ABSTRACT

Heavy metal pollution in soil and water, primarily caused by human activities like unregulated landfill practices, poses significant environmental and health risks. Landfill leachates, enriched with organic, inorganic, and xenobiotic substances, contaminate soil and groundwater, adversely affecting agriculture and ecosystems. To address this, effective heavy metal remediation is crucial. Eco-friendly biosorbents derived from agro-wastes have gained attention as cost-effective solutions. This study focuses on polyaniline (PAni), a redox-active conducting polymer with excellent adsorption capabilities. Two PAni-based bio-composites, incorporating sugarcane bagasse and sawdust, were synthesized to enhance heavy metal ion adsorption efficiency, offering a sustainable approach to environmental remediation.

In light of the above discussion, we have mainly focussed on the three main objectives-

Objective 1: Characterization of landfill leachate, groundwater and soil collected from open landfill sites in the Brahmaputra valley.

Objective 2: Characterization and application of PAni biocomposites (doped and undoped) for removal of toxic heavy metal from landfill leachate.

Objective 3: Assessment of the adsorption kinetics and equilibrium studies for the potential removal of toxic metals using polyaniline (PAni) biocomposite.

The investigated site is an 8-acre municipal waste landfill in Tezpur town that is close to the Morabharali River, a paleochannel of the Jiabharali river (92.81°E.26.63°N) and the surrounding area (soil and groundwater) is at great risk from pollution from the municipal rubbish disposal site

Characterization of landfill leachate, groundwater and soil collected from open landfill sites in the Brahmaputra valley.

The study aimed to evaluate the levels of hazardous metals (Zn, Cd, Cr, Pb, and Ni) in various environmental media—groundwater, soil, and leachates—around a landfill site and assess their impact on human health. A comprehensive human health risk assessment (HHRA) was conducted, considering all possible exposure pathways (oral, inhalation, and dermal). The study found significant ecological risks associated with the high concentrations of heavy metals in landfill soil, with these pollutants posing carcinogenic risks through direct intake, inhalation, and skin contact. Children exhibited hazard index (HI) values 6.5 times higher than adults, but both landfill workers and nearby residents had HI values within the safe limit (≤1). However, adults in residential areas had a higher Incremental Lifetime Cancer Risk (ILCR) compared to children. Hierarchical clustering analysis (HCA) categorized the monitoring sites into low (LP), moderate (MP), and high pollution (HP) groups, while principal component analysis (PCA) revealed key contributors to contamination across media. Four principal components explained 96.86% of groundwater variance, with PC1 highlighting Mn and Ni's prominence. Leachate analysis attributed major variances to Cr, Co, and pH (PC1, 48.25%) and anthropogenic sources such as Cu, Zn, and Pb (PC2, 20.98%). In soil, PC1 indicated the role of Cu and Zn from sources like automotive parts and electroplated goods (53.27%), with ash residues from tire burning contributing to high Zn concentrations.

Further analysis showed heavy metals in landfill leachates posing significant risks to plants and humans. Soil and leachate samples were assessed for physico-chemical properties, and phytotoxicity tests on *Solanum lycopersicum* (tomato), *Brassica nigra* (mustard), *Spinacia oleraceae* (spinach), and *Coriandrum sativum* (coriander) measured germination indices and relative growth. Pot experiments showed the highest germination index in *Coriandrum sativum* (67.51%) and the lowest in *Solanum lycopersicum* (48.24%). Petri dish tests revealed the highest germination index in *Brassica nigra* (82.34%) and the lowest in *Spinacia oleraceae* (14.81%). Heavy metal accumulation varied by plant and medium, with the roots of *Brassica nigra* and *Spinacia oleraceae* accumulating the highest levels of Cu, Mn, and Zn, while shoots of *Coriandrum sativum* had the lowest. Notably, Fe, Pb, and Cd were absent in leachates. These findings highlight the varying capacities of plants to tolerate and accumulate heavy metals, emphasizing the need for improved waste management practices to reduce environmental contamination and associated risks.

Characterization and application of PAni biocomposites (doped and undoped) for removal of toxic heavy metal from landfill leachate

Landfill leachates, highly toxic wastewaters laden with pollutants, pose significant environmental risks if not properly managed. This study explored the use of conductive polymer-based biocomposites, synthesized from polyaniline (PAni) modified sugarcane bagasse and sawdust, for heavy metal removal from leachates. The biocomposites were prepared via a straightforward synthesis method and characterized through techniques such as Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction spectroscopy (XRD), transmission electron microscopy (TEM), and energy-dispersive X-ray spectroscopy (EDX). Heavy metal concentrations in leachates were monitored using Inductive Coupled Plasma Mass Spectrometry (ICP-MS), which demonstrated the biocomposites' remarkable adsorption efficiency. Undoped PAni-sawdust biocomposites achieved the highest removal efficiencies for boron (75.59%) and chromium (53.49%), while doped variants showed maximum removal rates for cobalt (80.55%), nickel (67.89%), zinc (38.3%), silver (97.09%), cadmium (80.3%), and lead (74.25%). SEM and EDX analyses revealed insights into the biocomposites' ultrastructure and heavy metal adsorption mechanisms. These findings underscore the potential of PAni-based biocomposites as cost-effective and efficient adsorbents for environmental remediation of heavy metal-contaminated landfill leachates.

Assessment of the adsorption kinetics and equilibrium studies for the potential removal of toxic metals using polyaniline (PAni) biocomposite

Heavy metal remediation from wastewater is essential for environmental sustainability and public health. This study investigated the removal of lead (Pb) and cadmium (Cd) ions from aqueous solutions using biocomposites derived from sugarcane bagasse and sawdust—abundant agricultural and industrial byproducts. The biocomposites were enhanced with conductive polymers, including doped and undoped polyaniline (PAni), to improve adsorption efficiency. Batch experiments evaluated the effects of contact time, adsorbent dosage, pH, and initial metal ion concentration. Optimal removal efficiencies were achieved at an initial pH of 6.5–8, with maximum adsorption at 12 hours, stabilizing at 24 hours. Sorption was most

effective at a dosage of 0.5 g/mL, with Cd showing peak removal at 50 ppm and Pb at 10 ppm. Adsorption kinetics followed a pseudo-second-order model, indicating high affinity and efficiency. Regeneration experiments demonstrated the biocomposites' reusability over five cycles, retaining removal efficiencies above 92% for Cd and Pb ions. The use of PAni-doped and undoped sugarcane bagasse and sawdust offers an eco-friendly, cost-effective solution for wastewater treatment while addressing agro-waste management challenges. Despite growing concerns about pollution from unmanaged landfills, studies on eco-toxicological risks in northeast India remain scarce. This research highlights the dual benefits of heavy metal remediation and sustainable agro-waste utilization, emphasizing the need for focused efforts in pollution mitigation and public health protection.