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Policy, Regulation, and Governance of Sustainable Microbial Water Treatment Technologies in Nigeria: Pathways Toward SDG 6 Achievement

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ABSTRACT

This comprehensive review examines the current state and future potential of sustainable microbial water treatment technologies for addressing Nigeria's pervasive water quality and access challenges. Nigeria faces a critical public health crisis related to contaminated water sources, with studies revealing that non-potable water constitutes the majority of household supplies in urban and rural areas alike. This analysis synthesizes recent research on microbial contamination levels across Nigerian water systems, evaluates the technical feasibility and sustainability of various biological treatment technologies, and identifies implementation challenges and strategic pathways for integrating these solutions into public water management. The review incorporates evidence from bacteriological assessments of stored river water, sachet water production facilities, and household water sources across multiple Nigerian cities, revealing widespread contamination with pathogenic bacteria including *Escherichia coli*, *Salmonella*, and *Vibrio cholerae*. Technological solutions range from low-cost point-of-use systems like biosand filtration and ceramic filters to more advanced community-scale biological treatment processes and innovative locally-developed adsorbents. Significant barriers to implementation include fragmented regulatory frameworks, unreliable electricity supplies, financial constraints, and limited technical capacity. The review proposes a multidimensional implementation strategy that combines appropriate technology selection, policy reform, financial innovation, and community engagement. By integrating sustainable microbial water treatment technologies with supportive governance structures and climate-resilient planning, Nigeria can make substantial progress toward achieving Sustainable Development Goal 6 (clean water and sanitation for all), while addressing the interconnected challenges of public health protection, environmental sustainability, and economic development.

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INTRODUCTION

Nigeria faces a severe dual crisis of water scarcity and contamination. Despite abundant natural resources, approximately 60 million citizens lack access to potable water, with rural communities disproportionately affected (Amaefule *et al.*, 2023). This crisis extends beyond physical shortage to critical quality deterioration, as most available sources are tainted with dangerous microbial pathogens. A systemic failure of public infrastructure forces reliance on alternatives; a study in Ibadan found 86.8% of dry-season and 74.1% of wet-season household water samples failed safety standards, with no households using municipal tap water (Smith *et al.*, 2024).

The bacteriological contamination presents a dire public health threat. Studies document alarming pathogen levels across diverse sources. In Ekpoma, stored river water samples showed heterotrophic plate counts up to 1320×10^4 CFU/mL and total coliform counts reaching 4400×10^4 CFU/mL, vastly exceeding WHO limits (Uzoekwe *et al.*, 2024). Even packaged sachet water, a common alternative, is compromised, with samples in Jos containing up to 2.2×10^6 CFU/mL of total bacteria and 1.98×10^6 CFU/mL of *E. coli* (Anonymous, 2025). Prevalent isolates include *Staphylococcus aureus* (29.63%) and *E. coli* (20.37%), indicating widespread fecal and hygiene breaches (Anonymous, 2025).

The human and socioeconomic consequences are devastating. Waterborne diseases account for roughly 80% of illnesses in some regions, disproportionately affecting children (Izah *et al.*, 2025). Nigeria endures recurrent *cholera* outbreaks, with one 2024 episode causing 5,951 infections and 176 deaths (Izah *et al.*, 2025). The economic burden from healthcare costs and lost productivity is immense, heavily impacting vulnerable rural populations with limited access to care. The gender dimension is acute, as women and girls, typically responsible for water collection, sacrifice educational and economic opportunities when sources are distant or unsafe.
Key pathogens illustrate the scope of the threat. *Escherichia coli*, found in 25.7% of Ibadan household sources, causes diarrhea and septicemia (Smith *et al.*,

2024). *Salmonella* species, linked to typhoid fever, are isolated from stored water and wells (Smith *et al.*, 2024). *Vibrio cholerae* drives deadly *cholera* outbreaks from contaminated surface water (Izah *et al.*, 2025). Alarmingly, *Staphylococcus aureus* contaminates sachet water, causing skin infections (Anonymous, 2025), while *Klebsiella pneumoniae* predominates in river water, posing risks of pneumonia (Uzoekwe *et al.*, 2024). This pervasive microbiological contamination underscores an urgent need for sustainable treatment solutions.

2 SYSTEMIC FAILURES IN NIGERIA'S WATER MANAGEMENT INFRASTRUCTURE

2.1 Infrastructure Deficiencies and Centralized System Limitations

Nigeria's water challenges stem from deep-rooted systemic failures that span infrastructure, governance, and maintenance (Amaefule *et al.*, 2023). The country's centralized water treatment systems, largely established during the colonial era and early independence, have deteriorated under population pressures, inadequate investment, and poor maintenance. Ibadan's case exemplifies this decline: treatment plants at Eleyele and Asejire, originally designed to serve the municipal area, reportedly met less than 10% of daily demand even when the city's population was half its current size (Serra, 2013). This infrastructure gap has forced widespread reliance on alternative sources with questionable quality controls. The situation is compounded by unreliable power supplies that disrupt treatment plant operations, with unpredictable electricity cited as a major impediment to wastewater recovery, second only to capital expenditure requirements (Ngang and Frimpong, 2024).

2.2 Wastewater Management Crisis

The wastewater treatment situation parallels drinking water challenges, with approximately 90% of generated wastewater discharged untreated into the environment across Africa (Ngang and Frimpong, 2024). This practice creates a vicious cycle of contamination, as untreated sewage pollutes surface and groundwater sources that communities then depend on for drinking. Nigeria's wastewater management suffers from insufficient treatment facilities, inadequate sewer networks, and limited monitoring capacity. Treatment plants, where they exist, frequently operate below capacity due to technical constraints such as difficulties in determining correct coagulant dosages for fluctuating turbidity levels, which can spike to 5,000 nephelometric turbidity units during rainy seasons (Amaefule *et al.*, 2023). Perhaps most alarmingly, disinfection—the critical final barrier against pathogens—is often neglected, with treated effluent discharged directly into water bodies without proper pathogen inactivation (Ngang and Frimpong, 2024).

2.3 Governance and Policy Fragmentation

Effective water management is hindered by fragmented institutional frameworks and weak policy implementation (Amaefule *et al.*, 2023). Nigeria's water sector involves multiple agencies with overlapping mandates, including the Federal Ministry of Water Resources, National Water Resources Institute, River Basin Development Authorities, and environmental protection agencies at federal and state levels. This institutional complexity creates coordination challenges and accountability gaps. Regulatory enforcement remains inconsistent, as evidenced by the sachet water industry where despite NAFDAC certification requirements and production guidelines, studies reveal widespread non-compliance with basic microbiological standards (Anonymous, 2025). The regulatory framework for emerging approaches like decentralized water reuse is particularly underdeveloped, lacking explicit guidelines and standards (Erifeta and Erifeta, 2025).

2.4 Urban-Rural Disparities and Climate Vulnerabilities

Water infrastructure and service delivery exhibit pronounced spatial inequalities, with urban areas receiving disproportionate investment despite rural populations facing greater access challenges (Amaefule *et al.*, 2023). This urban bias in infrastructure planning exacerbates geographic inequities in water security. Additionally, Nigeria's water systems face growing climate-related pressures, including irregular rainfall patterns, increased flooding, and prolonged droughts that affect both water availability and quality (Amaefule *et al.*, 2023). These climate impacts interact with existing vulnerabilities, creating compound risks for water security. Flooding events, for instance, can overwhelm already inadequate sanitation systems, leading to widespread contamination of water sources and increased disease transmission (Izah *et al.*, 2025).

3 SUSTAINABLE MICROBIAL WATER TREATMENT TECHNOLOGIES: PRINCIPLES AND APPLICATIONS

3.1 Microbial Treatment Mechanisms and Technological Classifications

Sustainable microbial water treatment encompasses technologies that harness or emulate biological processes to remove or inactivate pathogens while minimizing environmental impacts and resource consumption (Boving *et al.*, 2022). These technologies can be categorized by scale (point-of-use, household, community), treatment mechanism (filtration, adsorption, disinfection), and technological complexity (traditional, advanced, experimental). A fundamental principle across these approaches is the recognition that appropriate technology selection must consider local conditions, including water quality parameters, available resources, technical capacity, and cultural acceptability (Oluwole, 2024). Unlike conventional chemical-intensive treatments, sustainable microbial approaches often leverage natural materials and processes, reducing dependence on imported chemicals and complex infrastructure while enhancing community ownership and maintainability (Boving *et al.*, 2022).

3.2 Point-of-Use and Household-Scale Technologies

At the household level, several low-cost technologies have demonstrated effectiveness for microbial pathogen removal in Nigerian contexts (Boving *et al.*, 2022):

- **Biosand Filtration:** This intermittent slow sand filtration system uses a biologically active layer (schmutzdecke) that develops on top of the sand bed to remove pathogens through biological predation, adsorption, and mechanical straining. Studies show effective removal of bacteria and protozoa with proper maintenance, though viral removal may be less consistent. Its advantages include minimal energy requirements, use of locally available materials, and simple operation (Boving *et al.*, 2022).

- **Ceramic Filtration:** Ceramic filters, often impregnated with colloidal silver, remove pathogens through mechanical exclusion (pores smaller than microorganisms) and antimicrobial action. These systems have shown >99% bacterial removal in field studies and are particularly suitable for household water treatment where centralized systems are unavailable. Local production using Nigerian clay materials offers potential for economic development and technology adaptation (Boving *et al.*, 2022).
- **Solar Water Disinfection (SODIS):** This simplest approach utilizes solar ultraviolet radiation and thermal effects to inactivate pathogens when water is stored in transparent containers and exposed to sunlight for 6+ hours. While highly dependent on weather conditions and requiring behavioral adaptation, SODIS represents a zero-cost option for microbial reduction when other alternatives are unavailable (Oluwole, 2024).
- **Natural Coagulants:** Locally available plant-based materials like *Moringa oleifera* seeds contain natural coagulating proteins that can clarify turbid water and substantially reduce microbial loads through sedimentation and antimicrobial effects. Studies in Nigeria have demonstrated their effectiveness as alternatives to chemical coagulants like alum and ferric chloride (Oluwole, 2024).

3.3 Community-Scale Biological Treatment Systems

For larger applications, several community-managed technologies offer sustainable pathogen control:

- **Constructed Wetlands:** These engineered systems mimic natural wetland processes, utilizing vegetation, substrates, and associated microbial communities to remove pathogens through filtration, adsorption, and biological degradation. They are particularly suitable for wastewater treatment and polishing of previously treated water, offering additional benefits of habitat creation and aesthetic value (Erifeta and Erifeta, 2025).
- **Slow Sand Filtration:** Scaling up the biosand principle, community slow sand filters provide biological treatment for small communities or institutions. These systems develop a robust schmutzdecke that effectively removes pathogens while requiring minimal operator skill. Properly designed slow sand filters can serve populations of 50-500 people with consistent microbial quality outputs (Oluwole, 2024).
- **Anaerobic Digestion with Post-Treatment:** While primarily for organic matter reduction and energy recovery, anaerobic digestion systems can be coupled with polishing units like constructed wetlands or filtration for pathogen reduction in wastewater treatment applications. This approach aligns with circular economy principles by recovering resources (biogas, nutrients) while treating water for safe discharge or reuse (Erifeta and Erifeta, 2025).

3.4 Innovative Locally-Developed Solutions

Nigerian researchers are developing context-appropriate technologies using indigenous materials and knowledge. A notable example is the clay-papaya seed adsorbent developed by Emmanuel Unuabonah and colleagues, which combines kaolinite clay with defatted papaya seeds to create an effective filter medium for removing heavy metals and microbial contaminants (Serra, 2013). This innovation, which won the Dhirubhai Ambani Award for Outstanding Chemical Engineering Innovation for Resource-Poor People, demonstrates how locally available materials can be transformed into effective water treatment solutions. The adsorbent is particularly efficient at removing cationic pollutants (heavy metal ions, dyes) and shows antimicrobial properties against pathogens like *E. coli*, *Salmonella typhi*, and *Vibrio cholerae* (Serra, 2013). Such innovations highlight the potential for technology localization that reduces costs, enhances sustainability, and builds local technical capacity.

Several sustainable microbial water treatment technologies offer viable solutions for Nigeria's contamination crisis, each suited to different scales and contexts. At the household level, the **Biosand Filter** provides high removal efficacy for bacteria and protozoa, though it is only moderately effective against viruses. Its key advantages are that it requires no chemicals, has low maintenance needs, and can be built with local materials. However, its slow filtration rate and need for periodic cleaning are limitations, with units costing an estimated $10-$50 (Boving *et al.*, 2022).

Another effective household option is the **Ceramic Filter**, which offers very high efficacy against bacteria and protozoa (moderate for viruses). It allows for immediate use and visual monitoring of water clarity but is breakable and suffers from declining flow rates. These filters typically cost $15-$60 per unit (Boving *et al.*, 2022). For the most resource-constrained settings, **Solar Water Disinfection (SODIS)** is a simple method that provides high pathogen removal with adequate sunlight exposure. Its primary benefits are zero energy cost and simple implementation, but it is highly weather dependent and requires clear containers, with a very low cost of $1-$5 for bottles (Oluwole, 2024).

For community-scale applications, **Constructed Wetlands** can achieve high pathogen removal with proper design. They offer multiple co-benefits, including aesthetic value and wildlife habitat, but are land intensive and require specific design knowledge. System costs range from $500 to $5,000 (Erifeta and Erifeta, 2025). Similarly, **Slow Sand Filters** are highly effective for community use, delivering very high removal rates for all pathogens with the advantage of consistent water quality and minimal operational skills. Their drawbacks are a large physical footprint and the need for skilled labor for cleaning, with systems costing $200-$2,000 (Oluwole, 2024).
An innovative, locally-developed solution is the **Clay-Papaya Seed Adsorbent**, which is suitable for both household and community scales. It shows high efficacy for removing metals and bacteria, though application for virus removal is still developing. Its strengths are the use of local, regenerable materials, making it a promising innovation, but it faces the limitation of still scaling up production, with costs currently under development (Serra, 2013).

4 IMPLEMENTATION STRATEGIES AND INTEGRATION PATHWAYS

4.1 Policy and Regulatory Framework Development

Successful integration of sustainable microbial technologies requires supportive policy environments that recognize and enable decentralized, nature-based solutions. Current Nigerian water policies primarily focus on centralized infrastructure, creating regulatory gaps for point-of-use and community-scale systems (Erifeta and Erifeta, 2025). Policy reforms should include:

- Development of **standards and certification protocols** for point-of-use treatment technologies, establishing minimum performance requirements for microbial reduction while allowing innovation in design and implementation (Oluwole, 2024).
- Integration of decentralized options into national water strategies, recognizing that a hybrid approach combining centralized and distributed systems offers the most realistic path to universal access given infrastructure constraints and geographical challenges (Amaefule *et al.*, 2023).
- Regulatory frameworks for **water reuse** that establish safety standards and monitoring requirements for non-potable applications, enabling communities to safely recycle water for agriculture, landscaping, and other uses while reducing pressure on freshwater sources (Erifeta and Erifeta, 2025).
- Strengthening of enforcement mechanisms for existing water quality standards, particularly in the packaged water industry where non-compliance with microbiological standards remains widespread despite certification requirements (Anonymous, 2025).

4.2 Technical Capacity Building and Knowledge Transfer

The effective operation and maintenance of sustainable water treatment systems requires local technical capacity that is currently underdeveloped in many Nigerian communities (Boving *et al.*, 2022). Capacity building initiatives should focus on:

- Training programs for community water operators on basic principles of biological treatment, routine maintenance procedures, and simple water quality monitoring techniques (Oluwole, 2024).
- Integration of appropriate technology education into technical and vocational education programs, creating a pipeline of skilled practitioners familiar with both conventional and sustainable treatment approaches (Boving *et al.*, 2022).
- Knowledge exchange networks that connect Nigerian researchers, technology developers, and implementing organizations to share lessons learned, troubleshoot common challenges, and accelerate innovation diffusion (Serra, 2013).
- Development of context-appropriate technical guidelines that account for local water quality variations, material availability, and maintenance capabilities rather than importing standardized designs from dissimilar contexts (Boving *et al.*, 2022).

4.3 Financial Models and Investment Strategies

Sustainable microbial technologies often face financing barriers despite lower lifetime costs compared to conventional systems, due to higher upfront requirements and unfamiliarity among financiers (Boving *et al.*, 2022). Innovative financing approaches include:

- **Microfinance and payment plans** that enable households to acquire point-of-use treatment systems through affordable installment payments, potentially linked to health or productivity benefits.
- **Results-based financing** mechanisms that tie disbursements to verified performance outcomes (e.g., reduction in waterborne disease incidence, sustained system operation), aligning incentives with long-term sustainability.
- **Blended finance structures** that combine public funding, development assistance, and private capital to de-risk investments in community-scale systems while ensuring affordability for low-income users.
- **Circular economy business models** that generate revenue from recovered resources (e.g., biogas from anaerobic digestion, compost from sludge, paid sanitation services) to offset treatment costs and create economic opportunities (Erifeta and Erifeta, 2025).

4.4 Community Engagement and Social Acceptance

Technology adoption ultimately depends on user acceptance and sustained behavior change, particularly for household-level interventions (Boving *et al.*, 2022). Effective engagement strategies include:

- **Participatory technology selection** processes that involve community members in assessing options based on their priorities, constraints, and cultural preferences rather than prescribing predetermined solutions.
- **Gender-sensitive implementation** that recognizes and addresses the different roles, knowledge, and decision-making authority of women and men regarding water collection, treatment, and use.
- **Behavior change communication** that goes beyond technical instruction to address perceptions, beliefs, and social norms related to water treatment and consumption, utilizing trusted community influencers and appropriate communication channels.
- **Long-term support structures** including local repair networks, replacement part supply chains, and ongoing technical assistance to prevent abandonment of systems when minor issues arise (Oluwole, 2024).

5 ECONOMIC CONSIDERATIONS, CLIMATE RESILIENCE, AND CIRCULAR ECONOMY INTEGRATION

5.1 Cost-Benefit Analysis and Economic Viability

Sustainable microbial water treatment technologies offer compelling economic advantages over conventional approaches when considering full life-cycle costs and broader socioeconomic benefits (Boving *et al.*, 2022). While upfront costs for some systems may be comparable to or slightly higher than conventional alternatives, operational savings from reduced chemical use, lower energy requirements, and simplified maintenance often result in superior long-term economics. More significantly, comprehensive economic assessments must account for avoided health costs associated with reduced waterborne disease incidence, including direct medical expenses, lost productivity, and educational disruptions (Izah *et al.*, 2025). Studies suggest that investments in water quality improvement typically yield benefit-cost ratios exceeding 2:1, with particularly high returns in high-disease-burden settings like Nigeria (Izah *et al.*, 2025). Additionally, locally-produced treatment systems (e.g., ceramic filters from Nigerian clay, natural coagulants from *Moringa* trees) create economic opportunities through local manufacturing, distribution, and maintenance services, contributing to broader community development beyond immediate health benefits (Boving *et al.*, 2022; Serra, 2013).

5.2 Climate Resilience and Adaptation Benefits

Sustainable microbial technologies exhibit inherent climate resilience characteristics that make them particularly valuable in the Nigerian context of increasing climate variability (Amaefule *et al.*, 2023). Unlike energy-intensive conventional treatments vulnerable to power disruptions, many sustainable options operate passively or with minimal energy inputs, ensuring continued function during electricity outages that plague Nigerian cities and rural areas alike (Oluwole, 2024). Systems like constructed wetlands and biosand filters demonstrate robust performance across varying water quality conditions, adapting to seasonal changes in source water turbidity and contamination levels better than chemical-dependent processes requiring precise dosing adjustments (Erifeta and Erifeta, 2025). Furthermore, nature-based solutions like constructed wetlands provide co-benefits for climate adaptation, including flood mitigation through increased water retention capacity, urban cooling effects, and carbon sequestration in biomass and soils (Erifeta and Erifeta, 2025). These multifunctional attributes align with climate-resilient development pathways that address water security while building adaptive capacity across sectors (Amaefule *et al.*, 2023).

5.3 Circular Economy Integration and Resource Recovery

The most advanced applications of sustainable microbial water treatment embrace circular economy principles that transform wastewater from a disposal problem into a resource opportunity (Erifeta and Erifeta, 2025). Biological treatment processes enable recovery of valuable resources including:

- **Nutrient recovery:** Technologies like anaerobic digestion and constructed wetlands capture nitrogen and phosphorus from wastewater, converting them into fertilizer products that can replace synthetic alternatives and enhance agricultural productivity while closing nutrient loops.
- **Energy recovery:** Anaerobic digestion of organic wastes in wastewater produces biogas (primarily methane) that can be used for cooking, heating, or electricity generation, offsetting fossil fuel consumption and reducing greenhouse gas emissions.
- **Water reuse:** Appropriately treated wastewater can be safely used for non-potable applications including agricultural irrigation, landscape watering, industrial processes, and toilet flushing, reducing pressure on scarce freshwater resources (Erifeta and Erifeta, 2025).
- **Biomass utilization:** Plant biomass from constructed wetlands and algal systems can be harvested for animal feed, compost production, or bioenergy feedstocks, creating additional value streams from treatment systems.

Implementing these circular approaches requires supportive policies that enable safe resource recovery, business models that capture value from recovered resources, and community acceptance of products derived from wastewater (Erifeta and Erifeta, 2025). Nigeria's National Climate Change Policy and Climate Change Act of 2021 provide a foundation for promoting such circular economy approaches in water management, though implementation mechanisms require further development (Amaefule *et al.*, 2023).

5.4 Monitoring, Evaluation, and Adaptive Management

Sustainable implementation requires robust monitoring frameworks that track both technological performance and broader impacts (Izah *et al.*, 2025). Key monitoring elements include:

- **Water quality surveillance** using appropriate indicators of microbial safety (e.g., *E. coli*, turbidity) and simplified testing methods accessible to community operators (Smith *et al.*, 2024).
- **System functionality assessments** that go beyond simple presence/absence metrics to evaluate consistent operation, maintenance practices, and user satisfaction (Oluwole, 2024).
- **Health impact monitoring** through linkages with health surveillance systems, enabling correlation between water quality improvements and disease incidence reductions (Izah *et al.*, 2025).
- **Socioeconomic outcome tracking** including time savings from reduced water collection, educational impacts, gender equity measures, and economic benefits from resource recovery.

Data from monitoring should feed into adaptive management cycles that enable continuous improvement of technologies, implementation approaches, and supporting policies based on real-world evidence rather than assumed effectiveness (Izah *et al.*, 2025). Digital tools including mobile data collection, remote sensors, and geographic information systems can enhance monitoring efficiency and data utilization while building Nigeria's digital water management capacity (Amaefule *et al.*, 2023).

6 CONCLUSION

Sustainable microbial water treatment technologies offer practical pathways for addressing Nigeria's interconnected water quality, access, and public health challenges. Leveraging biological processes and local materials, these solutions provide effective pathogen control while enhancing community resilience. However, realizing this potential requires moving beyond technical demonstrations to address systemic barriers in policy, finance, and governance. Nigeria needs integrated strategies that combine technology deployment with supportive regulations, innovative financing, and capacity building. The inherent climate resilience and circular economy potential of these systems make them especially valuable for the nation's future. A pluralistic approach, with sustainable microbial solutions as a central pillar, can transform the water crisis into an opportunity for improved public health, environmental sustainability, and inclusive development.

REFERENCES

Amaefule, E. O., Amarachi, A. S., Abuka, C. O., Nwaogazie, F. O., Nwabuko, C. N., & Divine, C. C. (2023). Water and wastewater treatment in Nigeria: Advancements, challenges, climate change and socioeconomic impacts. *Path of Science*, *9*(8), 2010–2031. https://doi.org/10.22178/pos.88-6

Anonymous. (2025). Bacteriological hazard analysis and critical control point assessment of sachet water production factories in Jos metropolis, Nigeria. *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*, *20*, Doc36. https://doi.org/10.3205/dgkh000565

Boving, T., Craver, V., Labhasetwar, P., & Sabatini, D. (2022). Sustainable groundwater treatment technologies for underserved rural communities in emerging economies. *Science of the Total Environment*, *802*, 149842. https://doi.org/10.1016/j.scitotenv.2021.149842

Erifeta, K. E., & Erifeta, G. O. O. (2025). On-site water reuse systems: A sustainable approach for urban water management in Nigeria. *International Journal of Environmental Sciences*. https://doi.org/10.47604/ijes.3511

Izah, S. C., Ogwu, M. C., & Aigberua, A. O. (2025). Modeling solutions for microbial water contamination in the global south for public health protection. *Frontiers in Microbiology*, *16*, 1504829. https://doi.org/10.3389/fmicb.2025.1504829

Ngang, B. A., & Frimpong, B. O. (2024). Wastewater management in Africa: Challenges and opportunities. *Environmental Health Insights*, *18*, 11786302241289681. https://doi.org/10.1177/11786302241289681

Oluwole, O. (2024). Water treatment systems in Nigeria: Choosing the right solution. *LinkedIn Pulse*. Retrieved from https://www.linkedin.com/pulse/water-treatment-systems-nigeria-choosing-right-solution-oluwole-qkvvf

Serra, C. (2013). Clean water for Nigeria. The World Academy of Sciences (TWAS). Retrieved from https://www.twas.org/article/clean-water-nigeria

Smith, S. I., Akingbade, O. A., Omonigbehin, E. A., Bamidele, M., & Odugbemi, T. O. (2024). Suboptimal bacteriological quality of household water in municipal Ibadan, Nigeria. *The American Journal of Tropical Medicine and Hygiene*, *110*(2), 346–355. https://doi.org/10.4269/ajtmh.23-0134

Uzoekwe, H. E., Enyidi, U. D., & Egbe, K. R. (2024). Detection and measurement of bacterial contaminants in stored river water consumed in Ekpoma. *Water*, *16*(18), 2696. https://doi.org/10.3390/w16182696.