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Research article

Monitoring and modeling leachate characteristics in simulated landfill conditions: Assessing tropical region impacts on solid waste degradation and pollution risks for climate resilient landfill management

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ABSTRACT

The widespread use of open dumping systems worldwide poses notable risks to groundwater and surface water supplies and increases air pollution. The current research lacks a comprehensive understanding of the biodegradation and leachate generation of high-organic waste (>70 %) in tropical landfills that operate during the dry season (under no infiltration conditions). This study aimed to simulate leachate generation and waste stabilization under dry season conditions in lab-scale landfill reactors operated at ambient temperatures to understand the fate and transport mechanisms of pollutants within the system. The two reactor dimensions were a cross-section of 1 × 1 m and a height of 1.1 m. The wet-to-dry solid waste ratio was kept at 73:27 and 62:38 for the two reactors. A first-order degradation kinetic model was developed to predict the biodegradation of fresh municipal solid waste, and changes in leachate quality over time were examined. High leachate concentrations were observed during the first 12 weeks, and the pH gradually increased to 6.5 by the end of week 54. The chemical and biochemical oxygen demand decreased from 50,250 to 13,980 mg/L (79.32 %) and from 92,160 to 19,560 mg/L (72.18 %), respectively. Leachate characteristics under varied and uncontrolled conditions were predicted using a modified first-order decay model. High prediction accuracy was observed for BOD_5 ($R^2 = 0.89$), COD ($R^2 = 0.82$), and VFA ($R^2 = 0.89$), indicating the model's goodness of fit. The study focuses on novel insights into moisture-limited MSW degradation and long-term high-strength leachate dynamics under tropical dry landfills.

1. Introduction

Urban sprawl and exponential population growth have contributed to an increased waste output (Laohalidanond et al., 2015). In India, solid waste disposal is a primary environmental concern because of insufficient garbage collection, inefficient door-to-door collection, inadequate waste management, and a lack of quantitative and qualitative data, leading to an increase in unhygienic and polluting dumpsites (Hamad, 2023; Mor and Ravindra, 2023). Of the 1359 landfills identified in India, 379 are currently in operation (CPCB, 2022). Landfills can seriously threaten the environment, including aquifers and surface water bodies, because they release a variety of pollutants through landfill gases (mainly CH_4, CO_2, CO, and H_2S) and landfill leachate, which includes heavy metals and refractory organic compounds (Alam et al., 2024; Xiang et al., 2025). Leachate also contains high levels of inorganic elements such as metals, chlorides, sulfates, nitrite, nitrate, and

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