Analytical Review of Microplastics Occurrence in Bottled Water, Tap Water, and Wastewater Treatment Plants

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Abstract. Currently, water availability and accessibility have become more challenging due to population growth, development of industrial and agricultural activities, and the effects of climate change. Various types of pollutants released by human activities threaten water quality and availability. Microplastics and emerging contaminants are currently affecting water resources and posing a risk to human health. The present study reviews the available studies that analyzed the abundance, shape, and size of microplastics in water, including glass, plastic, reusable, recyclable, and beverage bottled water, tap water, and wastewater treatment plant (WWTP) influent and effluent. Analysis of the collected data allowed comparison of microplastic abundance in different packaging water bottles, tap water, and raw and treated water from WWTPs. The analysis results suggest that microplastics in drinking water are mainly associated with water sources. Therefore, more attention should be paid to water treatment and purification processes and technologies. The type of packaging is also a crucial parameter to consider when quantifying microplastics in drinking water, although the use of glass bottles is recommended to minimize the potential associated risk to humans and ensure safe consumption. Increasing public awareness and knowledge about waste separation, the potential risks of microplastics to human health, and the urgent need for behavioral change in the management of waste, mainly plastic objects, remain the main keys to reducing the number of plastics entering our environment and our bodies.

1 Introduction

The availability of water resources depends on the quantity and quality of rainfall, so it is essential to protect and conserve water resources. Water scarcity due to the effects of climate change and overexploitation for socio-economic purposes are among the factors affecting the sustainability of water availability. Almost all socio-economic activities depend on the

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availability and quality of water, but these activities have a strong impact on water resources (Figure 1) [1-5]. The growth of human activities including agriculture, industrial and domestic activities are threatening the purity and availability of water resources, posing a risk to human health and threatening the survival of the Earth planet. Landrigan et al [6] reported that water pollution causes millions of deaths and more cases of disease every year.

Fig. 1. Main sources of water pollution.

Water pollution is not a new environmental and health concern. In fact, in the 1800s, society as a whole began to recognize that water pollution led to unsanitary and unhealthy living conditions that contributed to widespread disease and epidemics [7]. In the late 1800s, awareness of water pollution and the need to protect and conserve this natural resource led to basic research. In the mid-1850s, the first main sewer system was built to treat wastewater in Chicago in the United States, while in New England, sand filtration systems were developed by the Lawrence Experiment Station (LES), followed by other research and laboratory testing methods related to water quality [8].

Today, water pollution has become a pressing issue for stakeholders around the world, where water bodies are threatened by a variety of pollutants such as bacteria, parasites, toxic chemicals (e.g., heavy metals, radioactive elements), and solid waste such as plastics.

Plastic plays an essential role as a tool that facilitates the human lifestyle. Since its invention, plastics have brought immeasurable benefits to mankind [9], especially in the medical field. The invention of plastics has enabled the development of the healthcare industry [10] and provided access to medicines and medical treatment to a wide range of society [11]. However, the lack of awareness about the potential risk of plastics to the environment has led to the misuse and mismanagement of plastics and their associated wastes. Several studies have been conducted to assess and control the plastic waste in the environment, including soil and water. In this sense, the present study reviews the abundance and possible sources of plastics in drinking water stored in plastic bottles, glass bottles, beverage bottles, tap water, and raw and treated water from wastewater treatment plants around the world. This review also seeks to propose some recommendations for the management of microplastics in drinking water based on the analysis of available data from previous literature.

2 Methods and Materials

Plastic issue has become a burning topic in recent decades, especially several studies have reported its potential impacts on human health and ecosystem functioning. This study is based on data collected from databases such as Web of Sciences and Scopus. The search query focused on these main keywords: "plastics", "microplastics", "plastics in drinking water", "microplastics in groundwater"; "microplastics in plastic bottle", "microplastics in glass bottle", "microplastics in tap water", "microplastics in wastewater treatment plant", "plastic sources". No date range was used for this study. All types of documents were consulted, including proceedings, papers, and book chapters. We also used policy and technical reports in the present analysis as shown in Figure 2.

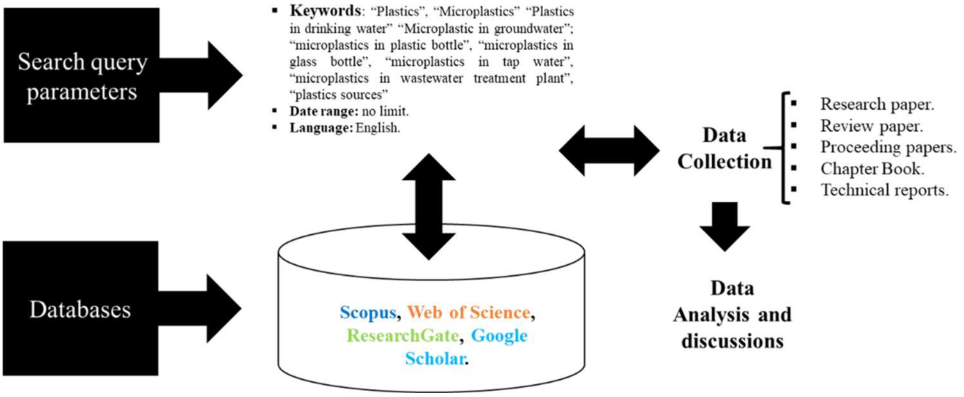


Fig. 2. Data collection flowchart.

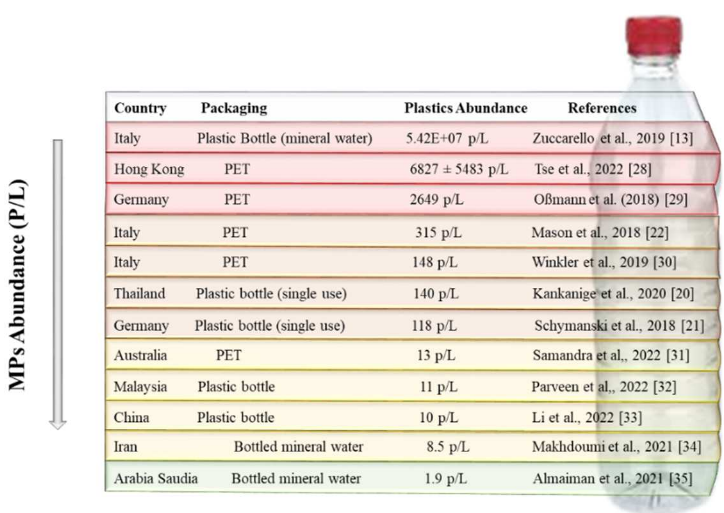
3 Results and discussions

3.1 Plastics in drinking water

Once discarded in nature, plastics break down into microplastics and nanoplastics due to mechanical and physical conditions. Plastic debris can come from a variety of sources and can easily enter freshwater systems [12]. Plastics have been found in groundwater, tap water, and bottled water [13-15]. They can be detected in drinking water through the degradation of plastic litter, surface runoff, industrial and wastewater discharges, and atmospheric deposition. They can also originate from landfills, which are considered a major source of microplastics in groundwater [16, 17]. In fact, Su et al [18] reported the occurrence of significant concentrations of microplastics in landfill leachate (4-13.0 items/L). In addition, the plastic equipment used for the purification or distribution of drinking water may be damaged or deteriorated and thus represent a source of microplastics in drinking water [19].

3.1.1 Microplastics in single use bottles

Figure 3 shows the abundance of microplastics in plastic bottles of mineral and table water collected from numerous countries. These bottles include different brands of plastic bottled water. The microplastic debris quantified in different water samples show values ranging from 1.9 to 5.42E^{+07} p/L (particles per liter). The values reported by Zurecarello et al [13] were higher than those found in other studies. These high values are due to the use of non-validated methods to quantify microplastics [13, 14, 15, 20-24]. The analysis of microplastics particles concentrations among studies indicate a variation in microplastic abundance that can be explained by the type of plastic bottle, the origin of the water, the level of purification, and the conditioning environment of the water in these bottles. The residence time of the water in the plastic bottle may also influence its abundance. In addition, the transportation and storage conditions of these water bottles can accelerate the degradation of plastics (e.g.; sunlight and moisture). In a research study conducted by Ahmed et al [25], where they investigated the potential effects of temperature change on bottled water quality, the temperature changes resulted in changes in the physicochemical properties of bottled water. Qiao et al [26] investigated the storage habits of polyethylene terephthalate (PET) bottled drinking water during summer in laboratory and car trunks. The results demonstrated the release of significant concentrations of antimony (Sb) from PET bottles in good agreement with the study of Al-Otoum et al. [27], which stated that the leaching of low concentrations of Sb from PET bottled water in Qatar due to temperature which was reported as the main factor affecting the release of Sb from plastics into water.



Country	Packaging	Plastics Abundance	References
Italy	Plastic Bottle (mineral water)	5.42E+07 p/L	Zuccarello et al., 2019 [13]
Hong Kong	PET	6827 ± 5483 p/L	Tse et al., 2022 [28]
Germany	PET	2649 p/L	Oßmann et al. (2018) [29]
Italy	PET	315 p/L	Mason et al., 2018 [22]
Italy	PET	148 p/L	Winkler et al., 2019 [30]
Thailand	Plastic bottle (single use)	140 p/L	Kankanige et al., 2020 [20]
Germany	Plastic bottle (single use)	118 p/L	Schymanski et al., 2018 [21]
Australia	PET	13 p/L	Samandra et al., 2022 [31]
Malaysia	Plastic bottle	11 p/L	Parveen et al., 2022 [32]
China	Plastic bottle	10 p/L	Li et al., 2022 [33]
Iran	Bottled mineral water	8.5 p/L	Makhdoumi et al., 2021 [34]
Arabia Saudia	Bottled mineral water	1.9 p/L	Almaiman et al., 2021 [35]

Fig. 3. Summary of peer-reviewed research works investigating MPs in plastic bottled table and mineral water.

3.1.2 Microplastics in glass bottles

The current trend is to replace plastic bottled water with glass bottled water to reduce the potential risks associated with drinking water in plastic bottles and the associated chemical leaching from PET plastics. However, studies conducted on glass bottled water to quantify microplastic content have shown significant concentrations of microplastics in glass bottled water. High levels of microplastics were found in Germany, followed by Italy (Figure 4). The levels reported for water in glass bottles remain less significant compared to those in plastic bottles. However, a comparison with the levels found in plastic bottled water from Australia, Malaysia, China and Iran (Figure 3) suggests that the source of the water is a possible source of microplastics in glass bottled water. However, it is recommended to use glass bottles instead of plastic bottled water.

MPs Abundance (p/L)

Country	Packaging	Plastics Abundance	References
Germany	Glass Bottle	3074p/L	Oßmann et al. (2018) [29]
Italy	Glass Bottle	195p/L	Mason et al., 2018 [22]
Thailand	Glass Bottle	52 p/L	Kankanige et al., 2020 [20]
Germany	Glass Bottle	50 p/L	Schymanski et al., 2018 [21]
Arabia Saudia	Glass Bottle	LOQ*	Almaiman et al., 2021 [35]

***LOQ**: below the limit of quantification*

Fig. 4. Summary of peer-reviewed research works investigating MPs in glass bottled table and mineral water.

3.1.3 Microplastics in beverage cartons and reusable/recyclable and returnable bottles

Microplastic concentrations in reusable plastic bottles were relatively higher than those found in plastic and glass bottles [29]. This suggests that the reuse of plastic bottles contributes to the increase in plastic content in plastic bottled water. The levels found in recyclable bottled water from Bangladesh were lower than those found in glass bottled water from Italy, Thailand and Germany [20, 21, 22]. Beverage cartons show only 11 p/L, a less significant concentration of plastic particles compared to the values recorded in glass bottled water (Figure 5).

MPs Abundance (p/L)

Country	Packaging	Plastics Abundance	References
Germany	PET, reusable	4889 p/L	Oßmann et al. (2018) [29]
Germany	PET, reusable	242 p/L	Giese et al. (2021) [36]
Bangladesh	PET, recyclable	35 p/L	Hossain et al. (2023) [37]
Hong kong	PET, reusable	19 p/L	Tse et al. (2022) [28]
Germany	Returnable bottle	14 p/L	Schymanski et al. (2018) [21]
Germany	Beverage bottle	11 p/L	Schymanski et al. (2018) [21]

Fig.5. Summary of peer-reviewed research works investigating MPs in reusable, recyclable and beverage cartons bottles of water.

Intercomparison of studies conducted on drinking water in different packaging materials and brands shows that levels vary within the same brand and from country to another. This suggests that microplastics in drinking water are mainly associated with the water source, but the use of microplastic bottles contributes to the increase in microplastic content. Therefore, more attention should be paid to water treatment and purification processes. The type of packaging is a crucial parameter to consider when quantifying microplastics in drinking water. Microplastics can be leached from both plastic bottles and beverage cartons because they are made of 20% polyethylene [38], and this percentage can vary depending on the bottle brand and the materials and models used.

3.1.4 Microplastics in Tap water

According to research conducted by Orb Media [39], bottled water contains approximately 50% more microplastics than tap water. Table 1 provides a summary of studies conducted on tap water samples collected from various countries around the world. The concentration of microplastic particles fluctuates between 0.01 and 9.24 p/L, indicating lower concentrations compared to bottled water. This suggests that other factors may influence the accumulation and increase of microplastic content in drinking water. However other studies highlighted high concentrations such as Tong et al. [24] study. This latter analyzed microplastic content in 38 water samples collected from different Chinese cities (from private households) and indicated concentrations fluctuated between 0 and 1247 with an average value of 440 p/L. In contrast, Zhang et al. [40] show low values compared to Tong et al. [24] findings (0.3 to 1.6 items/L). This is possibly related to the water sources, treatment and purification levels or due to the following techniques used for microplastic analysis and quantification in the two studies. The most common shapes of microplastics found are fragment and fibers, while the main polymers detected are polyethylene (PE) and polyethylene terephthalate (PET). This study investigated the distribution and characteristics of microplastics in tap water and two major water sources in Qingdao, China. The results showed that the microplastic abundance in tap water and water sources varied between 0.3 to 1.6 p/L and 0.2 to 0.7 p/L, respectively. The microplastic size ranged from 10 to 5000 µm appeared in black, grey, blue, and transparent colors. Fiber, as the common shape, contributed up to 99.2% of the identified microplastics. The most common polymers were rayon (48.9%), followed by polyethylene (PE) and polyethylene terephthalate (PET) (29.6%). The most common polymer pipers for buried water distribution were Polyvinyl Chloride (PVC) pipes, and they present 66% of the worldwide pipe network of buried potable water distribution [41]. PE was also reported among the first and most popular polymer pipes used for potable water distribution [42]. Accordingly, the detected types of polymers in tap water in these studies principally PE and PVC might have as their origin the pipes used for potable water. Chemicals, microplastics and nanoplastics can be leached from plastic pipes and contaminate water which may affect human health [43-44]. Plastic pipes are exposed to various environmental (freeze-thaw) and water quality (heating and chlorination) conditions, which can accelerate the release of microplastics and chemical leaching [44]. Thus, more attention must be given to microplastic leachate from pipes used for buried water distribution, as tap water can contribute to microplastic contamination as a source of this emergent contaminant to humans.

Table 1. Summary of studies that quantified microplastics in tap water from different countries around the world.

Country	**Packaging**	**Shape**	**Detected polymers**	**Particle Size**	**Abundance (p/L)** *(Mean concentrations)*	**Refrence**

USA	Tap water	Fragment/ Fibers	-	0.1–5 mm	9.24	[45]
Saudi Arabia	Tap water	fragment	PE, PS, PET, PA, PU	25–500 µm	1.9	[35]
Sweden	Driking potable water	fibres and fragments	PE, PA, PET, acrylic and PP	<150 and <20µm	0.174	[15]
Ecuador	Tap water	Fragment/ Fibers	-	0.1–5 mm	4.02	[45]
England	Tap water	Fragment/ Fibers	-	0.1–5 mm	7.73	[45]
France	Tap water	Fragment/ Fibers	-	0.1–5 mm	1.82	[45]
Germany	Tap water	Fragment/ Fibers	-	0.1–5 mm	0.91	[45]
India	Tap water	Fragment/ Fibers	-	0.1–5 mm	6.94	[45]
Indonesia	Tap water	Fragment/ Fibers	-	0.1–5 mm	3.23	[45]
Lebanon	Tap water	Fragment/ Fibers	-	0.1–5 mm	6.64	[45]
Slovakia	Tap water	Fragment/ Fibers	-	0.1–5 mm	3.83	[45]
Switzerland	Tap water	Fragment/ Fibers	-	0.1–5 mm	2.74	[45]
Uganda	Tap water	Fragment/ Fibers	-	0.1–5 mm	3.92	[45]
Belgium	Tap water	-	PET, PP, PS, PE, PVC	214 µm	0.01	[46]

3.1.5 Microplastics in wastewater treatment plant (WWTP)

Wastewater constitutes a source of microplastics in the environment and for humans [47-48]. WWTP receives different types of MPs including microbeads, microfibers, fragments, foam and pellets, which generally originate from the daily use of personal care products such as scrubbers, facial cleansers, sunscreen, cosmetics, scrubbers, shower gels, hair coloring, nail polish, eye shadow, and toothpaste [49]. The MPs used in these products are mostly made of (PE) and (PP). Table 2 shows MP concentrations measured in water samples collected from WWTP from different countries. It also shows the dominance of PET, PP and PE polymers, confirming that microplastics in wastewater are mainly associated with the daily use of personal care products in good accordance with Suaria et al. [49] findings. The total removal of microplastics from wastewater remains challenging mainly because of the gaps related to used analytical methods and techniques for the detection, and extraction and removal processes of microplastics [50]. As shown in Table 2, the concentrations of microplastics in raw water from wastewater plant (WTP) were lower than those in treated wastewater from the Czech Republic [51] explaining that the removal of microplastics from wastewater is incomplete, which is in good accordance with the results of Murphy et al. [52] and Wei et al. [53] findings.

Sludge and effluent of wastewater have been reported to contain a high quantity of microplastics as shown in Table 2 [54]. Okoffo et al. [55], reported that more than 80 of the plastic particles in WWTPs are retained in the sludge formed during the treatment processes of wastewater while no further treatment is done to move microplastics at WWTPs which means that important quantities of microplastics can be transferred moved and released into the environment, mainly soil and water. Noting that sludge and effluent are used as part of agricultural practices, and can easily reach and contaminate groundwater.

Table 2. Summary of studies carried out to quantify microplastics in raw and treated water from WWTPs.

Country	Packaging	Shape	Detected polymers	Particle Size	Abundance (*Mean concentrations)*	Reference
Netherlands	WWTP Raw sewage influents, effluents and sewage sludge	fibres, spheres and foams	-	10 and 5000 µm	68–910 L− 1, 51–81 L− 1 and 510–760 kg− 1 wet weight (ww),	[54]
Czech Republic	WTP raw water	fibres + fragments	PET and PP	1–50 µm	1473to 3605 MP.L−1	[52]
Czech Republic	WTP treated water	fibres + fragments	PET and PP	1–10 µm	from 338 to 628 MP.L−1	[52]
Belgium	Drinking water treatment plants	-	PET, PP, PS, PE, PVC	214µm	0.02 ± 0.03 MPs.L− 1	[46]
USA (San Francisco Bay)	Wastewater treatment plants	fibers and fragments			0.086 MP.L−1	[56]
Australia	Waste water	fibers and fragments	PET, PP and PE	>25µm	0,18-98 MP.L−1	[57]
Australia	Sludge	fibers and fragments	PET, PP and PE	>25µm	15.9-56 MP.L−1	[57]
China	wastewater influent	fibers, fragments, flakes, spheres and films	Rayon and PET	0.1–0.5 mm	196 MP.L−1	[58]
China	wastewater effluent	fibers, fragments, flakes, spheres and films	Rayon and PET	0.1–0.5 mm	9.04 MP.L−1	[58]

4 Water bottle packaging vs. circular economy concept and 3Rs (reduce, reuse, and recycle)

Plastic is an emerging pollutant that heavily affects terrestrial and oceanic environments. Numerous studies have been undertaken to analyze the occurrence of microplastics, quantify microplastics and identify their size, shapes and types of polymers. Plastics have also been detected in drinking water from the tap, glass, plastic and beverage carton bottles as well as in recyclable and reusable bottles. In both raw water and treated water in wastewater treatment plants (WWTPs), microplastic quantification indicated high concentrations suggesting that even after the treatment process, treated water can contain a significant amount of microplastics that can reach terrestrial environments and contaminate soil and water. Some gaps and challenges relating to technologies and analytical techniques for plastics detection, extraction and removal have been reported in numerous studies [48, 59-63].

The concern about the presence of microplastics in drinking water and its potential risk to humans has increased which led the European Drinking Water directive to add microplastics to the watch list of emerging compounds by 2024, so to push member states to proceed with precautionary measures to reduce the presence of microplastic if high quantities are reported [64].

Drinking water is usually stored in reusable plastic and glass bottles. The storage conditions including temperature and residence time of water in these bottles as well as the materials used for producing plastic bottles. All these factors influence the microplastic content in water. In the case of plastic bottled water, the adoption of circular economy and 3R (reduce, reuse, and recycle) cannot be completely implemented (Figure 6). The use of reusable plastic water may contribute to the increase of microplastics in drinking water. Instead it is recommended to reduce R1 our dependency on plastic bottles and use reusable glass bottles R2. Besides, reducing and recycling (R1 & R3) plastic bottles would help in reducing and limiting the quantity of plastics reaching groundwater and other terrestrial and oceanic environments. In this sense, increasing public awareness and knowledge about waste separation, the microplastic potential risk to human health and the urgent need to change their behavior toward managing their waste mainly plastic objects remain the main approach to mitigate the number of plastics entering our environment and bodies. Developing harmonized approaches for the detection and identification of microplastics in water and soil is an urgent need, as it would allow a better understanding of the quantity of plastics entering marine and terrestrial ecosystems. Additionally, the MPs' removal approaches and technological improvement must be taken as a priority, to prevent possible risks to humans.

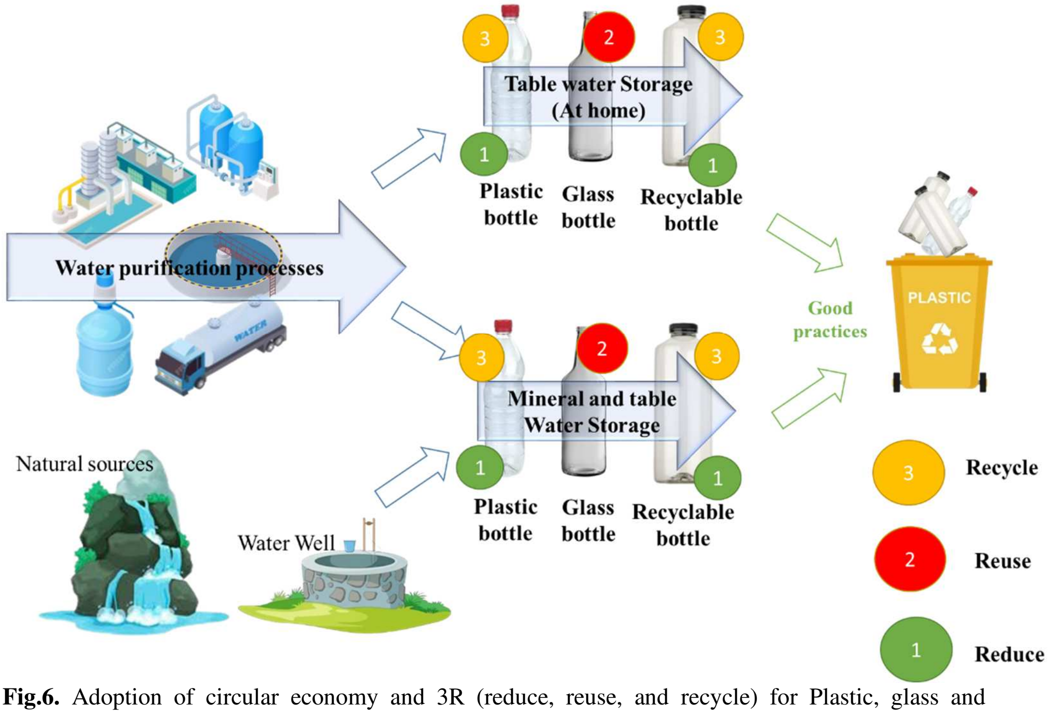


Fig.6. Adoption of circular economy and 3R (reduce, reuse, and recycle) for Plastic, glass and recyclable bottles.

5 Conclusions

The analysis of available data carried out on drinking water including bottled water and tap water has indicated large differences in microplastic quantity among countries. This reflects the existing gap regarding the quantity of microplastics in drinking water and factors influencing their accumulation.

The comparison of microplastic abundance in glass water bottles and plastic water bottles indicates that the use of plastic bottles contributes to the increase in microplastic content in drinking water. However, the presence of significant concentrations of microplastic also in glass-bottled water suggests that water from the exploitation source needs reliable examination.

The analysis of bottled water versus tap water suggests that there are multiple sources of microplastics in drinking water, including bottle packaging, pipes used in Buried Potable Water Distribution and treatment purification processes adopted for potable water, which make it difficult to accurately identify the specific origins of microplastics.

The intercomparison between raw and treated water from wastewater treatment plants (WWTPs) has shown that the treatment processes are unable to completely remove microplastics. Thus MPs' removal approaches and technological improvement must be taken as a priority to prevent possible risks to humans' health.

The adoption of the circular economy concept and the principles of reduce, reuse, and recycle (3Rs) would help reduce the number of plastics reaching groundwater and entering potable water. Accordingly, it is recommended to use glass bottles instead of plastic bottles to store water and it is required to reduce public dependency on plastic objects and increase awareness about waste separation and recycling, to prevent any potential effect associated with consuming microplastics in water.

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