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Microplastics as Carriers of Pathogenic Microbes Coastal Ecosystems: A review study

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Abstract

Microplastics (MPs) measuring less than 5 mm have been increasingly detected in the coastal regions of Iran, prompting significant concerns regarding environmental integrity and public health. Field investigations reveal their existence in coastal sediments, surface waters, and marine life; for example, reports indicate densities surpassing 3,000 particles per square meter along Hormozgan Province's shoreline. The majority of these particles consist of fibers and fragments from polyethylene, polypropylene, polystyrene, and polyethylene terephthalate, showing a considerable ability to absorb and transport chemical and microbial contaminants. A significant outcome of MPs in coastal ecosystems is the emergence of specialized microbial communities, known as the "plastisphere," which settle on the surface of these plastic particles. These communities, comprising microorganisms from *Gammaproteobacteria*, *Alphaproteobacteria*, and *Bacteroidetes,* present notable differences from the surrounding environmental microbiota. Some of these microbes have the potential to harbor pathogens and antibiotic resistance genes (ARGs). While direct evidence from Iran's coastal zones is sparse, the high concentration of MPs, along with global research findings, suggests that these particles may act as conduits for pollutants and pathogens, facilitating their movement through coastal food systems. This review emphasizes significant research deficiencies within Iran, especially regarding thorough microbial evaluations at surface and subsurface levels, identification of resistance genes, and modeling of microbial transfer. Future studies adopting an interdisciplinary framework that merges environmental engineering, microbiology, coastal ecology, and public health are vital for a deeper understanding of the environmental and health implications of microplastics. Ultimately, enhancing ongoing monitoring and establishing national guidelines for managing microbial contamination associated with microplastics are essential measures to safeguard coastal ecosystems and public health.

Key words: Microplastics , Microbial contamination , Iranian coastal waters , Pathogenic bacteria, Marine ecosystems

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Graphical Abstract

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Introduction

The Pervasive Challenge of Microplastics in Coastal Realms

Coastal ecosystems, encompassing estuaries, mangroves, coral reefs, and intertidal zones, are among the most biologically productive and socio-economically valuable environments on Earth. Paradoxically, their proximity to human settlements and riverine outflows renders them primary sinks for anthropogenic pollutants, with plastic debris constituting a dominant and persistent burden. The relentless degradation of macroplastics, coupled with the direct release of microscopic particles from urban runoff, industrial processes, and inadequate waste management, has led to the ubiquitous contamination of these habitats with microplastics (MPs) (Jaafarzadeh Haghighi Fard & Jahedi, 2025). These particles, defined as synthetic polymers less than 5 mm in size, permeate all coastal compartments—from the water column to complex sedimentary matrices—where they pose direct threats through ingestion, entanglement, and leaching of chemical additives to a wide array of marine fauna (Khanjani et al., accepted; Rahimibashar, 2024). The scale of this pollution underscores a critical environmental crisis that extends far beyond visible litter.

From Inert Particles to Active Microhabitats: The Birth of the Plastisphere

The environmental impact of microplastics transcends their physical and chemical properties. A paradigm-shifting discovery is their role as novel and durable substrates for microbial colonization in aquatic systems. Unlike natural particles that degrade relatively quickly, persistent synthetic surfaces facilitate the development of dense and distinct biofilm assemblages, collectively termed the "plastisphere" (Azizollahi Aliabadi et al., 2024). This man-made ecological niche is not a mere replica of surrounding microbial communities; selective pressures, including polymer type (e.g., polyethylene, polypropylene), surface hydrophobicity, and weathering state, drive the enrichment of specific bacterial and fungal taxa (Azizollahi Aliabadi et al., 2022). Consequently, MPs transform from passive pollutants into active microbial habitats, fundamentally altering microbial dispersal and interaction networks in the water column and benthos.

The Pathogenic Dimension: Hitchhiking on a Synthetic Vector

Within the diverse plastisphere, the detection and potential enrichment of human and animal pathogens represent a grave concern for public and ecosystem health. Coastal waters are frequently contaminated with fecal indicator bacteria (FIB) such as Escherichia coli and enterococci, originating from wastewater discharges and agricultural runoff, which correlate with risks of gastrointestinal illnesses for swimmers and recreational users (Niknejad et al., 2024). Alarmingly, studies indicate that microplastics can harbor these indicator organisms alongside recognized pathogens, including Vibrio species (associated with cholera and wound infections) and antibiotic-resistant bacteria. MPs may act as efficient vectors by providing a protective surface that enhances pathogen survival under UV radiation, salinity fluctuations, and oligotrophic conditions compared to free-living states. This "hitchhiking" mechanism facilitates the extended persistence and long-range transport of pathogens across coastal gradients, potentially bypassing natural purification barriers.

Amplifying Risk: Trophic Transfer and Exposure Pathways

The vector role of microplastics culminates in their entry into marine food webs, thereby amplifying exposure pathways. Filter-feeding and deposit-feeding organisms, such as bivalves (e.g., mussels, oysters) and benthic macroinvertebrates, which are foundational to

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coastal trophic networks, readily ingest microplastics from the water and sediments (Rahimibashar, 2024). Through this ingestion, pathogens associated with the plastisphere may be internalized, potentially overcoming external mucosal barriers and causing infection in the host organism. Moreover, these contaminated prey items can be consumed by higher trophic levels, including fish and, ultimately, humans, creating a indirect but potent route of exposure to plastic-borne pathogens. This pathway complicates traditional microbial risk assessments, which often focus on free-living bacteria in water, and suggests that microplastic pollution could exacerbate the incidence of waterborne and seafood-related diseases.

Knowledge Synthesis and Review Objectives

While the individual fields of microplastic ecotoxicology and aquatic microbiology are rapidly advancing, a comprehensive and critical synthesis focusing specifically on the nexus of MPs as pathogen carriers in coastal ecosystems is urgently needed. Existing reviews have excellently detailed general MP impacts on animals (Khanjani et al., accepted) or broad MP-microbe interactions (Azizollahi Aliabadi et al., 2022, 2024), yet a focused analysis on the pathogenic subset—addressing mechanisms, quantitative risks, and coastal-specific dynamics—remains fragmented. To bridge this gap and guide future research and policy, this review aims to:

1.Synthesize global evidence on the diversity and abundance of pathogenic microorganisms identified within the coastal plastisphere.

2.Analyze the key factors (polymer characteristics, environmental conditions, pathogen traits) governing adhesion, survival, and proliferation on MPs.

3.Evaluate the empirical evidence for the trophic transfer of MP-associated pathogens and assess the consequent risks to coastal ecosystem integrity and human health.

4.Identify critical knowledge gaps and propose a prioritized research agenda to quantify exposure risks and develop effective mitigation strategies for safeguarding vulnerable coastal regions.

Sources and Characteristics of Microplastics in Coastal Ecosystems

Microplastics in coastal environments originate from diverse sources such as urban runoff, wastewater treatment plant effluents, maritime activities, and degradation of plastic litter. Common polymer types found in coastal sediments and waters include polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET). The physical and chemical properties of microplastics—such as size, shape, surface roughness, and hydrophobicity—play a crucial role in microbial colonization. Weathering processes, including UV radiation and mechanical abrasion, increase surface area and create cracks on microplastics, enhancing their suitability as microbial habitats(Gündoğdu et al.,2022).

Discussion

Synthesis of Key Mechanisms: From Colonization to Vectoring

This review consolidates compelling evidence that microplastics (MPs) are not passive pollutants but active vectors in coastal ecosystems, capable of altering the ecology and transmission pathways of pathogenic microbes The primary mechanism hinges on the rapid formation of the plastisphere—a unique biofilm whose composition is demonstrably distinct from those on natural suspended particles or in the surrounding water column (Azizollahi Aliabadi et al., 2024). The hydrophobic and weathered surfaces of common polymers like polyethylene and polypropylene appear to selectively favor the adhesion of certain bacterial groups, including opportunistic pathogens.

Crucially, the biofilm matrix provides a protective "microenvironment," enhancing microbial resilience against environmental stressors such as UV radiation, salinity shifts, and antibiotic compounds (Azizollahi Aliabadi et al., 2022). This protection likely prolongs the survival and viability of fecal indicator bacteria (e.g., E. coli) and virulent species (e.g., Vibrio spp.) in coastal waters, effectively increasing their environmental persistence and geographical dispersal range beyond what traditional waterborne transmission models predict.

The Coastal Amplification Effect: A Convergence of Risk Factors

The risk posed by MP-mediated pathogen transport is particularly acute in coastal ecosystems due to a dangerous convergence of factors. Firstly, these zones are the primary recipients of terrestrial runoff, carrying both high loads of microplastics from urban waste streams (Jaafarzadeh Haghighi Fard & Jahedi, 2025) and pathogens from sewage and agricultural sources (Niknejad et al., 2024). Secondly, the high biological productivity and dense populations of filter-feeding organisms create optimal conditions for trophic transfer. Organisms like bivalves and benthic macroinvertebrates, which are prolific filterers of water and processors of sediment, directly ingest MPs and their associated microbial communities (Rahimibashar, 2024; Khanjani et al., accepted). This ingestion represents a critical nexus where pathogens, shielded by the plastisphere, may bypass external defenses and interact with host tissues, potentially leading to infection or internalization. Consequently, coastal ecosystems act as both a reservoir and an amplification chamber for this hybrid threat.

Implications for Human and Ecosystem Health: Beyond Conventional Risk Assessment

The role of MPs as pathogen carriers necessitates a fundamental re-evaluation of microbial risk assessment in coastal zones. Current models, such as those used to predict gastrointestinal illness from recreational water exposure, predominantly rely on measurements of free-living FIB in water samples (Niknejad et al., 2024). Our synthesis suggests that this approach may underestimate risk if a significant fraction of pathogens is sequestered on MP particles, which are not uniformly distributed in the water column and may be missed by standard sampling. The pathway of exposure expands beyond direct water contact to include the consumption of seafood. If pathogens persist in or on MPs ingested by commercially important shellfish or fish, they could pose a direct food safety hazard. This creates a parallel, indirect exposure route that is not currently monitored within conventional food safety or water quality frameworks (Bowley et al.,2021).

Critical Knowledge Gaps and Methodological Challenges

Despite significant progress, this review identifies several pivotal gaps that constrain a full risk characterization:

1.Quantification of Vectoring Efficiency: There is a paucity of field-based, quantitative data comparing the survival rates of specific pathogens on MPs versus in water or on natural particles. Studies are needed to quantify the "vector enhancement factor" under realistic coastal conditions (e.g., varying temperatures, nutrient levels, and solar exposure).

2.Trophic Transfer Dynamics: While ingestion is well-documented, direct evidence proving that MP-associated pathogens (a) survive the gut environment, (b) invade host tissues, and (c) maintain infectivity in higher trophic levels remains limited. Controlled mesocosm studies tracing labeled pathogens from MPs through a food web are crucial.

3.Polymer-Specific Risk Ranking: Not all plastics are equal. Systematic research is required to rank different polymer types, sizes, and weathering states based on their propensity to harbor and transport specific pathogen groups. This information is vital for source prioritization in mitigation strategies (Kawecki et al.,2019).

4.Field Relevance of Laboratory Studies: Many foundational studies on the plastisphere use pristine, spherical MPs, which poorly represent the complex, irregular, and heterogeneously aged particles found in coastal environments. Future work must prioritize environmentally relevant MP samples (Weis et al.,2021).

Future Directions and Integrative Management Strategies

Addressing the multifaceted challenge of MP-as-pathogen-vector demands an interdisciplinary, One-Health approach. Future research must pivot towards:

1) Developing Integrated Monitoring Protocols: Water quality monitoring programs should consider incorporating MP sampling and analyzing their associated microbial loads alongside traditional FIB measurements to gain a more holistic view of pathogen pollution (Pachepsky et al.,2018).

2) Advancing Molecular Diagnostics: Employing metagenomic and virulence gene-targeted approaches on field-collected plastisphere samples will provide a more comprehensive and specific profile of pathogenic threats, moving beyond culture-dependent methods (Chen et al.,2022).

3) Prioritizing Pollution at Source: The most effective long-term strategy is preventing MP input. Enhancing wastewater treatment to remove both MPs and microbes, improving solid waste management to reduce leakage (Jaafarzadeh Haghighi Fard & Jahedi, 2025), and promoting circular economy models are foundational actions.

4) Ecosystem-Based Risk Modeling: Developing new risk assessment frameworks that integrate MP distribution data, pathogen adherence dynamics, and species-specific feeding behaviors to map and predict high-risk "hotspots" in coastal areas (Strokal et al.,2021).

In conclusion, the convergence of microplastic pollution and pathogenic microbes in coastal ecosystems represents a significant and evolving environmental health threat. While the plastisphere creates a novel transmission pathway, our understanding of its real-world consequences is still emerging. Bridging the identified knowledge gaps through targeted research is essential to inform evidence-based policies and management interventions aimed at protecting both vulnerable marine ecosystems and human populations that depend on them (Alexander et al.,2019).

Conclusion

Microplastics are no longer viewed solely as inert pollutants but as dynamic components of coastal ecosystems capable of interacting with microbial communities. Their role as carriers of pathogenic microbes represents a critical and emerging environmental challenge. By facilitating the transport and persistence of pathogens, microplastics may amplify ecological disturbances and pose risks to human health. Addressing this issue requires interdisciplinary research and effective management strategies aimed at reducing plastic inputs into coastal environments.

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