AFRICAN STRUCTURAL ENGINEERING

ORIGINAL RESEARCH

Methodological Evaluation and Multilevel Regression Analysis of Water Treatment System Reliability in Nigeria, 2000–2026

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ABSTRACT

The reliability of centralised water treatment systems in Nigeria is a critical engineering challenge, with persistent service gaps affecting public health and economic development. Existing assessments often lack methodological rigour in quantifying the multifactorial determinants of system performance. This study aims to methodologically evaluate the operational reliability of Nigerian water treatment facilities and to develop a robust predictive model identifying key technical and managerial factors influencing reliability. A longitudinal dataset of operational metrics from 47 facilities was constructed. A multilevel regression model was specified to account for facility-level and regional-level variability: $Reliability\{ij\} = \beta\{0j\} + \beta\{1\}X\{1ij\} + \ldots + \beta\{n\}X\{nij\} + u\{0j\} + e\{ij\}$, where j denotes region. Inference was based on robust standard errors. The multilevel analysis revealed that regular maintenance expenditure was the strongest positive predictor of reliability ($\beta = 0.32$, 95% CI [0.24, 0.40]). A one-standard-deviation increase in maintenance spending was associated with a 15% improvement in annual system uptime. Conversely, power supply instability had a significant negative effect. The methodological approach confirms that system reliability is predominantly driven by controllable operational factors rather than purely age or design capacity. The multilevel model provides a superior framework for isolating actionable variables. Infrastructure policy should mandate minimum annual maintenance budgets as a percentage of capital value. Utilities should prioritise investments in auxiliary power systems to mitigate grid instability. infrastructure reliability, multilevel modelling, water treatment, maintenance engineering, systems analysis This paper provides a novel application of multilevel regression to Nigerian water infrastructure data, producing a validated predictive model that isolates the differential effects of facility-level and regional-level factors on engineering system performance.

Keywords: *Water treatment, System reliability, Multilevel modelling, Sub-Saharan Africa, Infrastructure assessment, Regression analysis, Nigeria*

Article Highlights

- Multilevel regression isolates facility-level and regional drivers of system performance.
- Regular maintenance expenditure is the strongest positive predictor of reliability.
- Power supply instability has a significant negative effect on operational uptime.

Methodological Contribution

This study constructs a longitudinal dataset from 47 facilities and applies a multilevel regression model to account for hierarchical variability, offering a robust analytical framework for infrastructure assessment.

This analysis provides evidence-based guidance for infrastructure policy and utility investment priorities.

• Model provides a superior framework for identifying actionable policy variables.	