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Microplastic pollution of drinking water in a metropolis

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ABSTRACT

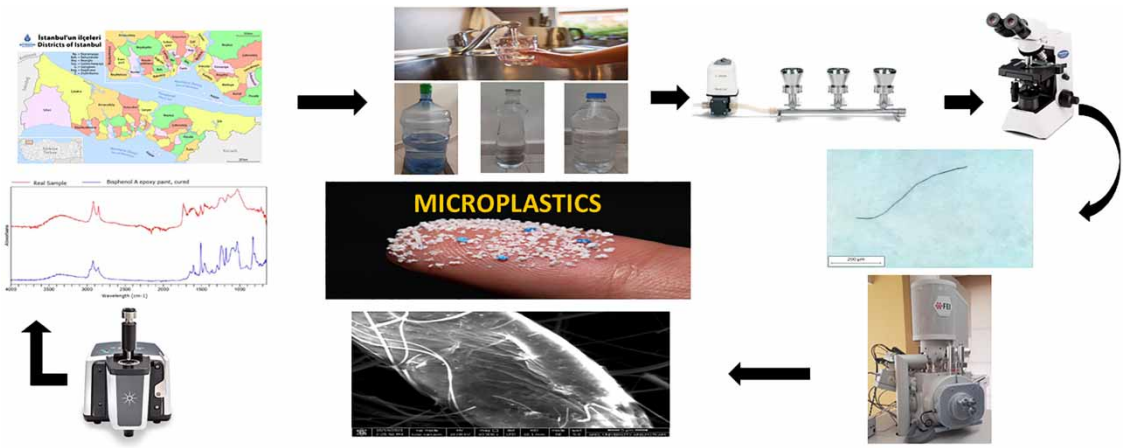
This study was conducted to identify microplastics (MPs) in drinking water from various sources in İstanbul that are known to pose potential health risks. One hundred drinking water samples were analysed. Samples were filtered with a glass filter (Ø: 1.0 μm). After filtration, microscopy was used, followed by SEM-EDS and ATR-FTIR identification to characterise MPs. Two shapes (fibers and fragments) and eight polymer types of MPs (ethylene propylene, neoprene, polyethylene, polyethylene terephthalate, polypropylene, polyvinyl chloride, polytetrafluoroethylene, vinyl chloride vinyl acetate copolymer) with sizes of 12–4892 μm (548 ± 777 μm) were detected. These MPs abundances ranged from 10 to 390 MP L^{-1} (134 ± 93 MP L^{-1}). In the identification of MPs detected in filters by FTIR spectroscopy, bisphenol A, which is used in the production of various plastics and described as an important public health problem, was detected in 9.74% of MPs. Within the scope of the Sustainable Development Goals, UNEP has a specific objective of ensuring access to safe, affordable drinking water (SDG 6). With a clear statement, it should be emphasised that MPs are a significant barrier to the provision of safe drinking water, and a comprehensive plan for overcoming this barrier should be developed.

Key words: ATR-FTIR, filtration, microplastic, SEM-EDS, water

HIGHLIGHTS

- At least 63.6% of drinking water is contaminated with MP.
- Tap water is critical for microplastic contamination (100%).
- PET, PVC, and EP are the three MPs found in water samples most frequently.
- Bisphenol A was one of the contaminants identified in tap water samples.

GRAPHICAL ABSTRACT



INTRODUCTION

The first semi-synthetic plastic production was made by the English metallurgical engineer Alexander Parkes in 1860, which he named 'parquetine'. After this material was introduced as a cellulose nitrate derivative, various materials such as celluloid, collodion, and bakelite were offered to humanity. The modern society of the 20th century has gradually adapted to a plastic-based culture, with organic polymer-derived plastics more common than materials such as ceramics, metal, or glass (Rasmussen 2021). Plastics, which are accepted as a great miracle in terms of being an alternative to the decreasing natural materials and their consumption is increasing day by day, have started to pose a risk for the environment, animal, and human health as a result of mismanagement of production residues and wastes (Thompson *et al.* 2009). Plastic materials that have been included in our lives in various ways, such as simple food packaging, cosmetics, cleaning agents, synthetic fibers, car tires, and clothes containing plastic, cause irreversible environmental problems in air, water, and soil quality (Fonseca *et al.* 2017; Periyasamy & Tehrani-Bagha 2022).

The particles and residues of these plastic wastes and oddment, which spread uncontrollably in the environment and range in size from 5 mm to 1 μm in size, are called microplastics (MPs) (Frias & Nash 2019). These are water-insoluble, smooth, or amorphous polymeric particles (Frias & Nash 2019). Primary MPs are microbeads of different sizes used industrially. They are released into the environment at stages such as production and transportation (Andrady 2017). Secondary MPs pose a risk by spreading to the air, soil, and seas due to the degradation of plastic materials and garbage under environmental conditions (Barnes *et al.* 2009; Andrady 2017; Zhao *et al.* 2023).

MPs have been reported in food, water, and air samples. Therefore, MPs with potentially harmful effects on human health can be taken into the body through diet or inhalation (Wright & Kelly 2017). MPs can be detected in human blood, urine, and breast milk, both on their own and with the many chemicals like cadmium, lead, bisphenol A (BPA), styrene, phthalates, polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), tetrabromobisphenol A (TBBPA), furan, and dioxin (Sjödin *et al.* 2003; Hauser & Calafat 2005; Talsness *et al.* 2009; Halden 2010). MPs, which are an essential component of general pollution, are considered to have a significant contribution to endocrine-disrupting effects (Halden 2010), disruption of thyroid hormone homeostasis (Sjödin *et al.* 2003), reproductive abnormalities, male and female reproductive diseases, pregnancy and respiratory health problems (Hauser & Calafat 2005; Swan *et al.* 2005; Lang *et al.* 2008; Swan 2008) and premature death (Landrigan *et al.* 2017). Some researchers are more cautious but sceptical (Seltenrich 2015).

Studies were carried out by Mason *et al.* (2018); Oßmann *et al.* (2018); Schymanski *et al.* (2018) for the detection of MPs in bottled waters and by Kosuth *et al.* (2018); Pivokonsky *et al.* (2018); Mintenig *et al.* (2019); Tong *et al.* (2020); Feld *et al.* (2021) for the detection of MPs in tap waters.

WHO reports that several research gaps need to be filled to better assess the risk of MPs in drinking water and inform management actions. Targeted, well-designed, and quality-controlled research studies should be conducted to better understand the MP formation and to better characterize the effectiveness of water treatment throughout the water supply chain, including the numbers, shapes, sizes, composition, and sources of MPs (Marsden *et al.* 2019). In this regard, risk definitions for water should be developed. WHO recommends that men consume 3 L of water per day and women consume 2.2 L. Most of these consumed waters are from tap water, bottled water, or a combination of the two. The risk of ingesting plastic from drinking water is currently unclear (Kieran *et al.* 2019). Also, concerns about the quality and safety of tap water have increased the consumption of plastic bottled water in recent years (Aris *et al.* 2013; Gambino *et al.* 2020).

The study's goal is to analyze MPs (between 1 μm and 5 mm) and discuss the potential risks to humans posed by their presence in drinking water from various sources in İstanbul.

MATERIALS AND METHODS

Sample collection and preparation for laboratory analysis

İstanbul is one of the world's most important metropolises, with a population of nearly 16 million and an 8,500-year-old history. Prior to the pandemic, the country welcomed 15 million international visitors in 2019. It is essential to manage all aspects of the water supply sources for this large city. In recent years, MPs have been scrutinized because they pose a threat to food and water resources and have been linked to environmental pollution. Due to these factors, İstanbul was selected for sampling (Republic of Türkiye Governorship of İstanbul 2022).

Drinking water in İstanbul is generally supplied from three different sources: natural spring water, natural mineral water, and tap water. For this reason, the sample set was collected from these sources. Sampling was carried out in January and

February 2022. Natural spring water (n:50) and natural mineral water samples (n:11) were purchased from the markets. These products were packaged in plastic and glass bottles under various brand names. Each sample volume was planned to be 1 L. For water in small-volume bottles, water bottles with the same batch and serial number were collected, and the sample volume was equalized to this amount.

The tap water samples (treated surface water) (n:39) were obtained from 39 districts (Adalar, Arnavutköy, Ataşehir, Avcılar, Bağcılar, Bahçelievler, Bakırköy, Başakşehir, Bayrampaşa, Beşiktaş, Beykoz, Beylikdüzü, Beyoğlu, Büyükçekmece, Çatalca, Çekmeköy, Esenler, Esenyurt, Eyüp, Fatih, Gaziosmanpaşa, Güngören, Kadıköy, Kağıthane, Kartal, Küçükçekmece, Maltepe, Pendik, Sancaktepe, Sarıyer, Silivri, Sultanbeyli, Sultangazi, Şile, Şişli, Tuzla, Ümraniye, Üsküdar, Zeytinburnu) that belong to İstanbul (Figure 1). Sample containers were rinsed in the laboratory with MP-free ultrapure water before being brought to the site. The sample bottles were filled to the brim with MP-free ultrapure water and rinsed; then, filtration was performed for contamination control of bottles. Tap water samples (1,000 mL) were collected from running taps (water flow rate: 3 L min^{-1}; after the tap was drained for 1 min) to avoid incidental contamination from the air and were placed in cork-cap glass sample vials, and the samples were quickly brought to the laboratory.

In order to guarantee the accuracy of our data, a series of quality assurance and quality control (QA/QC) measures were taken during the process, from field sampling to laboratory analysis, according to Wang *et al.* (2017). Cotton lab coats and nitrile gloves were worn to prevent contamination of the samples by airborne polymer particles and fibers. All consumables were chosen from glass and stainless-steel to prevent plastic contamination. The laboratory work surfaces were cleaned using MP-free ultrapure water and acetone, respectively, in an effort to minimize contamination to a negligible level or eliminate it completely. Field-blank tests were conducted in all selected sampling locations. At each location, 1 L of MP-free ultrapure water was taken as the blank sample. The experiment was conducted in triplicates. Blank samples were analyzed by the same procedure as for water samples. Method blank tests were also carried out to check potential contamination of distilled water and the air in the laboratory during the analysis process (Dubaish & Liebezeit 2013; Nuelle *et al.* 2014; Chae *et al.* 2015). Each analysis was carried out in triplicates. Potential MPs in the air were examined with Petri dishes with filters placed next to the samples in a laminar flow cabinet and left open for 1 h. Data about the level of contamination were obtained. Also, positive control samples were prepared by adding polypropylene (PP), polystyrene (PS), polyethylene (PE),

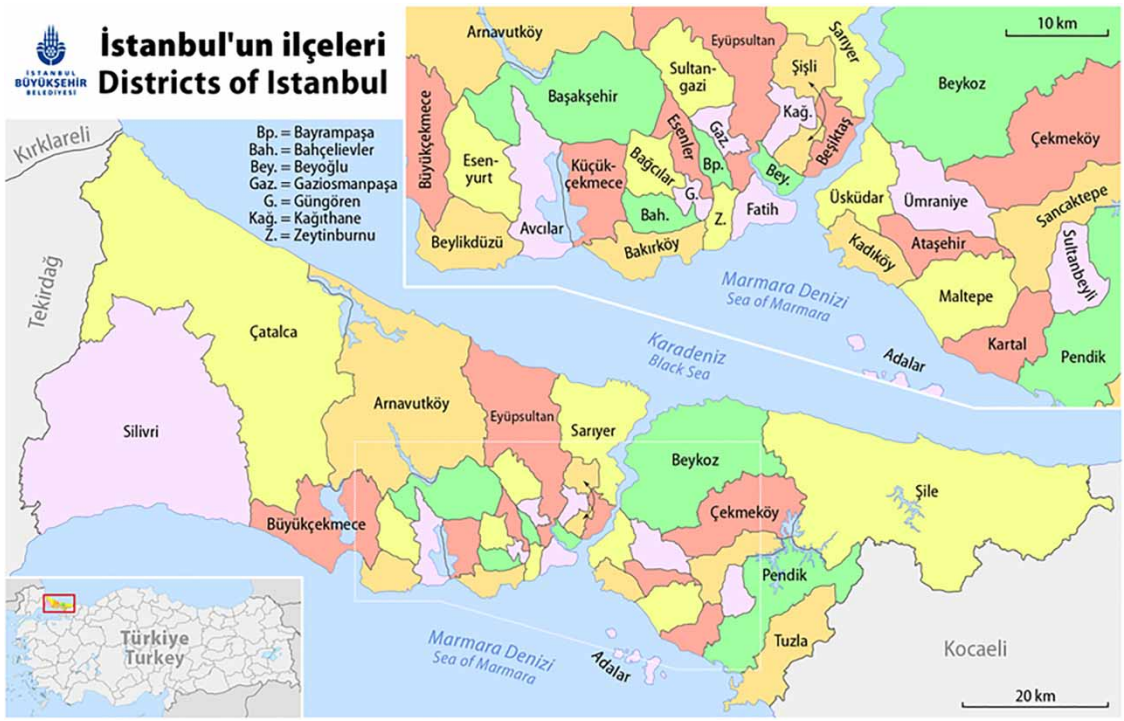


Figure 1 | Districts of İstanbul.

polyvinyl chloride (PVC), linear low-density polyethylene (LLDPE), and thermoplastic elastomers (TPEs) to MP-free ultrapure water and were included in the study to control the analysis.

Sample filtration

All water samples were shaken prior to filtration to maximize particle recovery from bottles. A 1,000 mL of water sample were filtered under laboratory conditions using a Whatman filter grade GF/B circles (pore size of 1.0 μm, glass microfiber filters, 47 mm) and a vacuum pump set to approximately 0.5–0.6 bar pressure (Liebezeit & Liebezeit 2014; Kosuth *et al.* 2018; Schymanski *et al.* 2018).

The filtration units were thoroughly rinsed using MP-free ultrapure water before the new sample filtration process. Two replicates of the same batch were processed for each sample of water. All filters were carefully transferred individually to new glass Petri dishes using metal tweezers and dried at room temperature and stored for subsequent analysis.

Morphological characterization

Glass filter papers were examined under a binocular biological microscope (Olympos CX31) with a camera (Canon A640) attached at a magnification level of 4× for particles thought to be MPs. They were photographed with Kameram Software 1.3.0.8 (Mikrosistem, Turkey), measured with IC Measure (The Imaging Source®, 2.0.0.286, Germany), and classified based on colors, shapes, and sizes. Particles determined by the detecting microscope to exceed 5 mm in any dimension were not counted as MPs.

Semi-quantitative identification of MPs by SEM-energy dissipative X-ray spectroscopy (EDS)

Fei Quanta™ 450 FEG-ESEM scanning electron microscopy (SEM) was used to perform morphological characterization and determine the elemental composition of the particles. A polymer image was detected and marked by a binocular microscope. Sample filters with particles were visualized under the microscope and were transferred using metal tweezers onto a conductive and adhesive carbon tape mounted on an aluminum SEM sample holder. SEM observations were made at superior low vacuum pressure mode and different magnifications operating at an acceleration voltage of 10.00 kV in the secondary electron and backscattering mode. Chemical characterization/element analysis of the selected area of microparticles was performed simultaneously with a semi-quantitative method, EDS.

Final identification of MPs by ATR-FTIR

The material chemical composition of MPs was identified using FTIR spectroscopy (Agilent Cary 630). Microparticles were detected in each filter under the dissecting microscope and marked with a fine-tipped water-based, acid-free architectural drawing pen (0.05 mm). The filter to be examined was placed on the FTIR spectroscopy crystal with these markings in mind. The results were evaluated using Agilent Polymer Handheld ATR Library, Agilent Elastomer Oring and Seal Handheld ATR Library and Agilent ATR General Library.

Statistical analysis

SPSS 21 was used to summarize dataset characteristics and distribution information. MP number and size dispersion in water samples (tap, mineral, and spring water) and the difference between packaging materials (returnable PET, single-use PET, and glass) were analyzed using analysis of variance (ANOVA) and post hoc Tukey honestly significant difference (HSD) test.

RESULTS

Tap water, mineral water, and spring water are the three sources of drinking water in İstanbul. Thereof, 11 different brands of glass bottled waters, 7 different brands of returnable PET water samples, 43 different brands of single-use PET water samples, and 39 tap water samples were analyzed for the presence of MPs.

Before analyzing the drinking water samples, the results of tests conducted to assess the adequacy of QA/QC measures were evaluated. According to the blank test results, 0.06 ± 0.02 MP L^{-1} was detected in field-blank samples, and 0.13 ± 0.06 MP h^{-1} was in air samples. No plastic particles were observed after passing 1 L of ultrapure water through the filter paper under vacuum filtration. The results of the blank tests confirmed that the background contamination was minimal and negligible. The recovery rates of the positive control samples prepared with PP, PS, PE, PVC, LLDPE, and TPE were calculated $98 \pm 2\%$, $96 \pm 4\%$, $95 \pm 4\%$, $87 \pm 7\%$, $89 \pm 6\%$, and $91 \pm 9\%$, respectively.

A total of 1,088 MPs was detected in the filters of 81 positive samples. There were between 10 and 390 MP L^{-1} in the water samples. MPs were detected in all tap water samples, 63.6% mineral water samples, and 70% spring water samples. Statistical information about the total number of MPs, number dispersion range and shape, color, polymer type, and size dispersion in all samples are provided in Table 1. The mean number of MPs found in positive samples of tap, mineral, and spring water was 188 ± 81, 54 ± 19, and 89 ± 76 MP L^{-1}, respectively. MPs exceeding 5,000 μm were excluded. However, MPs greater than 5,000 μm could not be detected in any of the samples classified as negative.

The size distribution of MPs across all water samples is shown in Table 2. The length of the MPs was calculated using IC Measure software. MPs were measured along the longest dimension. The percentages of MP size distribution in water samples were: 11–50 μm: 3.13%; 51–150 μm: 35.39%; and >151 μm: 61.48%. A statistical difference in the dimension of the MP particles was only observed in the case of tap water samples. It was determined that MPs detected in tap waters had the smallest particle dimension average. The MP size mean was 391 ± 69.8 μm, and the median was 159 μm.

Figure 2 illustrates examples of microscopic images of MPs detected from water samples. They were displayed as reddish brown, red, dark red, pink, blue, dark blue, purple, orange, green, greenish blue, black, and transparent in water samples. Among the MPs, 69.94% were blue, 19.30% were red, and 7.44% were reddish brown (Table 3). Of the detected MPs, 61.49% were fragments and 38.51% were fibers (Table 4).

The water samples contained eight different types of MPs: ethylene propylene (EP), neoprene (Neo), PE, polyethylene terephthalate (PET), polypropylene (PP), PVC, polytetrafluoroethylene (PTFE), and vinyl chloride vinyl acetate copolymer (VCVA). PET, PVC, and EP were the three MPs found in water samples most frequently. The ratios of these polymers in total were 19.39, 17.46, and 14.25%, respectively. In addition, ATR-FTIR spectroscopy detected a BPA peak in 9.74% of the MPs. Figure 3 depicts the outcomes of SEM-EDS observations of the surface morphologies of representative MPs. ATR-FTIR was used to determine the chemical composition of the microparticles (Figure 4).

When the MP number and size distribution of mineral water and spring water filled into bottles from different materials are examined, it has been determined that all the water samples in the returnable PET bottles that are refilled after being washed and sterilized in the filling facilities contain MPs. While this rate was 60.47% for disposable PET bottles, it was 81.82% for glass bottles (Table 5). The statistical evaluation revealed that the difference is significant ($p < 0.05$). The statistical evaluation of MP size distribution determined that the mean size of MPs in returnable bottles was smaller than in disposable PET and glass bottles.

DISCUSSION

In our study, all 39 tap water samples collected from consumer homes were contaminated with MPs ($\bar{x}$: 188 ± 81 MP L^{-1}). The main water supply of the city was flowing directly from the taps in all the sampled houses, and no intermediate storage was available. This point, taken into consideration during sampling, is important to eliminate individual errors that may arise from storage while evaluating. The convergence of the city to the edge of the water basins, the effect of industrial zones on water reserves, the rise in traffic, the increase in human movement, and the growing population are significant factors for MP contamination (Eriksen *et al.* 2013; Free *et al.* 2014; Dris *et al.* 2016; Republic of Türkiye Governorship of İstanbul 2022). MPs in all tap water indicate the potential risk of consuming tap water. Even though some sample locations originate from the same drinking water basins, the change in MP load is noteworthy. This diversity could be attributed to the quality of the plastic pipes in the water distribution systems, their age, and the length of the transmission line (Muhib *et al.* 2023).

Compared with similar studies, Kosuth *et al.* (2018) found tap water contained between 0 and 57 ($\tilde{x}$: 4.34) MP L^{-1}. Pivokonsky *et al.* (2018) determined concentrations ranging from 243 to 684 MP L^{-1} in the filtrated waters of drinking water treatment plants. Mintenig *et al.* (2019) detected MPs in 10 of a total of 24 water samples collected from the outlet unit of a water plant that supplies water to the city after the treatment process and from the fountains of the houses. They reported that the concentrations in the samples ranged from 0 to 7 MP L^{-1}. Tong *et al.* (2020) detected MPs in 36 of the 38 tap water samples they analyzed. The abundance of MPs in their samples ranged from 0 to 1,247 MP L^{-1} ($\tilde{x}$: 440 MP L^{-1}). The total number of MPs >100 μm in tap water samples from 17 locations in Denmark was determined as an average of 3.3 MP 50 L^{-1} (Feld *et al.* 2021). Geographical differences are the primary explanation for the disparities between these studies' findings. The distance of water basins to roads and airways, human and vehicle movements near the water protection area, the distance of the basin to the industrial zones, the weather conditions and climate at the time of sampling, drinking water

Table 1 | Statistical data of MPs at all water samples

Source	No. of samples (total)	No. of positive samples	Total MP number of all samples*	MP number dispersion in samples (MP L^{-1})		Shape	Color	Polymer type	Size dispersion of MPs in samples (μm)	
				Range (mean ± SD)	Median				Range (mean ± SD)	Median
Tap water	39	39 (100%)	739	10–390 ($188^{a} \pm 81$)	170	Fibers, fragments	Reddish brown, red, pink, blue, greenish blue, black, transparent	Ethylene propylene, Neoprene, Polyethylene, Polyethylene terephthalate, Polypropylene, Polyvinyl chloride, Polytetrafluoroethylene, Vinyl chloride vinyl acetate copolymer	12–4,882 ($391^{a} \pm 698$)	159
Mineral water	11	7 (63.6%)	38	30–80 ($54^{b} \pm 19$)	50	Fibers, fragments	Reddish brown, red, blue, dark blue, purple, orange	Ethylene propylene, Neoprene, Polyethylene, Polyethylene terephthalate, Polypropylene	52–3,416 ($972^{b} \pm 883$)	572
Spring water	50	35 (70%)	311	10–370 ($89^{b} \pm 76$)	70	Fibers, fragments	Reddish brown, red, dark red, pink, blue, green, black, transparent	Ethylene propylene, Neoprene, Polyethylene, Polyethylene terephthalate, Polypropylene	17–4,892 ($870^{b} \pm 965$)	514
Total	100	81 (81%)	1,088	10–390 (134 ± 93)	130	Fibers, fragments	Reddish brown, red, dark red, pink, blue, dark blue, purple, orange, green, greenish blue, black, transparent		12–4,892 (548 ± 777)	191

*MPs larger than 5,000 μm are disregarded.

[a,b]Each column was evaluated within itself separately, values in the same column with different letters are significantly different ($p < 0.05$).

Table 2 | Size dispersion of MPs at all water samples

	Size categorization of MPs					
Source	11 μm–50 μm n (%)	51 μm–150 μm n (%)	151 μm–250 μm n (%)	251 μm–500 μm n (%)	501 μm–1,000 μm n (%)	1,001 μm–5,000 μm n (%)
Tap water	22 (2.98%)	321 (43.44%)	160 (21.65%)	96 (12.99%)	63 (8.52%)	77 (10.42%)
Mineral water	0	4 (10.53%)	7 (18.42%)	5 (13.16%)	7 (18.42%)	15 (39.47%)
Spring water	12 (3.86%)	60 (19.29%)	50 (16.08%)	33 (10.61%)	57 (18.33%)	99 (31.83%)
Total	34 (3.13%)	385 (35.39%)	217 (19.94%)	134 (12.32%)	127 (11.67%)	191 (17.55%)

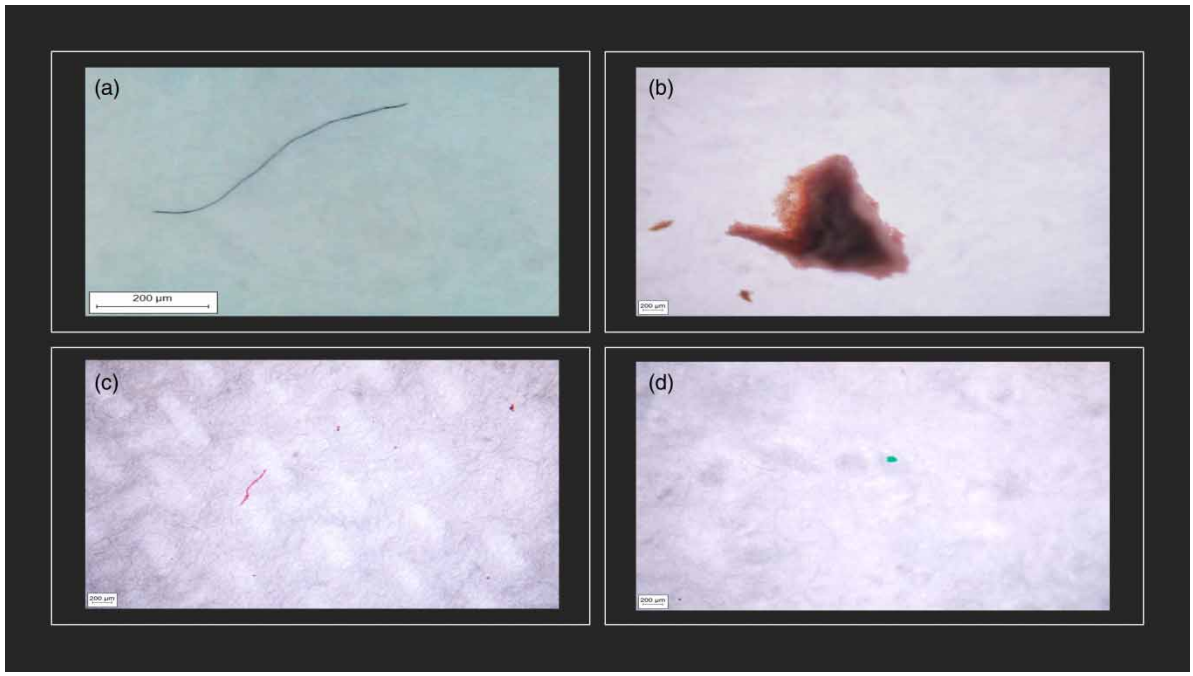


Figure 2 | Images of typical MPs detected from water samples: (a) 548 μm; (b) 1,725 μm; (c) 578 μm; (d) 113 μm.

Table 3 | Color dispersion of MPs at all water samples

	Color											
Source	Reddish Brown	Red	Dark Red	Pink	Blue	Dark Blue	Purple	Green	Orange	Greenish Blue	Black	Transparent
Tap water (739 MP)	74	144	0	1	502	0	0	0	0	3	8	7
Mineral water (38 MP)	2	5	0	0	27	2	1	0	1	0	0	0
Spring water (311 MP)	5	61	1	1	232	0	0	2	0	0	4	5
Total	81	210	1	2	761	2	1	2	1	3	12	12

treatment methods and the continuity of these methods can be considered as important determining factors. On the other hand, the material quality of drinking water transmission lines may also be related to the results (Muhib *et al.* 2023).

Our current study revealed that mineral and natural spring water samples contained less MP than tap water samples ($p < 0.05$). Bottled water, an alternative to tap water for consumption, reveals that PET bottles pose a risk of contamination with MPs. However, the risk is not as significant as that of tap water. In returnable PET bottles, the level of contamination is roughly double that of single-use bottles. This is due to MP contamination caused by airborne as a result of storing empty

Table 4 | Shape and polymer type dispersion of MPs at all water samples

Source	Polymer type	Filament no.	Fragment no.
Tap water	Vinyl chloride vinyl acetate copolymer	11	26
	Polyvinyl chloride	43	147
	Polytetrafluoroethylene	26	55
	Polyethylene	0	1
	Polypropylene	3	2
	Polyethylene terephthalate	55	156
	Neoprene	20	64
	Ethylene propylene	8	16
	Bisphenol A	23	83
Mineral water	Polyethylene	6	1
	Polypropylene	4	0
	Polyethylene terephthalate	3	1
	Neoprene	3	7
	Ethylene propylene	12	1
Spring water	Polyethylene	19	13
	Polypropylene	14	10
	Polyethylene terephthalate	14	19
	Neoprene	22	45
	Ethylene propylene	133	22
Total		419	669

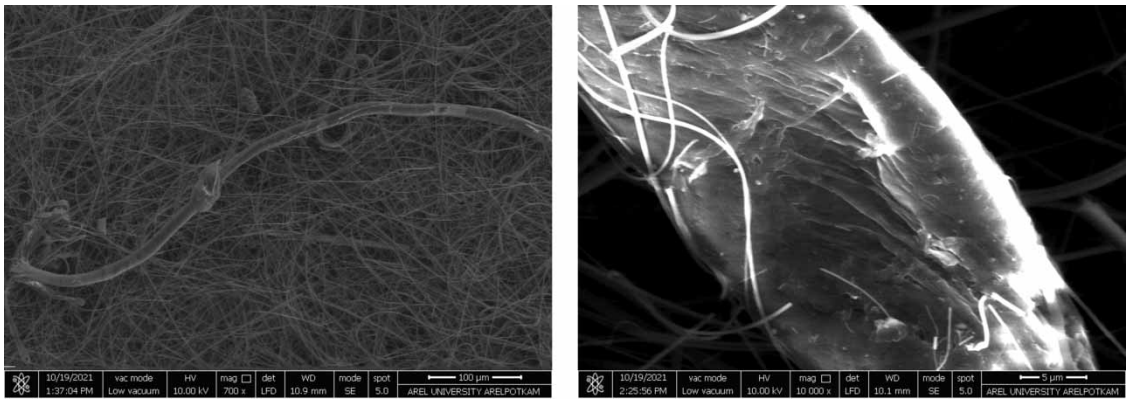


Figure 3 | SEM images of MPs.

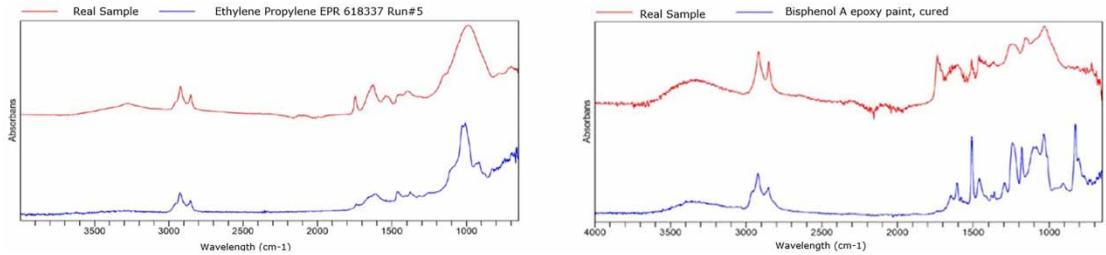


Figure 4 | Identification of MPs using ATR-FTIR.

Table 5 | Number and size dispersion of MPs at all samples by packaging material

Packaging Material	No. of samples (total)	No. of positive samples	Total MP number of all samples*	MP number dispersion in samples (MP L^{-1})		MP size dispersion in samples (μm)	
				Range (mean ± SD)	Median	Range (mean ± SD)	Median
Returnable PET	7	7 (100%)	110	70–370 ($157^{a} \pm 111$)	120	36–4,606 ($566^{a} \pm 801$)	230
Single-use PET	43	26 (60.47%)	184	10–220 ($71^{b} \pm 51$)	50	17–4,892 ($1,088^{b} \pm 1,004$)	805
Glass	11	9 (81.82%)	55	10–130 ($61^{c} \pm 49$)	50	52–4,225 ($823^{b} \pm 952$)	462

[a,b,c]Each column was evaluated within itself separately, values in the same column with different letters are significantly different ($p < 0.05$).

bottles in unsuitable conditions before transporting them to water-filling stations. In addition, it is believed that exposure to corrosion, ultraviolet light, and mechanical trauma contributes to the MP contamination level. MP contaminations are possible because of the MP load of detergents and disinfectants used for cleaning and disinfecting returnable PET bottles brought to the filling facilities, as well as the repeated corrosion of the bottles used with these agents and the effect of pressurized water (Muhib *et al.* 2023). The repeated impact of UV rays used to sterilize washed bottles is also a significant factor. The statistical analysis determined that glass bottles had the lowest level of contamination in terms of MP number ($p < 0.05$). For this reason, traditional glass bottles should be considered an alternative bottling method.

In a study on MPs in bottled water in Germany, the average concentration was 14 ± 14 MP L^{-1} in disposable plastic bottles, 118 ± 88 MP L^{-1} in reused PET bottles, and 50 ± 52 MP L^{-1} in glass bottles (Schymanski *et al.* 2018). Mason *et al.* (2018) reported that 93% of 259 bottled drinking water samples were tested for MP contamination in nine countries contained traces of MP contamination. It is stated that an average of 315 MP L^{-1} of water is detected in particles with sizes between 6.5 and 100 μm; an average of 10.4 MP was observed for particles with sizes greater than 100 μm. According to Zuccarello *et al.* (2019), each sample (n:30) of still or sparkling mineral water sold in PET plastic bottles (500 mL) in Catania-Italy contained MPs. The concentration was reported to be $5.42E+07 \pm 1.95E+07$ MP L^{-1}. Zhou *et al.* (2021) identified 215 MP particles in 69 PET plastic bottle samples from 23 brands (2–23 MP per bottle). Quantitative and qualitative MP analysis of water sold in bottles belonging to 10 water brands was conducted in Thailand using ATR-FTIR (50 μm) and confocal Raman spectroscopy (1–50 μm). The MP concentration was determined to be 140 ± 19 MP L^{-1} in single-use plastic bottles and 52 ± 4 MP L^{-1} in glass bottles (Kankanige & Babel 2020). They reported that plastic bottles contain significantly more than glass bottles and mentioned that packaging is the primary source of risk, but contamination can also occur during the manufacturing process.

In our study, the size of MPs in tap water samples was significantly smaller than in mineral and spring waters ($p < 0.05$). The percentages of size distribution in tap water samples were: 11–50 μm: 2.98%; 51–150 μm: 43.44%; and >151 μm: 54.13%. While the rate of <151 μm detected in spring waters was 23.15%, this rate was determined as 10.53% in mineral waters. A statistically significant difference in the mean size was only observed in returnable bottles ($p < 0.05$).

MP size is an important parameter for translocation in living organisms. This parameter determines absorption efficiency through the gastrointestinal, alveolar, and dermal epithelium. The gastrointestinal epithelium is permeable to particles of 150 μm. Over 90% of particles larger than 150 μm are eliminated via faeces. The alveolar epithelium absorbs particles of 10 μm in size. However, it was reported that <0.1–10 μm particles can pass through the blood–brain barrier and placenta, and particles of 2.5 μm and above enter the systemic circulation via endocytosis and phagocytosis (Millburn *et al.* 1967; Yang *et al.* 2009; Prietl *et al.* 2014; Kannan & Vimalkumar 2021).

According to Pivokonsky *et al.* (2018), 95% of MPs in tap water are between 1 and 10 μm in size. It was emphasized that treated water samples contained no MPs larger than 100 μm. Mintenig *et al.* (2019) determined that all microparticles in raw and drinking water samples were between 50 and 150 μm in size. Tong *et al.* (2020) determined that the average size in tap water samples ranged from 3 to 4,453 μm, with a median of 66 μm. The ratio of particles smaller than 50 μm to all MPs found in water samples is 31.25–100%. They detected in tap water samples particles in sizes 50–100 μm (1.47–31.25%), 100–300 μm (1.72–31.25%), 300–500 μm (1.18–7.69%), 500–5,000 μm (1.72–11.76%). The presence and size of MPs in tap water are affected by the filtration process and the length of the filters' cleaning periods. Plastic pipes in drinking water transmission lines may be an important explanation for different sizes (Muhib *et al.* 2023).

In a study conducted in Germany with bottled water, nearly 80% (n:38) of MPs were between 5 and 20 μm in size. The percentage polymer size distribution in single-use, returnable, glass bottled water was reported to be ≥100 μm 2%, 1%, 3%

and in size range of 5–100 μm 98%, 99%, 97%, respectively (Schymanski *et al.* 2018). Kankanige & Babel (2020) reported that 6.5–20 μm and 20–50 μm particle sizes significantly dominate the 50 μm fraction in disposable PET bottles. In a study greater than 1 μm in mineral waters, the average was 2,649 ± 2,857 μm for disposable plastic bottles and 4,889 ± 5,432 μm for reused PET bottles; it has been reported that an average of 6,292 ± 10,521 μm in size was detected in glass bottles (Oßmann *et al.* 2018).

MPs such as fibers, films, foams, foils, fragments, pellets, and spheres are distinguished by shape (Mason *et al.* 2016; Su *et al.* 2016; Anderson *et al.* 2017; Leslie *et al.* 2017). There are 74.42% fragments and 25.58% filaments among the total MPs (n:739) filtered from tap water samples. There are 65.90% filaments and 34.10% fragments among the total MPs (n:349) filtered from bottled water samples.

Plastic fragments in water may be caused by the decomposition of various plastic products, plastic fibers in water are often expected to be released from the wastewater of washing machines. Synthetic clothing can be seen as a primary source of environmental pollution due to the shedding of microfilaments during textile washing or various textile manufacturing processes (Tong *et al.* 2020; Mossotti *et al.* 2021).

Pivokonsky *et al.* (2018) reported that the most prevalent morphotype in filtrated tap water was a fragment. Tong *et al.* (2020) found three distinct shapes in tap water samples: 53.85–100% fragment, 1.18–30.77% fiber, and 2.24–36.36% sphere. Mason *et al.* (2018) found fragments to be the densest particle type (66%) in bottled water. Films (14%), fibers (13%), foams (5%) and pellets (3%) were followed, respectively. Fragments in water are believed to originate from various sources, such as plastic packaging materials for food and drinking water products or a cleaning agent (Zhang *et al.* 2015; Di & Wang 2018). Synthetic laundry and laundry detergent wastes, typically discharged from washing machines and transported by sewage water or air, are the source of plastic fibers in aquatic environments (Browne *et al.* 2011). In a Danish study by Feld *et al.* (2021), long filaments were the predominant form, with 82%. This was followed by fragments (14%) and films (4%) in tap water. Kankanige & Babel (2020) reported that the total particle content of single-use PET-bottled water in Thailand was composed of fibers (62.8%), followed by fragments (37.2%).

In our study, MPs were observed in various colors, such as reddish brown, red, dark red, pink, blue, dark blue, purple, orange, green, greenish blue, black and transparent. While the fibers were mainly blue, dark blue, red, and transparent, the fragments were primarily detected in black, dark red, reddish brown, brown, and greenish blue. The color factor in MPs is a unique feature that can be used to distinguish and pre-identify chemical compositions visually. Transparent particles are commonly referred to as PP, while white, transparent, and opaque colors (blue, red, brown, and black) are referred to as PE (Rocha-Santos & Duarte 2017). Kankanige & Babel (2020) reported that they frequently observed transparent, white, blue, red, brown, and black colored microparticles in their study of disposable PET bottles in Thailand and that they can be attributed to PP and PE. However, FTIR verification was considered necessary for a definitive diagnosis. Color pigments can be added to polymer mixtures in PET bottle production. It should also be considered that the colors detected by the microscope may be due to color pigments and additives used in manufacturing plastic packaging (Oßmann *et al.* 2018).

MPs' chemical composition is essential for identifying pollution sources and comprehending MPs' environmental fate (Eerkes-Medrano *et al.* 2015; Lambert & Wagner 2018; Li *et al.* 2018; Wu *et al.* 2018). Various polymers are manufactured plastic goods with a wide variety of applications. This study's most frequently observed plastic polymers were 45.1% PE, 28.5% PET, 20.5% PP, 3.2% PS, and 2.8% PVC. VCVA, PVC, PTFE, PE, PP, PET, Neo, and EP polymers were identified in tap water. ATR-FTIR analysis determined that 9.74% of the detected polymer microparticles contained BPA in tap water samples.

After oral ingestion, microplastics and nanoplastics can be dispersed into the blood and lymphatic system, and subsequently the liver, via absorption from the gastrointestinal tract. Risk assessment of MPs in food products should not only focus on the effects of MPs but also on the effects of chemical pollutants absorbed by them. MPs can absorb the majority of endocrine-disrupting pollutants, such as BPA, phthalates, and some brominated flame retardants, which can cause severe health problems. Detecting microparticles containing BPA, which has been shown to have adverse health effects, in tap water is likely one of the most significant findings of our research. BPA is a xenoestrogen that mimics the effects of estrogen in the body due to its hormone-like properties. Even though the effect is very weak, exposure over a lifetime could have undesirable effects. Despite its short half-life and non-bio accumulative nature, the sustained release of BPA into the environment results in the ecosystem's continued exposure. This raises concerns regarding the prevalence of materials containing BPA. According to the available data, BPA has also generally negative effects on wildlife (Dick Vethaak & Leslie 2016).

In their study of bottled water, Mason *et al.* (2018) identified 54% of the particles as PP, the most common type of polymer, which matches a common plastic used to make bottle caps. Mintenig *et al.* (2019) identified five types of polymers in raw and drinking water samples. The majority (62%) of the particles were characterized as polyester (PEST). In addition, PVC (14%), polyamide (PA) (9%), epoxy resin (9%) and PE (6%) particles were detected.

Tong *et al.* (2020) identified 14 types of plastic polymers from tap water samples. PE 26.8%, PP 24.4%, and copolymerize compounds of PE and PP (22.0%) were the most abundant polymer types. Polyphenylene sulfide (PPS) (7.3%), PS (6.5%), PET (3.3%) and others (poly alpha-methyl styrene (PMS), PTFE, polycarbonate (PC), polymethylmethacrylate (PMMA), polybutylene terephthalate (PBT), polybutene (PB), nylon, PVC) (9.8%). Kankanige & Babel (2020) reported that PET, PE, PP, and PA were found to predominate among the confirmed polymeric particles. Feld *et al.* (2021) identified PET, PP, PS, ABS (acrylonitrile butadiene styrene) and PU (polyurethane) in the tap water samples by μFTIR. Zhou *et al.* (2021), in their study in which a total of 69 separate bottles from 23 different brands were analyzed, they detected PP, PS, PE, PET, PU, PVC, PA, polyacrylic acid (PAA), polyacrylamide (PAM), polyethylene vinyl acetate (PEVA), and cellulose. While the proportions of MPs were distributed as PET (7%), PE (6%), PS (5%), and PA (4%), it has been reported that a large amount is cellulose and PA type, and this contamination may be derived from natural and synthetic fibers.

VCVA copolymers are used in densely filled floor coverings, construction elements, and equipment for adhesive purposes (Gilbert & Patrick 2017). Sedimentation and process tanks in drinking water treatment plants are coated with epoxy resin to prevent corrosion. Pipes in facilities and homes are typically made of PVC, PP, PE, and fittings are made of PA. Polymers are susceptible to wear over time and may pass into the water as microparticles. This could be the source of these plastic particles in tap water (Mintenig *et al.* 2019; Tong *et al.* 2020).

EP, identified in our study, is utilized for air and water tightness in closed circuit systems, whereas neoprene is utilized as an oil tightness gasket (Varol 2013). PTFE are the most common polymer particles in the environment, and their presence in water samples may be due to environmental contamination (Diaz-Basantes *et al.* 2020; Kutralam-Muniasamy *et al.* 2020).

In water treatment plants, PE is used to produce tanks, equipment, pumps, valves, diaphragms, bellows, and cylinders. PP stores cleaning agents, disinfectants, and chemical reagents (Pouzada 2021). Pivokonsky *et al.* (2018) noted that PMMA and PVC were found in water from water treatment plants. According to the reports, these particles enter the system from the treatment plants and are then transferred to the bottling plants, contaminating the bottled water. It has been reported that PTFE and other related components can also be transferred from treatment plants. In a study published by the Environmental Working Group, USA, Teflon-related chemicals are found in public water systems in 27 states (EWG 2015).

Dalmau-Soler *et al.* (2021) identified 16 fibers composed of PES and PP and 12 fragments primarily composed of PE in tap water regarding their shape and size. The fibers were larger than the fragments. PES was the most frequently detected (36%), and its presence is primarily attributed to the washing of synthetic clothing, followed by PP (21%) and PE (21%), both widely used in packaging, labelling, and construction (Geyer *et al.* 2017).

It has been reported that particles smaller than 1.5 μm may be absorbed, and larger particles may enter to organism through the transport mechanisms such as endocytosis and phagocytosis (Marsden *et al.* 2019; Kannan & Vimalkumar 2021). In contrast, a study on various mammalian species revealed a low level of the passage of particles up to 150 μm from the intestines to the lymphatic system (Kannan & Vimalkumar 2021). According to studies cited by the European Food Safety Authority (EFSA), approximately 1% of MPs of the specified size can be absorbed (Dris *et al.* 2016; EFSA 2016). Ingestion of MPs detected in water and food is an important public health marker. Ingested MPs can stimulate cytotoxicity and inflammatory response (Xu *et al.* 2004; Kwon *et al.* 2017). The widespread distribution of hydrophobic MPs in adipose tissue may result in the prolonged release of Vinyl chloride, which is one of the risk factors for the development of certain tumors (Mastrangelo *et al.* 2003). Besides, the tendency of microorganisms to hide in the porous structure of plastics can be viewed as a risk factor (Kirstein *et al.* 2016). Microparticles ingested by humans can cause chromosomal alterations that result in sterility, obesity, and cancer (Sharma & Chatterjee 2017).

CONCLUSION

Accurate and reliable detection of MPs in water is challenging. Analyses should be performed in a laminar flow cabinet using ultrapure water whose MP content has been tested prior to analysis. Instruments and equipment made of glass or stainless-steel metal should be used for analysis. Laboratory contamination mitigation, including these precautions, should be treated very sensitively.

The MP contamination level in drinking water is highly concerning. Increasing scientific worries regarding potential health risks associated with the ingestion of MPs make it crucial to conduct research to prevent contamination.

Avoiding the use of returnable PET in drinking water or at least minimizing their circulation will be crucial to reducing the MP risk. Improving the storage conditions of the empty bottles returned after use, keeping the bottle mounts closed during storage and storing the bottles out of direct sunlight should be considered as an important precaution.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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