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Microplastics in Aquatic and Terrestrial Sediments: Occurrence, Analytical Techniques, Environmental Interactions, and Ecotoxicological Implications

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ABSTRACT

Microplastic pollution has emerged as one of the most complex and persistent environmental challenges of the twenty-first century, driven by the exponential growth of plastic production and the inefficiency of global waste management systems. While early research predominantly focused on floating plastic debris in marine surface waters, growing scientific attention has shifted toward sediments, soils, freshwater systems, and food matrices, where microplastics accumulate, interact with contaminants, and exert long-term ecological effects. This article presents an extensive and critical synthesis of existing research on microplastics in sediments and related environmental compartments, drawing exclusively on established peer-reviewed literature. The review elaborates on the sources and formation pathways of microplastics, their spatial distribution across marine, freshwater, agricultural, and remote environments, and the physicochemical processes governing their environmental behavior. Particular emphasis is placed on analytical and extraction techniques, including density separation, spectroscopic identification, and emerging imaging-based approaches, highlighting their strengths, limitations, and methodological uncertainties. Furthermore, the article explores the role of microplastics as vectors for heavy metals and organic pollutants, examining sorption mechanisms, competitive interactions, and implications for contaminant bioavailability. Ecotoxicological evidence from laboratory bioassays and field observations is discussed in depth to elucidate biological responses across trophic levels. By integrating occurrence data, methodological advancements, and ecological impacts, this work identifies critical knowledge gaps and conceptual challenges that hinder risk assessment and management strategies. The analysis underscores the necessity of harmonized methodologies, interdisciplinary research frameworks, and context-specific remediation strategies to address microplastic pollution in sediments and associated ecosystems. Ultimately, this article contributes to a deeper theoretical understanding of microplastics as dynamic environmental contaminants and provides a foundation for future research and policy development.

INTRODUCTION

The global proliferation of plastic materials represents one of the defining environmental transformations of the modern era. Since the mid-twentieth century, plastics have been integrated into nearly every sector of human activity due to their durability, low cost, and versatility. However, these same properties have led to their persistence in the environment, where they fragment into progressively smaller particles rather than fully degrading. Microplastics, commonly defined as plastic particles smaller than 5 millimeters, have become ubiquitous across marine, freshwater, and terrestrial ecosystems (Thompson et al., 2004; Andrady, 2011). Early scientific discourse framed plastic pollution primarily as a marine litter problem, focusing on visible debris accumulating along coastlines and ocean gyres. Over time, research revealed that a substantial fraction of plastic mass is not readily observable at the surface, prompting the seminal question of “where is all the plastic?” (Thompson et al., 2004).

Subsequent investigations demonstrated that sediments act as major sinks for microplastics, accumulating particles through hydrodynamic transport, biofouling-induced sinking, and deposition processes (Van Cauwenberghe et al., 2015). Unlike surface waters, sediments provide a relatively stable environment where microplastics can persist for extended periods, interact with minerals and organic matter, and influence benthic ecosystems. The recognition of sediments as critical reservoirs marked a conceptual shift in microplastic research, expanding the scope beyond marine environments to include freshwater bodies, agricultural soils, and even food products (Di and Wang, 2018; Liu et al., 2018; Shi et al., 2023).

Despite the rapid expansion of literature, the study of microplastics in sediments remains methodologically fragmented and theoretically complex. Variations in sampling strategies, extraction techniques, particle size thresholds, and polymer identification methods have resulted in heterogeneous datasets that complicate cross-study comparisons (Claessens et al., 2013; Coppock et al., 2017). Furthermore, the ecological significance of microplastics extends beyond their physical presence. Acting as vectors for heavy metals and persistent organic pollutants, microplastics can alter contaminant transport pathways and potentially enhance bioavailability to organisms (Bakir et al., 2012; Brennecke et al., 2016; Lu et al., 2023).

The problem is further compounded by emerging sources of microplastics, such as disposable face masks and packaging materials, which release micro- and microparticles under environmental aging processes (Ma et al., 2022; Schymanski et al., 2018). These developments highlight the dynamic nature of microplastic pollution and the need for continuous reassessment of sources and pathways. Moreover, ecotoxicological studies have begun to reveal subtle yet significant biological effects, including altered feeding behavior, oxidative stress, and interactions with co-occurring pollutants (Martín et al., 2021).

While numerous reviews have addressed specific aspects of microplastic pollution, there remains a need for an integrated and deeply elaborated analysis that connects occurrence, methodology, contaminant interactions, and ecological effects within sedimentary contexts. This article aims to address this gap by providing an extensive, theory-driven synthesis based strictly on established peer-reviewed references. By examining microplastics as dynamic components of sedimentary systems rather than inert debris, this work seeks to advance conceptual understanding and inform future research directions and management strategies.

METHODOLOGY

The methodological foundation of microplastic research in sediments is inherently interdisciplinary, combining principles from sedimentology, analytical chemistry, polymer science, and ecotoxicology. The studies reviewed here employ a range of approaches designed to isolate, identify, and characterize microplastics within complex environmental matrices. A critical examination of these methods is essential for understanding the reliability and comparability of reported findings.

Sampling strategies represent the first methodological challenge. Sediment sampling must account for spatial heterogeneity, grain size distribution, and depositional dynamics. Coastal and marine sediment studies often utilize grab samplers or corers to collect surface layers where microplastics are most likely to accumulate (Claessens et al., 2011). In freshwater reservoirs and rivers, sampling is influenced by hydrological variability and anthropogenic inputs, necessitating site-specific designs (Di and Wang, 2018). Agricultural soil studies introduce additional complexity due to tillage practices and heterogeneous organic content (Liu et al., 2018).

Once collected, sediments undergo pre-treatment to remove organic matter and facilitate microplastic extraction. Chemical digestion using oxidizing agents is commonly applied, though concerns persist regarding potential polymer degradation and selective loss of certain plastic types (Van Cauwenberghe et al., 2015). Density separation remains the most widely adopted extraction technique, exploiting the lower density of most plastics relative to mineral particles. Solutions of varying densities are employed to recover a broad range of polymers, yet denser plastics may still be underestimated (Coppock et al., 2017).

Identification and characterization constitute the most analytically demanding stage. Visual sorting under microscopes is frequently used as a preliminary step, but it is prone to misidentification, particularly for small or pigmented particles. Spectroscopic techniques such as Fourier-transform infrared spectroscopy and micro-Raman spectroscopy have become the gold standard for polymer identification, enabling chemical confirmation at the micro-scale (Schymanski et al., 2018; Cai et al., 2019). Emerging imaging approaches, including near-field molecular spectral imaging combined with data mining, offer promising avenues for analyzing microplastics in complex matrices such as food products (Shi et al., 2023).

Methodological innovation has also focused on portability and efficiency. Small-scale and field-adaptable extraction methods aim to reduce contamination risks and logistical constraints, particularly in remote or offshore environments (Coppock et al., 2017; Budimir et al., 2018). However, trade-offs between simplicity, recovery efficiency, and analytical resolution remain a central concern.

The methodological diversity reflected in the literature underscores the absence of universally accepted protocols. While this diversity has facilitated innovation, it has also contributed to variability in reported concentrations and compositions. A critical methodological synthesis, therefore, is not merely descriptive but essential for interpreting results and identifying systematic biases.

RESULTS

Across diverse environmental contexts, the reviewed studies consistently demonstrate that microplastics are pervasive in sediments, though their concentrations, polymer types, and size distributions vary widely. Marine sediments along industrialized coastlines exhibit higher abundances compared to remote regions, reflecting proximity to urban centers and shipping activities (Claessens et al., 2011; Andrades et al., 2018). Nevertheless, even isolated locations such as remote islands show measurable microplastic contamination, emphasizing the long-range transport capabilities of plastic debris (Andrades et al., 2018).

Freshwater systems, including reservoirs and rivers, display microplastic profiles influenced by watershed characteristics and human activity. The Three Gorges Reservoir, for example, contains microplastics in both surface waters and sediments, with spatial patterns linked to hydrodynamics and anthropogenic inputs (Di and Wang, 2018). Agricultural soils in suburban regions similarly reveal significant microplastic and mesoplastic contamination, likely derived from plastic mulching, wastewater irrigation, and atmospheric deposition (Liu et al., 2018).

Polymer composition analyses indicate the dominance of polyethylene, polypropylene, and polystyrene across most environments, reflecting their widespread use and buoyant properties (Andrady, 2011). However, studies of bottled water and packaging reveal the presence of smaller-sized and pigmented particles, highlighting the contribution of consumer products to microplastic exposure pathways (Oßmann et al., 2018; Schymanski et al., 2018).

Beyond occurrence, experimental results demonstrate that microplastics actively interact with environmental contaminants. Laboratory studies show that the presence of microplastics can alter heavy metal sorption behavior on sediment minerals such as ferrihydrite, modifying metal affinity and potentially influencing mobility (Lu et al., 2023). Field and laboratory investigations further confirm that microplastics can adsorb persistent organic pollutants, acting as competitive sorbents in contaminated environments (Bakir et al., 2012).

Ecotoxicological bioassays reveal that microplastics alone and in combination with organic pollutants can elicit measurable biological responses. Polyethylene microplastics, when co-present with chemicals such as simazine and ibuprofen, influence toxicity outcomes, suggesting complex interactive effects rather than simple additive responses (Martín et al., 2021). These findings challenge the notion of microplastics as inert particles and underscore their role as active components of contaminant mixtures.

DISCUSSION

The synthesis of occurrence, methodological, and experimental findings reveals microplastics as multifaceted environmental contaminants whose impacts cannot be understood through simplistic frameworks. Sediments function not merely as passive sinks but as dynamic interfaces where microplastics interact with minerals, organic matter, and biota. This perspective has profound implications for risk assessment, as it shifts attention toward long-term accumulation and subtle ecological effects.

One of the central challenges identified is methodological inconsistency. Differences in extraction efficiencies, size thresholds, and identification techniques can lead to under- or overestimation of microplastic abundances. This variability complicates efforts to establish baseline concentrations or assess temporal trends. Harmonization of methods, while difficult, is essential for advancing the field (Claessens et al., 2013).

The role of microplastics as vectors for contaminants remains an area of active debate. While evidence supports their capacity to sorb heavy metals and organic pollutants, the ecological significance of this process depends on desorption dynamics and biological uptake pathways (Brennecke et al., 2016; Lu et al., 2023). Some argue that natural particles may play a more dominant role in contaminant transport, whereas others emphasize the unique surface properties and persistence of plastics. Resolving this debate requires integrated field and laboratory studies that consider realistic environmental conditions.

Ecotoxicological research highlights another layer of complexity. Biological responses to microplastics are influenced by particle size, shape, polymer type, and the presence of co-contaminants. The observed interactions challenge traditional single-stressor toxicological models and call for mixture-based approaches that reflect environmental realities (Martín et al., 2021).

Looking forward, future research must expand beyond descriptive surveys toward mechanistic and systems-level analyses. Advances in spectroscopic imaging, data mining, and portable extraction methods offer opportunities to improve detection and characterization (Shi et al., 2023; Coppock et al., 2017). Equally important is the development of remediation and management strategies tailored to freshwater and sedimentary environments, as highlighted by recent integrative frameworks (Madala et al., 2025).

CONCLUSION

Microplastics in sediments represent a persistent and complex environmental issue that transcends traditional boundaries between marine, freshwater, and terrestrial research. The body of literature reviewed here demonstrates unequivocally that microplastics are widespread, methodologically challenging to quantify, and ecologically significant. Their interactions with contaminants and organisms underscore the need to view them as active components of environmental systems rather than inert debris.

Progress in this field depends on methodological harmonization, interdisciplinary collaboration, and a shift toward integrative conceptual models. By synthesizing existing knowledge with extensive theoretical elaboration, this article provides a foundation for advancing research and informing policy responses. Addressing microplastic pollution in sediments is not merely a scientific challenge but a necessary step toward safeguarding ecosystem integrity in an increasingly plastic-dependent world.

REFERENCES

1. Andrady, A.L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62, 1596–1605.
2. Andrades, R., et al. (2018). Marine debris in Trindade Island, a remote island of the South Atlantic. Marine Pollution Bulletin.
3. Bakir, A., et al. (2012). Competitive sorption of persistent organic pollutants onto microplastics in the marine environment. Marine Pollution Bulletin.
4. Brennecke, D., et al. (2016). Microplastics as vector for heavy metal contamination from the marine environment. Estuarine, Coastal and Shelf Science.
5. Budimir, S., et al. (2018). Effective and easy to use extraction method shows low numbers of microplastics in offshore planktivorous fish from the Northern Baltic Sea.
6. Cai, H., et al. (2019). A practical approach based on FT-IR spectroscopy for identification of semi-synthetic and natural celluloses in microplastic investigation. Science of the Total Environment.
7. Claessens, M., et al. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Marine Pollution Bulletin.
8. Claessens, M., et al. (2013). New techniques for the detection of microplastics in sediments and field collected organisms. Marine Pollution Bulletin.
9. Cooper, D.A., et al. (2010). Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii. Marine Pollution Bulletin.
10. Coppock, R.L., et al. (2017). A small-scale, portable method for extracting microplastics from marine sediments. Environmental Pollution.
11. Di, M.X., & Wang, J. (2018). Microplastics in surface waters and sediments of the Three Gorges Reservoir, China. Science of the Total Environment, 616, 1620–1627.

12. Liu, M.T., et al. (2018). Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. Environmental Pollution, 242, 855–862.
13. Lu, X., et al. (2023). Microplastics existence affected heavy metal affinity to ferrihydrite as a representative sediment mineral. Science of the Total Environment, 859, 160227.
14. Ma, M.L., et al. (2022). Disposable face masks release micro particles to the aqueous environment after simulating sunlight aging. Journal of Hazardous Materials, 443, 130146.
15. Madala, P., Waikar, A., & Parate, H. (2025). Detection to remediation: Strategies for managing microplastic pollution in freshwater systems. International Journal of Computational and Experimental Science and Engineering, 11(3).
16. Martín, C., et al. (2021). Bioassays to assess the ecotoxicological impact of polyethylene microplastics and two organic pollutants. Chemosphere, 274, 129704.
17. Oßmann, B.E., et al. (2018). Small-sized microplastics and pigmented particles in bottled mineral water. Water Research, 141, 307–316.
18. Schymanski, D., et al. (2018). Analysis of microplastics in water by micro-Raman spectroscopy. Water Research, 129, 154–162.
19. Shi, Y.Z., et al. (2023). Visual characterization of microplastics in corn flour by near field molecular spectral imaging and data mining. Science of the Total Environment, 862, 160714.
20. Thompson, R.C., et al. (2004). Lost at sea: Where is all the plastic? Science, 304, 838.
21. Van Cauwenberghe, L., et al. (2015). Microplastics in sediments: A review of techniques, occurrence and effects. Marine Environmental Research, 111, 5–17.