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ORIGINAL RESEARCH

# A Bayesian Hierarchical Model for the Efficiency Diagnostics of Municipal Infrastructure Asset Systems in Uganda

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## ABSTRACT

**Background:** Municipal infrastructure asset systems in many developing nations face chronic inefficiencies, yet robust, data-driven diagnostic tools for their evaluation are scarce. Existing methods often fail to account for the hierarchical structure of asset data and inherent uncertainties in performance measurement.

**Purpose and objectives:** This study aimed to develop and validate a novel Bayesian hierarchical model to diagnose the technical efficiency of municipal infrastructure systems, providing a probabilistic framework for identifying performance drivers and potential gains.

**Keywords:** *Bayesian hierarchical modelling, municipal infrastructure, asset management, efficiency diagnostics, Sub-Saharan Africa*

### Article Highlights

- Bayesian hierarchical model quantifies municipal infrastructure efficiency with probabilistic uncertainty.
- Governance quality shows strongest effect on performance, with 95% credible interval [0.15, 0.31].
- Systemic underperformance is prevalent and linked to institutional rather than technical constraints.
- Probabilistic diagnostics enable targeted interventions for greatest marginal efficiency gains.

### Methodological Innovation

A Bayesian stochastic frontier model ($\ln(y_{ij}) = \beta_0 + \beta X_{ij} + v_{ij} - u_{ij}$) applied to a unique panel dataset of water, road, and drainage assets across multiple municipalities.

*This study provides a novel probabilistic framework for diagnosing municipal infrastructure efficiency in developing contexts.*