



Microplastic abundance, distribution, and composition in the surface water and sediments of the Yangtze River along Chongqing City, China

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Abstract

Purpose Microplastics are considered emerging pollutants and already currently present in measurable quantities in aquatic ecosystems. However, information on the current status of microplastic pollution in the upper Yangtze River, the most important water body in China, is insufficient. In the present study, the abundance and distribution of microplastics in the surface water and sediments were investigated to obtain the characteristics of microplastic pollution in Yangtze River along Chongqing City.

Materials and methods Ten sampling sites along Yangtze River in the Chongqing urban area were selected to collect surface water and sediment samples. Abundance and morphological characteristics of microplastics were determined by counting using a digital stereo microscope. Micro-Fourier transform-infrared spectroscopy (μ -FTIR) analysis was used to identify polymer type of the microplastics.

Results and discussion The abundance of microplastics ranged within 46.7–204 n L⁻¹ and 100–583 n kg⁻¹ dw (dry weight) in the surface water and sediment samples, respectively. Fibers and films were dominant in most of samples, and the average proportion of fibers reached 74.3% in surface water. Whether in surface water or sediments, most of the microplastics were less than 0.7 mm in size, and the average proportion of microplastics with a size of less than 0.3 mm reached 62.6% in the sediment samples. Moreover, fibrous and small were the primary characteristics of the microplastics. Polypropylene, polyvinyl chloride, high-density polyethylene, polyester, and wool fibers were identified in the surface water samples.

Conclusion The Yangtze River along Chongqing City is contaminated by microplastic, like many urban rivers. Anthropogenic activities, including sewage treatment effluents, might be the main sources of microplastic pollution in Yangtze River (Chongqing urban section). This study reveals the contamination and characteristics of microplastics in the Yangtze River along Chongqing and supplies important data for further research on microplastics in Yangtze River's basin.

Keywords Microplastic · Surface water · Sediment · Yangtze River · Chongqing

1 Introduction

Plastic products have been mass-produced and widely used in various fields since the early 1950s due to their low weight, bioinertia, durability, and impressive cost–performance ratio

(Phuong et al. 2016). The annual yield of global plastic production has increased to 359 million tons in 2018, 30% of which was produced in China (PlasticsEurope 2019). The dramatic increase in plastic production has resulted in serious plastic waste pollution in natural environments. For instance, the amount of plastic waste deposited into oceans has exceeded 250,000 tons in 2014 (Eriksen et al. 2014). Although plastics have a stable chemical structure and properties, large plastics are degraded into small pieces when they are subjected to waves, weathering, and ultraviolet rays (Moore 2008; Andrady 2011). Plastics with a size below 5 mm are defined as microplastics (Thompson et al. 2004). Microplastics are classified into primary and secondary categories depending on their manner of formation. The original size of primary microplastics is less than 5 mm, and the main

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sources are daily beauty and health products, such as scrub particles in toothpaste, facial cleanser, and cosmetics. Secondary microplastics are derived from the breakdown of larger plastic debris through natural weathering processes, and sources of secondary microplastics include beverage bottles, fishing nets, and plastic bags (Cole et al. 2011).

Primary and secondary microplastics have been detected in oceans (Cole et al. 2011; Eriksen et al. 2014; Yonkos et al. 2014; Faure et al. 2015), including the water surface and sediments. Cózar et al. (2014) investigated the global distribution of plastics at the surface of the open sea and found that the frequency of occurrence of plastic debris on the water surface is 88%. Faure et al. (2015) discovered that the average abundance of microplastics is 5700 items km⁻² in the Western Mediterranean and confirmed that most of the microplastics are secondary microplastics. Microplastics have also entered the food chain in the oceans and have been detected in many marine organisms (Cole et al. 2011; Ferreira et al. 2018). In addition, the distribution patterns of microplastics have been monitored using ocean surface circulation models (Lebreton et al. 2012; Maximenko et al. 2012). Increasing amounts of microplastics have also been identified in other environmental systems, especially in lakes and rivers, throughout the world (Li et al. 2018; Boots et al. 2019; Ding et al. 2019; Kumar et al. 2020; Zhang et al. 2020). In the past few years, microplastics have been detected in surface waters, sediments, and aquatic organisms (Eriksen et al. 2013; Zhang et al. 2015; Lin et al. 2018; Ding et al. 2019). For example, microplastics of varying concentrations have been found in Laurentian Great Lakes (Driedger et al. 2015), UK urban lake (Vaughan et al. 2017), Yangtze River (Zhang et al. 2015; Li et al. 2020), Pearl River (Lin et al. 2018), Dongting Lake (Wang et al. 2018), Qinghai Lake (Xiong et al. 2018), and several lakes in the Tibet Plateau (Jiang et al. 2019).

Microplastics exist in the environment in different forms, such as fibers, fragments, spheres, beads, and films, due to their various sources (Ding et al. 2019). Most microbeads are from daily beauty and health products which contain microplastic abrasives (Fendall and Sewell 2009), whereas fibers are commonly derived from laundry and fishing gear (Browne et al. 2011). In general, microplastic sources include industrial resin microbeads from manufacturing plants and fragmentation of large plastic through photolysis, abrasion, and microbial decomposition (Cole et al. 2011). Thus, domestic wastewater plays an important role in the continued increase of microplastics. Several researchers have suggested that local occurrence of microplastics is likely due to a nearby urban effluent (Eriksen et al. 2013), and the abundance of microplastics is related to population density.

Chongqing is a megacity in southwest China, and it is one of the four municipalities under the direct administration of the central government of the People's Republic of China (the other three are Beijing, Shanghai, and Tianjin). It is the most

populous Chinese municipality, with a population of 31.2 million in 2019. Chongqing is located in the Upper Yangtze River, and Jialing River feeds into Yangtze River in the Chongqing urban area. Data from extant literature indicated that the extensive use and discarding of plastics in Chongqing have considerably increased the microplastic burden of Yangtze River (Di and Wang 2018). Di and Wang (2018) investigated the distribution characteristics of microplastics in the surface water and sediments of the part of Yangtze River running from Chongqing to the Three Gorges Dam. The abundance of microplastics in the surface water was 1597–12,611 n m⁻³, and the most abundant site was located in Nan'an District of Chongqing close to a wastewater treatment plant. Fibrous microplastics accounted for the largest proportion, and microplastics with a particle size of less than 1 mm accounted for 79.8%. The components of microplastics were polycarbonate (6.3%), polyethylene (21.0%), polypropylene (PP, 29.4%), polystyrene (38.5%), polyvinyl chloride (PVC, 4.2%), and vinyl chloride/vinyl acetate copolymer (0.7%). Although several sampling sites in Chongqing urban area have been investigated in previous research, the microplastic pollution in the Yangtze River along Chongqing, especially in urban sections, remains unclear. Notably, pollutants in an upstream area migrate with the flow of river water. In addition, smaller size microplastics (micro size) were ignored in most research, although they are more likely to bioaccumulate. Thus, the properties of microplastic pollution in Yangtze River flowing along Chongqing City should be investigated, and microplastics of smaller size were analyzed.

The current study investigated the microplastic contamination in Yangtze River's urban section along Chongqing. Surface water and sediment samples were collected, and the abundance, size, and shape of microplastics collected were analyzed. The polymer types of microplastics were identified through micro-Fourier transform-infrared (μ -FTIR) analysis. The objectives were to gain insight into the pollution level of microplastics in Yangtze River's urban section along Chongqing and determine the major factors that affect microplastic pollution in urban rivers.

2 Materials and methods

2.1 Study areas and sampling sites

The Yangtze River is the longest river in Asia and the third longest river in the world. It is also the longest river in the world to flow entirely in one country. The total length of this river is 6300 km. The main stream originates in the eastern Tibetan Plateau and merges into the East China Sea in Shanghai. Yangtze River Basin covers one-fifth of the mainland's land area and nurtures one-third of the mainland's

population, and the Yangtze River Economic Belt is China's largest economic belt. Chongqing, the largest economic center city in the upstream of Yangtze River, is an important point that connects the Belt and Road Initiative and the Yangtze River Economic Belt. In this study, we selected 10 sampling sites along Yangtze River in the Chongqing urban area (Egongyan Bridge to Cuntan Yangtze River Bridge). Details on the location and sampling sites are shown in Fig. 1.

2.2 Sample collection

Samples, including surface water and sediments, were collected in April 2019. A stainless-steel bucket water

sampler (volume = 2.65 L; $\Phi = 15$ cm, $H = 15$ cm) was immersed to collect surface water (0–20 cm depth). In order to exclude large pieces of debris, a large mesh (1.0 cm) screen was placed at the open top (water inlet) of water sampler. The collected water was transferred and stored in a 2 L glass bottle, and each location was sampled three times. In addition, sediment samples were obtained to determine the presence of microplastics. From the same site with surface water sample, approximately 1 kg of sediments (shore shallow water area) was collected using a stainless-steel shovel, placed in an aluminum foil Ziplock bag, and preserved at 4 °C until analysis. Three replicates were obtained from each site.

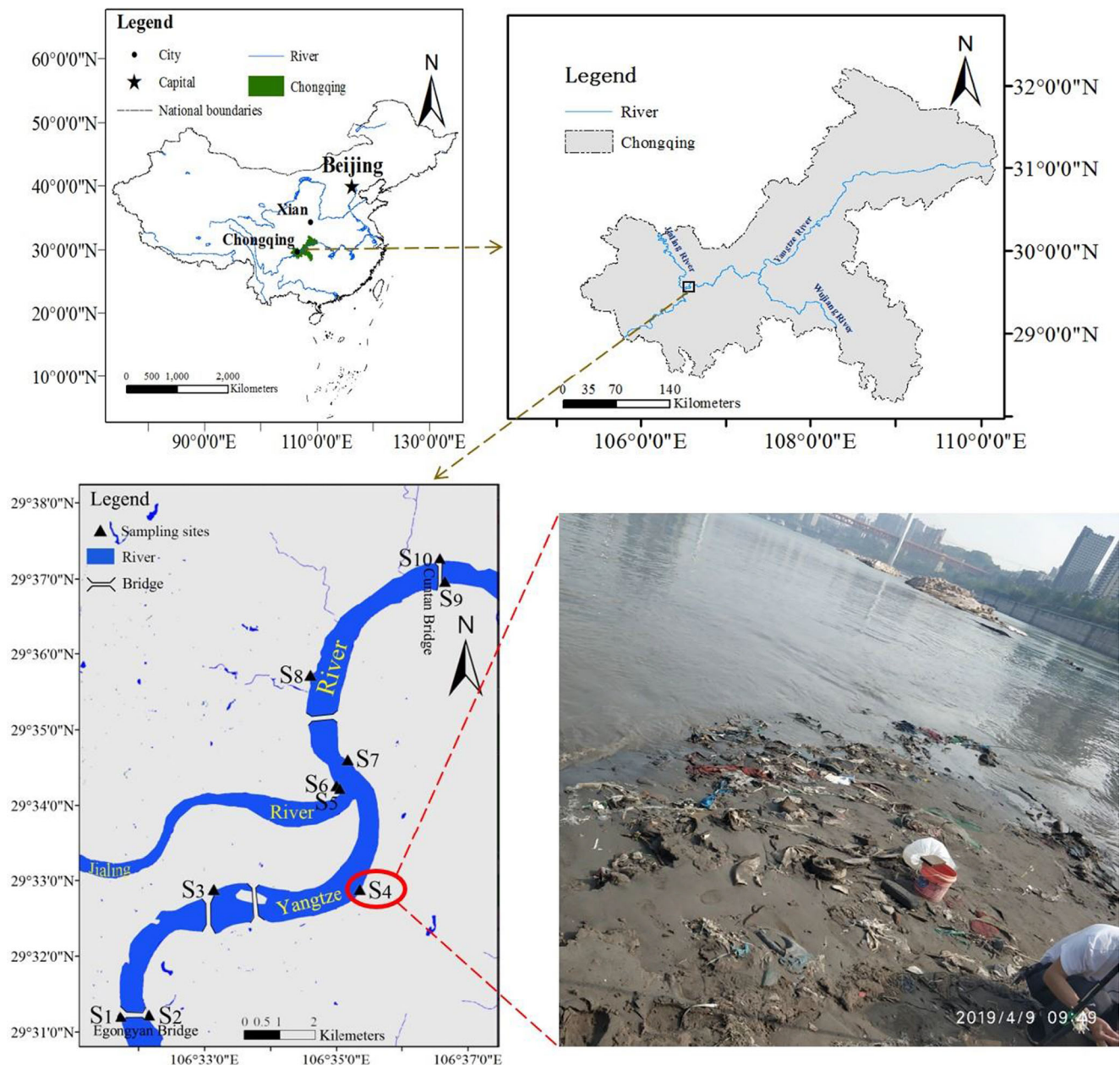


Fig. 1 Sampling sites in the Yangtze River along Chongqing City

2.3 Microplastic extraction from water and sediments

Each water sample was filtered through a 0.45 µm filtration membrane, and the substances on the filter membrane were pretreated with 30% H₂O₂ in covered glass bottles to eliminate the natural organic material in the samples. After 24 h of shaking in a constant-temperature oscillator at 50 °C in the dark, the samples were made to pass through a 0.45 µm glass microfiber filter membrane (GF/F, 47 mm Ø, Whatman) by using a vacuum pump. Then, the material on the filter membrane was washed into a separatory funnel with a saturated sodium chloride solution and shaken. The suspension liquid (when the suspension liquid is turbid, it needs to be centrifuged) was collected after 10 min of standing and passed through the same 0.45 µm glass microfiber by using a vacuum pump. The filter membrane was stored in a glass Petri dish and subsequently dried at 50 °C for 12 h (Wang et al. 2018).

The microplastics were separated from the sediment samples by using modified methods reported in previous literature (Nuelle et al. 2014). First, air-dried sediments were screened with a 0.833 mm stainless-steel sieve after chunks of impurities (stone, large plastic, etc.) were culled. Second, a saturated salt solution was added to 50 g of the sediment samples, and the suspension was made to stand for 24 h. Third, the suspension was stirred for 2 min, and the floating liquid was collected afterward. The same procedure was performed on the water samples.

2.4 Observation and identification of microplastics

The materials on the filter were observed under a stereo microscope (Optika, Italy) with a digital camera system. The suspected microplastics were photographed and analyzed in accordance with previous studies (Hidalgo-Ruz et al. 2012). The amount and properties (size, type, and shape) of microplastics were recorded. The units of microplastic abundance in the water and sediment samples were n L⁻¹ and n kg⁻¹ dw (dry weight), respectively. In addition, the chemical components of individual microplastics in the surface water from S6 were determined through micro-FTIR microscopy (Shimadzu, Japan) with a liquid nitrogen-cooled mercury cadmium telluride (MCT) detector in attenuated total reflection mode. The spectrum range was set to 4000–700 cm⁻¹ with 16 cscans for each measurement, and the spectral resolution was 4 cm⁻¹ for all samples.

2.5 Quality assurance and quality control

In order to avoid external microplastic pollution in the whole experimental process, experimenters wore cotton test suit and the nitrile gloves, and clothes were cleaned with a lint roller to remove any loose fibers. The collected water samples were placed into glass containers, which were rinsed three times

with ultrapure water and then baked at 120°C for 4 h. Meanwhile, all sampling tools, including water sampler, stainless-steel shovel, and aluminum foil Ziplock bags, were rinsed with ultrapure water in advance, and water sampler and stainless-steel shovel were washed with ultrapure water after sampling at each location. Three replicates were obtained from each sampling site. In addition, to examine potential contamination from the air during laboratory analysis, procedural blanks were also conducted in triplicate. The effect of 0.45-µm filter papers was investigated, and no microplastic was observed after filtering the air in the workplace for 2 h using a vacuum pump. The treatment of samples was conducted in a clean laminar flow cabinet. The workstation surrounding of the dissecting microscope was carefully cleaned before visual inspection.

2.6 Data analysis and statistical analysis

Statistical analysis was carried out using one-way analysis of variance (ANOVA) with an LSD post hoc test and Waller Duncan test (SPSS 19.0) to verify the significant difference between microplastics abundance at different sampling sites ($p < 0.05$). The OriginPro 9.1 and arcgis 10.2 software are used for figure and the space mapping drawn.

3 Results and discussion

3.1 Abundance of microplastics

The amounts of microplastics in the surface water and sediment samples were analyzed and are shown in Fig. 2. Microplastics were detected in all the samples, and the amount of microplastics ranged within 46.7–204 n L⁻¹ and 100–583 n kg⁻¹ dw for surface water and sediments, respectively. The abundance of microplastics in the samples indicated high spatial heterogeneity. Among the surface water samples, there was a significant difference between microplastics of the different sites groups (ANOVA $F = 42.947$, d.f. = 9 and 20, $p = 0.000$). The highest abundance (204 n L⁻¹) of microplastics was found in sample site S1, which was located near sewage discharge vents, possibly because of the lack of restrictions on microplastics in the sewage discharge standard. The lowest microplastic abundance (46.7 n L⁻¹) was found in sample S6, which was collected from the site where Jialing River joins Yangtze River. However, the average microplastic abundance of surface water reached 105 n L⁻¹; notably, high levels of microplastics in urban surface water have previously been detected in other areas (Lin et al. 2018; Yan et al. 2019). Among the sediment samples, there was a significant difference between microplastics of the different sites groups (ANOVA $F = 23.172$, d.f. = 9 and 20, $p = 0.000$), and the highest abundance (583 n kg⁻¹ dw) of microplastics was

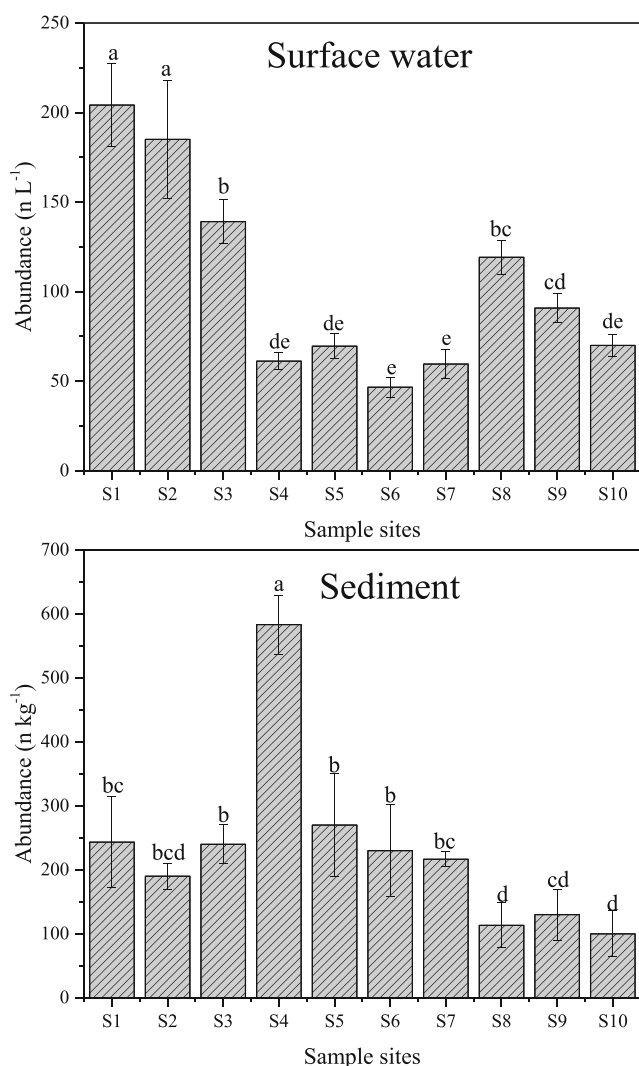


Fig. 2 The abundance distribution of microplastics in surface water and sediments of the Yangtze River along Chongqing City (data are presented as mean \pm SD ($n=3$)). Letters a–e indicate significant differences between samples according to one-way analysis of variance (ANOVA) and Waller Duncan test, $p < 0.05$. Results of LSD multiple comparisons were shown in table S1 and table S2

found in sample site S4, which is located near Nanbin Park. The lowest microplastic abundance ($100 \text{ n kg}^{-1} \text{ dw}$) was found in sample S10 collected from a site far from downtown. Meanwhile, the average microplastic abundance of the surface sediments reached $232 \text{ n kg}^{-1} \text{ dw}$. Many natural factors, such as source loading, plastic properties, and meteorological and hydrodynamic conditions, can influence the distribution of microplastics. Anthropogenic factors, such as solid waste (including plastic and textile) discarded against regulations and other pollutants discharged into rivers, should not be ignored (Cole et al. 2011; Horton et al. 2017; Wang et al. 2018; Ding et al. 2019).

For instance, municipal sewage discharge and plastic solid waste illegally disposed may increase the amount of microplastics in surface water and sediments. Images of the

sampling sites in the studied area are shown in Fig. 1. Many large pieces of plastic were observed, and these included daily life waste (woven bags, plastic bags, plastic toys, and other plastic products) and fishing gear abandoned in the river. These macroplastics would be broken down into microplastics and may be potential sources of microplastic in surface water and sediments. This situation is the reason for the relatively high abundance of microplastics in urban water bodies (water and sediments). The abundance of microplastics in the surface water of Yangtze River is higher than that reported in previous studies. Di and Wang (2018) studied the distribution characteristics of microplastics in the surface water and sediments of Yangtze River from Chongqing to the Three Gorges Dam. They found that the abundance of microplastics in surface water ranged within $1.6\text{--}12.6 \text{ n L}^{-3}$, and the sampling points where the abundance of microplastics is above 5 n m^{-3} were located in urban areas with high population density. The sample collected from Nan'an District of Chongqing had the highest microplastic abundance, and this sampling site is close to Jiguanshi and Tangjiatuo Wastewater Treatment Plants.

Meanwhile, the abundance of microplastics in the surface water was higher than that of surface water microplastics found in other fresh water (Table 1), and the major reasons are speculated as follows. First, the sample sites are located in urban areas of Chongqing, and previous studies have shown that the abundance of microplastics is positively correlated with the degree of urbanization and population density (Yonkos et al. 2014). The urban area of Chongqing has reached a high degree of urbanization and population density. Furthermore, the sample sites in this study are located in places involving frequent human activities or near sewage outlets, so that microplastic pollution is relatively obvious. Second, the use of different separation methods produces different results. In other related research, a trawl (aperture of hundreds of microns or more) or a 12 V Teflon pump plus stainless-steel sieve (pore size: tens of microns or higher) was used (Zhang et al. 2015; Di et al. 2019; Yan et al. 2019). Microplastics that are smaller than these particle sizes were consequently not considered. However, a previous study has shown that microplastics with a small particle size cannot be ignored (Cai et al. 2018). In our work, a $0.45 \mu\text{m}$ filter membrane was used for suction filtration. Thus, microplastics larger than $0.45 \mu\text{m}$ were separated, and high abundance was obtained.

3.2 Shapes of microplastics

Typical images of collected microplastics were obtained with a stereo microscope and are shown in Fig. 3. The microplastics detected in this study were classified as fiber, fragment, microbead, film, and foam in accordance with previous studies (Hidalgo-Ruz et al. 2012; Di and Wang 2018). As shown in Fig. 4a and b, fibers were numerically dominant

Table 1 Studies on microplastic pollution in China's inland water bodies

Water body	Location	Sample	Sampling	Size	Abundance	References
Yangtze River	Middle and lower reaches	SW, S	SW: trawled at a depth of 0–57cm S: grab sampler	0.3–5mm	SW: $(1.95-9.00) \times 10^5$ n/km ² Sediment: 7 to 66 n/kg	Xiong et al. (2019)
	Three Gorges Reservoir	SW, S	SW: pumped at a depth of 100 cm S: grab sampler	0.048–5 mm	SW: 1597 to 12,611 n/m ³ S: 25 to 300 n/kg	Di and Wang (2018)
	Xiangxi River	S	–	0–5mm	S: $0.55 \pm 0.12 \times 10^3$ to $14.58 \pm 5.67 \times 10^3$ n/m ²	Zhang et al. (2019)
Dongting Lake Hong Lake	Dongting Lake Hong Lake	SW	SW: pumped at a depth of 20 cm	0.05–5mm	SW: 900–2800 n/m ³ SW: 1250–4650 n/m ³	Wang et al. (2018)
Dongting Lake	West Dongting Lake	SW, S	SW: flow sampler a depth of 30 cm SW: stainless shovel at a depth of 2cm	0.045–5mm	SW: 616.67 to 2216.67 n/m ³ S: 320–480 n/kg	Jiang et al. (2018)
	South Dongting Lake				SW: 716.67 to 2316.67 n/m ³ S: 200–1150 n/kg	
Taihu Lake	Taihu Lake	SW, S	SW: 0–30 cm for plankton net samples S: grabbed sampler	0.05–5mm	SW: 3.4 to 25.8 n/L S: 11.0–234.6 n/kg	Su et al. (2016)
Urban lakes Hanjiang River	Wuhan Wuhan	SW SW	SW: pumped at a depth of 20 cm SW: pumped at a depth of 20 cm	0.05–5mm 0.05–5mm	SW: 1660.0 ± 639.1 to 8925 ± 1591 n/m ³ SW: 2600 to 3200 n/m ³	Wang et al. (2017)
Pearl River	Guangzhou City	SW, S	SW: water sampler at a depth of 0–50 cm S: grab sampler	0.02–5 mm	SW: 379 to 7924 items·m ⁻³ S: 80 to 9597 items·kg ⁻¹	Lin et al. (2018)
Buqu River	Tibet Plateau	SW, S	SW: water sampler at a depth of 0–30 cm S: stainless shovel	0.045–5mm	SW: 967 ± 141 items/m ³ S: 130 ± 71 items/kg	Jiang et al. (2019)
Yangtze River	Chongqing	SW, S	SW: water sampler at a depth of 0–20 cm S: stainless shovel	0.45µm–5mm	SW: 104 ± 52 items/L S: 232 ± 138.39 n/kg dw	This study

SW represents surface water; S represents sediment

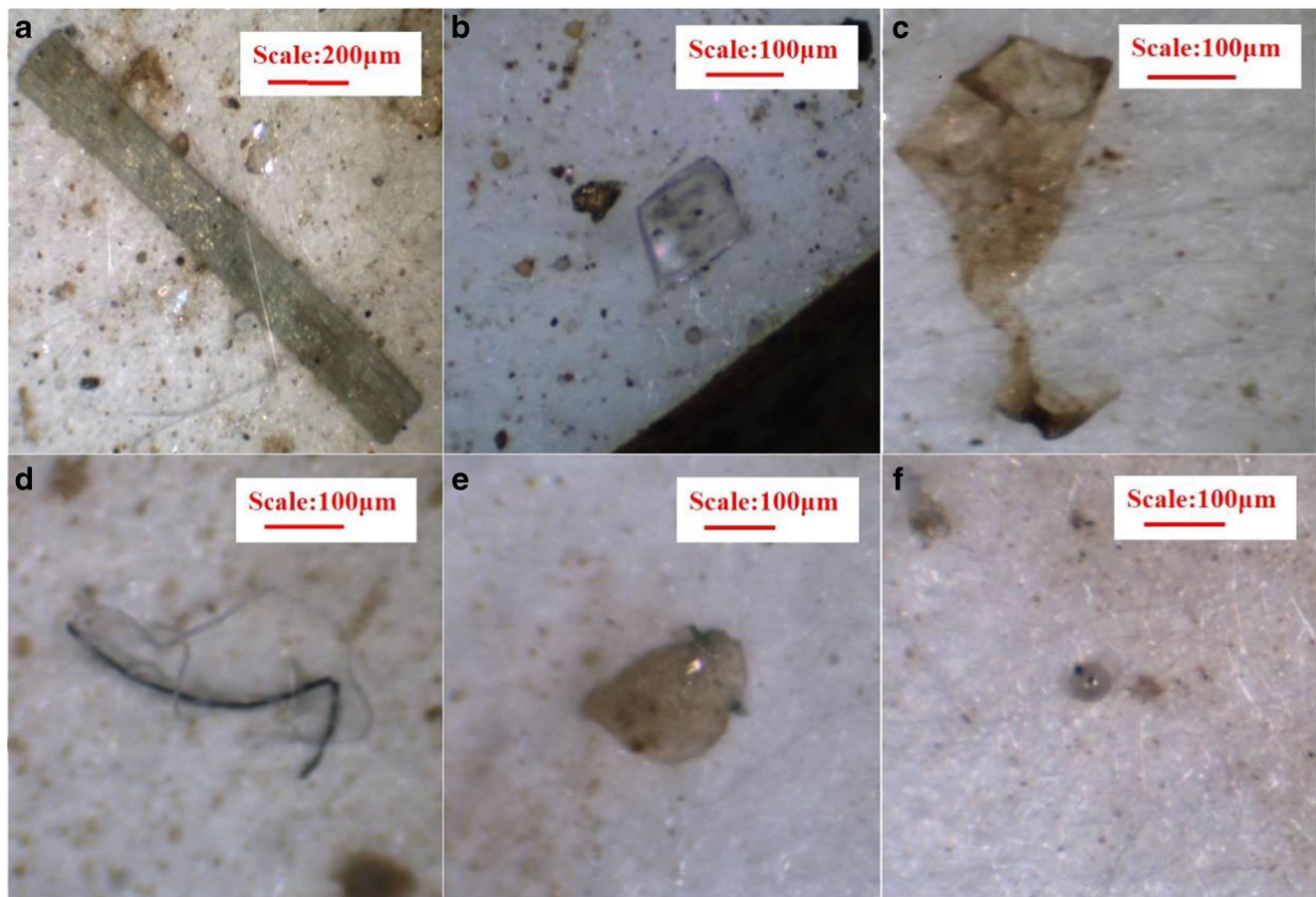


Fig. 3 Photographs of microplastics items identified by using microscope: foam (a), fragment (b and e), fiber (d), film (c), and microbead (f)

in most of the water samples. The percentage ranged from 46.4 to 86.8%, with an average proportion at 74.3%. This result might be attributed to the peeling of plastic fishing gear (Cole et al. 2011). Fishing activities can also increase the fiber presence in surface water (Di and Wang 2018). Meanwhile, domestic sewage, which contains fibers from washed clothes, could be the most important source of fibers (Browne et al. 2011). The proportion of films in this study ranged from 13.1 to 32.1%, and the average was 16.1%. Fibers accounted for the highest proportion (86.8%) in S3, and films showed the highest abundance (32.1%) in S6. In all microplastics collected from surface water, foams accounted for the least amount and were only detected in two surface water samples (S6 and S8); the average proportion was 0.48%. Generally, the order of the proportion of different types of microplastics from high to low was as follows: fiber > film > fragment > pellet > foam; fiber microplastics were the most important component. These results are consistent with the distribution of microplastics in the Pearl River (Lin et al. 2018) and Wuhan urban rivers (Wang et al. 2017).

Similar to what was observed in the surface water samples, the types of microplastics in the sediment samples were the same, and five shapes of microplastics were detected. However, the proportion of each type changed. The shape

distribution is shown in Fig. 4c and d. Although the proportion of foam (1.4%) in the sediments was similar to that in surface water and was the least abundant, the percentage of fibers in the sediments ranged only from 15.9 to 46.7%, and the average proportion decreased to 29.2% compared with the 74.3% for surface water. Additionally, the proportion of film ranged from 27.4 to 52.2%, and the average proportion increased to 38.6% compared with the 16.1% for surface water. The proportion of microbeads ranged from 5.0 to 21.5%, and the average proportion of microbeads and fragments increased to 15.0% and 15.8% compared with the 2.5% and 6.5% for surface water, respectively. Furthermore, among the sediment samples, films accounted for the highest proportion (52.1%) in S6, and fibers showed the highest abundance (46.7%) in S10.

In conclusion, whether in the surface water or sediments, the sum of fibers and films accounted for over 50% of the total microplastics in each sample. This result might be due to the fiber microplastics in surface water having a wide range of sources, including domestic sewage (laundry wastewater), broken fishing nets, and waterborne degraded tourist waste (Henry et al. 2019). Moreover, the proportion of fibers in surface water was higher than that in sediments because fibers with a line shape are difficult to sink and deposit on the river

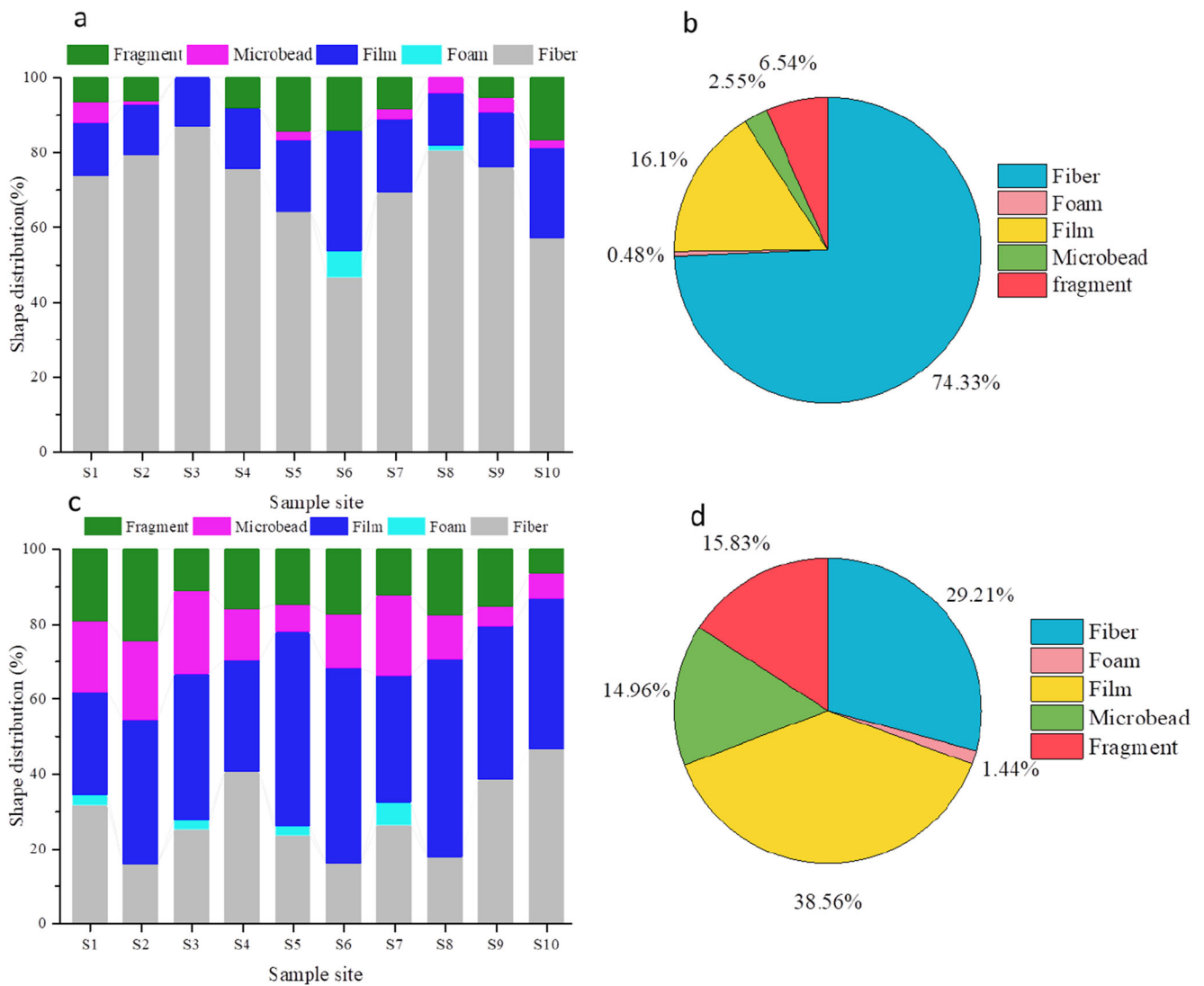


Fig. 4 The shape distribution of microplastics in surface water (a and b) and sediments (c and d) of the Yangtze River along Chongqing City (data are presented as mean ($n=3$), and results of one-way analysis of variance (ANOVA) were shown in table S3)

bed and prefer to be suspended in surface water (Zhao et al. 2015; Schwarz et al. 2019). Microplastics with a film shape mainly originate from the weathering and cracking of plastic products (packaging bags, agricultural film waste, and plastic wrap) and enter the natural environment under the action of external forces. However, films have a large specific surface area and provide sorption sites for fine sand and other materials, which increase their density; hence, they are co-deposited into the river bed eventually. Beads were found in most of the water samples and in all the sediment samples in this study. Although the number of beads was relatively small, the environmental impact of beads should not be ignored because of the strong migration capability of these pollutants (Schwarz et al. 2019). Meanwhile, the proportion of beads in the sediments was higher than that in surface water because manufactured plastic products, such as industrial microbeads and nurdles, entered the water environment several years ago

and sank into sediments. Cosmetic and cleaning products with plastic beads were listed as high-pollution, high-risk products by the Ministry of Ecology and Environment of the People’s Republic of China in 2017, and the production of personal care products and cosmetics containing plastic microbeads was banned by other countries. Thus, only a few of microbeads were found in the surface water and sediments, and the proportion of beads in the sediments was higher than that in surface water.

3.3 Size of microplastics

The size distribution of microplastics in the study samples is presented in Fig. 5. Microplastics were divided into three size categories, namely, group A (<0.3 mm), group B (0.3–0.7 mm), and group C (>0.7 mm). As indicated in Fig. 5a and b, the size distribution of microplastics in each sample differed.

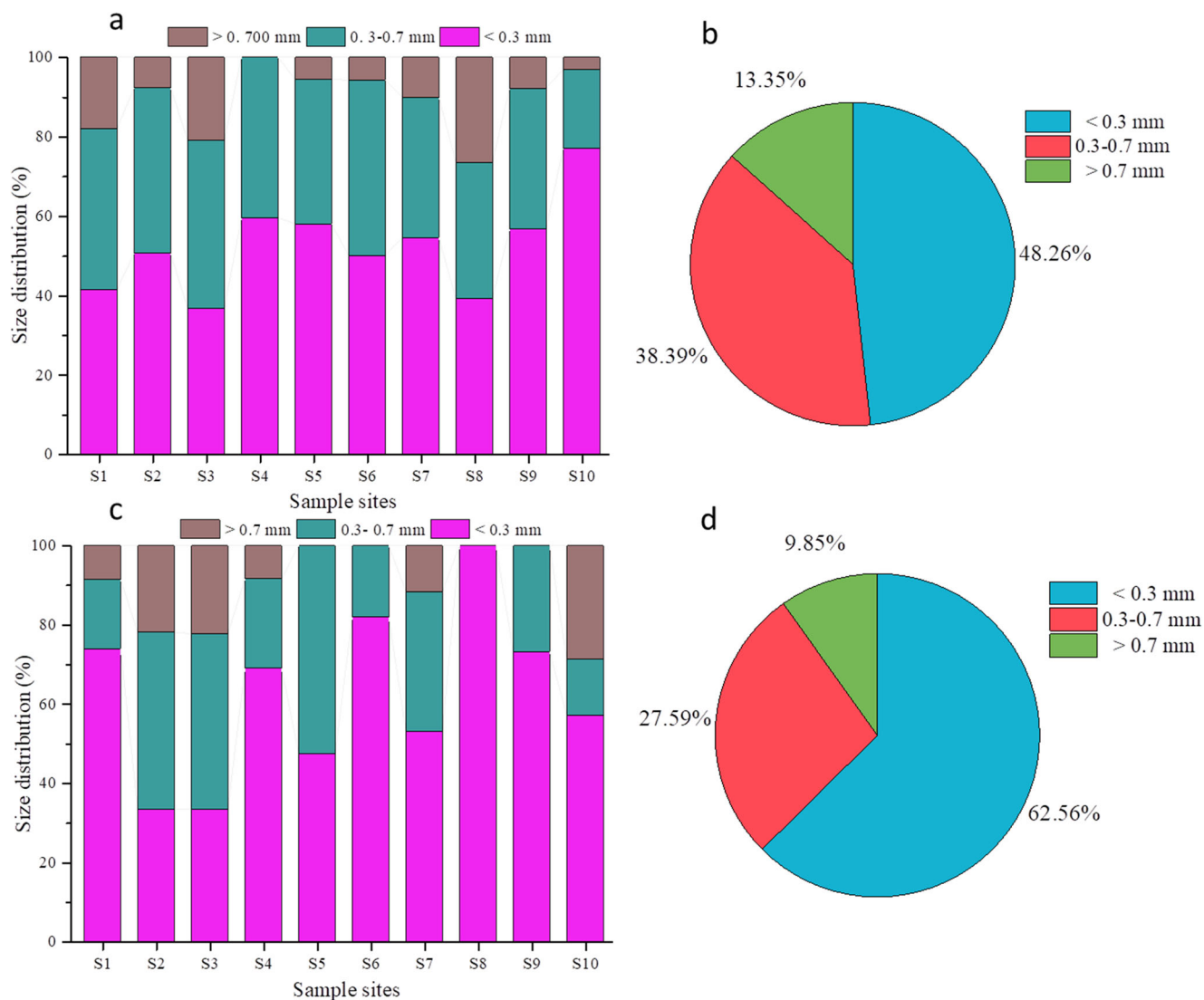


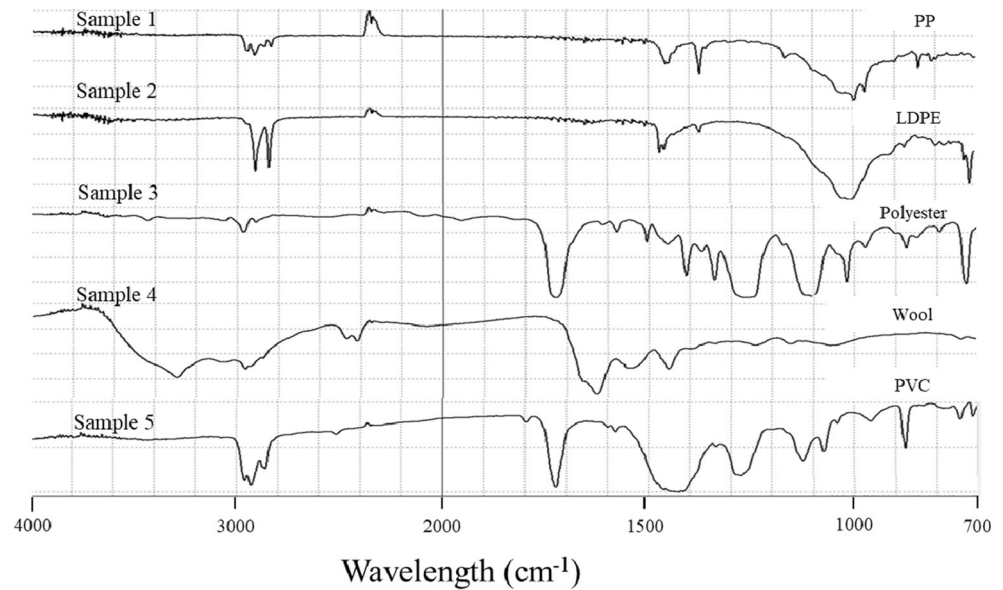
Fig. 5 The size distribution of microplastics in surface water (a and b) and sediments (c and d) of the Yangtze River along Chongqing City (data are presented as mean ($n=3$), and results of one-way analysis of variance (ANOVA) were shown in table S4)

The microplastics in group A were the most abundant in the majority of the water samples and accounted for 36.5–77.1% of the total amount of microplastics; the average proportion was 48.3%. Group A was followed by group B, which accounted for 19.8–44.2% of the total amount of microplastics. The microplastics in group C accounted for the smallest proportion and were not detected in sample S4. Generally, the size of the microplastics in the study samples was relatively small, and the proportion of microplastics in the classifications decreased as the size increased. This result is consistent with the conclusions obtained by many previous studies (Eriksen et al. 2013; Su et al. 2016; Wang et al. 2017; Di and Wang 2018; Yan et al. 2019). In addition, the average proportions of microplastics less than 0.3 and 0.7 mm were 48.3% and 86.6%, respectively, in all of the water samples. Previous studies have found that microplastics less than 0.333 mm account for about 50% of the total microplastics in

the surface water of Tai Lake (Su et al. 2016). Yan et al. investigated the distribution of microplastics in Pearl River along Guangzhou City and discovered that microplastics with a size of less than 0.5 mm account for more than 80% of the total (Yan et al. 2019). The large proportion of small plastic particles is probably due to the fact that large plastic debris can break down into small pieces of microplastics. Di and Wang (2018) discovered that microplastics with a size of less than 1 mm account for 79.8% of the microplastics in the Three Gorges Reservoir. In many survey areas, small-sized microplastics often have high abundance because large ones can be split into small particles (Browne et al. 2010; Zhang et al. 2015).

Similarly, the microplastics in group A (<0.3 mm) were the most abundant in the sediment samples and accounted for 33.3–100%, and the average proportion was 62.6%, which is shown in Fig. 5c and d. The microplastics in group B

Fig. 6 Typical μ -FTIR spectra of the microplastics collected from S6



(0.3–0.7 mm) and group C accounted for 0–52.2% and 0–28.7%, respectively. The average proportions were 27.6% and 9.8% for groups B and C, respectively. In general, microplastics of a small size accounted for a large proportion, and these trends are in line with the size distribution of microplastics in other study areas. Previous studies have found that microplastics with a size of less than 0.333 mm account for about 60% of the sediments in Tai Lake (Su et al. 2016). Ding et al. (2019) investigated the abundance and distribution of sediments in Wei River and discovered that microplastics with a size of less than 0.5 mm are the most abundant and that the proportion of microplastics with a size of larger than 1 mm is less than 10%. Similar results were obtained in studies on the microplastic size distribution in Lake Garda (Imhof et al. 2016), the Three Gorges Reservoir (Di and Wang 2018), and Qinghai Lake (Xiong et al. 2018) in China. The large number of small-sized microplastics may be explained by two factors. First, several large-particle microplastics can be decomposed into small particles. Second, surface runoff can increase the abundance of microplastics, and the sand in rivers can enhance the weathering of plastics.

3.4 Polymer identification of microplastics

Micro-FTIR is widely used to identify the composition of unknown particles (Li et al. 2018; Fan et al. 2019). On the basis of the results of the microplastic shape analysis, the microplastics collected from the surface water in S6 were used for further chemical composition analysis. As shown in Fig. 6, the following types of polymers were identified: polypropylene (PP, polyester, polyvinyl chloride (PVC), low-density polyethylene (LDPE)). PP has a low density, good heat resistance, good stress cracking resistance, and high bending

fatigue life; it is easy to suspend in surface water. Thus, PP is widely applied in household appliances, such as fresh-keeping boxes, food packaging bags, durable textiles, and pipes. PP can also be used to make agricultural mulch, fishing nets, packaging bags, and strapping ropes. LDPE has good chemical stability and high impact strength at low temperature, excellent electrical insulating properties, and transparent in thin film form, and it is difficult to dissolve in organic solvents, acids, alkaline solutions, and various salts. It is widely used in containers, dispensing bottles, wash bottles, tubing, and plastic bags. Polyester fiber is widely used in apparel fabric production because of its special chemical properties. Traditionally, PVC was used to make construction materials and daily supplies (pipes and plastic bags). However, the use of PVC in packaging is now strictly controlled by Chinese law because PVC is unstable under light and heat. For instance, several carcinogens are emitted when PVC is exposed to temperatures above 100 °C.

These polymers detected in the current study have been identified in other freshwater areas of China. PP and PVC were found in the Three Gorges Reservoir (Di and Wang 2018), Pearl River along Guangzhou City and Pearl River estuary (Yan et al. 2019), urban water areas in Changsha (Wen et al. 2018), and Dongting Lake (Jiang et al. 2018). Clothing fibers were found in several urban rivers, such as nylon in Wuhan (Wang et al. 2017) and polyester, rayon, cotton, and viscose in Shanghai (Peng et al. 2018). Polyester and wool fibers were detected in this study.

Previous studies have indicated that the dominant source of microplastics is secondary microplastics in the environment (Ryan 2015; Duis and Coors 2016). In the current study, fibers and films predominated in all the samples, and synthetic plastics, including PP, PVC, LDPE, and polyester, were identified. Thus, a series of plastic production, including plastic

package bags, ultra-thin films, and fishing gears, may enhance microplastic formation. Meanwhile, one kind of nonplastic fiber was identified as wool. Clothes washing also constituted a large portion of microplastics entering the water environment, as evidenced by the identification of polyester and wool. Given that the study area is located in Upper Yangtze River, the microplastics in water would migrate to Middle and Lower Yangtze River. Thus, the microplastics in freshwater must be given sufficient attention. The investigation of the status of microplastic pollution in other regions, in combination with studies on environmental and health risks, should be put on the agenda, and a comprehensive evaluation method and reasonable management and control system should be constructed.

4 Conclusion

Microplastics were detected in the surface water and sediments of Yangtze River along Chongqing City. The average abundance of the microplastics was 105 n L^{-1} and $232 \text{ n kg}^{-1} \text{ dw}$ for surface water and sediments, respectively. The highest abundance of microplastics in surface water was detected near sewage treatment effluents, and the highest abundance of microplastics in sediments was found near Nanbin Park. This result indicates that human activities might play an important role in microplastic pollution in the study area. Fibers and films were the numerically dominant shape in most of the water and sediment samples. Microplastics with a small size dominated in all the samples, and the average proportion of microplastics with a size of less than 0.3 mm was 48.3% and 62.6% for the surface water and sediment samples, respectively. In addition to PP, PVC, and LDPE, polyester, and wool fibers were also identified in the surface water samples. Thus, clothing fiber in urban rivers should not be ignored. In the future, additional studies on pollution source analysis and ecological risks should be conducted to prevent and control microplastic pollution in Yangtze River (especially Upper Yangtze River).

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