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Preliminary study of microplastics in bottled and tap water in Estonia

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Abstract. Microplastics (MPs) are a growing environmental concern due to their widespread occurrence and potential harmful impacts on ecosystems and public health. This preliminary study -assesses the prevalence of MPs in bottled and tap water in Estonia and reviews related research in the field. The study aimed to evaluate the occurrence of MPs and understand the potential influence of the water source and packaging material on water properties. The study encompassed 12 different bottled water products from 9 Estonian brands and tap water samples from Tallinn and Tartu. All the tested water samples contained MPs, predominantly fibers, with blue and transparent being the most common colors. The packaging material, bottle caps, or the water source did not influence the number of MPs found in bottled water. Interestingly, water packaged in glass bottles contained a higher count of MPs than in plastic bottles and tap water. The study underscores the need for further research to determine the sources of contamination.

Key words: bottled water, drinking water, microplastics, plastic pollution, tap water, water contamination.

INTRODUCTION

Microplastics (MPs), which are plastic particles smaller than 5mm, have become a substantial environmental concern due to their pervasive occurrence and potential detrimental impacts on ecosystems and public health (Amobonye et al., 2021; Gambino et al., 2022; Lamichhane et al., 2023). MPs enter the environment through various sources, including domestic, urban, and industrial effluents, surface runoff, and the breakdown of larger plastic materials (Ziajahromi et al., 2017; Hahladakis et al., 2018; Kyriakopoulos et al., 2022). Humans and other organisms ingest these minuscule fragments. MPs presence has been detected in a variety of organs, including in human brains, blood, and digestive systems (Hirt & Body-Malapel, 2020; Lamichhane et al., 2023; Osman et al., 2023). They are ubiquitously distributed throughout the environment (Hahladakis et al., 2018; Akdogan & Guven, 2019). MPs can infiltrate the human body via several pathways, including inhalation, dermal absorption, and notably, through food chain (Campanale et al., 2020; Yang et al., 2022). Drinking water serves as a significant vector for human exposure to MPs (Pivokonsky et al., 2018; Danopoulos et al., 2020; van Raamsdonk et al., 2020).

MPs have been frequently detected in bottled and tap water across all continents, whether it is packaged in polyethylene terephthalate (PET) or glass (Mason et al., 2018; Kirstein et al., 2021; Gambino et al., 2022). Research from Europe (Oßmann et al., 2018; Schymanski et al., 2018; Zuccarello et al., 2019; Bäuerlein et al., 2022; Nizamali et al., 2023), North America (Mason et al., 2018), South America (Pratesi et al., 2021; Nacaratte et al., 2023), Asia (Kankanige & Babel, 2020; Zhou et al., 2021; Praveena et al., 2022; Li et al., 2023; Syuhada et al., 2023), Australia (Samandra et al., 2022), and Africa (Ibeto et al., 2023) has shown the presence of MP pollution in drinking water. The concentrations of MPs in drinking water exhibit significant variability, ranging from 0.2 MPs per liter to thousands of MPs per liter, depending on factors such as geographic location, water source, and treatment methods (Oßmann et al., 2018; Feld et al., 2021; Gambino et al., 2022, 2023). The predominant polymers detected in these samples were PET and polypropylene (PP; Danopoulos et al., 2020; Gambino et al., 2023). A significant part of the MPs identified in bottled water appears to come from the bottle itself (Oßmann et al., 2018; Schymanski et al., 2018). The process of filling the bottles and the filtration systems used for water purification also seems to introduce MPs into the water (Danopoulos et al., 2020; Kankanige & Babel, 2020; Makhdoumi et al., 2021; Gambino et al., 2022). Research on the presence of MPs in drinking water is crucial due to potential health risks associated with their polymeric structure, additives, and surface-bound compounds or microorganisms (Hahladakis et al., 2018; Hirt & Body-Malapel, 2020; Gambino et al., 2022). For instance, diseases such as cancer, intestinal, pulmonary, cardiovascular, infectious, and inflammatory conditions can be triggered or influenced by the presence of MPs (Yang et al., 2022; Osman et al., 2023; Xu et al., 2024). Despite increasing studies, the health impacts of MP exposure remain unclear, as in vivo toxicity data for humans is still lacking, highlighting the need for further research (Gambino et al., 2022). To address chemical pollutant release, various global policy documents, national regulations, and international treaties, such as the Montreal Protocol, Stockholm Convention, and Minamata Convention, have been implemented (Kyriakopoulos et al., 2022).

Numerous techniques exist for identifying MPs. These include microscopic counting, scanning electron microscopy (SEM), pyrolysis gas chromatography/mass spectrometry, liquid chromatography, a tagging method, Fourier transform infrared spectroscopy (FITR), Raman spectroscopy (RM), and laser direct infrared (LDIR) technique (Hidalgo-Ruz et al., 2012; Song et al., 2015; Käppler et al., 2016; Baruah et al., 2022; Bäuerlein et al., 2022; Kyriakopoulos et al., 2022). Many of these methods are either costly, time-consuming, or both (Käppler et al., 2016; Baruah et al., 2022). Hence, cheaper methods like Rose Bengal staining or Nile Red staining have been used in other studies (Fischer et al., 2016; Tamminga, 2017; Hengstmann & Fischer, 2019; Lares et al., 2019). A new method for counting and sizing microplastic particles in bottled water uses Nile Red staining combined with Direct Microscopic Counting (DMC; Moshtaghizadeh et al., 2024). The Rose Bengal staining is safe, non-toxic, cost-effective, and suitable for detecting MPs (Fischer et al., 2016; Alonso-Vázquez et al., 2023). It binds to most natural materials or fibers but cannot stain synthetic particles, making them identifiable (Liebezeit & Liebezeit, 2014; Ziajahromi et al., 2017; Alonso-Vázquez et al., 2023). However, not all detected synthetic materials are necessarily MPs (Kosuth et al., 2018; Lares et al., 2019). The Rose Bengal staining enables the examination of the color of MPs, a task that Nile red, for instance, cannot accomplish (Fischer et al., 2016). Lares et al. (2019) observed that cellulose fibers did not turn pink when Rose Bengal stain was used, like other organic substances such as wool and sludge (Lares et al., 2019). Note that stereomicroscopes detect fewer MPs in samples than Raman Spectroscopy or FTIR because they cannot detect particles smaller than 100 micrometers (Song et al., 2015). Occasionally, even simple measurements of environmental MP contamination can be beneficial for various industrial applications.

MPs contamination has been recorded in the Baltic Sea (Schernewski et al., 2020; Kreitsberg et al., 2021; Narloch et al., 2022). The concentration of MPs in the water of the Baltic Sea ranges from 0.07 to 3,300 particles per cubic meter, while in the sediments, it varies from 0 to 10,179 particles per kilogram (Narloch et al., 2022). Yet, there is a data gap on MPs in the area's drinking water. The objective of this study was to evaluate the occurrence of MPs in both bottled and tap water in Estonia, and to investigate the potential influence of the source of water and packaging material on the properties of water.

MATERIALS AND METHODS

Samples and sample preparation

The experiment involved 12 different bottled water products from 9 different Estonian brands. 9 products were packaged in PET reusable bottles and 3 in glass bottles. In total, 62 samples were taken from 30 different bottles (54 samples from PET bottles and 8 samples from glass bottles). The caps of the PET bottles were made of high-density polyethylene (HDPE), and the caps of the glass bottles were made of aluminum. Two out of 12 products were carbonated, and the rest were non-carbonated. The shelf-life variation among the products was minimal, so it did not affect the results of the study. Additionally, 3 samples of distilled water, and samples from Tallinn and Tartu tap water (in total 6 samples from tap water) were also analyzed. The tap water from Tallinn and Tartu was obtained from a household faucet and collected in a 500 mL glass bottle. The bottles were rinsed three times with tap water, and the tap water was allowed to run for one minute at its highest strength before being filled. The bottles were closed immediately to minimize contamination from the air.

The analyses were - conducted in the laboratory of Tartu college, Tallinn University of Technology during March and April 2019. Cotton coats, powder-free nitrile gloves, and hair covers were worn in the laboratory. All bottles were labeled, cleaned, and rinsed with distilled water to avoid contamination of the samples from the outside of the bottles. The equipment used in the experiment was washed with distilled water before use. The surfaces were cleaned with ethanol. The filters were inspected under a microscope before filtration to check for any pre-existing contamination. To minimize the exposure to ambient air, the MP separation procedure was performed in a fume hood to avoid cross-contamination from airborne MPs and dust. The use of plastic materials was minimized throughout the process as much as possible.

Separation of microplastics

Rose Bengal was used as a colorimetric indicator. It is non-toxic and does not stain plastics retaining their color. Acetone was used as a solvent to enhance dye uptake and penetration. 50 mg of Bengal red ($C_{20}H_2Cl_4I_4Na_2O_5$, Sigma Aldrich) was dissolved in 50 mL of acetone (CH_3COCH_3, Sigma Aldrich, purity ≥ 99.5%; Allen, 2016; Maes et al., 2017). The dye solution was added to the sample bottles at a ratio of 100 µg per 100 mL. The bottles were incubated for 30 minutes. Water samples (5 mL) from various sources were filtered through glass fiber filters (Whatman Glass Micofiber 934-AH (GE Healthcare, United Kingdom, diameter of 90 mm, porosity of 1.5 µm), which were then placed in labeled 90 mm Petri dishes. The filters were dried for 24 hours at 50 degrees Celsius in a Memmert UFB-500 (Memmert, Germany) drying cabinet. After drying, filters were weighed with an analytical balance Precisa XT 120a (Precisa Gravimetrics AG, Switzerland, d = 0.0001 g) to find the total mass of solids. Contamination weight was obtained by subtracting dried filter weight from clean filter weight. Filters were observed under a stereomicroscope Euromex Nexius Zoom (Euromex, Netherlands), model NZ.1703-PG, at 100 × magnification. Photographs of the particles were taken using a Euromex Ultra HD camera, model no. VC.3036, and analyzed with the Euromex ImageFocus Plus software. MPs were classified based on the shape of the particles (Viršek et al., 2016). The counting of particles was not carried out. The acquired data was processed using R software, version 4.3.2. Basic summary statistics, such as the mean, median, and quartiles, were computed utilizing the base and stats packages. To compare groups pairwise Wilcoxon test was conducted. Graphs were created using the ggplot2 package and its dependencies.

RESULTS AND DISCUSSION

MPs in drinking water

This study presents the first evaluations of MP in bottled and tap water of Estonia. The analyzed samples contained both synthetic and natural particles (Fig. 1).

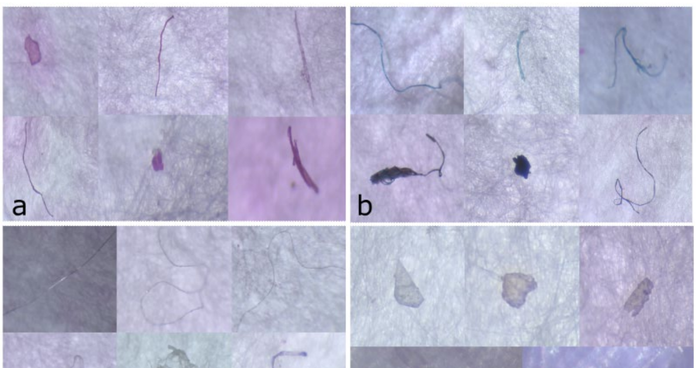

Figure 1. a) Natural particles colored with Bengal red; b) MPs light and dark blue; c) MP fibers; d) MP fragments from bottled water (top); round MP particles from tap water (bottom). 10× objective and 10×eyepiece.

However, visual inspection confirmed that synthetic particles were predominant on the filters. Only particles with a size greater than 100 µm were visually characterized. Rose Bengal colors natural particles distinctively pink (light or dark), leaving synthetic particles as they are (Fig. 1). This makes it easier to see and separate MPs from organic additives by visually sorting. In the current study, natural and synthetic particles were easily distinguishable.

All tested bottled water brands and tap water in Estonia were found to be contaminated with MPs larger than 100 µm. No MPs were found in distilled water samples, indicating that the samples were not contaminated with MPs during the measurements. The average contamination weight of water in glass bottles was slightly higher than in PET bottles and tap water, with values of 9.93 mg ± 3.47, 3.91 mg ± 0.84 and 3.49 mg ± 1.77 respectively (Fig. 2). This difference was not statistically significant. There are significant variations in the reported concentrations of MPs in drinking water (Kirstein et al., 2021; Gambino et al., 2022, 2023). Currently, it is uncertain whether these inconsistencies are due to variations in the systems studied, differences in measurement limits, the precision of the analytical methods used, or contamination during sample collection, processing, and analysis (Kirstein et al., 2021).

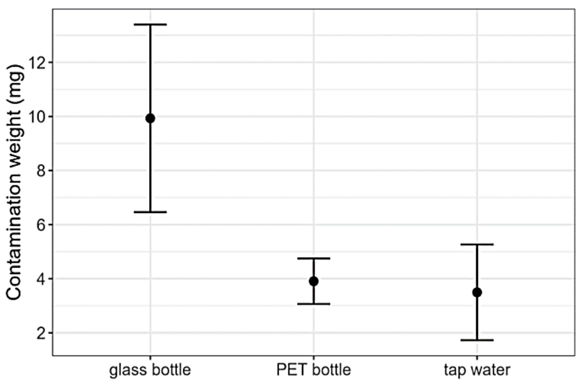

Figure 2. Average contamination weight of water in glass and PET bottles and tap water. The vertical bars indicate ± SE of the means.

Nevertheless, in this study the water in glass bottles showed the greatest MPs content. This could be attributed to the fact that the water, which originates from a natural spring, might have been already heavily contaminated before bottling (Table 1). Oßmann et al. (2018) reported also higher microplastic concentrations in glass bottles compared to PET bottles, although other studies suggest that glass bottles tend to have lower microplastic levels than PET bottles (Table 2; Kankanige & Babel, 2020; Buyukunal et al., 2023). This discrepancy could be due to differences in water quality before bottling and the level of MP contamination during the bottling process. MPs in bottled water could be attributed to processes such as packaging, manufacturing, and transportation (Mason et al., 2018; Kankanige & Babel, 2020; Makhdoumi et al., 2021). The machinery used for bottle cleaning could also be a significant contributor to MP contamination. The cleaning fluid might be polluted with MPs, which could originate from the abrasion of machine parts or from returned bottles that are already contaminated (Oßmann et al., 2018). However, it remains unclear why, in some studies, water in glass bottles is found to be more contaminated than in PET bottles. Additional research is needed to directly compare the MPs concentration per liter in drinking water in Estonia with that of other countries.

Table 1. Contamination weight of water in PET bottles (P1-9), glass bottles (G1-3) and tap water (T1-2)

Sample	Bottle material	Bottle color	Cap colour	Cap material	Type	Source	Depth	Mean contamination weight (mg±SE)
P-1	PET	blue	white	HDPE	Non-carbonated	groundwater	410	0.48 ± 0.25
P-2	PET	lightblue	lightblue	HDPE	Carbonized	mineral water	470	9.80 ± 0.84
P-3	PET	transparent	white	HDPE	Non-carbonated	groundwater	200	1.30 ± 0.27
P-4	PET	transparent	lightgrey	HDPE	Carbonized	spring water	125	2.15 ± 1.60
P-5	PET	transparent	white	HDPE	Non-carbonated	mineral water	81.5	5.70 ± 0.22
P-6	PET	transparent	darkblue	HDPE	Non-carbonated	groundwater	55	1.00 ± 0.17
P-7	PET	transparent	white	HDPE	Non-carbonated	mineral water	500	12.30 ± 0.93
P-8	PET	green	darkblue	HDPE	Non-carbonated	spring water	130	1.88 ± 1.12
P-9	PET	transparent	white	HDPE	Non-carbonated	mineral water	210	0.54 ± 0.29
G-1	glass	transparent	grey	Aluminium	Non-carbonated	mineral water	542	7.90 ± 0.92
G-2	glass	transparent	grey	Aluminium	Non-carbonated	mineral water	210	1.87 ± 0.43
G-3	glass	transparent	blue	Aluminium	Non-carbonated	spring water	130	25.07 ± 0.90
T-1					tap water	groundwater	400	6.97 ± 1.89
T-2					tap water	surface water	0	0.02 ± 0.02

In the current study, the packaging material did not significantly influence the number of MPs in the water (Table 1). While glass bottles do not contribute additional MPs, it was observed that reusable PET bottles can release MPs into the water over a period of time (Oßmann et al., 2018; Schymanski et al., 2018; Kankanige & Babel, 2020; Nizamali et al., 2023). The amount of MPs detected in the water is influenced by the quality of the plastic bottle (Zuccarello et al., 2019) and tends to increase as the bottle ages (Oßmann et al., 2018). Many studies have reported that reusable PET bottles have more contamination than single-use ones (Schymanski et al., 2018; Buyukunal et al., 2023). A study by Oßmann et al. (2018) found that single-use and reusable PET bottles contain 2,649 ± 2,857 and 4,889 ± 5,432 particles/L respectively, while glass bottles contain 6,292 ± 10,521 particles/L (Table 2).

Bottle caps can add to the MP pollution in both PET and glass bottles (Oßmann et al., 2018; Schymanski et al., 2018; Winkler et al., 2019; Weisser et al., 2021). The study by Winkler et al. (2019) demonstrated a notable increase in microplastic particles on PET and HDPE bottle necks and caps after repeated opening and closing. Caps subjected to 100 opening/closing cycles showed significant mechanical wear, with clear abrasions and deep grooves (Winkler et al., 2019). The presence of MPs in glass bottles could potentially be due to the abrasion of the caps against the hard glass bottleneck

(Schymanski et al., 2018). A strong correlation (r = 0.68, P = 0.049) has been reported between the plastic cap material (PE) and the main polymer type detected in bottled water (Al-Mansoori et al., 2025). However, this cannot explain all the different polymers detected in glass bottles, particularly the presence of polymers like PS, styrene-butadiene copolymer, or PET (Oßmann et al., 2018).

Tabel 2. Microplastic in bottled water. Particle size was measured up to 5,000 μm. Polypropylene (PP), polystyrene (PS), polyethylene (PE), polyethylene terephthalate (PET), polyurethane (PU), polyvinyl chloride (PVC), polyamide (PA), polyacrylic acid, polyacrylamide, PEVA (polyethylene vinyl acetate (PEVA), cellulose (CEL), neoprene (Neo), polyester + polyethylene terephthalate (PEST)

Origin of the material	N	Method	Packaging	Particle size (μm)	Avarage (particles/ liter)	Shape	Detected Polymers	Reference
9 countries	11	FTIR, Nile Red	PET glass PET glass	6.5–100 > 100	315 195 10.4 8.96	Fragment, Film, Fiber, Foam, Pellet	PP, Nylon, PS, PE, PEST	Mason et al., 2018
Germany	32	RM	PET single use reusable PET glass	≥1 μm	2,649 ± 2,857 4,889 ± 5,432 6,292 ± 10,521	na	PET, PE, PP	Oßmann et al., 2018
Germany	34	RM	PET single use reusable PET glass carton	5–1,359	14 ± 14 118 ± 88 50 ± 52 11 ± 8	na	PEST, PE, PP, PA, others	Schymanski et al., 2018
Thailand	10	FTIR, RM, Nile Red	PET glass	≥6.5	140 ± 19 52 ± 4	Fiber, Fragment	PET, PE, PP, PA	Kankanige & Babel, 2020
Saudi Arabia	28	FTIR	PET glass Aluminium	25–500	1.90	na	PE, PS, PET, PP, PA, PU, others	Almaiman et al., 2021
Iran	11	Rose Bengal, FTIR, RM	PET	1,280–4,200	8.5 ± 10.2	Fragment, Fiber	PET, PS, PP	Makhdoumi et al., 2021
China	23	FTIR, SEM	PET	> 25	16	Fiber, Fragmet	PET, PS, PU, CEL, others	Zhou et al. 2021
Malaysia	8	FTIR	PET	> 25	11.7 ± 4.6	Fragment	PET, PP	Praveena et al. 2022
Australia Imported to Australia	11 5	LDIR	PET PET	6–480	7 ± 6 25 ± 28	Fragment, Fiber	PE, PS, PP, PET, PA, others	Samandra et al., 2022
Indonesia	5	FTIR	PET	> 42	na	Fiber, Film	CEL, Cotton	Syuhada et al. 2022

Table 2 (continued)

Tyrkey	61	FTIR, SEM/ EDS	PET single use reusable PET glass	12–4,892	71 ± 51 157 ± 111 61±49	Fiber, Fragment	PE, PET, NEO, PP, others	Buyukunal et al., 2023
Nigeria	5	SEM/ EDS Nile Red	PET	20–100	from 6.67 ± 5.51 MP/0.75 L to 0.33 ± 0.57 MP/0.75 L	Fragment, Film, Pellet, Granule	PE, PVC, PET, PDMS	Ibeto et al., 2023
China	10	LDIR	PET glass	> 10	65.62 ± 44.65 87.94 ± 46.38	Film, Pellet, Fiber	CEL, PVC, PET, others	Li et al., 2023
Chile	12	Nile Red	PET	≤ 300	391 ± 125	fiber, Irregular shape	na	Nacaratte et al., 2023
India	12	FTIR, Nile Red	local national	> 10	212 ± 100 72 ± 36	Fragment, Fiber	PE, PET	Patil et al. 2024
UK	17	FTIR	PET glass metal	> 10	37 ± 11	Fragment, Fiber, Sphere	PE, PP, PET, others	Al-Mansoori et al., 2025

The quality of tap water depends on the region. In Istanbul tap water is more polluted with MPs than mineral and spring water, 188 ± 81, 54 ± 19, and 89 ± 76 particles per liter, respectively (Buyukunal et al., 2023). Most of the research indicates that bottled water tends to have a much higher MP contamination compared to tap water (Table 2, 3; Mason et al., 2018; Kirstein et al., 2021; Li et al., 2023). For example, this has been shown in Beijing (Li et al., 2023) and Germany (Kirstein et al., 2021). The findings of this study are consistent with this consensus (Fig. 2). The tap water from Tallinn was the cleanest, although it contained a small quantity of MPs (0.02 mg ± 0.04; Table 1). The higher amounts of microplastics detected in bottled water, relative to tap water, might be caused by the leaching of plastic particles during extended storage, particularly when exposed to heat or UV light from sunlight (Nirmala et al., 2023).

MP particles in tap water are generally smaller compared to those found in mineral and spring water (Buyukunal et al., 2023). For example, it has been observed that the number of MPs larger than 20 micrometers in tap water is usually under two particles per liter (Bäuerlein et al., 2022). Pivokonsky et al. (2018) reported that 95% of MPs in tap water are sized between 1 and 10 µm. However, a recent UK study found that the average size of microplastic particles in tap water (32.4 µm) was significantly larger than in bottled water (26.5 µm; Al-Mansoori et al., 2025). The current study could not identify particles smaller than 100 µm. Therefore, it is possible that tap water in Estonia may still contain a significant number of small MP particles.

No relationship was found between the weight of the contamination and the water source (Table 1), but all water sources like groundwater, mineral water, and spring water contained MPs. Other research has indicated that groundwater has the lowest concentration of MPs among different raw water sources, with less than one particle per liter (Weisser et al., 2021; Bäuerlein et al., 2022). It was surprising to find more MPs in

Tartu's tap water than in Tallinn's (Table 1), considering Tartu uses groundwater and Tallinn uses lake water. Surface water is currently considered a good source for drinking water, as treatment plants are effective at removing most microplastics, including those found in lake water (Pivokonsky et al., 2018). Groundwater in Tartu is likely contaminated with MPs during the treatment process. Plastic pipes used in water distribution systems may release microplastics, leading to higher concentrations of these particles in tap water (Tong et al., 2020). In the same time pipe scales can also adsorb large amounts of microplastics, affecting their distribution in water supply systems, indicating that stable pipe scales may contribute to improved water quality and safety (Chu et al., 2022).

Table 3. Microplastic in tap water. Particle size was measured up to 5,000 μm. Surface water (SW); groundwater (GW); desalinated water (DSW), polystyrene (PS), polyethylene (PE), polyethylene terephthalate (PET), polyurethane (PU), polyvinyl chloride (PVC), polyamide (PA), polyacrylic acid, polyacrylamide, polyethylene vinyl acetate (PEVA), cellulose (CEL), neoprene (Neo), polyester + polyethylene terephthalate (PEST), polyphenylene sulfite (PPS), polyvinylidene fluoride (PVDF), polyvinyl alcohol (PVA), high-density polyethylene (HDPE), poly-hexamethylene terephtalamide (PA6T)

Origin of the material	N	Water source	Method	Particle size (μm)	Avarage (particles/ liter)	Shape	Detected Polymers	Reference
14 countries	159	na	Rose Bengal	> 100	5.45	Fiber, Fragment, Film	na	Kosuth et al., 20218
Hong Kong	110	SW	Rose Bengal	> 2.7	2.181 ± 0.165	Fiber	na	Lam et al., 2020
China	38	na	RM	3–4,453	440 ± 275	Fragment, Fiber, Sphere	PE, PP, PPS, PS, PET, others	Tong et al., 2020
Saudi Arabia	2	DSW	FTIR	25–500	na	na	PE, PS, PET, PP, PA, PU, others	Almaiman et al., 2021
Denmark	17	GW	FTIR, stereo-microscope	10–100 > 100	0.2 ± 0.1 0.31 ± 0.14	Fiber, Fragment, Film	PP, PS, PET, others	Feld et al., 2021
Japan, USA, Finland, France, Germany	42	GW, SW	FTIR	19.2–4,200	39 ± 44	Fragment, Fibre, Sphere	PS, SEBS, PP, PES, PE, PVC, others	Mukotaka et al. 2021
Brazil	32	SW	Nile Red	6–50	194 ± 110 438 ± 316	na	na	Pratesi et al., 2021
China	na	SW	SEM, FTIR, RM	> 1	343.5	Fragment, Fiber, Sphere	PE, PP, PET, PA, PVC, others	Shen et al., 2021
Germany	18	GW	RM	> 10	0.65 ± 0.54 per blank	Fiber	PE, PP, PET, PS	Weber et al. 2021

Table 3 (continued)

China	na	SW	FTIR	> 10	13.23	Fragment, Fiber	Nylon, PEST, PET, PS, PVDF, others	Chu et al., 2022
Mexico	63	na, refill station	SEM-EDS, FTIR	> 20	42	Fiber, Fragment, Film	PET, vinyl polymers, PA, nylon, others	Pérez-Guevara et al., 2022
Mexico	22	na, refill station	FTIR	> 20	74.18 ± 48.76	Fiber, Fragment, Film	PVA, PP, PET, others	Shruti et al., 2022
Turkey	39	SW	FTIR	12–4,892	188 ± 81	Fiber, Fragment	PE, PET, NEO, PP, others	Buyukunal et al., 2023
China	1	na	LIDR	> 10	49.67 ± 21.43	Film, Pellet, Fiber	CEL, PVC, PET, others	Li et al., 2023
South Africa	na	na	SEM, Rose Bengal	> 20	14 ± 5.6	Fiber, Fragment, Pellet, Film	HDPE, PU, PET, PA6T, others	Ramaremisa et al. 2024
UK	177	GW, SW	FTIR	> 10	40 ± 16	Fragment, Fiber, Sphere	PP, PE, PVC, others	Al-Mansoori et al., 2025

Shape and color of the particles

The shape of the MPs is usually examined using an optical microscope. These small plastics are then categorized into groups such as fragments and microfibers based on their shapes (Viršek et al., 2016; Li et al., 2023). The current study identified fibers as the predominant form of MPs in both bottled and tap water in Estonia, followed by fragments and films (Fig. 1). Simultaneously, many other studies on bottled water have found that fibers are the most prevalent form of MPs (Table 2, 3; Kosuth et al., 2018; Zhou et al., 2021; Syuhada et al., 2023). For example, in Hong Kong, fibers constituted the majority (98.7%) of the MPs found (Lam et al., 2020). In Mexico City, water from refill stations and outdoor fountains was examined, showing that 65%–88% of the particles were fibers, while fragments represented 9%–28% (Pérez-Guevara et al., 2022; Shruti et al., 2022), and in Thailand, 62.8% of the total particle content was made up of fibers, with fragments being the second most prevalent type (Kankanige & Babel, 2020). Fibers where dominant MPs also in Denmark (Feld et al., 2021), Chile (Nacaratte et al. 2023) and South-Africa (Ramaremisa et al., 2024). However, this could be an overestimation as using a stereomicroscope can lead to a significant underestimation of fragment-type MPs and an overestimation of fiber-type ones (Song et al., 2015). In a study from Iran, 93% of the MPs found in bottled water in the province of Kermanshah were fragments (Makhdoumi et al., 2021). Similarly, research in South Eastern Nigeria (Ibeto et al., 2023), Malaysia (Praveena et al., 2022), Australia (Samandra et al., 2022) and India (Patil et al., 2024) revealed that fragments were the most frequently observed type of MP particles in the leading brands of bottled water in these areas. Conversely, in

China, films were identified as the primary type of MPs in both popular brands of bottled water and tap water in Beijing (Li et al., 2023). Other research showed that fibers were the most common (97%) MPs in tap water, while fragments were the most common (65%) in bottled water (Mason et al., 2018). The current study did not identify a significant difference between the MPs shape in tap and bottled water. This could be attributed to the influence of the water source on the types of MPs present in the water.

MPs of various colors - blue, transparent, white, black, yellow, and silver - were found in all types of water tested, including PET bottled water, water in glass bottles, and tap water. The color of the MPs was consistent across all water types. Blue and transparent MPs were the most frequently found. Light blue particles were only found as fibers, while dark blue particles were present as both fibers and fragments (Fig. 1, b). Transparent particles were mostly fibers (Fig. 1, c). Tap water had more transparent rounded MPs (Fig. 1, d). The major color of MP particles varies based on the geographical area. In the Mexico City region, the majority of MP particles (85%) found in water from outdoor refill stations were transparent (Shruti et al., 2022). In Malaysia, most MPs in bottled water were also transparent (96.5%), followed by blue ones (Praveena et al., 2022). Another study reported that most of the MPs (70–85%) were white. The authors suggested that the loss of color could be due to a preprocessing step involving peroxide treatment (Bäuerlein et al., 2022). In Thailand, fibers were typically found in blue, red, and transparent colors, while fragments were often black, bluish-green, brown, and transparent (Kankanige & Babel, 2020). In South Africa, most fibers were black (37.5%), followed by green (33.1%) and blue (15%; Ramaremisa et al., 2024). Similarly, in India, the majority of particles were black (50%), with other colors including transparent (16%), red (13%), orange (8%), blue (5%), yellow (5%), and green (3%;Patil et al., 2024). One potential source of colored particles in water could be the paper labels on glass and PET bottles (Oßmann et al., 2018).

CONCLUSION

This is the first study on MPs in drinking water in Estonia. This topic is significant due to its potential impact on public health and environmental management. MPs have been found in both tap water and bottled water across all continents. All the tested bottled water brands and tap water in Estonia contained MPs. The weight of contamination in water from glass bottles was slightly higher than in PET bottles and tap water, but the difference was not statistically significant. Fibers were the most common type of MPs found, with blue and transparent being the most common colors. Further research using FITR, Raman Spectroscopy, or LDIR is needed to accurately determine the composition of MPs in drinking water, to evaluate the MPs` concentrations per liter, and the daily intake of MPs in Estonia. Since tap water in Estonia is considered safe to drink and widely consumed, it is crucial to estimate the levels of small MPs in tap water across different cities and identify the sources of contamination in tap water. It is also important to measure the concentration of MPs more accurately in bottled water and other beverages. More research is needed on how MPs are absorbed and processed in the human body.

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