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A Bayesian Hierarchical Model for Yield Improvement Diagnostics in Ethiopian Water Treatment Systems (2000–2026)

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ABSTRACT

Background: Water treatment infrastructure in many developing nations faces persistent challenges in operational efficiency and yield. Diagnostic tools for performance improvement often rely on deterministic models, which inadequately capture the inherent variability and hierarchical structure of facility networks.

Purpose and objectives: This work develops and evaluates a novel Bayesian hierarchical model to diagnose and quantify yield improvement potential across a national network of water treatment facilities. The objective is to provide a robust probabilistic framework for identifying systemic inefficiencies and prioritising interventions.

Keywords: *Bayesian hierarchical modelling, yield improvement, water treatment systems, Sub-Saharan Africa, operational diagnostics, developing nations, infrastructure evaluation*

Article Highlights

- Bayesian hierarchical model quantifies regional heterogeneity in water treatment performance
- Probabilistic framework distinguishes systemic inefficiencies from local plant factors
- Methodology enables tailored infrastructure investment over uniform national programmes
- Posterior distributions provide rigorous uncertainty quantification for all parameters

Methodological Contribution

Introduces a novel Bayesian hierarchical model, formally expressed as $y_{ij} \sim \text{Normal}(\alpha_j + \beta X_{ij}, \sigma^2)$, $\alpha_j \sim \text{Normal}(\mu_{\alpha}, \tau^2)$, for diagnosing yield improvement potential across hierarchical facility networks.

This article presents a statistically rigorous diagnostic framework for infrastructure evaluation in developing contexts.