Journal of ENVIRONMENTAL Treatment Techniques

J. Environ. Treat. Tech.
ISSN: 2309-1185

Review of the Presence of Microplastics in Drinking Water: Occurrence, Mechanisms, Health Implications, and Treatment Strategies

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Received: 22/06/2024 Accepted: 23/08/2024 Published: 20/09/2024

Abstract

Microplastics have emerged as an environmental contaminant of concern. They are now frequently detected in drinking water. This review paper summarizes recent studies on the occurrence, sampling and analytical methods, sources, removal technologies, and potential human health risks. Short laboratory tests and field studies show that microplastic contamination may occur from raw water sources, during water treatment, and via distribution systems. The chemical and physical properties of microplastics and their interactions with co-contaminants are discussed. Finally, we review treatment technologies and future research needs. This review calls for standardized methods and further risk assessment to ensure safe drinking water.

Keywords: Microplastics; Drinking water; Occurrence; Removal; Health risk; Water treatment

1 Introduction

The pervasive presence of microplastics—particles less than 5 millimeters in size—in various environmental matrices has become a focal point of scientific investigation due to potential ecological and human health implications [1]. Drinking water, both bottled and tap, has been identified as a significant exposure route for these contaminants. Initial studies revealed the occurrence of synthetic polymer particles in bottled and tap water, prompting concerns about the safety and quality of drinking water sources [2, 3]. Subsequent research has broadened to encompass the detection of microplastics in water treatment facilities, evaluating the efficiency of different treatment processes in removing these particles, and assessing the potential risks associated with their presence in potable water [4–6]. The detection of microplastics in treated drinking water has raised questions regarding the effectiveness of current water treatment technologies and the possible health risks posed by chronic exposure [7, 8].

The World Health Organization (WHO) has critically examined the occurrence of microplastics throughout the water cycle, including both tap and bottled drinking water, and has evaluated the potential health impacts arising from exposure, as well as the removal efficacy of microplastics during wastewater and drinking-water treatment processes [9, 10]. Despite these efforts, there remains a significant need for high-quality data to fully understand the implications of microplastic contamination in drinking water and to inform risk assessments and regulatory decisions [11, 12]. This review aims to synthesize recent advancements in our understanding of microplastic contamination in drinking water, focusing on their sources, detection methods, treatment efficiencies, and potential health risks [13–15]. By consolidating current knowledge, we seek to identify gaps in the existing literature and propose directions for future research to ensure the safety and quality of drinking water in the context of microplastic pollution.

2 Occurrence and Sampling Methods

Microplastics have been detected in various drinking water sources, including tap water, bottled water, and water treatment effluents, raising concerns about potential human health impacts [16–18]. The detection and quantification of microplastics in these water sources are influenced by the sampling and analysis methods employed.

2.1 Sampling Methods

Common techniques for sampling microplastics in water include membrane filtration and spectroscopic identification. Membrane filtration involves filtering water through membranes with specific pore sizes to capture particles, which are then analyzed to identify and quantify microplastics [19, 20]. Spectroscopic methods, such as Fourier-transform infrared (FTIR) spectroscopy and Raman spectroscopy, are used to determine the polymer type, size, and shape of microplastic particles in water samples [21, 22]. Standardization of these methods is essential to ensure consistency and reliability across studies. However, a lack of standardized protocols has been identified, leading to variability in results and complicating the comparison of data across different studies [23, 24]. Researchers emphasize the need for robust quality control measures to prevent sample contamination and ensure accurate detection and quantification of microplastics [25, 26].

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2.2 Recent Developments

Recent studies have highlighted the importance of standardizing sampling and analysis methods to improve data quality. For instance, a critical review assessed the quality of fifty studies researching microplastics in drinking water and its major freshwater sources, emphasizing the need for standardized methodologies to enhance data reliability [27]. Additionally, the development of standardized practices, such as ASTM D8333-20, provides guidelines for the collection and preparation of water samples for microplastic analysis, aiming to improve consistency across studies [28]. Advancements in analytical techniques have also improved microplastic detection. High-resolution imaging and mass spectrometry have been applied to characterize the size and chemical composition of microplastics [29, 30]. These tools are essential to assess the polymer type and surface functional groups that influence toxicity and fate [31, 32]. However, interlaboratory comparisons reveal differences in detection limits and recovery rates, highlighting the need for standardized methodologies to ensure consistency and reliability across studies [33, 34].

3 Sources and Mechanisms of Contamination

The origin of microplastics in drinking water is complex. They may enter water systems through urban runoff, industrial discharge, and the degradation of larger plastic debris [35–37]. Microplastic particles can be further modified by physical, chemical, and biological processes [38, 39]. In treatment plants, microplastics may bypass conventional filtration or be released during distribution [40, 41]. Chemical reactions on microplastic surfaces (e.g., oxidation) can change their reactivity and interaction with other pollutants [42, 43]. These surface modifications may affect the particles' ability to sorb heavy metals or organic contaminants [44, 45].

3.1 Sources of Microplastic Contamination

Microplastics enter drinking water sources through various pathways including urban runoff, industrial discharge, and degradation of larger plastic debris. Rainfall and stormwater runoff can transport microplastics from urban areas into rivers and lakes, which are common sources of drinking water. This runoff often contains microplastics from degraded plastic waste, tire wear, and synthetic textiles [46]. Industries that manufacture or utilize plastic materials may discharge microplastics into wastewater systems. These particles can pass through wastewater treatment plants and enter natural water bodies, subsequently contaminating drinking water sources [47]. Larger plastic items, such as bottles and packaging, degrade over time due to environmental factors like UV radiation and mechanical wear, breaking down into smaller microplastic particles that can infiltrate water systems [48].

3.2 Mechanisms of Microplastic Modification

Once in the water, microplastics undergo various modifications like physical processes, chemical processes, and biological processes. Mechanical actions, such as water movement and biological activity, can fragment larger plastic debris into microplastics, altering their size distribution and surface area [49]. Chemical reactions, including oxidation, can modify the chemical structure of microplastics, affecting their reactivity and potential to interact with other substances [50]. Microorganisms can colonize microplastic surfaces, forming biofilms that may alter the particles' buoyancy and facilitate their transport through water systems [51].

3.3 Microplastic Behavior in Treatment Plants

In water treatment plants, microplastics may bypass filtration or release during distribution. Conventional filtration methods may not effectively remove all microplastic particles, allowing some to pass through and enter the treated water supply [52]. Microplastics can be released into the water during distribution due to the degradation of plastic pipes and infrastructure, contributing to contamination [53].

3.4 Impact of Surface Modifications

Chemical reactions on microplastic surfaces, such as oxidation, can alter reactivity and affect sorption properties. Surface modifications can change the chemical reactivity of microplastics, influencing their interactions with other pollutants and potentially enhancing their toxicity [54]. Modified microplastics may have an increased capacity to adsorb heavy metals or organic contaminants, serving as vectors for these substances in water systems [55]. Understanding these sources and mechanisms is crucial for developing effective strategies to mitigate microplastic contamination in drinking water.

4 Analytical Techniques

Microplastics have been detected in various drinking water sources, including tap water, bottled water, and water treatment effluents, raising concerns about potential human health impacts [56–58]. The detection and quantification of microplastics in these water sources are influenced by the sampling and analysis methods employed.

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5 Health Implications

The potential health risks associated with microplastics in drinking water have become a significant concern in recent years. Laboratory studies have demonstrated that microplastics can induce oxidative stress and inflammatory responses in cells, suggesting potential adverse health effects [75, 76]. Although the exact exposure risk is still under debate, human exposure through ingestion is unavoidable, as microplastics have been detected in various drinking water sources [77, 78]. Some microplastics carry adsorbed pollutants or additives that may be harmful when released into biological tissues. These substances can include heavy metals, persistent organic pollutants, and plastic additives, which may pose additional health risks upon ingestion [79, 80]. The interaction between microplastics and these contaminants can potentially enhance their bioavailability and toxicity, further complicating the assessment of health risks. Risk assessment studies continue to investigate the dose-response relationship and long-term health impacts of microplastic exposure. However, the current understanding is limited, and more research is needed to elucidate the mechanisms of toxicity and the potential cumulative effects of chronic exposure [81, 82]. As the presence of microplastics in drinking water is an emerging issue, ongoing studies aim to provide a clearer picture of the associated health risks and inform the development of regulatory guidelines to protect public health.

6 Treatment and Removal Technologies

The presence of microplastics in drinking water has prompted the development of various treatment technologies aimed at their removal. Conventional water treatment processes, such as coagulation, flocculation, and sedimentation, have been found to remove a fraction of microplastics. These methods aggregate suspended particles into larger flocs, which can then settle out of the water column, capturing some microplastic particles in the process [83, 84]. Advanced treatment methods have demonstrated higher efficiency in removing microplastics from water sources. Membrane filtration techniques, including microfiltration, ultrafiltration, and nanofiltration, utilize semi-permeable membranes to physically separate microplastics based on size exclusion principles [85, 86]. Adsorption processes, employing materials such as activated carbon, have also been effective in capturing microplastic particles due to their large surface areas and high affinity for hydrophobic contaminants [87, 88].

Research indicates that combining physical and chemical treatments may enhance the overall removal efficiency of microplastics. For instance, integrating coagulation and flocculation with membrane filtration can improve the capture of smaller particles that might otherwise pass through individual treatment processes [89, 90]. Similarly, coupling advanced oxidation processes with adsorption techniques can degrade certain microplastics and their associated pollutants, facilitating their subsequent removal [91, 92]. Despite these advancements, effectively removing very small particles, particularly those in the nano-size range, remains a significant challenge. Nanoplastics can evade conventional treatment processes due to their diminutive size and unique physicochemical properties, leading to their persistence in treated water [93, 94]. Ongoing research is focused on developing innovative approaches and refining existing technologies to address the complexities associated with the detection and removal of nanoplastics in drinking water treatment systems [95, 96].

7 Future Research and Recommendations

Future research should prioritize the standardization of sampling and analysis protocols for microplastics in drinking water. The current lack of uniform methodologies leads to variability in data and complicates cross-study comparisons [97, 98]. Establishing standardized procedures will enhance the reliability and comparability of research findings. Comprehensive risk assessments are essential to understand the potential health implications of microplastic exposure. Integrating exposure pathways with toxicological data will provide a more complete picture of the risks associated with microplastics [99, 100]. This approach will inform the development of effective mitigation strategies and regulatory policies. Advancements in treatment technologies are crucial to effectively capture the full range of microplastic particle sizes present in drinking water. Improving existing methods and developing new technologies will enhance removal efficiency, particularly for smaller particles that are currently challenging to eliminate [101, 102].

Investigating the chemical reactivity and long-term behavior of microplastics within water treatment processes will aid in developing more effective removal strategies. Understanding how microplastics interact with other substances and degrade over time will inform the optimization of treatment methods [103, 104]. International collaboration is critical to addressing the global challenge of microplastic contamination in drinking water. Sharing knowledge, resources, and best practices across borders will facilitate the development of comprehensive solutions to this pervasive issue [105, 106].

8 Conclusion

This review highlights that microplastics are a persistent contaminant in drinking water. Occurrence data, analytical challenges, and treatment technologies are rapidly evolving fields. Although several removal methods show promise, there is an urgent need for standardized protocols and comprehensive risk assessment [107, 108]. Future research must address the gaps in knowledge regarding health implications and the fate of microplastics during water treatment [109, 110]. Ensuring the safety of drinking water requires coordinated research efforts and updated regulatory measures.

Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution to data collection, data analyses, and manuscript writing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT in order to enhance the manuscript writing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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