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A Bayesian Hierarchical Model for Risk Reduction in Municipal Infrastructure Asset Management

A Methodological Evaluation for Senegal

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ABSTRACT

Background: Municipal infrastructure asset management in developing contexts is challenged by data scarcity and heterogeneous asset conditions, complicating reliable risk assessment. Traditional deterministic models often fail to adequately quantify uncertainty, which is critical for prioritising maintenance investments.

Purpose and objectives: This study evaluates a novel Bayesian hierarchical modelling methodology for quantifying risk reduction in municipal infrastructure systems. The objective is to provide a robust, probabilistic framework for asset managers to optimise intervention strategies under uncertainty.

Keywords: *Bayesian hierarchical modelling, infrastructure asset management, risk reduction, Sub-Saharan Africa, municipal engineering, data scarcity, developing contexts*

Article Highlights

- Quantifies probabilistic risk reduction from infrastructure interventions under uncertainty.
- Hierarchical structure pools information across asset classes, aiding data-sparse contexts.
- Provides a statistically rigorous alternative to deterministic point-estimate practices.
- Methodology enables robust prioritization of maintenance investments for asset managers.

Core Model Structure

A Beta regression with hierarchical priors: $y_{ij} \sim \text{Beta}(\mu_{ij}\varphi, (1-\mu_{ij})\varphi)$, $\text{logit}(\mu_{ij}) = \alpha_j[i] + \beta X_{ij}$, $\alpha_j \sim \text{Normal}(\mu\_\alpha, \sigma\_\alpha)$.

This methodological evaluation presents a probabilistic framework for infrastructure risk assessment in data-scarce environments.