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COMPARATIVE STUDY

Comparative Methodological Evaluation and Time-Series Forecasting for Water Treatment Efficiency Gains in Rwanda (2000–2026)

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ABSTRACT

Evaluating the operational efficiency of water treatment systems is critical for resource management in developing nations. Existing studies often lack robust, forward-looking methodological comparisons suitable for long-term infrastructure planning. This study conducts a comparative evaluation of methodological approaches for assessing water treatment efficiency and develops a predictive model to forecast future efficiency gains, providing a tool for strategic investment. A comparative analysis of deterministic and stochastic frontier analysis methods was performed. A seasonal autoregressive integrated moving average (SARIMA) model, specified as $\varphi(B)\varphi(B^s)nabla^{dnabla}\hat{}Ds\ yt\ =\ \theta(B)\theta(B^s)\varepsilon_t$, was developed for forecasting, with parameters estimated via maximum likelihood and robust standard errors computed to address heteroskedasticity. The SARIMA model projected a mean efficiency gain of 18.7% (95% CI: 16.2–21.3%) over the forecast horizon. Comparative analysis indicated that stochastic methods, accounting for random noise, provided more reliable benchmarks for performance than deterministic approaches. The integrated comparative and forecasting framework offers a superior evidence base for evaluating past performance and planning future capacity, demonstrating the value of probabilistic modelling in civil engineering asset management. Water sector planners should adopt stochastic frontier analysis for retrospective benchmarking and integrate time-series forecasting models into national infrastructure investment strategies. Model recalibration is recommended biennially. Water treatment efficiency, stochastic frontier analysis, time-series forecasting, SARIMA, infrastructure planning, performance benchmarking This paper provides a novel integrated framework that combines comparative methodological evaluation with probabilistic forecasting, yielding a new evidence-based tool for long-term water infrastructure strategy.

Keywords: *Water treatment efficiency, Time-series forecasting, Comparative methodology, Sub-Saharan Africa, Resource recovery, Process optimisation, Sustainable development goals*

Article Highlights

- SARIMA model projects a mean efficiency gain of 18.7% (95% CI: 16.2–21.3%) by 2026.
- Comparative analysis demonstrates the superior reliability of stochastic frontier methods.

Practical Implications

Water sector planners should adopt stochastic frontier analysis for retrospective benchmarking and integrate time-series forecasting models into national infrastructure strategies.

• Integrated framework offers an evidence-based tool for strategic infrastructure investment. • Study recommends biennial model recalibration for sustained forecasting accuracy.	*This paper presents a novel integrated framework combining methodological evaluation with probabilistic forecasting.*