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A Bayesian Hierarchical Model for the Cost-Effectiveness Diagnostics of South African Water Treatment Systems (2000–2026)

Anathi Botha[1,2] | **Thandiwe Nkosi**[3,4] | **Pieter van der Merwe**[2]
Kagiso Mokoena[2,5]

Department of Civil Engineering, Tshwane University of Technology (TUT) • *Stellenbosch University* • *University of Limpopo* • *Cape Peninsula University of Technology (CPUT)* • *Department of Civil Engineering, Cape Peninsula University of Technology (CPUT)*

Correspondence: abotha@gmail.com

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ABSTRACT

Background: Evaluating the cost-effectiveness of water treatment systems is critical for infrastructure investment and maintenance planning. Current assessments often rely on deterministic models that fail to adequately account for spatial heterogeneity, temporal variability, and inherent uncertainties in operational and financial data.

Purpose and objectives: This Data Descriptor presents a novel Bayesian hierarchical model designed to diagnose and measure the cost-effectiveness of municipal water treatment facilities. The objective is to provide a robust methodological framework that quantifies efficiency while formally incorporating uncertainty.

Keywords: *Bayesian hierarchical modelling, cost-effectiveness analysis, water treatment systems, Southern Africa, infrastructure diagnostics, engineering economics*

Article Highlights

- Bayesian hierarchical model quantifies cost-effectiveness with full uncertainty characterization.
- Analysis reveals substantial regional disparities in water treatment system performance.
- Methodology integrates plant-level data with regional economic variables for robust diagnostics.
- Framework supports targeted infrastructure audits and capital refurbishment planning.

Methodological Contribution

Presents a novel Bayesian hierarchical model ($\log(Cost_{it}) = \alpha_{j[i]} + \beta X_{it} + \varepsilon_{it}$) that moves beyond deterministic assessments to formally incorporate spatial, temporal, and parametric uncertainty in cost-effectiveness diagnostics.

This article provides a statistically rigorous framework for infrastructure investment planning.