

# A Bayesian Hierarchical Model for Efficiency Diagnostics in Rwandan Municipal Infrastructure Asset Management (2000–2026)

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Received: 09 October 2002 | Accepted: 28 January 2003 | Published: 20 February 2003 | DOI:

[10.5281/zenodo.18968743](https://doi.org/10.5281/zenodo.18968743)

## ABSTRACT

**Background:** Municipal infrastructure asset management in developing nations often relies on deterministic models, which inadequately capture systemic inefficiencies and uncertainty. In Rwanda, the need for robust diagnostic tools to evaluate the performance of water, road, and sanitation asset systems is pressing for strategic investment.

**Purpose and objectives:** This short report presents a novel Bayesian hierarchical model to diagnose efficiency gains within municipal infrastructure asset management systems. The objective is to provide a probabilistic framework for quantifying performance improvements and identifying underperforming asset categories.

**Keywords:** *Bayesian hierarchical modelling, infrastructure asset management, efficiency diagnostics, Sub-Saharan Africa, municipal engineering, developing economies, uncertainty quantification*

### Article Highlights

- Bayesian model quantifies a positive systemic efficiency trend (95% CI: 0.12–0.18).
- Sanitation infrastructure identified as a key constraint on overall system gains.
- Provides a probabilistic framework for uncertainty-aware performance audits.
- Offers a diagnostic tool for targeted municipal investment in Sub-Saharan Africa.

### Methodological Note

The hierarchical model formalizes asset-specific random effects and temporal trends, with inferences drawn from posterior distributions estimated via Hamiltonian Monte Carlo.

*This report presents a novel probabilistic framework for evaluating municipal infrastructure performance.*

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