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*Review Paper*

# Microplastics in Drinking Water: Current Knowledge, Quality Assurance and Future Directions

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## Abstract

Microplastics (MPs) have been found in both surface water and groundwater, which are sources of drinking water. Since one of the most important routes for MPs to enter the human body is through drinking water, the enormous buildup of MPs in waterbodies and the resulting effects on human health have caused social concern. However, our knowledge of drinking water treatment plant (DWTP) treatment techniques affects the removal of MPs, and there aren't any standardized or efficient quality assurance and quality control (QA/QC) measures for sampling and analysis. The current state of MPs in drinking water sources is described in this review, which also provides the most recent data on MPs removal by various DWTP units. Lastly, we propose practical QA/QC techniques to ensure the accuracy of MP analysis. This review intends to present the most recent data on MPs in drinking water and the effectiveness of MPs removal by DWTP units. It also advises that further research into the mechanisms of MPs removal be done in the future.

**Keywords:** Microplastic, drinking water, drinking water treatment plant, quality assurance and control, source water.

## Introduction

Plastics are widely utilized in a variety of industries because they are inexpensive, chemically stable, insulating, long-lasting, and water-resistant [1]. Recent data indicates that the production of plastics worldwide has climbed to 368 million tons annually, with projections reaching 33 billion tons by 2050 [2, 3]. Current plastic recycling rates are extremely low (only 9%), with approximately 79% of plastic waste being discharged into the environment [4]. When plastics entering the environment are subjected to multiple physical,

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chemical, and microbial factors, plastics may be broken down into numerous tiny plastic fragments or particles, which can even reach the nanometer size [5]. Following the traditional definition of engineered nanomaterials, plastics with particle sizes in the range of 1-5000 microns are called microplastics (MPs), while plastics with sizes in the range of 1-1000 nm are called nanoplastics (NPs) [6, 7]. Until now, MPs have been discovered in several environmental media, including waters (such as lakes [8], rivers [9], groundwater [10], oceans [11], and soils (such as farmlands [12] or even Arctic lands [13]).

Global concern has been raised by the "white pollution" brought on by the massive buildup of plastics in the environment. Despite the fact that freshwater (surface and groundwater) is the primary source of human drinking water, the presence of MPs in the aqueous environment has been extensively reported in the literature [14]. There is evidence that the amount of microplastics in drinking water varies from zero to thousands of particles per liter across the globe [15]. Due to their large specific surface area, MPs/NPs have the potential to adsorb/interact with contaminants widely present in environmental media, including heavy metals, antibiotics, engineered nanomaterials, and pathogenic bacteria. [16-19]. As a result, MPs in drinking water may present a risk to people, and their concentration in water must be strictly regulated. At the Second United Nations Environment Assembly, MPs pollution was ranked as the second-most crucial scientific topic in the area of environmental and ecological science study [14]. Furthermore, the General Office of the State Council of China issued the "Action Plan for the Control of New Pollutants" in 2022, which clearly pointed out that MPs, as an emerging pollutant, are in urgent need of environmental risk assessment and pollution control [20]. Recently, attempts have been made to remove microplastics from drinking water using several conventional drinking water treatment technologies, including coagulation, sedimentation, sand filtering, and membrane separation [15, 21, 22]. However, because of the ambiguous removal mechanism and the constrained technical parameters, the removal of MPs in the drinking water treatment process remains a significant challenge. In addition, there are many MPs currently available for acquisition, analysis, and QA/QC methods that need to be reviewed up to date.

This assessment methodically and critically summarizes the current state of MPs in drinking water sources, together with the most recent data on MPs removal by various DWTP units. The evaluation lists the QA/QC measures currently in use, along with their benefits and drawbacks. This review intends to present the most recent data on MPs in drinking water and the effectiveness of MPs removal by drinking water treatment plant units. It also advises that further research into the mechanisms of MPs removal be done in the future. Finally, the effective QA/QC recommendations in this review are designed to enhance the accuracy of microplastics analysis.

## Sources, Abundance and Impacts of Microplastics in Drinking Water

### *Sources of Microplastics*

Figure 1 summarizes the origin, migration, and fate of MPs in the environment. The study of MPs in surface and groundwater is gaining attention because of its close relevance to drinking water [1]. Numerous studies have reported on MP contamination in surface waters. The abundance of MPs (>333 μm) in 29 Great Lakes tributaries in six states of the United States had an average abundance of 1.9 particles/m$^3$ and a maximum of 32 particles/m$^3$ [23]. Interestingly, another study used

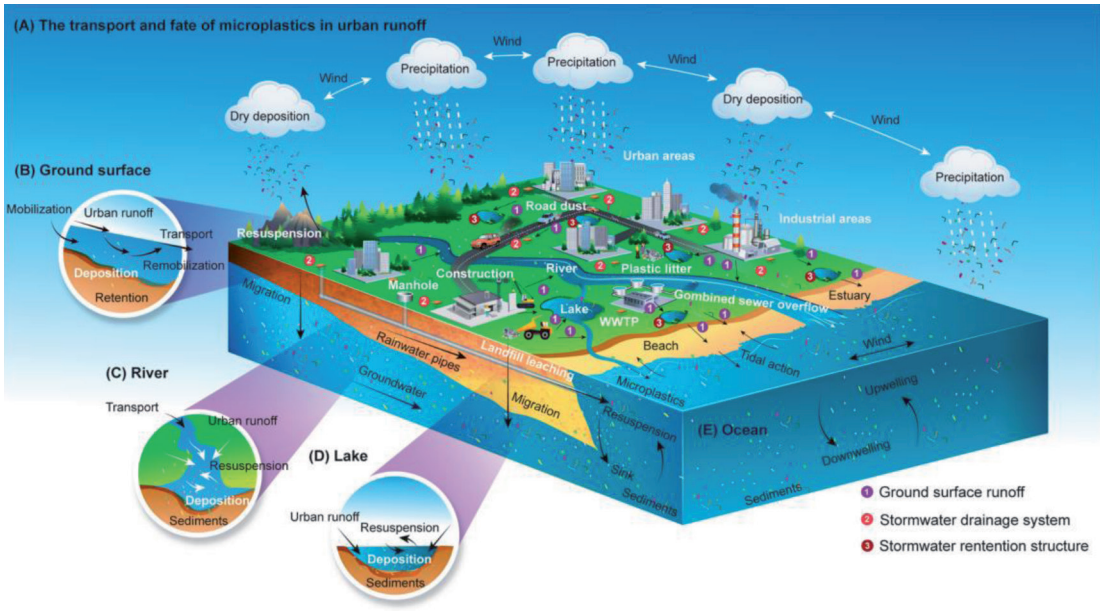


Fig. 1. Transport pathways and mechanisms, and the fate of MPs [30]. Copyright 2022 Elsevier.

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a 106-μm manta trawl to sample and analyze MPs in the Great Lakes basin and found MPs abundances of about 7.6 particles/m$^3$, four times higher than in the previous study [24]. Despite being employed in the majority of surface water investigations published so far, the Manta trawl has the drawback of being unable to assess plastic particles that are smaller than the mesh size [25]. A growing number of studies have recently started to concentrate on MP contamination in groundwater. The presence of MPs (>20 μm) in German groundwater was determined by FTIR by Mintenig et al. (2019) [26]. They mentioned that only small amounts of polymer particles (only 0~7 MPs/m$^3$, mean = 0.7 MPs/m$^3$) were observed in groundwater or in their tap water. Another study identified fibrous MPs at a maximum concentration of 15.2 particles/L in springs and wells in two karst aquifers in Illinois, USA [27]. Around 25% of the world's drinking water supply comes from groundwater found in karst aquifers, making it a significant source of water [28]. Because karst aquifers are open systems that can be contaminated by surface pollutants, the finding of MPs in groundwater is also important to note [29].

Managing the concentration of MPs in drinking water proves to be a successful strategy because MPs are most commonly ingested through water [31]. Furthermore, the source water in DWTP is mostly surface water and groundwater, which may contain varying levels of MPs contamination [32]. Our current understanding of the global concentration of MPs in raw water, tap water, groundwater, and bottled water is presented in Figure 2. Overall, the range of 0 to 6614 MPs/L represents a wide range of MP concentrations in diverse drinking water sources, and the abundance of MPs in groundwater is often significantly lower than in surface water [33]. It is important to keep in mind that MP concentrations can differ significantly between different water sources, different areas within a single water body, and sampling times [34]. For example, Pivokonsky et al. (2018) found that raw water MPs concentrations (≥1 μm) in two DWTPs near the Uchlava River in the Czech Republic varied widely, with mean concentrations of 23 and 1296 MPs/L [35], respectively. In addition, in a study with multiple sampling, MPs in raw water were detected at 113 MPs/L only once, while in other samples they were close to 0 [36].

## Abundance of Microplastics in Drinking Water

A summary of the abundance of MPs in bottled water and tap water was presented by Kirstein et al. (2021 a) [37] (Figure 3). The MPs reported in bottled water varied by six orders of magnitude, from 0.0001 to 930 MPs/L, whereas MPs in tap water ranged from 1.4 MPs/L to 5.42107 MPs/L (Figure 3). In general, MP concentrations in bottled water appeared to be higher compared to tap water, possibly due to the decomposition of MPs on the plastic bottle packaging [38]. The higher variability in MPs exhibited in different drinking water studies may be related to the region, as shown in Figure 2, in addition to important factors such as seasonality, water source, processing and production, packaging, and transportation [37]. It is important to note that the MPs abundance study in Figure 3 is not entirely reliable due to the significant variations in the study population, analytical techniques, and QA/QC measures across studies [39]. Therefore, to ensure the accuracy of the data, future studies should concentrate on the variability of the study subjects and offer efficient QA/QC measures.

## Impacts of Microplastics on Human Health

The damage of MPs to body health is a pressing issue in public health, as they are now widely present in

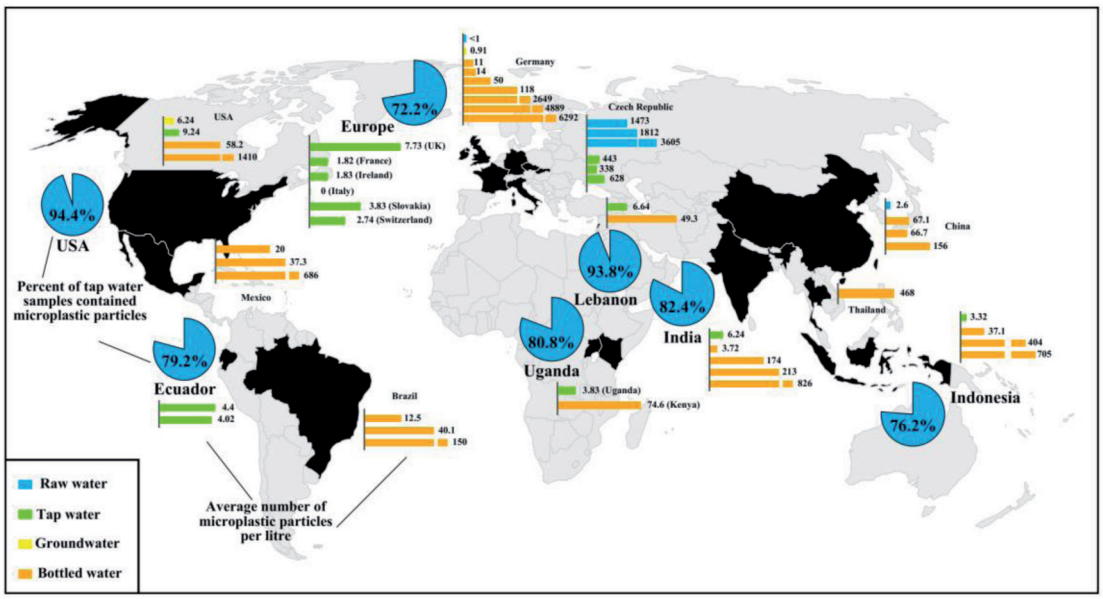


Fig. 2. Global Presence of MPs in Raw Water, Tap Water, Groundwater, and Bottled Water [32]. Copyright 2020 Elsevier.

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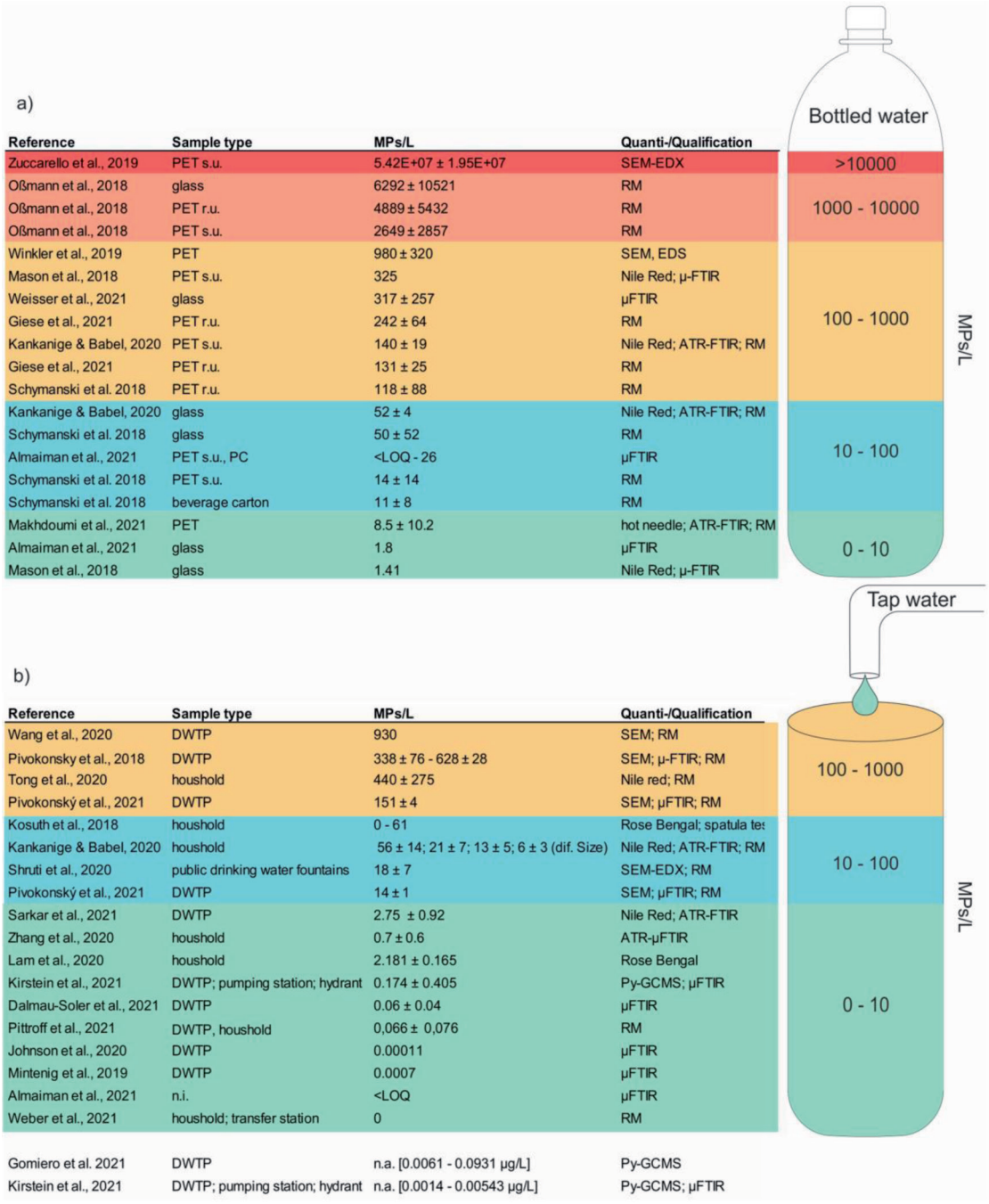

a)

| Reference | Sample type | MPs/L | Quanti-/Qualification |
|---|---|---|---|
| Zuccarello et al., 2019 | PET s.u. | 5.42E+07 ± 1.95E+07 | SEM-EDX |
| Oßmann et al., 2018 | glass | 6292 ± 10521 | RM |
| Oßmann et al., 2018 | PET r.u. | 4889 ± 5432 | RM |
| Oßmann et al., 2018 | PET s.u. | 2649 ± 2857 | RM |
| Winkler et al., 2019 | PET | 980 ± 320 | SEM, EDS |
| Mason et al., 2018 | PET s.u. | 325 | Nile Red; µ-FTIR |
| Weisser et al., 2021 | glass | 317 ± 257 | µFTIR |
| Giese et al., 2021 | PET r.u. | 242 ± 64 | RM |
| Kankanige & Babel, 2020 | PET s.u. | 140 ± 19 | Nile Red; ATR-FTIR; RM |
| Giese et al., 2021 | PET r.u. | 131 ± 25 | RM |
| Schymanski et al. 2018 | PET r.u. | 118 ± 88 | RM |
| Kankanige & Babel, 2020 | glass | 52 ± 4 | Nile Red; ATR-FTIR; RM |
| Schymanski et al. 2018 | glass | 50 ± 52 | RM |
| Almaiman et al., 2021 | PET s.u., PC | <LOQ - 26 | µFTIR |
| Schymanski et al. 2018 | PET s.u. | 14 ± 14 | RM |
| Schymanski et al. 2018 | beverage carton | 11 ± 8 | RM |
| Makhdoumi et al., 2021 | PET | 8.5 ± 10.2 | hot needle; ATR-FTIR; RM |
| Almaiman et al., 2021 | glass | 1.8 | µFTIR |
| Mason et al., 2018 | glass | 1.41 | Nile Red; µ-FTIR |

b)

| Reference | Sample type | MPs/L | Quanti-/Qualification |
|---|---|---|---|
| Wang et al., 2020 | DWTP | 930 | SEM; RM |
| Pivokonsky et al., 2018 | DWTP | 338 ± 76 - 628 ± 28 | SEM; µ-FTIR; RM |
| Tong et al., 2020 | houshold | 440 ± 275 | Nile red; RM |
| Pivokonský et al., 2021 | DWTP | 151 ± 4 | SEM; µFTIR; RM |
| Kosuth et al., 2018 | houshold | 0 - 61 | Rose Bengal; spatula tes |
| Kankanige & Babel, 2020 | houshold | 56 ± 14; 21 ± 7; 13 ± 5; 6 ± 3 (dif. Size) | Nile Red; ATR-FTIR; RM |
| Shruti et al., 2020 | public drinking water fountains | 18 ± 7 | SEM-EDX; RM |
| Pivokonský et al., 2021 | DWTP | 14 ± 1 | SEM; µFTIR; RM |
| Sarkar et al., 2021 | DWTP | 2.75 ± 0.92 | Nile Red; ATR-FTIR |
| Zhang et al., 2020 | houshold | 0.7 ± 0.6 | ATR-µFTIR |
| Lam et al., 2020 | houshold | 2.181 ± 0.165 | Rose Bengal |
| Kirstein et al., 2021 | DWTP; pumping station; hydrant | 0.174 ± 0.405 | Py-GCMS; µFTIR |
| Dalmau-Soler et al., 2021 | DWTP | 0.06 ± 0.04 | µFTIR |
| Pittroff et al., 2021 | DWTP, houshold | 0,066 ± 0,076 | RM |
| Johnson et al., 2020 | DWTP | 0.00011 | µFTIR |
| Mintenig et al., 2019 | DWTP | 0.0007 | µFTIR |
| Almaiman et al., 2021 | n.i. | <LOQ | µFTIR |
| Weber et al., 2021 | houshold; transfer station | 0 | RM |
| Gomiero et al. 2021 | DWTP | n.a. [0.0061 - 0.0931 µg/L] | Py-GCMS |
| Kirstein et al., 2021 | DWTP; pumping station; hydrant | n.a. [0.0014 - 0.00543 µg/L] | Py-GCMS; µFTIR |



Fig. 3. MPs in bottled water and in tap water [37]. Copyright 2021 Elsevier.

environmental matrices and in the water people consume [40]. According to the latest data, human exposure to MPs may range from 74,000 to 121,000 annually [41]. Ingestion through contaminated food/water is one of the principal channels by which MPs enter the body [42]. There is evidence that MPs/NPs can be taken up by plants [43, 44], as traditionally engineered nanomaterials are, and thus enter the edible parts of plants [45, 46]. Furthermore, an increasing number of MPs are detected in tap water and bottled drinking water, raising growing concerns about their fate and toxic effects [33, 47]. Most of the MPs ingested by humans are excreted (up to 90%) and also identified in human feces [48]. MPs in the gastrointestinal system may lead to inflammatory responses, increased permeability, disruption of cellular function, and changes in intestinal microbial composition and metabolism [49]. The protein corona on the surface of MPs may help facilitate the passage of MPs through the gastrointestinal tract [50].

Notably, A minority of MPs can enter the human bloodstream through the cells of the gastrointestinal wall, thus potentially entering various organs or tissues of the body through the blood circulation pathway [51]. MPs may be affected by these same mechanisms, as they have been shown to translocate to the circulatory system in vivo after oral administration [50]. As research continues,

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MPs are being found in an increasing number of human tissues or organs, including blood [51], lungs [52], breast milk [53], and placenta [54]. According to recent analyses of the possible health effects of MPs particles, exposure to MPs may cause oxidative stress, inflammation, genotoxicity, apoptosis, and necrosis in humans [55, 56]. These consequences could eventually result in tissue damage, fibrosis, or even malignancy [56]. Although it is not clear how MPs interact with human tissues, the discovery of MPs in the human body is certainly a wake-up call: the total amount of MPs ingested by humans must be strictly controlled.

## Conventional Treatment Process of Microplastics in DWTP

### *Conventional Treatment Process*

Coagulation, flocculation, sedimentation, filtration, and disinfection are the primary steps in the water treatment process that DWTP must use to ensure the safety of public drinking water [57]. Screening and sedimentation are often required for surface water containing large amounts of gravel or large objects, while coagulation/filtration can be performed directly on most groundwater. After the screening and sedimentation steps, the coagulants were added to raw water. The mixture then enters a settling tank where the heavy flocculated particles settle to the bottom, similar to wastewater treatment [57]. The water is filtered rather than treated secondarily, as opposed to wastewater treatment, where the filtering device is usually a sand filter. The final filtrate is usually chlorinated or otherwise disinfected before entering the water supply.

There is less published information about the effect of DWTP on MPs removal. According to a recent literature review published this year, only 31 relevant studies on DWTP have been published, of which 8 have reported on the removal of MPs from the full-scale DWTP process [33]. Most of the current studies only consider a single-process situation and are mostly laboratory simulations. More importantly, we now do not know how various conventional treatment processes affect MPs removal or how process parameters can be optimized to enhance MPs removal. Since MPs are lighter and more likely to float on the water's surface, air flotation may be a crucial step in the efficient removal of MPs. More and more DWTPs are using activated carbon (AC) as an additional process to improve water quality. In addition, some advanced processes are considered to be the most effective methods for MPs removal, but they are also the most costly [58]. Figure 4 shows the common processes and corresponding sample sampling points in DWTP units.

### *Mps Removal by Treatment Process in DWTP*

Due to the substantial physical similarities between MPs and suspended particulates, conventional treatment methods have been shown to be efficient in eliminating MPs from raw water. As the first and most critical MPs removal process, coagulation-precipitation can effectively remove the most MPs, with reported MPs removal efficiencies ranging from 17-71% [59]. According to Wang et al., coagulation-sedimentation processes had a removal efficiency of 40.5–54.5% and decreased the MPs abundance from 6614 MPs/L to 3472 MPs/L [60]. It is remarkable that coagulation can only result in the adsorption/capture of MPs by flocs, while MPs remain within the flow and enter the settling tank/air floatation tank together. Sarkar et al. (2021) found that the removal rate in the coagulation/flocculation was close to 0, whereas about 61% of the MPs were removed in the clarifier [61]. Due to the low density of MPs, which are probably floating on the water's surface, air flotation is thought to be one of the most efficient removal processes. Similarly, Pivokonsky et al. (2018) reported that air flotation, used in traditional drinking water treatment methods (coagulation/flocculation, flotation, sand filtration, and activated carbon filtration), removed the most MPs, up to 83% [35]. In another study, they also indicated that coagulation and sedimentation processes removed 62% of MPs, while activated carbon filtration removed only 6% of MPs [31]. There are no studies on the impact of the most recent process disinfection on the abundance of MPs, although the process disinfection can cause MPs to indicate aging

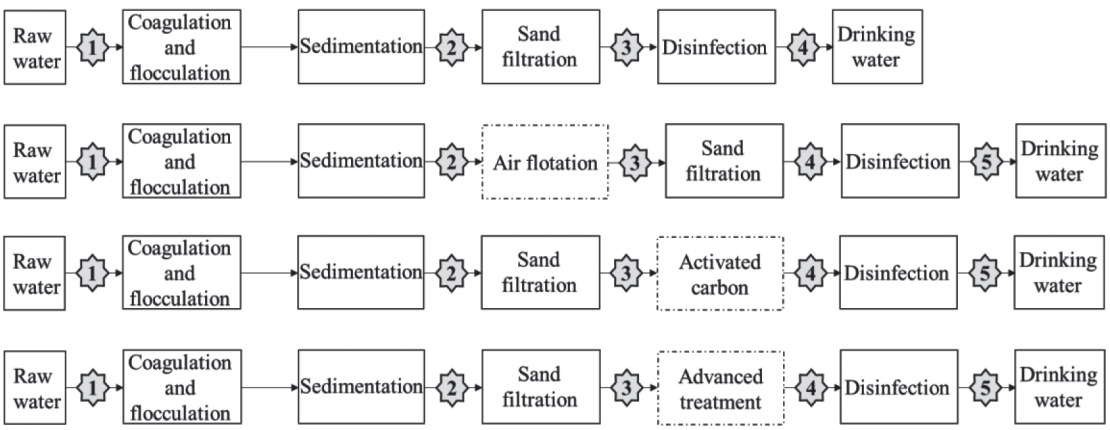


Fig. 4. Process to be investigated and detailed sampling points.

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[62]. Even the existence of MPs was reported to reduce the efficiency of disinfection [63].

Overall, the coagulation-precipitation process was considered the best approach for the removal of MPs. The majority of recent studies have demonstrated a positive correlation between the MPs' particle size and the effectiveness of coagulation and sedimentation [64]. The main reason may be that large MPs may adhere to flocs more easily than small ones, leading to a greater probability of their deposition [60]. Given that fibers are more readily adsorbable on the floc surface, the coagulation-sedimentation procedure had the maximum removal effectiveness for them (50.7–60.6%) [60]. Undoubtedly, more experimental research is required to survey the removal efficiency of conventional treatment processes for different MP particle sizes. Some advanced treatment process technologies have demonstrated extremely strong removal of MPs, such as membrane separation technology [58]. According to a recent study, ultrafiltration and reverse osmosis treatment decreased the amount of MPs in water from 2.2 MPs/L to 0.28 and 0.21 MPs/L, respectively [10]. The results indicate that MPs can be rapidly removed from drinking water samples using membrane separation technologies, but future research needs to take economics and potential membrane contamination issues into account.

## Quality Assurance and Quality Control

Investigating MP pollution in the environment requires a precise identification of MP's environmental presence. However, there have been reports of contentious sampling and laboratory analysis techniques, and the subject of environmental research on MP is still in its infancy. For the selection of sampling sites, sample collection, laboratory analysis, and QA/QC, there have never been any generally acknowledged standards. By conducting a thorough review of the current literature, this project created a QA/QC program for MPs for the collection, analysis, and reporting of MPs in DWTP procedures.

### *Sample Collection of Mps*

The detailed location of the DWTP had to be the focus of the selection of sampling sites. When sampling drinking water sources, direct collection of raw water extracted from DWTPs is the best option. The source water extracted from different DWTPs is different, and the depth of extraction varies. Additionally, because MPs have a low density, there is a greater chance that they may float on the surface water [65]. As a result, the abundance of MPs in surface water noted in many recent reports might not correspond to the abundance in the DWTP's source water. If the source water of the DWTP is extracted from the surface water, the depth and specific coordinates of the pumped water need to be clarified; if it is groundwater, the depth of the aquifer also needs to be recorded. Notably, most of the raw water in the DWTP is pumped from the source water and transported via pipeline to a storage tank/reservoir. Some of the source water will naturally settle for a period in an outdoor open storage tank, a step that also has the potential to introduce MP contamination. Therefore, the potential for contamination of the source water with MP in the transport/storage facility also needs to be identified. If there is a possibility of contamination, the water will be sampled for direct pumping. In addition, when selecting a source water sampling site, it must be clear whether this portion of the water has been pretreated (some drinking water plants will have a portion of pretreatment prior to coagulation, which may include sieving, storage, pre-chlorination, pH adjustment, etc.).

It is noteworthy that the abundance of MPs is closely associated with the location of DWTP. The main influences on MP abundance are anthropogenic factors like population density and human activity [66]. The quantity of MPs in drinking water will also be substantially influenced by the environmental circumstances surrounding the water source. In order to prevent MP contamination, several sources near the DWTP and in the upstream environment, such as wastewater treatment outfalls, indirectly produced drinking water from water reuse, landfills, etc., should be identified. In addition, some sampling locations might be located in zones that need government/departmental permits. For example, certain pumping sites may be located in limited areas, such as nature reserves, etc. [67, 68]. Drinking water sampling needs the permission and backup of DWTP faculty leaders and employees. Overall, the guideline for selecting sampling sites is to clearly reflect the real situation of MPs in the source water. For the effluent after each treatment unit, sampling was performed using the sampling tap pair in the DWTP. Most DWTPs are currently equipped with sampling taps, but if they are not, they are pumped. The Table 1. summarizes the details of DWTP and source water when selecting sampling points.

### *QA/QC in Sampling*

Although the new custom sampling method is effective in reducing the possibility of airborne contamination of MPs collected over a long period of time, on-site QA/QC measures must still be ensured. Specifically, field QA/QC measures include field blanks, field replicates, and variability measurements for sample collection and analysis. As is standard procedure for environmental monitoring of chemical contaminants, field blanks and replicates are collected in the same way as samples, and additional descriptions of QA/QC measures are shown in the Table 2 [69].

More replicates could theoretically provide statistically more reliable data, but consumption time and cost must also be considered simultaneously. Collecting one field blank and a duplicate for every 20 samples is the typical procedure for environmental contaminants monitored by one San Francisco Bay Water Quality Regional Monitoring Program [70]; Another regional monitoring

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Table 1. Details of DWTP and source water

| Sampling site details | Description |
|---|---|
| Detailed Location of DWTP | Provide detailed coordinates of latitude and longitude. |
| Population served (million people) | The number of people who will be provided with drinking water by DWTP. |
| Average daily processing capacity ($m^3$/day) | How many cubic meters of drinking water will be provided per day. |
| Potential sources of MPs contamination | Whether there are potential sources of MP pollution upstream or in the surrounding area, such as water after the wastewater treatment plant / indirect water reuse, drinking water discharge into surface water or groundwater, landfills, etc. |
| Type of source water | Surface water, groundwater, or other. |
| Depth of pumping (m) | Surface water: how many meters below the water surface to sample? Groundwater: depth and water layer. |
| Detailed location of sampling | Detailed coordinates of water pumping/direct inflow of source water. |

program for MPs contamination in San Francisco Bay involves taking at least 1 field blank and replicating it for every 10 samples [71]. It is recommended to sample one field blank sample at a time and repeat every ten samples.

It is worth noting that field blanks have not been considered in most of the current studies, and the few that have been involved were more or less flawed. Field blanks should repeat each step of the sampling process rather than a simplified version of the sampling process as much as possible in order to provide a true picture of the extent of site contamination [72]. For example, simply pouring the blank water through a sieve or rinsing the bottle/container does not reflect the likelihood of site contamination. The blank water used for field blanks should be distilled/ultrapure water, and the blank water should be fully characterized prior to use to avoid the introduction of MPs contamination. In this study, we will take the same approach to restore the field contamination situation as much as possible, including blank water passing through a 5 mm sieve at the same flow rate for the same amount of time, with the blank water immersed in a container, etc. To evaluate the cleanliness of the sample containers, it is also necessary to collect rinsed water samples and blank bottles.

Since most of the water bodies in drinking water plants are continuously flowing, i.e., non-static and non-homogeneous, the variability of samples during field measurements can be provided by field replicate experiments. When collecting samples simultaneously and sequentially, for example, the collection difficulty and similarity between field replicates may differ significantly. A recent report states that the relative percentage difference (RPD) in total particles between the two methods is less than 30% [71]. Specifically, simultaneous collection involves collecting two field duplicate samples simultaneously by separating the effluent through a Y-shaped manifold, while sequential collection involves collecting the first specimen from the primary sample and then immediately sampling a second. Since this study used a mixed sample collection method with a large time span, a more suitable method is the simultaneous collection of MPs samples.

## Laboratory Analysis

The quality and comparability of MP analytical results depend significantly on the laboratory environment [73]. Numerous studies reporting suggestions to enhance the accuracy of MP analytical techniques have been published [39, 74]. The laboratory should have a blank control and be free of MPs particles or fibers, as it will serve as the primary site for analysis. The laboratory analysis should be conducted in a clean laboratory and certified to handle samples in a laminar flow cabinet (such as laminar flow cabinet class ISO 3). The laboratory and laminar flow cabinets will be cleaned again before each experiment to ensure cleanliness. The cleanliness will be assessed regularly by the analysts using particle measurement devices. In addition, a series of precautions should be taken to reduce MP contamination, including hand washing, no makeup, and a ban on nail polish. In addition, the MPs analysis process places extreme demands on laboratory personnel's clothing, and even clothing containing synthetic fibers worn under a laboratory coat may produce

Table 2. On-site QA/QC measures

| Measures | Description | Recommend |
|---|---|---|
| Field blanks | Providing measurements of procedural and background contamination during sampling. | 1 time/10 samples |
| Field replicates | Perform fully consistent duplicate sampling. | |
| Variability measurements for sample collection and analysis | Variability is calculated by comparing the abundance of MPs in field replicates. | |

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MP contamination. As a result, everyone involved in the sample and analysis process must be aware of the inside clothing requirements. The outside must be covered with a cotton or antistatic lab coat (no particles).

It is currently a recommended practice to avoid the use of disposable laboratory gloves and masks to reduce the potential for sample contamination. However, since sample preparation for MPs may involve the use of hazardous chemicals, such as $H_2O_2$, to break down organic matter in the sample [75], experimenters should use nitrile lab gloves for risky procedures like $H_2O_2$ ablation and try to avoid using gloves whenever safety permits. The possible contamination of gloves and masks will be strictly checked by analyzing the blank samples of the operation process. Overall, laboratory analysis should be critically thought out and possibly modified based on the MP contamination that may occur during the MP determination.

Various storage and analysis glass containers are baked in a muffle furnace at 550°C to fully remove particles firmly adhered to the walls of the containers. Aluminum foil was used to wrap the hygienic and simple-to-use containers, which were then kept in a fume hood until needed. In addition, all particle-free water used in the analysis was obtained by filtering Milli-Q water through 0.7 μm GF/F. To ensure the cleanliness of the water, a blank test (analysis water blank) was performed after each preparation of particle-free water. There is also the possibility of contamination by MPs in chemicals, such as hydrogen peroxide, which will be used in large quantities in the digestion process. Therefore, this project will also conduct a chemical blank test for chemicals that are used in large quantities. If there is a potential for contamination, the chemicals will be filtered using polycarbonate (PC) filters (1.2 μm pore size) following the method of Weber et al. (2021) [76]. In order to choose the best filtration technique, it is crucial to keep in mind that this filtration phase also has the potential to introduce MP contamination. As a result, the filtered chemicals should also be examined for particles. Although the laminar flow cabinets significantly improve air purity, it is still advisable to evaluate the risk of sample contamination during sample handling and preparation (air blanks) during the experiment. On the lab bench where the samples are produced, as well as in the laminar flow cabinet/fume hood, open beakers holding particulate-free water can be utilized (air blank).

Since the MP analysis is performed on a standard analytical window slice, to demonstrate the cleanliness of the standard analytical window slice, it is recommended that a blank sample with only ethanol added (instrument blank) be measured after every 10 samples tested. In addition, to ensure the accuracy and performance of the instrument drift and sensitivity, it is recommended that MPs standards be added for calibration before and during the entire analytical run. Similar to QA/QC measures for field sampling, the laboratory analytical process should also include laboratory blanks, laboratory replicates, and spiked recoveries to assess method validity and ensure accurate quantification of MPs. Although we have fully described the measures and importance of maintaining laboratory cleanliness in the previous subsections, contamination of MPs can occur for a variety of reasons. Therefore, in addition to the air blanks described above, analytical blanks should be performed for the entire course of the experiment. Similar to field blanks, laboratory blanks are expected to repeat each step of sample handling and analysis whenever possible to effectively give enough detail to evaluate the real extent of background pollution.

Again, laboratory replicates are mandatory. It is recommended that in subsequent studies, previously collected duplicate samples be evaluated for accuracy of laboratory analysis and assays. In addition, the use of spiked recoveries is recommended to assess the reliability of laboratory extraction methods. Specifically,

Table 3. Laboratory analysis of QA/QC measures

| Measures | Description | Recommend |
|---|---|---|
| Analysis of water blanks | Testing the water for the presence of MP contamination. | After each preparation of filtered ultrapure water |
| Chemical blanks | Testing the chemical for the presence of MP contamination. | Before use |
| Air blanks | Open beakers with particulate-free water that will be placed in the laminar flow cabinet/fume hood and on the lab bench where the samples are prepared can be used to assess the risks of sample contamination [77]. | 10 |
| Instrumental blanks | Inspection of window panels before and during analysis with LDIR. | Before use and then 1 time/20 samples |
| Instrument Accuracy and Sensitivity | Midpoint calibration standards are injected both prior to and throughout the entire analytical run in order to assess instrument drift and sensitivity for accuracy and performance. | Before use and then 1 time/20 samples |
| Laboratory blanks | The sample was prepared in the same way, the aqueous samples were replaced with 0.7 μm GF/F filtered Milli-Q water. | 1 time/10 samples |
| Laboratory replicates | Using duplicate samples that had already been collected, the sample was prepared exactly the same way as the original sample. | 1 time/10 samples |
| Spiked recovery rate | Addition of standard MPs particles before sample preparation for analysis. | 10 |

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known quantities of particles of various sizes, forms, and polymers (preferably MPs not otherwise contained in the analyzed media) are added to the source/drinking water media prior to initiating the analysis of field samples. The MPs in the media are then processed and separated according to the methods used for analytical sample preparation, and finally, the recoveries are determined by MPs characterization. Since many of the current studies do not address spiked recoveries, there is currently no acceptable method or recovery standard. Therefore, it is recommended that subsequent studies determine acceptable recovery limits through a series of experiments and report the recovery of spiked samples. Lastly, the QA/QC measures recommended in laboratory analysis are summarized in Table 3.

Future Approaches to Microplastic Elimination

An increasing number of countries are recognizing the threat of microplastics in drinking water. The European Union, for example, aims to mitigate this threat by reducing microplastic emissions by 30% by 2030 [78]. As of now, the EU does not have a comprehensive law applicable to microplastics. However, the EU adopted a revised Drinking Water Directive in December 2020, which includes emerging contaminants such as microplastics on a watch list [79]. Similarly, a growing number of countries are listing microplastics as potential contaminants in order to determine their impact on human health as soon as possible. As described in the previous section 3, conventional drinking water treatment processes can remove 90% or more of microplastics. However, more powerful methods may be needed in the future to effectively remove microplastics from drinking water.

There is no doubt that advanced filtration technologies, such as ultrafiltration, nanofiltration, and reverse osmosis, have nearly 100% microplastic removal efficiency [80, 81]. Among them, nanofiltration membranes are even effective in removing nanosized plastic particles, and thus may be the most important tool for ensuring safe drinking water in the future [82]. However, advanced filtration technologies may suffer from clogging and membrane contamination problems, especially when nanoscale plastics are present in large quantities [83]. Moreover, advanced filtration technologies treat less drinking water and are more costly, preventing large-scale diffusion for the time being. Therefore, other alternative purification methods are needed, such as the use of magnetic nanoparticle composites to remove microplastic contaminants from water. A recent study prepared Magnetic Polyoxometalate-Supported Ionic Liquid Phases (magPOM-SILPs), which resulted in 100% removal of 1 μm and 10 μm microplastic orbs [84]. More importantly, these special magnetic materials can be quickly separated from water with a magnet and can be used again and again. However, the aqueous environment in which the material was validated was not the actual environment, and only the removal of regular PS beads was investigated [84]. Another study on magnetic carbon nanotubes also reported 100% removal of microplastics [85], but there were some reports of less efficient removal, the reason for which may be related to the water quality and the type, shape, and particle size of the microplastics [86]. In conclusion, the removal efficiency of magnetic nanomaterials is indisputable, but there is a need to design more efficient magnetic nanomaterials in the future and to further investigate the effects of various environmental factors on microplastic removal.

Photocatalytic degradation is a promising technology that can break down microplastics in a relatively short period of time by irradiating specific materials and microplastics with UV light. The removal efficiency depends on the light conditions, free radicals, and microplastic type, and can usually be as high as 90% or more. $TiO_2$ Nanoparticle Film prepared by Nabi et al. (2020) can achieve 98.4% mineralization of microplastics when irradiated with UV light [87]. Biological methods rely on the degradation capabilities of enzymes and organisms, and their efficiency may vary depending on the enzyme and organism species and environmental conditions [88]. Several studies have shown that enzymes are a key factor in the ability of organisms to efficiently degrade microplastics [89, 90]. Considering the complexity of nature, it is expected that nature-based methods for more efficient removal of microplastics will be discovered in the future.

## Outlooks

MPs in drinking water are receiving more and more attention, and the future direction of research should focus on the following issues. (1) Control of MPs pollution sources. There is an urgent need to clarify the sources of MPs in water bodies and to set new reasonable policies to reduce the abundance of MPs in the environment. (2) The establishment of sampling, analysis, and QA/QC methodology. The most important feature of MPs is the low environmental concentration, especially in drinking water. And due to the popularity of plastic products, there is a high risk of contaminating the samples during the process of sampling, sample preparation, and analysis. Therefore, a reasonable methodology must be established to characterize the real presence in the environment. (3) Focus on the generation and removal of nanoplastics. nPs have the potential to cause more serious health hazards due to their larger specific surface area. Moreover, it is now difficult to accurately characterize NPs in the environment, due to limited analytical techniques. (4) Reveal the adsorption or interaction of MPs with other contaminants. MPs may adsorb contaminants in the environment, and some contaminants in the environment also accelerate the fragmentation of microplastics. More research is urgently needed to explore the potential mechanisms of their interactions. (5) Development of advanced instruments. There is an urgent need for more advanced instruments to analyze MPs and NPs in the environment more rapidly and economically. (6) Risk

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assessment of microplastics in drinking water. More assessments of the toxic effects of MPs in drinking water are needed to provide more accurate toxicity thresholds. In addition, there is a need to assess long-term, slow ingestion rather than sudden treatment with high concentrations of MPs. (7) Optimization of methods for the removal of MPs from drinking water. A small number of studies have reported the removal of MPs from drinking water, but how process parameters affect the removal of MPs remains unknown. In addition, future research should also consider the economics of MPs removal, so new and efficient MPs removal technology still needs to be further developed. (8) Use advanced methods such as machine learning. In subsequent studies, the use of advanced machine learning methods to predict the toxicity of MPs, or to predict the treatment efficiency of MPs in drinking water treatment is encouraged.

## Conclusion

The number of studies, reports, and standards pertaining to MPs in drinking water is increasing exponentially as concerns are heightened by rising production, associated contamination, and established biological impacts. Although sampling and QA/QC protocols for the majority of environmental pollutants have been thoroughly documented, it is challenging to directly apply them to MPs due to their specificity. Therefore, this review describes the latest research in the field and collects representative data and methods, since methods now vary widely and QA/QC differences will lead to unreliable conclusions. Given the substantial body of research currently in existence, this review offers a set of QA/QC measures to enhance the precision and dependability of analytical data for MPs by contrasting different approaches. In future studies, more attention should be paid to the removal mechanisms of MPs, and their interaction with contamination in the environment. In addition, more detailed as well as more advanced QA/QC measures and instrumental analysis methods should be considered so that the true presence of MPs in drinking water can be more accurately understood.

## Contribution

Honghao Liu-Fund acquisition, investigation, methodology and writing. Yang Fan-Review & Editing. Pingfan Zhou-Validation, visualization, writing and reviewing.

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## Conflict of Interest

The authors declare no conflict of interest.

## References

1. MACLEOD M., ARP H.P.H., TEKMAN M.B., JAHNKE A. The global threat from plastic pollution. Science, **373** (6550), 61, **2021**.
2. EUROPEPLASTIC. Plastics—the facts 2020. An analysis of European plastics production, demand and waste data, Volume **2022**, **2020**
3. LAU W.W.Y., SHIRAN Y., BAILEY R.M., COOK E., STUCHTEY M.R., KOSKELLA J., VELIS C.A., GODFREY L., BOUCHER J., MURPHY M.B., THOMPSON R.C., JANKOWSKA E., CASTILLO CASTILLO A., PILDITCH T.D., DIXON B., KOERSELMAN L., KOSIOR E., FAVOINO E., GUTBERLET J., BAULCH S., ATREYA M.E., FISCHER D., HE K.K., PETIT M.M., SUMAILA U.R., NEIL E., BERNHOFEN M.V., LAWRENCE K., PALARDY J.E. Evaluating scenarios toward zero plastic pollution. Science, **369** (6510), 1455, **2020**.
4. GEYER R., JAMBECK J.R., LAW K.L. Production, use, and fate of all plastics ever made. Science Advances, **3** (7), e1700782, **2017**.
5. AZEEM I., ADEEL M., AHMAD M.A., SHAKOOR N., ZAIN M., YOUSEF N., YINGHAI Z., AZEEM K., ZHOU P., WHITE J.C., MING X., RUI Y. Microplastic and Nanoplastic Interactions with Plant Species: Trends, Meta-Analysis, and Perspectives. Environmental Science & Technology Letters, **9** (6), 482, **2022**.
6. JIANG Y., ZHOU P., MA T., ADEEL M., SHAKOOR N., LI Y., LI M., GUO M., RUI Y. Effects of two Mn-based nanomaterials on soybean antioxidant system and mineral element homeostasis. Environmental Science and Pollution Research, **30**, 18880, **2022**.
7. JIANG Y., ZHOU P., ZHANG P., ADEEL M., SHAKOOR N., LI Y., LI M., GUO M., ZHAO W., LOU B., WANG L., LYNCH I., RUI Y. Green synthesis of metal-based nanoparticles for sustainable agriculture. Environmental Pollution, **309**, 119755, **2022**.
8. FISCHER E.K., PAGLIALONGA L., CZECH E., TAMMINGA M. Microplastic pollution in lakes and lake shoreline sediments - A case study on Lake Bolsena and Lake Chiusi (central Italy). Environmental Pollution, **213**, 648, **2016**.
9. CORCORAN P.L., BELONTZ S.L., RYAN K., WALZAK M.J. Factors Controlling the Distribution of Microplastic Particles in Benthic Sediment of the Thames River, Canada. Environmental science & technology, **54** (2), 818, **2020**.
10. ZIAJAHROMI S., NEALE P.A., RINTOUL L., LEUSCH F.D. Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics. Water Research, **112**, 93, **2017**.

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11. CUNNINGHAM E.M., EHLERS S.M., DICK J.T.A., SIGWART J.D., LINSE K., DICK J.J., KIRIAKOULAKIS K. High abundances of microplastic pollution in deep-sea sediments: Evidence from Antarctica and the Southern Ocean. Environmental science & technology, **54** (21), 13661, **2020**.
12. CHEN Y., LENG Y., LIU X., WANG J. Microplastic pollution in vegetable farmlands of suburb Wuhan, central China. Environmental Pollution, **257**, 113449, **2020**.
13. BERGMANN M., MÜTZEL S., PRIMPKE S., TEKMAN M.B., TRACHSEL J., GERDTS G. White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Science Advances, **5** (8), eaax1157, **2019**.
14. HORTON A.A., WALTON A., SPURGEON D.J., LAHIVE E., SVENDSEN C. Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of The Total Environment, **586**, 127, **2017**.
15. NOVOTNA K., CERMAKOVA L., PIVOKONSKA L., CAJTHAML T., PIVOKONSKY M. Microplastics in drinking water treatment–current knowledge and research needs. Science of The Total Environment, **667**, 730, **2019**.
16. SHAKOOR N., ADEEL M., AZEEM I., AHMAD M.A., ZAIN M., ABBAS A., HUSSAIN M., JIANG Y., ZHOU P., LI Y. Interplay of higher plants with lithium pollution: Global trends, meta-analysis, and perspectives. Chemosphere, **310**, 136663, **2022**.
17. ZHOU P., ADEEL M., GUO M., GE L., SHAKOOR N., LI M., LI Y., WANG G., RUI Y. Characterisation of biochar produced from two types of chestnut shells for use in remediation of cadmium- and lead-contaminated soil. Crop and pasture science, **2022**.
18. ZHOU P., GUO M., LI M., HAO Y., LIU M., RUI Y. Investigation and analysis of trace elements in farmland soil in shanghe county shandong province. Fresenius Environmental Bulletin, **30** (6), 5789, **2021**.
19. BAQUERO F., MARTÍNEZ J.-L., CANTÓN R. Antibiotics and antibiotic resistance in water environments. Current Opinion in Biotechnology, **19** (3), 260, **2008**.
20. GOSC. General Office of the State Council of China. Action Plan for the Control of New Pollutants. In China, G. O. o. t. S. C. o., Ed. General Office of the State Council of China: **2022**
21. MA B., XUE W., HU C., LIU H., QU J., LI L. Characteristics of microplastic removal via coagulation and ultrafiltration during drinking water treatment. Chemical Engineering Journal, **359**, 159, **2019**.
22. BARBIER J.-S., DRIS R., LECARPENTIER C., RAYMOND V., DELABRE K., THIBERT S., TASSIN B., GASPERI J. Microplastic occurrence after conventional and nanofiltration processes at drinking water treatment plants: Preliminary results. Frontiers in Water, **4**, **2022**.
23. BALDWIN A.K., CORSI S.R., MASON S.A. Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology. Environmental Science & Technology, **50** (19), 10377, **2016**.
24. CABLE R.N., BELETSKY D., BELETSKY R., WIGGINTON K., LOCKE B.W., DUHAIME M.B. Distribution and Modeled Transport of Plastic Pollution in the Great Lakes, the World's Largest Freshwater Resource. Frontiers in Environmental Science, **5**, 45, **2017**.
25. LI J., LIU H., PAUL CHEN J. Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water Research, **137**, 362, **2018**.
26. MINTENIG S.M., LÖDER M.G.J., PRIMPKE S., GERDTS G. Low numbers of microplastics detected in drinking water from ground water sources. Science of The Total Environment, **648**, 631, **2019**.
27. PANNO S.V., KELLY W.R., SCOTT J., ZHENG W., MCNEISH R.E., HOLM N., HOELLEIN T.J., BARANSKI E.L. Microplastic Contamination in Karst Groundwater Systems. Groundwater, **57** (2), 189, **2019**.
28. FORD D., WILLIAMS P.D. Karst hydrogeology and geomorphology. John Wiley & Sons: **2007.**
29. WHITE W.B. Geomorphology and hydrology of karst terrains. Oxford University press: Oxford and New York, **1988**.
30. WANG C., O'CONNOR D., WANG L., WU W.-M., LUO J., HOU D. Microplastics in urban runoff: Global occurrence and fate. Water Research, **225**, 119129, **2022**.
31. PIVOKONSKÝ M., PIVOKONSKÁ L., NOVOTNÁ K., ČERMáKOVÁ L., KLIMTOVÁ M. Occurrence and fate of microplastics at two different drinking water treatment plants within a river catchment. Science of The Total Environment, **741**, 140236, **2020**.
32. SHEN M., SONG B., ZHU Y., ZENG G., ZHANG Y., YANG Y., WEN X., CHEN M., YI H. Removal of microplastics via drinking water treatment: Current knowledge and future directions. Chemosphere, **251**, 126612, **2020**.
33. JINKAI XUE S.H.-A.S., JIANFEI CHEN, ARIANA DOUCET, KELVIN TSUN WAI NG. What have we known so far about microplastics in drinking water treatment? A timely review. Frontiers of Environmental Science & Engineering, **16** (5), 58, **2022**.
34. LENAKER P.L., CORSI S.R., MASON S.A. Spatial Distribution of Microplastics in Surficial Benthic Sediment of Lake Michigan and Lake Erie. Environmental Science & Technology, **55** (1), 373, **2021**.
35. PIVOKONSKY M., CERMAKOVA L., NOVOTNA K., PEER P., CAJTHAML T., JANDA V. Occurrence of microplastics in raw and treated drinking water. Science of The Total Environment, **643**, 1644, **2018**.
36. JOHNSON A.C., BALL H., CROSS R., HORTON A.A., JÜRGENS M.D., READ D.S., VOLLERTSEN J., SVENDSEN C. Identification and Quantification of Microplastics in Potable Water and Their Sources within Water Treatment Works in England and Wales. Environmental Science & Technology, **54** (19), 12326, **2020**.
37. KIRSTEIN I.V., GOMIERO A., VOLLERTSEN J. Microplastic pollution in drinking water. Current Opinion in Toxicology, **28**, 70, **2021**.
38. MASON S.A., WELCH V.G., NERATKO J. Synthetic polymer contamination in bottled water. Frontiers in chemistry, 407, **2018**.
39. SCHYMANSKI D., OßMANN B.E., BENISMAIL N., BOUKERMA K., DALLMANN G., VON DER ESCH E., FISCHER D., FISCHER F., GILLILAND D., GLAS K., HOFMANN T., KÄPPLER A., LACORTE S., MARCO J., RAKWE M.E.L., WEISSER J., WITZIG C., ZUMBÜLTE N., IVLEVA N.P. Analysis of microplastics in drinking water and other clean water samples with micro-Raman and micro-infrared spectroscopy: minimum requirements and best practice guidelines. Analytical and Bioanalytical Chemistry, **413** (24), 5969, **2021**.
40. PRATA J.C. Airborne microplastics: consequences to human health? Environmental Pollution, **234**, 115, **2018**.
41. COX K.D., COVERNTON G.A., DAVIES H.L., DOWER J.F., JUANES F., DUDAS S.E. Human Consumption of Microplastics. Environmental Science & Technology, **53** (12), 7068, **2019**.
42. WRIGHT S.L., KELLY F.J. Plastic and human health: a micro issue? Environmental Science & Technology, **51** (12), 6634, **2017**.
43. SUN X.D., YUAN X.Z., JIA Y., FENG L.J., ZHU F.P., DONG S.S., LIU J., KONG X., TIAN H., DUAN J.L., DING Z.,

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WANG S.G., XING B. Differentially charged nanoplastics demonstrate distinct accumulation in Arabidopsis thaliana. Nature Nanotechnology, **15** (9), 755, **2020**.
44. ZHOU P., ADEEL M., SHAKOOR N., GUO M., HAO Y., AZEEM I., LI M., LIU M., RUI Y. Application of Nanoparticles Alleviates Heavy Metals Stress and Promotes Plant Growth: An Overview. Nanomaterials, **11** (1), 26, **2021**.
45. SHAKOOR N., ADEEL M., ZAIN M., ZHANG P., AHMAD M.A., FAROOQ T., ZHOU P., AZEEM I., RIZWAN M., GUO K., JILANI G., AHMAR S., MAQBOOL S., MING X., RUI Y. Exposure of cherry radish (Raphanus sativus L. var. Radculus Pers) to iron-based nanoparticles enhances its nutritional quality by trigging the essential elements. NanoImpact, **25**, 100388, **2022**.
46. ZHAO W., LIU Y., ZHANG P., ZHOU P., WU Z., LOU B., JIANG Y., SHAKOOR N., LI M., LI Y. Engineered Zn-based nano-pesticides as an opportunity for treatment of phytopathogens in agriculture. NanoImpact, **28**, 100420, **2022**.
47. OßMANN B.E., SARAU G., HOLTMANNSPöTTER H., PISCHETSRIEDER M., CHRISTIANSEN S.H., DICKE W. Small-sized microplastics and pigmented particles in bottled mineral water. Water Research, **141**, 307, **2018**.
48. SCHWABL P., KÖPPEL S., KÖNIGSHOFER P., BUCSICS T., TRAUNER M., REIBERGER T., LIEBMANN B. Detection of various microplastics in human stool: a prospective case series. Annals of internal medicine, **171** (7), 453, **2019**.
49. PRATA J.C., DA COSTA J.P., LOPES I., DUARTE A.C., ROCHA-SANTOS T. Environmental exposure to microplastics: An overview on possible human health effects. Science of The Total Environment, **702**, 134455, **2020**.
50. ENSIGN L.M., CONE R., HANES J. Oral drug delivery with polymeric nanoparticles: the gastrointestinal mucus barriers. Advanced drug delivery reviews, **64** (6), 557, **2012**.
51. LESLIE H.A., VAN VELZEN M.J., BRANDSMA S.H., VETHAAK A.D., GARCIA-VALLEJO J.J., LAMOREE M.H. Discovery and quantification of plastic particle pollution in human blood. Environment International, **163**, 107199, **2022**.
52. PAULY J.L., STEGMEIER S.J., ALLAART H.A., CHENEY R.T., ZHANG P.J., MAYER A.G., STRECK R.J. Inhaled cellulosic and plastic fibers found in human lung tissue. Cancer epidemiology, biomarkers & prevention: a publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology, **7** (5), 419, **1998**.
53. RAGUSA A., NOTARSTEFANO V., SVELATO A., BELLONI A., GIOACCHINI G., BLONDEEL C., ZUCCHELLI E., DE LUCA C., D'AVINO S., GULOTTA A. Raman Microspectroscopy Detection and Characterisation of Microplastics in Human Breastmilk. Polymers, **14** (13), 2700, **2022**.
54. RAGUSA A., SVELATO A., SANTACROCE C., CATALANO P., NOTARSTEFANO V., CARNEVALI O., PAPA F., RONGIOLETTI M.C.A., BAIOCCO F., DRAGHI S. Plasticenta: First evidence of microplastics in human placenta. Environment International, **146**, 106274, **2021**.
55. DUSZA H.M., KATRUKHA E.A., NIJMEIJER S.M., AKHMANOVA A., VETHAAK A.D., WALKER D.I., LEGLER J. Uptake, Transport, and Toxicity of Pristine and Weathered Micro-and Nanoplastics in Human Placenta Cells. Environmental Health Perspectives, **130** (9), 097006, **2022**.
56. DE-LA-TORRE G.E., PIZARRO-ORTEGA C.I., DIOSES-SALINAS D.C., AMMENDOLIA J., OKOFFO E.D. Investigating the current status of COVID-19 related plastics and their potential impact on human health. Current Opinion in Toxicology, **27**, 47, **2021**.
57. MASSCHELEIN W.J. Unit processes in drinking water treatment. CRC Press: Boca Raton, **2020**.
58. TALVITIE J., MIKOLA A., KOISTINEN A., SETÄLÄ O. Solutions to microplastic pollution–Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Research, **123**, 401, **2017**.
59. TANG W., LI H., FEI L., WEI B., ZHOU T., ZHANG H. The removal of microplastics from water by coagulation: A comprehensive review. Science of The Total Environment, **851**, 158224, **2022**.
60. WANG Z., LIN T., CHEN W. Occurrence and removal of microplastics in an advanced drinking water treatment plant (ADWTP). Science of The Total Environment, **700**, 134520, **2020**.
61. SARKAR D.J., SARKAR S.D., DAS B.K., PRAHARAJ J.K., MAHAJAN D.K., PUROKAIT B., MOHANTY T.R., MOHANTY D., GOGOI P., KUMAR S. Microplastics removal efficiency of drinking water treatment plant with pulse clarifier. Journal of Hazardous Materials, **413**, 125347, **2021**.
62. DE ARAGÃO BELÉ T.G., NEVES T.F., CRISTALE J., PREDIGER P., CONSTAPEL M., DANTAS R.F. Oxidation of microplastics by O3 and O3/H2O2: Surface modification and adsorption capacity. Journal of Water Process Engineering, **41**, 102072, **2021**.
63. CARRé E., PÉROT J., JAUZEIN V., LOPEZ-FERBER M. Impact of suspended particles on UV disinfection of activated-sludge effluent with the aim of reclamation. Journal of Water Process Engineering, **22**, 87, **2018**.
64. RADITYANINGRUM A.D., TRIHADININGRUM Y., SOEDJONO E.S., HERUMURTI W. Microplastic contamination in water supply and the removal efficiencies of the treatment plants: A case of Surabaya City, Indonesia. Journal of Water Process Engineering, **43**, 102195, **2021**.
65. KOOI M., KOELMANS A.A. Simplifying microplastic via continuous probability distributions for size, shape, and density. Environmental Science & Technology Letters, **6** (9), 551, **2019**.
66. BROWNE M.A., CRUMP P., NIVEN S.J., TEUTEN E., TONKIN A., GALLOWAY T., THOMPSON R. Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. Environmental Science & Technology, **45** (21), 9175, **2011**.
67. WANG K., LIU J., MI T., ZHOU P., MUHAMMAD A., RUI Y. Comparison of copper and zinc contents in peel and pulp of apple and grape in different regions. Fresenius Environmental Bulletin, **30** (11A), 12691, **2021**.
68. ZHOU P., ZHANG P., GUO M., LI M., WANG L., ADEEL M., SHAKOOR N., RUI Y. Effects of age on mineral elements, amino acids and fatty acids in Chinese chestnut fruits. European Food Research and Technology, **247** (8), 2079, **2021**.
69. BRANDER S.M., RENICK V.C., FOLEY M.M., STEELE C., WOO M., LUSHER A., CARR S., HELM P., BOX C., CHERNIAK S. Sampling and quality assurance and quality control: a guide for scientists investigating the occurrence of microplastics across matrices. Applied Spectroscopy, **74** (9), 1099, **2020**.
70. YEE D., FRANZ A., WONG A., ROSS J., TROWBRIDGE P. Quality assurance program plan for the regional monitoring program for water quality in San Francisco Bay. San Francisco Estuary Institute: Richmond, CA, **2014**.
71. MILLER E., SEDLAK M., LIN D., BOX C., HOLLEMAN C., ROCHMAN C.M., SUTTON R. Recommended best practices for collecting, analyzing, and reporting microplastics in environmental media: Lessons learned from comprehensive monitoring of San Francisco Bay. Journal of Hazardous Materials, **409**, 124770, **2021**.

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72. PRATA J.C., REIS V., DA COSTA J.P., MOUNEYRAC C., DUARTE A.C., ROCHA-SANTOS T. Contamination issues as a challenge in quality control and quality assurance in microplastics analytics. Journal of Hazardous Materials, **403**, 123660, **2021**.
73. KOELMANS A.A., MOHAMED NOR N.H., HERMSEN E., KOOI M., MINTENIG S.M., DE FRANCE J. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. Water Research, **155**, 410, **2019**.
74. HERMSEN E., POMPE R., BESSELING E., KOELMANS A.A. Detection of low numbers of microplastics in North Sea fish using strict quality assurance criteria. Marine Pollution Bulletin, **122** (1), 253, **2017**.
75. ZHOU Q., CHEN J., ZHANG D., PAN X. Evaluation of organic matter removal by H2O2 from microplastic surface by nano-physicochemical methods. Green Analytical Chemistry, **3**, 100035, **2022**.
76. WEBER F., KERPEN J., WOLFF S., LANGER R., ESCHWEILER V. Investigation of microplastics contamination in drinking water of a German city. Science of The Total Environment, **755**, 143421, **2021**.
77. KIRSTEIN I.V., HENSEL F., GOMIERO A., IORDACHESCU L., VIANELLO A., WITTGREN H.B., VOLLERTSEN J. Drinking plastics? – Quantification and qualification of microplastics in drinking water distribution systems by µFTIR and Py-GCMS. Water Research, **188**, 116519, **2021**.
78. BEGHETTO V., GATTO V., SAMIOLO R., SCOLARO C., BRAHIMI S., FACCHIN M., VISCO A. Plastics today: Key challenges and EU strategies towards carbon neutrality: A review. Environmental Pollution, **334**, 122102, **2023**.
79. WARNER L.-M., FLEIG L., GROSSI V., HöLLER S., KöNIG L.M., KAHLICH C., GEFFERT K. Drinking Water from the Tap for Individual and Planetary Health: A Call for Action for Behavioural and Public Health Scientists. European Health Psychologist, **23** (1), 958, **2023**.
80. BARBIER J.-S., DRIS R., LECARPENTIER C., RAYMOND V., DELABRE K., THIBERT S., TASSIN B., GASPERI J. Microplastic occurrence after conventional and nanofiltration processes at drinking water treatment plants: Preliminary results. Frontiers in Water, **4**, 886703, **2022**.
81. ENFRIN M., LEE J., LE-CLECH P., DUMEE L.F. Kinetic and mechanistic aspects of ultrafiltration membrane fouling by nano-and microplastics. Journal of Membrane Science, **601**, 117890, **2020**.
82. BÜNING B., RECHTENBACH D., BEHRENDT J., OTTERPOHL R. Removal of emerging micropollutants from wastewater by nanofiltration and biofilm reactor (MicroStop). Environmental progress & sustainable energy, **40** (3), e13587, **2021**.
83. JOO S.H., LIANG Y., KIM M., BYUN J., CHOI H. Microplastics with adsorbed contaminants: Mechanisms and Treatment. Environmental Challenges, **3**, 100042, **2021**.
84. MISRAA., ZAMBRZYCKI C., KLOKER G., KOTYRBAA., ANJASS M.H., FRANCO CASTILLO I., MITCHELL S.G., GüTTEL R., STREB C. Water Purification and Microplastics Removal Using Magnetic Polyoxometalate-Supported Ionic Liquid Phases (magPOM-SILPs). Angewandte Chemie International Edition, **59** (4), 1601, **2020**.
85. TANG Y., ZHANG S., SU Y., WU D., ZHAO Y., XIE B. Removal of microplastics from aqueous solutions by magnetic carbon nanotubes. Chemical Engineering Journal, **406**, 126804, **2021**.
86. WANG J., SUN C., HUANG Q.-X., CHI Y., YAN J.-H. Adsorption and thermal degradation of microplastics from aqueous solutions by Mg/Zn modified magnetic biochars. Journal of Hazardous Materials, **419**, 126486, **2021**.
87. NABI I., BACHA A.-U.-R., LI K., CHENG H., WANG T., LIU Y., AJMAL S., YANG Y., FENG Y., ZHANG L. Complete Photocatalytic Mineralization of Microplastic on TiO2 Nanoparticle Film. iScience, **23** (7), 101326, **2020**.
88. TANG K.H.D., LOCK S.S.M., YAP P.-S., CHEAH K.W., CHAN Y.H., YIIN C.L., KU A.Z.E., LOY A.C.M., CHIN B.L.F., CHAI Y.H. Immobilized enzyme/microorganism complexes for degradation of microplastics: A review of recent advances, feasibility and future prospects. Science of The Total Environment, **832**, 154868, **2022**.
89. SANLUIS-VERDES A., COLOMER-VIDAL P., RODRIGUEZ-VENTURA F., BELLO-VILLARINO M., SPINOLA-AMILIBIA M., RUIZ-LOPEZ E., ILLANES-VICIOSO R., CASTROVIEJO P., AIESE CIGLIANO R., MONTOYA M., FALABELLA P., PESQUERA C., GONZALEZ-LEGARRETA L., ARIAS-PALOMO E., SOLÀ M., TORROBA T., ARIAS C.F., BERTOCCHINI F. Wax worm saliva and the enzymes therein are the key to polyethylene degradation by Galleria mellonella. Nature Communications, **13** (1), 5568, **2022**.
90. OTHMAN A.R., HASAN H.A., MUHAMAD M.H., ISMAIL N.I., ABDULLAH S.R.S. Microbial degradation of microplastics by enzymatic processes: a review. Environmental Chemistry Letters, **19**, 3057, **2021**.