Microplastics in Fresh Water Resources

Florian R. Storck, TZW Karlsruhe; Stefan. A.E. Kools, KWR Watercycle Research Institute; Stéphanie Rinck-Pfeiffer, GWRC.

Microplastic residues in fresh water resources has become a topic of interest attracting the attention of the public and authorities. Microplastic pollution has been an issue for a number of years in the marine research field[1]. However, investigations on the occurrence in fresh water systems including drinking waters and wastewater treatment is still in an early stage and research, mainly in Europe, has only just commenced. There is currently very little knowledge and expertise on microplastic residues in drinking water and its potential impact. The media has circulated misinformation on the suspected occurrence of microplastic in drinking water which has spread fear and uncertainty amongst the public. This brief compiles the current state of knowledge on the subject of microplastics as currently known by the Global Water Research Coalition (GWRC) members. It includes recent information and grey literature, thus updating and going beyond the information presented in the year 2013 in the STOWA report[2].

Definition

Microplastics are commonly defined as particles or fibers with a diameter < 5 mm consisting of polymers. A lower limit has not yet been defined, but the term "micro" implies 1 µm. However, most studies investigated particles > 300 µm [3]. Currently, the categories "large" (1 mm to 5 mm) and "small" (<1 mm) have been introduced[4,5]. The lower limit is mostly determined by the mesh size of the sieve or net used for sample filtration and by the application of spectral and optical analysis for identification[1,3].

Origin / emission of microplastics to the environment

Global annual plastic production in 2012 was 288 Mega Ton (Mt) (Europe 58 Mt, US 57 Mt) and has strongly increased for the past 60 years (however, European production recently stagnated). The latter numbers include mainly high production volume polymers like polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC), polyurethane (PU), polystyrene (PS) and polyethylene terephthalate (PET). The overall tonnage is even higher when considering fibers of PET, polyamide (PA) and polyacryl[6]. One source of microplastics are cosmetic and personal care products designed for gentle friction ("Micropearls", "Peeling") such as soap, hand and facial cleansers, tooth paste, shower gels, deodorants and shampoo[7, 8]. These particles are often < 300 µm and may contain additives like dyes (unpublished data TZW). This aspect has been the focus of environmental NGO's in the Netherlands, in the US and in Germany, resulting in increased public awareness at the general public and leading to policies to reduce the use of plastics in cosmetic products.
Sandblasting with microplastic particles[7, 9] and abrasion from plastic articles (tyres) are further sources of microplastics in the environment. Washing clothes made of synthetic fibers can

release up to 1,900 microplastic fibers per item or > 100 per L of wastewater[10]. Wastewater entering European wastewater treatment plants (WWTPs) contained 15 to 200 particles per L (ppL) of which wastewater treatment removed 90 % to 99.9 % with the lower efficiency for particles of 20 to 300 µm diameter and higher efficiency for larger particles[10–14]. In Australian WWTP effluent, 1 ppL was detected, mostly polyester, acryl or polyamide, reflecting the use of these polymers in textiles[10]. Microplastics are thus not completely retained during wastewater treatment and up to 160 particles per served inhabitant per hour (>20 to 300 µm) end up in receiving waters (average of two large WWTP: 97 particles per served inhabitant per hour[12]).

Retention of microplastic particles during wastewater treatment

Retention of microplastics in wastewater treatment plants has been investigated but results are limited. During conventional treatment, microplastics are mainly retained by sedimentation[12,13]. It is believed [11] that the removal is increased by a grease/oil trap or by flotation (injection of air bubbles). For a small Swedish WWTP, mechanical, chemical and biological treatment was estimated to remove 99.9 % of the microplastic particles > 300 µm. Most of the particles were detected in the sludge, with higher retention efficiency for fibers than for fragments [14]. Preliminary results indicate low retention of microplastics on sand filters both for the fractions that are >300 µm and from 20 µm to 300 µm[12]. Membrane filtration reduced the number of microplastic particles per m³ produced by up to 85 % to 95 % [12, 13]. Due to the lack of defined methodological approaches and the limited number of treatment processes investigated, further systematic research on the retention and removal of microplastics during wastewater treatment is needed.

Occurrence of microplastics in freshwater

A number of European and American rivers and lakes have been assessed for microplastics with different sampling methods and different mesh sizes (Table 1). In most studies, the number of plastic particles increased strongly when smaller-meshed nets or filters were used for sampling. In Switzerland, the top 10 cm of the water column of several lakes contained 0.1 to 2 particles/m³ (>300 µm, equal to 0.04 mg/m³ to 0.7 mg/m³), while in the River Rhone 0.11 mg/m³ were detected [4]. In the French River Seine, 3 to 108 particles/m³ (>80 µm) and 0.28 to 0.47 particles/m³ (>330 µm) were reported[15]. In the top 16 cm of the River Rhine in Germany 387 particles/m³ were observed [16]. For the River Danube in the Austrian section, a depth profile indicated that lower density particles can be expected in the upper layers of the river[17,18] and up to 141 particles/m³ (>500 µm, equals 700 mg/m³) were detected, most of which were released by an industrial site[19]. However, more detailed investigations of the River Danube revealed only 0.3 mg/m³ microplastics (0.5 to 5 mm[17]). A mean of 18 particles/m³ were detected in a channel near Chicago, Illinois (0.33 to 2 mm[20]) and an average of 43,000 particles/km² in the Laurentian Great Lakes (0.33 to >4.7 mm[9]). River Rhine bank sediments near Frankfurt, Main, in Germany contained mainly PE, PP and PS microplastics [21]. Concentrations of microplastics are thus mostly much lower compared to total solid content (e.g. River Rhine near Basel 2013: 6 to 63 mg/L, [22]).

Table 1: Microplastics in rivers and lakes.

Country	River/Lake	Sampling depth	Size	---------------- Concentration ----------------			Source
Unit	-	m	mm	particles per m^3	mg per m^3	1000 particles per km^2	-
CH	Swiss Lakes	0 - 0.1	0.3 - 5	0.1 - 2	0.04 - 0.7	11 – 220	4
CH	Rhone	0 - 0.1	0.3 - 5	0.29	0.35	n.r.	4
F	Seine	n.r.	0.08 - 5	3 - 108	n.r.	n.r.	15
F	Seine	n.r.	0.33 - 5	0.28 - 0.47	n.r.	n.r.	15
DE	Rhine	0 - 0.16	0.3 - 5	387	n.r.	56 – 68	16
AT	Danube	0 - 8 [17,18] 0 - 0.5 [19]	0.5 - 5	< 141	< 700	n.r.	17 - 19
AT	Danube	0 - 8	0.5 - 5	n.r.	0.3	n.r.	17
US	Channel near Chicago	0 - 0.4	0.33 - 2	18	n.r.	n.r.	20
US	Laurentian Great Lakes	0 - 0.16	0.33 - 4.7	n.r.	n.r.	43	9

n.r. – not reported / no information available

Microplastic sampling, extraction and detection

Microplastic particles are often sampled with Neuston or plankton nets or Manta trawls in surface water and rarely with filters in technical systems like WWTPs. They are separated by:

- flotation,
- centrifugation,
- density separation and/or
- digestion with acids, bases or enzymes from natural inorganic and organic matrices[1].

Further sample enrichment or separation in size fractions (field flow fractionation, filtration) is common practice.
Detection, i.e. chemical identification of polymers, can be achieved with:

- Raman spectroscopy[23, 24],
- Fourier transform infrared spectroscopy (FTIR [25]) or
- pyrolysis followed by gas chromatography coupled to mass spectrometry (pyr-GC-MS[26]).

To date, there are no standardized methods for the choice of mesh size, sampling, clean-up, enrichment and detection, complicating a comparison of different studies. In many studies, an identification of polymers is reported to be assessed by the naked eye[3, 27–29]. However, a reliable identification and distinction from non-plastics without analytical tools is not possible for small particles (Figure 1).

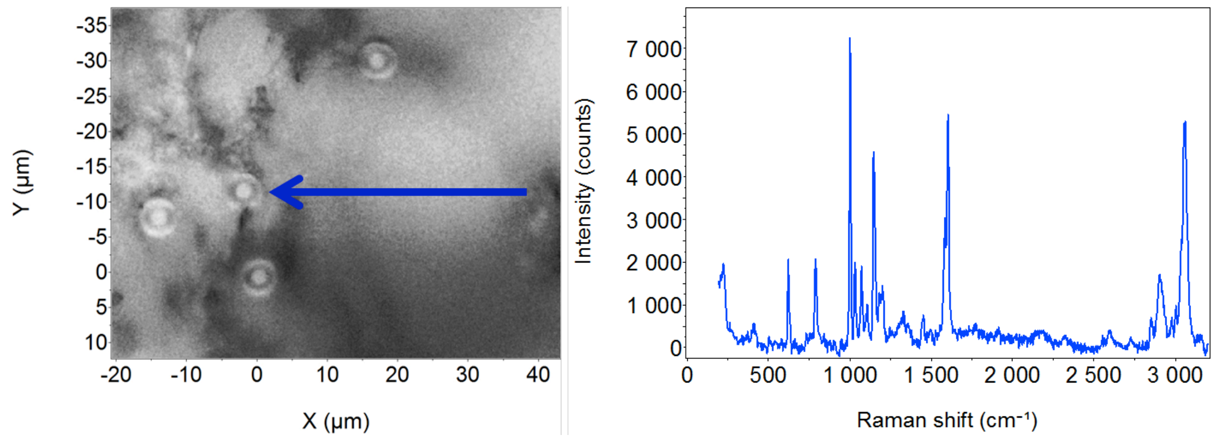

Figure 1: Spherical polystyrene particles (2 µm) on a filter. Microscopic view (left) and Raman spectrum (right).

Microplastics as a potential carrier of pollutants

Polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and polybrominated diphenyl ethers (PBDE) are pollutants and have been investigated in association with microplastics[4]. Pollutant concentrations were reported mostly in a similar order of magnitude as environmental endpoints including sediments, suspended matter or fish tissue[24]. Due to the small percentage of microplastics contained in total suspended matter, the additional contribution of microplastic-associated pollutants (e.g. $4\ ng/m^3$ for PAH, considering data from [4]) to the total pollutant load in surface waters seems to be small. For marine microplastic, more information is available[30–32]. Analogous to freshwater systems, concentration ranges of pollutants in marine microplastic and in sediments or organisms are often similar and the additional contribution of microplastic-associated pollutants seems to be small. Available data both on chemical and biological threads associated with freshwater microplastics are rare and further research is needed.

Toxicology and ecotoxicology

Available ecotoxicological and toxicological studies have mostly been restricted by the methodological gaps in analysis and detection, and thus research on this topic is also required. The uptake of several types of fine particles have been studied in mammalian (including human) gastrointestinal systems and transport into blood and lymph was observed[33]. Moreover, transfer of polystyrene particles via the placentas to fetuses has been reported[34]. Particle toxicity studies showed evidence of the toxicity of plastic particles in diverse biological systems. Besides cytotoxicity[35], inflammatory effects and transfer into capillary space were observed (e.g. rat lung[36, 37]). Concentrations of nano-polystyrene (PS) between 0.22 and 103 mg nano/L reduced population growth and reduced chlorophyll concentrations in the algae, while exposed Daphnia magna showed a reduced body size and severe alterations in reproduction [38].

Relevance of microplastics for public water supplies

Water suppliers using waste water or surface water as a direct or indirect raw water resource are likely to be most affected by the potential presence of microplastic particles. Larger particles, as investigated in many studies, will presumably be retained during membrane filtration, media filtration, bank filtration, artificial recharge or underground passage. Data on the occurrence of very small microplastic particles in freshwater systems and their behavior during water treatment are still completely lacking at this stage. The different specific surface properties and charge of microplastics, natural inorganic particles, organic debris, and bacteria complicate analog deductions from conventional particle elimination studies. In addition, the rapid colonization of microorganisms on microplastic particles, as shown in the marine environment [25], could be of concern. There are currently no comprehensive studies on microplastics in raw water resources, their behavior during drinking water treatment and their potential occurrence in drinking waters, thus this is an priority area for research.

Implications for wastewater treatment

Wastewater, receiving waters and wastewater affected surface water serve as raw water resources for drinking water production. First results suggest that microplastics are not completely retained in WWTP. Therefore, the retention of microplastics during wastewater treatment and the release from WWTPs should be closer investigated – and – if necessary, monitoring programs should be prescribed and techniques for better retention should be developed or the use of available efficient techniques should be regulated by law.

Most important gaps to fill

Regarding public water supply, it is **most important** to achieve information on particles **< 300 µm**. There is a lack of standardized sampling protocols and analytical methods to determine the occurrence of microplastics in fresh water resources, waste water, sludge/sediments and biological matrices. Moreover, retention during water treatment – both waste water and drinking water - and potential exposure of consumers via drinking water must be investigated. Finally, the toxicology of microplastics and overall relevance for drinking water production must be evaluated. The following priorities are seen for the near future:

- Development and harmonization of a sampling protocol for microplastics in aqueous matrices
- Development and harmonization of analytical methods for identification of polymers and quantification of particle size and particle concentration
- Investigation of microplastics retention during drinking water treatment
- Investigation of retention during wastewater treatment and release of microplastics from WWTPs
- Depth-oriented monitoring of surface water
- Definition of size fractions relevant for future monitoring programs
- Toxicological studies with relevant size fractions

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