

Wastewater Treatment Techniques, Quality Monitoring, and Compliance with Regulatory Standards in Nigeria

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Abstract

Innovative wastewater treatment techniques, recycling systems, circular economy, and quality monitoring and enforcement of regulatory standards are vital for sustainable urban water development. This study offers a thorough analysis and review of the literature on wastewater treatment methods in Nigeria, spanning from traditional approaches to cutting-edge technologies like membrane bioreactors, trickling filters, activated sludge systems, anaerobic digesters, and constructed wetlands. It also investigates deeper into the existing quality monitoring systems, emphasizing the function of microbiological and physicochemical parameters in determining effluent quality. Wastewater management is a critical issue for Nigeria due to rapid urbanization, industrial growth, and the health risks associated with untreated effluents. While global advances in treatment technologies exist, Nigeria still faces institutional, technical, and financial challenges. The need for efficient wastewater treatment, strict quality monitoring, and regulatory compliance has increased in Nigeria due to the country's increasing problems with water pollution, rapid urbanization, and industrialization. Effective adherence to national and international standards has been hampered by inadequate infrastructure, a lack of technical know-how, and inadequate enforcement of environmental laws. Ultimately, aligning Nigeria's wastewater treatment and monitoring systems with global best practices is crucial to protecting public health, preserving aquatic ecosystems, and achieving the Sustainable Development Goals (SDGs). There is a great need for a multi-stakeholder approach involving government, industry, and communities to strengthen regulatory frameworks, enhance treatment infrastructure, and ensure sustainable water quality management.

Keywords: Innovative wastewater treatment techniques, quality monitoring, environmental regulation, pollution control, compliance

INTRODUCTION

Water is an invaluable natural resource used by all living organisms for survival. It can be the difference between life and death, depending on how it manifests and is handled. Sanitation and access to clean water are essential for human survival, health, and well-being. Access to pure water is made

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possible by the ongoing nature of diverse human endeavors. However, the majority of the water sources in the world are contaminated by the liquid and solid waste generated after using pure water [1]. Water is a vital resource for economic growth, environmental sustainability, and human life. Rapid urbanization, industrialization, and population increase have made water pollution a global problem in recent decades. Nigeria, Africa's most populous nation, has serious problems with wastewater generation and insufficient treatment facilities. If wastewater is not properly managed, it

can seriously jeopardize aquatic ecosystem integrity, agricultural productivity, and human health. As a result, maintaining environmental regulations, treating wastewater, and monitoring quality have become essential elements of the nation's sustainable growth [2].

Wastewater treatment protects public health, preserves aquatic ecosystems, and enables water reuse. The performance of a treatment plant is a function of influent characteristics, process selection and control, operator capacity, and the effectiveness of monitoring and compliance systems. Regulators set effluent limits to ensure that receiving water meets designated uses (e.g., drinking water source protection, recreation, and aquatic life). Utilities and industries must therefore align treatment techniques with verified performance, documented through defensible monitoring and reporting. Safe management of wastewater is essential for public health, environmental protection, and circular economy opportunities (water reuse and energy recovery). Globally, progress on safely treated wastewater is measured under SDG indicator 6.3.1; country estimates are improving with better data coverage [3]. In Nigeria, the latest SDG data indicate a substantial proportion of domestic wastewater is reported as safely treated (SDG indicator reporting); however, substantial regional and institutional gaps remain, and many municipal/industrial discharges still cause pollution [4]. In Nigeria, the federal government launched a national water quality push in 2025, which includes establishing 12 national water quality reference laboratories and a national roadmap for water quality management — a major step toward improved monitoring and enforcement [5].

Stormwater, industrial effluents, agricultural runoff, and home sewage are the main sources of wastewater in Nigeria. These wastewaters contain a variety of pollutants, such as pathogens, heavy metals, organic matter, and nutrients, that can degrade water quality if discharged untreated. However, the development and implementation of wastewater treatment technologies remain uneven across the nation. Urban centers such as Lagos and Abuja have better, albeit limited, infrastructure compared to rural and peri-urban areas, where open defecation and indiscriminate discharge into water bodies are common practices. Despite the critical importance of proper wastewater treatment, Nigeria has continued to struggle with inadequate sanitation infrastructure, insufficient monitoring systems, and weak enforcement of environmental laws [6].

The consequences are evident in the widespread contamination of surface and groundwater resources, leading to waterborne diseases such as cholera, dysentery, and typhoid. Additionally, the unregulated discharge of industrial effluents has exacerbated environmental degradation, particularly in oil-producing regions of the Niger Delta. The regulatory framework governing wastewater treatment in Nigeria is primarily managed by the National Environmental Standards and Regulations Enforcement Agency (NESREA) under the Federal Ministry of Environment. NESREA has developed effluent limitation guidelines and standards for various sectors [7]. However, enforcement remains a significant challenge due to limited technical capacity, poor funding, and lack of political will. This has resulted in a regulatory gap that allows industries and municipalities to discharge untreated or partially treated wastewater into the environment [8].

This study aimed to investigate the various wastewater treatment techniques employed in Nigeria, evaluate the existing water quality monitoring practices, and assess the level of compliance with regulatory standards. The findings of this study will contribute to the body of knowledge on environmental management and public health in Nigeria. It will provide insights for policymakers, environmental regulators, municipal authorities, and industry stakeholders on the current state of wastewater treatment and monitoring systems. Furthermore, the study will highlight practical solutions for enhancing compliance with national and global standards, ultimately supporting Nigeria's efforts toward achieving the United Nations Sustainable Development Goals (SDGs), particularly Goal 6: Clean Water and Sanitation [9].

LITERATURE REVIEW

Overview of Wastewater Treatment

Wastewater treatment refers to the techniques used to remove impurities from sewage or industrial wastewater to create an effluent that is acceptable for release into the environment or appropriate for reuse. The main goal is to reduce the detrimental effects of wastewater on ecosystems and public health. Three primary (physical), secondary (biological), and tertiary (chemical and advanced) stages are commonly used in wastewater treatment worldwide. Large municipal facilities in Nigeria frequently employ traditional (conventional) treatment techniques, such as activated sludge processes, trickling filters, and sedimentation. However, because of the high initial and ongoing expenses, the use of sophisticated methods, such as membrane bioreactors, artificial wetlands, and anaerobic digestion, is still restricted. Inadequate wastewater treatment and sanitation facilities, along with a scarcity of reusable water, mostly impact rural areas and rural populations worldwide. In underdeveloped nations, 82% of the rural population lacks access to basic sanitation [10]. For water management, sustainable development takes into account environmental, technological, and sociocultural aspects; however, in the majority of developing nations, economic considerations play a crucial role in the decision-making process. Most urban wastewater treatment facilities are centralized systems, which are costly, with sewage collection accounting for approximately 80% of the necessary investments. However, rural locations are distinguished by relatively few people and dispersed household patterns, in contrast to cities where centralized treatment methods are appealing due to the dense population. Because of this, decentralized systems are a reasonable solution for wastewater treatment [11]. Decentralized systems, which are typically straightforward and affordable, are an option for small towns with low population densities looking to address their financial wastewater treatment issues. However, decentralized systems require excellent quality management to guarantee routine maintenance and inspection [12].

Wastewater Treatment Techniques in Nigeria

Several wastewater treatment approaches are employed in Nigeria, depending on the source and intended use of the treated water. Some of the common methods include:

- *Septic tanks and soakaways*: These are prevalent in residential areas and small institutions, especially where centralized sewage systems are unavailable. However, they are often poorly maintained, leading to groundwater contamination.
- *Waste stabilization ponds (WSPs)*: These are commonly used in small towns and are cost-effective for treating municipal wastewater. Despite their simplicity, they require large land areas and are affected by seasonal changes.
- *Activated sludge process*: This is used in some urban centers and industrial settings. It involves aerobic treatment and is effective in reducing biochemical oxygen demand (BOD) and suspended solids but requires skilled operation and regular maintenance.
- *Constructed wetlands*: Although relatively new in Nigeria, they offer low-cost and sustainable options for wastewater treatment, especially in rural areas.
- *Industrial effluent treatment plants (ETPs)*: These are designed specifically to treat industrial wastewater and vary in complexity based on the type of industry. However, compliance is inconsistent due to poor enforcement of regulations.

Water Quality Monitoring Systems

In order to evaluate the efficacy of treatment procedures and guarantee adherence to environmental regulations, water quality monitoring is crucial. State Environmental Protection Agencies (SEPA), NESREA, and the National Water Resources Institute (NWRI) are among the government organizations in Nigeria that monitor water quality. BOD, chemical oxygen demand (COD), total suspended solids (TSS), heavy metals, nutrients, and pathogenic organisms are among the important characteristics that are tracked. However, a number of issues plague the monitoring systems, such as a lack of funds, low technical capability, restricted access to lab equipment, and a lack of agency-to-agency data exchange [13].

Regulatory Standards and Compliance

Nigeria's main environmental protection regulatory agency, NESREA, enforces effluent discharge standards according to sector-specific rules. The Nigerian Environmental Society, the Federal Ministry of Water Resources, and international organizations such as the WHO are among the other organizations involved. The goal of NESREA's regulations is to guarantee that effluent released into the environment does not include more contaminants than are allowed. However, corruption, a lack of political will, and a lack of technical capability frequently result in insufficient enforcement. Numerous companies contribute to the pervasive pollution by operating without effluent treatment facilities or by releasing untreated sewage into water bodies [14].

International Best Practices

Countries such as South Africa, India, and Brazil have made significant progress in wastewater management by adopting integrated water resource management (IWRM) principles, encouraging public-private partnerships, and utilizing smart monitoring technologies. Nigeria can learn from these models by:

- Investing in decentralized and modular treatment systems.
- Strengthening legal frameworks and enforcement mechanisms.
- Enhancing community participation and awareness.
- Leveraging international funding and technical support.

RESEARCH METHODOLOGY

This study is structured as a descriptive and exploratory study. The descriptive component aims to present a current picture of wastewater treatment technologies and monitoring practices in Nigeria. The exploratory aspect seeks to identify gaps, challenges, and opportunities in the regulatory and institutional framework. A combination of primary and secondary data sources was used to achieve the research objectives.

Study Area and Population

This study was conducted in selected urban and industrial areas across Nigeria, including Lagos, Port Harcourt, Abuja, Kano, and Enugu. These locations were chosen because of their diverse population sizes, varying levels of industrial activity, and existing wastewater infrastructure. The study population comprised environmental regulatory officials, municipal water authorities, industry representatives, and residents affected by wastewater discharge.

DATA COLLECTION METHODS

Primary Data Collection

Structured questionnaires were administered to municipal authorities and environmental agencies to gather information on treatment technologies, monitoring systems, and enforcement practices. Semi-structured interviews were conducted with NESREA officials, environmental consultants, and plant managers in selected industrial facilities. These interviews provided deeper insights into the challenges of compliance and regulatory oversight. Focus group discussions were also held with community members and local NGOs in areas affected by poor wastewater management. These discussions offered valuable perspectives on public awareness and the perceived effectiveness of regulatory measures.

Secondary Data Collection

Secondary data were sourced from government reports, regulatory agency publications, academic journals, conference proceedings, and international environmental databases. Key documents reviewed included the NESREA effluent standards, WHO water quality guidelines, and previous studies on wastewater management in Nigeria.

Data Analysis Techniques

Quantitative data from questionnaires were analyzed using descriptive statistics, such as means, frequencies, and percentages. Statistical tools, such as SPSS and Microsoft Excel, were used to organize and visualize the data. Qualitative data from interviews and focus groups were analyzed thematically. Themes such as regulatory compliance, infrastructure challenges, and community awareness were identified and discussed in relation to existing literature. Comparative analysis was conducted to assess compliance with national and international wastewater discharge standards. Additionally, case studies from selected treatment facilities were used to illustrate successful practices and highlight areas needing improvement.

Design of Wastewater Treatment System

A pre-treatment system is created in this phase to remove solid waste and prevent sand from building up and impairing the next stage of treatment [1].

This design is divided into three stages. The first stage is the primary stage, which includes grit removal, screening, and sedimentation. Grit removal involves the removal of glass, metal, and heavy inorganic materials, such as sand and gravel. Grit refers to these substances (sand and any gritty stuff). Lastly, it is intended to eliminate surplus grease or oil. The equalization basin, grit chamber, and screens make up the pre-treatment. To keep moving mechanical parts and pumps free of needless damage caused by friction, the grit chamber must be cleared of grit and other debris heavier than organic matter. Aerated grit chambers, equalization basins, detritus tanks, and rectangular horizontal flow types are among the various types of grit chambers [15].

Generally, screens are used to remove large items such as paper, metal, plastic, and rags. These units are placed at the beginning of the treatment plants at the entrance of the pumping station to protect the mechanical installations. They also prevent the entry of these materials with sewage into other treatment stages. The second stage is sedimentation or settling (primary treatment) [16].

The third stage is known as secondary treatment or biological treatment, which involves exposing wastewater to influential microbial growth so that contaminants can be consumed by them. Many different types of microorganisms are involved, such as bacteria, fungi, algae, and rotifers. When these organisms come into contact with biodegradable organic materials, they break them down into inert products, such as water, carbon dioxide, and additional cell material. Two forms of growth can be used to accomplish the biological treatment process: attached growth biological treatment and suspended growth biological treatment [17]. The last stage is known as the tertiary stage, which involves nitrogen removal and pH control. Processes such as nitrification (an aerobic microbial process carried out by specialized bacteria) and denitrification (a natural soil microbial process that releases nitrogen (N) gases into the atmosphere via the conversion of nitrate (NO_3^-)) are also used. Adjustments are also made to maintain the required pH level [18, 19].

Figure 1 shows a wastewater system, and Figure 2 indicates wastewater treatment using the Internet of Things (IoT).

Conventional Unit Processes (Preliminary → Primary → Secondary)

- *Screens, grit removal, primary clarifiers*: remove coarse solids, grit, and a portion of the settleable organic load. CEPT (chemically enhanced primary treatment) can increase solids/phosphorus removal when needed. (Textbook/practical standard.)
- *Activated sludge and variants (CAS, SBR, extended aeration, oxidation ditch)*: established for organic removal and—when configured—nitrification. Key performance levers: sludge age (SRT), DO control, and return activated sludge (RAS) management. (Refer to standard engineering texts and reviews.)
- *Attached growth processes (trickling filters, RBCs, MBBR, IFAS)*: good for retrofit and for improving nitrification without large reactor volumes. MBBR/IFAS are common energy-efficient upgrades in constrained urban plants [20].

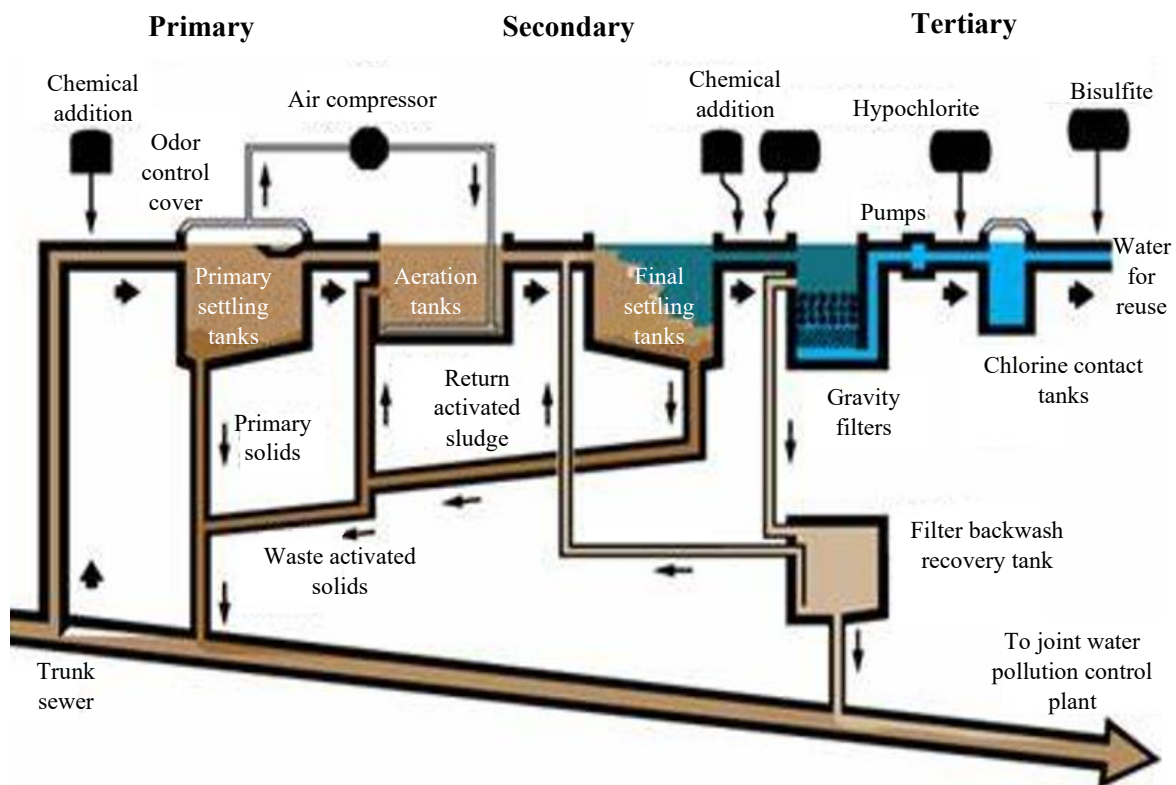


Figure 1. Diagram of a wastewater treatment system.

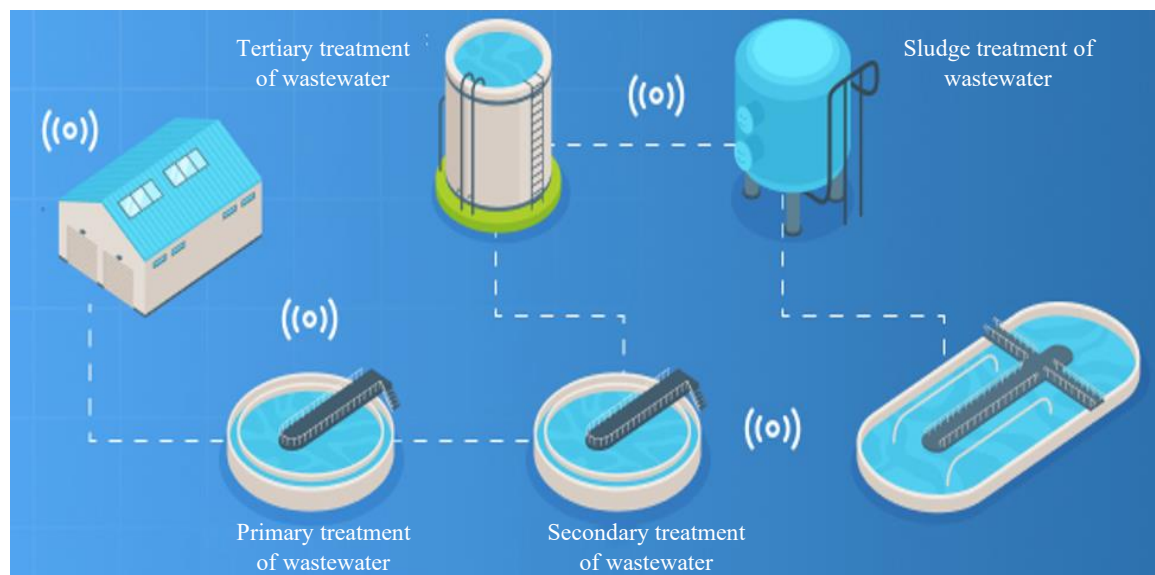


Figure 2. Wastewater treatment using Internet of Things (IoT).

Advanced and Hybrid Systems

- *Membrane bioreactors (MBRs)*: allow very low suspended solids and are widely used for reuse applications; membrane fouling control and energy for aeration/scouring are the main operating expenditure (OPEX) drivers. Recent MBR reviews guide fouling mitigation and hybrid configurations.
- *AOPs and ozone/polishing*: effective for micropollutant removal and disinfection without residual ultraviolet (UV)—often combined with activated carbon (GAC/PAC) to remove oxidized by-products. Their use for potable reuse or sensitive receiving water is growing.

- *Nature-based systems (constructed wetlands, vermifilters):* extremely promising for decentralized, low-cost treatment. Recent full-scale vermifilter studies have reported very high percent reductions in BOD, COD, and TSS under appropriate loading and climatic conditions. These are particularly attractive for abattoirs, small settlements, and institutional facilities.

Sludge/Biosolids Management and Resource Recovery

Anaerobic digestion for biogas, dewatering, struvite recovery, and composting are proven pathways. Selecting the appropriate route depends on sludge characteristics, land availability, and regulatory limits for metals/pathogens.

Monitoring, QA/QC and Data Management

Key parameters and monitoring strategy are:

- *Core parameters:* BOD₅, COD, TSS, pH, temperature, DO, NH₃-N, NO₃⁻, TP, fecal indicators (E. coli/fecal coliform), metals (where relevant), and turbidity. For reuse or micropollutants: Selected pharmaceuticals, and total microplastics monitoring as needed.
- *Sampling design:* influent/post-secondary/effluent/receiving water; grab vs. flow-proportional composites; storm event sampling for combined sewer overflows (CSOs) or overloaded networks.
- *Online sensors:* pH, DO, turbidity, conductivity, ammonia sensors, and ultraviolet transmittance (UVT) (for UV systems) are essential for process control.

Laboratory and National Monitoring Capacity (Nigeria Update)

The federal establishment of 12 water quality reference laboratories (2025) is a major institutional investment designed to decentralize analytical capacity, strengthen surveillance, and support enforcement and community water safety planning. This should materially improve sample turnaround, QA/QC, and permit verification if fully operational and networked.

QA/QC and Data Governance

Field duplicates, blanks, spike recoveries, calibration logs, chain of custody, and proficiency testing are minimum requirements. Digital data systems (SCADA + electronic lab notebooks + audit trails) increase transparency and support enforcement.

Challenges—Technical, institutional, and financial

Nigeria faces challenges in wastewater treatment, monitoring, and regulatory compliance, with existing frameworks often proving ineffective due to poor infrastructure, inadequate regulatory enforcement, insufficient technical capacity among staff, and a lack of investment in treatment technologies. Most of the challenges are categorized into three aspects:

- *Technical:* aging or undersized plants, intermittent power, membrane fouling, sludge disposal constraints, and increasing micropollutant loads.
- *Institutional:* overlapping remit, weak enforcement, insufficient lab capacity (improving with 2025 labs), and low operator training.
- *Financial:* Many utilities lack cost-recovery, tariffs are low, and capital for advanced systems is limited—making decentralized or hybrid low-energy systems attractive in many contexts.

Regulatory Frameworks and Compliance

The regulatory and institutional framework in Nigeria includes:

- NESREA enforces environmental standards, including effluent limits under the Surface and Groundwater Quality Control Regulations.
- State-level agencies (e.g., Lagos State Wastewater Management Office) also regulate, but enforcement is often weak.
- *Persistent challenges:* overlapping mandates, poor funding, and weak monitoring capacity.

National Regulation

NESREA is Nigeria's principal environmental enforcement agency with regulations governing effluent discharge and water quality (Surface and Groundwater Quality Control Regulation and industry-specific regulations). Facilities are required to meet permit parameters and report monitoring results. Legal instruments and schedules set numeric effluent limits for different sectors [21].

State Regulators and Local Institutions

States such as Lagos have specialized offices (Lagos State Wastewater Management Office, Lagos State Water Regulatory Commission) and state guidelines requiring central on-site treatment for large developments; these offer a model for subnational governance, but enforcement varies. Recent surveillance studies in Lagos have shown the presence of pathogens in wastewater canals, underlining the continuing public health risk [22].

Gaps in Enforcement and Capacity

Multiple analyses and sector reviews identify weak enforcement capacity, fragmented responsibilities across ministries and agencies, insufficient financial resources, and lack of operator training as major constraints to consistent compliance. Strengthening inter-agency coordination and transparent permitting/enforcement data are repeated recommendations [23].

Typical Regulatory Architecture

- *Effluent permits*: Specify numeric limits (e.g., BOD₅, TSS, NH₃-N, TP, fecal indicators), narrative standards (no visible oil/grease, no nuisance), monitoring frequency, and reporting.
- *Receiving water protection*: Water quality based effluent limits (WQBELs) complement technology-based standards.
- *Pre-treatment programs*: Industrial users receive categorical limits to protect publicly owned treatment works (POTWs) and biosolids quality.
- *Sludge (biosolids) rules*: pathogens (Class A/B), vector attraction reduction, and metal limits.
- *Reuse regulations*: Define log-reduction targets and fit-for-purpose quality for agriculture, industrial cooling, groundwater recharge, and potable reuse [24, 25].

Illustrative benchmarks (verify locally before design/operation):

- Secondary treatment effluent often targets BOD₅ ≤ 30 mg/L and TSS ≤ 30 mg/L, with pH 6–9.
- Nutrient-sensitive waters may require NH₃-N ≤ 1–5 mg/L, TN ≤ 10–15 mg/L, TP ≤ 0.1–1.0 mg/L depending on the receiving water objectives.
- Disinfection targets for unrestricted reuse frequently require E. coli nondetect or stringent log reductions using multi-barrier approaches.

Compliance Strategy

- *Permit mapping*: Translate each limit and monitoring requirement into an operational checklist (who/what/when/how).
- *Critical control points (CCPs)*: Identify process steps whose failure risks non-compliance (e.g., aeration blowers, return sludge pumps, UV intensity).
- *Action levels*: Set internal “early-warning” thresholds tighter than permit limits (e.g., 80% of limit).
- *Operational controls*: Standard operating procedures (SOPs) for startups/shutdowns, storm events, toxic shock, and bypass prevention.
- *Documentation and reporting*: Maintain calibration records, lab bench sheets, chain of custody, and incident logs; report exceedances per permit timelines.
- *Capacity development*: operator certification, refresher training, vendor support for instruments, and safety programs.

Safety and Environmental (HSE) Management

- *Worker safety:* Confined space entry, H₂S monitoring, electrical isolation/LOTO, pathogen exposure control, chemical handling (chlorine, acids/bases), and ergonomics.
- *Community protection:* Odor management, vector control, traffic safety, noise abatement.
- *Environmental safeguards:* spill prevention, chemical storage, emergency power, flood protection, and greenhouse-gas accounting (N₂O from nitrification/denitrification, CH₄ from digestion).

Cost, Energy, and Sustainability

- *Capex vs. Opex trade-offs:* MBRs deliver superior quality with higher energy and membrane costs; ponds/wetlands minimize energy but require land.
- *Energy intensity:* Aeration is typically 40–60% of plant electricity—optimize with real-time DO/ammonia control and blower turndown.
- *Resource recovery:* Biogas (CHP), struvite precipitation (P recovery), and side stream deammonification (ANAMMOX) for energy and chemical savings.
- *Life-cycle view:* Consider embedded carbon in materials, sludge end-use, and resilience benefits of decentralized/cluster systems in peri-urban areas.

Case-Type Snapshots (Illustrative)

- *Compact urban plant upgrade:* CAS → IFAS + cloth media + UV. Result: ammonia compliance without major tank expansion; energy rises modestly but within tariff.
- *Industrial food processor:* High-strength COD equalization + anaerobic Expanded Granular Sludge Bed (EGSB) reactor + aerobic MBR; energy offset via biogas; final RO for reuse in cooling towers.
- *Small town, land-rich:* facultative ponds + polishing wetlands; seasonal performance managed via baffles, algae control, and winter detention time.

Emerging Challenges and Research Frontiers

- *Micropollutants and PFAS:* Treatment trains with GAC/(Reverse Osmosis) RO/AOP; prioritize source control.
- *Antimicrobial resistance (AMR):* Surveillance of antibiotic resistance genes (ARGs) and disinfection optimization and sludge management to reduce dissemination.
- *Microplastics:* Advanced screening, DAF, membrane barriers; upstream product stewardship.
- *Climate resilience:* wet-weather storage, flood-resilient siting/electricals, and heat-aware biological control.
- *Digital twins and AI:* Soft sensors, anomaly detection, and model predictive control (MPC) to balance energy and permit risk.

Implementation Roadmap

- *Characterize influent and receiving water:* Seasonality, toxics, peak flows.
- *Set performance objectives:* Permit limits plus internal targets; reuse goals if applicable.
- *Select processes:* Match to objectives/constraints using multi-criteria analysis (cost, land, energy, skills, and risk).
- *Pilot or bench studies:* Verify kinetics, membrane fouling potential, coagulant demand.
- *Design and procurement:* Include redundancy, bypass control, online monitoring, and constructability.
- *Commissioning and training:* Gradual ramp-up, SOP validation, safety drills.
- *Operate, monitor, and optimize:* QA/QC, data analytics, and preventive maintenance.
- *Review and adapt:* Annual performance audits, energy and chemical benchmarking, and regulatory updates.

CURRENT TRENDS AND CONTEXT IN NIGERIA

Stronger Monitoring Infrastructure

- *12 National water quality reference laboratories:* Set up across Nigeria under the National Water Quality Reference Laboratories and Monitoring Network Programme to bolster water quality surveillance.
- *Freshwater restoration and source water protection programme:* Aligned with President Tinubu's Renewed Hope Agenda, aiming to safeguard water sources.
- *Ongoing standards development:* New regulations for ambience and irrigation water quality are being drafted, alongside community water safety planning (CWSP) and national drinking water quality standards.

Regulatory Framework and Enforcement Challenges

The regulatory bodies include NESREA, which oversees environmental compliance and has broad enforcement powers. The LSWRC (Lagos State Water Regulatory Commission) enforces water and wastewater standards within Lagos State.

Implementation gaps: Reports suggest that despite having laws on paper, enforcement remains low due to coordination issues, political interference, and revenue-driven motives.

Treatment Coverage and Technology Uptake

- *Low treatment rate:* Less than 10% of wastewater is treated nationally. Most Nigerian wastewater is discharged untreated, posing environmental and health risks.
- *Industrial case study:* A beverage plant in Benin City improved effluent quality but still exceeded NESREA limits for several parameters (e.g., COD, TDS, phosphate, and oil and grease), highlighting operational or design limitations.
- *Coagulation and adsorption locally used:* Studies in Anambra State found these methods effective for removing bacteria, organic matter, turbidity, and heavy metals from wastewater.

Decentralized and Sustainable Technologies

- *Rural and decentralized systems:* Community-based filtration, biodigesters, constructed wetlands, and solar-based systems are emerging as viable alternatives, especially in rural or peri-urban settings.
- *Vermifilters:* Low-cost, nature-based filters using earthworms for pollutant removal show promising efficiency (e.g., BOD₅ 90%, TSS 98%) and could be suitable for off-grid contexts.

Growing Demand and Private Sector Involvement

- *Industrial wastewater market growth:* Driven by stricter regulations and industry demands, sectors such as oil and gas, manufacturing, and food processing are increasingly adopting advanced technologies, such as membranes, filtration, and reverse osmosis.
- *Public-private collaboration:* Initiatives such as Water Health International (WHI) and biodigester programs exemplify private sector engagement in water treatment and sanitation services (Table 1).

Integrating Nigeria Trends with General Principles

Here's how the general treatment and compliance framework maps onto Nigeria's specific context:

NIGERIA-FOCUSED CASE STUDIES AND TRENDS

Federal Monitoring Push (2025 Labs and Roadmap)

The Federal Ministry of Water Resources and Sanitation launched a National Water Quality Conference (February 25, 2025) and announced 12 reference labs and a national roadmap — a foundational step for improving monitoring, outbreak response, and regulation. Timely commissioning, staffing, supply chains for reagents, and coordination with NESREA/States will determine the real impact.

Table 1. Assessment of wastewater management practices and investment opportunities in Nigeria

General principle	Nigeria situation
Monitoring infrastructure	Growing with 12 labs, but still worryingly insufficient in some regions.
Regulations and compliance	A strong legal framework exists. Enforcement is the weak link.
Treatment techniques	Industrial and urban core facilities use standard methods (sedimentation, biological, coagulation), but performance is mixed.
Decentralized solutions	Increasing interest in vermifilters, biodigesters, constructed wetlands—especially in underserved areas.
Private and renewables investments	Emerging opportunities in wastewater-to-energy, reuse, solar-powered systems, especially in industrial sectors.

Industrial Performance (Benin City Beverage Plant)

Site studies of industrial wastewater treatment plants (WWTPs) have documented cases where effluent exceeded prescribed NESREA limits for COD, TDS, oil and grease, and nutrients — highlighting the need for pre-treatment, operational optimization, and periodic independent audits.

Decentralized Pilots: Vermifiltration and Wetlands

Multiple small-scale and pilot projects in Nigeria and neighboring regions show that vermifilters and constructed wetlands can deliver robust BOD/TSS reductions and be cost-effective community options for abattoirs, estates, and schools — suitable where land is available and skilled operation is limited. Recent studies show high removal rates under design guidance (BOD reduction often >70–90% in well-operating systems).

Private Sector and Market Growth Forecasts

Market reports project growth in Nigeria’s water and wastewater service market (mid- to high-single-digit CAGR), driven by industrial compliance needs and municipal upgrades; public-private partnerships and operation and maintenance (O&M) contracting are emerging models.

CONCLUSION

The important aspects of wastewater treatment methods, quality control, and regulatory compliance in Nigeria have all been investigated in this study. Nigeria has entered a decisive phase in wastewater governance with the launch of a nationwide monitoring infrastructure. The biggest challenges lie not in technology availability but in institutional capacity, financing, and enforcement. By combining advanced and low-cost treatment options, strengthening regulation, and expanding monitoring, Nigeria can protect public health, safeguard ecosystems, and meet SDG 6.3 targets for safely treated wastewater. Nigeria faces challenges in wastewater treatment, monitoring, and regulatory compliance, with existing frameworks often proving ineffective due to poor infrastructure, inadequate regulatory enforcement, insufficient technical capacity among staff, and a lack of investment in treatment technologies. It is clear from a combination of primary and secondary research that although a number of treatment technologies are in use, such as WSPs, activated sludge processes, and septic systems, their efficacy is limited by a lack of infrastructure, irregular maintenance, and a lack of technical know-how. Furthermore, cutting-edge techniques such as anaerobic digestion and artificial wetlands are still underutilized, especially in rural and peri-urban regions where sanitation issues are most acute. Nigerian water quality monitoring is still in its infancy because of a lack of funds and sophisticated technology, despite being supported by national organizations like NESREA and several state environmental agencies. Effective detection, management, and prevention of pollution occurrences are jeopardized by this insufficiency. In conclusion, while Nigeria has made some strides in formulating regulatory standards and deploying basic wastewater treatment infrastructure, significant efforts are still required to bridge the gap between policy and practice. Addressing these gaps will demand a coordinated approach that integrates technological innovation, regulatory reform, and community engagement to protect water resources and promote sustainable development. Effective wastewater management unites

proven treatment techniques with rigorous monitoring and a proactive compliance culture. From primary clarification to advanced oxidation and membranes, process choices must be tailored to influent characteristics, regulatory endpoints, and local capacity. High-quality monitoring—rooted in sound sampling design, validated laboratory methods, and reliable online sensors—creates the feedback loop needed to keep systems stable and within permit limits. As pressures mount from population growth, climate variability, and micropollutants, utilities and industries should prioritize resilient, energy-aware treatment trains, digitalized monitoring, and continuous improvement to protect public health and the environment.

RECOMMENDATIONS

1. The government should be involved in the formulation of policies, execution, and maintenance of projects.
2. To prevent inequity and effort duplication, the state government and other organizations in charge of rural water delivery should properly coordinate the processes.
3. Increased funding for this industry is necessary to guarantee efficient coverage and timely service delivery.
4. The government should ensure good water quality standards and service efficiency.
5. Rural communities should be involved so that their needs can be specified in the design of wastewater systems.
6. Wastewater systems should be designed to minimize environmental impacts and promote sustainability.
7. Operationalize the 12 water quality labs urgently (staffing, supply chains, accreditation, and data portal) and ensure open sharing of routine monitoring results to improve transparency and enforcement.
8. *Adopt a tiered treatment approach:* conventional biological treatment for towns, MBR + polishing for reuse/potable recharge projects, and nature-based systems (Constructed Wetlands (CWs), vermifilters) for decentralized/rural needs. Use multi-criteria selection (land, energy, O&M capacity).
9. *Strengthen industrial pre-treatment and pollution charges:* require categorical pre-treatment for high strength/disruptive industrial streams, with frequent independent audits.
10. *Scale operator training and certification:* create national operator certification, refresher courses, and digital SOPs.
11. *Finance and Public–Private Partnership (PPP) models:* leverage concession/PPP models for larger WWTPs and microfinance/impact funds for decentralized community systems; link resource recovery (biogas, struvite) to revenue streams.
12. *Surveillance of emerging contaminants (PFAS, ARGs, micropollutants):* start targeted monitoring pilots in high-risk industries and urban centers and build analytical capacity in new labs.

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