



Microplastic sampling techniques in freshwaters and sediments: a review

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Abstract

Pollution by microplastics is of increasing concern due to their ubiquitous presence in most biological and environmental media, their potential toxicity and their ability to carry other contaminants. Knowledge on microplastics in freshwaters is still in its infancy. Here we reviewed 150 investigations to identify the common methods and tools for sampling microplastics, waters and sediments in freshwater ecosystems. Manta trawls are the main sampling tool for microplastic separation from surface water, whereas shovel, trowel, spade, scoop and spatula are the most frequently used devices in microplastic studies of sediments. Van Veen grab is common for deep sediment sampling. There is a need to develop optimal methods for reducing identification time and effort and to detect smaller-sized plastic particles.

Keywords Microplastic pollution · Freshwater systems · Polymer · Sampling · Water · Sediment

Introduction

Ecosystems and their different organisms have been widely impacted by anthropogenic activities such as the discharge of pollutants (Hamidian et al. 2019; Mirzajani et al. 2016, 2015; Padash Barmchi et al. 2015; Rezaei Kalvani et al. 2019), including emerging contaminants (Jafari Ozumchelouei et al. 2020) such as microplastics. Endurance, flexibility, lightweight, being low cost and being waterproof allows for plastic use in different applications, leading to their accumulation in the environment (Pellini et al. 2018; Razeghi et al. 2020). Plastic materials are used in a wide variety of

markets and industries, including packaging, building and construction, electrical, agriculture, consumer and household appliances such as toothpaste and facial scrubbers, etc. (Wu et al. 2018). According to data from Plastics Europe, world production of plastics reached 335 million tons in 2016 (Plastics Europe 2018). It is estimated that by 2050, this may increase to 33 billion tons (Horton et al. 2017). By then, 12,000 million metric tons (Mt) of plastic waste will have been accumulated in landfills and natural environments (Geyer et al. 2017). Recently, a sharp increase is induced in plastic waste production such as masks, gloves, and plastic shopping bags by the coronavirus disease (COVID-19) pandemic (Gorrasi et al. 2020). Once plastics are discharged into aquatic environments, they can persist for up to 50 years. Complete plastic mineralization may take hundreds or thousands of years (Holland et al. 2016).

Microplastics are generally defined as plastic particles smaller than a specified upper size limit (< 5 mm). However, sometimes smaller size limits have also been proposed. Currently, there is no specific lower size cutoff for this definition (Connors et al. 2017). Since the 1970s when the first reports of micro-sized particles were published, marine plastic pollution has been of concern (Carpenter and Smith 1972; Carpenter et al. 1972; Colton et al. 1974). Plastic debris in the ocean was recognized by the United Nations Environment Program (UNEP) as an emerging

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global environmental issue (Kershaw et al. 2011). However, “microplastics” were first described by Thompson and colleagues in 2004. They reported the occurrence and presence of plastics around 50 μm in size on shorelines and in water column (Thompson et al. 2004). Microplastics are commonly defined as plastic particles with sizes below 5 mm (Hidalgo-Ruz et al. 2012).

Depending on the way in which microplastics are produced, they can be classified into two classes as primary or secondary. Primary microplastics are small plastic particles released directly into the environment by domestic and industrial effluents, spills and sewage discharge or indirectly by runoff. Secondary microplastics are formed as a result of fragmentation of larger plastic particles already present in the environment. Fragmentation takes place due to UV radiation (photo-oxidation), mechanical transformation (e.g., via waves abrasion) and biological degradation by microorganisms (de Sá et al. 2018; Thompson et al. 2009).

There are hundreds of commercially available plastic materials. Polypropylene and low- and high-density polyethylene are the three most common used plastic polymers in packaging. Polyvinyl chloride, polyurethanes, polyethylene terephthalate, polystyrene and polyester are also widely used due to their various applications (Plastics Europe 2018).

In terms of shape, microplastics fall into five main groups. Fragments are three-dimensional and hard jagged-edged particles. Pellets have hard rounded shape. Fibers are fibrous or thin uniform plastic strands, and films are thin, two-dimensional plastic pieces. Foam is a mass of tiny bubbles (i.e., styrofoam-type material) (Anderson et al. 2017; Rezaia et al. 2018). Using different measuring instruments, different results may be obtained in terms of shape, size and type of microplastics. The major sampling techniques are shown in Fig. 1.

Despite extensive research on microplastics in marine environments, less effort has been made to monitor microplastics in freshwaters. Freshwaters include water in ice sheets, ice caps, glaciers, icebergs, bogs, ponds, lakes, rivers, streams, marshlands, wetlands and groundwater. Freshwaters are generally characterized as having low concentrations (less than 1000 mg L^{-1}) of dissolved salts and other total dissolved solids (American Meteorological Society 2012). Although the ocean floor is considered to be the ultimate fate of marine microplastics, inland water bodies might also be a terminal or transient sink for microplastics (Z. F. Wang et al. 2018b). Freshwater bodies can have comparable plastic concentrations to marine waters.

Microplastics can cause several harmful physical effects on humans and living organisms through such mechanisms as entanglement and ingestion. They can cause blockage of the gastrointestinal tract or inflammatory responses and consequently a range of adverse effects. Some effects

include lower energy reserves, reduced reproduction/growth, oxidative damage, metabolism disruption, cellular lesions, starvation and even death (Ding et al. 2018; Ogonowski et al. 2016). Exposure of microplastics to a cohort of human adults (hand-face skin, head hair and saliva) has been reported (Abbasi and Turner 2021).

The trophic transfer of microplastics in the aquatic food web has been demonstrated by researchers (Farrell and Nelson 2013; Setälä et al. 2014). Microplastics’ large surface area to volume ratio provides a high association potential for environmental contaminants. Microplastics have an affinity for certain hazardous hydrophobic organic chemicals, non-essential trace elements and persistent organic pollutants. Some examples include polychlorinated biphenyls, dichlorodiphenyltrichloroethane, additives, plasticizers and heavy metals (Brennecke et al. 2016; Hartmann et al. 2017; Holland et al. 2016; Koelmans et al. 2016; Naqash et al. 2020).

Wastewater treatment plants receive large amounts of microplastics among other pollutants. However, efforts of treatment (Mojoudi et al. 2018, 2019) including biological methods (Alavian et al. 2018; Hamidian et al. 2016; Mansouri et al. 2013; Mirzajani et al. 2017) remove most of these emerging pollutants.

Different microplastics treatment methods include sorption and filtration, biological removal and ingestion, and chemical treatments. Sorption of microplastics on green algae is based on charged microplastics. Membrane technology regarding durability, influent flux, size and concentration of the microplastics in water and wastewater have shown good efficiency. Coagulation and agglomeration processes, using Fe-based and Al-based salts, are also reported. Electrocoagulation technique and photocatalytic degradation using TiO_2 and ZnO semiconductors are used as robust and environmentally friendly techniques. Microplastics ingestion by organisms is also discussed as a removal strategy. However, sorption and filtration processes coupled with membrane bioreactors lead to higher microplastics removal compared to other methods (Hamidian et al. 2021; Padervand et al. 2020). Othman and coworkers reviewed microplastics degradation through enzymatic processes (Othman et al. 2021). ZnO nanorod photocatalysts excited by visible light were used to degrade low density polyethylene film in water (Tofa et al. 2019).

Inland waters and marine environments are facing similar issues related to microplastics presence. However, some differences like physical and chemical characteristics of water cannot be ignored. Here we review techniques for sampling microplastics in waters and sediments with focus of the following issues:

- a. What is the evolution of the number of scientific studies on microplastics in freshwater and sediment?

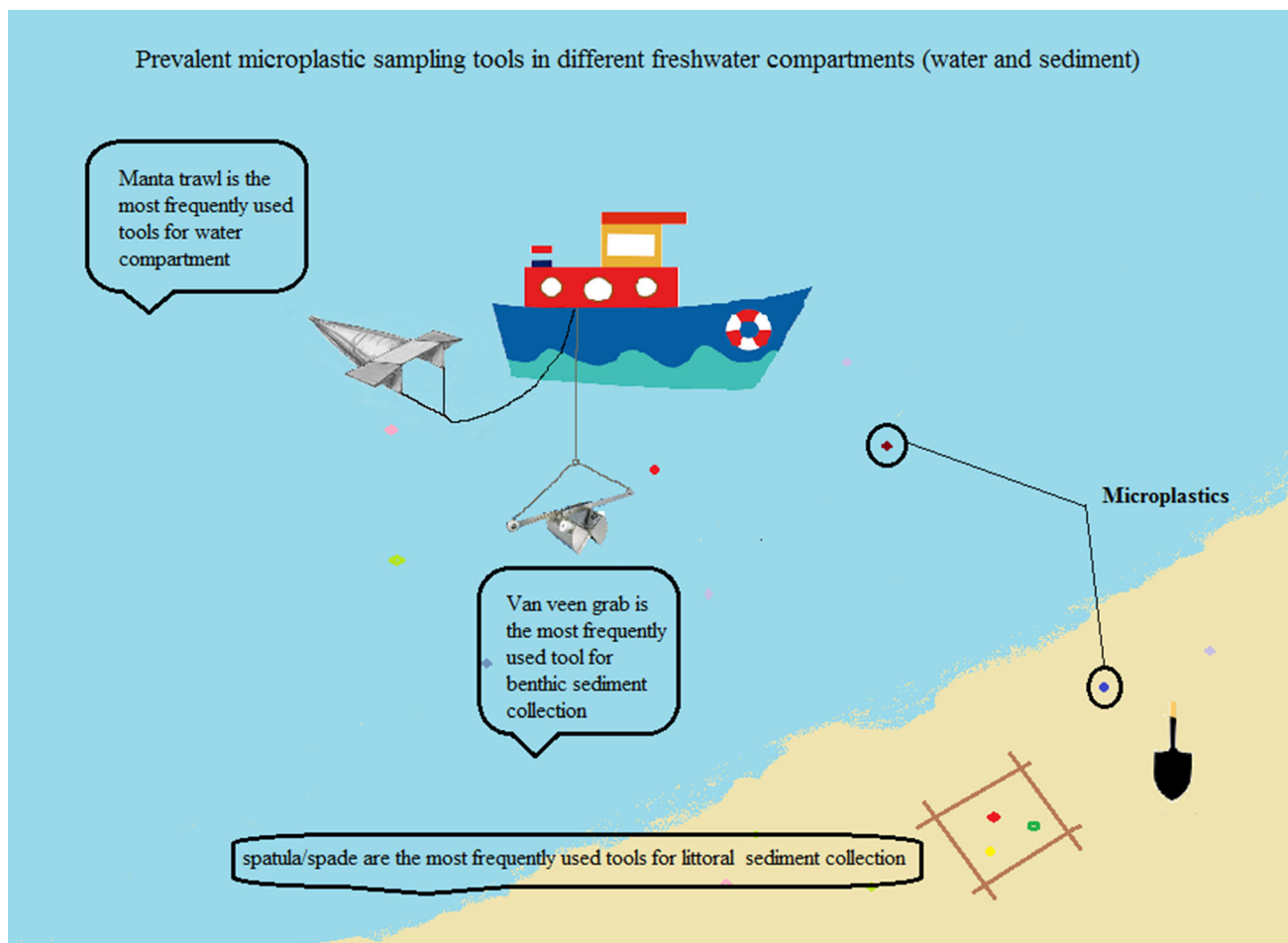


Fig. 1 Common techniques to sample microplastics

- Which freshwater compartments are more commonly investigated for microplastics?
- Which sampling matrix, water or sediment, is most frequently studied?
- What are the most common sampling methods in water and sediment studies?
- What are the advantages and disadvantages of sampling methods?

Data acquisition

Literature was gathered through online search in the ISI Website of Knowledge, Science Direct and Google Scholar using keywords and phrases including “microplastic” OR AND “freshwater”, OR AND “plastic particle”, OR AND “plastic fragment”, OR AND “pellets” OR AND “river” OR AND “estuary” OR AND “lake”. The retrieved articles were then screened by study area, of which studies in water and sediment of inland water systems were selected including rivers, estuaries, lakes, reservoirs, estuaries, etc.

After identifying candidate research, the abstracts of all studies reporting microplastics in freshwater ecosystems were studied. It is worthy noticing that microplastic research solely on microplastics in freshwater species was excluded. However, a combination of water or sediment studies with biota or all three (water, sediment and biota) were included simultaneously. A total of 150 published pieces of research between 2010 and 2020 were retrieved and evaluated. Details of each study were recorded in an EXCEL spreadsheet for subsequent analysis. This information was used to determine the extent and depth of current microplastic research and to identify important data gaps.

Microplastics presence in freshwater environments

Research papers with an emphasis on microplastics in inland water bodies are mostly published in the last ten years. Microplastics have been recorded along shorelines of the Tamar estuary, UK (Browne et al. 2010). In two urban rivers

(the Los Angeles River and the San Gabriel River), Southern California, microplastics were found 16 times more abundant than macroplastics and three times heavier than the bigger particles (Moore et al. 2011). Zbyszewski and Corcoran (2011) scrutinized the distribution and degradation of plastic particles along the beaches of Lake Huron, Canada (Zbyszewski and Corcoran 2011). The first ecosystemic review, assessing microplastics in different compartments, including water, sediment and biota, was reported by Faure et al. in Lake Geneva, Switzerland. Plastics were found on every beach and in the surface layer of Lake Geneva. However, no plastics were observed in biota in this study (Faure et al. 2012). Studies detecting microplastics in different freshwater compartments across continents and even in remote areas (Free et al. 2014; Zhang et al. 2016) are summarized in Tables 1–4.

The numbers of microplastic studies in freshwater environments increased rapidly from four in 2013 to 37 studies in 2019 and 27 papers as of September 2020 (Fig. 2).

In the early stages, it was suggested that the chemical types of microplastics in freshwater seem to be less diverse compared to those collected from the marine salty environment. This observation was attributed to the higher density of seawater, which enables more types of plastic materials with different densities to float on the surface of the water (Zhang et al. 2015). However, this is not always the case, because the processes of controlling distribution and exposure to plastics particles are not necessarily restricted to a specific environmental compartment. Polymers with higher density (density $> 1.0 \text{ g mL}^{-1}$) were observed in freshwater environments (Moore et al. 2011; Zhou et al. 2020). Negatively buoyant particles (e.g., polyester, rayon, nylon and cellulose acetate) may remain suspended in water (Baldwin et al. 2016). There may be differing degrees of physical and chemical characteristics, such as storms and wave action and saline water in marine systems. But plastics in freshwater systems still experience physical and chemical degradation (Andrady et al. 2011). It was suggested that polymer density alone is not the most significant control on microplastic particle fate within the aquatic environment. Microplastic morphology, incorporation into copolymeric materials during manufacturing and inclusion within aggregates of varying overall densities may play major roles in microplastics distribution (Hendrickson et al. 2018).

The ability to capture plastic particles from water or sediment matrix and separating them from organic and mineral material are challenging. Identifying types of plastics in the samples and on different surfaces is also important (Costa et al. 2021). It is suggested that microplastics in freshwater systems are similar to those in marine environments, and they are exposed to similar threats (Holland et al. 2016). Therefore, microplastic characteristics, detection methods, methods of analysis and impacts on biota are suggested to be similar.

Sampling procedure and tools

Choice of preservation techniques in different stages of microplastic studies largely depend on the research question (Lusher et al. 2017), economic proportionality of the methods and also the study compartment. Microplastics have now been reported in a range of freshwater environments, including surface water, water column, benthic sediments, littoral sediments and aquatic biota. Three main strategies are identified for sampling. They include selective sampling, volume-reduced sampling and bulk sampling. Different sampling strategies may be selected when the type of matrix to be examined for microplastics (water or sediment or biota) has been taken into account. Selective sampling in field consists of direct collection of items from the environment which are recognizable by the naked eye. This method is usually used on the surface of shore sediments and is more practical for large microplastics (1–5 mm). Bulk samples refer to samples where the whole volume of the sample is taken without reducing it during the sampling process. Volume-reduced samples in both sediment and water samples refer to samples where the volume of the bulk sample is usually reduced during sampling. Only a portion of the sample is preserved in this method, and it is mostly used for water samples (Hidalgo-Ruz et al. 2012).

Water compartment

In water samples, microplastic burden in the measuring units is much lower compared to that in sediment samples. Consequently, analysis of water samples requires higher sampling volumes (Huppertsberg and Knepper 2018). Volume-reduced methods are on-site filtration by nets or sieving. They are more suitable for water samples as they give a promising specimen volume without the need to transfer the whole to the laboratory. Therefore, resulting in a relatively small concentrated final sample. Here we discuss three main water sampling methods, including trawls, pump samplers and grab samples.

Trawls and nets

Different types of trawls and nets like manta, neuston or plankton nets and bongo net are used (Fig. 3). Trawl is usually deployed off of a boat, submerged and towed on a linear course at a low speed for a set time or distance (Hidalgo-Ruz et al. 2012; Sighicelli et al. 2018). The area of each sampling is calculated by multiplying the towing distance with the width of the trawl. The volume of water through the net uses either a flow meter or calculations based on the distance traveled by boat at a constant speed

Table 1 Microplastic studies in water of inland water bodies around the world

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
River–estuary	1	Three Gorges Dam—China	Trawl with a rectangular opening 50 cm high by 100 cm wide, and 1.5 m long, 112-mm-mesh size nylon net with a 500-mL polyethylene collecting bottle at the end	Sheets, PP, 500 μm –1.6 mm	Zhang et al. (2015)
	2	The North Shore Channel (NSC) in Chicago, Illinois (IL), USA	Two neuston nets (0.92 \times 0.42 m and 0.36 \times 0.41 m), 333 μm mesh size	Fiber	McCormick et al. (2014)
	3	29 Great Lakes tributaries, USA	Neuston net 1.5-m-long net with an opening 100 cm wide by 40 cm high, 333 μm mesh size	Fibers, 0.355–0.999 mm	Baldwin et al. (2016)
	4	Inflow (Red and Assiniboine rivers) and outflow (Nelson River) of Lake Winnipeg, Canada	Manta trawl 295 cm long, an aperture width of 61 cm, and a height of 18 cm, 333 μm mesh size	Fibers	Warrack et al. (2018)
	5	Tamar Estuary, UK	Manta net 0.50 m by 0.15 m, 300 μm mesh size	Fragments, PE, 1–3 mm	Sadri and Thompson (2014)
	6	Los Angeles and San Gabriel Rivers, USA	Manta trawl 0.9 m \times 0.15 m, 333 μm mesh size, hand nets 0.46 m \times 0.25 m, 800 μm mesh size and 0.43 m \times 0.22 m, 500 μm mesh size, streambed 0.15 m \times 0.15 m, 333 mesh size, rectangular net 0.45 m \times 0.25 m, 333 mesh size	Foams, PS, \geq 1 mm and < 4.75 mm	Moore et al. (2011)
	7	Danube River, Austria	Stationary conical drift nets 0.5 m diameter, 1.5 m long, 500 μm mesh size	–	Lechner et al. (2014)
	8	Four Estuarine Rivers in the Chesapeake Bay (Patapsco, Magothy, Rhode, and Corsica rivers), USA	Manta net 70 cm wide, 330 μm mesh size	–	Yonkos et al. (2014)
	9	Yangtze Estuary and East China Sea, China	Teflon pump passed through a 32- μm steel sieve, neuston trawl 30 \times 40 cm^2 opening, 333 μm mesh size	Fibers, > 0.5–1 mm	Zhao et al. (2014)
	10	Rhine River—Switzerland	Manta trawl with rectangular opening of 60 cm \times 18 cm, mesh 300 μm mesh size	Opaque spherules, PS	Mani et al. (2015)
	11	Solent estuarine complex (Hamble, Itchen and Test rivers), UK	Plankton net trawl, 300 μm mesh size	Fibers, blue, black, clear, white	Gallagher et al. (2016)
	12	Three urban estuaries (Jiaojiang, Minjiang and Oujiang Estuaries), China	Teflon pump passed through a 333- μm steel sieve	Fibers, PP, < 0.5–1 mm, < 1–2 mm	Zhao et al. (2015)
	13	Pearl River along Guangzhou city and Pearl River estuary, China	Water sampler passed through a 50- μm stainless steel sieve	Films, PA, < 0.5 mm	Yan et al. (2019)

Table 1 (continued)

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
	14	Saigon River, Vietnam	A bucket and plankton net, 300 μm mesh size	Fibers, PES	Lahens et al. (2018)
	15	Hudson River, USA	Grab sample, metal bucket (3L)	Fibers, PET	Miller et al. (2017)
	16	Raritan River, New Jersey, USA	Plankton nets 0.2 m diameter, 0.51 m long, 153 mm mesh size	–	Estahbanati and Fahrenfeld (2016)
	17	Rivers State, Nigeria	Plankton net	–	Briggs et al. (2019)
	18	Meuse, Rhine, Europe	–	Fibers	Brandsma et al. (2013)
	19	Goose Creek, Little Kickapoo Creek, and East Branch of the DuPage River, USA	Neuston nets 0.52 m \times 0.36 m, 333 μm mesh size	Pellets, PE	McCormick et al. (2016)
	20	Rhine, Dalälven, Danube and Po Rivers, Europe	Manta net internal width 60 cm, 330 μm mesh size, Pump, waste free water sampler mesh size 3.2 mm	Fragments, pellets, PE	van der Wal et al. (2015)
	21	Jade system, south North Sea, Germany	Grab sample, PE bottle (100 ml) passed through 1.2- μm cellulose nitrate filters	Fibers	Dubaish and Liebezeit (2013)
	22	Snake River and Palisades Reservoir, USA	–	Fibers	McDevitt and Perez (2016)
	23	29 Rivers, Japan	Plankton net 30 cm \times 75 cm, 335 μm mesh size	–	Kataoka et al. (2019)
	24	Snake River and Columbia River, USA	Grab sample, glass jars, mean volume 1.85 L, plankton net, 100 μm mesh size	Fibers, 100–333 μm	Kapp and Yeatman (2018)
	25	Rhine River, Germany	Manta trawl 60 cm \times 18 cm rectangular aperture, 300 μm mesh size	PS-DVB ion-exchange resins	Mani et al. (2019a)
	26	Gallatin River watershed, USA	Grab sample, stainless steel bottles (1L)	Fibers, Semi-synthetic cellulose, PES, 0.1–1.5 mm	Barrows et al. (2018)
	27	Changjiang Estuary, China	A screw pump (100 L) passed through a stainless steel sieve 60 μm pore size	Fiber, PE	Zhao et al. (2019)
	28	Changjiang Estuary, China	A pump (100 L) passed through stainless steel sieve 70 μm mesh size	Fibers, PE0.07–1.0 mm	Xu et al. (2018)
	29	Pasig River, Philippines	Two Manta trawl 25.7 cm diameter opening and 10.4 cm diameter opening, 355 μm mesh size	Fragments, 1.16 \pm 0.42 mm	Deocaris et al. (2019)
	30	Danube River, Austria	Net 600 \times 600 mm opening, 500, 250, 41 μm mesh size, BFG basket sampler 300 \times 600 mm opening, 500 μm mesh size	–	Liedermann et al. (2018)

Table 1 (continued)

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
	31	Muskegon River, Milwaukee River, and St. Joseph River, USA	Grab samples, 2-L glass bottle passed through a 0.363 μm mesh (surfaces water), Wading seine nets (biota)	Fibers, < 1.5 mm	McNeish et al. (2018)
	32	Clyde, Bega and Hunter estuaries, Australia	Horizontal surface tows using 45 μm mesh size (biota), vertical tows 37 μm net (biota)	Fragments, 45–100 μm	Hitchcock and Mitrovic (2019)
	33	Douro estuary, Portugal	A conical 1 m diameter, 4 m long, 500 μm mesh size (biota)	–	Rodrigues et al. (2019)
	34	Ofanto River, Italy	Plankton nets 2.5 m long with an opening of 55 cm \times 55 cm, 333 μm mesh size	Fragments, flakes, PE, 500–1000 μm , 1000–2000 μm	Campanale et al. (2020)
	35	Yellow River, China	Stainless steel bucket (5 L)	Fibers, 50–100 μm	Han et al. (2020)
	36	Swiss Rhine River catchment at Brugg and the downstream German-Dutch border at Rees (Germany and Switzerland)	Manta trawl 60 cm \times 18 cm, 300 μm mesh size	Fragments, PE, 0.3–1 mm	Mani and Burkhardt-Holm (2020)
	37	Urban waters of seven cities in the Tuojiang River basin, China	Steel sampler (25 L) passed through 50 μm mesh size sieve	Fibers, PP, 0.5–1 mm	Zhou et al. (2020)
	38	Manas River, China	Stainless steel drum (2.5 L)	Fibers, PP, 0.3–1.0 mm	G. Wang et al. (2020)
	39	Minjiang River watershed, Southeast China	Metal pail passed through 300 μm mesh size	Fibers, PET, 1–2 mm	Huang et al. (2020)
	40	Meuse river and in Netherlands and the Dommel, Germany	A centrifugal water pump passed through of 300, 100, and 20 μm mesh size sieve	PE, 0–1000 μm	Mintening et al. (2020)
	41	Cherating river and mangrove, Malaysia	Conical nylon plankton net 0.3 m \times 1 m, 100 μm mesh size	Fragments, 0.5–1.0 mm	Pariatamby et al. (2020)
	42	Yulin River, China	Teflon pump (0.05 m ³) passed through 64 μm stainless steel sieve mesh size	Lines/fibers, PE, 64–100 μm	Y. Mao et al. (2020)
	43	Qing River, Beijing, China	Stainless steel bucket (20 L) passed through stainless steel 5000 μm mesh size	Fragments, PE, EPR	C. Wang et al. (2020)
Lake–reservoir	1	3 connected urban lakes and drainage playa wetlands, Lubbock, Texas, USA	Grab sample (3.50 L) passed through sieve (> 300, 250–299, 180–249, 106–179, and 53–105 μm mesh size)	53–105 μm	Lasee et al. (2017)
	2	Lake Hovsgol (mountain remote lake), Mongolia	Manta trawl 16 cm high \times 61 cm wide and a 3 m long, 333 μm mesh size	Lines/fibers, 0.355–0.999 mm, 1.00–4.749 mm	Free et al. (2014)
	3	Laurentian Great Lakes (Lakes Superior, Huron and Erie), USA	Manta trawl with a rectangular opening 16 cm high \times 61 cm wide, and a 3 m long, 333 μm mesh size	Pellets, 0.355–0.999 mm	Eriksen et al. (2013)

Table 1 (continued)

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
	4	Lake Winnipeg, Canada	Manta 61 cm wide × 18 cm high and a 3 long, 333 μm mesh size	Fibers	Anderson et al. (2017)
	5	Dongting Lake and Hong Lake, China	12 V DC Teflon pump (20 L) passed through 50 μm mesh size	Fibers, PP, PE, 50–330 μm, 330–1000 μm	W.F. Wang et al. (2018)
	6	Western Lake Superior, USA	Manta net 85 cm wide × 14 cm high and a 3 m long, 333 μm mesh size	Fibers, PVC	Hendrickson et al. (2018)
	7	Lake Michigan, USA	Manta trawl 61 cm wide × 16 cm high and a 3 m long, 333 μm mesh size	Fragments, PE, 0.355–.999 mm	Mason et al. (2016)
	8	Lake Maggiore, Iseo and Garda, Italy	Manta trawl 60 × 20 cm, 300 μm mesh size	Fragments, PE	Sighicelli et al. (2018)
	9	Urban Lakes in Changsha, China	40 L water passed through 45 μm mesh size	Lines, 50–500 μm	Yin et al. (2019)
	10	Feilaixia Reservoir in the Beiji River, China	Conical plankton 20 cm diameter, 112 μm mesh size	Films, PP, 0.6–2 mm	Tan et al. (2019)
	11	Lake Ulansuhai, China	12-V DC Teflon pump passed through 48 μm mesh size	Fibers, PE, < 0.5 mm	Wang et al. (2019)
	12	Mecklenburg Lake District in Mecklenburg-Western Pomerania, Germany	Pump water samples, Manta trawl	Irregular particles, PE, PET, 0–1000 μm	Tamminga et al. 2020
	13	Wuliangshuai Lake, northern China	Stainless steel buckets (20L) passed through 75 μm mesh size sieve	Fibers, PS, < 0.5 mm	R. Mao et al. (2020)
Stream	1	Six Mile Creek and Fall Creek streams, USA	Neuston net 1 × 0.5 m, 333 μm mesh size	Fibers	Watkins et al. (2019b)
Stream–lake	1	Streams and wetlands, Victoria, Australia	Grab surface, polypropylene jars (5L) (water), dip nets (biota)	Fibers, PES, rayon, 0–1 mm	Nan et al. (2020)
Pond	1	North of Jutland, Denmark	A positive displacement pump passed through 10 μm stainless steel mesh size	PP	Liu et al. (2019)
River–estuary–lake	1	Urban lakes and urban reaches of the Hanjiang River and Yangtze River, Wuhan, China	12 V DC Teflon pump (20 L) passed through 50 μm stainless steel sieve	Fibers, PET, 50–500 μm (or < 0.5 mm)	W.F. Wang et al. (2017)
City creeks–rivers–estuary and coastal waters	1	City creeks (Shanghai), rivers (Suzhou River and Huangpu River), an estuary (Yangtze Estuary) and coastal waters (East China Sea), Yangtze Delta area, China	Metal pail (5 L) passed through 20 μm mesh size filter, air lift pump	Fibers, PES, 0.1–1.0 mm	Luo et al. (2019)
River water–wastewater–total atmospheric fallout	1	Greater Paris–Seine River, France	Manta trawl 330 μm mesh size, Plankton net 80 μm mesh size	Fibers, 1001–5000 μm	Driss et al. (2015)

Table 1 (continued)

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
River–atmospheric fallout–urban runoff–WWTP effluents–CSOs	1	River Marne, France	Manta trawl 80 and 300 μm mesh size	Fibers	Dris et al. (2018)
Surface water, storm water runoff, agricultural runoff, and treated wastewater effluent	1	Lake Ontario of the Laurentian Great Lakes in Canada	Stainless steel bucket (4 L) passed through 10 μm mesh size filter	Fibers	Grbić et al. (2020)
Urban prairie creek	1	Wascana Creek, northern outskirts of Regina, Canada	Conical net (water), seine nets, gill nets, conventional tackle, and minnow traps (biota)	Fibers	Campbell et al. (2017)

(Sadri and Thompson 2014). However, because the net's immersion depth changes constantly with waves, wind and boat movement, it is difficult to estimate the exact volume of water being filtered.

Campanale et al. (2020) collected microplastics by three surface plankton nets fixed in the middle of Ofanto River, in order to reduce the spatial and temporal variability (Campanale et al. 2020). In order to ensure that the most representative body of water is being sampled, factors such as time, location and length of trawls in relation to the strength of tides should be carefully considered. Furthermore, the trawling distance using nets varies depending on the abundance of floating microplastics. It should further consider whether the trawl direction with reference to the prevailing wind direction could have an effect on the abundance and size of particles captured within the trawl (Zhang et al. 2018). In these methods, nets are limited by a single mesh size that is sometimes clogged by suspended material (e.g., organic matter or phytoplankton) (Liedermann et al. 2018; Sadri and Thompson 2014).

Types of microplastics are closely related to the mesh size of tools used for specimen collection. For instance, smaller-sized mesh used in some studies could increase plastic particles of certain shapes (e.g., fibers) to a concentration several orders of magnitude higher than those collected using nets with a larger mesh size. On that account, the abundance of microplastics is largely underestimated by researchers who used a trawl for sample collection (Z.F.Wang et al. 2018b). By using manta trawl, a significant fraction of actual small microplastic particles is very likely to be underestimated because they might pass through the net.

Regarding the limitations of obtaining sufficient water volumes while avoiding net clogging, it was strongly recommended to use tandem nets with different mesh sizes. This helps to better characterize smaller microplastics (Anderson et al. 2017). Dris et al. (2018) had a 250-times higher probability of sampling fibers when using an 80- μm mesh compared to a 330- μm mesh (Dris et al. 2018). Double neuston net trawl (500 μm mesh size) was used as sampling tool in assessing microplastics in surface waters of Lake Superior. No difference was detected between the paired net samples, suggesting that single net sampling produces a representative estimate of microplastic particle condition within a body of water (Cox 2018). A comparison study was conducted between a manta net and a neuston net for microplastics in ocean surface water. Results showed that the manta net tended to have slightly higher densities of microplastics than those of the neuston net. However, no statistical difference was observed. Neuston net is relatively stable in rough water although efforts are needed to maintain the net in submerged depth. Manta net tends to jump in rough water (Michida et al. 2019). Sampling with the manta trawl to function properly requires relatively calm conditions (Anderson et al. 2017). Modified BfG basket sampler used for the Austrian Danube River, clearly showed the necessity of a strong and stable equipment carrier. The nets were positioned on the surface, in the middle of the water column, and at the bottom of the river and with different mesh sizes (Liedermann et al. 2018).

Nets alone may fail to deliver the overall pattern of microplastic pollution in an area, because there does not seem to be sufficiently retaining fibers and small microplastics.

Table 2 Microplastic studies in sediment of inland water bodies around the world

Study compartment	Number	Study area	Sampling tool	Dominant microplastic characteristics (shape, polymer type, size)	Reference
River– estuary	1	Rivers and tidal flat of urban districts, Shanghai, China Littoral sediment	Shovel (0.5 m × 0.5 m quadrat, depth of 5 cm)	Spheres, PP, 100–500 µm	Peng et al. (2018)
	2	Changjiang Estuary, China Benthic sediment	Box corer (depth of 5–10 cm)	Fibers, rayon, 0–100 µm, 100–500 µm, 500–1000 µm (SMP)	Peng et al. (2017)
	3	Beijiang River littoral zone, China Littoral sediment	Stainless steel shovel (0.2 m × 0.2 m quadrat, depth of 2 cm)	PE	J.D. Wang et al. (2017)
	4	St. Lawrence River, Canada Benthic sediment	Petite Ponar grab (225 cm ² area), and Peterson Grab (930 cm ² area, depth of 10–15 cm)	Microbeads, PE	Castañeda et al. (2014)
	5	Tamar Estuary, UK Littoral sediment	–	Fibers, PES, < 1 mm	Browne et al. (2010)
	6	Rivers Rhine and Main, Germany Littoral sediment	Stainless steel spoon (30 cm ² area)	Fragments, PS, 63–200 µm	Klein et al. (2015)
	7	Thames River Basin, UK Littoral sediment	Stainless steel Scoop (depth of 10 cm)	Fragments, fiber, PET, 1–2 mm	Horton et al. (2017a)
	8	Gulf of Mexico estuaries (Mobile Bay, AL), USA Littoral sediment	(0.25 m × 0.25 m quadrat, depth of 3–6 cm)	Hard plastics, PE, 0.2–1 mm	Wessel et al. (2016)
	9	10 rivers, northwest UK Benthic sediment	Cylinder resuspension technique	Microbeads	Hurley et al. (2018)
	10	Two sandy beaches (Santubong and Trombol) in Kuching, Sarawak, Malaysia Littoral sediment	Stainless steel scoop (0.2 m × 0.2 m quadrat, depth of 2 cm)	PP, PE	Noik and Tuah (2015)
	11	Atoyac River Basin, Central Mexico Benthic sediment	Van Veen grab sampler, trowel	Films	Shruti et al. (2019)
	12	Urban river in Scotland (River Kelvin), UK Littoral sediment	A spade (depth of 8–10 cm)	Fibers	Blair et al. (2019)
	13	Derwent Estuary, Tasmania, Australia Benthic sediment	Sediment corer (depth of 104 cm)	Fibers, < 63- > 100 µm	Willis et al. (2017)
	14	Rhine River, Germany Benthic sediment	Steel spade, buckets of a chain dredging (depth of 52 cm and 111 cm)	APV, 62–125 µm	Mani et al. (2019b)
	15	Vitória bay estuarine system (SVB), Brazil Benthic sediment	Van Veen grab sampler	Fibers	Neto et al. (2019)
	16	River Tame and four of its tributaries, Birmingham, UK Benthic sediment	Stainless steel scoop (depth of 5–10 cm)	FragmentS, PE, 63–< 250 µm, 250–< 1000 µm	Tibbetts et al. (2018)
	17	Brisbane River, Australia Benthic sediment	Ponar stainless steel grab sampler (depth of 0–3 cm)	Films, PE, 3–4 mm	He et al. (2020)

Table 2 (continued)

Study compartment	Number	Study area	Sampling tool	Dominant microplastic characteristics (shape, polymer type, size)	Reference
	18	Liaohe estuary, Daliao River and Shuangtaizi River Benthic sediment	Steel grab sampler	Films, PE	Xu et al. (2020)
	19	Thames River, Ontario, Canada Benthic sediment	Stainless steel petite ponar grab sampler (depth of 90–100 cm)	Pellets, PE, 1–5 cm	Corcoran et al. (2019)
	20	Warnow estuarine, Germany Benthic sediment	Van Veen grab, Sediment trap	PS	Enders et al. (2019)
	21	River Yongfeng, China Benthic sediment	Peterson Gravity Sampler	Films, PE, 200–500 μm , 500–1000 μm	Rao et al. (2020)
	22	Jagir Estuary, Surabaya City, Indonesia Benthic sediment	Ekman dredge sampler	Lines/fibers, PES, small MP (1 μm -1 mm)	Firdaus et al. (2020)
Stream	1	Seven water streamssurrounding the lagoon of Bizerte, Northern Tunisia Littoral sediment	Stainless steel spatula (0.25 m \times 0.25 m quadrat, depth of 2–3 cm)	Fibers, PP	Toumi et al. (2019)
Lake–reservoir	1	Subalpine lake Garda, Italy Littoral sediment	–	PE	Imhof et al. (2013)
	2	Lake Ontario, Canada Littoral sediment and Benthic sediment	Glew gravity corer, shipek grab, ponar grab, split spoon corer	Fragments, PE	Ballent et al. (2016)
	3	Lake Ontario, Canada Littoral sediment and Benthic sediment	Mini box corer (depth of 30 cm)	Pellets, PE, 1–5 cm	Corcoran et al. (2015)
	4	Remote lakes in Tibet plateau, China Littoral sediment	Shovel (20 cm \times 20 cm quadrat, depth of 2 cm)	PP, 1–5 mm	Zhang et al. (2016)
	5	Beaches of Lake Huron, Canada Littoral sediment	Stainless steel trowel	Pellets, PE, < 5 mm	Zbyszewski and Corcoran (2011)
	6	Great Lakes, North America Lake Erie and St. Clair, USA Littoral sediment	Stainless steel trowel	Fragments, PE	Zbyszewski et al. (2014)
	7	Edgbaston Pool, Birmingham, UK Littoral sediment and Benthic sediment	HTH gravity corer (depth of 10 cm)	Fibers, Films	Vaughan et al. (2017)
	8	Setúbal Lake, Portugal Littoral sediment	Stainless steel shovel (0.25 m \times 0.25 m quadrat, 3 cm depth)	Fragments	Blettler et al. (2017)
	9	Beaches of Lake Garda, Italy Littoral sediment	Sediment cores (depth of 10 cm)	1–50 μm	Imhof et al. (2018)
	10	Lake Erie, Canada Littoral sediment and Benthic sediment	Shipek sediment grab sampler and passive sediment trap, split spoon sampler, Petite Ponar grab sampler	Fibers, PE	Dean et al. (2018)

Table 2 (continued)

Study compartment	Number	Study area	Sampling tool	Dominant microplastic characteristics (shape, polymer type, size)	Reference
	11	Subalpine Lake Garda, Italy Littoral sediment	Sediment cores (depth of 5 cm)	–	Imhof et al. (2016)
	12	Three Gorges Reservoir, China Littoral sediment	Stainless steel Trowel (20 cm × 20 cm, depth of 2 cm)	Sheet, PP, 1–5 mm	Zhang et al. (2019)
	13	Hampstead Pond (Lake), UK Benthic sediment	Piston corer (depth of 212 cm)	Fibers	Turner et al. (2019)
	14	Lake Mjøsa and Lake Femunden, Norway Benthic sediment	Kajak-Brinkhurst sediment corer (depth of 3 cm), Van Veen grab (depth of 10–15 cm)	Fibers, PS, Small microplastics < 1 mm	Lusher et al. (2018)
	15	Lake Victoria, Uganda, Africa Littoral sediment and Benthic sediment	Stainless steel trowel (0.5 cm × 0.5 cm quadrat, depth of 5 cm), Ponar grab	Films (shoreline), filaments (lake), PE, 0.3–1 mm (lake) 1–2 (shoreline)	Egessa et al. (2020)
	16	Donghu Lake, Wuhan, china Benthic sediment	Piston gravity sampler (depth of 57 cm)	Fibers, PET, < 0.5 mm	Dong et al. (2020)
	17	Lake Ziway, Ethiopia Benthic sediment	Ekman grab sampler (depth of 0–2 cm)	Fragments, PE, 0.15–5 mm	Merga et al. (2020)
	18	Donting Lake, China Littoral sediment and Benthic sediment	Stainless steel shovel (0.25 m ² area, depth of 2 cm), grab sampler	Fibers, PET, PE, < 0.5 mm	Yin et al. (2020)
River– estuary– lake	1	Vembanad Lake, Kerala, India Benthic sediment	Van Veen grab (25 cm ² area)	Films, Foams, LDPE	Sruthy and Ramasamy (2017)
	2	Urban water areas in Changsha, China Littoral sediment	Shovel (depth of 5 cm)	Fragments, PS, < 0.5 mm	Wen et al. (2018)
	3	Coastal plain river network (Wen-Rui Tang River watershed) in eastern China Benthic sediment	Peterson grab (32 cm × 20 cm, depth of 0–15 cm)	Fragments, PE, 20–100 μm	Z.F. Wang et al. (2018)
	4	Skudai and Tebrau river, Malaysia Benthic sediment	Box corer	1001–5000 μm	Sarijan et al. (2018)
	5	Cecina river estuary, Tuscany, Italy Littoral sediment and Benthic sediment	Wide mouth glass jars 1 L by scientific scuba divers (depth of 5 cm)	Fragments, > 500 μm	Blašković et al. (2018)
Lagoon	1	Lagoon of Venice, Italy Benthic sediment	Box corer (depth of 0–5 cm)	Fragments, PE, < 100 μm	Vianello et al. (2013)
	2	Complex Lagoon-Channel of Bizerte, Northern Tunisia Littoral sediment	Stainless steel spatula (0.25 m × 0.25 m quadrats, depth of 2–3 cm)	Fibers	Abidli et al. (2016)

Table 3 Microplastic studies in water and sediment of inland water bodies around the world

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
River–estuary	1	Three Gorges Reservoir, China	12 V DC Teflon pump (25 L), passed through 48- μ m stainless steel sieve (water) and Van Veen grab (0.25 m ² area) (sediment)	Fibers, PS, < 0.5 mm	Di and Wang (2018)
	2	Five urban estuaries of KwaZulu-Natal, South Africa	Conical zooplankton net (300 μ m mesh size) (water) and sediment corer (depth of 10 cm) (sediment)	Fragments	Naidoo et al. (2015)
	3	Pearl River along Guangzhou City, China	Water sampler (5 L) (water), Van Veen grab (depth of 5 cm) (sediment)	Fibers, PP, 0.02–0.5 mm, 0.5–1 mm	Lin et al. (2018)
	4	Antuá River, Portugal	Water pump (55 μ m mesh size) (water), Van Veen grab (depth of 12 cm) (sediment)	Foams, PE, PP	Rodrigues et al. (2018)
	5	Ottawa River, Canada	Bottle sampling and Manta trawls (100 μ m mesh size) (water), Ekman bottom grab sampler (sediment)	Fibers	Vermaire et al. (2017)
	6	Charleston Harbor and Winyah Bay, two developed estuaries in US	Sea surface microlayer collection apparatus (4L) (water) and stainless steel trowel (0.25 m \times 0.25 m transect) (sediment)	Fragments, 150–499 μ m	Gray et al. (2018)
	7	Slum and industrial area of Ciwalengke River, Majalaya, Indonesia	Grab samples with glass container (1L) (water), Ekman grab sampler and shovel (sediment)	–	Alam et al. (2019)
	8	Pearl River catchment, China	Plankton net (160 μ m mesh size) (water), grasp bucket and gravity corer (depth of 54 cm) (sediment)	Sheets, PP, LDPE, < 0.25 mm	Fan et al. (2019)
	9	Wei River, China	Bulk sampling using clean pump (5L) passed through 75 μ m mesh size (water), grab (sediment)	Fibers, < 0.5 mm	Ding et al. (2019)
	10	Tibet Plateau Rivers, China (Buqu River (the source of the Yangtze	Large flow sampler (water) and a stainless steel shovel (depth of 2 cm) (sediment)	Fibers, PET (sediment samples), PE (water samples), < 0.5 mm	Jiang et al. (2019)
	11	Middle and lower reaches of the Yangtze River, China	A fishery administration vessel (AVANI trawl net 333 μ m mesh size), A plankton net (64 μ m mesh size) (water) and grab sampler (sediment)	Sheets, PP, 0.3–0.5 mm, 0.5–1 mm	Xiong et al. (2019)
	12	Nakdong River, South Korea	Stainless steel beaker, submersible pump (water), Van Veen grab (depth of 2 cm) (sediment)	Fragments, PP	Eo et al. (2019)
	13	Mohawk River, USA	Manta trawl (333 μ m mesh size) (water) and Ekman grab sampler was (sediment)	Fibers, fragments	Smith et al. (2017)
	14	Ebro River Delta, Northeastern Iberian Peninsula, Spain	Neuston net (5 μ m mesh size) (water), stainless steel spoon (0.2 m \times 0.2 m quadrant, depth of 2.5 cm) and van Veen grab sampler (sediments)	Fibers, PE, 200–500 μ m	Simon-Sánchez et al. (2019)
	15	Yongjiang River, Nanning City, South China	12 V DC Teflon pump (10 L) passed through 50- μ m-mesh size sieve (water) and Van Veen grab (sediment)	Fibers, PE, 330–1000 μ m and 1–3 mm	Zhang et al. (2020)

Table 3 (continued)

Study compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
	16	Maozhou River, China	Stainless steel bucket (5L), depth of 50 cm (water) box corer, depth of 20 cm (sediment)	Fragments, 10 μm –0.1 mm	Wu et al. (2020)
	17	Chao Phraya River, Bangkok, Thailand	Manta trawl 2 m long, width of 50 cm, and a height of 20 cm, 300 μm mesh size (water), Van Veen grab sampler (sediment)	Fragments, PP, 0.5–1.0 (water samples) 0.053–0.5 mm (sediment samples)	Ta et al. (2020)
	18	Ravi River in urban center (predominant drains and canals of Lahore district), Lahore, Pakistan	Stainless steel spatula, 0.3 m \times 0.3 m quadrat, depth of 1 cm (sediment)	Fragments, PE, 150–300 μm (sediment samples), and large size MPs 300 μm –5 mm (water samples)	Irfan et al. (2020)
	19	Magdalena River, Colombia	Neuston net 20 μm mesh size (water), metal shovel, depth of 5 cm (sediment)	Fibers, PP	Martínez Silva and Nanny (2020)
Lake–reservoir	1	Lake Bolsena and Lake Chiusi, Italy	Manta trawl 300 μm mesh size 60 cm \times 18.5 cm (water), 0.25 m ² area, depth of 3 cm (sediment)	Fibers, < 0.3 mm, 0.3–0.5 mm	Fischer et al. (2016)
	2	Dongting Lake, China	Flow sampler (30L), passed through 45 μm mesh size (water) and Stainless shovel 0.3 m \times 0.2 m quadrat, depth of 0–2 cm (sediment)	Fibers, PET (sediment sediment), PE (water sediment), < 0.5 mm	Jiang et al. (2018)
	3	Six dams near Ithaca, USA	Grab sample 1 L plastic bottles (water), plastic scoop (sediment samples)	Fibers	Watkins et al. (2019a)
	4	Danjiangkou Reservoir, China	12 V DC Teflon pump (20L), depth of 0–20 cm (water), grab (sediment)	Fibers, PP, group 1 (48 μm – 0.5 mm), group 2 (0.5–1 mm), group 3 (1–2 mm),	Di et al. (2019)
	5	Lakes along the middle and lower reaches of Yangtze River Basin, China	Neuston plankton net 74 μm mesh size (water), Van Veen grab (sediment)	Fibers, PET, 20–50 μm	Li et al. (2019)
Stram	1	18 streams in and around the city of Auckland, New Zealand	Phytoplankton net 63 μm mesh size (water) and scooped with container, depth of 5 cm (sediment)	Fragments, fibers (water samples), fragments (sediment samples), poly(hexadecyl) methacrylate (PHM), ethylene/ethyl acrylate copolymer (EEAC), 63–500 μm	Dikareva and Simon (2019)
Fish ponds	1	Central and Eastern European region	Jet pumps, passed through 2 mm mesh size strainer, depth of 10–20 cm (water), Veen grab sampler and a hand spade (sediment samples)	PP	Bordós et al. (2019)
River–estuary–lake–WWTPs	1	River Barrow, River, Nore, Lough, Lurgan (Cushina, Co. Offaly) and River Liffey (Newbridge, Co. Kildare), Ireland	-	PS	Cedro and Cleary 2015

Table 4 Microplastic studies in water, sediment and biota of inland water bodies around the world

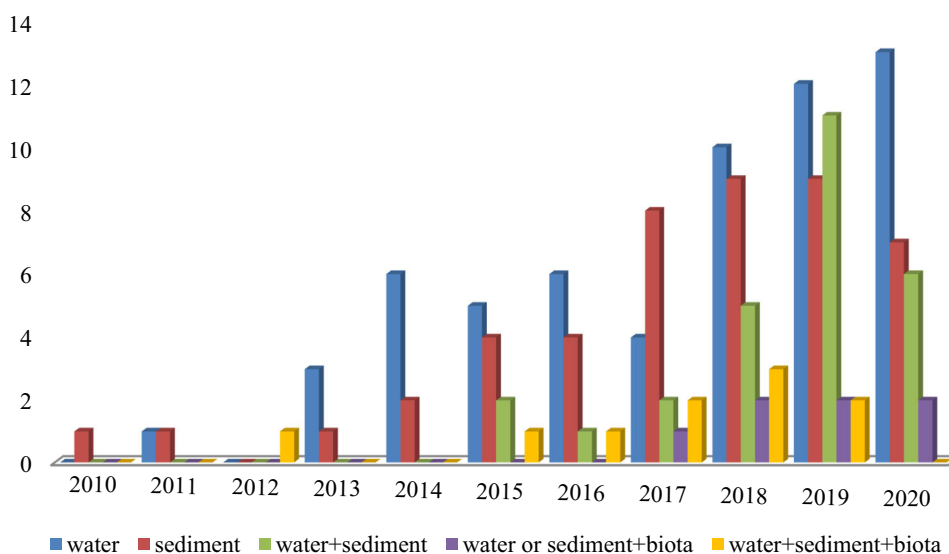
Water compartment	Number	Study area	Sampling tools	Dominant microplastic characteristics (shape, polymer type, size)	Reference
River– estuary– lake	1	Xiangxi Bay of Three Gorges Reservoir, China	Surface trawl 50 × 100 × 150 cm, 112 μm mesh size (water) and Petersen grab (sediment)	Sheets, PP, 1–5 mm	Zhang et al. (2017)
	2	Qinghai Lake, China	Trawl net 50 × 100 × 150 cm, 112 μm mesh size (water) and stainless steel shovel, 0.2 m × 0.2 m quadrat, depth of 0–2 cm (sediment)	Sheets, PP, PE, 0.112–0.5 mm	Xiong et al. (2018)
	3	Taihu Lake, China	Nylon plankton net 333 μm mesh size and steel sampler (5L) (water), Peterson sampler (sediment) and a bottom fauna trawl (biota)	Fibers, 100–333 μm, 333–1000 μm	Su et al., (2016)
	4	Lake Geneva, Switzerland	Manta trawl 300 μm mesh size (water), fishes and birds were collected by a fisherman	< 5 mm, PS	Faure et al. (2012)
	5	Poyang Lake, China	Steel sampler (20 L), passed through 50 μm mesh size (water), Van Veen grab (sediment), fish samples were obtained from an aquatic product market	Fibers, PP, 0.1–0.5 mm	Yuan et al. (2019)
River– estuary– lake	1	Six of the largest Swiss lakes and some rivers-Switzerland	Manta trawl 300 μm mesh size (water), multi-mesh gillnets and vertical benthic and pelagic nets (biota)	Fragments, PE, > 300 μm	Faure et al. (2015)
	2	Middle-Lower Yangtze River Basin, China	Steel bucket (5 L), depth of 0.12 cm (water), Peterson sampler, depth of 10 cm (sediment), bottom fauna trawls (biota)	Fibers, PES, 0.25–1 mm	Su et al. (2018)
Pond	1	Storm water pond, Viborg, Denmark	Bulk samples (10 L), glass bottles, depth of 10 cm (water), Sediment corer, depth of 5–8 cm (sediment), gill net and fishing net (biota)	PP	Olesen et al. (2019)
Small water bodies	1	Yangtze River Delta, China	Steel bucket (water), stainless steel spatula, depth of 0–5 cm (sediment)	Fibers, PES, < 0.5 mm	Hu et al. (2018)
River, Canal, WWTPs, Sea	1	Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota, Netherland and Germany	Bulk sample, glass bottles (2L) (water) and grab samples and Van Veen grab (sediment)	Fibers, 10–300 μm	Leslie et al. (2017)

Pump samplers and grab samples

Volume reduction pump sampler and grab samples are also used in some of the research papers. Pump sampling consist of pumping water manually or using a motor through an inline filter. Grab sampling method includes using a bucket to collect water and sieve the water in the field (Han et al. 2020; Miller et al. 2017; Y. Mao et al. 2020a). A fixed amount of bottle is also submerged, filling with surface water for laboratory analysis (Barrows et al. 2018; Dubaish and Liebezeit 2013). Water collected using pumps or bulk samplers is taken from different depths with different volumes. Due to the high variability of microplastic spatial

distribution, the sampling area covered is limited and using a pump or bulk sampler may not be representative. Therefore, taking multiple replicates is suggested (Zhang et al. 2018). However, pumps can be used to collect large volumes of water, which may be advantageous in areas where the density of microplastics is suspected to be low (Crawford and Quinn 2017). Water volume could be variable from 5 mL to 500 L (Braun et al. 2018). In addition, they do not possess the limitation caused by pacific sampling mesh tool. Based on literature reviews, significantly more microplastic particles are present in smaller size ranges. A combination of volume-reduced net-based sampling and bulk sampling seems to be very helpful

Fig. 2 Frequency and trend of studies ($n = 150$) on the presence of microplastic particles in freshwater environment in different matrix including water, sediment, water + sediment, water or sediment + biota and water + sediment + biota



in estimating the missing fractions and enables a greater spatial resolution (Fischer et al. 2016).

Comparison between different water sampling methods

In the comparison of manta trawling and pump sampling methods in microplastic sampling from water of Lake Tollense, Germany, different results were observed in the abundance of microplastics, microplastics shape and size. It was suggested that manta trawl is not sufficient in retaining fibers and small microplastics from water samples. Therefore, the pump sampling approach with the filtration of large water volumes is necessary to generate reliable results. However, the pump sampling covers small microplastics. Small plastic particles are greater in number. Volume-reduced sampling covers large microplastics, being less abundant but still important. Fibers detected in the manta samples were unevenly spread across the whole size range. Fibers found in the pump samples showed distinct positively skewed distribution peaking at > 500–600 μm in length. The most abundant polymer composition in manta trawl samples was polyethylene and polyethylene terephthalate for the pump sampling method (Tamminga et al. 2020).

Lahens and colleagues utilized a bucket and 300- μm plankton net. Bulk water sampling was used for anthropogenic fiber analysis and 300- μm -mesh size plankton net exposition for fragment analysis (Lahens et al. 2018). In the study of Su and colleagues, the average abundance of microplastics was found to be higher in plankton net samples rather than bulk surface water samples (Su et al. 2016). In general, water sampling volumes depend on the solid richness and the target microplastic size range. Barrows et al. (2017) compared grab samples to the

conventional neuston net approach. Grab samples collected three orders of magnitude more microplastics than the net approach (Barrows et al. 2017).

In comparison between manta trawl and in situ pump filtration methods, it was found that the pump sampling method is more accurate in volume measurement and versatile for point sampling and filter size choice. However, due to the lower sampling volume, it might be more suitable for sampling in areas with a higher level of contamination. On the other hand, the trawling method has the ability to cover and sample a larger area and therefore overcomes some of the problems related to patchiness (Karlsson et al. 2020). A combination of volume-reduced net-based sampling and bulk sampling seems to be very effective in comprehensive monitoring of microplastic in aquatic environment.

Sediment compartment

Because of such characteristics as buoyancy and extreme durability, synthetic polymers are present in rivers, lakes and oceans and accumulate in sediments all over the world. Microplastic durability makes it highly resistant to degradation from decades to millennia in its polymer forms (Mathalon and Hill 2014). Small plastic particles are easily accessible to a wide range of aquatic organisms, accumulating in their cells and tissues and ultimately transferred through the food web. Most plastics are extremely durable and persistent (Sharma and Chatterjee 2017).

Microplastics in water compartment may be diluted due to seasonal variation in water volume and water dynamic behavior. For sediment compartments, with a static environment, dilution barely happens, and sediments can easily act as accumulation environments. Sediments are a site of

microplastics accumulation and the habitat of benthic organisms, which are key components of food webs. In microplastic scientific assessment, sediment samples are taken from both the subtidal and benthic part of freshwater bodies. This issue affects the life quality of the organisms in ecosystems, both in benthic and littoral sediment zone. For example, microplastics were recorded in fecal samples and feathers of waterbirds from contaminated wetlands in South Africa. Plastic particles can fill the gizzard and possibly block the pyloric valve leading into the intestine (Reynolds and Ryan 2018). Microplastics were present in the benthic fish species and benthic organisms of the Caspian Sea, and the abundance of plastic particles in animals near the shore was greater than in the central part (Bagheri et al. 2020). High doses of microplastics led to fewer species and fewer juvenile isopods and periwinkles in European flat oysters and their associated benthic communities (Green 2016).

Sampling tools are selected with regard to sampling places. Sampling is performed in various directives with respect to the analysis of nutrients or pollutants, such as metal ions or persistent organic substances (Braun et al. 2018).

Manual grab samplers

Sediment manual grab methods utilize tools such as hand spades and stainless steel spoon for littoral and beach environments (Fig. 3). As sampling of sediments is facilitated compared to that of the water column, monitoring shore sediments appears to be advantageous. Moreover, non-buoyant particles can be analyzed in sediment samples rather than in water surface samples (Klein et al. 2015). Therefore, sampling from different compartments can give a comprehensive outlook of microplastic pollution problem.

Deep sediment samplers

Different kinds of grabs and corers are suggested to be suitable for deeper sediment sampling. Ekman and Van Veen grab samplers are deployed to study benthic sediment (Merga et al. 2020; Neto et al. 2019; Sruthy and Ramasamy 2017). Deep sediment sampler can provide a look at the changing abundance and microplastic debris in lake sediments that span a century to present day. These particle can contribute to the discussion on plastic wastes as stratigraphic markers for the Anthropocene (Turner et al. 2019; Vaughan et al. 2017). For specimen transition, the use of glass bottle is recommended. However, plastic or aluminum foil bags can also be used. In the case of plastic

container utilization, blank control should be included to prevent bias in the study results (Zhang et al. 2018). Care must also be taken to homogenize the sample during further processing.

Comparison between different sediment sampling methods

Surface sediment in shore zone could reflect long-term interfacial interaction between waters and terrestrial environment (Yu et al. 2016). Shore sediment sampling consists of multiple transects at a right angle from the water line and the placement of quadrats along the transects. Transects may be visually scanned for bigger microplastics in the field. The surface layer can be removed to a proximate depth and sieved or transferred to the laboratory for separation steps (Ballent et al. 2016; Egessa et al. 2020). Variation in plastic abundance at different natural beach zones (water line, drift line and high-water line) in Lake Garda was investigated. Results showed that the water line contained the lowest level of plastic particles, whereas the highest proportion of plastic debris was observed in the drift line and high-water line (Imhof et al. 2018). Core samples have the advantage of being able to see depth profile and to study potential microplastic trends in considerable time periods. Surface analysis of these microplastics may show higher degradation effects due to longer time period. However, surface particles may be more exposed to degradation factors.

Sediment sampling tools are selected with regard to sampling places and sampling purposes, as they may show different aspects.

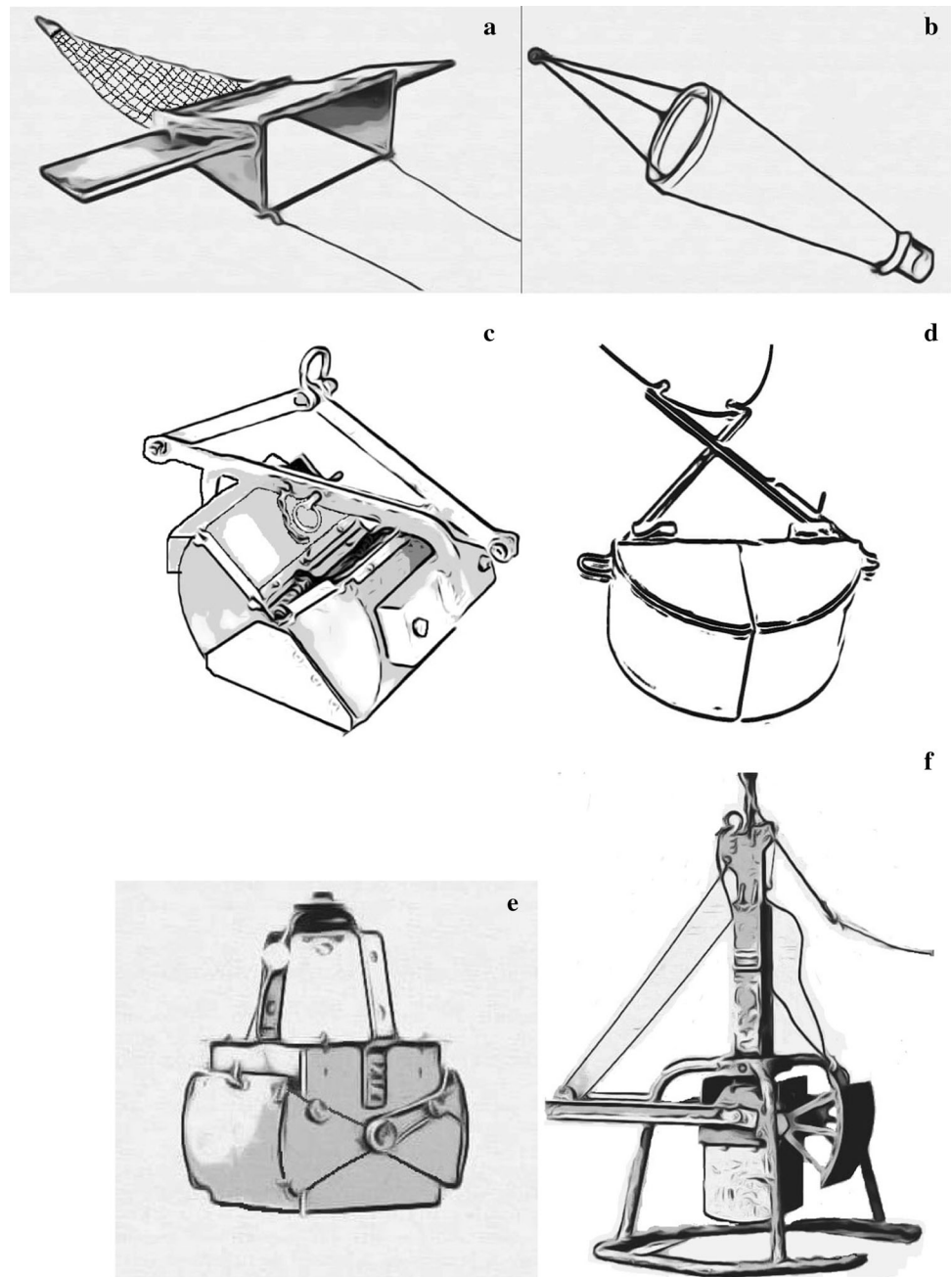
Sample preservation

Samples were are usually preserved with 5% methyl aldehyde and stored at 4 °C before analysis (Zhang et al. 2015) or fixed in 2.5% formalin (Zhao et al. 2014) or submerged in ~ 40% ethanol (EtOH) (Mani and Burkhardt-Holm 2020).

Discussion

No standardized methods exist for selecting mesh size, sampling, clean up, enrichment and detection, making the comparison of different studies complicated. Improving methods is needed to save time and effort in identifying microplastics in different compartments. To the best of our knowledge, water compartments are the most investigated matrix, assessed for microplastics in freshwater

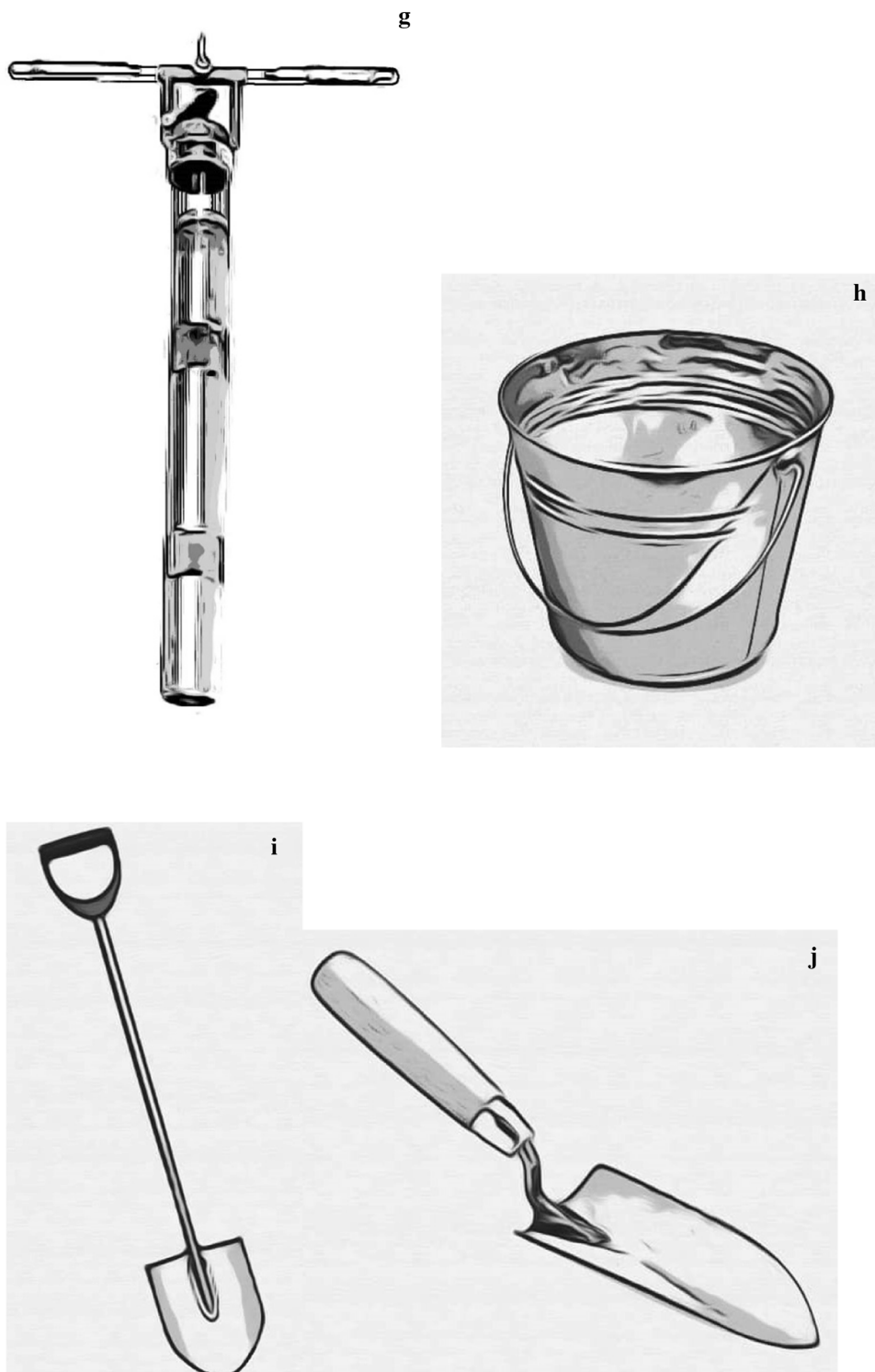
Fig. 3 Microplastics sampling tools in freshwater studies; **a** manta trawl, **b** plankton net, **c** Petite ponar grab **d** Van Veen grab, **e** Ekman grab sampler, **f** box corer, **g** sediment corer, **h** metal pail, **i** shovel, **j** trowel



environments (102/150). Rivers and estuarine systems are the most frequently studied compartments for microplastic detection, both in water and in sediment (85/150). This may be due to the reported importance of rivers and estuaries as a vector for microplastics transfer to seas and oceans. Littoral or shore sediments and bottom sediment are frequently assessed for microplastics in reviewed studies. Many microplastic studies used Manta nets to collect surface water samples (Fig. 4). Van Veen grabs and simple hand tools like trowels and stainless steel spoons

were the most frequently used tools for the bottom and littoral sediments, respectively (Fig. 5). They are also the most common sediment sampling tools from benthic and beach zones and seem to be appropriate for microplastic studies. Regarding sampling tool characteristics, both false positive and false negative results in analyses of small microplastics occur. In recent studies, there is a tendency to detect microplastics in both water and sediment at the same time. The simultaneous detection of microplastics in the water and sediment compartment gives a better perspective

Fig. 3 continued



of the situation in the ecosystem. The lack of uniformity in reporting the numbers of microplastics, mostly due to employing different units, is considerably noticeable in reviewing papers. This makes the comparison of results

difficult and challenging. Some studies have reported microplastic numbers or weights per volume of sampled water or per total dry matter for sampled sediments (particles/kg); the latter is highly recommended.

Fig. 4 Frequency of water sampling tools, used in microplastic freshwater studies

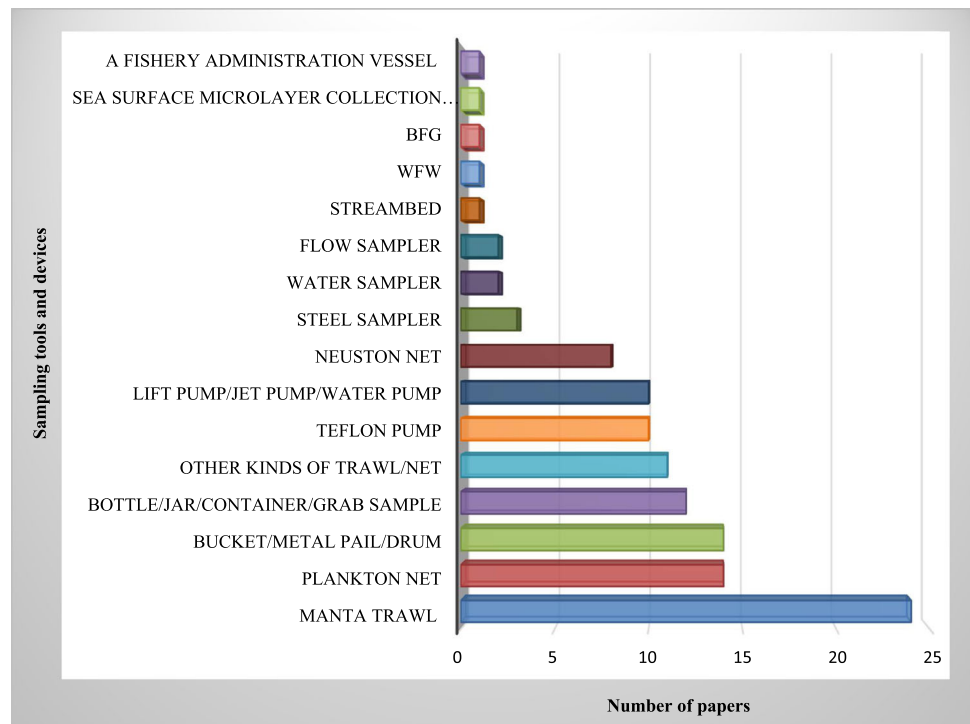
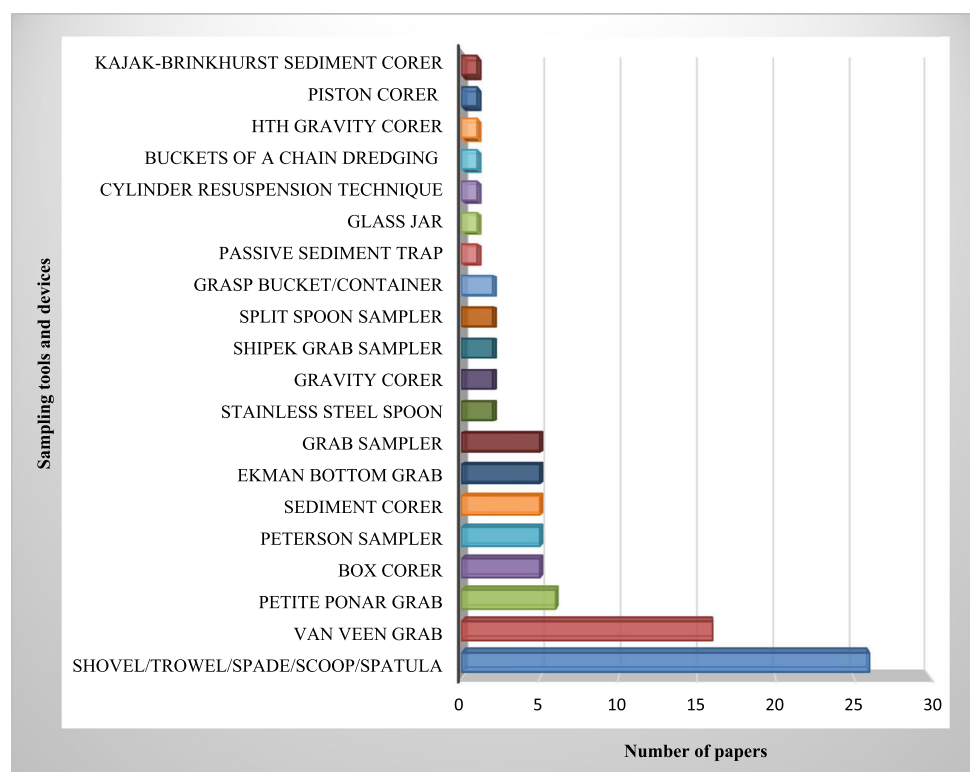


Fig. 5 Frequency of sediment sampling tools, used in microplastic freshwater studies



Conclusion

Employing suitable and reliable sampling, treatment and identification methods is crucial to evaluate microplastic pollution. Sampling and experimental techniques should be

standardized to more effectively assess microplastics. Although a smaller mesh size is more appropriate, the choice of trawl or sieve mesh size depends greatly on the study purpose. The kind of environment being studied, e.g., a dynamic river with high water velocity or a calm

eutrophic lake or wetland, is also of importance. The exact sampling volume, place and depth must be chosen carefully to ensure that samples represent water body characteristics. Sample volumes should be large enough to minimize overestimation induced by scaling up results, especially for water samples. The pump sampling approach with the filtration of large water volumes is necessary to generate reliable results in the spatial association between microplastic pollution in the surface waters and sediments. The trawling method has the ability to cover a larger area during sampling. To cover different microplastic size and shape, it is advantageous to combine both volume reduction and bulk sampling methods for surface water. More research is required to extend the understanding of representative in the study of microplastics as a key factor for the potential development of reliable data.

Authors' contributions Razeghi and Hamidian had the idea for the article, Razeghi performed the literature search and data analysis, Razeghi and Hamidian drafted, and Wu, Zhang and Yang critically revised the work.

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Declarations

Conflicts of interest The authors have no conflict of interests to disclose.

Consent for publication All authors agreed with the content and all gave explicit consent to submit, and they obtained consent from the responsible authorities.

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