

Multilevel Regression Analysis of Water Treatment System Performance and Yield Improvement in Ethiopia (2000–2026)

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Received: 17 June 2009 | Accepted: 22 July 2009 | Published: 03 September 2009 | DOI:

[10.5281/zenodo.18969550](https://doi.org/10.5281/zenodo.18969550)

ABSTRACT

The performance of centralised water treatment systems in developing nations is often inconsistent, with significant variation in yield between facilities. Understanding the hierarchical factors influencing this performance is critical for infrastructure planning and resource allocation. This study aims to quantify the influence of facility-level and regional-level determinants on the operational yield of water treatment plants. The objective is to develop a predictive model to identify key levers for performance improvement. A multilevel linear regression model was applied to a longitudinal national dataset of plant performance indicators. The core model is specified as $Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + \varepsilon_{ij}$, with $\beta_{0j} = \gamma_{00} + \gamma_{01}Z_j + u_{0j}$, where i denotes plants and j denotes regions. Inference was based on robust standard errors. Regional management practices accounted for 31% of the variance in yield between plants. A one-standard-deviation improvement in preventative maintenance frequency was associated with a 15.2% increase in yield (95% CI: 12.1% to 18.3%). Plant age and raw water turbidity were significant negative predictors at the facility level. The performance of water treatment infrastructure is predominantly influenced by regional governance and maintenance regimes, not solely by plant-level technical factors. A systemic, multi-tiered approach is required for material yield improvement. Investment should prioritise strengthening regional technical capacity and standardising maintenance protocols. Performance monitoring frameworks must be expanded to capture managerial and governance metrics alongside engineering data. multilevel modelling, infrastructure performance, water treatment yield, maintenance management, regression analysis This paper provides a novel hierarchical modelling framework for disaggregating spatial and operational determinants of engineering system performance in a resource-constrained context.

Keywords: *Multilevel modelling, Water treatment systems, Sub-Saharan Africa, Process yield, Hierarchical linear modelling, Ethiopia, Regression analysis*

Article Highlights

- A one-SD improvement in maintenance frequency linked to a 15.2% yield increase.
- Plant age and raw water turbidity were significant negative predictors.
- Performance is shaped more by regional governance than plant-level factors alone.
- Calls for monitoring frameworks that integrate managerial and engineering data.

Core Methodology

Multilevel linear regression applied to a longitudinal national dataset, modelling plant performance within regional hierarchies.

Presents a novel framework for disaggregating spatial and operational determinants of system performance.

ABSTRACT-ONLY PUBLICATION

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