AFRICAN STRUCTURAL ENGINEERING

Bayesian Hierarchical Modelling for Risk Reduction in Rwandan Water Treatment Systems

A Methodological Case Study

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ABSTRACT

Background: Water treatment infrastructure in developing nations faces significant reliability challenges due to heterogeneous operational conditions and sparse monitoring data. Conventional engineering risk assessments often lack the probabilistic rigour to quantify uncertainties across multiple facility types and regions, hindering targeted investment.

Purpose and objectives: This case study presents and evaluates a novel Bayesian hierarchical modelling framework for the probabilistic risk assessment of water treatment systems. Its objective is to quantify the reduction in failure risk achievable through specific infrastructure interventions within a real-world network.

Keywords: *Bayesian hierarchical modelling, Risk reduction, Water treatment systems, Sub-Saharan Africa, Infrastructure reliability, Developing nations, Methodological evaluation*

Article Highlights

• Quantified a 42% median reduction in annual critical failure probability post-intervention.

• Hierarchical structure revealed greater risk variance in smaller, rural facilities.

• Provides a probabilistic framework for prioritising infrastructure investment.

• Formally accounts for uncertainty across heterogeneous operational conditions.

Core Statistical Model

Bayesian hierarchical logistic regression: $\text{logit}(p\_ij) = \alpha\_j + \beta X\_ij$, with group-level intercepts $\alpha\_j \sim \text{Normal}(\mu\_\alpha, \sigma\_\alpha)$. Posterior distributions estimated via MCMC sampling.

This study presents a methodological framework evaluated on operational data from a real-world network.

📄 ABSTRACT-ONLY PUBLICATION

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