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A Multilevel Regression Analysis of Efficiency Gains in Ugandan Water Treatment Systems

A Methodological Case Study (2000–2026)

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ABSTRACT

Background: Evaluating the operational efficiency of water treatment infrastructure in developing nations is critical for resource allocation and sustainable development. Traditional single-level regression models often fail to account for the hierarchical structure of facility data, such as plants nested within districts and regions, potentially leading to biased inferences.

Purpose and objectives: This case study presents a methodological framework for applying multilevel regression modelling to assess efficiency gains in water treatment systems. Its objective is to demonstrate the model's superiority in quantifying the variance in efficiency attributable to different organisational levels and identifying key predictive factors.

Keywords: *Multilevel modelling, Water treatment efficiency, Sub-Saharan Africa, Infrastructure evaluation, Regression analysis, Sustainable development goals, Operational performance*

Article Highlights

- Three-level linear mixed-effects model quantifies variance across plants, districts, and regions.
- Chemical dosing accuracy shows significant positive association with plant efficiency scores.
- Methodology demonstrates structural appropriateness for nested engineering performance data.
- Recommends tailored policy interventions at regional and district levels.

Core Statistical Model

$y_{ijk} = \beta_0 + \beta X_{ijk} + u_k + v_{jk} + \varepsilon_{ijk}$, where y_{ijk} is the efficiency score for plant i in district j and region k, X represents plant-level covariates, and u_k, v_{jk}, and ε_{ijk} are independent random effects.

This analysis demonstrates the methodological advantages of multilevel regression for hierarchically structured infrastructure data.