

Review



Contaminated Stormwater Containing Microplastics: Health Risks and Ecological Concerns

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Abstract: Stormwater contamination by microplastics has become a growing environmental concern, with significant implications for human health and ecosystems. Microplastics in stormwater pose potential health risks through a direct pathway by ingesting contaminated food, such as seafood and agricultural products. They contaminate soil and water sources, indirectly affecting crops and contributing to microplastic ingestion. Ecologically, microplastics can disrupt aquatic ecosystems, affecting biodiversity and the function of aquatic organisms. Beyond summarizing current knowledge, this review aims to provide a focused perspective on the challenges in assessing the human health risks and ecological concerns associated with microplastics in contaminated stormwater, while highlighting future research priorities for improving integrated risk assessment. Findings highlight current challenges and demand in addressing microplastic contamination, including gaps in monitoring, treatment strategies, and the need for more effective pollution control measures.

Keywords: human health; urban runoff; biodiversity; food chain; ecosystem; pollution control

1. Introduction

Plastic pollution is a global issue nowadays [1]. The fragmentation of plastic debris into microplastics that are less than 5 mm in size and that are pervasive and enduring contaminants found in various ecosystems. Microplastics are widespread in lakes, rivers, oceans, soil, atmosphere, organisms, and other ecological settings [2–5]. Significantly, stormwater contamination with microplastics has emerged as a substantial ecological challenge, driven by increasing urbanization and plastic usage [6–8]. The primary source of contaminated stormwater carrying microplastics into ecosystems is illustrated in Figure 1.

A recent literature review showed that the concentration of microplastics in stormwater varied between 0.02 and 15,499 items L⁻¹ [6]. Most microplastics measured between 100 µm and 500 µm, with polyethylene being the dominant type in stormwater systems worldwide. As tiny plastic particles, microplastics pose a remarkable risk to terrestrial, freshwater, and marine environments [9,10]. Due to their bioaccumulative properties, microplastics are considered exceptionally harmful to aquatic ecosystems compared to other pollutants. They impact health risks and their complex interactions with ecological concerns. The challenges associated with microplastic contamination in stormwater can cause potential health risks for humans through direct exposure and consumption of contaminated water and food chains. Indeed, microplastic ingestion by marine organisms raises concerns regarding bioaccumulation and biomagnification, posing risks to human health through seafood consumption as well as agricultural products [11–13]. Therefore, this work addresses microplastic challenges from stormwater, particularly the health risks associated with environmental problems. This perspective review aims to critically evaluate the current understanding of the human health risks and ecological concerns associated with microplastics transported by contaminated stormwater. It highlights the major exposure pathways, potential toxicological effects,



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and ecological consequences across natural ecosystems. In addition, the review outlines future research priorities to improve mechanistic understanding, exposure assessment, and integrated risk evaluation.

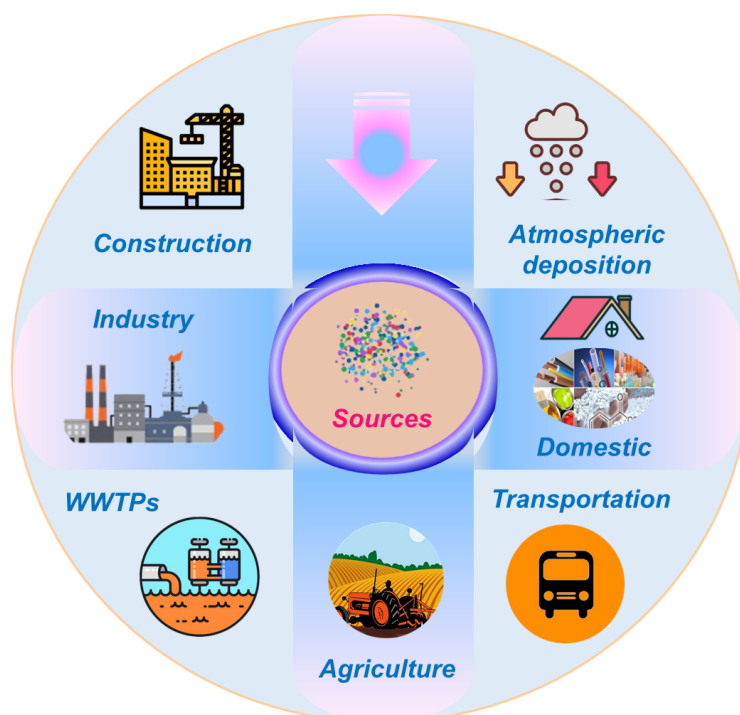


Figure 1. Source of contaminated stormwater carrying microplastics into ecosystems (Contaminated stormwater transports microplastics from major sources, including construction, industry, wastewater treatment plants, agriculture, transportation, domestic activities, and atmospheric deposition, into ecosystems. Simple icons illustrate each source, highlighting their contributions to environmental microplastic pollution).

This review was based on a comprehensive survey of peer-reviewed literature retrieved from Scopus, Web of Science, and Google Scholar. The literature search employed combinations of keywords including “microplastics”, “stormwater”, “urban runoff”, “human health risks”, “ecological concerns”, “ecotoxicity”, “risk assessment”, and “ecosystems”. Relevant articles published in English were screened for their relevance to microplastics in contaminated stormwater and their associated health and ecological impacts. Additional references cited in key publications were also examined to ensure broad coverage of the topic. The selected studies were critically evaluated and synthesized to summarize current knowledge on health risks and ecological concerns. Particular attention was given to identifying challenges in risk assessment, exposure pathways, and toxicity evaluation. Based on the synthesized evidence, knowledge gaps and future research priorities were identified to support the development of more robust risk assessment frameworks.

2. Occurrence and Challenges Related to Ecological and Human Health Risks

2.1. Occurrence and Distribution

Microplastics are widely detected in stormwater systems across urban, suburban, and rural environments worldwide. As rainwater flows over roofs, roadways, and other impermeable surfaces, it mobilizes plastic particles derived from sources such as tire wear, littered plastics, and the weathering of plastic materials [14]. As an example, stormwater runoff and rainwater were sampled at seven sites across Hong Kong to evaluate microplastic contamination [15]. The median microplastic concentration in stormwater runoff (185 items L⁻¹) was approximately 4.6-fold greater than that measured in rainwater (40 items L⁻¹). Polypropylene, polyethylene, and polystyrene were the predominant polymer types, while fragmented particles represented the most common morphology. More than 60% of the detected microplastics in runoff were smaller than 300 µm, suggesting a predominance of fine particles. Ecological risk assessment using the Polymer Risk Index (PRI) also indicated that these microplastics posed moderate to high ecological risks.

The maximum average microplastic concentration (7740.4 ± 10,901.5 items L⁻¹) was observed in stormwater samples from Italy [6]. Among microplastic polymers, polyethylene was the most abundant in stormwater systems

globally. Analysis of stormwater samples from 15 locations in Calgary, Canada, collected under both baseflow and rainfall conditions, revealed ubiquitous microplastic contamination, with concentrations ranging from 0.7 to 200.4 items L⁻¹ (mean = 31.9 items L⁻¹) [16]. The widespread occurrence of microplastics demonstrates that urban stormwater runoff is a key vector for their transport to aquatic environments.

A study conducted in metropolitan Melbourne reported that industrial areas exhibited the highest concentrations of microplastics in both road dust (2410 items kg⁻¹) and stormwater (35 items L⁻¹), followed by commercial (2130 items kg⁻¹ and 27 items L⁻¹) and residential areas (1970 items kg⁻¹ and 24 items L⁻¹) [8]. Fragments and fibers were the predominant microplastic morphologies across all land-use types. Hydrodynamic forces within the stormwater drainage network were suggested to promote the fragmentation of larger plastic particles into smaller microplastics. Ecological risk assessment based on the hazard index indicated greater risks in industrial catchments than in commercial or residential areas. The findings also identified stormwater runoff as a major pathway transporting microplastics from urban road dust into receiving aquatic ecosystems.

In short, their occurrence, abundance, and spatial distribution can be influenced by land use, hydrological conditions, seasonal rainfall, and anthropogenic activities [6,17,18]. As stormwater serves as a major pathway for transporting microplastics into aquatic environments, these pollutants have become an increasing concern because of their persistence, widespread distribution, and ability to adsorb and transport hazardous contaminants. In addition, microplastics can accumulate in aquatic organisms and facilitate the transfer of pollutants through the food web, posing potential risks to ecosystem integrity and human health.

2.2. Challenges to Health Risks Associated with Ecological Concerns

Contaminated stormwater containing microplastics poses considerable environmental and health risks (Table 1). Microplastics detrimentally impact ecosystems and human well-being due to their chemical composition, extended persistence, and toxic effects. Figure 2 demonstrates the potential impacts of microplastics on natural ecosystems. Initially, microplastics in stormwater runoff present significant threats to aquatic ecosystems [17,19,20]. Microplastics pose threats/risks to marine ecosystems due to their ubiquitous presence in various environments [10,21]. Studies have indicated that storm and rain events can alter microplastic levels in diverse aquatic environments. Stormwater runoff serves as pathways for multiple micropollutants, including microplastics, transporting them from the land into water bodies upon deposition. Moreover, the association of organic pollutants with microplastics is a complex and concerning issue due to the potential environmental and health risks involved [22,23]. Microplastics, due to their large surface area, small size, and chemical composition, can act as carriers for various organic pollutants, including “persistent organic pollutants” (POPs), e.g., pesticides, “polycyclic aromatic hydrocarbons” (PAHs), “polychlorinated biphenyls” (PCBs), and other hydrophobic organic compounds. They can also carry heavy metal(loid)s from urban areas to water supply resources through stormwater [24]. The adsorption of these coexisting contaminants is governed by mechanisms such as hydrophobic interactions, electrostatic attraction, pore filling, hydrogen bonding, and surface complexation, depending on the physicochemical properties of both the microplastics and the pollutants [25,26]. Further, microplastics present in stormwater can attach microbes, e.g., pathogens and plastics-degrading bacteria. This amalgamation forms a microecosystem known as the ‘plastisphere’ [27,28]. The combined presence of chemical pollutants and microorganisms on microplastics may further induce synergistic toxic effects, enhancing pollutant bioavailability, facilitating pathogen transport, and increasing ecological and human health risks compared with exposure to individual contaminants alone [25,29].

Table 1. Challenges to health risks associated with ecological concerns from microplastic-contaminated stormwater.

Challenge	Description	Key Impacts	References
Bioaccumulation in food chains	Microplastics are ingested by aquatic organisms, transferring pollutants up the food web to humans	Food safety risks Biomagnification of contaminants	[7,30]
Human health exposure	Microplastics adsorb heavy metal(loid)s and persistent organic pollutants (POPs), increasing toxin mobility Potential ingestion and inhalation of microplastics through contaminated water and seafood	Increased toxic exposure Potential adverse health effects	[11,20,31]
Ecosystem degradation	Increased runoff pollution and transport of toxic chemicals during heavy rain Accumulation in sediments and waterways disrupts habitats and affects biodiversity	Habitat degradation Biodiversity loss Impaired ecosystem functions	[8,17,19]

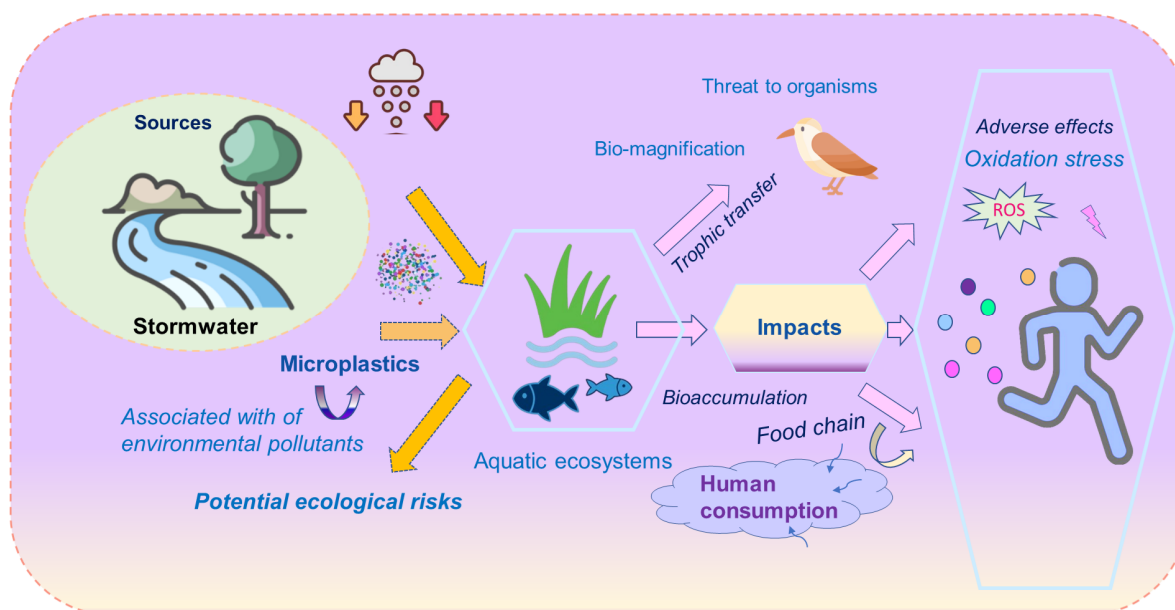


Figure 2. Potential impacts of microplastics on natural ecosystems (Stormwater transports microplastics and associated pollutants into aquatic ecosystems, where they accumulate in plants and aquatic organisms, leading to bioaccumulation and biomagnification through the food web. This process poses ecological risks and increases human exposure to contaminated seafood, potentially causing adverse health effects such as oxidative stress and other toxic responses).

Living organisms in marine and freshwater ecosystems can potentially ingest microplastics. Entanglement and/or ingestion of microplastics are prevalent concerns for the health of aquatic life. Interactions associated with aquatic living organisms, for instance, uptake by marine species such as fish and others or ingestion by filter-feeding organisms, play an essential role in determining microplastics' fate and potential ecological effects [32]. Microplastics in the ecosystems are readily ingested by aquatic forms such as mussels, fish, and zooplankton. Upon ingestion, they can cause intestinal obstructions and/or pseudo-satiety, leading to energy loss, growth inhibition, immune stress, and mortality [33–35]. Health and environmental concerns associated with microplastics include their capacity to absorb microcontaminants [36]. This microplastic debris contains various types of toxic additives incorporated during manufacturing, and they can also absorb trace elements and organic micropollutants, amplifying the potential exposure risk to marine life [9]. Besides, microplastics can comprise polymers containing harmful organic and inorganic additives like stabilizers, plasticizers, and flame retardants. Additives utilized in plastics production, e.g., endocrine-disrupting compounds (EDCs), such as “polybrominated diphenyl ethers” (PBDEs) and phthalates, have been discovered to bioaccumulate in biota [21,37,38]. These additives, along with the microplastics themselves, can be absorbed by marine plants and then up to higher trophic [39]. It poses a potential risk to humans by polluting food chains with microplastics and adsorbing toxic chemicals.

Microplastics can be bioaccumulated when organisms continuously ingest or absorb them from contaminated water, sediment, or food, resulting in their gradual buildup within tissues or the gastrointestinal tract [40–42]. These particles may then be transferred through predator–prey interactions, contributing to trophic transfer across aquatic food webs. Although the biomagnification of microplastic particles themselves remains under debate, there is growing evidence that microplastics and their associated contaminants can be transferred to higher trophic levels. This transfer may increase ecological risks by facilitating the accumulation of hazardous chemicals in aquatic organisms.

As an emerging pollutant, microplastics could potentially cause biological stress and/or physical damage due to their association with harmful chemicals. Significantly, the occurrence of microplastics can induce oxidative stress in the body, potentially leading to chronic inflammation or tissue damage as serious consequences [31,43–45]. Additionally, since a significant portion of the population receives and uses drinking water from freshwater sources, microplastics in these water sources could pose health threats to human beings [36]. The accumulation of microplastics in the cells and tissues can pose potential chronic biological effects and human health risks (Figure 3). The damage mechanisms are multifaceted, involving physical, chemical, and immunological responses. These may include respiratory problems, gastrointestinal issues, immune system dysfunction, chromosome alterations, infertility, and other related health concerns [30]. Microplastics also illustrate potential risks of causing (sub)-chronic toxicity, acute toxicity, toxic effects on development, genetic damage, and even cancer types [31].

Prolonged inflammation and irritation induced by microplastic can potentially cause cancer through DNA/RNA damage [40,46]. It raises critical issues in our world. Understanding the dynamics of microplastic contamination in stormwater is essential for developing effective mitigation strategies and safeguarding water resources.

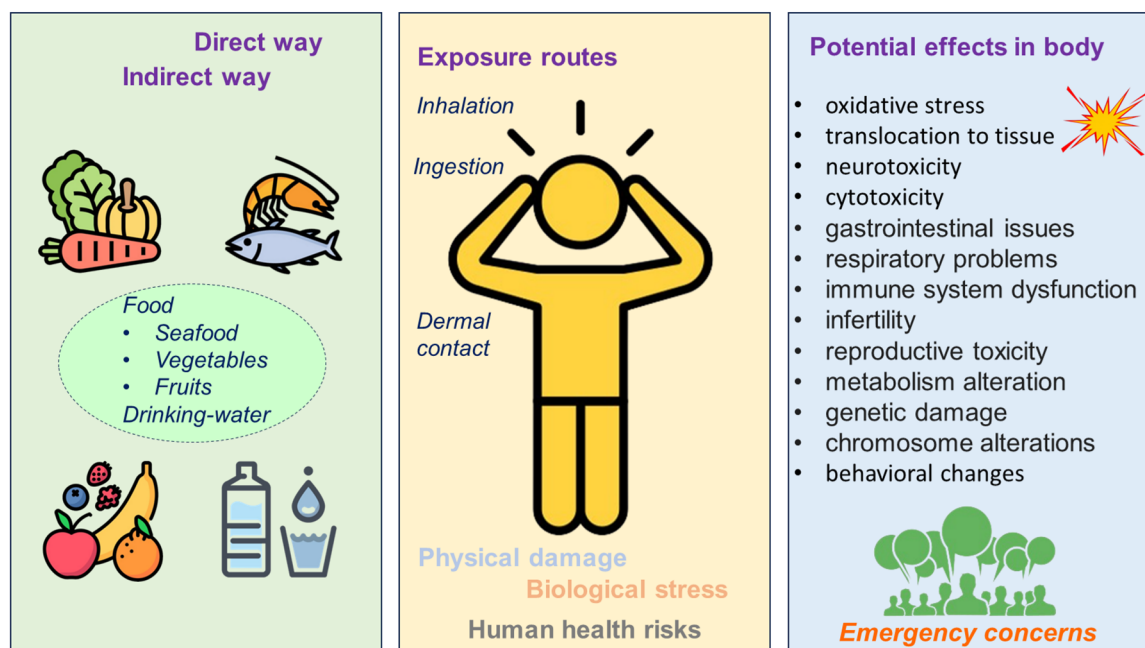


Figure 3. Microplastics-contaminated challenges to human health (Microplastics can enter the body directly by ingestion through contaminated food, such as seafood and agricultural products, or contaminate drinking water or by inhalation from airborne particles. They can also be absorbed through dermal contact with products containing microplastics. Indirectly, microplastics contaminate soil and water sources, affecting crops and contributing to microplastic ingestion. Through bioaccumulation, microplastics accumulate in organisms across different trophic levels, ultimately impacting human health).

Briefly, the inadvertent ingestion of microplastics and their associated additives by organisms can induce physical damage and diverse biological, physiological, behavioral, and molecular responses [47]. In addition, by serving as vectors for chemical contaminants, microplastics may exacerbate toxic effects through combined exposure, posing significant risks to ecosystems. These combined ecological and public health concerns underscore the urgent need for greater attention, comprehensive monitoring, and effective management and mitigation strategies to minimize their long-term environmental impacts.

3. Future Prospects

As mentioned, contaminated stormwater serves as a significant pathway for microplastics to enter aquatic environments, posing multiple health risks and ecological concerns. During rainfall events, urban runoff collects microplastics from various sources, such as road surfaces, tire wear, plastic litter, and degraded infrastructure. These particles are then transported through drainage networks and discharged untreated into rivers, lakes, and coastal waters. Once in the environment, microplastics can accumulate in water/sediments, be ingested by aquatic organisms, and transfer through food webs, ultimately threatening biodiversity and human health through seafood consumption and water use. It is crucial to develop and apply practical solutions to address microplastic contamination in stormwater (Figure 4). Selected green infrastructure strategies, e.g., bioretention systems, permeable pavements, and constructed wetlands, have shown considerable potential for reducing microplastic pollution in stormwater [14,17]. The ability of green infrastructure systems to retain microplastics is affected by several design and operational factors, including system configuration, filter media properties, vegetation, and hydraulic loading conditions. Future research should focus on optimizing green infrastructure designs to improve the long-term retention and removal of microplastics from stormwater.

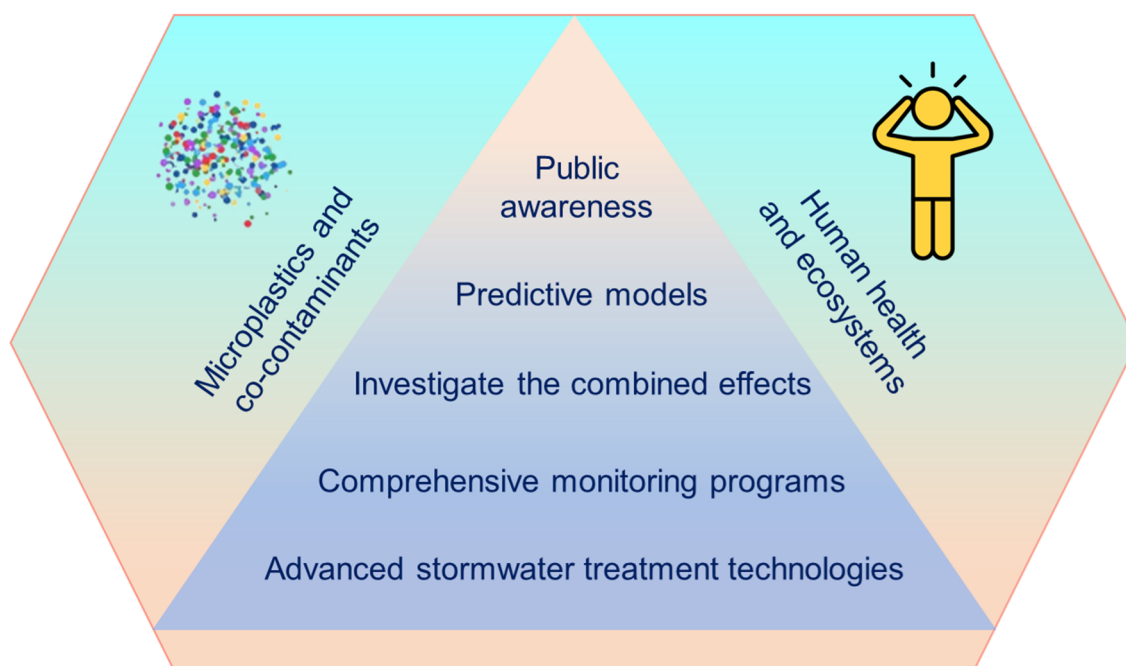


Figure 4. Future research directions and management strategies (A hexagonal diagram illustrates the link between microplastics and co-contaminants and their impacts on human health and ecosystems. A central triangle highlights five key actions: advanced stormwater treatment, comprehensive monitoring, investigation of combined effects, predictive modeling, and public awareness, emphasizing integrated strategies to mitigate microplastic pollution).

Future work should focus on developing advanced stormwater treatment technologies capable of effectively removing microplastics of various sizes and types [17]. Comprehensive monitoring programs are needed to track microplastic levels in urban runoff and receiving waters. Further research should also investigate the combined effects of microplastics and co-occurring contaminants on human health and ecosystems [48]. Additionally, predictive models (e.g., AI-based approaches) could help assess the fate and transport of microplastics during extreme weather events.

Current risk assessment frameworks for stormwater-borne microplastics remain limited by insufficient exposure data, inconsistent methodologies, and a lack of standardized toxicity assessment protocols. The combined effects of microplastics and co-occurring contaminants are still poorly understood, creating significant uncertainties in evaluating human health and ecological risks [49]. Future research should therefore focus on developing more robust, standardized, and integrated risk assessment frameworks to support evidence-based management and decision-making. Strengthening human health risk assessment requires a better understanding of chronic exposure pathways, dose–response relationships, and the toxicity of environmentally relevant microplastics. Finally, raising public awareness and implementing sustainable urban drainage solutions will be essential to mitigate microplastic pollution at the source.

4. Conclusions

In short, the health risks associated with microplastics are a complex interplay of their physical properties, the chemical additives they contain, and the environmental pollutants they may carry. The combination of physical, chemical, and adsorbed contaminants can amplify the health risks. The presence of microplastics might lead to increased exposure to harmful chemicals, both from the plastics themselves and the pollutants they adhere to. Microplastics in stormwater runoff pose significant environmental and health risks. Environmentally, they can accumulate in high concentrations in soil and water bodies, leading to widespread pollution and transporting additional contaminants like heavy metal (loid)s and toxic organic substances. This pollution can severely impact aquatic ecosystems. For human health, microplastics in stormwater runoff can contaminate drinking water and the food supply, posing risks through direct exposure and/or the transfer of harmful microorganisms that may adhere to the plastics. Greater integration of ecological and human health perspectives is needed to improve the assessment of risks posed by stormwater-borne microplastics. Future studies should combine ecotoxicological, environmental, and human exposure data to develop holistic risk assessment frameworks that better reflect real-world conditions. Standardized methodologies and interdisciplinary studies are needed to reduce uncertainties and support evidence-

based risk management. By shedding light on the potential pathways through which microplastics infiltrate human and ecological systems, our findings emphasize the urgent necessity for holistic strategies to mitigate this critical environmental threat.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

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Data Availability Statement

No new data were generated or analyzed in this study.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the author(s) used ChatGPT 4.0 for grammar correction and language refinement. After using this tool, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the published article.

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