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Narrative Review

Microplastics in groundwater and their effects

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ABSTRACT

This paper is a narrative review on microplastics (MPs). The properties and behavior of MPs in the environment are emphasized, noting that they are groundwater pollutants, are harmful to biotic and abiotic environments, exhibit stable and unique chemical properties, and persist in the environment for prolonged periods. They are resistant to biodegradation, precipitate and accumulate in the bodies of microorganisms. The routes of exposure to MPs in work environments are highlighted, noting that deposition is the main route of human exposure to MPs. The risk assessment for MPs is implemented with the polymer hazard index ecological hazard index, the hazard quotient, and the ecological hazard quotient. The pollution load index, which is related to the microplastic concentration coefficient, and the MPs pollution risk index are utilized. The effects of MPs on humans are highlighted, the main ones being thyroid disorders, headaches, cardiovascular problems and obesity. The prevention and control of MPs pollution is mentioned through the Operation Clean Sweep program, which includes containment measures and employee awareness training. The new contributions of my narrative review are mentioned, which lie in strengthening research on the mechanisms of interactions of MPs with human health and the complete clarification of the organs in which inhaled particles are deposited. Another contribution is the elimination of biochar limitations such as the quantification of the dynamic accumulation of MPs in the environment.

Keywords: inflammation, inhalation, mitigation, risk

Introduction

Groundwater is an important source of water for various purposes, including drinking and agriculture. Groundwater maintains ecosystem health, supports aquatic habitats, and contributes to biodiversity. Groundwater is utilized in emergency situations, such as floods. The world's groundwater supply is a vital component for sustaining life on Earth. Groundwater quality reflects multiple environmental factors, both natural and anthropogenic. Groundwater quality assessment is crucial to safeguard public health and to improve the sustainability of groundwater resources. MPs are plastic debris with diameters less than 5 mm and various shapes, such as fibers and fragments.[1] The percentage of MPs in sizes 1–5 mm, 0.2–1 mm, 0.1–0.2 mm, and <0.1 mm were 16%, 26%, 29% and 29%, respectively.[2] MPs originate from thermal degradation, biodegradation and the degradation of plastic residues.[3] MPs enter the environment in two main ways: as primary MPs, used in personal care products, and as secondary MPs. The former have a defined and usually round shape and size. Primary MPs are used in blasting technology, which includes blasting acrylics, engines, and boat hulls to remove rust and paint. Secondary MPs originate from the decomposition of car tires and contain stabilizers and flame retardants.[4] They originate from the chemical and biological processes of plastic particles. Exposure to sunlight causes the photodegradation of secondary MPs. The latter is caused by UV radiation promoting oxidation of the polymer matrix, leading to bond breakdown, fragmentation, and slow degradation. MPs have recently emerged as groundwater contaminants. MPs are harmful to biotic and abiotic environments. MPs on beaches have enhanced oxygen availability, resulting in rapid degradation and brittleness, forming cracks and "yellowing." The loss of structural integrity makes MPs susceptible to fragmentation resulting from abrasion, wave action, and turbulence. MPs can further degrade and become nanoplastics in size, although the smallest microparticle currently reported in the oceans is 1.6 μm in diameter. They pose a challenge to water safety due to their characteristics.[5] Inadequate occupational health facilities and services cause great human losses, harming the health, well-being and quality of life of workers. The use of personal protective equipment is a key element of workplace safety and an effective measure to protect workers' health from microplastics.[6]

The materials of MPs are polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), polyamide (PA), and polypropylene (PP).7 PE, PET, PP and PVC alter anaerobic microbial communities in sludge and suppress methane production. PE is a widely produced polymer, often used in single-use plastics and synthetic fabrics, and is mainly released into the environment through wastewater disposal. PET is a flexible thermoplastic polymer commonly used in the manufacture of beverage bottles, food packaging and synthetic fabrics, and is distinguished by its strength and excellent gas barriers. PET is denser than water and tends to settle into sediment layers, where it can accumulate and pose a risk to benthic organisms.8 PET and PP are among the most widespread microplastics worldwide and are frequently detected in necropsied human lung tissue and myocardial tissue.[9] PP exhibits moderate abundance and mobility, and under certain hydrodynamic conditions, can accumulate in hot spots.[10] PA and PP have been shown to enhance sludge solubilization and hydrolysis, stimulate key enzymatic activities and, therefore, improve methane production.[11] PVC is used to manufacture medical devices and consumables due to its excellent chemical stability, optical transparency, and mechanical flexibility.[12] PS and PVC have been detected in human tear fluid, meibomian gland, and vitreous humor.[13] MPs exhibit stable and unique chemical properties and persist in the environment for prolonged periods. They are resistant to biodegradation, precipitate and accumulate in the bodies of microorganisms and persist throughout the food chain when consumed.[14] MPs are modified depending on temperature and pH.[15] The production of MPs has skyrocketed over the past eight decades to over 8.3 billion metric tons, with 80% of MPs being released into the environment. [16] MPs in the ocean amount to 12.7 million tons per year, with approximately 51 trillion microplastic particles in the ocean.[17] Annual MPs production amounts to over 280 million tons.[18] MPs production reached 348 million tons in 2017.[19]

Routes of exposure to microplastics in work environments: Wastewater treatment plants receive MPs from domestic and industrial wastewater, and MPs are widespread in urban wastewater.[20] The abundance of MPs in wastewater treatment plants can reach up to 3 × 104 particles/L.[21] MPs enter the human body through inhalation, ingestion, and skin contact.[22] The importance of microplastics entering the human body through ingestion of contaminated food or water is well documented by the fact that microplastics are detected in various foods.[23] Human exposure to MPs via ingestion is estimated at 0.1–5 g/week and fecal microparticle portion concentrations serve as a practical biomarker for assessing ingestion-based exposure, representing approximately 94% of total daily excreted portions.[24] Annual estimates of human consumption of MPs range from 39,000 to 52,000 particles, making dietary exposure the primary route for human interaction with MPs.[25] Factors that influence the transport and deposition of particles in the human airways are particle shape, density and concentration, flow regimes, airway geometry, breathing intensity and particle size. The latter two have the most significant effect on particle deposition.[26]

Recycling MPs can reduce carbon emissions by 30% to 80%, and chemical recycling can achieve a 50% reduction in climate change impacts by breaking MPs down into their basic building blocks through hydrolysis, pyrolysis, and gasification.[27] Mechanical recycling is used in primary and secondary processes and includes collection, sorting, washing, shredding and separation. PET, PE and PP are suitable for mechanical recycling. For PET, enzymatic degradation, a recycling method that uses esterases of the cutinase class, is preferred. Enzymes have an advantage over chemical recycling due to their selectivity for specific depolymerization and leave other components unaffected.[28] PP recycling reduces plastic waste and greenhouse gas emissions while conserving mineral resources. Challenges remain regarding the degradation of mechanical properties and the variability in the quality of recycled PP. Effective recycling strategies are needed to maintain the material’s performance.[29] Recycling PA by acidolysis achieves lower environmental impacts than conventional hydrolysis, highlighting its potential as a more sustainable recycling route. PA can be recycled using dicarboxylic acids to depolymerize it, creating recycled products that are used to produce new materials.[30] Nanotechnology has proven effective in combating MPs pollution and constitutes a strong technological basis for the design of materials for various application areas such as packaging and textiles. It is gaining increasing importance in our complex world and a growing number of applications are demonstrating its high-performance capability on a regular basis. Its unique ability to define materials and structures at the nanoscale opens up new opportunities to address some of the most pressing challenges.[31] The physicochemical properties of nanomaterials, their high surface-to-volume ratio, and tunable surface chemistry enable efficient adsorption, degradation, and separation of MPs, even at low concentrations.[32] Nanomaterials are incorporated into membrane technologies to improve their permeability, ensure safe recovery of nanomaterials, be much more reactive, and have higher uptake capacity compared to bulk materials. Carbon nanomaterials and nanocomposites catalyze photocatalytic degradation, selective adsorption, and antimicrobial activity. [33]

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Risk assessment of microplastics: The risk of MPs is significant due to their easy transport by winds and the longevity of polymeric structures.[34] The risk assessment is implemented based on the polymer hazard index, the ecological risk index, the hazard quotient and the ecological risk quotient. The latter two are advantageous because they incorporate species sensitivity distributions and probabilistic diversity adjustments to prioritize global mitigation. Comprehensive ecological risk assessment requires integrating particle size, shape, density, polymer hazard, abundance, and mass concentration. Assessing the ecological risks of microplastics remains difficult due to methodological inconsistencies in detection.[35] The pollution load index for each station is related to the MPs concentration factor. An index value less than 10 represents the minimum risk and an index value greater than 30 represents the highest risk.[36] The microplastic pollution risk index was developed to describe the multidimensional risk profile of microplastics by incorporating factors such as shape, size, color, and polymer durability. It incorporates the characteristics of the polymer's risk, abundance, size, and color.[37] The most reliable quantitative risk-based thresholds for ecosystems still contain moderate to high uncertainties. The main source of uncertainty in assessing the risk of microplastics to the biosphere stems from their multifaceted nature, such as size, shape, polymer type, and the presence of chemical additives. The development of harmonized assessment methodologies and benchmarks, together with enhanced research, holds significant promise for strengthening confidence in risk thresholds with more reliable conclusions.[38] The risk assessment of MPs in natural processes refers to their environmental burden, which is enhanced by photoaging by altering the adsorption capacity of microplastics to pollutants. Photoaged MPs have a higher risk of human exposure.[39]

Impact of microplastics on workers: MPs agents have harmful effects on human health, as they release harmful additives, degrade the environment, are involved in ecological hazards and cause toxicological effects.[40] The effects of microplastics include oxidative stress, DNA damage, and can disrupt the gut microbiome, causing dysbiosis.[41] Exposure to MPs causes limited larval body length, reduced heart rate, and disturbances in redox homeostasis.[42] Sol et al.'s study reported that MPs have the potential to obstruct the digestive tracts of aquatic organisms by releasing harmful compounds.[43] MPs cause mental disorders, headaches and are implicated in developmental disorders and hyperactivity.[44] Health impacts include thyroid disorders, obesity and diabetes and are exploited as habitats for disease-carrying insects and pathogenic bacteria.[45] The study by Pauly et al. documented that human exposure to MPs causes acute and chronic lung inflammation.[46] MPs agents have negative effects on the human endocrine system, as phthalates and bisphenol-A modify it, causing metabolic disorders.[47] Winiarska et al.'s study points out that ingestion of MPs particles through food has been associated with cancer risk in humans.[48] Ingestion of MPs particles causes pathological stress, false satiety and inhibition of enzyme production.[49] PS-MPs inhibit the function of catalase, which disrupts the activity of superoxide dismutase and glutathione peroxidase.[50] PS and PVC are associated with functional impairments of the respiratory, gastrointestinal, reproductive and immune systems, causing damage to corneal tissue. Exposure to PS/PVC causes inflammation of the ocular surface through mitochondrial damage and disruption of lipid metabolism.

Microplastics prevention and control: The prevention and control of MP pollution include the adoption or promotion of best available techniques, as reflected in integrated environmental permitting. The Operation Clean Sweep program includes implementing actions to minimize risks, such as containment measures and a training program to raise employee awareness. New containment measures can be introduced in the MPs processing and management industry, including mandatory pre-treatment of stormwater. New industries should create separate sewage systems and incorporate wastewater treatment, independent of wastewater treatment. As a pretreatment system for stormwater that is likely to carry MPs, a hydrocarbon separation-decantation unit is recommended. It retains settling and floating particles before their discharge into watercourses or the general drainage network of the industrial zone. The design of hydrocarbon separation-decantation systems could be optimized and adapted to specifically address the retention of MPs from industrial sources.[51]

Regulations, guidelines, gaps and future lines of research on microplastics: The European Union aims to reduce MPs releases by 30% by 2030, focusing on limiting the use of intentionally added MPs in products and minimizing unintentional releases of MPs. There is no comprehensive EU legislation specifically addressing MPs. Some targets are covered by the European Chemicals Agency restriction proposal, which targets intentionally added MPs, which unfortunately account for 5% of total plastic.[52] For MPs, the European Union has issued the Single-Use Plastics Directive, the Waste Framework Directive, the Packaging and Packaging Waste Directive, and the Marine Strategy Framework Directive.[53] Global legislation aims to manage the risks and impacts of plastic bag litter with strategies such as levies and bans. The latter have effectively controlled pollution by MPs at the regional level, particularly reducing the use of low-density PE bags.[54] The 2019 European Union directive on single-use plastics and combating their impact on the environment includes the withdrawal of single-use plastic products such as cutlery, plates, straws, cotton buds and drink stirrers. Sticks that attach to and support balloons and their mechanisms, products made of Oxo-degradable plastic, beverage and food containers, and expanded polystyrene cups, lids, and covers are withdrawn. The directive sets a 90% collection target for all single-use plastic bottles by 2029.[55] The 2018 European Union directive includes measures to prevent packaging waste and promote reuse and recycling. The directive covers all packaging placed on the market and all packaging waste. Member States must ensure that packaging placed on the market can be reused or recovered. The European Commission is examining ways to improve packaging design to enable reuse and promote high-quality recycling, thereby achieving the targets. The latter includes achieving that by 31 December 2025, at least 65% by weight of all packaging waste must be recycled. By 31 December 2030, at least 70% by weight of all packaging waste must be recycled.[56] The urgent need for further research on MPs is underlined by the need to understand the mechanisms of interactions of microorganisms with human health and to develop effective regulatory measures. It is still unclear where inhaled particles are deposited in the respiratory tract by the complex agents. Accurate prediction of deposition patterns is important to facilitate clinicians in monitoring patient health and managing risks associated with MPs exposure.[57] Knowledge gaps limit our ability to manage MP-related pollution in deltaic systems. This is due to the fragmented focus of existing studies, which often examine MPs in isolation from sediment processes, metal interactions, or land-use feedbacks. There is insufficient evidence for the accumulation of MPs in floodplains, particularly those used for agriculture, despite their frequent flooding and exposure.[58] Biochar can remove MPs, but several challenges prevent its large-scale application. One challenge lies in understanding how variations in the algae feedstock affect the final properties of the biochar. Another challenge is developing strategies to preserve useful elements such as nitrogen, oxygen and sulfur during production at high temperatures.[59] Traditional MPs extraction methods present difficulty in monitoring dynamic molecular events executed by MPs and inability to uncover unknown signaling interaction networks. Traditional models are difficult to quantify the dynamic accumulation of MPs in the microenvironment. In vitro cell experiments cannot simulate the complexity of cell-matrix interactions. It is difficult to accurately detect low-concentration, small-sized micro particles, and the sample pretreatment steps are complex and prone to loss. Future research lies in developing a method that will eliminate the above difficulties to enable the effective removal of MPs.[60] Coral reefs are not exposed to single pollutants and toxicity experiments must include mixtures of MPs of different polymers, sizes and shapes as a function of pH, temperature and chemical pollutants.[61]

Discussion

My narrative review concerns MPs that originate from thermal degradation and the degradation of plastic residues, enter the environment as primary MPs and as secondary MPs and pose a challenge to water safety due to their characteristics. The production of MPs has skyrocketed over the last eight decades to over 8.3 billion metric tons, their annual production amounts to over 280 million tons, and their production skyrocketed to 348 million tons in

2017 (table 1). The abundance of microplastics in wastewater treatment plants reaches 3 × 104 particles/L. Human exposure to MPs through ingestion is estimated at 0.1-5 g/week with annual consumption ranging from 39,000 to 52,000 particles. Recycling of MPs has the potential to reduce carbon emissions by 30% to 80%, and chemical recycling achieves a 50% reduction in climate change impacts. It is noted that the MPs risk assessment is done with the pollution load index where an index value less than 10 represents the minimum risk and an index value greater than 30 represents the highest risk. The most reliable quantitative risk thresholds for ecosystems continue to contain moderate to high uncertainties with their main sources being size, shape, polymer type and the presence of chemical additives. The release of harmful additives, the induction of toxicological effects, oxidative stress and inhibition of enzyme production are reported, highlighting the effects of MPs on humans. Prevention and control of MPs pollution includes the implementation of mandatory pre-treatment of stormwater by improving the design of hydrocarbon separation-deposition systems. The European Union aims to reduce MPs by 30% by 2030. The European Union directive sets a 90% collection target for all single-use plastic bottles by 2029. The European Commission promotes the achievement, by 31 December 2025, of at least 65% by weight of all packaging waste being recycled and by 31 December 2030, of at least 70% by weight of all packaging waste being recycled. The need to overcome difficulties such as nitrogen, oxygen and sulfur conservation and monitoring dynamic molecular events with the inability to uncover unknown signaling interaction networks is emphasized in order to strengthen the effectiveness of biochar.

Table 1: Illustration of microplastic production in the period 1950-2017 and the future estimate for 2050 and 2060.

	1950	2010	2017	2050	2060
Microplastic production (million tons)	2	275	348	600	155-265

Conclusion

MPs enter the human body through inhalation, ingestion and skin contact, and the factors that influence particle deposition in the human airways are the shape, density and concentration of the particles and the intensity of breathing. The risk of microplastics is high due to their easy transport by winds and the longevity of polymeric structures. Assessing the risk of microplastics remains difficult due to methodological inconsistencies in detection. The development of harmonized assessment methodologies, combined with enhanced research, promises to strengthen confidence in risk thresholds and in reliable conclusions. MPs cause DNA damage, mental and developmental disorders, lung inflammation and cancer. PS and PVC cause damage to corneal tissue and disruption of lipid metabolism. Prevention and control of MPs pollution is achieved by creating separate sewage systems for new industrial developments and a hydrocarbon separation-dewatering unit is recommended for a pre-treatment system for rainwater. Biochar has the potential to remove MPs, and it is difficult to accurately detect low concentrations and small-sized MPs, with the sample pretreatment steps being complicated.

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