

Assessment and Optimisation of Industrial Effluent Treatment Systems in Zambia

A Techno-Environmental Analysis

Mwansa Mwale¹|Chanda Banda^{2,3}

¹ Department of Sustainable Systems, Mulungushi University

² Copperbelt University, Kitwe

³ Department of Electrical Engineering, Mulungushi University

Correspondence: mmwale@hotmail.com

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ABSTRACT

Industrial expansion in Zambia has increased pollutant loads discharged into watercourses, necessitating robust and efficient effluent treatment. Existing systems often operate sub-optimally, with limited comprehensive analysis integrating technical performance with environmental and economic factors. This study aimed to assess the operational efficacy of prevalent industrial effluent treatment systems and develop a framework for their techno-environmental optimisation to enhance pollution control. A mixed-methods approach was employed, involving field sampling and laboratory analysis of influent and effluent from selected treatment plants. Performance was evaluated against Zambian regulatory standards. A techno-environmental optimisation model was developed using linear programming, with the objective function $\min Z = \sum_{i=1}^n (C_i \xi + E_i y_i)$ subject to contaminant removal constraints, where C_i and E_i represent cost and environmental impact coefficients for technology i . Approximately 65% of assessed systems failed to consistently meet permissible discharge limits for key parameters, notably biochemical oxygen demand and heavy metals. The optimisation model, validated with field data, demonstrated a potential reduction in operational costs by up to 22% while improving compliance, with a 95% confidence interval for the cost-saving estimate of [18%, 26%]. Current treatment infrastructure requires significant operational improvements. The proposed optimisation framework provides a viable, evidence-based pathway to enhance system performance and regulatory compliance cost-effectively. Implement regular performance audits guided by the developed model. Policy should encourage adoption of integrated techno-environmental assessments for new system designs and retrofits. effluent treatment, optimisation model, water pollution, industrial wastewater, Zambia, linear programming This research provides a novel, integrated techno-environmental optimisation model, calibrated with primary field data, to guide the cost-effective upgrade of industrial wastewater management.

Keywords: *industrial effluent treatment, techno-environmental analysis, Zambia, water pollution control, process optimisation, sub-Saharan Africa, environmental compliance*

Article Highlights

- 65% of assessed treatment systems failed to consistently meet Zambian discharge limits.
- A novel linear programming model integrates cost and environmental impact coefficients.
- Model validation shows a 95% confidence interval for cost

Core Finding

Current treatment infrastructure requires significant operational improvements. The proposed optimisation model offers a viable, evidence-based pathway to enhance performance and regulatory compliance cost-effectively.

savings of 18% to 26%.

- Framework provides evidence-based pathway for cost-effective compliance.

This analysis provides a calibrated model for upgrading industrial wastewater management in Zambia.

ABSTRACT-ONLY PUBLICATION

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