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REVIEW ARTICLE

An Investigation into the Efficiency of Drinking Water Treatment Plants for Removal of Microplastics: A Review Study

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KEYWORDS

Drinking water;
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ABSTRACT: As a new type of potentially menacing micropollutant, microplastics (MPs) are extensively released in water, and humans may be exposed to them through drinking water. The effectiveness of conventional drinking water treatment plants (DWTPs) for the elimiation of MPs differs in terms of the plant size and shape. This paper aims to study the treatment efficiency of DWTPs for MPs removal. This work summarizes the MP components (types, sizes, forms, and abundance) in potable water sources, and critically reviews the elimination performance and impacts of MPs in different potable water treatment systems. In order to detect MPs in drinking water, Fourier Transform Infrared Spectrometry (FTIR) (25%), Raman Spectroscopy (15%), and other methods (40%) were used. The highest removal efficiency of DWTPs (99.99%) was achieved in England and Wales and the lowest removal efficiency (49.69%) in China (Tianjin). In this study MPs in the inlet (surface and ground waters) DWTPs vary significantly, ranging from zero to 6614 MP particles/L. MPs were observed at minimum size of 163 nm and maximum size of 5 mm. Finally, further research needs to be carried to explore the release of MPs from DWTPs.

INTRODUCTION

Nowadays, macroplastics (MaPs) and microplastics (MPs) can be considered ubiquitous in the terrestrial and aquatic environments. These micropollutants can emerge from different sources[1]. MPs are defined as plastic particles below 5 mm in size, and can be more broken down into nanoparticles (NPs) with diameters between 1 nm and 100 nm or 1000 nm depending on their structure [2]. MPs and NPs are also defined as plastic particles with diameters <5 mm and <100 nm, respectively[3]. Polymer types are categorized based on their toxic effects and size, including nanometer (1–999 nm), small micrometer (1–9 µm), medium micrometer (10–500 µm) sized, and larger than 500 µm[4]. Considering their sources, MPs are commonly categorized as either primary or secondary. Primary MPs are plastic MPs made for special works within user products such as personal care products, medicines, textiles, food packaging, cosmetic microbeads, and air filters(Figure1) [2, 5].

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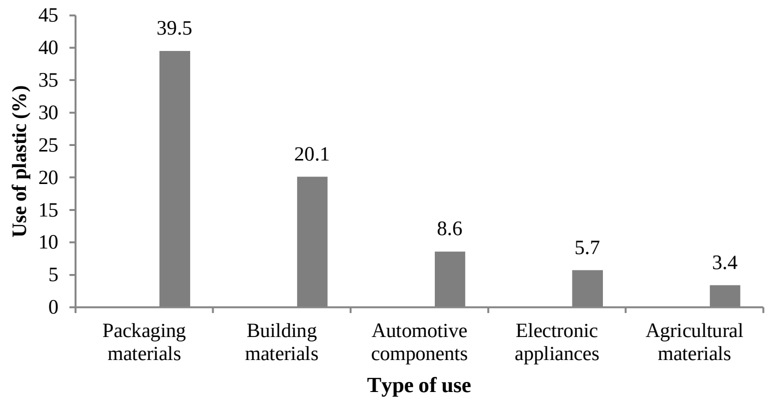

Figure 1. Plastic use from global perspective [6].

MPs have different shapes including fibers, lines, beads, flakes, sheets, granules, rundles, films, spheres, foams, pellets, and fragments [7]. The most commonly encountered MPs consist of polyethylene terephthalate (PET), polyethylene (PE) (Low-Density PE, Linear-Low-Density PE, High Density PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polylactic acid (PLA), polyamide (PA), polycarbonate (PC), poly alpha-methylstyrene (PMS), polytetrafluoroethylene (PTFE), polyurethane (PU), polycarbonate (PC), poly butylene terephthalate (PBT), nylon, polybutene (PB), poly methyl methacrylate (PMMA), and acrylonitrile butadiene styrene (ABS)[8].Several research studies have indicated that MaPs and MPs can have a considerable adverse effect on the aquatic environment, such as bacteria, algae, arthropods, echinoderms, bivalves, rotifers, and fish [2, 9, 10]. The MPs and NPs contamination in the environment have possible effects on human health. Three major exposure pathways to NPs and MPs are via inhalation, ingestion, and the skin. NPs and MPs cause harmful effects in humans and can affect their estrogenic activity, reproduction, growth, mortality, multiple molting, and immune responses[11, 12]. Freshwater bodies are the dominant potable water sources for human use and are therefore suspected as potential sources of MPs to humans. Some raw water samples from elected drinking water treatment plants (DWTPs) have been already evaluated for MPs and their elevated level was certified[13, 14]. Presently, the traditional water treatment systems are not designed for MPs elimination, and the occurrence of MPs may affect the whole potable water treatment process, including coagulation, filtration, and disinfection[15]. MPs have also been newly reported in potable waters and their sources like raw and treated water from DWTPs, tap water, and bottled water[16]. The exposure to MPs via potable water has been approximated at up to 4700 particles/person/year or 12.9 particles/person/day[17]. This level may, however, be as low as 1 particle/person/year for advanced DWTPs[18]. There are several studies that provide the data related to the level of MPs in potable water or their freshwater sources, for instance surface and ground waters or wastewater, while there are a few numbers of comprehensive reviews on MPs removal by DWPTs. This study aims to focus on a current overview of MPs removal by DWPTs, to identify strengths and weaknesses. Another main objective of this review was to investigate the pollution of potable water.

METHODS AND MATERIALS

The principal focus of this review is on the MPs removal methods and processes. Databases like Google Scholar, Science Direct, and Web of Science were used to retrieve several papers on the topic. Keywords like “polymer”, “microplastics”, “micro-sized plastic”, “nanoparticle”, “microparticle”, “drinking water”, “sphere”, “tap water”, “water treatment”, “surface water”, and “ground water” were added to the above mentioned techniques to retrieve proper papers. A total of 106 peer reviewed publications were accessed according to the significance of titles to the study. After reviewing their abstracts, these articles were further narrowed down to 60. After thoroughly screening the articles, 25 were selected for this review, excluding the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reference[19]. Information on the type of water, MPs size, analysis method, treatment system, comments, and references were collected. This omits several review articles that offer insights into the varying removal efficiencies of each treatment system.

This excludes various review articles providing an understanding of different removal efficiencies of each treatment system. Different types of waters like to surface water, sea water, ground water, and tap water were investigated in this study. The characteristics of studies on MPs in waters are shown in Figure 2. Among all investigated papers on MPs in the water environment, the oldest one was from 2013 and the most recent from 2024. In 2021 alone, 34 papers focused their survey on MPs in the aquatic environment. A total of 25 studies reviewed articles focusing on the MPs specifications, such as MPs composition, shape, size, and abundance; and 14 studies focused on removal efficiency of MPs in DWTPs; and 25 studies focused on concentration of MPs in waters such as rivers, lakes, canals, and seas. Technologies for the detection of MPs and NPs composition include Fourier-transform infrared spectroscopy (FTIR), Raman spectroscopy (RM), pyrolysis gas chromatography/mass spectrometry (PyrGC-MS) and scanning electron microscopy plus energy-dispersive X-ray spectroscopy (SEM-EDS), inductively coupled plasma mass spectrometry (ICP-MS), Nile Red, Rose Bengal, Fluorescent, Attenuated Total Reflection-Fourier transform infrared (ATR-FTIR) spectroscopy, electron microscopy, field flow fractionation (FFF) or dynamic light scattering (DLS) techniques(Figure 3)[8, 20].

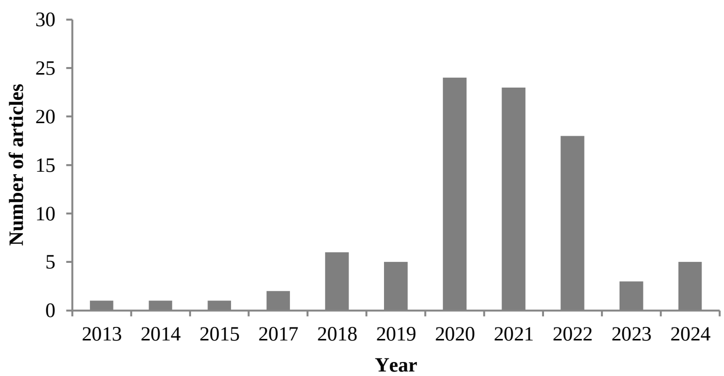

Figure 2. Characteristics of studies on MPs in waters.

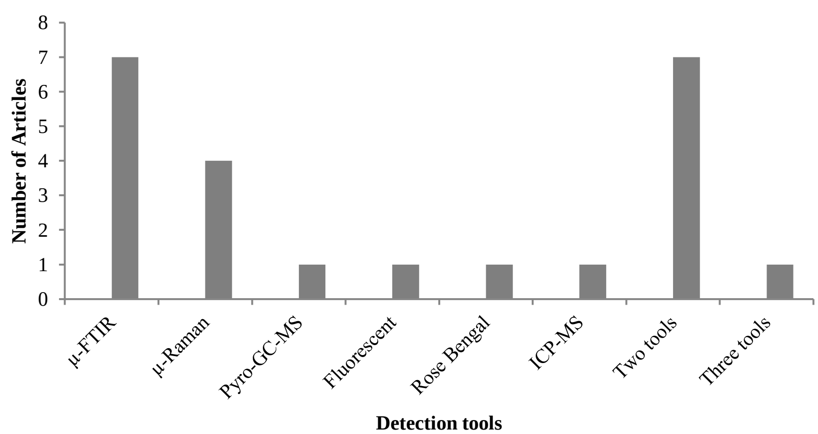

Figure 3.Summary of detection methods.

RESULTS AND DISCUSSION

MPs in DWTPs

DWTPs utilize a range of water treatment methods to deliver safe potable water to consumers through tap water systems. The most frequently utilized in these facilities include coagulation, flocculation, followed then sedimentation, filtration and disinfection[21]. There are two methods on how to estimate MP or NP elimination: (1) measuring MPs or NPs at the influent and effluent to the facility (DWTPs, or after particular technical stages) and comparing the findings, and (2) evaluating MP or NP elimination performance by various processes in lab scale[22]. In general, based on finding of this study, significant removal rates were noted at different DWTPs as detailed below: 57.2-67.6% removal of MPs≥6.5 µm[23], 63-85% removal of MPs 25-100 µm[24], 82.1-88.6% removal of MPs 1-100 µm[25], 81.18% removal of MPs 5 µm-5 mm[26], 76% removal of MPs 351–1000 µm[27], 87% removal of MPs 8-374 µm[28], 99.9% removal of MPs>100 µm and 86.9% for MPs 10 – 20 µm[29], 81.1-99.4% removal of MPs 310–560 nm[30],70-83% removal of MPs 0.2–100µm[31], and 99.99% removal of MPs 63–90µm[32] (Tables 1 and 2). Only 14 studies reported levels of MPs inlet and outlet of water at DWTPs (Table2). The removal efficiency MPs by DWTPs was range from 49.69% to 99.99% (Table2).Coagulation process removed suspended solids and colloidal matters from raw water through charge neutralization, adsorption, and enhancement. The most commonly used coagulants are Aluminium (Al) and iron (Fe) salts[32]. Rapid gravity filters can intercept suspended and colloidal matters to enhance the safety and health of potable water.

Based on the finding of this study regarding coagulation and sedimentation usage, the removal efficiency of 5 µm-5mm granular, 10 µm-20 µm granular MPs and 5–10 µm granular MPs was 42.5%, 59.5%, and 32.5%, respectively[26]. The removal efficiency of micro-flocculation and sand filtration for 5 µm-5mm granular MPs, 20 µm-5 mm granular MPs, and 5–20 µm granular MPs was 25%, 70.3%, and 25.8%, respectively; removal efficiency of ozonation and BAC filtration for 5 µm-5mm granular MPs, 20 µm-5 mm granular MPs, and 5–20 µm granular MPs was 58.97%, 84.5% and 58.7%, respectively. The removal efficacy of sand filtration and pulse clarifier for MPs was 23.72% and 60.90%, respectively[24]. A study by Pivokonsky et al. reported the efficacy of coagulation/flocculation/sedimentation for MPs removal at a DWTP supplied by surface water to be 62% (>1µm) [33]. In a study, Li et al. reported the use of ultrafiltration for removal of MPs with a mean size of 1 µm from potable water [34]. Another study reported membrane bioreactor usage for removal of PVC from polluted surface water[35]. In a study by Velasco et al. the efficacy of DWTPs in removing MPs and synthetic fibers from potable water was reported to be 97% and 96%, respectively[36]. A study by Wang et al. reported the elimination efficiency of DWTP for MPs removal and revealed that about 50% of MPs was eliminated by the coagulation-flocculation sedimentation process[37]. Xu et al. used pretreatment and ultrafiltration/hydrogen peroxide process for NPs removal from surface and ground waters and identified PVC, PMMA, PET, PE, PP, and PS. They reported the predominant composition in both waters to be PP (32.9-69.9%) and PE (21.3-44.3%)[38]. One study reported the composition of the identified MPs in tap water as PS, PVC, PA, and PO with an abundance of 1.67-2.08 µg/L, and sizes of 58-255nm[38]. A study by Li et al. indicated the use of ozonation and chlorination process for NPs removal from drinking water with 96.3 % for ozonation and 4.2% for chlorination within 30 min[39]. Araniti et al. demonstrated that the efficacy of coagulation for removing PS and PE from potable water was 92.4% and 72.1%, respectively[40]. A study used coagulation process for removal of PET from drinking water and reported that the maximum removal performance of 91.45% was achieved when the value of poly‑aluminum chloride (PAC) and anionic polyacrylamide (PAM) was 200 mg/L and 100 mg/L, respectively[41]. A study by Na et al. reported the use of coagulation/sedimentation, sand filtration, and UV-based oxidation for removal of PS from water. The elimination efficiencies for 20, 45, and 90 µm MPs were 77.4-95% but that for 10 µm MPs was 33-41.1%[42]. Another study showed that employing pre-oxidization by hypochlorite, permanganate, and ozone as a pre-treatment stage before conventional drinking water treatment enhanced the removal of PE MPs from water[37]. Various studies have focused on MP particles elimination from water by coagulation. The elimination performance of PS and PE MPs was 77.83% and 29.70%, respectively with the polyaluminium chloride (PAC) dosage of 90 mg/L[42]. A different study showed that the removal efficiencies for 20, 45, and 90 µm MPs (PS) ranged from 77.4% to 95.3%, whereas the efficiency for 10 µm MPs was comparatively low at approximately 33% to 41.1% using the coagulation/sedimentation method.[42]. Wang et al. used conventional dissolved air flotation (DAF) for removal of MPs from fresh water. They obtained the optimal removal efficiency to be 32%–38% at 0.4–0.5 MPs[42]. One study reported the use of photocatalysis and microbial techniques for degradation of MPs in water in pilot scale [43].

In a study, Pizzichetti et al. used membranes for removal of PS and PA from fresh water and obtained an elimination efficiency of above 94% [44]. All the municipal DWTPs illustrated perceptible MP removal performance (an average level of 83 %), but the magnitude of MPs in the potable water generated was still high [45].Another research indicated a comparatively lowMP concentration in treated water in contrast to raw water, likely because of an effective removal rate of 90% in DWTPs [8].

Size and shape of MPs in drinking water

The shape of MPs is regarded as an essential indicator to more effectively identify the source(s) and breakdown of MPs [46]. To date, almost all studies (64) have used the lower size limit of 5 mm to define MPs (Table 1, 2, 3). The MPs size in this study ranges from 163nm to 5 mm (Table 1) and MPs of various shapes were reported. In this study, MPs detected in raw water were in the main shapes of fibers (40%), fragments (35%), spheres (12%), and pellet, granular, and bead (13%) (Table 1 and Figure 4).

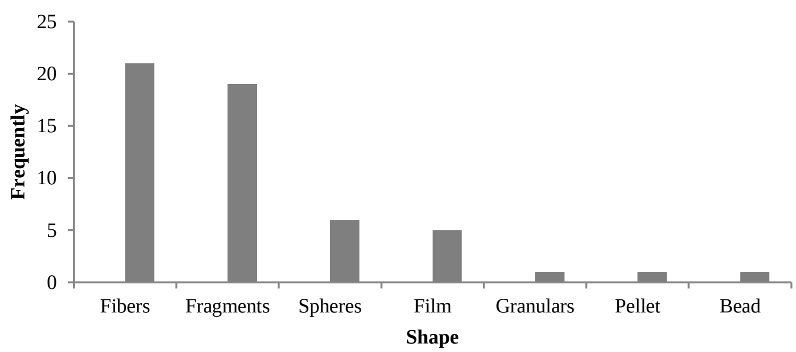

Figure 4. Characteristics of polymer shape of MP particles.

In a study, nearly 95 % of the MPs, which were each fragments or fibrous, were <10 µm in all the water samples evaluated. Moreover, most research studies evaluated spherical NPs (81.6%), followed by fibers (8.4%), fragments (7.2%), and films (2.8%)[2]. A study by Pivokonsky et al. indicated that the MPs occur in water in different shapes of fragments (53.85 to 100%), fibers (1.18 to 30.77%), and spheres (2.27 to 36.36%)[31]. Wang et al. found four different forms of MPs in the samples from the Qing River in which fragments (917.28 ± 1011.90 µm) were the most frequently observed, followed by fibers (1193.52 ± 1462.66 µm), films (606.62 ± 368.40 µm), and pellets (279.50 ± 208.97 μm)[47]. A study by Koelmans et al. indicated that fragments, fibers, films, foams, and pellets were the most frequently detected shapes of MPs in surface water samples[48]. In a study by Mukotaka et al., the average levels of the fragmental, fibrous, and spherical MPs for all samples were 35 ± 43 (90.4%), 3.5 ± 4.3 (9.0%), and 0.2 ± 0.8 particles/ L (0.6%), respectively and fragments were the predominant form[49].One study reported that 95% of all MPs in water are below 10 μm (the particles were divided into six categories: 0.2–1 μm, 1–5 μm, 5–10 μm, 10–50 μm, 50–100 μm, >100 μm)[50]. A study by Wang et al. indicated that MPs occur in surface water (Manas River Basin, China) in shapes of fibers, fragments, films, etc. They found fibers to be the predominant shape of MPs sized 0.3-1mm[51]. Another study showed that fibers (53.8%) and fragments (30.2%) were predominant in fresh water, respectively[46]. A study by Vibhatabandhu et al. indicated that fibers and fragments were dominant in surface water and accounted for 35% and 34% of the total MPs sized 125–5000 μm, respectively[52]. A study reported the concentration of fibers and other shapes in raw water (film, foam, fragment, pellet) to be 10.59–61.54% and <10%, respectively[53]. In a review study, main shapes of MPs detected in studies were fibers(95%), fragments(86%), and films (74%)[54].

MPs composition in drinking water

A total of 25 reviewed studies provided data about polymer composition of MPs. Based on this study, the main polymer types found in waters were PP, PS, PE, PA, PET, PVC, PPS, PE, PP, PBA, ABS, PTT, PMMA, PU, LDPE, PVAC, CP and VINYON(Table 2**)**. PP**,** PE, PET, PVC, PA, and PS are the most abundant MP materials in potable water systems(Figure 5) and fibers, fragments, and spheres are the most frequently observed forms(Figure 4), PE and PP possess densities under 1 g/cm^3 and float, while PS has a density near that of water, PVC and PET have densities of 1.3-1.7 g/cm^3. A study by Wang et al. showed that 18 kinds of MP polymers were identified in all waters, among the polymers identified, PE and Epoxide resin(EPR) were the most plentiful, comprising 39.47% and 67.47% of the MPs in all samples, respectively[47]. In a study, the chemical composition of the detected MPs included PE 26.7%, PP 24.4%, PE+PP 22%, PPS 7.3%, PS 6.5%, PET 3.3%, etc., (PMS, PTFE, PC, PMMA, PBT, PB, nylon, PVC) 9.8%[55].The virgin-NPs employed in the studies were chiefly particles of polystyrene PS 60% and polyethylene PE 18%[2].

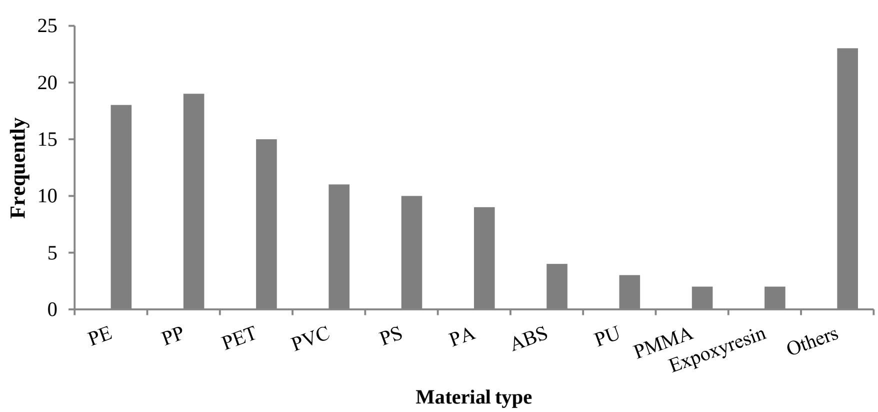

Figure 5. Characteristics of polymer type of MP particles.

Others: PEST, PBA, PVAC, CP,PAN, PPT, PVDF, PTFE, LDPE, VINYON, NYLON, PAM, PES, PO, PC, PBT, acrylic, rayon, cellulose acetate rubber, silicone rubber, polyoxymethylene, and polysiloxane.

In a study by Wenfeng et al., the main polymer types found in the surface water samples were reported to be PP, PS, and PE[56]. Approximately 90% of plastic generated worldwide, however, falls into one of six groups: HDPE, LDPE, PP, PVC, PS, and PET[57]. A study by Pittroff et al. indicated that the main polymer types found in the raw and potable water were PE, PET, PP, and PA 86% ± 111%, 10% ± 25%, (3% ± 6%, and 1% ± 4%, respectively[16]. A study reported the global order of polymers to be as PE ≈ PP > PS > PVC > PET in potable water and freshwater sources[16]. Two studies reported that worldwide plastic demand would cause an arrange of PE > PP > PVC > PET > PS[58]. In a study, Khant and Kim noted that PE and PET are the most frequently observed MPs in ground water systems and fragments and fibers are the most frequent forms[59]. A study by Li et al. indicated that about 70% of the total MPs found in freshwaters included polymers PE, PP, PS, and PET[60]. Mukotaka et al. showed that the main polymer types found in tap and drinking water were PS, PP, PES, SEBS, PVC, and PE[49]. In a study, Shi et al. noted that abundance levels of MPs range from 4 particles/L to 72 particles /L, with a mean of 29 particles /L. MP polymers, such as PA, PE, PP, PVC and PA, were detected in surface and ground waters [61]. One study indicated that the polymers identified in water were PP> PET> PS> PE in dry season, i.e., April, and PET> PP> PE ≈ PS in wet season, i.e., July[51]. A review study indicated that types of the MPs in fresh waters were PE 20.9%, PET 19.3%, PP 18.1%, PE 20.8%, PP 15.9%, and PA 13.6%[46]. Yan et al. reported the main polymer types found in the raw water to be PP (31.47%), PE (27.3%), PS (9.66%), PVC (7.92%), PET (11.73%) and non-plastic(11.9%)[53].

MPs in drinking water –quantity

MPs were identified in different waters, such as natural freshwater, raw and treated water at DWTPs. The findings of the various studies vary considerably, ranging from 0.00 to 6614 MP particles per liter (Table 1). Based on the findings of this study, for the detection of MPs in potable water, most researchers used Fourier Transform Infrared Spectrometry (FTIR) (25%), Raman Spectroscopy (15%), and other methods(40%), including SEM, Nile Red:ATR-FTR.RM, Rose Bengal, Fluorescent, Pyrolysis GC-MS, ICP-MS, and DLS- SEM(Table 1 and Figure 3). The arrange of frequency for various methods used in the reviewed research works were in the categories of µ-FTIR ≈ Two tools > µ-Raman ≈ Pyr- GC-MS ≈ Three tools ≈ Fluorescent ≈ Rose Bengal ≈ ICP-MS. Among two tools, different combinations were used, such as µ-FTIR and µ-Raman, SEM and µ-Raman, Stereoscopic microscope and FTIR, ATR-FTIR and Raman spectroscopy, DLS and SEM, stereomicroscope and µ-Raman ,etc.(Figure 3).In a study, Perumal and Muthuramalingam used FTIR (74%), Raman Spectroscopy (14%), and SEM-EDS (12%) to detect MPs in aquatic environment [62]. One study reported the use of FTIR(95%), and Raman Spectroscopy(92%) for detection of MPs in drinking water[63]. Lu et al. reported that they used FTIR (69%), Raman Spectroscopy (27%), and SEM-EDS (4%) for identification of MPs in fresh waters[46]. Frond et al. used optical microscopy, FTIR spectroscopy, and Raman Spectroscopy for identification of MPs in drinking water[63]. The selection of technique used for identifying and quantifying MPs and NPs depends on the research issue, aim, sample medium and environmental level of plastic particles[64]. A study by Wang et al. reported the MPs detected in samples from the Qing River to be 0.35 ± 0.22 and 0.32 ± 0.26 particles/L[47]. Lestari et al. reported that the MP concentration in the surface, middle, and bottom of the Surabaya river, Indonesia, was 1.47–43.11, 0.76–12.56, and 1.43–34.63 particles/m,^{3} respectively[65]. Prata et al. reported that the MP abundance in Douro river was 231 particles/L with a size of 2 –5000 µm and the most abundant (84%) sizes were <40 µm[66]. A study by Kosuth et al. demonstrated that the levels of MPs (mean ±SD) in tap water samples collected from 14 nations, including Cuba, Ecuador, England, France, Germany, India, Indonesia, Italy, Ireland, Lebanon, Slovakia, Switzerland, Uganda, and the USA were7.17,4.02±3.20, 182,0.91±1.29, 6.24±6.41, 3.23±3.48, 1.83, 0, 6.44±6.38, 3.83±4.47, 2.74±3.87, 3.29±3.17, 9.24±11.8, and 3.57±1.79 particles/L, respectively[57]. A study by Pittroff et al. indicated that the mean level of identified MPs was 0. 66 ±0.76 MP/L ranging from 0.00 1 to 0.197 MP/L in raw and drinking water[16]. A study by Koelmans et al. showed that MPs were present in freshwaters and potable water with magnitude of 1.10^{-5} -10^{5} particles/L[48]. Koelmans et al. showed the levels of MPs in tap water to be 1.9-225 particles/L with a mean level of 39±44 particles/L, and size of 19-4200 µm[49]. Mukotaka et al. reported various types of MPs in tap water samples from Japan, the European Union, and the USA with the overall average levels of 29±45 particles/L, 66± 37 particles/L and 46 ±32 particles/L, respectively[49]. A study by Zhang et al. reported the MP concentration in tap water and water sources (Qingdao, China) to vary from 0.3 to 1.6 particles/L and 0.2 to 0.7 particles /L, respectively. They reported the MPs size to range from 10 to 5000 µm [67]. A study found the concentration of MPs to range from 5 ± 2 to 91 ± 14 particles/ L in potable water in Mexico City with a mean of 18 ± 7 particles/ L[68]. A study by Krystynik et al. indicated that the levels of MPs before and after treatment were 3605 ± 497 particles/ L and 628 ± 28 particles/ L, respectively[50].

Table 1. Sepecifications and abundance of MPs found in potable water (surface and ground waters, and tap water).

Type of water	Size of MPs	Analysis method	Treatment system	Shape	Comments**	Ref
Groundwater	50 and 150 µm	µ -FTIR analyses	DWTP* +Aeration and filtration	Fibers, fragments	Abundance: 0 to0.007 particles / L and average of 0.0007 particles /L polymer type: PE, PA, PVC, PEST, and epoxy resin	[69]
Drinking water	Above1 µm	Pyrolysis GCMS	DWTP	Fibers	Abundance: 6.1 to 93.1 µg/m^3 per sites polymer type: PE (21–82%), PA (0–36%).PET(0–35%), PP(33%), and PS(2%)	[70]
Surface water	50 to 5000 µm	Micro-Raman spectroscopy	Pre-ozonation, coagulation/flocculation with sedimentation, sand filtration and ozonation with granular activated carbon filtration	Fibers, fragments, spheres (83.3 %)	Abundance :0.029 particles/L, polymer type :PE(38.7%), PP, PS, PET, PVC,ABS, acrylic resin, epoxy resin, polyoxymethylene, PMMA, polysiloxane and silicone rubber	[71]
Drinking and freshwater	6.5- 300 µm	ATR-FTIR spectroscopy, + Raman spectroscopy	Water treatment plant(conventional)	Fragments, films, pellets, fibers	polymer type: PE, PP, PET, PA, and PVC, removal efficiency 67.6 % (dry)and 57.2 % (rainy) in seasons	[23]
Tap water	20 µm to 5 mm	µ -FTIR	DWTP+ ultrafiltration/ reverse osmosis, ozonation/carbon filtration stage	Fragment, fibers	Abundance: 0.96 ± 0.46, removal efficiency of 93 ± 5%, polymer type: PES and PP	[72]
Surface water (river)	25–100 µm	Nile Red, ATR-FTR,RM	DWTP + pulse clarification	Fibers and films/ fragments	Abundance: 17.88 particles/L, removal efficiency: pulse clarification 63% and sand filtration 85%	[24]
Surface water(Yangtze River)	1–100 µm	Micro-Rama, SEM	ADWTP: Coagulation/ flocculation, sedimentation, sand filtration, ozonation and GAC filtration	Fibers, fragment, spheres	Abundance: 6614 ± 1132 particles/L, polymer type: PET, PE, PP, PAM, and others, removal efficiency 82.1–88.6%	[73]
Tap water	3 to 445 µm	Micro-Raman spectroscopy	DWTP	Fragments (53.85 to 100%), fibers (1.18 to 30.77%) and spheres (2.27 to 36.36%)	Abundance: 440 ± 275 particles/ L, polymer type: PE, PP, PET, PA, PPS,PE+PP, and others	[55]
Surface water (River)	0.2–100 µm	µ -FTIR and µ -Raman spectroscopy	DWTP+ Coagulation/flocculation and sand filtration	Fragment, fibers, spheres	Abundance: 1473 ± 34 particles/ L, polymer type: PE, PP, PET, PA, PPS, PVC, PBA, PTT, PMMA, and others, removal efficiency (DWTP) 70-83%	[31]
Surface water (River)	5 µm-5 mm	µ -micro-Raman	DWTP +Coagulation & sedimentation, Ozonation & BAC filtration, Micro-flocculation & sand	Over 98%, granular, fibers, fragments	Abundance: 3444.7 MPs/L, removal efficiency (DWTP) 81.18% for total size, polymer type; PE, PP, PET, PVC, and VINYON(70.4%)	[26]

			filtration			
Surface water (River)	351–1000 µm	µ -FTIR	Sub -Drinking water treatment plant(SDWTP): aeration, pre-sedimentation, coagulation, flocculation-sedimentation, filtration, and disinfection	Fiber, fragments	Abundance: 26.8–35 MPs/L, polymer type :PE,PP, LDPE, removal efficiency SDWTP:54%-76%	[27]
Drinking water	8-374 µm	µ-FTIR and Py-GCMS	DWTP	Fibers, fragments	Abundance: the average174 ± 405 MPs/m^3, polymer type: PE(87%), PP, PS, PA, PVC, and PU	[28]
Surface water	63-90 µm	µ -FTIR	DWTP	Fibers, fragments	Abundance: the average 4.9 MPs/L,99.99% removal efficiency, Polymer type: PET, PE, PP,PS, and ABS	[32]
Drinking water	180 nm – 125 µm	Fluorescent	Coagulation/flocculation combined with sedimentation (CFS) and filtration	Fragment, spheres	Removal efficiency: 99.9% for particles more than 100 µm and 86.9% for 10 – 20 µm, Polymer type: PS, and PE	[29]
Surface water	360 ± 206 to2174 ± 510 nm	dynamic light scattering (DLS), SEM	DWTP (conventional)	Spheres	Removal efficiency: DWTP without coagulation:81.1%, Overall (conventional): 99.4%, polymer: PS	[30]
Drinking water	5-296 µm	µ -Raman microscope	In line filtration and ultrafiltration	Fibers, fragments	Polymer type: PVC,PET, and Nylon, UF removal efficiency of 95%, in line filtration>UF	[74]
Surface water	150–499 µm	Rose Bengal	DWTP	Fragments, Fibers (97.8%)	Abundance: 2.181 ± 0.165 particles/ L	[75]
Tap water	> 100 µm	µ-FTIR	DWTP	Fragment, Fibers (82%), beads, films	Abundance: 0.2 ±0.1, Polymer type: PET, PP, PS, ABS and Rubber	[76]
Freshwater	> 1 µm	µ-FTIR and Raman	DWTP	Fragment, Fibers	Abundance: mean 2753, Polymer type: PE (26.8%), PET, PP, PS, removal efficiency 87%	[15]
Surface water	163.5 nm ± 0.3 nm	ICP-MS	DWTP+ Rapid sand, AC filtration, Ozoniation	Not specified	Abundance: 1.7. 10^{12} particles/ L, removal efficiency 99.9%	[77]
Surface water	45-500 µm	Stereomicroscopy and µ-Raman spectroscopy	DWTP+ coagulation, flocculation, anthracite-sand filtration, and chlorination	Fibers, fragments, films	Abundance: 42 ± 18 particles/ L, Polymer type: PVC,PET-PEST,PU,PE-PP, PBT, and PAN, removal efficiency(conventional):52% and overall: over 80%	[78]
Surface water	10->100 µm	µ -FTIR	DWTP+ pre-ozonation/ sedimentation/ sand filtration	Not specified	Abundance: 2.2 ± 1.3 particles/ L, Polymer type: PE and PP>60%,PET,PMMA,PA, and PS removal efficiency(overall):99.13%	[79]
Surface water	1-->100 µm	µ-FTIR, µ-Raman spectroscopy	DWTP(conventional)	Fibers, fragment, spheres	Abundance:1996±268 to 2808±80 particles/ L, Polymer type: PP(27.3%),PET(15.1%),PS,PTFE,PU, PA,PBT,PVDF,PVC,PC, removal efficiency: 41.2% to 59.0%,	[80]
Surface water	> 200 µm	µ-FTIR	DWTP	fragments, fibers	Abundance: 134.79, Polymer type: nylon(50.53%),PEST26.70%),PVDF,PS,PP,PVC,PET, removal efficiency 49.69%	[81]
Drinking water	20 µm and 5 mm	Stereoscopic microscope and (FTIR)	DWTP	Fragment, fibers, films	Abundance: 4.23 particles/L, Polymer type: rayon, cellulose acetate , PES, PP, PA and PE, removal efficiency (overall) 98.3%	[82].

*The conventional treatment process (including coagulation/flocculation, sedimentation and sand filtration,**MP concentration ranges/mean in inlet,

Table 2.Removal efficiency of MPs in potable water treatment plants in a few countries.

Country/region	MPs level (MPs/L) of raw water	MPs level (MPs/L) of treated water	Removal efficiency	Ref
Thailand	1590.8 ± 148.8	609.1 ± 84.7	62.4 ± 5.2 %	[23]
Indonesia	26.8–35	8.5–12.3	76%	[27]
India	17.86 ± 2.66	2.75 ± 0.92	85.39%	[24]
Czech Republic	1473±34 to 3605±497	338±76 to 628±28	70-83%	[31]
England and Wales	4.9	0.00011	99.99%	[32]
Spain(Barcelona)	0.96 ± 0.46	0.06 ± 0.04	93 ± 5%	[72]
Spain	4.23	0.075	98.3%	[82]
China(Changsha)	2173 to 3998 mean:2753	338 to 400 mean:351.9	87%	[15]
China(Tianjin)	134.79	95.63	49.69%	[81]
Canada	42 ± 18	20 ± 8	52%	[78]
South Korea	2.2 ± 1.3	0.02 ± 0.02	99.13%	[79]
Switzerland	0.195 to 0.1435	0 to0.008	97%	[36]
Brazil	330.2	105.8	68%	[83]
Iran	1996±268 to 2808±80	971±103 to 1401±86	41.2% to 59.0%	[80]

MPs in surface waters

We reviewed the MPs concentration in surface water (river, sea, and lake) from different countries (i.e; USA, China, France, Hungary, Germany, Netherlands, Switzerland, Siberia, Indonesia, Portugal, Dutch, Poland, Thailand, UK, Jamaica, Brazil, and Greenland) (Table 3). Based on the results of this study regarding surface waters, the highest MPs concentration of 100-900 (particles/L) was achieved in Germany (Elbe River) and the lowest concentration of 0.00004 ±0.00004 to 0.0033 ± 0.0021 (particles/L) was found in Switzerland (Rhine River) (Table 3). In this study, MPs sized 2 -5000 µm were identified (Table 3). MPs concentration in surface water samples taken at Riyadh and Al-Jubail ranged from 1.9 ± 0.15 items/L to 5.1 ± 0.38 particles/L with an average of 3.2 ± 0.2 particles/L and from 0.2 ± 0.3 particles/L to 0.5 ± 0.22 particles/L with an average of 0.2 ± 0.1 particles/L, respectively[84]. A study by Nan et al. reported the MPs concentration with a mean abundance of 0.40 ± 0.27 particles/L in surface water of Victoria, Australia[85]. A study by Park et al. reported the MPs concentration with an average of 0-42.9 particles/m^3 in surface water (Han River) of South Korea[86]. Yan et al. reported the MPs concentration with an average abundance of 19,8600 particles/L in surface water of Pearl River, China[87]. In a study, Shen et al. reported that the MP occurrence in Dongting Lake, Taihu Lake, and Poyang Lake, China, was detected to be < 1–2.8, 3.4–25.8, and 5–34 particles/L, respectively[15]. Vibhatabandhu et al. reported the MPs concentration with an average abundance of 9.97 ± 18.55 particles/L in surface water of the Inner Gulf of Thailand[52]. Haddout et al. reported the MPs abundance of 10-168 particles/m^{3}in surface water of the Atlantic coast, Morocco[88].

Table 3. Summary of MPs pollution in surface water of the world.

Country/Region	Water body type	Level (particles/L)	Particle size	Ref
USA	Lake	Mean :0.00027	333 μm	[89]
USA	Sea	Mean : 30.8 ± 12.1	63 to 2000 μm	[90]
China(East China Sea).	East China Sea	Mean:0.000167	>0.5 mm	[91]
China(Wuhan)	lakes and rivers	Range:1.6 to 8.9	More than80% < 2000 μm	[92]
China (Jiaozhou Bay)	Surface Sea water	Range :0.20 to 0.120	Below 0.5 to 4 mm	[93]
China(Beijing)	Qing River	Range:;0.17 ± 0.11 to 0.26 ± 0.20	Fragments(917.28 ± 1011.90), fibers(1193.52 ± 1462.66), films(606.62 ± 368.40), and pellets(279.50 ± 208.97) μm	[47]
China	Manas River Basin	Mean:14 ± 2 to 17 ± 4	0.3 to 1mm	[51]
China	Dongting Lake and Hong Lake	Mean: 1.2 and 2.3	50 μm	[94]
China	Qinhuai river	Range: 1467 ± 0.223 to 20.567 ± 3.233	>100 μm to 5000 μm	[53]
France	River Seine	Mean :30	>100 μm	[95]
Hungary	Lakes and rivers	Mean : <1	>100 μm	[96]
Germany	Elbe River	Range :100 to 900	10 to 100 μm	[97]
Netherlands	Amsterdam canal water	Range :48 to 187	(61% 10–300 μm, 39% >300 μm	[98]
Thailand	Chao Phraya River and Maeklong River	Range: 0.40 to 2.40	82.1%>300 μm	[99]
Switzerland	Lake Sassolo	Range:2.6 to 4.4	125 μm to 5 mm	[100]
Switzerland	Rhine River	Mean : 0.00004 ± 0.00004 to 0.0033 ± 0.0021 ,0.0027± 0.0004 to 0.0063 ± 0.0026	>0.3mm	[101]
Siberia	Nizhnyaya Tunguska River	Range :0.00120 ± 0.0070 to 0.00453 ±0.00 204	0.30 to 1.00 mm	[102]
Indonesia	Surabaya River	Surface water: Range:0.01.47 to 0.04311, middle water: 0.00076 to 0.01256, and bottom water: 0.00143 to 0.03463	1 to 5 mm	[65]
Portugal	Douro river	Median:231	2 to 5000 μm	[66]
Dutch	Meuse and Dommel rivers	0.067 and 11.532	20 μm	[103]
Poland	Vistula River	1.6 -2.55	<5 mm	[104]
U.K(Birmingham)	Tame River	Mean:165	250 μm to 1 mm	[105]
Greenland	Sea Gyre	Mean:2.43	100 to 5000 μm	[73]
Jamaica(Kingston Harbor)	River	Mean:0.00076	300 to 5000 μm	[106]
Brazil	Sinos River	Mean:330.2	Not specified	[83]

CONCLUSIONS AND FUTURE RESEARCHES

MPs and the methods employed for their removal from water present a difficult challenge that needs to be addressed soon. According to the results of this research, the highest removal efficiency of DWTPs (99.99%) was achieved in England and Wales and the lowest removal efficiency (49.69%) was found in China (Tianjin). The most frequently observed MPs in potable water are PE, PET,PP, PVC and PS; and fibers, fragments, and spheres represent the most commonly found shapes. This research contributes to bridging the knowledge gap re garding emerging microplastic contamination in drinking w ater and water sources, which is alarming because of the possible human exposure to MPs. Based on the review of the current research status of MPs, the following recommendations are proposed for improvement of future research:

1- Future research needs to be focused on the elimination of small-sized plastics (< 10–20 μm) in DWTPs, because these particles are very hard to be eliminated yet could cause further considerable health concerns if ingested.

2- The association between the properties and behavior of MPs during various treatment processes is suggested to be explored in the future.

3- As MPs are non-degradable durable constituents, their fate after elimination from water should also be evaluated.

4- It is clear that upcoming ecotoxicology evaluations must incorporate the growing presence of secondary plastics, like fibers, especially since certain chemicals present on and within plastics are recognized as toxic to humans.

5-additional research is required to better understand the prevalence,shape,types of polymers,and sizes of particles,particularly for the smaller plastic particles.

6-The significant variability in the results complicates the comparison of different findings, research and form a broad conclusion about risks to human health.

7- DWTPs should be upgraded (e.g., ultrafiltration/reverse osmosis, ozonation/carbon filtration stage) with the aim to remove MPs.

8- Most research should focus on the development of new technological novelties on elimination techniques of MPs in DWTRs which can act as a preventive scale.

9- Reporting MPs data like shapes, plastic types, and sizes should be standardized and coordinated to enhance inter-comparability across future research studies.

10-Future studies should concentrate on the possible emission of MPs from deteriorating plastic pipes used in drinking water distribution networks and the harmful impacts of MPs on human health.

11- Standard methods should be used for sampling and analyzing MPs in potable-water and fresh water.

Finally, weaknesses and strengths of studies related to MPs in the environment include:

Weaknesses

There is no admissible limit for MPs in potable water.

It is ambiguous which treatment stage was responsible for the elimination of MPs from raw water.

There are inadequate studies related to the effects of size, shape, material composition, and other properties of MPs on DWTPs.

More notice has been paid to wastewater treatment plants (WWTPs) than to DWTPs for the elimination of MPs from the environment.

Strengths

Most of the DWTPs showed appreciable MPs removal efficiency of about 70-80%.

This study helps address theknowledge deficit regarding the pollution of drinking water and water sources by emerging microplastics (MPs).

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Conflict of interests

The author declare no conflict of interest.

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