will enhance resilience against water scarcity and promote equitable access to clean water, supporting Nigeria's sustainable development goals.

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