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Presence of microplastics in drinking water from different freshwater sources in Flanders (Belgium), an urbanized region in Europe

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Abstract

Microplastics (MPs) are emerging contaminants of concern in aquatic ecosystems. Up to now, only a few studies about MP contamination in drinking water have been published. In this study, we analysed drinking water originating from ground water, surface water and treated sewage water for the presence of MPs, collected in different drinking water treatment plants (DWTP, $n = 9$) and water taps (TW, $n = 9$) in the geographic region of Flanders (Belgium). We report measured microplastic concentrations, size distributions, and polymer types using µFTIR spectroscopy in the range of 25–1000 µm. The MPs' abundances in the DWTP and TW samples were on average 0.02 ± 0.03 MPs L^{-1} and 0.01 ± 0.02 MPs L^{-1}, respectively. We did not find significant differences comparing the obtained MP concentrations according to the origin of the water. Polypropylene (PP) and polyethylene terephthalate (PET) were the most common polymer types detected in the samples. Next, based on several theoretical assumptions, we extrapolated the measured MP concentrations in our samples to cover the full theoretical MP size range (1–5000 µm) to obtain estimates of the actual MP contamination levels. The rescaled particle concentrations (1 µm – 5000 mm) were on average 5.59 MPs L^{-1} and 3.76 MPs L^{-1} for the DWTP and TW samples, respectively. Based on a standard consumption of two liters of drinking water per day in combination with the measured concentration in this study, Flemish people consume 0.02 MPs per capita per day via drinking water. These findings contribute in our understanding of the microplastic pollution of drinking water, which is of concern due to the potential uptake of MPs in the human body.

Keywords: Microplastic analysis, Tap water, Ground water, Surface water, Sewage water

Introduction

Small particles called microplastics (MPs), defined as plastic particles larger than 1 µm and smaller than 5 mm (longest axis), can easily get ingested by marine and terrestrial animals, including humans, and thus are raising concerns regarding accumulation in the body and potential toxicity (Wright and Kelly, 2017). Nonetheless, up to now, effects of MPs on organisms are not completely clear yet (Campanale et al., 2020; Granek et al., 2020). It is challenging to understand their impact due to different physical–chemical properties that make microplastics multifaceted stressors (Campanale et al., 2020). The potential negative effects on organisms after exposure to MPs can be categorised into two main groups: physical effects and chemical effects. The former category is related to the particle size, shape, and the concentration of microplastics, while the latter category is related to hazardous chemicals that are associated with MPs

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(Campanale et al., 2020). Recent studies described the occurrence of MPs in nearly all environmental aquatic matrices (e.g. Ricciardi et al., 2021; Rodrigues et al., 2018; Van Cauwenberghe et al., 2013, 2015; Vivekanand et al., 2021). As expected, MPs have also entered the food chain and can be ingested by humans via e.g. seafood (Van Cauwenberghe and Janssen, 2014), honey (Liebezeit and Liebezeit, 2015), and salt (Iniguez et al., 2017). Proof of this ingestion was found by studying MPs presence in human faeces in different parts of the world (Schwabl et al., 2019; Zhang et al., 2021). Evaluating approximately 15% of Americans' caloric intake, Cox et al. (2019) estimated that annual MPs consumption ranges from 39,000 to 52,000 particles over a lifetime depending on age and sex. In 2019, the WHO requested further research to assess the risks of MPs exposition and to investigate possible harmful effects on human health (WHO, 2019).

In addition to food, beverages are a significant area of research, especially drinking water, as it is consumed regularly. Microplastic load in drinking water is not thoroughly studied yet, however some data on bottled and tap water is available. So far, a limited number of studies have been reported in regard to the occurrence of MPs in bottled mineral water (e.g. Mason et al., 2018; Oβmann et al., 2018; Schymanski et al. 2018; Zhou et al., 2021). Schymanski et al. (2018) identified small plastic particles in bottled drinking water (118 ± 88 MPs L^{-1} in returnable, and 14 ± 14 MPs L^{-1} in single-use plastic bottles) and concluded that packaging materials were mainly responsible for the contamination. Up to now, MP contamination in tap water has only been investigated by very few research papers as well (Kosuth et al., 2018; Pivokonsky et al., 2018; Mintenig et al., 2019; Tong et al., 2020). Therefore, the purpose of this study was the identification of microplastics MPs in large volumes of drinking water derived from different sources in a densely populated region in western Europe, i.e. Flanders (Belgium). The samples were taken across Flanders at two different places in the supply chain: (1) purified water from drinking water treatment plants (DWTPs) and (2) drinking water from conventional household taps to assess the level of contamination with MPs. A detailed analysis of MP concentration, types and sizes according to the source can provide indications whether the levels of contamination differ between water sources. This study aims to contribute to close the knowledge gap for MPs larger than 25 µm in Flemish drinking water.

Material & Methods

Sample collection

To investigate the concentration of MPs in drinking water, samples were collected from both drinking water treatment plants (DWTP) and tap water (TW) in Flanders. In total, eight drinking water treatment plants, spread across Flanders, were selected (Fig. 1). The selection took into account the source of the water that would be purified into drinking water: both groundwater ($n=3$) and surface water sources ($n=4$) were included. The installations that use groundwater represent both centres that pump up deep or shallow groundwater with or without an extra purification step. Samples were also collected in DWTP Torreele, where purified waste water

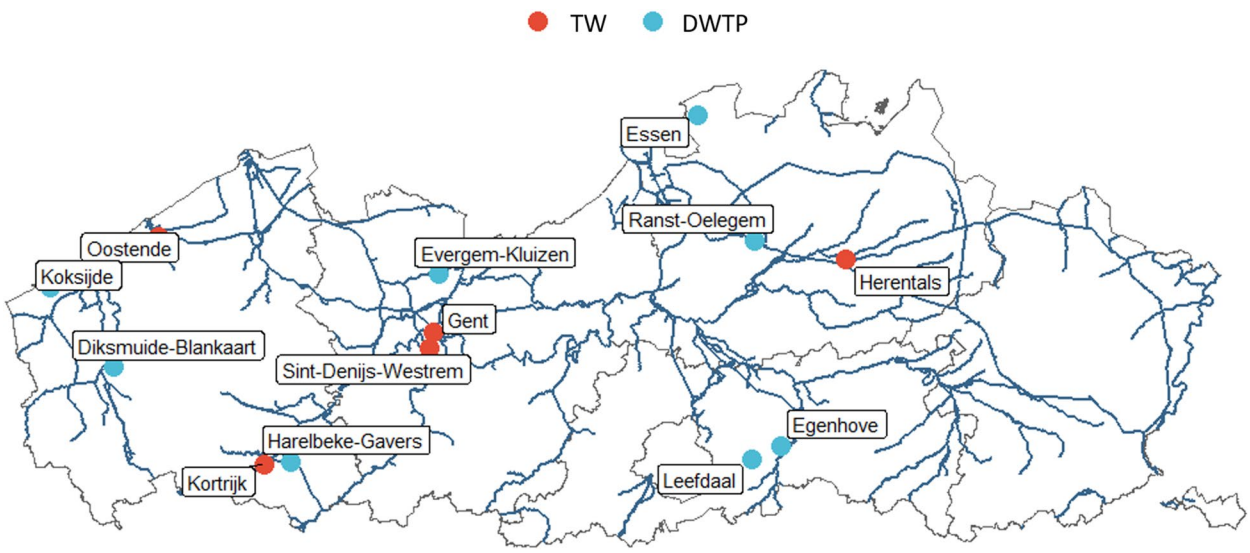

Fig. 1 Sampling locations selected to determine the extent of the microplastic pollution in drinking water in Flanders in tap water samples (TW) in red and drinking water treatment plants (DWTP) in blue

(effluent from a waste water treatment plant, WWTP) is used to produce drinking water after additional purification steps (including infiltration into the soil). At this sampling location, two samples were collected. In addition, samples were also taken from TP at five different locations (Fig. 1). On two of these locations, sampling was repeated three times to get an idea of the variation in MP concentrations. Full details of the selected sampling locations and dates can be found in Table 1.

On each sampling location, approximately 300 L of water was filtered over a cellulose nitrate membrane filter (pore size 8.0 µm, ⌀ 47 mm, Whatman AE99). This membrane filter was enclosed in a filtration system consisting of stainless steel, that was connected via a tube to an outgoing water pipe of the DWTP or tap. Additionally, negative control samples were produced to determine the extent of contamination in the samples during the sampling or extraction process (Fig. S1). An identical set-up was always placed in series after the sampling device for the production of blank samples. Hence, water that passed the actual sampling filter, subsequently, also passed through the filter in this blank set-up. Hence, MPs that were found on this blank filter can only be the result of contamination during removal of the filter or the MP extraction process. For two locations (Ghent and Kortrijk), three consecutive replicates of tap water were collected. Information about the flow and pressure on the tap was collected with a flow meter, and the sampled volume was also determined. After sampling, the membrane filters were stored in glass Petri plates, then packed in aluminium foil and transported to the lab. Upon receipt in the lab, the – in total 18 – samples were stored at − 20 °C until further processing.

Sample treatment: microplastic extraction

The cellulose filter(s) were mixed with 50 mL potassium hydroxide (KOH, AnalaR NORMAPUR) per filter in a glass beaker and then placed in a warm water bath (Memmert WTB) at 60 °C for 24 hours to digest the cellulose filter(s). The resulting solution was filtered over a polytetrafluoroethylene (PTFE) filter (pore size 10.0 µm, ⌀ 25 mm, Omnipore Membrane filter, Merck) through a glass filter system. Both the measuring cup and the filtration system were rinsed three times with filtered deionized water and once with a 0.1% Tween® 80 solution. Subsequently, the filter was dried at room temperature for 24 hours in a dust-free environment.

Microplastic characterization

The dried PTFE filters were analyzed by FTIR spectroscopy (Nicolet iN10 FT-IR Microscope; Thermo Fisher Scientific, Madison, Wi, USA). The entire surface of the filter was scanned and the spectrum of each pinpointed particle was determined (100 µm step-size scanning, 150 × 150 µm aperture, spectral resolution 16 cm^{-1}, reflection mode, spectral range 1300–4000 cm^{-1}). The obtained spectra were identified based on their correlation (Pearson correlation, threshold match 75%) with

Table 1 Summary of sample collections in eight drinking water treatment plants (DWTPs) and five water taps (TW) in Flanders. Water sources are: groundwater (GW), surface water (SW) or purified effluent water from a waste water treatment plant (WWTP)

	Location	*Latitude N*	*Longitude E*	*Time*	*Source sample*	*Source water*	*# replicates*
1.	Essen	51.4272	4.42956	31/01/2020 11:50–13:00	DWTP	GW	1
2.	Evergem - Kluizen	51.1538	3.72092	10/02/2020 10:04–12:05	DWTP	SW	1
3.	Egenhove	50.8616	4.65406	22/01/2020 9:15–11:45	DWTP	GW (no purification)	1
4.	Ranst - Oelegem	51.2130	4.58311	14/02/2020 10:20–12:20	DWTP	SW	1
5.	Leefdaal - Puttebos	50.8384	4.57556	17/01/2019 11:10–12:26	DWTP	GW	1
6.	Diksmuide - Blankaert	50.9870	2.83743	18/02/2020 10:15–11:50	DWTP	SW	1
7.	Harelbeke - De Gavers	50.8303	3.32310	19/02/2020 9:30–11:20	DWTP	SW	1
8.	Koksijde - Torreele	51.1222	2.66041	24/01/2020 9:30–10:35 26/02/2020 8:15–9:40	DWTP	WWTP	2
9.	Sint-Denijs-Westrem	51.0278	3.69702	31/01/2020 11:10–12:26	TW	GW	1
10.	Oostende	51.2116	2.95459	21/02/2020 9:15–11:45	TW	SW	1
11.	Herentals	51.1793	4.83453	6/03/2020 9:30–10:35	TW	GW	1
12.	Ghent - Coupure	51.0539	3.70741	16/03/2021 14:27–15:54;23/03/2021 9:41–11:07; 23/03/2021 11:16–13:30	TW	SW	3
13.	Kortrijk	50.8249	3.25133	22/03/2021, 10:12–11:39; 22/03/2021, 12:36–13:50; 22/03/2021 13:58–14:55	TW	GW	3

known spectra in the reference library (in-house and commercial library). Furthermore, information was collected on the length and width of the particle. All unidentified particles (non-plastics or match to reference plastics lower than 75%) were removed from the data set.

Quality control

We applied precautions to avoid contamination as part of the so-called good field and laboratory practices (GLP). A cotton lab coat was worn both during the sampling and processing of the samples in the laboratory. Extractions were performed in a closed laboratory environment, under a laminar flow (Potteau, Heule) that was regularly cleaned thoroughly. All lab material was pre-rinsed three times with deionized water and stored free of dust. Bottles, measuring cups and samples were sealed with aluminum foil or with watch glasses to avoid air-borne contamination. Glass, metal or stainless steel laboratory material was used if possible. The use of plastic equipment was avoided as much as possible, but if it could not be replaced, possible contamination was tested a priori by analysis of blank samples and methods were adjusted as needed.

After the sampling set-up was installed, it was first rinsed with the water to be sampled (without filter). The created blank sample controls were processed in the lab, similarly as the other samples. To date, no standardized methods are available to account for these controls in analyses. We corrected our data for possible contamination during sampling and processing using the limit of detection (LOD) and the limit of Quantitation (LOQ) (Uhl et al., 2018):

$$LOD = Average_{Blanc} + 1.645 \times Standard\ deviation_{Blanc} \quad (1)$$

$$LOQ = Average_{Blanc} + 3 \times Standard\ deviation_{Blanc} \quad (2)$$

LOD and LOQ values were calculated per polymer type. We consider all concentrations found in samples below the LOQ for a particular polymer type to be unreliable to quantify due to possible contamination, and these values are thus not reported. Instead, we reported "<LOQ". This analysis was performed per sample per polymer type. The obtained LOD and LOQ values per polymer type are listed in Table S1.

Rescaling of the environmental microplastic concentrations

Due to the practical size-detection limitations of the FTIR spectroscopic method, the measured MPs range between 25 µm and 1000 µm. A more correct default MP size range would include all particles between 1 and 5000 µm, corresponding to the MP definition (Koelmans et al., 2020). Assuming that the particle size distribution in both surface waters and sediment follow a power law distribution, the measured number concentrations (25–1000 µm) can be translated for the default MP size ranges (1–5000 µm) using the correction factor (CF) as proposed by (Koelmans et al., 2020; Kooi et al., 2021):

$$CF = \frac{\int_{x_{1D}}^{x_{2D}} bx^{-a}}{\int_{x_{1M}}^{x_{2M}} bx^{-a}} = \frac{x_{2D}^{1-a} - x_{1D}^{1-a}}{x_{2M}^{1-a} - x_{1M}^{1-a}} \quad (3)$$

In the formula subscripts x_{1D}, x_{2D}, x_{1M} and x_{2M} refer to the minimum default size (1 µm), maximum default size (5000 µm), minimum measured size (25 µm) and maximum measured size (1000 µm), respectively. MPs larger than 1000 µm were removed from the dataset for fitting the power law. The fitting power law exponent, a, was calculated by fitting the log-transformed power law distribution to the measured size distribution (PoweRlaw package, R studio). To ensure good estimates of the power law exponent a, the fit was bootstrapped ($n = 100$) to obtain means and standard deviations for a (Clauset et al. 2009). The CF was calculated for both DWTP and TW, separately. The measured particle concentrations were subsequently corrected by multiplying the measured concentration with the calculated CF.

Statistical analyses

All statistical tests were executed in R Studio. The Shapiro-Wilk test of normality and Levene's test of homogeneity of variances were applied as pre-tests to all metric data. Differences between locations and environmental factors in terms of MP concentrations were statistically analysed using ANOVA or the non-parametric alternative, Kruskal-Wallis. Both analyses were followed by an appropriate post-hoc analysis for pairwise comparisons. Differences were considered statistically significant if the p-value was less than 0.05.

Correlations with environmental factors or other metadata (continuous variables) were studied by calculating the Spearman Rank correlation. Graphs were produced using the ggplot2 package (version 4.0.3) available in R.

Results & discussion

Our study's objective was to quantify and investigate the presence of MPs in drinking water and their associated sources across the geographic region Flanders. Below, we only report blank corrected concentrations, as all identified particles below the respective LOQ values were removed from the dataset. We therefore only report those concentrations of which the quantification is considered reliable.

Microplastic contamination in Flemish drinking water production centres

We found an average ± SD of 0.02 ± 0.03 MPs per liter of drinking water in the samples taken in the DWTPs (detailed information available in Table S2). In three different DWTPs – Essen, Egenhove and Gavers – no MPs were found. In the DWTP of Kluizen and Leefdaal-Puttebos, concentrations were reported below the LOQ values. For these samples, hence, an insufficient volume was sampled to ensure an adequate number of collected MPs. MP concentrations in the other locations varied between 0.01 MPs per L and a maximum of 0.06 MPs per L (in one of the replicates of DWTP – Torreele). The observed differences in MP concentration between sampling locations were not correlated with the water pressure on the tap (cor = 0.15; $p = 0.75$), the flow rate (cor = 0.41; $p = 0.42$), the duration of the sampling and/or loading of the filters (i.e. the number of filters needed for the sampling was used as a proxy; cor = 0.20; $p = 0.67$). However, comparing the MP concentrations according to the origin of the water (SW, GW and WWTP effluent water), it is noticeable that drinking water produced from groundwater does not appear to contain MPs, even not in the case of DWTP-Egenhove where no further purification of the ground water is done (Fig. 2). The purified water from WWTP effluent contains on average more MPs (0.05 ± 0.02 MPs/L) compared to drinking water obtained from surface water (0.02 ± 0.02 MPs/L). However, due to the limited data, the observed differences in MP contamination according to the source are not significant ($p = 0.123$). More data should be collected to confirm these results.

Properties of the recovered microplastics

Polypropylene (PP) is the most common polymer type (85.42%) found in drinking water after purification in DWTP. In the DWTP-Blankaert and DWTP-Oelegem, only PP was found. In addition, PE (14.58%) was also found, albeit only in the DWTP of Toreele (23.33% of the sample). Other polymer types were not present in the analyzed samples or were found in concentrations below the LOQ values. In our dataset, the size distribution of the particles reveals that the smallest particles (25–100 µm) occur in the highest concentration (Fig. 3). Average length of the MPs found is 214 ± 209 µm.

Microplastic contamination in Flemish tap water

The samples from Sint-Denijs-Westrem, Oostende and Herentals, contained no MPs larger than 25 µm. In the samples from Ghent and Kortrijk, most replicates had concentrations lower than the calculated LOQ values and were, hence, set to zero for further analysis (See Table S3).

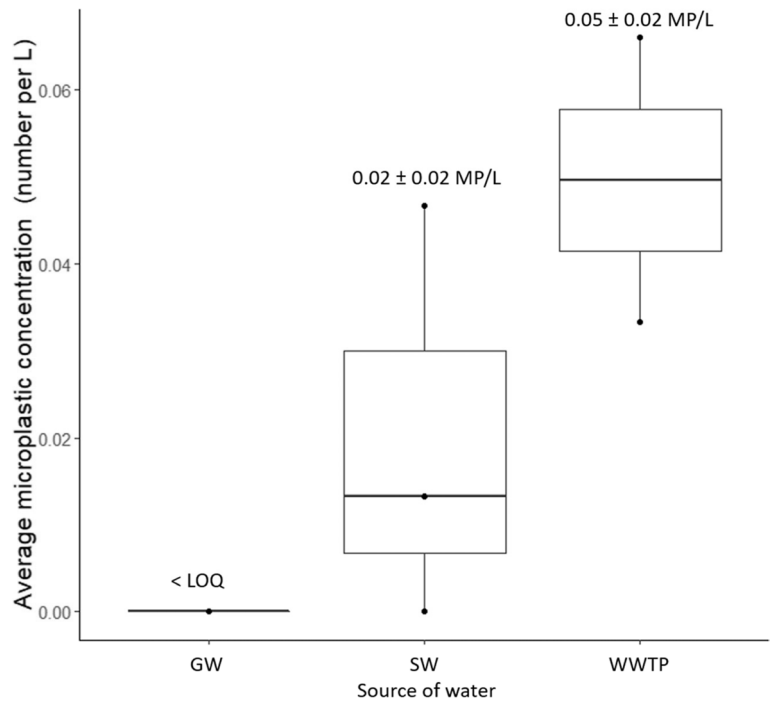

Fig. 2 Average concentration (and standard variation) per type of source water (GW = ground water; SW = surface water; WWTP = water from waste water treatment plant effluent) used for drinking water production

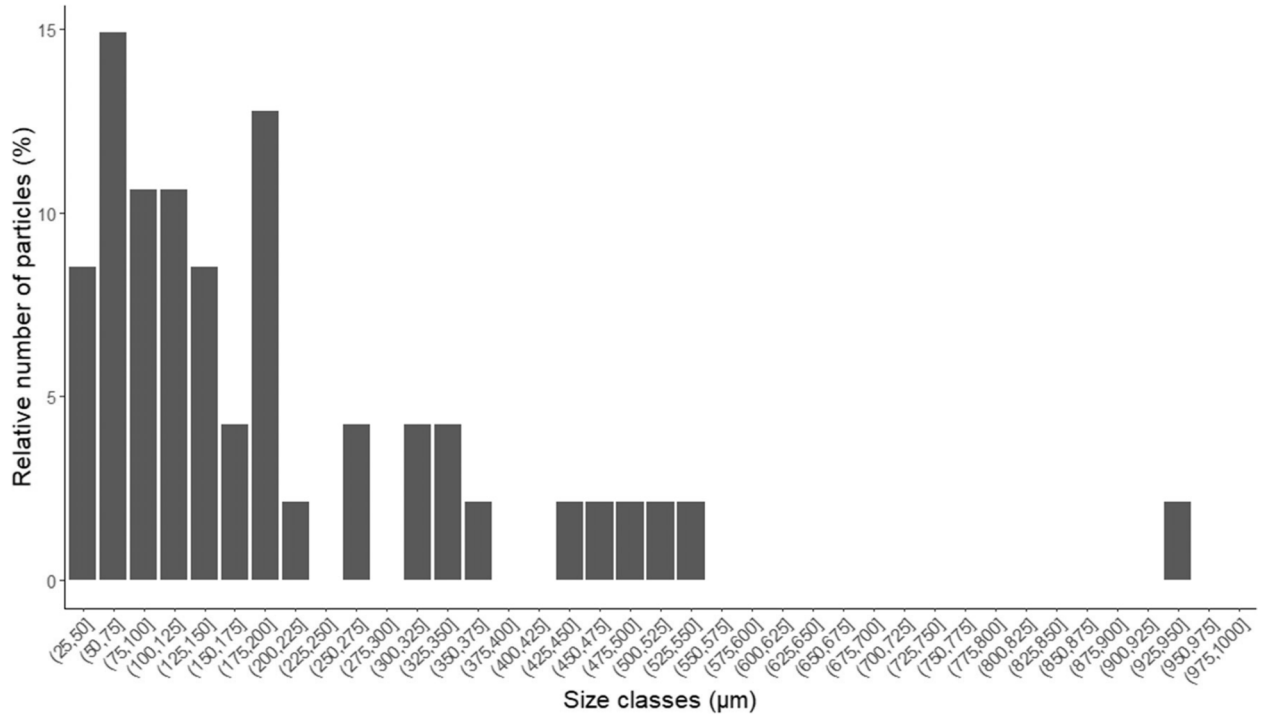

Fig. 3 Size distribution of observed microplastic particles in all samples collected at drink water treatment plants. Based on 48 particles

The average MP contamination in Flemish tap water was 0.01 ± 0.02 MPs per L with a maximum observed concentration of 0.05 MPs per L found in one of the samples in Ghent. The average concentration of the tap water in Ghent was 0.02 ± 0.03 MPs per L and in Kortrijk 0.01 ± 0.01 MPs per L. The variation in the repeated samples in Ghent was large since one sample contained the maximum concentration that was observed and the other two replicates contained concentrations lower than LOQ values. In Kortrijk, two out of three samples had comparable MP concentrations and one sample contained concentrations lower than LOQ values (Table S3). The measured concentrations are lower compared to previously reported MP concentrations in tap water (Cox et al., 2019). Although the tap water in Ghent and Kortrijk have different sources, due to the current data it is not possible to add a conclusion on the source-specific MP load of tap water.

Properties of the recovered microplastics

Recovered MPs were mainly identified as PET (40.74%) and PP (33.33%), but other polymer types such as PVC(14.81%), PS (7.41%) and PE (3.7%) were also found. Comparing the two sampling locations with MP concentrations > LOQ, the polymer composition was more diverse in the sampling location in Ghent compared to the one in Kortrijk. PVC and PE particles were only found in Ghent and not in Kortrijk (Fig. 4).

Most of the particles were around 50–75 µm in size (44%), with an average length of 140 ± 271 µm. The limited amount of particles ($n = 27$) hampers a good analysis (Fig. 5).

Global patterns of microplastic contamination in drinking water

Data on MP contamination in drinking water is rather scarce. Up to now (December 2021), as far as we know, seven (peer-reviewed) studies have investigated the presence of MPs in drinking water treatment plants, comparable to the DWTP samples collected in Flanders in this study (Fig. 6). However, the comparison of our dataset to these studies is not straightforward due to the use of diverse methods to collect (1) samples (e.g. differences in sampling volumes and methods: bulk sampling/filtration), and to (2) identification methods and associated reliability and size classes. Therefore, comparison between previously published results and our results should be performed with caution.

In general, drinking water derived from groundwater sources appears to generally contain low amounts of MP contamination; which we also observe in our study. Mintenig et al. (2019) identified MPs in drinking water – derived from groundwater purification – from

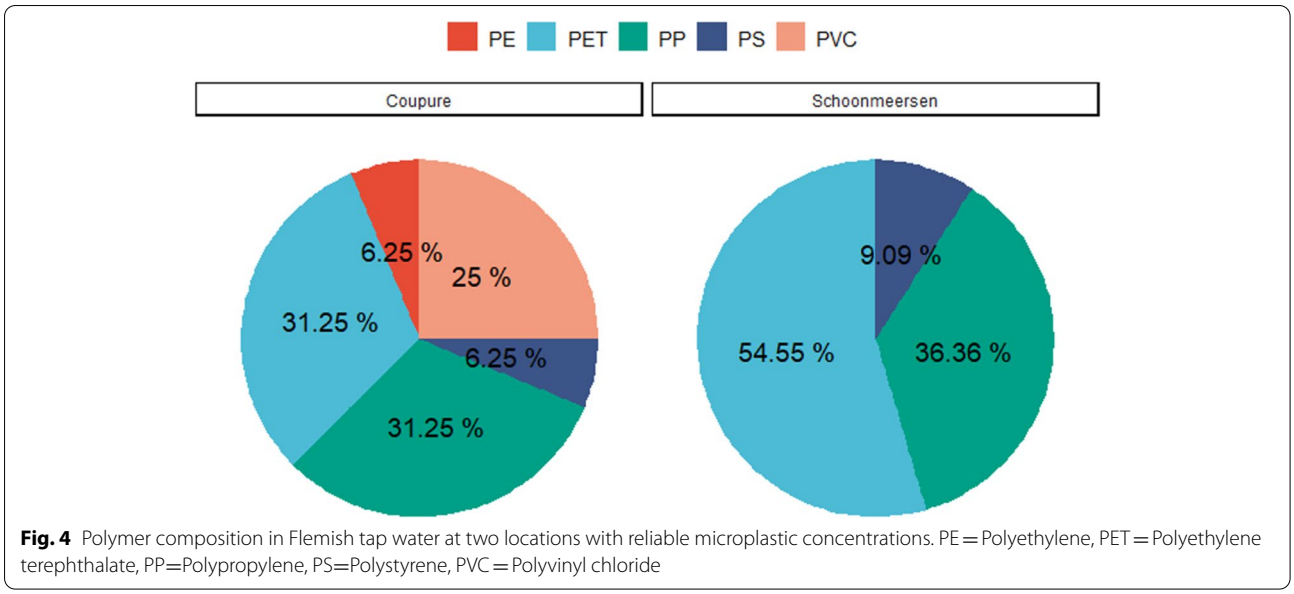

Fig. 4 Polymer composition in Flemish tap water at two locations with reliable microplastic concentrations. PE = Polyethylene, PET = Polyethylene terephthalate, PP=Polypropylene, PS=Polystyrene, PVC = Polyvinyl chloride

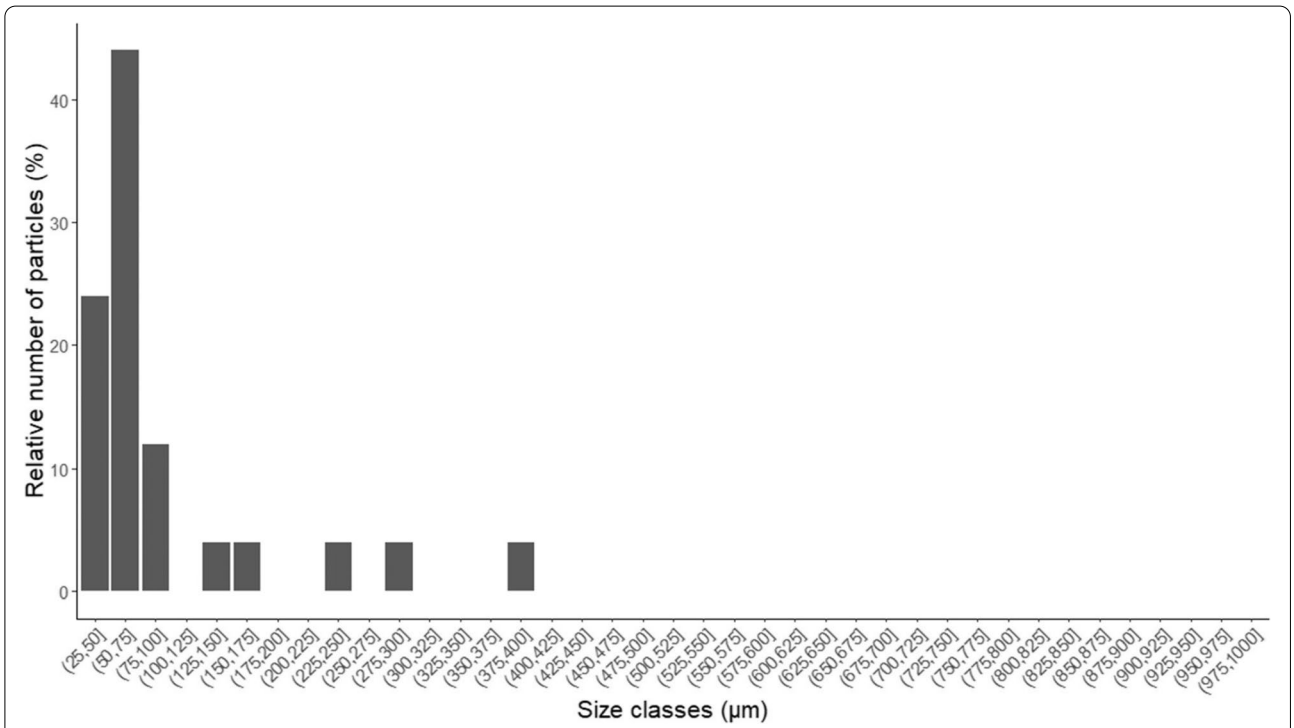

Fig. 5 Size distribution in Flemish tap water based on 27 particles

five different drinking water treatment plants in Germany. On average, they recovered 0.0007 MPs per L. As seen both in previously published research and in our data, drinking water derived from surface water, generally contains a higher MPs concentration compared to drinking water from groundwater sources. For example, in Norway no plastics were detected (< LOQ) and in Sweden 0.12 MP per L recovered in drinking water from surface water sources (Uhl et al., 2018; Kirstein et al., 2021a, respectively). The results of the current study coincide with these results. In contrast, a study conducted in the Czech Republic reported much higher

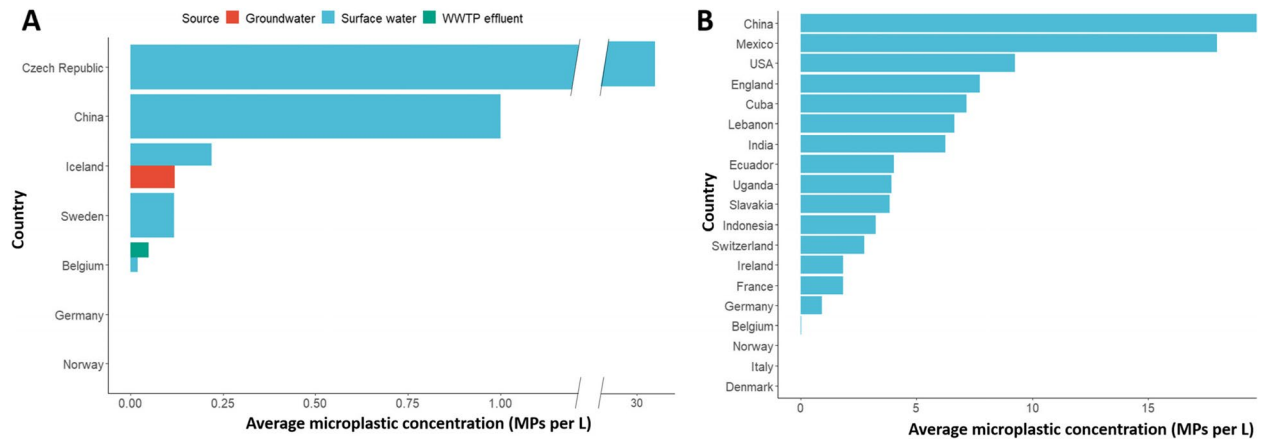

Fig. 6 Comparison between reported microplastic concentrations in drinking water treatment plants (DWTP) (**A**) and tap water (**B**). References for DWTP: Pivokonsky et al., 2018; Wang et al., 2020; McQuilkin et al., 2020; Kirstein et al., 2021a; current study; Mintenig et al., 2019; Uhl et al., 2018. References for tap water: Kosuth et al., 2018; Uhl et al., 2018; Strand et al., 2018, Shruti et al., 2020; Tong et al., 2020; Weber et al., 2021; Zhang et al. 2019; this study

contamination levels of MPs in drinking water obtained from surface water: i.e. 338 ± 76 to 628 ± 28 MPs L^{-1}, although concentrations depended on the DWTP, suggesting treatment effects on MP contamination levels (Pivokonsky et al., 2018). Importantly, in this study 95% of these particles were reported to be between 1 and 10 µm in size. If we would only consider particles larger than 10 µm, then Czech drinking water contains on average 23.48 MPs L^{-1}(Pivokonsky et al., 2018). No previously published papers were found discussing the MPs contamination in drinking water derived from purified effluent of waste water treatment plants, so no comparison is possible.

Focusing on tap water (sampling drinking water from taps in households), the MP concentrations in Flanders are low and comparable to observations in Denmark (<LOD; Strand et al., 2018), Italy (0 MPs L^{-1}; Kosuth et al., 2018), Norway (< LOQ; Uhl et al., 2018) and Germany (0.45 MPs L^{-1}; Weber et al., 2021). In the USA, on average 9.24 MPs L^{-1} are flowing through the taps (Kosuth et al., 2018). The tap water in China seems to contain the most MP particles (440 ± 275 MPs L^{-1} and 343.5 MPs L^{-1}), although the analytical method used in this study could have caused an overestimation (Tong et al., 2020; Shen et al., 2021). Measurements in the US and Cuba showed higher MP concentrations of 9.24 ± 11.8 and 7.17 MPs L^{-1}, respectively (Kosuth et al., 2018). The huge variation in the data but also in the used methods makes comparisons challenging. If we would only consider studies that used the same analysis method (FTIR/Raman spectroscopy) and reported the same size class, we would only be able to compare our results with the studies of Uhl et al. (2018) and Weber et al. (2021) which found no MPs in tap water.

In literature, often a more diverse polymer composition is observed relative to the current study. Pivokonsky et al. (2018) found that the majority of the MPs (>70%) comprised of PET (polyethylene terephthalate), PP (polypropylene) and PE (polyethylene). Mintenig et al. (2019) identified the MP particles in the samples as polyethylene, polyamide, polyester, polyvinylchloride or epoxy resin, between 50 and 150 µm in size.

Rescaling of the measured microplastic concentrations

As mentioned before, the size definition of MPs (default size range 1–5000 µm) doesn't coincide with the measured size range (25–1000 µm) due to practical limitations of the analytical methods. Based on the method described by Koelmans et al. (2020), we were able to rescale the measured size range to cover the default size range, under the assumption that the calculated power law distribution and exponent value are valid beyond the upper and lower detection bounds. Based on the particle size distribution of particles found in the DWTPs, a general CF of 279.67 was calculated, corresponding to a calculated mean exponent of 2.75 ± 0.90. No other rescaled data is available to compare the CF or exponent values, however, other studies have reported power-law exponents between 1.2 and 2.93 for plastic fragmentation (Mohamed Nor et al., 2021). When using this CF to recalculate the concentration of MPs between 1 µm and 5000 µm based on the measured concentrations in DWTP samples, the general average rescaled particle concentration is 5.59 MPs per L. In drinking water obtained from surface water sources, a rescaled

concentration of 5.59 MPs per L was calculated, while in the reused WWTP effluent water an average concentration of 13.98 MPs per L was found (using the same CF and exponent value). A location-specific rescaling was not possible due to the limited number of MP particles found at each location.

Based on the particle size distribution of the particles found in the tap water, a CF of 376.42 was calculated, corresponding to a calculated mean exponent of 2.84 ± 0.80. Based on the calculated CF, the rescaled particle concentration in tap water in Flanders is 3.76 MPs per L. The worst-case scenario would result in a rescaled MP concentration of 18.82 MPs per L in the tap water in Ghent (maximum measured concentration of 0.05 MPs per L), although this is an estimation and more data are necessary to confirm these results.

Since this rescaling method applied here is not yet a general practice, it is not yet possible to reliably compare our rescaled results to other published datasets. In future studies, the predicted MP concentration of the smallest particles should be confirmed by measurements since deviation of these estimations might occur due to size-selective processes such as wind mixing, aggregation, settling and beaching (Kooi et al., 2021).

Human body burden and human health risk of microplastics

It is important to frame this (limited) MP contamination of drinking water in our daily lives (Koelmans et al., 2017). Based on a standard consumption of two liters of drinking water per day and based on the measured concentration in this study (average of 0.01 MPs per L tap water), Flemish people would consume 0.02 particles per capita per day via drinking water. If the rescaled concentrations are used, the daily consumption would be on average 7.52 MPs per capita. In the most extreme scenario (measured concentration: 0.05 MPs per L; rescaled concentration: 18.82 MPs per L), Flemish people would ingest 37.64 MPs on a daily basis, based on only the consumption of tap water. Comparing our findings with the results of Tong et al. (2020), Chinese inhabitants may ingest up to about 440 microplastics d^{-1}. Based on several international studies (Kosuth et al., 2018; Mason et al., 2018; Schymanski et al., 2018; Wiesheu et al., 2016), Cox et al. (2019) calculated a mean concentration of 94.37 MPs per L for bottled water and 4.23 MPs per L in tap water, resulting in a daily consumption of less than 12 MPs per day from tap water. However, the study of Cox et al. (2019) did not include the smaller particles < 10 µm. These estimates of average daily uptake are lower compared to the estimates of the World Health Organization (WHO, 2019), which estimate an daily uptake of 20.8 MPs per L per capita via drinking water. However, these estimates are based on the consumption of both tap water and bottled water and in the most extreme scenario (worst case scenario). It is already known that the MP concentrations in tap water are lower than those in bottled water (water in plastic bottles). Cox et al. (2019) calculated a mean concentration of 94.37 MPs per L for bottled water and 4.23 MPs per L in tap water, based on several international studies (Kosuth et al., 2018; Mason et al., 2018; Schymanski et al., 2018; Wiesheu et al., 2016). The plastic packaging material seems to be responsible for this higher MP load. Other beverages packed in glass, aluminum cans or Tetra Pak cartons do not contain these high MP concentrations (Mohamed Nor et al., 2021). In the current study, no bottled water was investigated, which means that no reliable comparison can be made between Flemish tap water and bottled water.

The potential risks for human health resulting from MP ingestion are hardly understood, and information on MP uptake and fate gained through animal and cell toxicity studies is currently still very limited (Kirstein et al., 2021b; Yee et al., 2021). MPs may reach the gastrointestinal system through contaminated water, possibly leading to inflammatory responses, cell function disruption, increased oxidative stress, and changes in the gut microbe composition and metabolism (Prata et al., 2020; Tamargo et al., 2022; Yee et al., 2021). After digestion, MPs could be adsorbed in the intestine wall, as their translocation to the circulatory system after oral administration has been demonstrated in vivo (Wright and Kelly, 2017). In order to be able to carry out a risk assessment for MPs ingestion in humans based on drinking water samples, a safe threshold value is required, a so-called Derived No Effect Level (DNEL). To date, however, no epidemiological or other relevant studies on the effects of ingested MPs in humans have been published. Animal data is scarce and inadequate. In addition, the limited number of toxicology studies in rats and mice exposed to dietary MPs are of questionable reliability and relevance, with some effects observed only at very high concentrations that would overwhelm metabolism and therefore not necessarily demonstrate the potential toxicity effects seen at lower, more relevant concentrations that could occur. Based on the limited amount of evidence so far, no firm conclusions can be drawn about the risk associated with the absorption of MPs via drinking water. To date, no study has quantitatively determined the risk of MPs exposure in humans. At the moment there are no indications showing a link between exposure to MP particles via drinking water and human health. However, the World Health Organization (WHO, 2019) has carried out a risk assessment for contaminants associated with MPs and concluded that the concentrations of these substances are unlikely to have a negative impact on our

health, i.e. a low risk ("low concern for human health"). In conclusion, there is currently no evidence that MPs via drinking water pose a widespread risk to human health (SAPEA, 2019).

Conclusions

The content and characteristics of microplastics present in drinking water from different drinking water treatment plants and water taps was determined. The MPs' abundances, in the range of 25–1000 µm, in the DWTP and TW samples were on average 0.02 ± 0.03 MP L^{-1} and 0.01 ± 0.02 MP L^{-1}, respectively. We did not find any significant differences comparing the obtained MP concentrations according to the origin of the water (i.e. ground water, surface water and treated sewage water). Polypropylene (PP) and polyethylene terephthalate (PET) were the most common polymer types detected in the samples. Next, based on several theoretical assumptions, we extrapolated the measured MP concentrations in our samples to cover the full theoretical MP size range (1–5000 µm) to obtain estimates of the actual MP contamination levels. We predicted the rescaled particle concentrations were on average 5.59 MP L^{-1} and 3.76 MP L^{-1} for the DWTP and TW samples, respectively. Further research should focus on the determination of small-sized MPs (< 25 µm) in freshwater ecosystems in order to provide better insight into their sources and routes to potable water.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40550-022-00091-8.

Additional file 1.

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Authors' contributions

All the authors contributing to this work are listed in the names section. Colin Janssen designed and conceptualized the study with input from all co-authors. Ilias Semmouri and Maaike Vercauteren wrote the main manuscript text. Ilias Semmouri, Maaike Vercauteren, Emmanuel Van Acker and Emmy Pequeur contributed in data collection and analysis. Ilias Semmouri, Maaike Vercauteren, Colin Janssen and Jana Asselman discussed and interpreted the results critically. Colin Janssen and Jana Asselman provided funding. All authors reviewed the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

The dataset(s) supporting the conclusions of this article is (are) included within the article (and its additional file(s)).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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