

Sustainability Assessment of Biopolymer–Stabilized Municipal Solid Waste Fines: Carbon Footprint, Economic Performance, and ESG–SDG Integration

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Abstract:

The management of Municipal Solid Waste (MSW) presents a critical global challenge, with Municipal Solid Waste Fines (MSWF)—the fine fraction generated during MSW processing—offering potential for reuse in geotechnical applications when suitably stabilized. This study presents a comprehensive sustainability assessment of MSWF stabilization using two bio-based stabilizers, Xanthan Gum (XG) and Agar Gum (AG), in comparison with conventional lime stabilization. The assessment integrates carbon footprint analysis, financial evaluation, Environmental, Social, and Governance (ESG) considerations, and alignment with Sustainable Development Goals (SDGs) 9, 11, 12, 13, and 15.

Results indicate that AG exhibits a carbon-negative profile, generating -2.53 kg CO_{2e} per ton of MSWF, whereas XG and lime result in emissions of 17.76 kg CO_{2e}/ton and 102 kg CO_{2e}/ton, respectively. From an economic perspective, lime and XG demonstrate comparable short-term costs of approximately ₹516/ton, while AG incurs a higher initial cost of ₹2073.5/ton; however, AG offers long-term economic advantages through potential carbon credit revenues, particularly under high-value carbon markets. ESG evaluation highlights the superior environmental and social performance of bio-based stabilizers, with AG standing out due to its carbon sequestration potential and reduced ecological disturbance.

The dual sustainability strategy of MSWF reuse and biopolymer adoption demonstrates strong alignment with multiple SDGs, supporting sustainable infrastructure development, urban resilience, responsible material use, climate mitigation, and biodiversity conservation. Overall, the findings emphasize the potential of bio-based stabilizers to advance circular economy-driven waste management and environmentally responsible geotechnical practices, providing valuable insights for policymakers, engineers, and sustainability stakeholders.

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).