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Microplastic pollution in surface sediments of urban water areas in Changsha, China: Abundance, composition, surface textures

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ABSTRACT

Microplastics pollution in the global marine environment has received much recent research attention. However, microplastics contamination of the freshwater environment has not been fully studied, especially with respect to the surface sediments of urban water areas in China. This study investigated surface sediment samples from twelve selected sites in Changsha, China. The average microplastic concentrations in the surface sediments of the urban water areas ranged from 270.17 ± 48.23 items·kg^{-1} to 866.59 ± 37.96 items·kg^{-1}, and the highest concentration of microplastics was found in Yuejin Lake sediments. Most of the collected microplastics were transparent, and most were classified as fragments. Most microplastics (58.31%) were smaller than 1 mm across all samples. Raman analysis indicated that polystyrene dominated the sediments samples. This study provided framework for future studies of microplastics pollution in the surface sediment of urban water areas in China.

1. Introduction

Plastics are durable and inexpensive and are thus widely used in daily life, as well as in industrial, scientific, and technological applications (Chen et al., 2015; Cozar et al., 2014; Ren et al., 2018). Plastic production has increased sharply since the 1950s (Cheng et al., 2016; Xue et al., 2018). Global plastic production in 2016 was 335 million metric tons (PlasticsEurope, 2017; Zhou et al., 2018). Most plastic litter carried by lakes and rivers to the oceans, and some of these plastic litter may accumulate in sediments (Jambeck et al., 2015; Zhou et al., 2018). The large amounts of plastic debris already present in marine environment have caused serious environmental problems (Cozar et al., 2014; Huang et al., 2018). Under the influence of several natural and artificial factors, bigger plastics could degrade and consequently be fragmented into small-sized plastic (Gong et al., 2018; Thompson et al., 2004). Microplastics include primary microplastics with dimensions < 5 mm and broken products known as secondary microplastics. Primary microplastics are produced intentionally by industry (such as pellets, microbeads, etc.) and secondary microplastics are a result of bigger plastic degradation and fragmentation (Gong et al., 2017a, 2017b; Wan et al., 2018). Microplastics that are spread over surface waters and sediments are harmful to some cetaceans and aquatic crustaceans, causing the illusion of satiety, in which indigestible microplastics fill the stomach, as well as possible, toxic effects from chemicals embedded in the microplastics, including heavy metals, PCBs, and other additives (Cozar et al., 2014; Li et al., 2016; Velzeboer et al., 2014).

Several studies have explored the distribution of microplastics across the oceans, the potential threats posed by microplastics to marine organisms, and the effects of microplastics on the marine food web (Gutow et al., 2015; Liang et al., 2017). Recently, the contamination of freshwater by microplastics has become an area of increasing concern (J. Li et al., 2018; X. Li et al., 2018). Most of these studies were focused on lakes and inland rivers, including Taihu Lake, China; the Great Lakes, USA; and the Rhine River, Europe. (Eriksen et al., 2013; Mani et al., 2016; Su et al., 2016). Additionally, it has been shown that surface waters in urban areas have relatively high concentration of microplastics (Vaughan et al., 2017; J. Wang et al., 2017; W. Wang et al., 2017). However, the degree of microplastic contamination in the freshwater surface sediments of urban areas remains

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unclear. This knowledge gap has inhibited studies of the effects, transport and fate of microplastics in water and sediments (Dris et al., 2015; Mani et al., 2016; J. Wang et al., 2017; W. Wang et al., 2017).

Due to its rapid economic development, China produces most of the world's plastic: > 80 million tons. In China, however, waste plastics are not typically properly discarded, and microplastics are not yet surveyed under national environmental monitoring programs. Even in many highly populated urban areas, microplastic pollution is to date unassessed (Gong et al., 2017a, 2017b; Tan et al., 2015; Wu et al., 2017; Zhang et al., 2015).

Changsha, a central Chinese megalopolis with 7.6 million permanent residents, has numerous rivers and lakes (Xu et al., 2012a, 2012b). Especially, Xiangjiang River which is the largest river in Hunan Province, flows through the middle of the city into China's second largest freshwater lake, Dongting Lake (C. Zhang et al., 2016; K. Zhang et al., 2016). These rivers and artificial lakes could be the sinks and sources of microplastics, derived by human activity and sewage discharges. However, these rivers and artificial lakes are important for urban life: some supply water and others are used for aquaculture (Deng et al., 2013; Tang et al., 2014). Microplastics may also be transported into the Dongting Lake via the Xiangjiang River (Xu et al., 2012a, 2012b). Dongting Lake has a rather large number of aquaculture and agriculture activities. Surface sediments are important for microplastic transport (Long et al., 2011). Microplastics in rivers and lakes tend to accumulate in sediments through sedimentation (Peng et al., 2018). In general, sediments reflect long-term interactions between the water and the land (Peng et al., 2018). Microplastics trapped in sediments may be released by an external force, transforming the sediment itself into a source of microplastics surface water contamination (Gong et al., 2009). In order to better understand the relation between urban life and urban water areas, more studies are needed about microplastics pollution in surface sediments of urban water areas.

Because of the relationship between urban life and urban water areas, the pollution of the urban surface sediments by microplastics pollution must be considered. Here, the abundance, composition, and surface textures of microplastics in the surface sediments of urban water areas in Changsha were studied. The scope of this study included eight urban lakes and the urban parts of the Xiangjiang River in Changsha. The study might provide a useful reference for the monitoring of inland freshwater ecosystems.

2. Methods and materials

2.1. Samples collection

Changsha includes more than twenty lakes in the urban area. Eight major lakes and four urban estuaries of tributaries of the Xiangjiang River were chosen as sampling sites in this study (Fig. 1, Table 1). All sites were sampled in January 2018: 48 lake sediment samples and 12 river (estuary) sediment samples. The sampling sites were equally distributed. At each sampling site, about 1000 g of sediment at 5 cm depth was shoveled onto aluminum foil, and then sealed in a marked bag. All samples were transferred to the laboratory and preserved at 5 °C.

2.2. Laboratory analysis

The analytical methods used to isolate microplastics in the sediments were based on those of Thompson et al. (2004) and Masura et al. (2015) with modifications (Baldwin et al., 2016; Hammer et al., 2016). Briefly, 100 g of each wet sediment sample (as measured with an analytical balance) was transferred to a clean beaker. The sample was dried at 65 °C in an oven (202-2AB, Taisite, China), and then weighed again. In this study, the concentration of microplasitcs in each dried sediment sample was used to calculate microplastics abundance. To remove any organisms that might affect the observation of microplastics in the sediment samples, samples were digested with a 30% H_2O_2 and Fe (II)

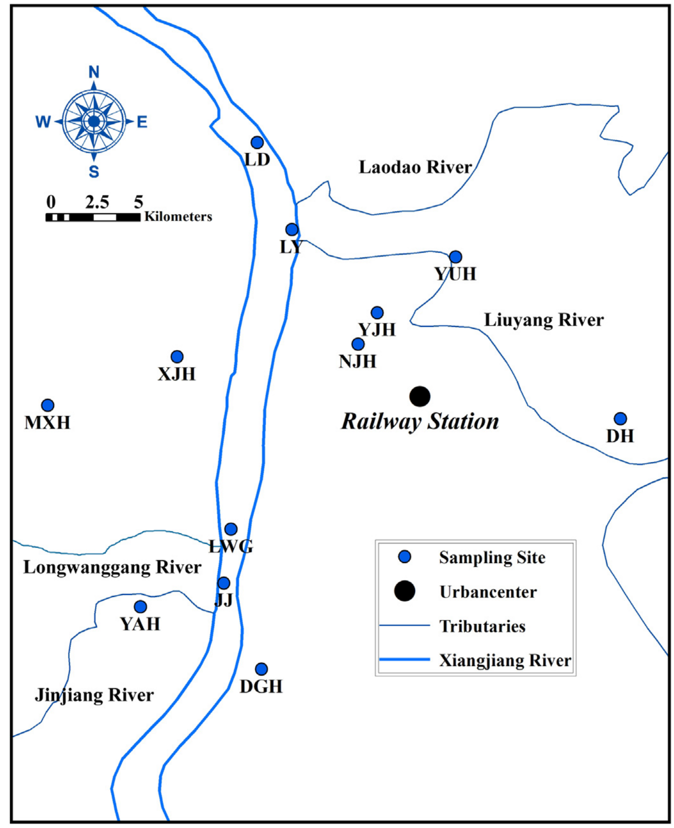

Fig. 1. Sampling sites of sediments from urban surface water in Changsha: Urban lakes (XJH -Xianjia Lake; YUH - Yue Lake; etc) and urban zones in Xiangjiang River (LD - Laodao River; LY - Liyuyang River; etc). Blue lines portray the urban rivers. Black point portrays the urban center of Changsha. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Geographical coordinates, site location and types of functional zones of each sampling site.

Sampling site	Abbrev.	Latitude (N)	Longitude (E)	Functional zone
Xianjia Lake	XJH	28.213087	112.932773	Park
Yue Lake	YUH	28.244993	113.021597	Park
Nianjia Lake	NJH	28.217138	112.99048	Park
Yuejin Lake	YJH	28.227201	112.996624	Park
Meixi Lake	MXH	28.197576	112.891469	Park
Yang Lake	YAH	28.133265	112.921113	Park
Dong Lake	DH	28.193318	113.079161	Aquiculture
Donggua Lake	DGH	28.113362	112.959679	Aquiculture
Jinjiang River	JJ	28.140838	112.947702	Xiangjiang Branch
Longwanggang	LWG	28.158005	112.947894	Xiangjiang Branch
Laodao River	LD	28.281565	112.958273	Xiangjiang Branch
Liuyang River	LY	28.253695	112.969388	Xiangjiang Branch

solution (catalyst). The mixed sample solution was allowed to sit until no organisms were visible (generally 24 h). To extract microplastics from the sediment samples, zinc chloride granules were added to above sediment digestion solution to obtain a solution density of 1.5 g·cm^{-3}. This solution was then stirred for 5 min using a magnetic stirrer and a clean stir- bar. The mixture was then transferred to a density separator and settled for 48 h. After 48 h, the solution was vacuum-filtered onto a GF/C filter to collect microplastics in the supernatant. Filter was placed on a pre-cleaned petri dish and inspected visually using a 50× magnification dissecting microscope (SZX7; Olympus, Japan). The surface characteristics of the microplastics were studied using scanning electron microscope (SEM; Hitachi S-4800, Japan) (Hidalgo-Ruz et al., 2012; J. Wang et al., 2017; W. Wang et al., 2017).

Microplastics particles from different sampling sites were grouped based on morphological characteristic, including size, shape and color. Microplastics were divided into six size classifications: < 0.5 mm, 0.5–1 mm, 1–2 mm, 2–3 mm, 3–4 mm, 4–5 mm. Particles were also morphologically classified as a fiber, foam, film, or fragment. Microplastics defined as fibers had long, thin shapes, while plastic debris in thin layers were defined as films. Foams were defined as polymer materials that were dispersed with large numbers of gas microspores. Plastic debris that cannot fit in any of the 3 types is defined as fragment.

Microplastic concentration was calculated per kilogram of dry sediments (items·kg^{-1}). A total of 68 samples were chose and identified using micro-Raman spectroscopy (Renishaw 2000, 532 nm laser, Raman shift 100–3500 cm^{-1}). Polymer types were identified by comparing the spectra of each sample to the Hummel Polymer Sample Library and the Raman Sample Library.

2.3. Statistical analysis

SPSS 22.0 (IBM, USA) was used for all statistical analyses. Pearson correlation analysis was used to test the correlation between microplastic abundance at a given sampling site, and the distance of the giving sampling site from urban center. P-value $<$ 0.05 was considered statistically significant.

2.4. Quality assurance and quality control

Potential contamination from laboratory exposure was evaluated using blank tests. In brief, it was possible that the distilled water used to wash containers and to prepare solutions throughout the microplastic analysis, or even the air in the lab, might be contaminated with microplastics. We tested for possible microplastic contamination by filtering 40 L distilled water onto a GF/C filter. The filter was then placed in a pre-cleaned petri dish and left uncovered, in the laboratory, for 14 days. After 14 days, all filters were examined under a stereoscopic microscope. No microplastics were found in these blank test filters. The blank tests indicated that chance of microplastic contamination from the laboratory air or distilled water was negligible and could be ignored. In addition, before analyzing any samples, the workplace was cleaned with 70% alcohol to avoid contamination during analysis. All pieces of apparatus were rinsed three times with distilled water and covered with tinfoil to avoid contamination with airborne fibers.

3. Results and discussions

3.1. Abundance and distribution

The results indicated that the sediments of the lakes and rivers of Changsha were widely contaminated with microplastics (Fig. 2. and Table 2). There was significant variation in the distribution of microplastics. Microplasitc concentration ranged from 270.17 ± 48.23 items·kg^{-1} to 866.59 ± 37.96 items·kg^{-1}. According previous studies have suggested many explanations for uneven microplastics distribution, including hydraulic conditions and the surrounding environment (Auta et al., 2017; Cozar et al., 2014; Horton et al., 2017). The highest microplastic concentration in west Changsha was identified in Yuejin Lake, while the highest microplastic concentration in east Changsha was identified in Yang Lake. Yuejin Lake was the highest contaminated site in this study. The microplastics abundance was achieved to 866.59 ± 37.96 items·kg^{-1}. Yuejin Lake is located in Martyr Park, the most famous park in Changsha. Martyr Park is a scenic spot, located in the center of the city. This park is visited by five million people per year. It was therefore unsurprising that microplastic pollution in Yuejin Lake was worse than at other sites. Based on stable nature of sediment, it could reflect the long-term level of microplastic pollution (Peng et al., 2018). Urban area had higher density and anthropogenic activities which lead to higher microplastic concentration (J. Wang et al., 2017; W. Wang et al., 2017). This phenomenon was consistent with previous studies. High levels of sediment microplastics have previously been identified in other densely populated areas, including Juhu beach, India (Jayasiri et al., 2013); Beijiang River, China (J. Wang et al., 2017; W. Wang et al., 2017); Edgbaston Pool, Birmingham, UK (Vaughan et al., 2017); and rivers in Shanghai, China (Peng et al., 2018). In contrast, relatively remote sites found lower microplastic concentrations, such as Lake Huron, USA (Baldwin et al., 2016) and Siling Lake, China (C. Zhang et al., 2016; K. Zhang et al., 2016). The main source of microplastics abundance in this area might come from residents and visitors littering contribution (Foekema et al., 2013; Huang et al., 2017a, 2017b, 2017c). A large number of studies suggested that human activity was one of the most important reasons of microplastic pollution (Hidalgo-Ruz et al., 2012; Mani et al., 2016; Yonkos et al., 2014).

Many park visitors used disposable items, made of low-quality plastic, such as containers for food and drink or items that protected the user from rain and sun. These types of disposable plastics were fragile, and, when exposed to external forces, were easily cracked into microplastic fragments, which then enter the lake. The relatively low flow velocity in the lake allows the microplastics to settle into the sediment. Indeed, Yuejin Lake was known as a heavily polluted artificial reservoir since 1958. Loosing management policies and a weak sense of environmental protection have resulting in the dumping of substantial amounts of microplastics and plastic litter into the lake, either directly by local residents or via river inflows. The local government (the State Council of China) published a “Circular of the General Office of the State Council on restrictions on the use of plastic shopping bags for production and sales”, which proposed restrictions on the production and use of plastic shopping bags, in an attempt to control plastic waste and thus limit plastic contamination. Although such restrictions might bring about some changes in the status of microplastic pollution, in Martyr Park, the five million annual tourists to this park continue to bring microplastics to Yuejin lake.

Another site in this study had high concentrations of microplastics for an entirely different reason. The second highest concentration of microplastic (779.12 ± 252.10 items·kg^{-1}) was found in the Yang Lake, located in southwest of Changsha. Yang Lake is now a natural park with clear water and beautiful scenery. As this park is a long way from the city center, there were not many visitors come to this place. This park is also under strict management. However, even though it was a tightly managed wetland park today, only a few years ago, it was a place where heavily polluted vegetable growing area with frequent floods. This polder was formed of reclaimed land. Published studies have shown that frequent flooding was an important source of microplastics (Gündoğdu et al., 2018; Veerasingam et al., 2016). In addition, agricultural mulch, which had been used extensively since the 1970s, may be an important source of microplastics in this area surrounded by farmland. Despite the reduction in flood events and the stricter management of the Yang Lake area, microplastic pollution from previous years was identified in the sediment. Although microplastics in sediment are not visible to the naked eyes, ecological risks remain exist. Therefore, it is possible that dredging Yang Lake might remediate the microplastic pollution. Indeed, another lake inclued in this study, Nianjia Lake, was dredged prior to data collection. Nianjia Lake was also located in Martyr Park, adjacent to Yuejin Lake. However, dredging removed the top layer of the sediment, which was most rich in microplastics. Tellingly, the microplastic concentration in the sediment of Nianjia Lake was 557.63 ± 65.14 items·kg^{-1}, much lower than that of Yuejin Lake.

Yue Lake is a newly excavation lake, also located in a park. Yue Lake had a microplastic concentration of 536.34 ± 88.61 items·kg^{-1}. As this lake is close to the Hunan Television Station, intense human activities might be an important source of microplastics in the sediments

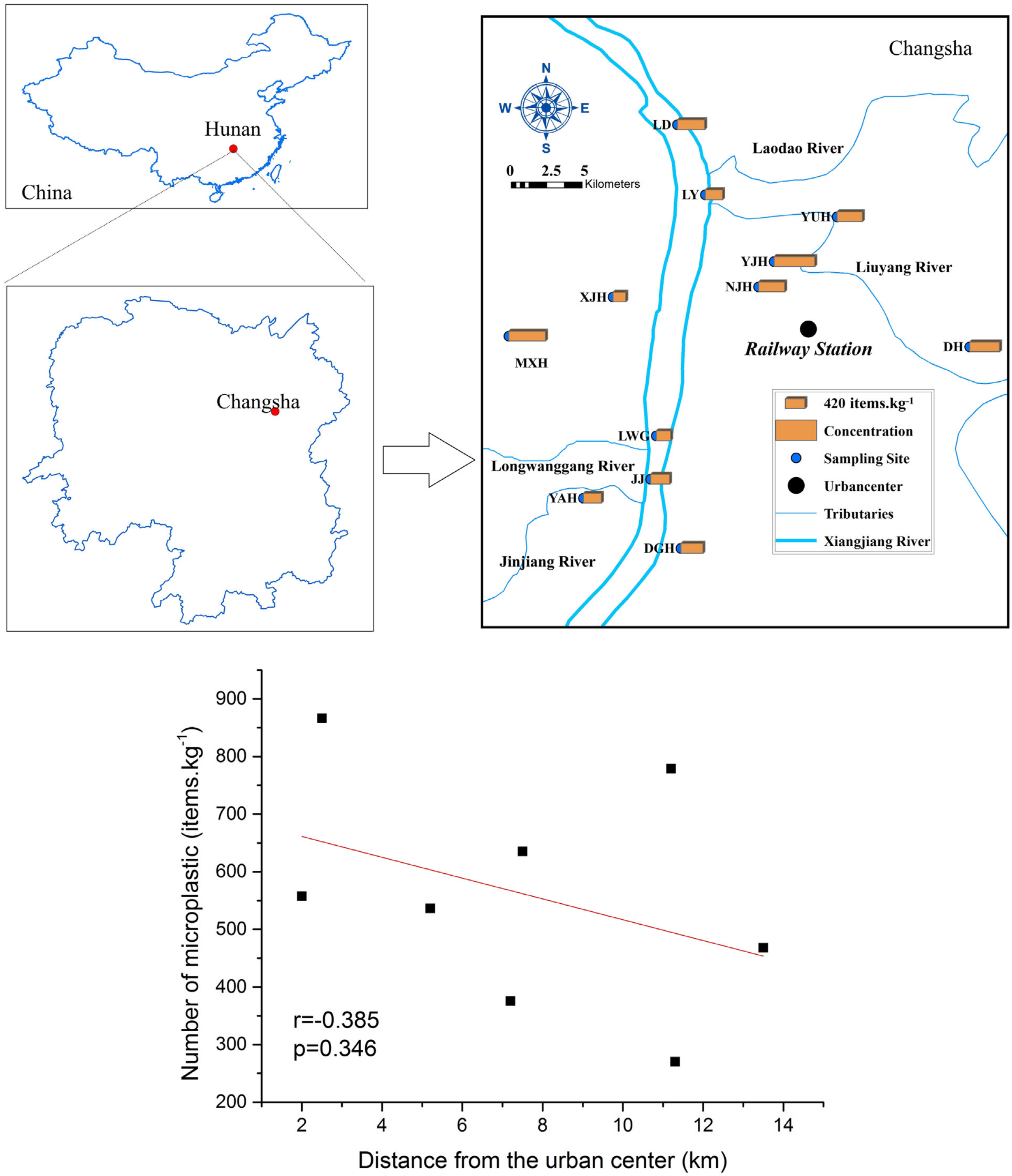

Fig. 2. A) Distribution map according to microplastics concentration in sampling sites; B) Correlation between microplastics concentration and distance from the urban center (Pearson test).

of Yue Lake. Donggua Lake, which is used as a fishery, is also a newly excavated lake. Donggua Lake had a sedimentary microplastic concentration of just 468.03 ± 147.91 items·kg^{-1} in the sediment. Nevertheless, sampling indicated that the water in Donggua Lake was dirty. If Donggua lake is not properly managed over the coming years, domestic plastic litter and debris from fishing nets are likely to cause a sharp increase in the level of microplastic pollution in the lake. Dong Lake, Xianjia Lake and Meixi Lake are all adjacent to universities, with similar surrounding environments and population densities. However, the levels of microplastic contamination among these sites differed. Dong Lake had significantly more microplastics (635.18 ± 197.20 items·kg^{-1}) than did the other two lakes near universities. The microplastic concentration in Xianjia Lake and Meixi Lake were 375.55 ± 175.23 items.kg^{-1} and 270.17 ± 48.23 items·kg^{-1} respectively. This difference might because two surrounding wastewater treatment plants (Huaqiao and Langli wastewater treatment plant are near Dong Lake). Current wastewater treatment measures do not effectively remove all of the microplastics carried in domestic sewage. Indeed, large quantities of microplastics were often found in the water discharged from waste water treatment plants (J. Li et al., 2018; X. Li et al., 2018; Talvitie et al., 2017). There was no significant relationship between microplastic abundance and the distance from the lake

Table 2
The mean microplastic concentration in the sampling sites (items·kg^{-1}).

Sites	Concentrations (items·kg^{-1})	SD
XJH	270.17	48.23
YUH	536.34	88.61
NJH	557.63	65.14
YJH	866.59	37.96
MXH	779.12	252.10
YAH	375.55	175.23
DH	635.18	197.20
DGH	468.03	147.91
JJ	401.78	177.22
LWG	307.55	94.73
LD	580.79	310.35
LY	364.90	244.69

sampling sites to the hypothesized urban center (Pearson correlation, $P > 0.05$). The result was different from the Pearson correlation analyses of surface water (J. Wang et al., 2017; W. Wang et al., 2017). In contrast to surface water, the sinking of microplastics into sediments is a slow, complex process. When exploring the distribution of microplastics in lake environments, effects from the long-term accumulation of microplastics in sediments could not be ignored (Di and Wang, 2018).

The Xiangjiang River is the most important source of drinking water for 7 million people in Changsha. This water quality of this river thus deserves more attention. In this study, four river sampling sites were distributed in the estuaries of four Xiangjiang tributaries: the Longwanggang River, the JinJiang River, the Liuyang River, and the Laodao River. Microplastics were easier to collect in estuaries than in other parts of a river due to the special hydraulic conditions of estuaries (Zhao et al., 2014). Here, the highest microplastic concentration at any

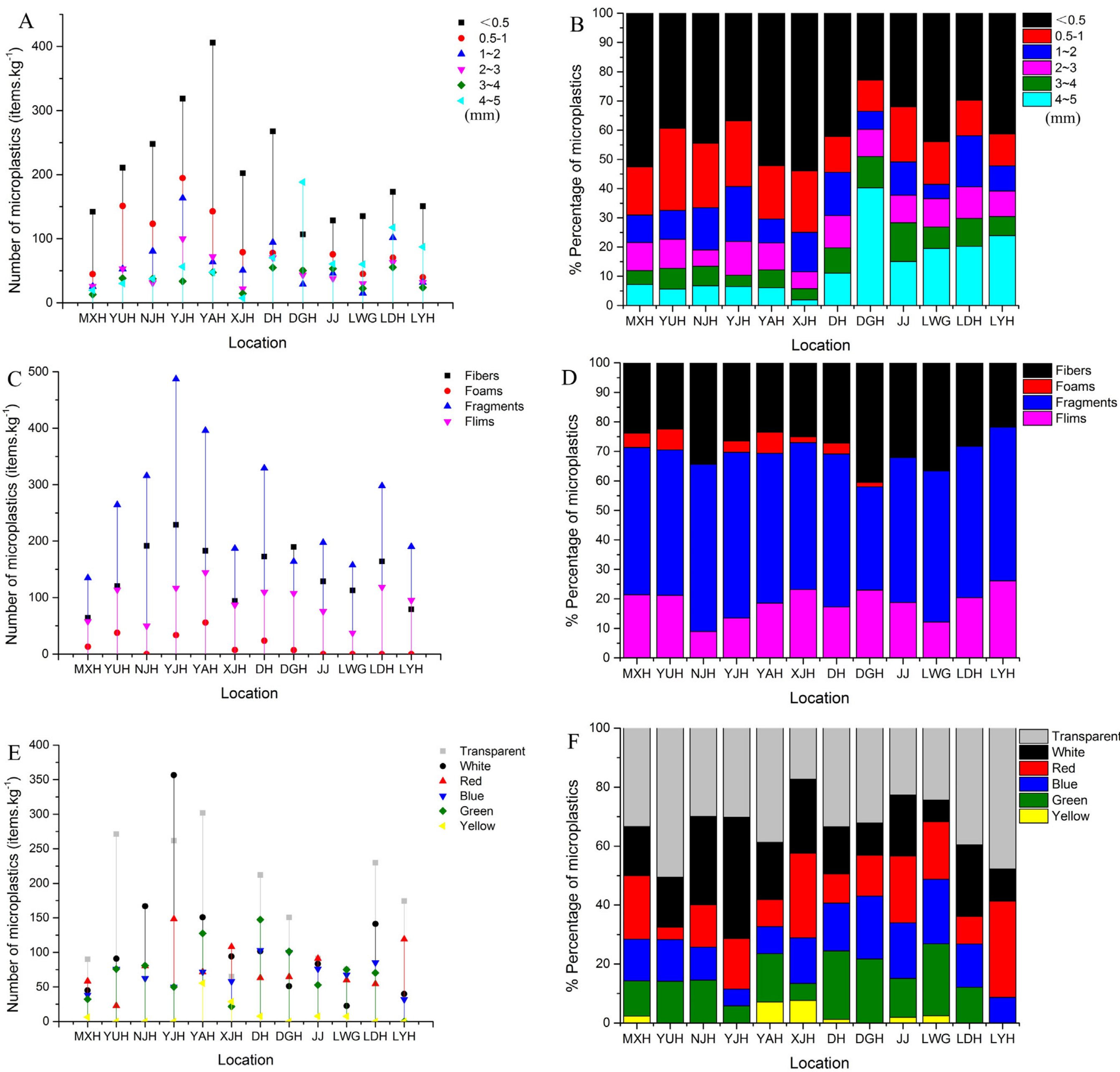

Fig. 3. Number and percentage of microplastics concentration collected in sediments of twelve sampling sites of Changsha, China, according to size (A,B), shape (C,D) and color (E,F). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

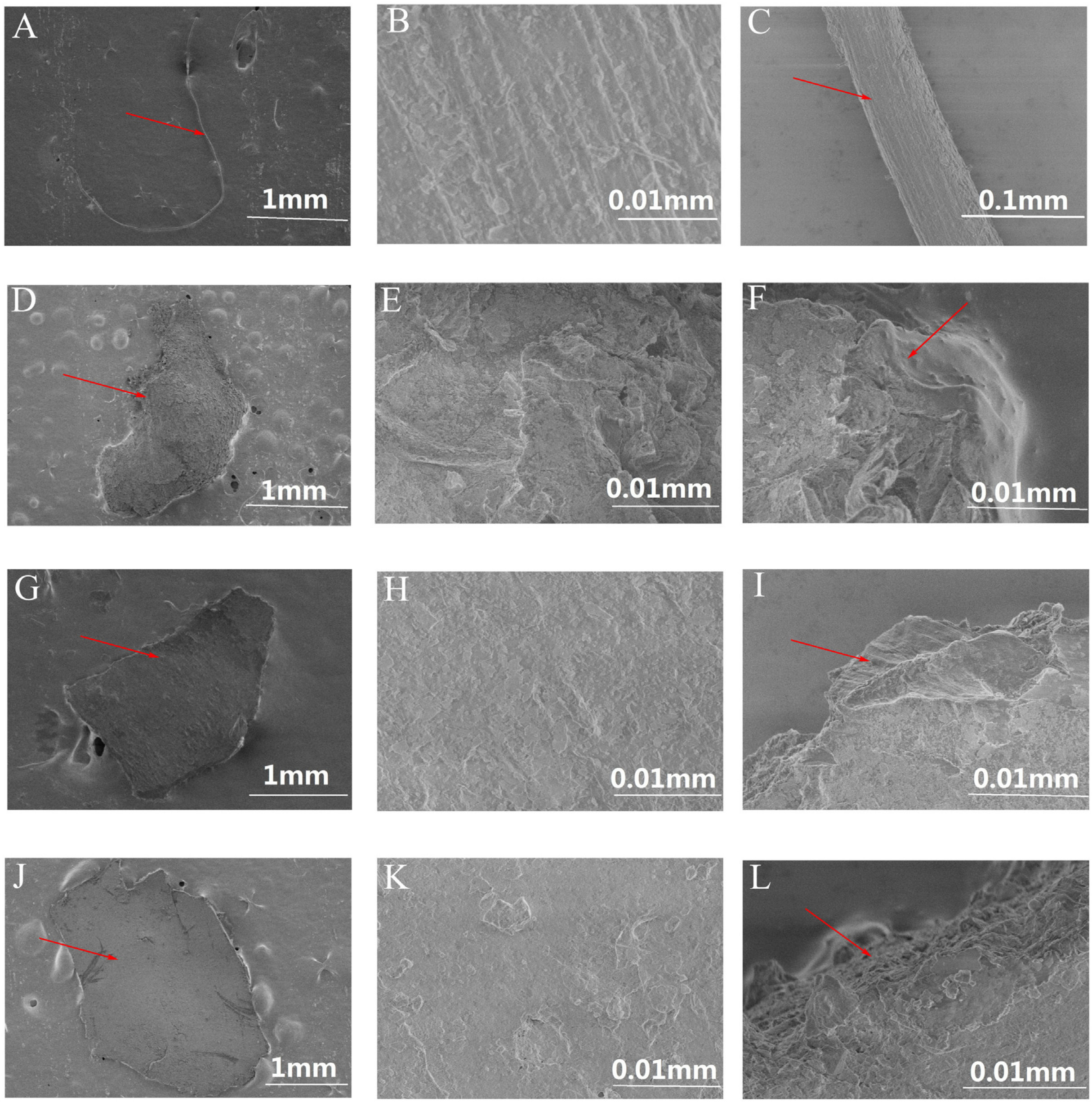

Fig. 4. The SEM images of different types microplastics, A–C) fiber, D–F) foam, G–I) film, J–L) fragment.

river sampling site was identified in the Laodao River with 580.79 ± 310.35 items·kg^{-1}. This concentration was even higher than that of some lakes in this study. This phenomenon might occur due to the proximity to the dam near its downstream. Changsha Comprehensive Hub, which was built in 2008, turned the Xiangjiang River in Changsha, Zhuzhou and Xiangtan into a reservoir. The exist of the dam decreased water velocity which facilitated the deposition of microplastic particles in the sediment rather than flowing away with the water. It was therefore reasonable that the Laodao River, which was nearest to the dam, was most affected. The three more distant estuaries (the Liuyang River, the Jinjiang River and the Longwanggang River) had lower concentrations of microplastics than did the Laodao River.

3.2. Composition and morphological characteristics

Fig. 3 presented the composition of microplastics pollution according to size (A,B), shape(C,D) and color (F,D). Fig. 4 and Fig. 5 showed photographs and SEM images of four types of typical microplastics (fiber, film, foam and fragment). The results in Fig. 3. A and B showed that most of microplastics in these sampling sites were smaller than 1 mm. This phenomenon might indicate the fact that large pieces of plastic could be broken down into various small-sized plastics by various forces, including physical, chemical and microbe forces (Su et al., 2016; J. Wang et al., 2017; W. Wang et al., 2017; Zhao et al., 2015; Zhao et al., 2014). The abundance of microplastics smaller than 1 mm in most of these sample points exceeded 50%. This result was consistent with previous studies of freshwater areas, including the Laurentian Great Lakes, USA (Eriksen et al., 2013); Lake Hovsgol, Mongolia (Free et al., 2014); the Wuhan urban lakes, China (J. Wang et al., 2017; W. Wang et al., 2017); and the Three Gorges Reservoir, China (Di and Wang, 2018).

In the Fig. 3 C and D, it depicted that the dominant shape of the collected sediment samples was fragment with 50.82%. Fragments were present in all sampling sites in this study. Packaging materials, containers, toys and other articles used in daily life all could be the sources of the fragments (Baldwin et al., 2016; J. Wang et al., 2017; W. Wang et al., 2017). Various factors such as sunlight and wind-force increase made bigger plastics degradation and possible fragmentation

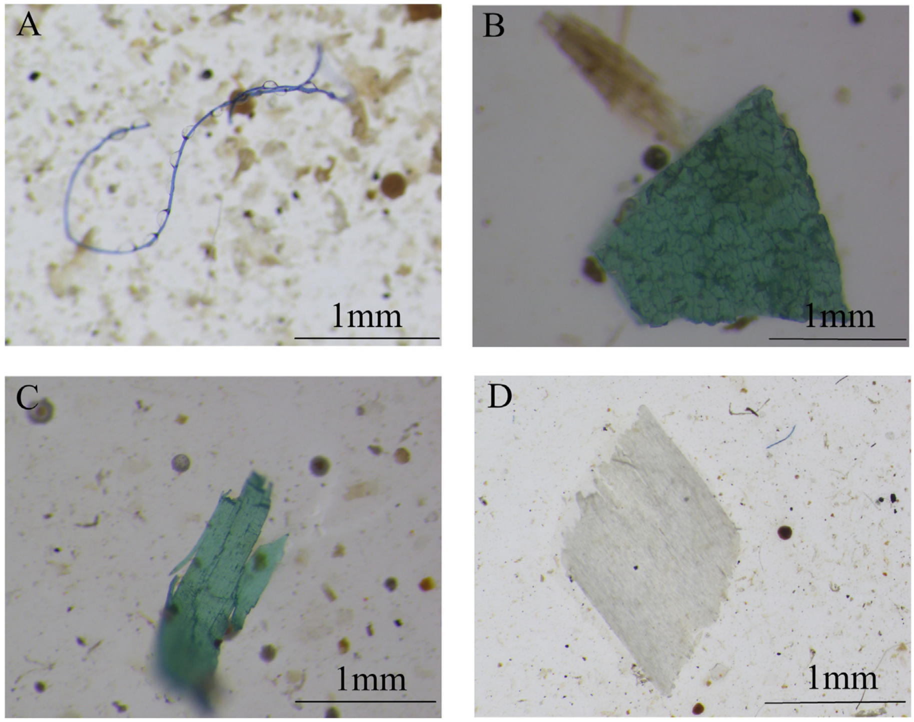

Fig. 5. The stereoscopic microscope (SZX7, Olympus, Japan) photos of different types and different colors microplastics, A) blue fiber, B) green fragment, C) green fragment, D) white film. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

breakdown or crack into microplastics (Carr et al., 2016; Cesa, 2017; Huang et al., 2017a, 2017b, 2017c). Compared with macroplastics, it is easier for large quantities of small microplastics to enter the surface water and to accumulate in sediments under certain conditions. As an urban agglomeration with a population of 7 million, Changsha consumes a wide range of goods, including plastics. The recent boom the fast-food and takeaway industries has intensified the use of plastics in Changsha.

Fiber was another microplastic type found in all sampling sites, accounting for 28.15% among all collected samples. These fibers were often existed in water from laundry and daily cleaning products such as microfibers from cosmetics and disposable facial towel (Hernandez et al., 2017; Peng et al., 2017). Similar to other cities, domestic sewage from Changsha was treated in wastewater treatment plant after pass through sewers pipes. However, the sewage treatment methods used at present do not effectively remove fibers from sewage. Fibers were discharged from the drainage pipes of wastewater treatment plant, entered the surface waters, and eventually accumulated in the sediment. In the Xiangjiang River and Donggua Lake, shards from fishing nets were also a source of fibers (Huang et al., 2017a, 2017b, 2017c; Pellini et al., 2018).

The third most common shape was the film with the percentage of 18.14% in the collected samples. Compared with the hardness of fragments, thinner, softer plastic bags might be the main source of the films (Cheng et al., 2016; Teuten et al., 2007). Mulching used in engineering and agriculture was also potential source (Mohamed Nor and Obbard, 2014; Thompson et al., 2004). Foam was the microplastic types with lower representativeness with a value < 10%. The foam had a special ability to resist collision and was used as a sound isolator. Foam was widely used in building, aerospace, daily necessities manufacturing. The density of foam was low and thus led them to easily floating on the surface water. However, foam had large numbers of gas micropores and thus easily adsorbed different substances. Different substances on foam enlarged foam's density and then made part of foam sink into the sediment (Huang et al., 2016; Mohamed Nor and Obbard, 2014).

As depicted in Fig. 3 E and F, microplastics were categorized by colors: transparent, red, white, blue, green and yellow. Transparent microplastics were the dominant color among all samples. Plastic bags used extensively in daily life by citizens might be the potential of transparent microplastics. Many colored microplastics like fibers and films, especially with red and blue pigments might lose their color during or after entering in the surface water. While, a great contribution with colored microplastics might also mainly come from domestic wastewater (example laundry) discharged from residential areas and wastewater treatment plants. Aquatics perched in the sediments tended to ingest colored microplastics, which could cause damage to their health (Foekema et al., 2013; Huang et al., 2015; Qu et al., 2018).

Fig. 4 and Fig. 5 presented the SEM images and stereoscopic microscope photos of different types of microplastics. From Fig. 4, the SEM images demonstrated that the surface of microplastics was coarse and rugged. There existed a great deal of flakes, pits and grooves on the surface of different microplastics. These characteristics could improve microplastics superficial area and enhanced their ability to absorb the heavy metals and organics pollutions. The Fig. 5 showed the stereoscopic microscope photos of different types and different colors microplastics (SZX7, Olympus, Japan). All microplastics might be easily swallowed by the aquatic organisms, inhibiting aquatic's growth and damaging health. At the same time, additives embedded in the microplastics might be released into the aquatic environment, leading to secondary pollution and biological toxicity. The impact of microplastics on aquatic life requires future study.

3.3. Polymer identification

A total of 68 microplastics were analyzed by micro-Raman spectroscopy to identify the type of polymer, which was widely used to identify the composition of unknown particles (Jung et al., 2018; Renner et al., 2017; Tagg et al., 2015). Six typical Raman spectra were shown in Fig. 6. As demonstrated in Table 3, polystyrene (PS) represented the polymer with highest proportion in all microplastics analyzed (29.41%), followed by polyethylene (PE) and polyethylene

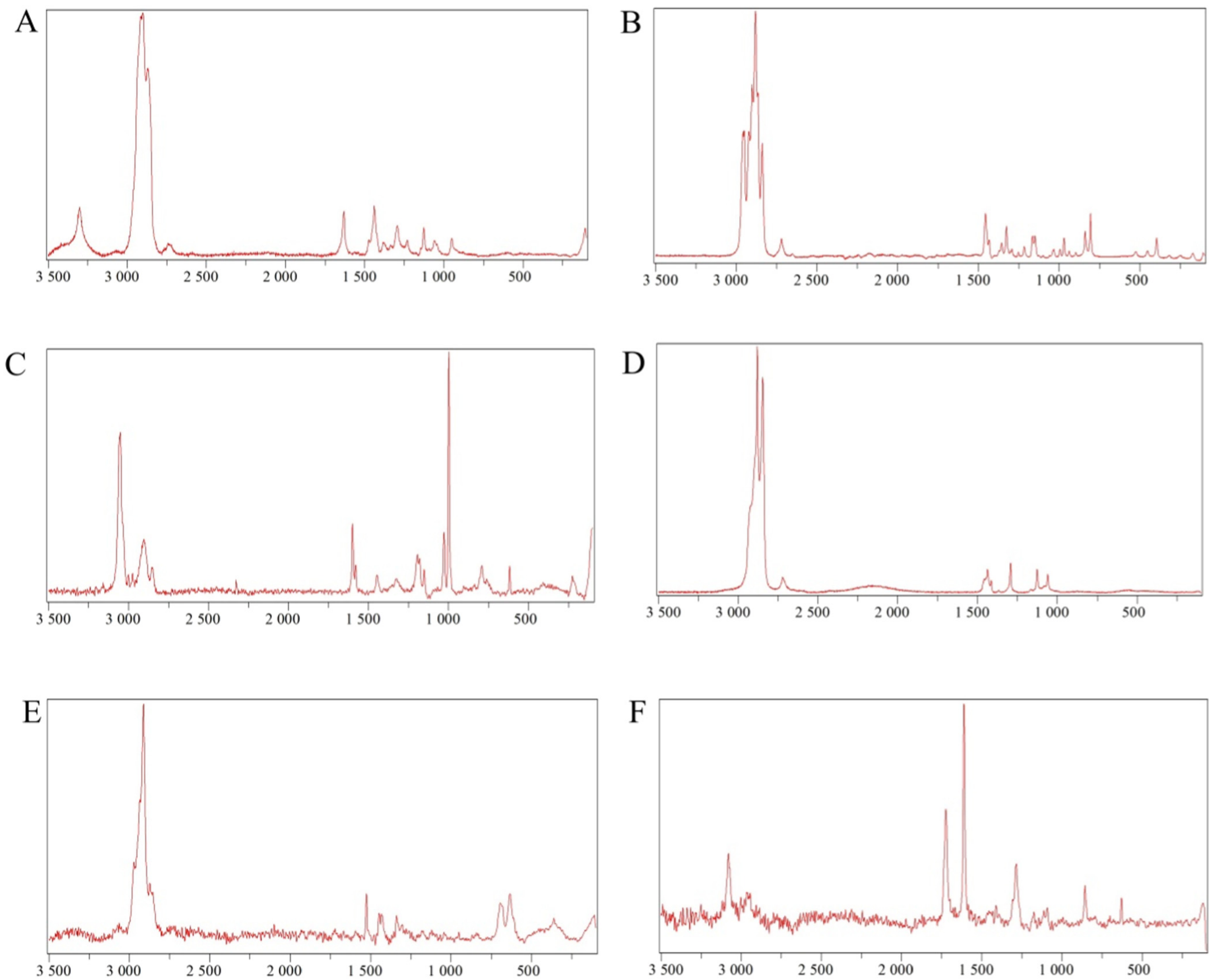

Fig. 6. Typical mirco-Raman spectra of the randomly selected microplastics, (a) PA, (b) PP, (c) PS, (d) PE, (e) PVC, (f) PET.

Table 3
Polymer-types for the result of the micro-Raman spectroscopy.

Type	Fiber	Foam	Film	Fragment	Total	Percentage (%)
PET	5	0	3	2	10	14.71
PP	1	0	1	7	9	13.24
PE	4	1	1	7	13	19.12
PA	7	0	0	0	7	10.29
PS	0	2	5	13	20	29.41
PVC	0	0	0	5	5	7.35
Non-plastic	3	0	0	1	4	5.88
Total	20	3	10	35	68	100.00

terephthalate (PET) with a proportion of 19.12% and 14.71%, respectively. Few particles were identified as polypropylene (PP), polyamide (PA) and polyvinyl chloride (PVC). Four selected particles were found not to be plastic (J. Wang et al., 2017; W. Wang et al., 2017; Wen et al., 2018). These particles might be natural fibers and glass particles.

Polystyrene was needed in many light industries, such as daily decoration, lighting instructions and packaging. Polystyrene was nontoxic and tasteless. This material also had great insulation, durability, easy coloring and could be copolymerized with other types of rubber polymer materials to produce other products. Polyethylene and polypropylene had excellent mechanical features, including heat resistance, stable chemical properties, and great electrical insulation. They were widely used in household appliances, pipes and packaging. Although their density was slightly lower than that of freshwaters between 0.92 and 0.95, polyethylene and polypropylene still existed in the sediment. Both internal and external reasons might cause low-density particles to enter the sediment. For instance, the structure of the plastics might change during manufacture. Natural conditions, such as temperature, waves, salinity, or wind, might also affect particles deposition. In addition, organismal and external forces could change the surface- to-volume ratio of the particle, and possibility of sediment deposition.

Polyethylene terephthalate and polyamide were the most common varieties of thermoplastic polyester. Polyethylene terephthalate has been widely used in garment making for many years. Due to its excellent thermoplastic properties, polyethylene terephthalate was also used in the manufacture of plastic bottles and camera films. Almost all plastic beverage bottles were made from polyethylene terephthalate. Polymide, commonly known as nylon, was a useful raw material with high strength fibers. Polymide often replaced natural fibers and metal wires in clothing and industry. Formerly, polyvinyl chloride was used to be make pipes and plastic bags. However, polyvinyl chloride was unstable when exposed to light and heat. After exposure to temperatures above 100 °C, polyvinyl chloride emitted various types of carcinogens, including hydrogen chloride. Therefore, the use of polyvinyl chloride in packaging was strictly controlled by Chinese law. In addition, the sharp decline in physical strength at high temperatures also made this material unsuitable for use in pipes.

The types of particles found in this study were similar to those found in other freshwater areas of China, such as the Siling Lake basin (Di and Wang, 2018; Zhang et al., 2017), Shanghai (Mani et al., 2016), the Yangtze River Estuary (Su et al., 2016), and the Three Gorges Reservoir. Sediments could reflect long-term pollution, and are thus of great importance to environmental pollution evaluation (Nel et al., 2018; Smith et al., 2018). Microplastics are emerging pollutions, and the mechanisms by which these enter the ecosystem requires in-depth study. It is necessary to further explore microplastic pollution using a variety of research methods (Sadri and Thompson, 2014; Zhao et al., 2015).

4. Conclusions

The surface sediments of the urban water areas of Changsha were ubiquitously contaminated with microplastics. And the *P* value ($P > 0.05$) indicated there was no significant correlation between microplastic abundance and the sampling sites distance to the urban center. Compared with the lakes tested, the Xiangjiang River had lower concentrations of microplastics. The most common microplastic types were fibers, transparent and tiny particles. Polystyrene was the most common polymer- type. However, there are still many gaps and deficiencies to understand the environmental behavior of microplastics in urban water areas, and further investigations on microplastics in the urban areas of rivers and lakes are required in the future.

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