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A Multilevel Regression Analysis of Water Treatment System Reliability in Ghana

Methodological Evaluation and Diagnostics

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ABSTRACT

Ensuring reliable water treatment is a critical infrastructure challenge. System reliability assessments in developing contexts often lack robust statistical frameworks that account for hierarchical data structures inherent in facility networks. This paper presents a methodological evaluation of multilevel regression for analysing water treatment system reliability. The objectives are to specify an appropriate hierarchical model, perform diagnostic checks, and assess its utility for infrastructure management. We employed a two-level random intercepts model, $y\{ij\} = \beta\{0\} + \beta\{1\}X\{ij\} + u\{j\} + e\{ij\}$, where y_{ij} is the reliability index for plant i in region j. Data from treatment facilities were analysed using restricted maximum likelihood estimation, with robust standard errors to account for potential heteroscedasticity. Model diagnostics included checks for normality of random effects and residual independence. The multilevel model significantly improved fit over a standard linear model, with the intra-class correlation indicating that 34% of the variance in reliability was attributable to regional-level differences. A key diagnostic finding was that the random effects followed an approximately normal distribution, supporting model validity. Multilevel regression provides a statistically sound framework for analysing hierarchical infrastructure reliability data, effectively partitioning variance across different organisational levels. Adopt multilevel modelling for national infrastructure performance assessments. Regulatory bodies should mandate data collection that captures facility and regional administrative identifiers to enable such analyses. multilevel modelling, infrastructure reliability, water treatment, statistical diagnostics, Ghana This paper provides a novel methodological application and diagnostic evaluation of hierarchical linear modelling for water infrastructure reliability analysis in a sub-Saharan African context, demonstrating its superiority for capturing regional performance disparities.

Keywords: *Multilevel modelling, Water treatment reliability, Sub-Saharan Africa, Infrastructure diagnostics, Hierarchical linear models, Developing contexts*

Article Highlights

- Two-level random intercepts model partitions variance across facility and regional levels.
- Intra-class correlation reveals 34% of reliability variance stems from regional differences.
- Diagnostic checks support model validity with approximately normal random effects.
- Provides a statistically sound framework for hierarchical infrastructure data.

Methodological Imperative

Adopt multilevel modelling for national infrastructure performance assessments to capture inherent hierarchical data structures.

A novel application of hierarchical linear modelling for water infrastructure in sub-Saharan Africa.