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Research Article

Microplastic and Bacterial Contamination in Drinking Water: "Emerging Risks to Public Health and Safety"

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ABSTRACT

Drinking water is essential to human health, yet increasing evidence suggests that it is increasingly contaminated with both microplastics and harmful bacteria. Microplastics, small plastic particles less than 5 millimeters in size, are pervasive in water sources worldwide, including tap and bottled water. Simultaneously, bacterial contamination continues to represent a significant threat to drinking water quality and public health, especially in areas with inadequate sanitation. This review critically examines the implications of both microplastic and bacterial contamination in drinking water, focusing on the sources, health risks, and interactions between the two contaminants. Moreover, the review discusses strategies to mitigate these threats, highlighting the need for more effective water treatment technologies and stronger environmental regulations. Addressing these dual contaminants is crucial to ensuring safe drinking water and protecting public health.

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INTRODUCTION

Safe drinking water is essential for human health, but the increasing presence of microplastics and harmful bacteria in water sources presents significant risks. While bacterial contamination has long been a major

concern for water quality and public health, the discovery of microplastics in drinking water has added a new layer of complexity (Kosuth et al., 2018). Plastics are persistent environmental pollutants, and those measuring between 1 μm

and 5 mm are classified as microplastics (MPs). These tiny plastic fragments can originate from two primary sources: primary MPs, which are intentionally manufactured with microscopic dimensions for consumer use, and secondary MPs, which result from the fragmentation and degradation of larger plastic materials. These particles are now ubiquitous in both environmental and human systems (O'Connor et al., 2022). Pathogens and polymers can each cause disease independently; however, environmental and medical researchers are increasingly exploring the potential of polymers to transport pathogenic bacteria and transmit diseases to hosts in water environment (Beans, 2023; Beloe et al., 2022). Simultaneously, bacterial contamination remains a persistent global issue, with pathogens such as *Escherichia coli*, *Salmonella*, and *Vibrio cholerae* contributing to waterborne diseases (Forstinus & Ikechukwu, 2016; Manetu & Karanja, 2021; Shayo et al., 2023). This review critically explores the dual contamination of drinking water by microplastics and bacteria, considering their health impacts and potential interactions.

Microplastic Contamination in Drinking Water

Microplastics are introduced into drinking water from multiple sources, including plastic packaging, synthetic textiles, and the

degradation of larger plastic waste in the environment (Beans, 2023; Nash et al., 2023; Whiting et al., 2022). Research has shown that microplastics are pervasive in freshwater ecosystems and bottled water (Kanhai et al., 2020). A study revealed that 93% of bottled water samples tested globally contained microplastic particles, with some samples showing concentrations exceeding 10,000 particles per liter (Kosuth et al., 2018). These findings underscore the widespread contamination of drinking water, with implications for human health.

Microplastics are small enough to be ingested and accumulate in the human body, raising concerns about their potential health effects. Research has shown that microplastics may carry toxic chemicals such as bisphenol A (BPA) and phthalates, which are linked to endocrine disruption and developmental issues (Campanale et al., 2020; Noventa et al., 2021; Usman et al., 2020). Additionally, microplastics are believed to cause inflammation, oxidative stress, and disruptions in metabolic and immune systems. Despite growing awareness of these risks, much of the science surrounding microplastic toxicity remains in its early stages, with additional research needed to fully understand the long-term health effects (Yee et al., 2021).

Table 1: Overview of Microplastic Detected in Drinking Water Sources

Microplastic Type	Polymer Composition	Common Sources	Size Range (μm - mm)	Detection Method
Fibers	Polyester, Nylon	Textile runoff, laundry wastewater	10 μm – 5 mm	FTIR, Raman spectroscopy
Fragments	Polyethylene (PE), Polypropylene (PP)	Packaging materials, plastic degradation	1 μm – 3 mm	FTIR, SEM
Films	PVC, LDPE	Food wrappers, plastic bags	10 μm – 2 mm	Raman spectroscopy
Beads	Polystyrene	Personal care products	0.1 μm – 1 mm	Microscopy, FTIR

Bacterial Contamination in Drinking Water

Bacterial contamination remains one of the leading causes of waterborne diseases, contributing to significant morbidity and mortality worldwide. Pathogenic bacteria such as *E. coli*, *Salmonella*, and *Vibrio cholerae* are

typically introduced into water sources through fecal contamination, often as a result of improper waste disposal or agricultural runoff. Waterborne diseases are responsible for approximately 1.4 million deaths each year, largely due to inadequate sanitation and poor

water treatment practices, particularly in low- and middle-income countries (Desissa, 2016; Wen *et al.*, 2020).

Bacterial pathogens can survive and proliferate in water sources, especially when water treatment and sanitation systems are ineffective. Even in developed nations, incidents of waterborne disease outbreaks have occurred due

Table 2: Common Pathogenic Bacteria Detected in Drinking Water and Their Health Implications

Bacterial Species	Common Sources	Associated Diseases	WHO Standard (CFU/100 mL)
<i>Escherichia coli</i>	Fecal contamination	Diarrhea, gastroenteritis	0
<i>Salmonella spp.</i>	Animal waste, sewage	Typhoid fever, food poisoning	0
<i>Vibrio cholerae</i>	Contaminated water	Cholera	0
<i>Legionella pneumophila</i>	Biofilms in plumbing	Legionnaires' disease	Not specified*

Note: There is no specific guideline value set for *Legionella spp.* in drinking water. The guidelines stress

the importance of controlling *Legionella* through effective water management strategies rather than relying on a fixed concentration threshold.

The Interaction Between Microplastics and Bacterial Contamination

Microplastics have become widespread due to uncontrolled plastic use. As they migrate, microorganisms colonize their surfaces, forming what is known as the plastisphere (Beloe *et al.*, 2022; Manetu & Karanja, 2021). This plastisphere can harbor human pathogenic bacteria, posing risks of disease transmission. Additionally, microplastics in drinking water may interact with bacterial pathogens, potentially exacerbating health risks. The plastisphere also adsorbs significant amounts of antibiotics, creating a favorable environment for the development and spread of antibiotic resistance genes (Li *et al.*, 2023). Emerging pollutants in the environment may further enhance the abundance and diversity of these genes. Furthermore, the plastisphere can adsorb heavy metals, promoting co-resistance between antibiotic resistance genes and heavy metal contamination (Tuvo *et al.*, 2023).

Microplastic particles provide surfaces for bacterial colonization, forming biofilms protective bacterial clusters that enhance resistance to environmental stressors, including disinfectants and antimicrobial treatments. This environment supports the growth of bacteria such as *E. coli*, contributing to the persistence of pathogenic bacteria even after water treatment. In aquatic ecosystems, microplastics pose serious ecological risks. They interact with small organisms like bacteria and microalgae that

to contamination of drinking water supplies, such as the Flint water crisis in the United States and several outbreaks in European countries. Preventing bacterial contamination requires effective disinfection methods, including chlorination, ultraviolet (UV) treatment, and filtration, as well as robust sanitation infrastructure.

colonize plastic debris, serving as vectors for biological and chemical contaminants. Microplastics in water provide a suitable environment for the growth of bacteria such as *E. coli*, contributing to the persistence of pathogenic bacteria even after water treatment (Beloe *et al.*, 2022; Koelmans *et al.*, 2019; Nash *et al.*, 2023).

Furthermore, the presence of microplastics may facilitate the spread of antibiotic-resistant bacteria. Studies have shown that bacteria growing on microplastic surfaces can acquire resistance to antibiotics, which may pose a significant challenge to public health efforts aimed at controlling waterborne diseases (Beloe *et al.*, 2022; Manetu & Karanja, 2021). This interaction between microplastics and bacterial pathogens could further complicate the treatment of contaminated drinking water (Forstinus & Ikechukwu, 2016; Shayo *et al.*, 2023). The dual presence of microplastics and microbial pathogens in drinking water reflects an intricate contamination dynamic. Figure 1 maps out the main sources and transport routes, while Figure 2 provides mechanistic insight into how microplastics enhance bacterial colonization and persistence. This dual contamination increases the complexity of ensuring safe drinking water and calls for integrative treatment approaches that address both physical and biological pollutants.

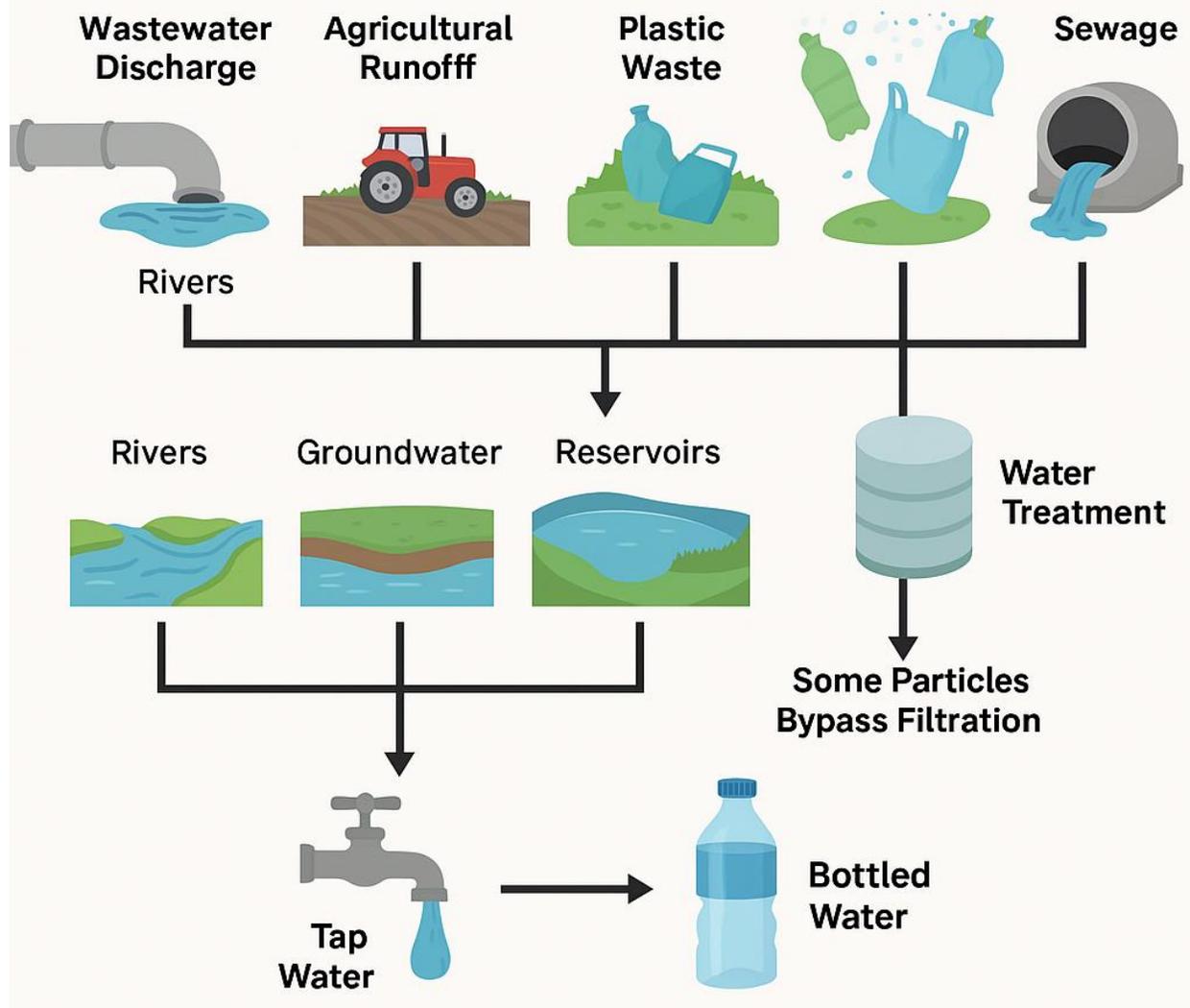


Figure 1: Conceptual Representation of Microplastic and Pathogenic Bacteria Pathways into Drinking Water Systems. Contaminants move through aquatic environments such as rivers, groundwater, and reservoirs, ultimately reaching treated water supplies like tap and bottled water.

Numerous studies have highlighted how both microplastics and microbial pathogens infiltrate drinking water systems through complex and interrelated pathways (WHO, 2022; Sharma *et al.*, 2023). Contamination often begins with surface-level pollution from urban waste,

agricultural runoff, or sewage discharge, which flows into freshwater reservoirs and groundwater systems. Despite treatment processes, some particles and microbes evade removal, posing health risks to end use

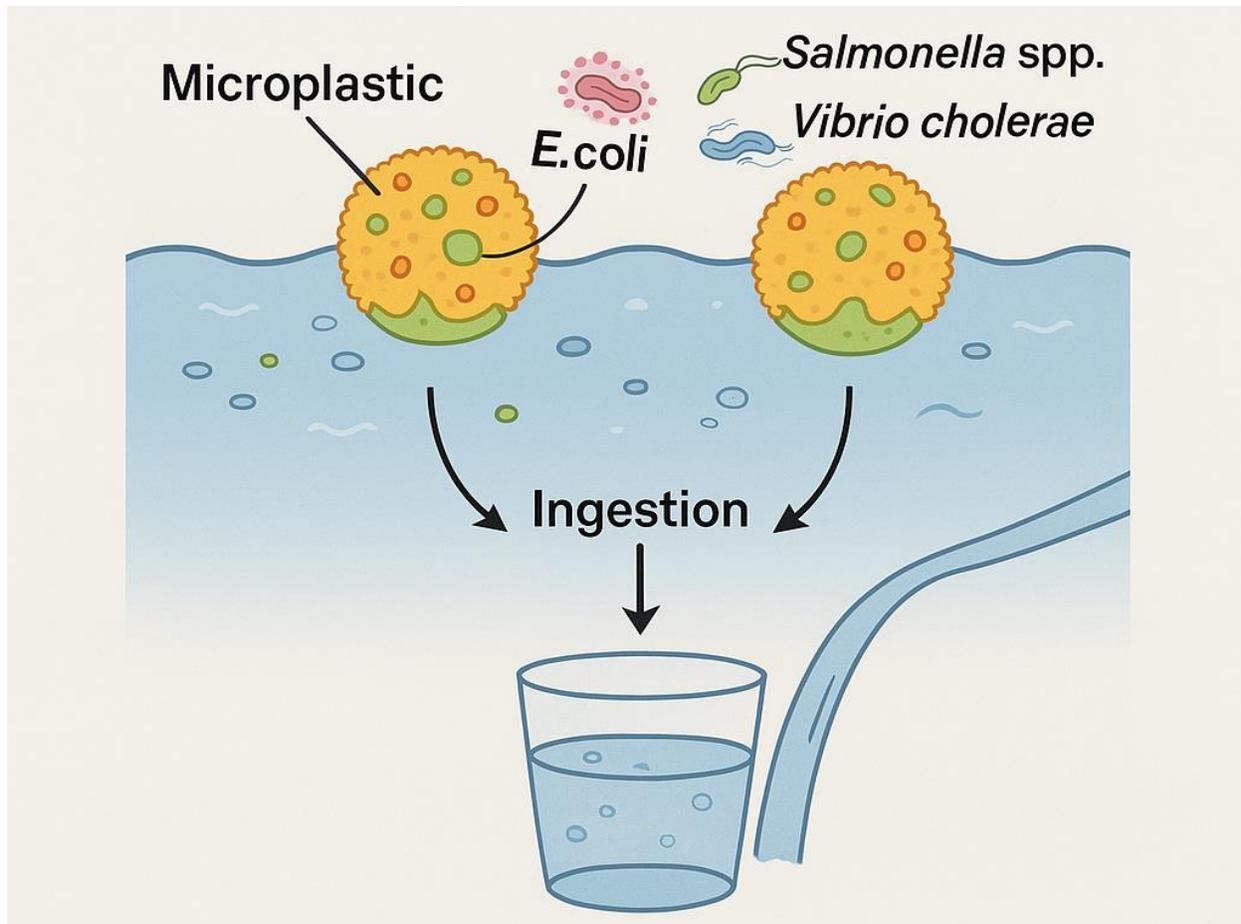


Figure 2: Schematic diagram illustrating how microplastics in water bodies serve as vectors for pathogenic microorganisms such as *E. coli*, *Salmonella* spp., and *Vibrio cholerae*.

Recent evidence suggests that microplastics not only act as pollutants but also serve as carriers for microbial contaminants (Yang et al., 2024). The surfaces of microplastics facilitate the attachment of bacteria and the formation of biofilms, enabling extended survival and mobility of pathogens in aquatic systems. This microbe-plastic interaction amplifies the risk of exposure through ingestion of contaminated water.

Health Risks and Public Safety

The health risks associated with microplastics and bacterial contamination are multifaceted (Beans, 2023; Li et al., 2023). Microplastics are primarily a long-term risk, with studies suggesting that they can cause gastrointestinal issues, inflammation, and potential endocrine disruption (Azambuja et al., 2024; Zhong et al., 2023). The small size and chemical composition

of microplastics allow them to enter human tissues, where they may accumulate over time. However, the precise health effects of chronic microplastic ingestion are still not fully understood, and further research is needed to determine their role in disease development. Bacterial contamination, in contrast, often leads to acute health issues, particularly gastrointestinal infections and waterborne diseases (Li et al., 2023). Ingesting contaminated water can lead to symptoms such as diarrhea, vomiting, and dehydration (Xu et al., 2018). If left untreated, these infections can lead to serious complications, including organ failure and death. The interaction of bacterial pathogens with microplastics may exacerbate these risks by enhancing bacterial survival in drinking water, making infections harder to treat (Kosuth et al., 2018; Nash et al., 2023).

Mitigation Strategies

To address the dual threat of microplastic and bacterial contamination, effective water treatment is crucial. Advanced filtration systems, such as reverse osmosis and nanofiltration, have been shown to remove both microplastics and bacterial pathogens from drinking water (Beans, 2023; Beloe *et al.*, 2022; Koelmans *et al.*, 2022). However, these technologies may be cost-prohibitive for many regions, particularly in developing countries where waterborne diseases remain a significant public health challenge. In addition to improving water treatment technologies, strict regulations on plastic waste management are needed to reduce the amount of microplastics entering the environment. Banning single-use plastics, promoting recycling, and encouraging the use of biodegradable alternatives can help curb the global prevalence of microplastic contamination in water sources (Koelmans *et al.*, 2019). Similarly, improvements in water infrastructure and sanitation are essential for preventing bacterial contamination and protecting public health.

Research Gaps and Future Directions

The increasing presence of microplastics and bacterial contamination in drinking water has emerged as a significant public health concern (Kristanti *et al.*, 2022; Wen *et al.*, 2020). Despite growing awareness, several research gaps remain unresolved. For instance, the complex interactions between microplastics and bacterial pathogens are not yet fully understood, particularly regarding their potential to serve as carriers that promote bacterial persistence and virulence. Furthermore, the mechanisms through which microplastics influence human health, including their possible role in enhancing antibiotic resistance, require deeper investigation. Current detection methods for microplastics are inconsistent, making it challenging to compare findings across studies. This challenge is especially worrisome in developing regions, where water treatment infrastructure may be inadequate, heightening the risk of contamination. Moreover, current risk assessment models often overlook the potential health impacts arising from the combined exposure to microplastics and bacterial pathogens.

To address these gaps, future research should focus on establishing standardized techniques for

detecting and measuring microplastics in drinking water systems. Additionally, epidemiological studies are essential to better understand the relationship between microplastic exposure and its potential impact on public health (Besseling *et al.*, 2019; Koelmans *et al.*, 2022). Furthermore, investigating the environmental factors that promote bacterial colonization on microplastic surfaces can provide insights into their role in pathogen transmission. Advancing water treatment technologies to effectively remove both microplastics and bacterial contaminants is equally important. Finally, developing comprehensive regulatory frameworks and promoting public awareness, especially in regions with limited access to safe water will play a vital role in mitigating these emerging risks and enhancing public health protection.

Conclusion

The dual threat of microplastic and bacterial contamination in drinking water presents significant challenges to public health and water safety. Microplastics, while an emerging concern, are increasingly found in water sources worldwide, and their potential health risks are only beginning to be understood. Simultaneously, bacterial contamination remains a persistent issue, particularly in regions with poor sanitation infrastructure. The interaction between microplastics and bacteria may increase the risks posed by these contaminants, highlighting the need for integrated water management strategies that address both issues. Improving water treatment technologies, regulating plastic waste, and strengthening water sanitation infrastructure are essential steps toward ensuring safe drinking water for all.

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