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ISSN 2959-6157

Atmospheric chemistry of microplastics: Transport, environmental impacts, and governance

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Abstract:

The presence of microplastic particles, defined as plastics less than 5mm in dimension, presents a significant environmental challenge. Their ubiquity and the potential risks they pose for ecosystems and human health are widely recognized. This article delves into the atmospheric chemistry surrounding microplastics, examining their sources, impacts, and management. It reviews existing literature on their environmental occurrence, evaluates the processes they undergo in the atmosphere, their interaction with atmospheric elements, and the efficiency of current remediation strategies and policy measures. The analysis uncovers that microplastics (MPs) can carry harmful substances like heavy metals and persistent organic pollutants, facilitating their transport to diverse environmental contexts, thereby compromising air and water quality. The potential health repercussions, such as respiratory and cardiovascular problems, are also discussed. Effective removal techniques are identified, including Dissolved Air Flotation and coagulation methods that utilize metals, and emphasize the urgency for regulatory measures to combat microplastic contamination. This research contributes to a more profound comprehension of microplastics' intricate environmental behavior and their possible effects. It offers valuable perspectives for devising strategies to curb their pollution, highlighting the significance of sustainable material use and responsible waste management. These insights are pivotal for shaping policies and directing future research to mitigate the environmental and health hazards of microplastics.

Keywords: Microplastics; Atmospheric Chemistry; Environmental Impacts; Waste Management; Policy Interventions.

1. Introduction

The emergence of microplastics (MPs) as an acute environmental concern has captivated much attention, given their pervasive impact on diverse ecosystems and potential health risks. Microplastics, a term encompassing a variety of minute particles differing in size and shape, have traditionally been associated with aquatic and soil environments. Yet, recent studies have drawn attention to their atmospheric presence. These tiny particles, emanating from the degradation of larger plastic waste and textile fibers, can become airborne and distributed globally by winds and currents [1].

Understanding the atmospheric behavior of these particles is crucial; they can fracture further under environmental factors or chemically interact with pollutants, possibly forming new hazardous compounds [2]. Furthermore, their inhalation may pose respiratory and cardiovascular threats to humans and contribute to ecosystems' pollution levels.

This article aims to consolidate current knowledge on the subject, identifying the primary sources of microplastics and assessing their environmental and health implications, with a focus on their atmospheric interactions. It endeavors to identify research shortfalls and recommends directions for future exploration to better comprehend and mitigate the atmospheric influence of microplastics.

2. Sources of Microplastics

Found across varied environments, microplastics—ranging from 1 micrometer to 5 mm—originate from an array of sources mirroring the widespread application of plastics. Residential, industrial, and commercial activities release them into wastewater, with textile-related processes significantly contributing to this influx. Outdoor sources include litter and material wear, which release microplastics directly or degrade into smaller fragments over time.

Research has demonstrated microplastics' adverse effects on living organisms, including bioaccumulation and cellular or molecular consequences, which vary depending on the organism type and particle characteristics [3].

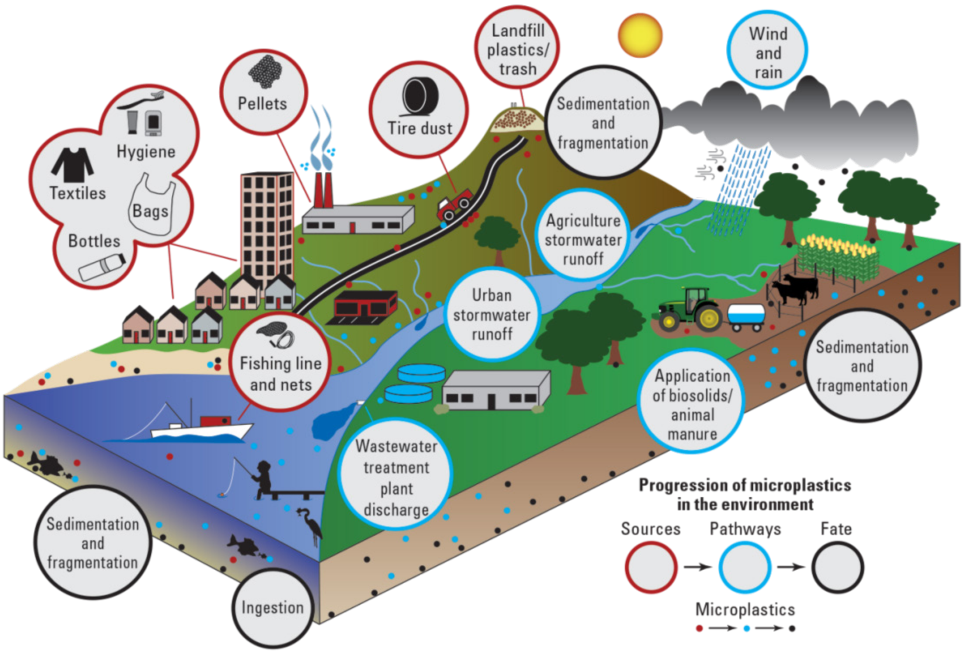

Fig. 1 Microplastics Sources, Pathways and Fate Conceptual Diagram [4]

Microplastics, minute fragments prevalent in our environment, often mirror the patterns of our plastic use, human activities, and their distribution methods. These minuscule pollutants can be introduced into water systems through stormwater or dispersed through the air, journeying swiftly to various locales. Research has measured microplastics in the atmosphere, underscoring their potential for widespread dispersal. Polyethylene and polypropylene, chiefly due to their use in agriculture for weed control, frequently appear in soil and sediment samples. Studies indicate that farmland enriched with biosolids from sewage treatment facilities serves as a repository for these particles, which can then spread via runoff. An analysis suggests microplastics in soil may surpass six million tons. Surface waters play a significant role in moving microplastics, eventually contributing to the marine load.

ISSN 2959-6157

3. Hazards of Microplastics

3.1 For Plants

The rising concern regarding microplastics‘ impact on plants is well-founded. The nature, size, and chemical groups of these plastics are closely linked to their harmful effects on plant growth. Not only do primary impacts, such as physical damage, warrant attention, but also the secondary risks, like additives and absorbed pollutants from the environment, which pose a threat to plants. Chemicals leaching from microplastics can have profound effects on plant health.

Furthermore, these tiny pollutants present a looming danger to ecosystems and their inhabitants. Originating from land and farms, their eventual distribution in soil and the resulting impact on subterranean life, including beneficial fungi and earthworms, remains underexplored. The increasing production trend predicts a rise in environmental levels and associated risks. Microplastics can hinder plant development by obstructing water and nutrient uptake and accumulating within plant tissues. They also indirectly influence plants by altering soil properties and affecting microbial and faunal populations, potentially reshaping plant communities and productivity [5].

The pervasive presence of microplastics and their even smaller counterparts, nanoplastics (NPs), underscores a pressing environmental issue accentuated by their durability and prevalence in farming. Current literature reflects increasing scrutiny over their sources, movement, and biological implications. The ways in which plants absorb and distribute these particles reveal significant variations between roots and leaves. Climate change, agricultural practices, and soil organisms are pivotal in their transport. Nanoplastics, notably, can more readily penetrate plant cells. The driving force behind their movement within plants hinges on the process of transpiration [6].

3.2 For Humans

On the human health front, microplastics are omnipresent particles whose rising annual release has sparked health concerns. The amplified use of masks during the COVID-19 pandemic has only heightened human exposure. Inflammatory lung responses in rats and fibrosis in mice have been documented following exposure to these plastics. Reports of microplastics found in human feces, blood, placentas, and respiratory tracts are emerging, inciting increased toxicological research (Fig. 2). Understanding the interactions between microplastic exposure and human health informs risk assessments and regulatory policies.

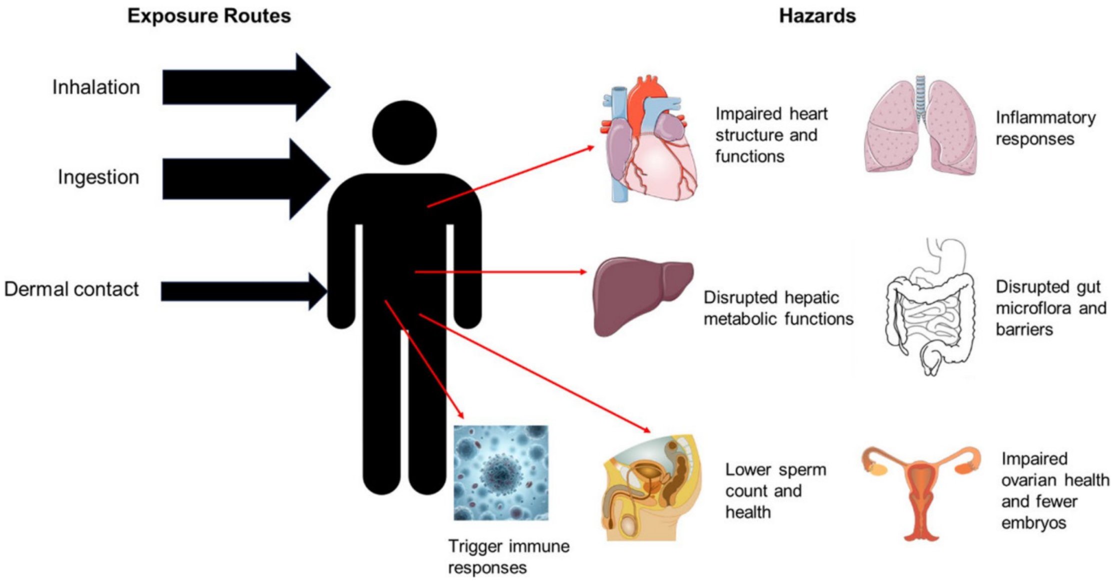

Fig. 2 Health risk of human exposure to microplastics [7]

In aquatic research, the concentration and traits of microplastics in seawater have been extensively studied. Freshwater, wastewater, and groundwater studies are now gaining momentum. Europe, with its high population density and shared water resources, leads research into microplastics in wastewater. Since microplastics can shift across different mediums and accumulate at the bottom of aquatic settings, studying their overall concentration and characteristics poses challenges. This review contemplates the inherent properties of microplastics, sampling methodologies, and the sway of environmental conditions.

3.3 For ecological environment

Diverse marine species, ranging from the smallest plankton to larger fish and bottom-dwelling invertebrates, are known to ingest microplastics. Such consumption can harm these organisms, blocking their ability to feed and causing a false sense of fullness that decreases their nutrient intake and energy levels. As an illustration, Kaposi and colleagues observed that sea urchin larvae consumed microplastics in relation to their concentration in the environment, which led to increased mortality rates. Even if the effect was subtle, survival rates went down markedly—starting from about three-quarters for the untreated group to just over a third following five days of exposure to high concentrations of microplastics.

The study also highlighted the role of microplastic shape in potential feeding preferences and the physical stress they can cause. This work underscores the necessity for precise exposure assessments to inform risk evaluations about microplastics in marine ecosystems. There is also a phenomenon known as the „Trojan horse effect," where microplastics carry other pollutants such as persistent organic compounds or metals into the digestive tracts of marine animals when ingested. The significance of this effect is still under review, but considering the prevalent presence of plastic debris in water bodies, and the affinity of plastics to absorb organic pollutants, this matter demands further research. Reports have found concentrations of plastic-related substances like flame retardants and phthalates in marine life, pointing to microplastics as a possible contamination pathway.

Conversely, Koelmans and others applied a biodynamic model to estimate the exposure of lugworms and cod to chemicals like nonylphenol and bisphenol A through microplastic consumption. These researchers concluded that the risk posed to these species by such chemicals via microplastic ingestion is likely minimal. Additionally, there‘s a chance that microplastics might bind some contaminants so tightly that they‘re not absorbed by the organism, a mechanism similar to what occurs with black carbon [8].

4. Governance of microplastics

4.1 Dissolved Air Flotation (DAF)

Turning to water treatment technologies, Dissolved Air Flotation (DAF) is a technique used to separate particles from water using air bubbles. In this three-stage process, pressurized air is dissolved in water and then released, creating microbubbles that attach to microplastics, causing them to rise to the surface and be removed. Adding chemicals like Polyaluminium Chloride enhances the efficacy of this technique by promoting flocculation. DAF is particularly adept at removing lighter microplastics like PP and PE, while denser types such as PVC and PET are more challenging to extract. Although DAF is widely employed across various industries and has proven to be highly effective, optimization studies are necessary to refine the use and dosage of flocculating agents and to ascertain ideal operational conditions [9].

4.2 Metal-Based Coagulation

Furthermore, the metal-based coagulation method uses chemicals that cause microscopic particles to clump together for easier removal. This process, not to be confused with flocculation, relies on neutralizing the electrical charge on particles. Commonly used substances include salts of iron, aluminum, titanium, and zirconium. Research into the efficacy of these methods has shown promising results, like the work of Ramirez and colleagues who found that certain biopolymers could outperform traditional aluminum salts in neutralizing the charge of polystyrene latex microplastics, making them easier to remove from water, especially over a wider pH range. The amount of coagulant required is influenced by the initial acidity or basicity of the liquid we‘re treating. When this starting point is on the acidic side, it doesn‘t take much of the substance to reach a neutral charge balance in the mixture. Ma and colleagues found that aluminum-based agents were more effective than iron-based ones for extracting certain plastic particles from water. They also noted that smaller particles were easier to remove, though the typical process did not always achieve high success rates [10].

4.3 Photochemical method

Turning to the photochemical method, studies have observed that when dealing with certain plastics, radicals containing oxygen - which are quite reactive due to their unpaired electrons - tend to target and modify the chemical structures of the plastics. For example, they may add onto or break bonds within the polymer chains, potentially transforming the material into different chemical compounds, including various types of ketones.

4.4 Mitigation Strategies and Policy Frameworks

In terms of policy discussion, there‘s reason for cautious optimism about reducing the spread of microplastics thanks to combined efforts of legislation, community engagement, and scientific inquiry. Moves to ban certain single-use plastics in various regions worldwide, alongside efforts to clean up our oceans by both professional and volunteer groups, are steps in the right direction. Education and incentives to rethink how we use and dispose of plastic materials play a critical role as well. The push toward a circular economy, prioritizing the reduction and

ISSN 2959-6157

recycling of materials, is essential for the long-term viability of these strategies.

The plastics industry has introduced the prospect of bioplastics as an alternative to traditional plastics, some of which degrade more readily. However, translating this to actual environmental benefit is complex; bioplastics still pose similar challenges since under typical conditions, they too can break down into microplastics. Further research is needed to understand the full lifecycle impacts of these materials on aquatic ecosystems.

Although many wastewater treatment methods are capable of removing a portion of microplastics, numerous studies suggest that improvements and additional stages are necessary for more thorough removal. We know that these treatments are there—some already employed and others under development—but the consensus is that more can be done.

Realistically, strategies should focus on reducing or preventing the introduction of microplastics into the soil, particularly within the agricultural sector, to safeguard the food supply. This means decreasing the amount of plastic present in various organic materials that we use, like compost or sludge from water treatment processes. There‘s also growing interest in using plastics that can break down more easily in the environment, such as bioplastics or other degradable polymers. Recently, a significant research initiative has begun to deepen our understanding of how microorganisms might help break down these materials.

Despite recognizing the threat that plastic waste poses to the oceans—a staggering 12.7 million metric tons are estimated to enter marine environments from land annually—global policy has yet to fully address the regulations necessary to mitigate this risk. High-level discussions, such as those at G7 meetings, have acknowledged the issue, but substantial action is still needed [11].

5. The prospect of microplastics treatment

Understanding and addressing microplastics (MPs) require a comprehensive grasp of their behavior, environmental prevalence, and potential health hazards. Recent reports highlight the significant role of an international agreement on plastic pollution, particularly its impact on reducing general plastic pollution in South Africa. Research globally underscores the immediate necessity for robust policies and laws to mitigate the presence of MPs in our natural world.

Motivating people to collect waste plastic for recycling and repurposing it into new products, like construction materials, can boost participation in waste reduction efforts. Additionally, adopting a circular economy approach aligns with the government‘s ambition to entirely eliminate waste going to landfills by 2030, as articulated in the National Development Plan. This model revolves around minimizing waste and resource use, enabling resource regeneration, but it requires more extensive application to realize its full benefits.

6. Conclusion

Microplastics have the capability to penetrate diverse environments, threatening both land and water habitats. They‘re detrimental to plant life and human health, potentially carrying chemicals that escalate pollution and degrade ecosystem vitality.

Future research should further unravel the mysteries of microplastics, especially their atmospheric interactions and prolonged effects on our well-being. Crafting effective policy measures and advancing technologies to curb this pollution is imperative. This involves enhancing waste handling practices, encouraging recycling, and exploring alternative materials that break down more benignly.

The relevance of microplastics research escalates as more evidence emerges of their omnipresence and possible damaging impacts. Such research shapes policy-making, waste management approaches, and public consciousness, propelling us toward more responsible plastic use and pioneering pollution abatement technologies. Ongoing investigation will be crucial to developing strategies that minimize the repercussions of microplastics on our planet and health.

Further inquiry should delve into the dispersal of microplastics, their interactions with various habitats, and their enduring human health implications. There‘s also a pressing call to create and refine cost-effective solutions for extracting microplastics from different settings and to evaluate the efficacy of policy measures aimed at diminishing microplastic contamination. International collaboration and policy initiatives remain vital for confronting this widespread challenge.

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