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MORALITY BEFORE KNOWLEDGE

Microplastics in drinking water: Addressing human health risks and removal strategies

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ABSTRACT

Background: Microplastics (MPs) have emerged as significant environmental contaminants increasingly detected in drinking water. Originating from plastic waste, textiles, and industrial effluents, MPs can infiltrate water systems and resist conventional treatment processes. Their small size and ability to carry toxic substances such as plasticizers, heavy metals, and persistent organic pollutants raise serious concerns regarding human health and water safety. **Methods:** This study employed a narrative review approach by synthesizing literature published between 2021 and 2025 from PubMed, Dimensions AI, and ScienceDirect. The review examined the sources of MPs in drinking water, associated human health risks, detection methods, removal technologies, and existing regulatory frameworks. **Findings:** The review found that MPs in drinking water pose considerable health risks through chemical leaching, bioaccumulation, and physical damage. Smaller particles, particularly nanoplastics, are difficult to detect and can bypass conventional filtration systems. Exposure to MPs is associated with endocrine disruption, gastrointestinal disorders, neurodegenerative diseases, and other long-term health impacts, especially among vulnerable groups such as children and pregnant women. Advanced treatment technologies, including nanofiltration, reverse osmosis, and electrocoagulation show potential for effective removal, although economic and operational limitations hinder large-scale implementation. The study also identified major policy gaps, including the absence of standardized global regulations and safety thresholds for MPs. **Conclusion:** Microplastic contamination in drinking water represents a growing threat to public health and water quality management. Improved detection methods, stronger regulatory frameworks, advanced treatment technologies, and public health education are urgently needed to reduce exposure and ensure safer drinking water systems worldwide. **Novelty/Originality of this article:** This study provides a comprehensive and up-to-date synthesis of microplastic contamination in drinking water by integrating health risk assessment, detection challenges, treatment technologies, and policy analysis within a single review. It highlights critical gaps in regulation and emphasizes the need for global standardization and interdisciplinary solutions.

KEYWORDS: drinking water; environmental contamination; human health risks; microplastics; public health; regulatory frameworks; removal strategies.

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1. Introduction

Microplastics (MPs) are increasingly recognized as pervasive anthropogenic pollutants of global concern, defined as plastic particles ranging from 1 μm to 5 mm in size that originate from the degradation of larger plastic debris or are directly manufactured at microscopic scales (e.g., microbeads) for industrial and consumer uses (Yadav et al., 2025). These particles include various morphologies such as fibers, fragments, and beads, which differ in shape, polymer type, and surface properties, influencing their environmental fate and interaction with biological systems (Yang et al., 2024). The primary sources of MPs include the fragmentation of discarded plastic waste, synthetic textiles, industrial effluents, and personal care products containing microbeads; once released into the environment, MPs are highly persistent due to their resistance to biodegradation and physical disruption (Wikipedia n.d.; Cai et al., 2025).

The global prevalence of MPs in the environment is now well-documented, extending beyond aquatic systems to include soils and even the atmosphere. Evidence shows that MPs have been detected in freshwater and marine environments across the globe, from heavily populated basins to remote regions, highlighting their ubiquitous presence in environmental media (Cai et al., 2025). MPs have been found in rivers, lakes, and drinking water sources, and are transported through soil erosion, wastewater discharges, and atmospheric deposition, contributing to a complex contamination landscape (Sharma et al., 2024). Recent review revealed that freshwater bodies and groundwater systems often show significant MP loads, indicating that the raw water entering drinking water treatment plants (DWTPs) frequently contains plastic particles of varying sizes and compositions (Lee et al., 2024). Such widespread distribution emphasizes that the problem of MPs is not confined to marine environments but extends to all critical components of the hydrological cycle.

Understanding the presence of MPs in drinking water is particularly important because drinking water is a primary pathway for human exposure. Both bottled and tap water have been shown to contain measurable levels of MPs, raising public health questions about long-term exposure and potential toxicity (Borenstein, 2024). Although the full spectrum of health effects remains incompletely characterized, MPs may act as carriers of toxic chemicals (such as plasticizers, heavy metals, and persistent organic pollutants) and microorganisms, increasing their potential to disrupt physiological processes upon ingestion (Sekar et al., 2024). In addition to ingestion through water, exposure routes include inhalation and dermal contact, yet drinking water remains the most direct and consistent route for human uptake of MPs from environmental sources (Sekar et al., 2024).

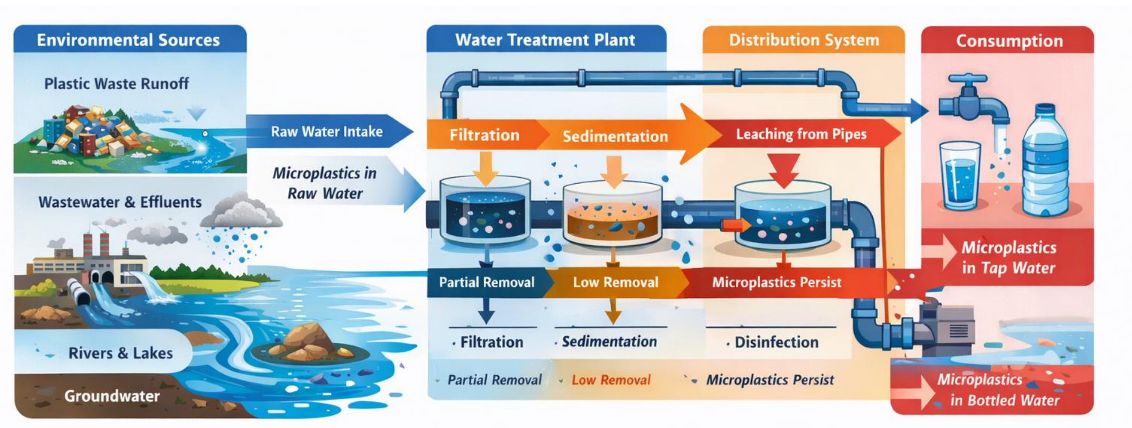

Fig. 1. Microplastic contamination pathways in drinking water

This narrative review is motivated by growing scientific evidence that MPs are not adequately removed by conventional water treatment systems and may reach consumers across diverse settings. As illustrated in Figure 1, MPs enter drinking water supplies through multiple pathways, including raw water contamination, inadequate removal during treatment processes, and leaching from distribution materials and bottled water packaging. These contamination pathways demonstrate that even sophisticated drinking water treatment plants (DWTPs) lack design elements specifically targeting microscopic plastic particles, enabling MPs to persist from source water to the point of consumption (Cai et al., 2025).

Despite the documented presence of MPs in drinking water, research gaps persist in understanding their health impacts and the effectiveness of detection and removal strategies. Several studies note large variations in reported MP concentrations, primarily due to methodological inconsistencies in sampling and analytical techniques, which complicate comparable risk assessments across regions (Yang et al., 2024). There is also limited evidence quantifying how specific polymer types behave during treatment and distribution, particularly for particles smaller than 10 μm, which are more likely to cross biological barriers and accumulate in tissues (Yang et al., 2024). These knowledge gaps underscore the need for standardized protocols and integrated studies that link environmental contamination with human exposure and toxicological outcomes.

Table 1. Overview of types of microplastics in drinking water

Type of microplastic	Typical sources	Size range	Polymer composition	Characteristics and behavior
Fibers	Textile fibers, Synthetic fabrics (e.g., polyester, nylon), Laundry waste	1 μm – 5 mm	Polyethylene terephthalate (PET), Nylon, Polyester	These fibers are often released during the washing of synthetic clothing. Their small size allows them to pass through filtration systems in wastewater treatment plants and may persist in aquatic environments.
Fragments	Plastic waste breakdown, Plastic packaging, Discarded plastic debris	< 1 μm – 5 mm	Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC)	Result from the degradation of larger plastic items, breaking into smaller pieces over time. Fragments have a high surface area-to-volume ratio, making them more likely to carry pollutants or toxic substances.
Beads	Personal care products (e.g., exfoliants), Cosmetics (e.g., face wash), Cleaning agents	0.1 μm – 5 mm	Polymethyl methacrylate (PMMA), Polyethylene (PE), Polypropylene (PP)	Manufactured for use in personal care products but are often not biodegradable. Due to their smooth surface and high buoyancy, they are more likely to float in water, increasing the chances of ingestion by aquatic organisms.
Films/Sheets	Packaging materials, Agricultural plastic films, Litter decomposition	< 1 μm – several cm	Polyethylene (PE), Polyvinyl chloride (PVC), Low-density polyethylene (LDPE)	Thin plastic sheets that can break into tiny pieces over time. These MPs tend to accumulate in sediment and water bodies, posing threats to benthic organisms and potentially affecting the food chain.
Pellets	Industrial plastic pellets (nurdles), Manufacturing waste	1 mm – several cm	Polypropylene (PP), High-density polyethylene (HDPE), Polystyrene (PS)	Pre-production plastic pellets used in manufacturing processes that often spill into the environment. These pellets are often mistaken for food by marine life and can bioaccumulate, contributing to ecological disruption.

The problem statement for this review centers on the uncertainties surrounding the risks posed by MPs in drinking water. Although MPs have been detected in treated water supplies worldwide, the public health implications of chronic ingestion remain largely unclear due to limited long-term epidemiological evidence (Yang et al., 2024). Potential ecological impacts include disruption of aquatic food webs and bioaccumulation of toxic substances, which may ultimately influence human health through the consumption of contaminated water and food derived from aquatic ecosystems (Yarahmadi et al., 2024). Moreover, the lack of harmonized regulatory frameworks and standardized analytical methods has hindered the development of evidence-based guidelines for MP monitoring and control in water systems.

To address these gaps, this narrative review aims to synthesize contemporary research on MPs in drinking water with a focus on human health risks and removal strategies, providing a comprehensive overview of current knowledge and identifying priority areas for future investigation. The key research questions guiding this study are: what are the human health risks associated with MPs in drinking water? What are the most effective methods for detecting and removing MPs from drinking water?. Table 1 summarizes the common types of microplastics detected in drinking water sources, their primary sources, and key characteristics relevant to their environmental behavior and potential health impacts.

2. Methods

2.1 Study design and research question

This study employed a narrative review to synthesize existing literature on microplastics in drinking water, focusing on human health risks and removal strategies. The narrative review approach was chosen for its ability to integrate findings from various disciplines, such as toxicology, environmental science, water treatment, and public health, allowing a comprehensive analysis of the topic. The central research question is: What are the human health risks associated with microplastics in drinking water, and what are the most effective strategies for their removal?

2.2 Information sources and search strategy

A comprehensive literature search was conducted across three databases: PubMed, Dimensions AI, and ScienceDirect on January 5, 2026. The search focused on studies published from 2021 to 2025. The search terms were tailored to ensure comprehensive retrieval of relevant studies, including experimental studies, observational research, and case studies. To retrieve policy documents included in this study grey literature search was conducted to retrieve publications from reputable organizations such as WHO, EU, EPA. In PubMed, search strings included MeSH terms, title and abstract keywords, and Boolean operators (“AND and “OR”) while title and abstract keywords with Boolean operators (“AND and “OR”) were used for the other databases that do not feature MeSH terms. The search strategy employed in this study are presented in Table 2.

Table 2. Search strategy

Database	Search strings	Search yield	Filters applied	Yield after application of filters
PubMed	First Search string dedicated to retrieve publications on health impacts: ((("Microplastics" OR "Microplastic contamination" OR "microplastic exposure"[MeSH Terms]) AND ("Microplastics"[Title/Abstract] OR "Microplastic contamination"[Title/Abstract] OR "microplastic	60	2021 to 2025, Free full text, English	11

	exposure"[Title/Abstract])) AND (("Drinking water"[MeSH Terms]) AND ("Drinking water"[Title/Abstract]))) AND (("Human health" OR "Health risks" OR "health impact"[MeSH Terms]) AND ("Human health"[Title/Abstract] OR "Health risks"[Title/Abstract] OR "health impact"[Title/Abstract]))			
	SecondSearch string dedicated to retrieve publications on removal strategy: ((("Microplastics" OR "Microplastic contamination" OR "microplastic exposure"[MeSH Terms]) AND ("Microplastics"[Title/Abstract] OR "Microplastic contamination"[Title/Abstract] OR "microplastic exposure"[Title/Abstract])) AND (("Drinking water"[MeSH Terms]) AND ("Drinking water"[Title/Abstract]))) AND (("Removal strategies" OR "Water filtration" OR "Water purification" OR "water purification"[MeSH Terms]) AND ("Removal strategies"[Title/Abstract] OR "Water filtration"[Title/Abstract] OR "Water purification"[Title/Abstract] OR "water purification"[Title/Abstract]))	7	2021 to 2025, Free full text, English	2
Dimensions AI	"Microplastics" AND "Drinking water" AND "Human health" AND "Removal strategies" OR "Water filtration" OR "Water purification"	357	2021 to 2025, research articles, open access	154

2.3 Eligibility criteria

Studies were included if they met the following criteria: original research articles published in English from 2021 to 2025. Eligible studies must have reported on microplastic concentrations in drinking water, the health effects of microplastics (e.g., toxicological impacts), and the effectiveness of removal technologies. Studies not published from 2021 to 2025 and those not focused on drinking water, reviews, or those without relevant outcomes were excluded.

2.4 Study selection and search results

The study selection process was rigorous and occurred in two phases. Initially, title and abstract of articles were screened to assess their relevance to the research questions. Full-text articles were retrieved for detailed evaluation, and those that met the inclusion criteria were included in the review. Duplicates identified across multiple databases were removed in Zotero. The screen process was handled by two independent reviewers and discrepancies resolved by discussion.

Based on the search, a total of 1,443 records were initially identified from PubMed, ScienceDirect, Dimensions, and grey literature. After applying appropriate filters, 1,182 records were excluded. Screening of 261 records based on titles and abstracts resulted in 43 reports being assessed for eligibility. Ultimately, 30 studies were included in the review, after excluding 13 reports that did not address the outcomes of interest. The selection process is presented in Figure 2.

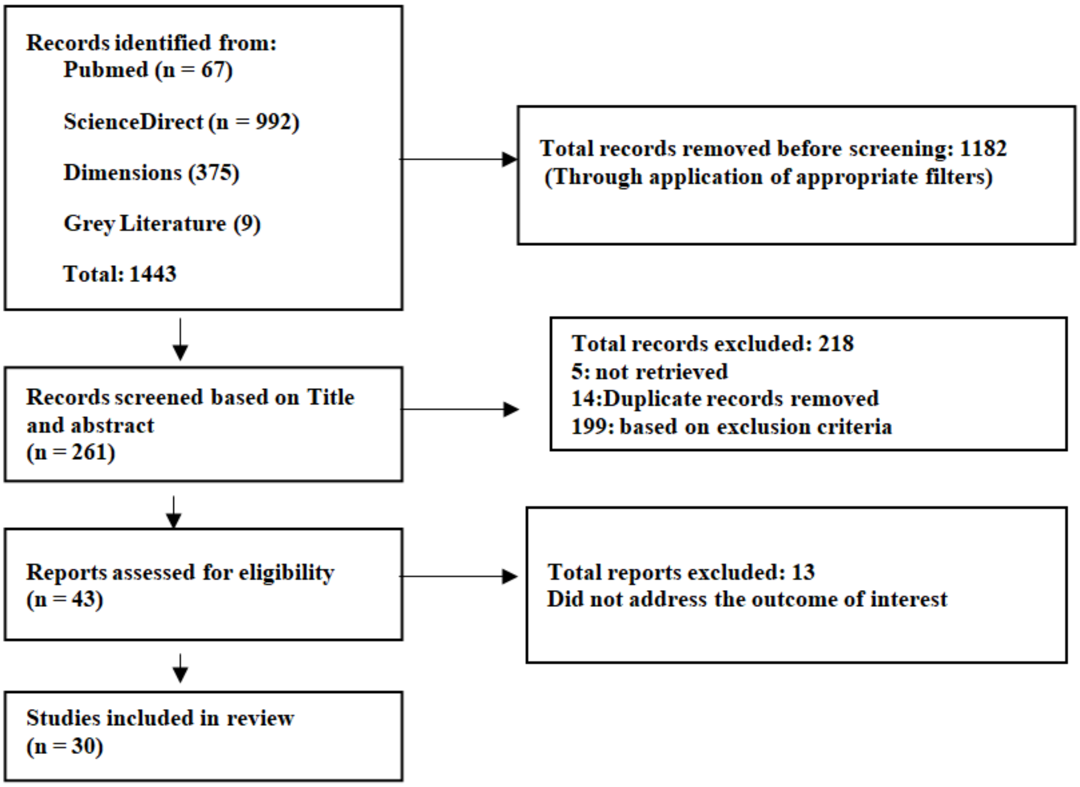

Fig. 2. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram

2.5 Data synthesis and interpretation

The data synthesis was narrative in nature, focusing on the integration of findings from the included studies. The narrative synthesis grouped studies around key themes such as health risks, microplastic sources, and removal strategies. The synthesis provided a qualitative analysis of these themes.

The interpretation stage involves assigning meaning to data obtained after collection and processing. In this review, the interpreted data focuses on microplastic contamination in drinking water, including reported concentrations, exposure pathways, and associated human health risks. At this stage, findings from selected studies are synthesized to identify patterns, inconsistencies, and knowledge gaps across the literature. Interpretations are contextualized within current toxicological frameworks and public health standards to assess potential risks to human populations. Additionally, documented removal strategies are examined to evaluate their reported efficiency, scalability, and limitations, thereby informing recommendations for future research and policy interventions.

2.6 Publication

The publication stage is the final stage of the research. The purpose of the publication stage is to make the research results available to a wide audience. In this narrative review, synthesized findings on microplastics in drinking water, human health risks, and removal strategies are organized into a structured manuscript for dissemination. This stage ensures that interpretations and recommendations derived from the literature reach academic, policy, and public health stakeholders. By publishing the review, the study contributes to broader scientific discourse, supports evidence-based decision-making, and highlights areas requiring further investigation into microplastic exposure and mitigation.

3. Results and Discussion

3.1 Microplastic sources and pathways

Microplastics (MPs) in drinking water originate from various anthropogenic and environmental sources, with plastic degradation, industrial activities, and wastewater treatment plants being major contributors. Studies show that plastic waste, particularly polyethylene (PE), polypropylene (PP), and polystyrene (PS), break down into microplastics in water sources, including rivers, lakes, and wastewater treatment plants (Hassan et al., 2025; Al-Mansoori et al., 2025). These microplastics often accumulate in the water supply chain, from raw water to treated water, with contamination levels varying based on local waste management practices and water treatment infrastructure (Li et al., 2024; Weber et al., 2021).

Transport mechanisms of microplastics through water treatment systems are complex. Conventional filtration methods, such as sand filtration and granular activated carbon, are capable of removing some microplastics, but smaller particles (<100 μm) often bypass these treatments and remain in treated water (Cherian et al., 2023). Membrane filtration and reverse osmosis are more effective in removing microplastics, but challenges remain in achieving complete removal due to the small size and biological persistence of microplastics (Ramirez Arenas et al., 2021). Plastic pipes in distribution systems have also been identified as a significant pathway for microplastic contamination, contributing to higher concentrations in household taps (Li et al., 2024).

3.2 Human health risks associated with microplastics

3.2.1 Toxicological effects

Microplastics (MPs) have raised growing concerns regarding their toxicological effects on human health. MPs can leach harmful chemicals into drinking water, including plasticizers, phthalates, and bisphenol A (BPA), which are known to disrupt the endocrine system and cause developmental, reproductive, and metabolic disorders (Rodríguez-Barroso et al., 2025; Li et al., 2024). Chemical leaching from plastic polymers, particularly polyethylene terephthalate (PET) and polystyrene (PS), has been shown to release toxic substances into the water, which can then be ingested by humans (Kirstein et al., 2021; Weber et al., 2021). Studies suggest that the leached chemicals from microplastics can accumulate in human tissues, potentially leading to chronic diseases such as cancer, cardiovascular diseases, and neurodegenerative conditions (Hassan et al., 2025; Gálvez-Blanca et al., 2024).

Moreover, physical damage from microplastics is another major concern. Smaller particles, especially those in the nanoplastic range (<100 nm), are capable of penetrating cell membranes, leading to cellular toxicity and inflammation. Research has indicated that the ingestion of these particles can result in intestinal irritation, inflammation, and oxidative stress (Carter et al., 2023; Bhat & Janaszek, 2024). MPs are also capable of inducing immune responses similar to foreign pathogens, thereby triggering chronic inflammatory diseases in the gut, liver, and other organs (Velasco et al., 2025). The long-term effects of such exposure are still not fully understood, but growing evidence suggests that these particles may contribute to autoimmune disorders, inflammatory bowel diseases, and other gastrointestinal disturbances (Cherian et al., 2023).

Additionally, microplastics have been shown to adsorb environmental toxins, such as heavy metals and persistent organic pollutants (POPs), which can further increase their toxicity. Once ingested, these toxic substances may be released into the human body, exacerbating the risks associated with MPs (Hassan et al., 2025). These findings underscore the synergistic toxicity posed by microplastics, where their small size and high surface area make them effective carriers for other harmful contaminants, amplifying their harmful effects on human health (Mohan et al., 2023).

3.2.2 Vulnerable populations

Certain groups of people are at a higher risk of experiencing negative health outcomes due to microplastic exposure. Children and pregnant women are particularly vulnerable populations. Children, due to their smaller body size and developing immune systems, may be more susceptible to the toxic effects of microplastics. Additionally, early-life exposure to microplastics may lead to long-term developmental and neurological consequences, as indicated by animal studies (Carter et al., 2023; Gálvez-Blanca et al., 2024). For pregnant women, the ingestion of microplastics has the potential to adversely affect fetal development, as these particles may cross the placenta and lead to toxicity or inflammatory responses in the fetus (Bhat & Janaszek, 2024).

Elderly individuals and those with compromised immune systems are also more vulnerable to the health risks posed by microplastics. With age, the body's detoxification mechanisms become less efficient, and the accumulation of microplastics in tissues could increase the risk of degenerative diseases, such as Alzheimer’s or Parkinson’s disease (Weber et al., 2021). Moreover, individuals with pre-existing conditions, such as asthma or cardiovascular diseases, could experience exacerbated symptoms due to the inflammatory effects of microplastics on the body.

3.3 Analytical methods for detecting microplastics in water

3.3.1 Detection techniques

Detecting microplastics (MPs) in drinking water has proven to be a significant challenge due to their small size, diversity of polymers, and low concentrations. However, several detection techniques have been developed and refined over the years to identify and quantify microplastics in environmental and drinking water samples. The most commonly used techniques include microscopy, spectroscopy, and chemical analysis, each with distinct advantages and limitations.

3.3.1.1 Microscopy and spectroscopy

Optical microscopy is one of the most widely used techniques for microplastic detection due to its simplicity and relatively low cost. In this method, water samples are filtered, and the retained particles are analyzed under a microscope to determine the presence and size of microplastics. This method works particularly well for larger microplastic particles (greater than 10 μm) but can struggle with smaller particles due to their low visibility (Carter et al., 2023; Kirstein et al., 2021). For smaller particles, fluorescence microscopy is often employed. It involves the use of fluorescent dyes, such as Nile Red, which selectively stain hydrophobic surfaces of plastic particles, making them easier to identify. This approach has been useful for distinguishing microplastics from organic debris, although its quantification potential is somewhat limited (Negrete Velasco et al., 2025).

Raman Spectroscopy and Fourier Transform Infrared (FTIR) Spectroscopy are powerful techniques used to identify and characterize the polymer type of microplastics. Both methods are highly effective for identifying the chemical structure of microplastics and distinguishing between different polymer types, which is essential for understanding the source and potential toxicity of the particles (Weber et al., 2021; Gálvez-Blanca et al., 2024).

Raman Spectroscopy, for instance, uses laser-induced scattering to provide a detailed spectrum that can be used to identify specific polymer types, even in complex water matrices. FTIR Spectroscopy, on the other hand, relies on the absorption of infrared light by materials, allowing for the detection of polymer functional groups that are characteristic of specific plastic types (Hassan et al., 2025). These methods are particularly beneficial for distinguishing between various types of microplastics, such as polyethylene (PE), polypropylene (PP), and polystyrene (PS), and are often used for detailed chemical analysis after preliminary filtration and identification (Cherian et al., 2023).

3.3.1.2 Chemical analysis and other techniques

In addition to spectroscopic techniques, chemical analysis methods such as pyrolysis-gas chromatography-mass spectrometry (Py-GCMS) and high-performance liquid chromatography (HPLC) have been employed to identify and quantify microplastics in water (Mohan et al., 2023). Py-GCMS is particularly useful for analyzing small particles by heating them to break down complex polymers into smaller molecules that can be analyzed and identified (Rodríguez-Barroso et al., 2025). This method allows for the identification of polymer types and other chemical residues, providing insight into the potential contaminants associated with microplastic particles. HPLC, on the other hand, is often used for more sensitive analyses, particularly when combined with various detectors such as UV absorbance or fluorescence (Carter et al., 2023). However, these methods tend to be more expensive and time-consuming than spectroscopy and microscopy.

Additional methods such as thermal desorption-gas chromatography-mass spectrometry (TD-GCMS) and electrochemical sensors have been explored, though they are less commonly used in routine water quality monitoring. Electrochemical sensors offer the potential for real-time monitoring of microplastics in water, but further research is needed to improve their sensitivity and specificity (Weber et al., 2021). Similarly, methods like Nile Red staining are effective in identifying hydrophobic MPs, but require validation against other methods to ensure reliability (Mohan et al., 2023).

3.3.2 Challenges in detection

3.3.2.1 Small size of microplastics

While significant progress has been made in the development of microplastic detection methods, several challenges persist that hinder the accurate detection and quantification of microplastics in drinking water including: small size of microplastics, complex water matrix, lack of standardized methods, detection limits, time and cost. One of the major challenges in detecting microplastics is their small size. Microplastics range from 1 μm to 5 mm in diameter, with many of the most concerning particles falling below 100 μm in size (Rodríguez-Barroso et al., 2025). These small particles are difficult to detect using conventional water treatment monitoring equipment. Standard filtration methods often fail to capture the smallest microplastics, leaving them in treated water that is consumed by humans. Additionally, smaller particles tend to aggregate or adhere to other substances, making them harder to isolate and analyze (Weber et al., 2021).

3.3.2.2 Complex water matrices

The complexity of water matrices is another significant challenge. Water samples are often contaminated with a wide range of organic material, biological particles, and inorganic salts that can interfere with the detection of microplastics. For example, particles such as algae, sediment, and organic detritus can be difficult to distinguish from microplastics using microscopy and can interfere with the accuracy of spectroscopic methods (Hassan et al., 2025). As such, pre-treatment steps, such as acid digestion, are often used to remove organic and inorganic contaminants before analysis (Cherian et al., 2023). However, this adds complexity to the detection process and may not always be effective in completely isolating microplastics from other particles.

3.3.2.3 Lack of standardized methods

There is currently no universal protocol or standardized method for microplastic detection in drinking water, leading to significant variability in results across studies. Differences in sample preparation, detection techniques, and analysis protocols can result in discrepancies in the reported concentrations of microplastics in drinking water. For instance, studies using microscopy may report higher concentrations of microplastics due to the inability to distinguish smaller particles, while studies using spectroscopy may report lower concentrations due to detection limits (Carter et al., 2023; Li et al., 2024). This lack of standardization makes it difficult to compare findings across different research studies and hinders efforts to establish consistent guidelines for microplastic contamination in drinking water (Weber et al., 2021).

3.3.2.4 Detection limits, times, and cost

Many detection techniques have inherent detection limits that make it challenging to identify and quantify very small microplastics. For example, Raman spectroscopy and FTIR typically have detection limits of 10 μm, which means that smaller particles may go undetected, even though they can pose significant health risks (Hassan et al., 2025). Additionally, the recovery rates for microplastics during filtration and analysis can vary widely, with studies reporting recovery rates of between 50% and 90%, depending on the technique and the particle size (Bhat & Janaszek, 2024). This introduces further variability in the accuracy of microplastic concentration measurements.

Many advanced detection techniques, such as Py-GCMS and Raman Spectroscopy, are time-consuming and costly. These methods require specialized equipment and technical expertise, making them less accessible for routine monitoring of drinking water. This may limit their application in large-scale water quality monitoring programs (Carter et al., 2023).

3.4 Microplastic removal techniques in drinking water treatment

Microplastic contamination in drinking water is a growing concern, particularly because traditional water treatment processes were not designed to remove particles as small as microplastics. Over the past decade, researchers have explored both conventional and emerging treatment techniques to improve the removal of these persistent pollutants from drinking water. Below is a detailed discussion of both traditional and advanced techniques, highlighting their effectiveness in reducing microplastic concentrations.

3.4.1 Conventional methods: Coagulation and flocculation

Coagulation and flocculation are common processes in water treatment facilities, where chemicals (e.g., alum, ferric chloride) are added to bind with particles in the water, causing them to clump together and form larger aggregates, or flocs, which can then be removed by sedimentation and filtration. These processes are efficient at removing larger particles but show limited efficacy when dealing with microplastics smaller than 10 μm, which may not aggregate effectively (Hassan et al., 2025). Studies by Rodríguez-Barroso et al. (2025) and Bhat & Janaszek (2024) suggest that while coagulation can remove larger microplastics, it is less effective for smaller, more dispersed particles, which pass through conventional filtration.

3.4.2 Conventional methods: Sand and granular activated carbon (GAC) filtration

Sand filtration is another traditional method commonly used in water treatment plants to remove particulate matter. This process involves passing water through a bed of sand, where larger particles are trapped. While sand filtration is effective for removing particles larger than 10 μm, microplastics smaller than this threshold are able to pass through the filter. As Cherian et al. (2023) and Mohan et al. (2023) report, sand filtration's removal efficiency is insufficient for microplastics, especially those smaller than 100 μm, which can remain in treated water and pose a risk to public health.

Granular activated carbon (GAC) is widely used to adsorb organic contaminants, chlorine, and other pollutants in drinking water. GAC filtration has been explored for its potential to adsorb microplastics as well. Hassan et al. (2025) found that GAC filtration can remove larger microplastics effectively, especially plastic fragments and beads. However, smaller particles, particularly those less than 1 μm, often pass through the GAC filters, which limits the overall removal efficiency for microplastics. Weber et al. (2021) highlighted that while GAC is efficient in removing organic contaminants, it is less effective for microplastics unless paired with additional filtration

3.4.3 Membrane filtration

Membrane filtration, including ultrafiltration (UF) and microfiltration (MF), has shown better effectiveness in removing microplastics compared to conventional methods. These processes work by forcing water through a semi-permeable membrane that allows smaller water molecules to pass through while retaining larger particles, including microplastics. Kirstein et al. (2021) demonstrated that microfiltration membranes with pore sizes of 0.1 to 1 μm can efficiently remove microplastics, particularly larger particles. However, nanoplastics (<100 nm) still pose a challenge for traditional filtration membranes, as their small size allows them to pass through these filters.

3.4.4 Emerging techniques: Nanofiltration (NF)

With the increasing awareness of microplastic contamination, new emerging technologies have been developed and tested for their ability to remove microplastics from drinking water more effectively. These techniques are designed to target the smaller, more challenging particles that conventional methods often miss. Nanofiltration (NF) is an advanced membrane filtration technology that operates at a finer scale than microfiltration. NF membranes have pore sizes ranging from 1 to 10 nanometers, allowing them to remove not only larger particles but also much smaller microplastics and nanoplastics. Carter et al. (2023) demonstrated that NF can achieve high removal efficiencies for microplastics smaller than 1 μm, which makes it particularly effective in removing contaminants from drinking water. Despite its high efficiency, NF is more expensive and requires higher energy consumption compared to traditional methods, making it less feasible for large-scale applications unless coupled with cost-reducing technologies (Cherian et al., 2023).

3.4.5 Emerging techniques: Electrocoagulation

Electrocoagulation (EC) is a relatively new technology that uses an electrical current to generate coagulation agents in the water. These agents help microplastics clump together into larger particles that can then be removed by sedimentation or filtration. Mohan et al. (2023) found that EC could effectively remove a broad range of microplastics, particularly fibers and small fragments, by facilitating the formation of larger aggregates. Bhat & Janaszek (2024) further confirmed that EC was particularly useful for removing microplastics in highly turbid water, where traditional coagulation methods struggle. This method has the potential for lower operational costs and greater flexibility, making it an attractive alternative in diverse water treatment settings.

3.4.6 Emerging techniques: Activated carbon adsorption

Activated carbon adsorption is an established technology for removing a wide range of contaminants, including organic chemicals and pollutants, from water. Activated carbon (AC) works by adsorbing pollutants onto its large surface area. Studies have shown that AC adsorption can effectively remove larger microplastics, particularly fibers and fragments. However, nanoplastics remain difficult to remove using AC, due to their small size and poor interaction with the carbon surface (Weber et al., 2021). Some researchers, including Gálvez-Blanca et al. (2024), suggest that combining activated carbon with other advanced filtration techniques, such as reverse osmosis, could improve the removal of smaller microplastics.

3.4.7 Emerging techniques: Reverse Osmosis (RO)

Reverse osmosis (RO) is a proven water purification technology that is particularly effective in removing small micropollutants, including microplastics. RO operates by applying pressure to force water through a semipermeable membrane that only allows water molecules to pass through while rejecting contaminants like salts, bacteria, and microplastics. Studies, such as those by Kirstein et al. (2021) and Rodríguez-Barroso et al. (2025), have demonstrated that RO can achieve over 99% removal efficiency for microplastics of varying sizes, including nanoplastics, making it one of the most effective treatments for this purpose. However, RO systems are expensive, require high energy inputs, and can result in water wastage, which limits their widespread adoption in some regions (Cherian et al., 2023).

3.4.8 Effectiveness of current methods

The comparison of current water treatment methods reveals that conventional methods, such as sand filtration and coagulation, are only partially effective in removing microplastics, particularly when dealing with smaller particles (Rodríguez-Barroso et al., 2025). While granular activated carbon can remove larger microplastics, it falls short when dealing with sub-micron particles (Weber et al., 2021). Nanofiltration and reverse osmosis are highly effective in removing both larger microplastics and nanoplastics, but their high operational costs and energy requirements can make them less feasible for widespread use, especially in resource-limited settings.

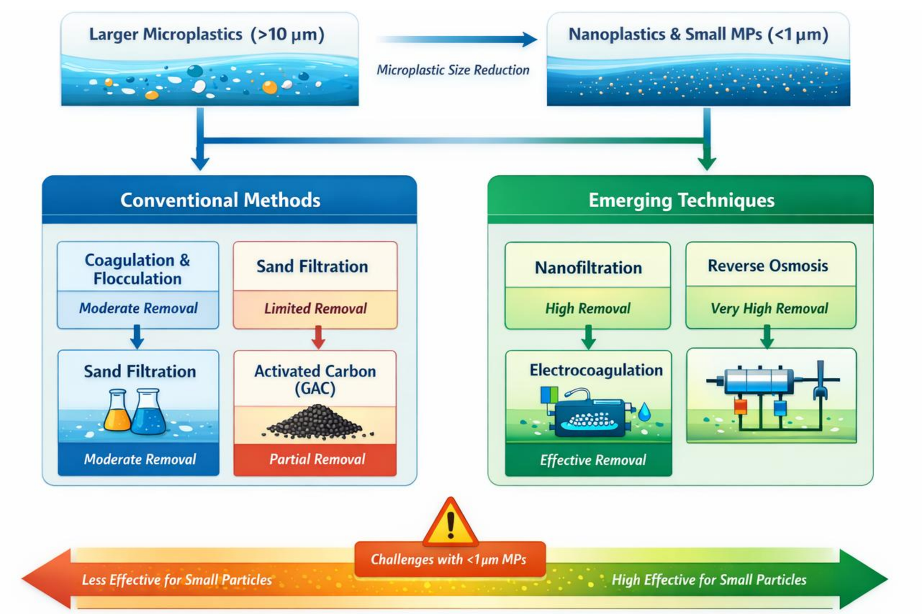

Fig. 3. Conventional and emerging water treatment methods for microplastics

Electrocoagulation offers a promising alternative with its ability to remove a broad range of microplastic types at relatively lower costs. However, it is still in the experimental phase and needs further optimization and large-scale validation (Bhat & Janaszek, 2024). Activated carbon adsorption, when combined with other advanced filtration methods, holds potential for improving the removal of microplastics, but it faces challenges in dealing with the smallest particles.

3.5 Regulatory standards and guidelines

3.5.1 World health organization (WHO)

The WHO recognized microplastics as an "emerging concern" in its Microplastics in Drinking-Water report, which synthesizes the available evidence on their occurrence, potential health impacts, and treatment outcomes (WHO, 2019). Although WHO does not currently prescribe a numeric safety limit for MPs in water, it recommends national governments and water authorities to begin systematic monitoring and risk assessment and to strengthen analytical methods to better understand human exposure and outcomes. WHO highlights that the presence of MPs has been confirmed in both tap and bottled drinking water, raising questions about the sufficiency of current water safety frameworks (WHO, 2019).

3.5.2 European union (EU)

The EU has taken significant steps toward regulating microplastics as part of its broader water quality framework, though formal enforceable limits are still in development. Under the EU Drinking Water Directive 2020/2184, microplastics are being integrated as an emerging contaminant category that requires harmonized measurement and monitoring at the Member State level. A Commission Delegated Decision (EU) 2024/1441 now establishes a standardized methodology for detecting and quantifying microplastics in water intended for human consumption, designed to produce consistent, inter-comparable data across countries. This harmonized method supports future inclusion of MPs on the "watch list" of substances monitored under the Directive (European Commission, 2026; Stephens, 2024).

Despite this progress, the current EU methodology only covers MPs larger than 20 µm, a limitation increasingly questioned by scientists because most MPs found in drinking water are much smaller and potentially more biologically active. A recent study by Hagelskjær et al. (2025) notes that the majority of MPs in potable water are smaller than the EU's current detection threshold, highlighting the need for regulatory revision to encompass fine particles (<20 µm) that may pose greater risk. In addition to the drinking water context, the EU has also adopted Regulation (EU) 2023/2055, which restricts the intentional addition of microplastics to products, including cosmetics and other consumer goods, as part of the broader REACH chemical regulation. This measure aims to reduce microplastic release into the environment and ultimately limit entry into water systems (European Union, n.d.).

3.5.3 United states environmental protection agency (EPA)

Unlike the EU and WHO, the U.S. EPA has not established specific regulatory limits for microplastics in drinking water. The EPA recognizes microplastics as a contaminant of emerging concern and supports a growing body of research into their prevalence, behaviour, and potential health effects. Its research programs provide definitions and support analytical method development but do not yet include enforceable concentration limits for microplastics in tap water (US EPA, 2022).

The U.S. Safe Drinking Water Act (SDWA) requires that the EPA identify and regulate contaminants that pose risks to health. However, microplastics have not yet been placed on the EPA's Contaminant Candidate List (CCL) with recommended regulatory thresholds. This means that while the EPA may be collecting and studying data, there are currently no nationwide enforceable numerical standards for MPs in U.S. drinking water (Wikipedia, 2025).

3.5.4 Other initiatives and standards

Outside of WHO, EU, and EPA guidance, there are emerging international standards that may influence regulatory approaches. For example, ISO 24187 provides general guidelines for sampling, preparation, and analysis of microplastics in environmental matrices and can be applied to drinking water monitoring. This standard is not a regulatory limit, but it helps improve comparability and reliability of analytical data across laboratories, a critical step toward future regulatory thresholds (Measurlabs, 2024).

3.5.5 Policy gaps and regulatory challenges

3.5.5.1 Absence of numeric limits and size-based detection thresholds

Despite these global efforts, significant gaps and inconsistencies remain in regulatory frameworks addressing microplastics in drinking water, as follows. One of the most striking regulatory gaps is the lack of legally enforceable limits for microplastics in drinking water in most jurisdictions. Neither WHO nor EPA has established a maximum allowable concentration (e.g., particles per liter or mass) for microplastics in drinking water. In the EU, while monitoring methodologies are being standardized, numeric regulatory thresholds have not yet been defined. This absence makes it difficult to evaluate compliance and enforce protection strategies (WHO, 2019; FDA, 2024).

Current regulatory approaches often rely on size thresholds for microplastic monitoring. The EU standard, for example, focuses on particles larger than 20 µm, omitting smaller microplastics and nanoplastics that may pose greater health risks due to their potential for cellular uptake and systemic distribution. Hagelskjær et al. (2025) study shows that >90 % of MPs detected in potable water are smaller than this regulatory cutoff, implying that the current regulatory focus may underestimate true exposure and risk.

3.5.5.2 Variability in analytical methods and regulatory inconsistency across regions

The lack of harmonized global standards for analytical methods remains a major barrier. Although ISO 24187 and EU methodology provide frameworks, many countries still use different sampling protocols, detection technologies, and reporting standards. Without globally accepted protocols, data from different regions cannot be reliably compared, complicating efforts to derive universal health-protective limits (Measurlabs, 2024).

Regional and national differences further complicate the regulatory landscape. While the EU has moved toward methodological harmonization, the U.S. EPA focuses on research without regulatory limits, and many low- and middle-income countries lack specific monitoring or guidance altogether. This inconsistency means that protections against microplastic contamination can vary dramatically, potentially leaving populations in some regions without adequate safeguards (FDA, 2024).

3.5.5.3 Limited risk assessment data

Finally, many regulatory bodies cite the insufficient evidence on health effects as justification for withholding strict limits. The WHO report notes that while microplastics are widely present in drinking water, conclusive evidence linking specific exposure levels to defined health outcomes is still limited. This data gap hinders the establishment of quantitative standards and underscores the need for longitudinal epidemiological and toxicological studies to inform policy (WHO, 2019).

3.6 Technological innovations and research advancements in detection

The detection of microplastics (MPs) in drinking water have become an increasingly important area of research due to their growing presence in water systems and the potential risks they pose to human health. The detection of microplastics in water has historically been challenging due to their small size, diversity of polymers, and the complexity of water matrices. However, recent innovations in analytical technologies have significantly improved the ability to detect microplastics with greater sensitivity and precision.

3.6.1 Advanced spectroscopy and microscopy techniques

Recent advancements in spectroscopic and microscopic technologies have enhanced the ability to detect microplastics in water. Raman Spectroscopy and Fourier-transform infrared spectroscopy (FTIR) are considered some of the most effective tools for identifying and characterizing microplastics. These techniques provide detailed chemical fingerprints of microplastics, enabling the identification of polymer types at very low concentrations. Bhat & Janaszek (2024) and Rodríguez-Barroso et al. (2025) have noted that FTIR can now detect microplastics as small as 1 μm, significantly improving the sensitivity of microplastic detection in drinking water. Similarly, Raman Spectroscopy has shown promise in distinguishing between various plastic polymers, even in complex mixtures, allowing for better quantitative analysis (Hassan et al., 2025).

In addition to these techniques, the development of fluorescence microscopy combined with specific staining techniques (e.g., Nile Red) has improved the visualization and quantification of microplastics in water. This method works by staining the hydrophobic surfaces of microplastic particles, enabling their identification under a fluorescence microscope. Carter et al. (2023) highlighted the increasing use of this method for identifying microplastics in water samples with high efficiency, particularly for smaller microplastics.

3.6.2 High-resolution imaging

High-resolution imaging techniques, including scanning electron microscopy (SEM) and transmission electron microscopy (TEM), have also seen significant improvements. These methods are capable of identifying nanoplastics (<1 μm), which were previously difficult to detect due to their small size. Kirstein et al. (2021) demonstrated the application of SEM to identify sub-micron particles in complex water matrices, providing detailed morphological analysis of microplastic contamination. The integration of energy dispersive X-ray spectroscopy (EDX) with SEM also enables chemical analysis of microplastic particles, helping to identify their polymer composition, which is essential for assessing their potential toxicity (Weber et al., 2021).

3.6.3 Automated and AI-Based Detection Systems

The integration of artificial intelligence (AI) and machine learning algorithms with detection technologies is revolutionizing the field of microplastic monitoring. AI-based systems can now automatically analyze microscopy and spectroscopic data to identify and classify microplastic particles with high accuracy, reducing the need for manual analysis. Cherian et al. (2023) discussed the development of automated image analysis systems that leverage deep learning algorithms to classify microplastics based on size, shape, and polymer type. This innovation significantly improves the efficiency and scalability of microplastic detection in large water treatment facilities.

3.6.4 Portable detection devices

Portable microplastic detection devices have also become a focal point of recent research. These devices are designed for on-site monitoring of microplastics in water sources, offering a more convenient and cost-effective approach compared to laboratory-based methods. Mohan et al. (2023) explored the development of handheld fluorescent microplastic analyzers that use Nile Red staining for rapid identification. Such devices are beneficial for field sampling and can help water authorities monitor microplastic contamination in real-time.

3.7 Public health implications and risk communication

3.7.1 Risk perception

The perception of microplastic risks in drinking water among the public has evolved significantly in recent years, largely due to the increasing awareness of microplastic contamination in the media and scientific communities. However, public understanding of the health risks posed by microplastics in drinking water remains varied and often insufficient. Research studies, by Agnew et al. (2024), reveal that while microplastic contamination is a growing concern, many individuals still have limited knowledge about the health implications associated with these pollutants. Several factors contribute to this phenomenon as follows.

3.7.1.1 Limited awareness of microplastics

Despite the growing body of scientific literature on microplastics, the general public's awareness remains low. A survey conducted by Gálvez-Blanca et al. (2024) in Spain found that while 80% of participants had heard of microplastics, only 40% understood their potential risks in drinking water. This gap highlights a major barrier in public health communication: the complexity of scientific information related to microplastics, which often makes it difficult for the public to fully understand the potential health threats posed by these pollutants. Studies also indicate that people often confuse microplastics with other forms of plastic waste, not fully appreciating their toxicity or bioaccumulation potential (Weber et al., 2021).

3.7.1.2 Media influence and government communication

The media plays a critical role in shaping public perception of environmental risks, including microplastic contamination in drinking water. Research by Pop et al. (2023) found that while the media has increasingly covered the topic of microplastic pollution, coverage tends to be sensationalized, often focusing on dramatic imagery and the global scale of microplastic contamination without providing clear context or actionable information. This approach can exaggerate public concern and lead to misconceptions about the actual risks, such as the likelihood of harmful exposure to microplastics in drinking water. Conversely, limited media coverage on microplastics may downplay their risks, leaving individuals unaware of the potential long-term health impacts.

Government institutions and regulatory bodies have made efforts to communicate the risks of microplastics in drinking water, but challenges remain in conveying the urgency of the issue. Public health authorities, such as the World Health Organization (WHO), have highlighted microplastics as an emerging concern, but WHO's guidelines on microplastic contamination in drinking water still focus primarily on monitoring and research rather than providing specific regulatory limits (WHO, 2019). This approach may inadvertently contribute to public uncertainty and hesitation regarding the seriousness of the issue. In countries like the United States, the EPA has not yet included microplastics in the Contaminant Candidate List for regulated drinking water pollutants, leading to perceived inaction among the public (US EPA, n.d.). Governments need to strengthen their communication efforts to effectively address the growing public interest and concern regarding microplastics and their potential health impacts.

3.7.2 Health education

Education is a crucial tool in empowering the public to take action against microplastic contamination in drinking water and to foster informed decision-making. The findings from Agnew et al. (2024) study suggest that public health campaigns aimed at educating individuals on the risks of microplastics can play a significant role in enhancing awareness, improving perception, and motivating behavior change. There are several strategies that can be employed to improve public understanding of microplastics in drinking water:

3.7.2.1 Clear communication of risks and public awareness campaigns

One of the first steps in health education is ensuring that the risks of microplastic contamination are clearly communicated. Scientific evidence on the health impacts of microplastics, including their potential to cause toxicological effects, bioaccumulation, and inflammation, needs to be made accessible and understandable to the public. Simplified information, presented through infographics, public service announcements, and social media platforms, can help make complex scientific data more digestible.

Governments and environmental organizations need to launch targeted awareness campaigns focused on microplastic contamination. According to Bidashimwa et al. (2023), such campaigns can highlight the sources of microplastics (e.g., plastic waste, synthetic fibers, industrial discharges), potential risks to human health, and the availability of filtration technologies to reduce exposure. Collaborations between governments, non-governmental organizations (NGOs), and media outlets can ensure that educational messages reach a wide audience. Additionally, campaigns can highlight practical steps people can take to reduce microplastic exposure, such as installing home filtration systems, avoiding the use of single-use plastics, and opting for bottled water with lower microplastic contamination.

3.7.2.2 Promoting water quality awareness and community engagement

Educating the public on the importance of water quality—and the role of filtration technologies in improving water safety—is another essential element of health education. Cai et al. (2025) suggested that increasing awareness of available water treatment technologies, such as reverse osmosis and activated carbon filters, could empower consumers to take control of their water safety. Furthermore, local government authorities should be encouraged to invest in monitoring and publishing data on microplastic contamination levels in public water supplies, making it more accessible to the public and helping to raise awareness of the issue.

Community-based educational programs can also be an effective way to engage individuals at a local level. For example, public workshops, school programs, and online webinars on microplastic pollution can raise awareness of the sources of contamination, detection methods, and solutions. Such initiatives help create community-driven solutions and encourage individuals to advocate for better water management practices at the local level (Seifi et al., 2025; Raimi et al., 2021).

3.7.2.3 Integration with sustainable practices

Another important educational strategy is to link microplastic awareness with broader environmental sustainability practices. By highlighting the connection between plastic waste, water quality, and environmental health, education campaigns can motivate individuals to take broader actions, such as reducing plastic consumption and adopting more sustainable lifestyles. Such integrated campaigns may lead to holistic behavior changes that not only mitigate microplastic contamination in drinking water but also address larger environmental challenges (Matavos-Aramyan, 2024).

4. Conclusions

It was found that microplastics (MPs) in drinking water pose significant human health risks, with chemical leaching, bioaccumulation, and physical damage being the primary mechanisms of harm. MPs are capable of carrying harmful substances such as plasticizers, heavy metals, and persistent organic pollutants, which can disrupt endocrine function, cause neurodegenerative diseases, and contribute to gastrointestinal disorders. Vulnerable populations, particularly children and pregnant women, face a higher risk of adverse health effects due to their developing systems and smaller body sizes. Despite considerable progress in the detection of MPs through techniques such as Raman spectroscopy, microscopy, and chemical analysis, significant challenges remain, particularly with smaller particles like nanoplastics (<100 nm), which often escape detection using conventional methods. Emerging water treatment technologies, including nanofiltration, reverse osmosis, and electrocoagulation, offer promise for more effective microplastic removal but face economic and operational constraints, limiting their widespread adoption. Conventional methods, such as sand filtration and granular activated carbon, are still the primary treatment strategies but have proven inadequate in addressing sub-micron microplastics.

The review highlights critical policy gaps, including the absence of standardized regulatory limits for microplastics in drinking water, which hampers the establishment of universally accepted safety thresholds. Although organizations like the WHO and EU have made significant strides in raising awareness and developing monitoring guidelines, policy harmonization is necessary to establish global regulations. Furthermore, public health communication and education are vital to improving awareness about microplastic risks and empowering individuals to reduce exposure through filtration systems and other preventive measures.

Future research must address several key areas: the long-term health effects of microplastic exposure, the development of standardized detection methods, and the optimization of emerging water treatment technologies for widespread implementation. Additionally, regulatory frameworks need to evolve to define safe microplastic limits in drinking water and ensure more effective monitoring and removal techniques globally. These steps are essential to protecting public health and improving water quality management in the face of growing microplastic contamination.

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During the preparation of this work, the author used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

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