EVALUATION OF MICROPLASTIC POLLUTION IN THE INDIAN NORTHWEST COASTAL AREA: SEASONAL EFFECTS, CO-CONTAMINANTS, AND REMEDIATION

ABSTRACT

Microplastic (MP) pollution has emerged as a pervasive global threat, significantly impacting ecosystems and human health. MPs, originating from diverse sources, accumulate in various environments and interact with co-contaminants such as persistent organic pollutants (POPs) and heavy metals, amplifying ecological and health risks. This research addresses key aspects of MP contamination, including seasonal variations, remediation strategies, co-contaminant interactions, and biodegradation of associated pollutants. Employing advanced analytical techniques, the study aims to develop innovative, sustainable approaches to mitigate MP pollution and its associated hazards.Seasonal dynamics of MP pollution were assessed along the northwest coast of India, specifically Gorai Beach, through a first-of-its-kind comprehensive investigation. Sand samples collected across pre-monsoon, monsoon, and post-monsoon seasons were analyzed for MP abundance, morphotype, size, color, and polymer composition. The results revealed significant seasonal variations, with the highest MP abundance observed during the monsoon (7326.6 particles/kg). Predominant polymer types included high-density polyethylene (HDPE) and polypropylene (PP), while pellet-shaped and blue-colored MPs were the most abundant morphotypes. Scanning electron microscopy (SEM), Raman spectroscopy, and atomic force microscopy (AFM) further characterized MPs, revealing their potential to adsorb co-contaminants. Notably, the polymer hazard index indicated extreme danger during the post-monsoon season, emphasizing the critical role of MP morphotypes in contaminant interactions. The study explored advanced remediation techniques for MPs and nanoplastics (NPs), focusing on innovative eco-friendly solutions. Iron oxide nanoparticles (Fe3O4) achieved a removal efficiency of 62–87% for MPs within 12 hours, while enzyme-induced calcite precipitation (EICP) successfully sequestered polystyrene nanoparticles (PSNPs) with a 96% removal rate within 30 minutes. EICP leveraged electrostatic attraction and calcite entrapment, as confirmed by scanning electron microscopy, X-ray diffraction, and thermogravimetric analysis. These findings demonstrate the potential of combining biological and mineralization processes for NP remediation, providing a sustainable approach for water treatment. Further investigation into co-contaminants associated with MPs

revealed significant adsorption of heavy metals (e.g., Cr, Mn, Cd) and organic compounds (e.g., phthalates, triglycerides) by HDPE and PP pellets, particularly during the monsoon season. Analytical techniques, including SEM-EDX, ICP-MS, and GC-MS, identified hazardous compounds exceeding WHO guidelines, underscoring the need for targeted remediation strategies to mitigate environmental risks. In addressing terephthalic acid (TPA), a priority pollutant derived from polyethylene terephthalate (PET), the study demonstrated the biodegradation potential of Rhodococcus erythropolis (MTCC 3951). This bacterium efficiently degraded TPA, producing polyhydroxyalkanoate (PHA) biopolymers as a by-product, offering a dual benefit of pollution control and biopolymer synthesis. Optimized degradation conditions included a temperature of 30 °C, pH 8.0, and 200 rpm agitation speed, enabling robust TPA removal even in industrial wastewater.To enhance the sustainability of TPA remediation, R. erythropolis cells were immobilized in kappa-carrageenan (KC) cryogels. These cryogels, strengthened through freeze-thaw cycles, exhibited superior stability, reusability, and biodegradation efficiency across multiple cycles. Characterization studies confirmed the cryogels' structural integrity and potential for eco-friendly bioremediation.