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Sustainability Analysis of Municipal Solid Waste Fines Stabilization Using Biopolymers: CO_2 Emissions, Financial Evaluation, ESG, and SDG Alignment

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Abstract

The management of Municipal Solid Waste (MSW) has become a pressing global challenge, with Municipal Solid Waste Fines (MSWF)—the fine fraction of processed MSW—emerging as a potential resource for geotechnical applications when appropriately stabilized. This study conducts a comprehensive sustainability analysis of three MSWF stabilization methods: biobased stabilizers Xanthan Gum (XG) and Agar Gum (AG), and traditional lime. The analysis evaluates carbon footprints, economic viability, Environmental, Social, and Governance (ESG) impacts, and alignment with Sustainable Development Goals (SDGs) 9, 11, 12, 13, and 15. Results reveal that AG is carbon-negative, producing -2.53 kg CO_2e per ton of MSWF, while XG emits 17.76 kg CO_2e/ton, and lime emits a substantial 102 kg CO_2e/ton. Financially, lime and XG are cost-competitive at approximately ₹516/ton, whereas AG, at ₹2073.5/ton, offers long-term economic benefits through carbon credits, particularly in high-value carbon markets. ESG analyses highlight the superior environmental and social performance of bio-based stabilizers, with AG excelling due to its carbon sequestration potential and minimal ecological disruption. Both sustainability approaches—reusing MSWF and adopting biopolymers—align strongly with SDGs, promoting sustainable infrastructure, urban development, responsible consumption, climate action, and biodiversity protection. This study underscores the potential of bio-based stabilizers to transform waste management and geotechnical engineering, offering a pathway toward resilient and environmentally responsible construction practices. These findings provide actionable insights for policymakers, engineers, and sustainability practitioners aiming to integrate circular economy principles into infrastructure development.

Keywords: Municipal Solid Waste Fines (MSWF); Sustainability analysis; Bio-based stabilizers; Xanthan Gum (XG); Agar Gum (AG); Lime stabilization; Carbon footprint; CO_2e emissions; Environmental, Social, and Governance (ESG)