

# Integrated Wastewater Quality Assessment, Risk Analysis, and Rehabilitation Costing for Sustainable Sanitation in African Aviation Infrastructure

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**Abstract:** The assessment of sanitation and wastewater management at Murtala Muhammed International Airport (MMIA), Lagos, was conducted to quantify sewage generation, evaluate effluent quality, and identify the rehabilitation needs of the sewage treatment plant (STP). Passenger and facility usage data indicated an annual sewage output of 1,117,087 cubic meters, equivalent to 255.04 cubic meters per day; when including contributions from service vehicles, the total increased to 275.04 cubic meters per day. Laboratory analyses revealed widespread non-compliance with benchmarks established by LASEPA, NESREA, WHO, and ICAO: treated effluent exceeded permissible limits for colour (854 Pt-Co versus 250), total suspended solids (154 mg/L versus 100), chloride (493 mg/L versus 250), chemical oxygen demand (201 mg/L versus 200), and biochemical oxygen demand (50.25 mg/L versus 20–50), while dissolved oxygen levels were critically low at 0.53 mg/L (versus  $\geq 2$ ). Microbial indicators persisted positive for total and faecal coliforms. Field inspections confirmed that the STP has been largely non-operational for over three years due to critical mechanical failures. The findings indicate severe risks of groundwater contamination, disease transmission, and regulatory violations. It is recommended that immediate rehabilitation, preventive maintenance, and the integration of sanitation strategies into the airport's master plan be undertaken to restore compliance and resilience, thereby contributing to the achievement of SDG 6.

**Keywords:** Airport sanitation; Effluent quality compliance; Murtala Muhammed International Airport; Public health risk; Rehabilitation costing; Wastewater treatment plant

## Highlights

- MMIA generates  $\approx 275.04 \text{ m}^3/\text{day}$  of sewage inflow, including  $\sim 20 \text{ m}^3/\text{day}$  from service vehicles.
- Treated effluent consistently exceeds limits for colour, TSS, chloride, COD, and BOD.
- Dissolved oxygen levels remain critically low (0.53 mg/L) with persistent total and faecal coliform contamination.
- The sewage treatment plant (STP) has been non-operational for over three years due to major mechanical failures.
- Rehabilitation is technically feasible at an estimated cost of ₦331,779,071 ( $\sim \$236,985.05$ ), with a well-defined scope of works.

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Figure 3.4. Risk matrix (colour-coded likelihood vs impact) for MMIA wastewater management. (Highlights Very High risks for regulatory non-compliance, sanitary hazards, and groundwater contamination; High risks for infrastructure failure and peak-day discharge events.)

## **I. Introduction**

Sanitation and wastewater management are fundamental components of airport infrastructure, directly influencing passenger health, environmental integrity, and compliance with regulatory standards. As international air travel continues to grow, airports increasingly function as urban centres that generate substantial quantities of wastewater originating from terminals, restrooms, dining establishments, and aircraft servicing operations (Ilyas & van der Hoek, 2020). In contrast to municipal systems, airport wastewater poses heightened risks due to its elevated concentrations of detergents, oils, nutrients, and microbial contaminants, thereby necessitating treatment systems that conform to rigorous effluent discharge standards (WHO, 2017; ICAO, 2018).

Despite their importance, wastewater systems at airports in low- and middle-income countries are often inadequate, causing unsafe discharges, groundwater pollution, and reputational damage (Mensah *et al.*, 2024). These issues mirror broader sanitation shortages in Sub-Saharan Africa, where over 70% of wastewater is untreated (UNEP, 2022). For major airports like Nigeria's Murtala Muhammed International Airport (MMIA), these problems threaten public health and compliance with ICAO and WHO standards.

To the best of our knowledge, this constitutes the inaugural peer-reviewed research to quantify wastewater generation, effluent quality, operational status, and rehabilitation costs at an African international airport, thereby establishing a foundational baseline for future scholarly investigations and policy development. The current investigation evaluates wastewater management at MMIA with four specific objectives: (i) to quantify sewage loading based on passenger traffic and facility utilisation, (ii) to assess the effluent quality of raw and treated sewage in accordance with LASEPA and NESREA standards, (iii) to scrutinise the operational status of the sewage treatment plant, and (iv) to project the financial resources requisite for its rehabilitation. By integrating laboratory analyses, engineering evaluations, and field inspections, this study provides the first comprehensive assessment of wastewater treatment performance at Nigeria's premier international airport. The findings contribute to global discourse on airport sanitation resilience, align with Sustainable Development Goal 6 (clean water and sanitation), and offer practical insights for comparable facilities in developing regions.

## **II. Methods**

### **Study Area**

Murtala Muhammed International Airport (MMIA) is located in Ikeja, Lagos State, Nigeria, at the following geographical coordinates: Latitude 6°34'22.79" N and Longitude 3°19'9.60" E. The airport handles more than two million passengers annually and generates wastewater from terminal restrooms, catering services, aircraft servicing operations, and ancillary facilities. A sewage treatment plant (STP), commissioned in 1977, was established to manage inflows from the international terminal. However, its operational efficiency has declined significantly in recent years, raising concerns about compliance with environmental regulations and public health standards.

### **Analytical Workflow**

The methodology of this study was designed to follow a sequential approach. First, sewage loading was estimated using passenger traffic data and facility utilisation assumptions. Second, wastewater sampling and laboratory analysis were conducted to assess the quality of the effluent. Third, a field inspection and operational assessment of the STP were carried out. Fourth, engineering costing was performed to determine rehabilitation requirements. Finally, governance and financing models were benchmarked to evaluate scalability and regional applicability. A schematic representation of this process is presented in Figure 2.1.

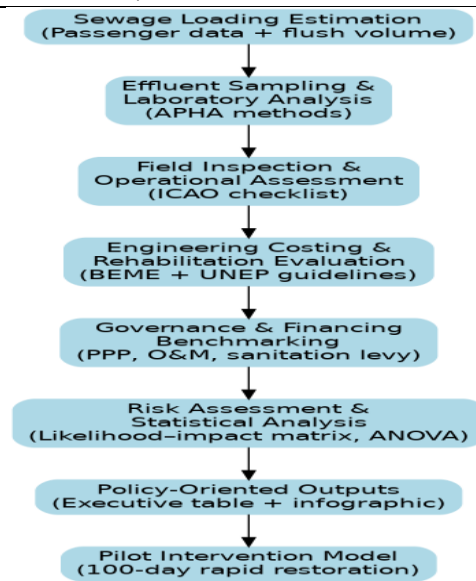


Figure 2.1. Methodology flowchart showing sequential steps in wastewater and sanitation assessment at MMIA.

## Sewage Loading Estimation

### Data Sources and Assumptions

Passenger statistics from FAAN (2013–2023) show a ten-year average of 1,960,799 passengers annually, rising to 2,123,741 in 2023–2024, with an 8.31% growth rate. According to WHO guidelines, 25% of passengers used the restrooms. Post-remodelling, the terminal had 263 toilets, each with a 2017 L cistern. Additional wastewater from service vehicles was 20 m<sup>3</sup>/day, per ICAO standards.

### Equations for Sewage Volume

The annual sewage volume ( $Q_{\text{year}}$ ) in litres per year was calculated as:

$$Q_{\text{year}} = P_{\text{pax}} \times f \times v \quad (1)$$

where  $P_{\text{pax}}$  indicates the number of passengers using toilets,  $f$  is the number of flushes per visit (assumed as 1), and  $v$  is the flush volume in litres. The daily sewage load ( $Q_{\text{day}}$ ) is calculated as:

$$Q_{\text{day}} = \frac{Q_{\text{year}}}{365} \quad (2)$$

The total daily inflow ( $Q_{\text{total,day}}$ ) was calculated by adding the contribution of service vehicles:

$$Q_{\text{total}} = Q_{\text{day}} + Q_{\text{vehicles,day}} \quad (3)$$

### Sensitivity Analysis

Sensitivity ranges for operational uncertainties were set: restroom usage fraction ( $r$ ) between 20% and 35%, flush volume ( $v$ ) between 6 and 9 litres, and flushes per user ( $f$ ) between 1 and 1.2. These outputs helped create a hypothetical time-series narrative (Section 3.2a) to illustrate how passenger growth impacts wastewater generation.

## Effluent Sampling and Laboratory Analysis

### Sampling Design

Effluent samples were collected on March 20, 2025, from the raw influent and final effluent, following the guidelines of the APHA (2017). Samples in sterilised polyethylene bottles were preserved at  $4 \pm 2^\circ\text{C}$  and analysed within 24 hours.

### Laboratory Parameters

The analyses covered:

- Physical parameters: colour, turbidity, total solids, conductivity, temperature, and pH.
- Chemical parameters: chloride, sulphate, nitrate, phosphate, chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (DO), oil and grease, and phenols.
- Trace metals: Ca, Mg, Zn, Fe, Cr, Pb, Cd, Ni, and Mn.

d. Microbiological indicators: total plate count, total coliforms, and faecal coliforms.

The results were compared with the discharge limits stipulated by the Lagos State Environmental Protection Agency (LASEPA) and the National Environmental Standards and Regulations Enforcement Agency (NESREA). For parameters not specified in the local standards, the World Health Organisation (who) guidelines were utilised.

### **Quality Control Procedures**

Quality control involved field duplicates (10%), method blanks, calibration standards, and certified reference materials. Analyses met APHA criteria, with data reliability ensured through a chain-of-custody and repeated analysis of outliers.

### **Prospective Multi-Season Monitoring Design**

Recognizing the limits of a single sampling, a multi-season monitoring framework is proposed to improve representativeness. It includes at least three campaigns in dry and wet seasons, during peak and off-peak passenger days, at multiple points across influent, intermediate, and final effluent stages. Microbiological parameters would be monitored weekly during peak wet seasons, while physicochemical and trace metal analyses would be done monthly and quarterly. This supports trend analysis with repeated-measures ANOVA, Mann–Kendall tests, and compliance tracking.

### **Field Inspection and Operational Assessment**

The field assessment of the Sewage Treatment Plant (STP) involved direct observation, photography, and interviews with operators. It evaluated comminutors, rotors, aeration tanks, sludge pumps, dosing systems, and control units, following the guidelines of ICAO (2018). Units were categorised as operational, degraded, or non-operational.

### **Engineering Costing and Rehabilitation Evaluation**

A bill of engineering measurement and evaluation (BEME) was prepared to quantify rehabilitation costs, including sludge evacuation, equipment replacement, refurbishment, installation of monitoring systems, construction of drying beds, and laboratory facilities. Prices from Lagos market rates in 2024 were validated with local suppliers. Costs followed UNEP (2022) guidelines, recommending equipment renewal and environmental monitoring.

### **Governance and Financing Benchmarking**

To assess scalability, governance, and financing frameworks, benchmarking used case evidence from African hubs. The models include: (i) outsourcing operations with KPI-based contracts; (ii) ring-fenced sanitation levies; (iii) performance-based public–private partnerships; and (iv) utility-led service contracts. KPIs used are compliance, downtime, and energy intensity (kWh/m<sup>3</sup>).

### **Risk Assessment Methodology**

Risks were evaluated utilising a likelihood–impact matrix (refer to Figure 3.4). The likelihood spectrum extended from Rare to Almost Certain, while the impact ranged from Minor to Severe. Risks were classified into four categories: Low, Moderate, High, and Very High, based on effluent exceedances, microbial hazards, and infrastructure conditions.

### **Statistical Analysis and visualization**

Data were analysed employing descriptive statistics, with compliance rates determined in accordance with standards established by LASEPA, NESREA, and WHO. For prospective datasets covering multiple seasons, it is advisable to utilize inferential statistical methods such as ANOVA, mixed-effects models, and Mann–Kendall tests. visualization techniques incorporated include bar plots depicting exceedances, heatmaps illustrating compliance, and time-series trend analyses. Reference standards were indicated by dashed horizontal lines within the figures to aid interpretation.

### **Policy-Oriented Visualization Outputs**

Two decision-support tools were pre-specified: (i) an executive summary table linking parameter exceedances to health/environmental implications and short- and medium-term interventions, and (ii) an infographic integrating the methodology flowchart with corrective actions. These outputs were designed to enhance readability for policymakers and regulatory agencies.

### **Pilot Intervention Model for Scalability**

A 100-day pilot for MMIA, scalable to other African airports, has four phases: Phase 1 (Days 1–20) includes bypass sealing and desludging; Phase 2 (Days 21–60) focuses on aeration overhaul and DO restoration; Phase 3 (Days 61–90) covers disinfection and sludge bed reactivation; Phase 4 (Days 91–100) includes commissioning, SOPs, and operator training. Weekly compliance checks link PPP or O&M payments to effluent quality.

### **Ethical and Regulatory Compliance**

Facility access was authorised by FAAN, and sampling followed biosafety protocols outlined by APHA (2017). Benchmarks were based on standards from LASEPA, NESREA, and WHO. Data and records are available from the author upon request.

### III. Results and Discussion

#### Sewage Loading Estimates

The sewage at MMIA, resulting from passenger activity, was estimated using FAA traffic data and WHO assumptions. The yearly volume is about 1,117,087 m<sup>3</sup>, with a daily average of 3.05 m<sup>3</sup>/s (around 1,117,087 m<sup>3</sup>). Service vehicles add roughly 20 m<sup>3</sup> daily, totaling 275.04 m<sup>3</sup> per day—similar to medium-sized municipalities. Jomo Kenyatta Airport has similar inflow levels (Njoroge *et al.*, 2023). ICAO (2018) highlighted the importance of accurate inflow estimates for proper plant capacity planning: underestimation risks overload, and overestimation reduces efficiency. Table 3.1 shows the sewage load at MMIA.

Table 3.1. Estimated sewage loading at MMIA.

| Parameter                         | Value                           |
|-----------------------------------|---------------------------------|
| Annual passenger load (2013–2014) | 2,123,741                       |
| Proportion using toilets (25%)    | 530,935 persons                 |
| Toilets in service                | 263                             |
| Average cistern flush             | 8 L/use                         |
| Annual sewage load                | 1,117,087 m <sup>3</sup>        |
| Daily sewage load                 | 255.04 m <sup>3</sup> /day      |
| Service vehicle contribution      | 20 m <sup>3</sup> /day          |
| <b>Total inflow</b>               | <b>275.04 m<sup>3</sup>/day</b> |

#### Effluent Quality Assessment

Laboratory analyses showed extensive non-compliance in both raw and treated sewage samples (see Table 3.2). The treated effluent exceeded limits for colour (854 Pt-Co vs. ≤250), total suspended solids (154 mg/L vs. 100 mg/L), chloride (493 mg/L vs. 250 mg/L), chemical oxygen demand (201 mg/L vs. 200 mg/L), and biochemical oxygen demand (50.25 mg/L vs. 20–50 mg/L). Dissolved oxygen was critically low at 0.53 mg/L (≥2 mg/L), and coliform bacteria remained present. These violations suggest inadequate treatment, common in Nigerian STPs due to poor maintenance (Olalekan *et al.*, 2021). Elevated BOD and coliforms pose risks of pathogen transmission and groundwater contamination (WHO, 2017).

Table 3.2. Effluent quality of raw and treated sewage at MMIA compared with standards.

| Parameter       | Raw  | Treated | Standard (LASEPA/NESREA) | Compliance      |
|-----------------|------|---------|--------------------------|-----------------|
| Colour (Pt-Co)  | 486  | 854     | 250                      | Non-compliant   |
| TSS (mg/L)      | 222  | 154     | 100                      | Non-compliant   |
| Chloride (mg/L) | 693  | 493     | 100–250                  | Non-compliant   |
| COD (mg/L)      | 326  | 201     | 40–200                   | Non-compliant   |
| BOD (mg/L)      | 81.5 | 50.25   | 20–50                    | Borderline/High |
| DO (mg/L)       | 0.48 | 0.53    | ≥2                       | Non-compliant   |
| Coliforms       | +VE  | +VE     | Nil                      | Non-compliant   |

Figure 3.1 presents a comprehensive analysis of wastewater quality, highlighting exceedances in physicochemical parameters (panel a), persistent microbial contamination (panel b), the composition of inflows (panel c), and the compliance gap with respect to standards (panel d).

Composite Figures: Wastewater Quality and Compliance at MMIA

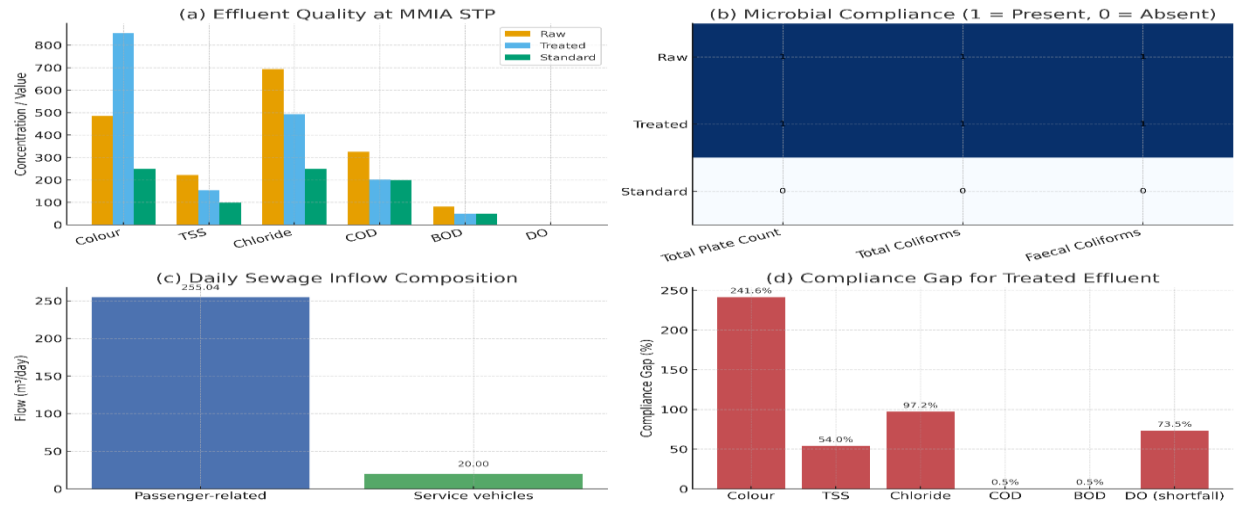


Figure 3.1. Composite wastewater analysis at MMIA STP.

## Illustrative Temporal Narrative

A single sampling in March 2025 used passenger growth trends (2013–2023) and seasonal factors (+25% wet, +20% dry) to project future effluent issues, shown in Figure 3.3. It emphasises that rising passenger numbers could worsen effluent exceedances, underscoring the need for urgent repairs and ongoing monitoring.

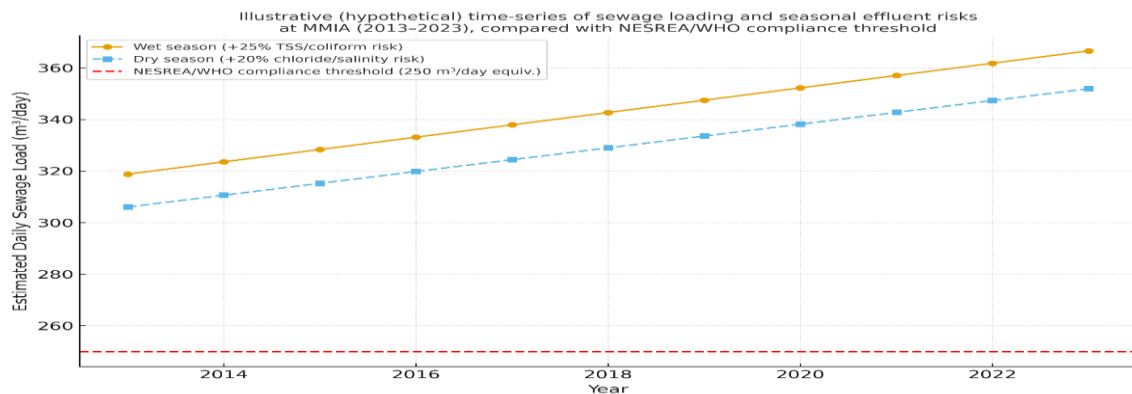


Figure 3.2. Illustrative (hypothetical) time-series of sewage loading and seasonal effluent risks at MMIA (2013–2023), compared with NESREA/WHO compliance threshold.

## Policy-Oriented Summary of Exceedances

An executive summary in Table 3.2a highlights exceedances, health and environmental risks, and interventions, offering policymakers accessible, pragmatic short- and medium-term solutions.

**Table 3.2a.** Executive summary of effluent exceedances, associated risks, and recommended interventions for MMIA.

| Parameter | Exceedance vs limit | Health/Environmental implications         | Priority interventions (0–6 mo)            | Medium-term actions (6–24 mo)                         |
|-----------|---------------------|-------------------------------------------|--------------------------------------------|-------------------------------------------------------|
| Colour    | 3.4× above          | Recalcitrant organics; poor aesthetics    | Optimise aeration and coagulant dosing     | Introduce tertiary polishing (filtration/UV)          |
| TSS       | 1.5× above          | Sediment transport; pathogen carriage     | Clarifier desludging, pump repair          | Install sludge drying beds, automate wasting          |
| Chloride  | ~2× above           | Salinity stress; infrastructure corrosion | Source control from aircraft waste streams | Segregated drainage with corrosion-resistant fittings |
| COD       | Slight exceedance   | Oxygen demand on receiving waters         | Aeration tuning; DO control                | Step-feed or IFAS upgrades                            |

|           |                 |                                         |                                          |                                               |
|-----------|-----------------|-----------------------------------------|------------------------------------------|-----------------------------------------------|
| BOD       | Borderline-high | Oxygen depletion; microbial persistence | COD measures + shock-load management     | Construct equalisation tanks                  |
| DO        | 74% below       | Anaerobiosis; odour                     | Blower/diffuser restoration              | SCADA-linked aeration                         |
| Coliforms | Persistent      | Pathogenic risk                         | Immediate disinfection (chlorination/UV) | Redundant disinfection with online monitoring |

### Plant Operational Status

The inspection (Plate 3.1) showed the Sewage Treatment Plant (STP) was non-operational due to critical failures in comminutors, rotors, sludge pumps, and drive systems. Operators rely on direct sludge evacuation instead of treatment. Similar failures elsewhere caused untreated discharges and outbreaks (Adewale *et al.*, 2019). ICAO (2018) mandates continuous operation for airport STPs, and MMIA's current status violates these standards.



Plate 3.1. Field survey photograph of the unserviceable sewage treatment plant equipment at MMIA.

### Costing for Rehabilitation

The engineering assessment estimated the rehabilitation costs at ₦331,779,071 (approximately \$236,985.05), encompassing sludge removal, rotor and pump replacement, comminutor refurbishment, dosing and monitoring systems, sludge drying beds, and laboratory setup. The detailed breakdown is provided in Table 3.3.

Table 3.3. Cost estimate for rehabilitation of MMIA STP.

| Item description                                                                                                            | Amount (₦)                     |
|-----------------------------------------------------------------------------------------------------------------------------|--------------------------------|
| Sludge evacuation, mechanical replacement of rotors and pumps, dosing systems, drying beds, laboratory, and ancillary works | ₦331,779,071<br>(\$236,985.05) |

Figure 3.2 shows the engineering rehabilitation process: condition assessment, costing, repairs, commissioning, and monitoring.

**Engineering Evaluation Pathway for Rehabilitation of MMIA STP**

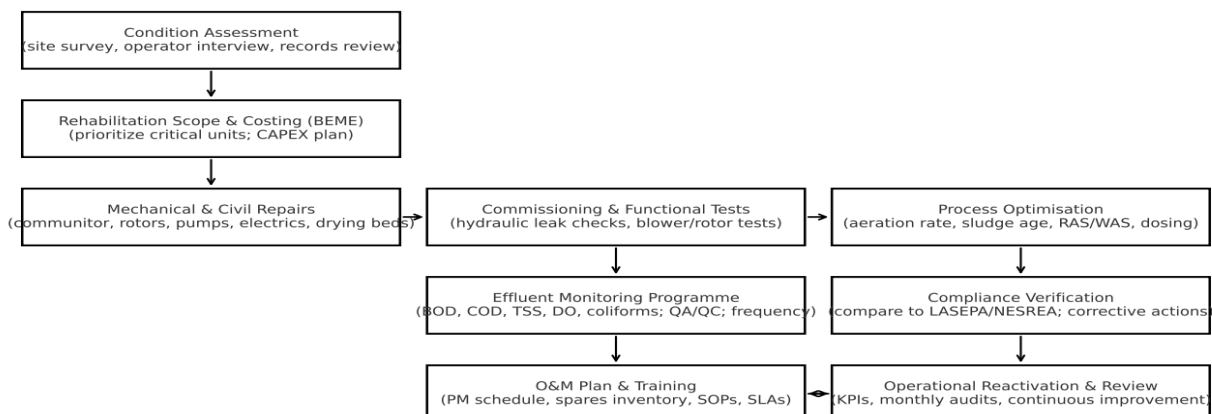


Figure 3.3. Engineering evaluation pathway for rehabilitation of MMIA STP.

## Environmental and Public Health Implications

Untreated effluent poses risks to groundwater, contributes to eutrophication, and harbours pathogens. Surveys revealed sewage within 10 meters of boreholes and staff housing, well below the WHO safety setback of 50-100 meters. Such practices have resulted in cholera and typhoid outbreaks in Nigeria (Okoye *et al.*, 2020). This highlights that wastewater mismanagement at MMIA compromises the safety of staff and communities, and jeopardizes Nigeria's compliance with ICAO and WHO standards.

## Comparative Insights

The issues at MMIA exemplify broader challenges faced by African airports. In Addis Ababa, the gradual expansion of sanitation services has resulted in operational bottlenecks (Abebe *et al.*, 2021), whereas in Nairobi, insufficient investment has perpetuated health risks (Njoroge *et al.*, 2023). These circumstances expose systemic deficiencies in infrastructure within Sub-Saharan airports, where passenger volumes exceed available capacity. Therefore, the rehabilitation of wastewater systems should be incorporated into comprehensive master planning.

## Synthesis and Scalability

This study represents the inaugural comprehensive evaluation of wastewater management at MMIA, encompassing sewage loading, testing, inspections, and associated costs. The findings validate instances of non-operational infrastructure, effluent exceedances, and compliance risks. Rehabilitation efforts are both feasible and economically prudent; however, ensuring sustainability necessitates the institutionalization of maintenance protocols and continuous monitoring.

A 100-day pilot program is designed to restore operational capacity and establish a replicable framework for African airports. Phase 1 (Days 1–20) encompasses bypass sealing and desludging procedures. Phase 2 (Days 21–60) emphasises aeration system overhauls and dissolved oxygen (DO) restoration. Phase 3 (Days 61–90) aims to enhance disinfection processes and reactivate sludge beds. Phase 4 (Days 91–100) involves commissioning activities, development of Standard Operating Procedures (SOPs), and operator training. It is advisable to conduct weekly compliance assessments. Public-Private Partnership (PPP)/Operation and Maintenance (O&M) contracts are contingent upon verified effluent quality.

## Risk Assessment

The risk analysis depicted in Figure 3.4 indicates that regulatory non-compliance, microbial hazards, and groundwater contamination are categorised as Very High risks. Infrastructure failure and peak-day overloads are classified as High risks, primarily attributable to effluent exceedances, equipment outages, and safety setbacks. Absence of prompt rehabilitation and continuous monitoring may result in violations, health threats, and damage to the organization's reputation.

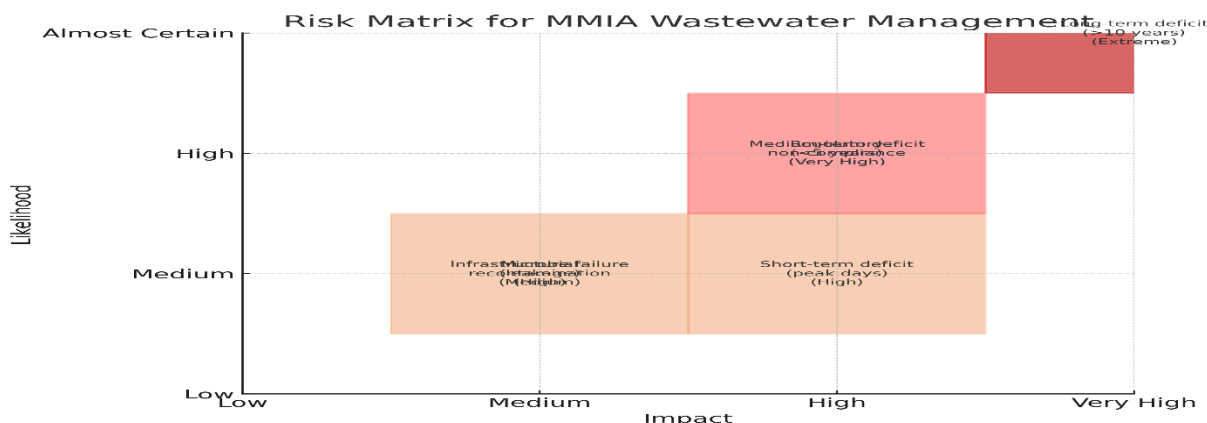


Figure 3.4. Risk matrix (likelihood vs impact) for MMIA wastewater management.

## Limitations and Future Work

This study was limited by a single-date sampling, which did not account for seasonal variations. Future research should incorporate multi-seasonal sampling across hydrological extremes. Cost estimates based on BEME, rather than comprehensive life-cycle operations and maintenance (O&M), introduce financial uncertainty. The analysis also did not consider emerging contaminants, such as pharmaceuticals, microplastics, and per- and polyfluoroalkyl substances (PFAS), which are increasingly significant in aviation wastewater. Furthermore, the case study was restricted to a single Nigerian airport; broader research encompassing multiple African airports would enhance generalizability and inform regional guidelines.

## IV. Conclusion and Recommendations

This study demonstrates that wastewater management at Murtala Muhammed International Airport (MMIA) is inadequate and operationally deficient. The airport produces approximately 275 m<sup>3</sup>/day of sewage, comparable to that of a medium-sized municipality; however, its sewage treatment plant (STP) has largely been non-operational for several years. Effluent testing reveals

ongoing non-compliance with standards established by LASEPA, NESREA, WHO, and ICAO, with violations observed in parameters such as colour, TSS, chloride, COD, BOD, low dissolved oxygen levels, and microbial contamination. These issues pose significant risks of groundwater pollution, eutrophication, and pathogen dissemination, thereby jeopardising public health, regulatory adherence, and Nigeria's international aviation reputation. The findings indicate that targeted rehabilitation and management reforms could restore effective treatment functions, safeguard communities, and ensure MMIA's sanitation practices meet international standards.

### **Recommendations**

- Immediate Rehabilitation – Prioritize the repair of critical mechanical units, the restoration of aeration and disinfection systems, and the installation of an on-site laboratory for routine effluent monitoring.
- Preventive Maintenance and Monitoring – Institutionalise standard operating procedures for preventive maintenance, supported by continuous effluent monitoring in accordance with ICAO environmental health guidelines.
- Strengthened Regulatory Oversight – Reinforce compliance through discharge permits, periodic audits, and enforcement by LASEPA and NESREA to ensure ongoing adherence to national and international standards.
- Safe Setback Design – Redesign and manage septic drainage and discharge fields to comply with WHO-recommended setbacks (50–100 m from boreholes and groundwater abstraction points).
- Integration into Airport Planning – Incorporate wastewater infrastructure rehabilitation into MMIA's long-term master plan, aligned with projected passenger growth and future operational demands.
- Capacity Building and Partnerships – Enhance operator competence through structured training, while fostering collaborations with universities, research institutions, and regulatory bodies for technical support and innovation.

### **Policy Statement**

Revamping wastewater management at MMIA is not only a regulatory obligation but also a strategic necessity for safeguarding passenger health, protecting the environment, and sustaining Nigeria's aviation competitiveness. Implementing these recommendations will position MMIA as a benchmark for resilient and sustainable airport sanitation in Africa, thereby advancing national commitments to Sustainable Development Goal 6 (Clean Water and Sanitation).

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### **Authors' Contributions**

Gambo A.T: Conceptualisation, fieldwork, data analysis, manuscript drafting, Methodology design,

Coker A.O.: Supervision and critical review.

Adefisoye S.A: Data validation, interpretation, and editing.

All authors read and approved the final manuscript.

### **Conflict of Interest**

The authors declare that they have no known financial or personal relationships that could have influenced this work.

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Data Availability.

Data supporting this study (laboratory sheets, calculation records, and costing summaries) are available from the corresponding author upon reasonable request.

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