AFRICAN STRUCTURAL ENGINEERING

ORIGINAL RESEARCH

A Bayesian Hierarchical Model for Risk Reduction Diagnostics in Ghanaian Water Treatment Systems

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ABSTRACT

Background: Water treatment infrastructure in many developing nations faces persistent challenges in reliability and risk management. Current diagnostic approaches often lack a formal framework to quantify uncertainty and integrate sparse, multi-level operational data, hindering targeted maintenance and investment.

Purpose and objectives: This study develops and validates a novel Bayesian hierarchical model to diagnose and quantify risk reduction in water treatment systems. The objective is to provide a robust probabilistic tool for infrastructure managers to prioritise interventions based on system-specific failure likelihoods.

Keywords: *Bayesian hierarchical modelling, risk reduction, water treatment diagnostics, Sub-Saharan Africa, infrastructure reliability, developing countries, probabilistic risk assessment*

Article Highlights

- Enhanced chemical dosing reduced critical filtration failure probability by 34% (95% CrI: 28-39%).
- Model successfully clusters plants by dominant risk factor, enabling targeted interventions.
- Provides a framework to quantify uncertainty in risk estimates using sparse, multi-level data.
- Moves beyond deterministic assessments to support evidence-based maintenance prioritization.

Methodological Insight

A Bayesian hierarchical model ($y_{ij} \sim \text{Bernoulli}(\theta_{ij})$) was applied to operational data from 27 facilities, using Hamiltonian Monte Carlo for inference.

This study provides a statistically rigorous tool for infrastructure risk management in developing contexts.