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Microplastics in surface waters and sediments of the Wei River, in the northwest of China

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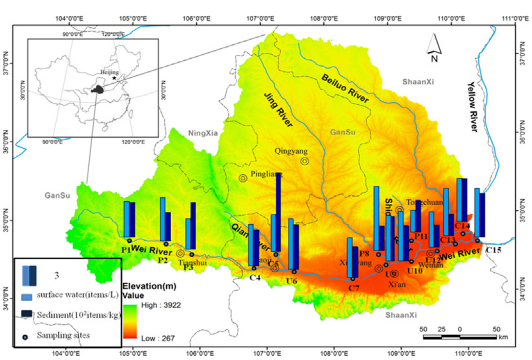
HIGHLIGHTS

- Microplastics were investigated in Wei River in the northwest of China.
- The microplastics in the water samples of the Wei River are lower than the microplastics in the sediments.
- Fiber and small size (<0.5 mm) were the dominant types and size in water samples and sediments of Wei River.

GRAPHICAL ABSTRACT



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ABSTRACT

Microplastic pollution is an increasingly important environment problem. Many studies show the occurrence of microplastics in our environmental system. However, the freshwater system is less understood, especially in northwest China. We investigated the occurrence and characteristics of microplastics in the Wei River Basin, which is located in northwestern China. The Wei River is the largest tributary of the Yellow River and runs through three major provinces. In the Wei River, the concentration of microplastics in the surface waters varied from 3.67 to 10.7 items /L and in the sediments, the abundance of microplastics varied from 360 to 1320 items/kg. Fiber (50.1%)was the dominant types in water samples and sediments. The small size (<0.5 mm)(68.1%)were the main size of microplastics in Wei River. The types of microplastics were polyethylene, Polyvinyl chloride and polystyrene, as identified using a Fourier transform infrared spectrometer. This study could be a valuable reference for better understanding the microplastics pollution in inland northwestern China.

1. Introduction

With the development of technology, plastic is playing an increasingly important material role, and it is widely applied to all walks of life (Long et al., 2015). In addition, plastics also an integral part of our daily life, from clothes to food packages and from personal care products

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to electronics (Jenna et al., 2015). The manufacturing industry is the primary source of plastics, followed by the decomposition of large plastics (Fendall and Sewell, 2009; Murray and Cowie, 2011; Wright et al., 2013). However, due to improper management, a large amount of plastic waste has entered the environment (Jambeck et al., 2015). Plastic waste in the environment is broken down into tiny plastics by physical, chemical and other processes. These small-sized particles are prone to accumulate, migrate and transform in the environment, and when their sizes are smaller than 5 mm, they can be defined as microplastics (Farrell and Nelson, 2013; Pellini et al., 2018). Microplastics have a small size, large specific surface area and strong hydrophobicity, and thus they are ideal carriers of many hydrophobic organic pollutants and heavy metals, which easily cause many environmental problems. In addition, microplastics can also remain in organisms for a long time, and transfer and enrichment occur in food webs, posing a threat to the balance of the ecosystem (He et al., 2018; Jambeck et al., 2015; Wright et al., 2013). For instance, plastic is broken down into microplastics during the tillage, and some remain on the surface of the soil while others are buried under it. Because plastic that is embedded in the soil is less affected by light and temperature, it is difficult to decompose, which may interfere with the root system development of crops and cause serious soil environmental problems (Kasirajan and Ngouajio, 2012; Lithner et al., 2011; Liu et al., 2018; Yang et al., 2011). The plastic remaining on the soil surface is difficult to remove from the soil following the effects of light and high temperatures, and it moves vertically downward, eventually being transported to deeper soil. The harm of microplastics in the environment has been increasingly reported, and the problem was recognized as a new type of pollution in the environment (Browne et al., 2010; Ryan et al., 2009).

To evaluate the ecological environmental risk of microplastics comprehensively, it is essential to characterize their abundance, distribution, and potential sources. For microplastics research, the academic community began with marine plastics that have been found throughout global coastlines (Lechner et al., 2014; Morritt et al., 2014; Wagner et al., 2014). Microplastics have even been discovered in deep sea sediments (Van Cauwenberghe et al., 2013). Similarly, microplastics have been found in the oceans of China, for instance in the Bohai Sea (Zhang et al., 2017b), the Xiamen coastal areas (Tang et al., 2018), the Yellow Sea and the East Sea (Zhang et al., 2019), with the moderate abundance levels compared with other seas around the world. In comparison with the ocean, the microplastic abundance in inland waters was found to be closely related to the population density (Eriksen et al., 2013; Yonkos et al., 2014). In addition, the microplastics pollution in many freshwaters is comparable to or more serious than that in the marine waters (McCormick et al., 2016b; Yonkos et al., 2014). Thus, microplastic pollution from inland waters deserves more attention (Horton et al., 2017; Mccormick et al., 2016a). At present, some research institutions have performed surveys on the microplastics pollution levels in fresh water:such as the Laurentian Great Lakes (Driedger et al., 2015; Peng et al., 2017), the US urban lake (Vaughan et al., 2017). Preliminary studies have shown that microplastics are ubiquitously present in various freshwater habitats around world.

As far as we know, the fates and sources of microplastics in the rivers and lakes of China have been investigated in the Three Gorges Reservoir (Di and Wang, 2018b), the Taihu Lake (Su et al., 2016), Tibet Plateau lakes (Zhang et al., 2016), Dongting Lake (Wang et al., 2018a), and Changjiang (Peng et al., 2017). The results show that the dominant types of microplastics are fiber. Their abundances were found to be higher than that of marine environments. However, due to the vast territory and many inland waters of China, the current research on surface waters is primarily concentrated in the southeast regions, while research on inland waters in the northwest has not been as common. Therefore, microplastics research in the inland waters of the northwest can not only fill the gaps regarding microplastics pollution in China's freshwater environments, but they can also assist researchers in further understanding the impact of different economic developments and the industrial division of labor on the distribution of microplastics.

The Wei River, the largest tributary of the Yellow River, is located in the northwest of China, where with a total length of 818 km and a total drainage area of 134,766 km^2. The Wei River, crossing the Guanzhong Plain, forms a unique basin, which has a large population and a lot of farmland. It is the birthplace of Chinese civilization and it runs through the largest cluster of cities in western China. In 2009, the Wei River Basin, has carried a population of 3,251,000. Agricultural land accounts for about 60% of the total area of the basin. It is the one of the four largest granaries in China. However, due to the excessive use in agricultural activities and improper management of wastes, these plastics can be artificially discarded into river, causing a great deal of pollution in the Wei River (Li et al., 2011; Wei, 2017). In this study, the microplastic pollution in the Wei River was investigated, revealing the characteristics and distribution of microplastic pollution in the basin, and we have analyzed the sources of the microplastics.

2. Materials and methods

2.1. Research area and sampling sites

The Wei River originates in Gansu province, and it is the largest tributary of the Yellow River in China. It originates north of the Niaoshu Mountains in Gansu province, and it primarily flows through Gansu, Ningxia and Shaanxi provinces. In this study, we selected 15 sampling sites from Wushan county of Gansu province to the sites where the Wei River meets the Yellow River, including the entire Wei River basin. These sampling sites can represent the microplastic pollution situation of the entire Wei River basin. Details on the location and sampling sites are shown in Fig. 1 and Table S1.

2.2. Sample collection

Water and sediment samples were collected in the winter of 2017. The precipitation in winter is mainly snow, but the external precipitation will not produce much water in the Wei River Basin. So the amount of water in the Wei River is in a relatively stable range during sample collection in winter. During the sample collection process, our team collected multiple parallel samples of water samples and sediments. On the same river cross section, we collected three samples on the middle, left and right sides of the river.

The bulk surface water was collected into 5 L glass bottle using a clean pump and filtered through a stainless steel sieve with a mesh size of 75 μm (Zhang et al., 2017a; Zhao et al., 2015). Surface water was collected six times repeatedly. The stainless steel sieve was not replaced in the whole process, and the water flow was smaller as it went to the back. The remaining material from the sieve were rinsed into glass bottle by using Milli Q water. Before the laboratory analysis, samples were placed in 4 °C refrigerator.

Sediment samples are collected similarly to water samples. Sediment was obtained from the grab (B-10104, Ravenep). At the same site, each sampling point collected a certain amount of sediment, which was placed in a sealed bag. In order to obtain more detailed information, 5 kg sediment was collected and brought back to the laboratory for analysis. Finally sediment samples were kept in the refrigerator for further analysis.

2.3. Sample preparation

Microplastics in the surface water were separated by using the previously reported method with little adjustment (Zhao et al., 2015). First, to dissolve the natural organic material in the water samples, all the water samples were treated with 30% H_2O_2 at 65 °C and 100 rmp for 12 h. Then, all the samples were pretreated with sodium chloride to increase the density of the water samples. Then, the entire solution was

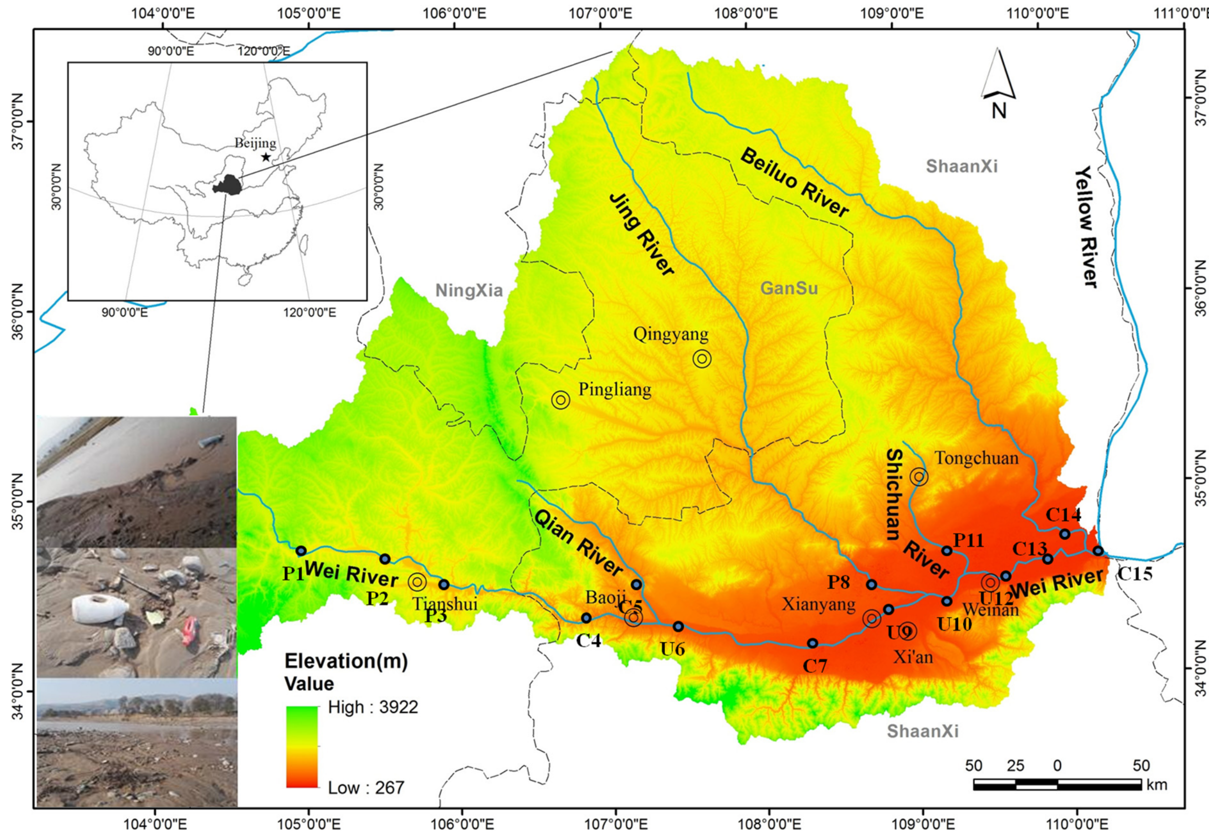

Fig. 1. Geographic locations and sampling sites in surface waters and sediments of the Wei River.

stirred with a clean glass rod for 2 min and allowed to settle for 24 h. After that, the supernatant was passed through 0.45 μm filter papers using a vacuum pump. The filter papers were placed in a clean culture dish and dried at 50 °C for 24 h while waiting for the microscopic observations (Wang et al., 2017).

The microplastics were isolated from sediments samples by this method with modifications (Nuelle et al., 2014; Wang et al., 2018b). First, all sediment samples were dried at 70 °C for 24 h to a constant weigh. And saturated salt solution were added to 100 g of dried sediment samples from each site. All samples were stirred with a clean glass rod for 2 min and settled for 24 h. Next, to degrade organic matter, the suspension were added to 30% H_2O_2 at 100 rmp at 65 °C for 24 h. For filtration, the solution was poured through filter paper aided by a vacuum pump and then rinsed with Milli Q water. Finally, the remaining procedure was the same as the water samples.

To avoid potentially artificial and airborne plastic contamination in the laboratory, all instruments and vessels were rinsed carefully with ultrapure water and wrapped tightly in plastic wrap. In short, keep the laboratory clean at all times. Laboratory coats and gloves were worn during the entire process of sample collection and laboratory analysis. Meanwhile, blank experiments were conducted. Experiments show that no piece of microplastic was found in the blank controls.

2.4. Observation and identification of microplastics

Materials on the filter papers were observed under a metallographic microscope with digital camera (MV5000(R/TR), Nanjing Jiangnan Novel Optics Co, Ltd). The suspected microplastics were photographed by digital camera and distinguished primarily on the basis of classification criteria developed in previous studies (Hidalgo-Ruz et al., 2012). The size, type and shape were recorded. For the number of microplastics in water samples, the unit is the number of microplastics per liter (items/L). And for sediment, it's the amount of microplastic per kilogram (items/kg). Finally, those typical plastics were selected from each sample were determined the specific structure by scanning electron microscopy (SEM) (Nova Nano SEM-450, FEI).

2.5. Statistical analysis

The abundance of microplastics in surface water from each sampling site was calculated dividing the amount of microplastics determined by the volume of water sample and the weight of sediment. Statistical analyses were performed with the Principal component analysis (PCA) and the Pearson correlation method. The relationship between microplastic abundance and each sampling site was tested by Pearson correlation method.

The Principal component analysis (PCA) is a statistical procedure that is orthogonalized to make it a few independent indicators. These indicators can be used to assess the situation in an area (Uddin et al., 2019). In this study, the PCA is done by eigenvalue decomposition of a data correlation matrix (Abdi et al., 2013). The PCAs of the 5 variables describing the distributions of microplastic types in the surface water and sediment from the Wei River. The Principal Component Analysis uses raw count data to analyze the relationship between the type of microplastics and the sampling sites. Finally, the results of PCA indicate the distribution of microplastics by component score. All samples were used to assess differences in the abundance of microplastic.

3. Result and discussion

3.1. Abundance and distribution of microplastics

In this work, the number of microplastics collected from all of the surface waters and sediments is presented in Fig. 2. The number of

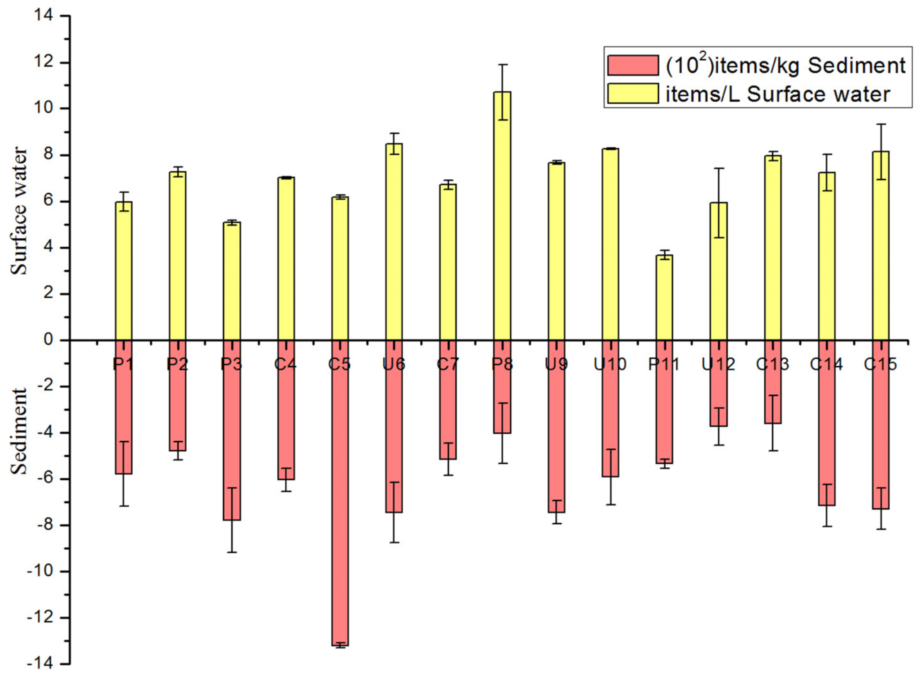

Fig. 2. Abundance distribution of microplastics collected from the Wei River.

microplastic particles in the surface waters varied from 3.67 to 10.7 items/L. In the sediments, the abundance varied from 360 to 1320 items/kg. Compared with other inland freshwater systems, the microplastic abundance in the Wei River was comparatively high, and the contamination was more severe.

Fig. 2 shows that the abundance of microplastics in the surface water varied from 3.67 to 10.7 items/L. It can be observed that these sites with microplastic abundance higher than 6.5 items /L were almost located densely populated areas and agricultural planting areas. Agricultural production and anthropogenic activities may lead to the presence of plastic waste and other pollutants in the river (Wang et al., 2018c). Sample site P8, which was located in the lower reaches of the Jinghe River near extensive agricultural planting areas, had the highest microplastic number. Sample U6, which was collected from the lower reaches of Baoji city, was the first big city where the Wei River flows. However, there are also exceptions, e.g., site P3 and site P11 were collected near agricultural areas. In particular, sample P11 was obtained at the largest countryside site near Shichuanhe River which is characterized by extensive agricultural planting. However, the lowest average abundances of microplastics were observed at site P11 (3.67 items /L). The lower microplastic abundances observed in these samples could be connected to the sand content rate in the river. The proportion of sand in river sediments at this site is 1.11% (Fig.S1), which is higher than that of all the previous points. Therefore, sand could carry plastic wastes within the watershed to accumulate in sediment. In addition, we found that the microplastic concentration has a tendency to increase gradually as the river flows from the countryside to the city. Sample C7was collected at a rural area around Xian Yang city. Sample U9 was collected from the lower reaches of Xian Yang city cluster that flows through the Wei River. The concentrations of microplastics at the two sampling sites were obviously different. As the river gets closer to the city, the microplastics concentrations increase gradually. Site C4 and site U6 have the same tendency. This result indicated space correlations between microplastic pollution in the river and the distance to the urban centers. As far as we know, many studies have addressed the microplastics pollution in inland freshwater systems. Many studies about microplastics are listed in Table S2. A relatively high abundance of microplastics has also been found in the Three Gorges (1597–12,611 items/L) (Di and Wang, 2018b). Nevertheless, a comparatively lower quantity of microplastics was found in Northeast Geenland (2.4 items/L) (Morgana et al., 2018). That microplastic abundance is comparable to the abundance detected in Taihu Lake (3.4–25.8 items/L) (Su et al., 2016). In the Wei River, the pollution status of the microplastics was at middle level.

The number of total observed microplastics in the sediment is shown in Fig. 2. The highest abundance was collected at site 5 with its large wetland park, which is characterized by a very low surface flow velocity. Sample C15 was detected at the intersection of the Wei River and the Yellow River. The Wei River became wider and the water flow rate became slower. Therefore, the high microplastic abundance may be connected to the decrease in river flow velocity, which is conducive to the sedimentation of dense plastic particles. However, it must be noted that the microplastic abundances in the surface waters and sediments were not directly proportional to some extent. Sample U9 had the third highest microplastic concentration (745 items/kg), but by contrast, the number detected in the same of surface water site was 1 to 2 orders of magnitude lower than those collected in sediment. Site U9 was located in the downstream of Xian and Xian Yang. Because this area is engaged in the reasonable management of its solid waste, the abundance of microplastics in the water was reduced. However, microplastics in sediments do not change as quickly as they do in water, and many years of accumulation keep them at a high level in sediments. The microplastic abundance observed here was much higher than the abundance found in the lakeshore sediments of the Edgbaston pool in the UK, which reached 25–30 particles/100 g(Vaughan et al., 2017), but it was comparatively lower than that found in the lakeshore sediment of the Yangtze river basin (25–340 items/kg) (Peng et al., 2017).

3.2. Shape and size of microplastics in Wei River

The typical microplastics selected from all the samples were identified as presented in Fig. 3. Fibers and films were the more dominant types of microplastic observed here (Fig. 3a). According to the images of the microplastic types under the microscope (Fig. 3d, g, j, m, and p) and compared with previous research, the microplastics collected

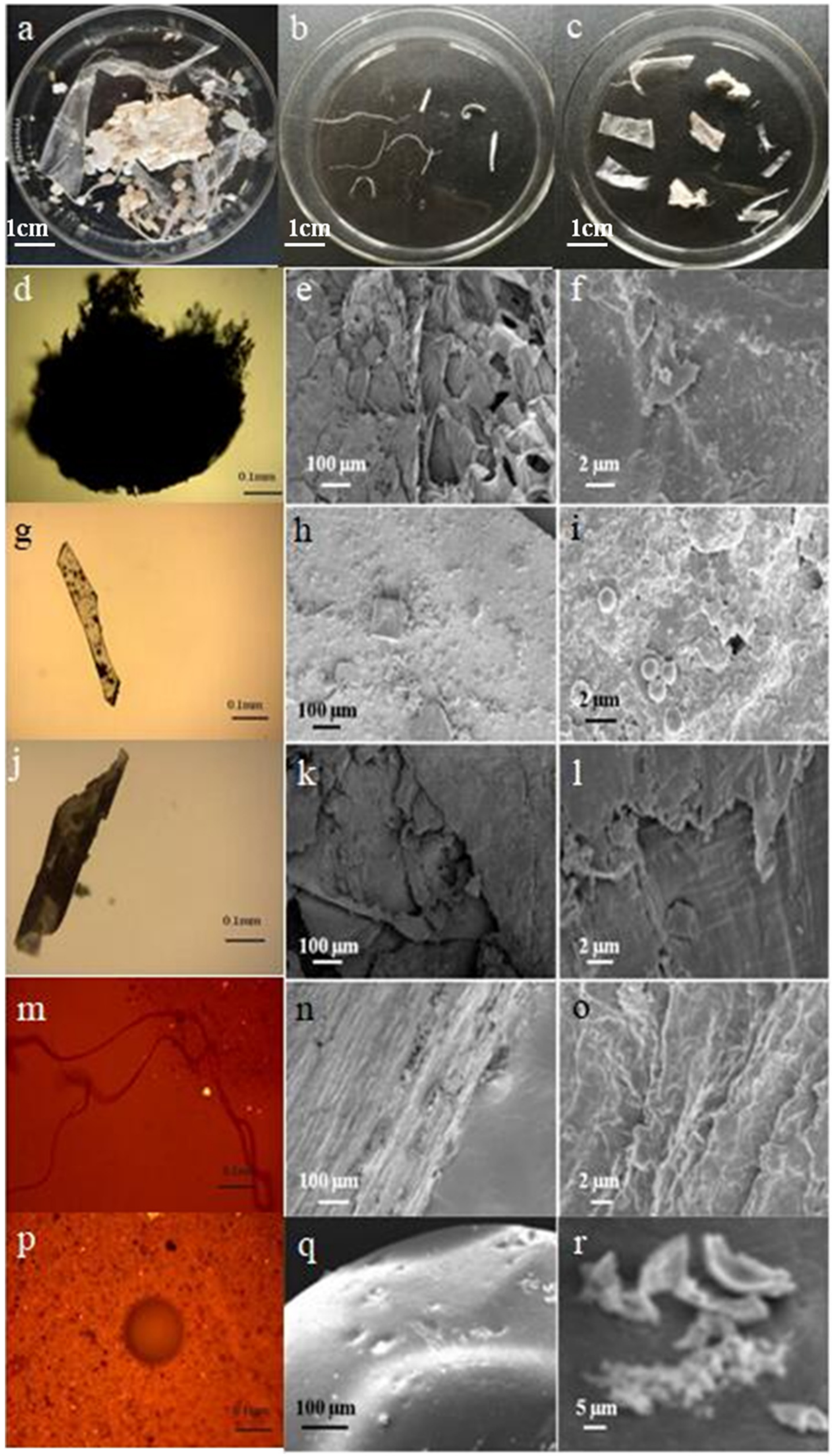

Fig. 3. Photographs of microplastics items identified using digital camera(a, b, c), microscopes(d, g, j, m, p) and SEM (e, f, h, I, k, l, n, o, q, r) Microplastics found in Wei river (a), fiber(b, m, n, o), film(c, j, k, l),. foam(d, e, f), fragment(g, h, i) and pellet(p,q, r)).

in the Wei River could be classified into five groups, namely fibers, fragments, pellets, films and foams. The standard of this classification is bound to the shape characteristic of the microplastic. In addition, the morphologies of microplastics were investigated by SEM. In brief, Fig. 3(e–f) shows the flat and layered structure of foam (Dong et al., 2018). The foam composes a number of irregular flakes, which are obviously torn with clearly visible cracks. However, it can be observed in Fig. 3f that the sample surface is smooth. Therefore, we can observe that the degree of internal weathering is lower than that from external weathering. This weathering may be caused by a reaction with organic matter in the environment. As illustrated in Fig. 3(g–i), the fragment is a small piece or part of large plastic items and has a regular edge shape. In addition, the surface of the fragment is rough and has abundant pores. Particles are observed on the surface. The particles coming from the environment may be adsorbed onto the surface. This result may be related to the degrees of weathering in the environment, which can enhance their ability to absorb metal ions and organic pollutants (Guo et al., 2013; Guo et al., 2018). In Fig. 3(j–l), the film is a part of a plastic product that has a very thin and fragile layer. Moreover, the film contains more folded structures and has no fixed shape at the edge. A film is greatly affected by the environment, and its surface cracking marks are obvious, which illustrated that the degree of aging is greater than that of the other four types of microplastics. In Fig. 3m, fibers are microplastics that are long and thin. The SEM image of fibers (Fig. 3n and o) show that the surface is rough and there are a number of pores. Many broken residues are adsorbed onto the surface. In addition, some curled filaments are present on the surface. The above results show that the hackly surface of fibers allow the contaminants to concentrate on the surface, which is caused by long-term oxidation in the environment (Guo et al., 2018). In Fig. 3(p–r), the pellet is a plastic material that is shaped like an ovoid sphere, or it is disc-shaped or cylindrical. In addition, the SEM analysis shows that the pellet consists of hackly layers with abundant pores, which may be attributed to the effects from the environment (Li et al., 2018).

The relative abundance of microplastics in different samples is presented in Fig. 4a, which showed that the fiber was the dominant species in water samples, accounting for 38.25% to 61.95% of the total microplastics quantity. In the sediments, the ratio of fibers was highest, accounting for 42.25% to 53.20%. The fibers might be, to a great extent, attributed to the decomposition of agricultural equipment and sewage containing fibers from clothes (Claessens et al., 2011). In addition, fishing gears, atmospheric deposition and surface runoff are also potential sources of plastic fibers (Browne et al., 2011). Films were also widely present in surface water and sediment, accounting for 17.4% to 38.2% and 23.9% to 31.8% on average for the surface water and sediment, respectively. Domestic sewage-containing films from discharged plastic

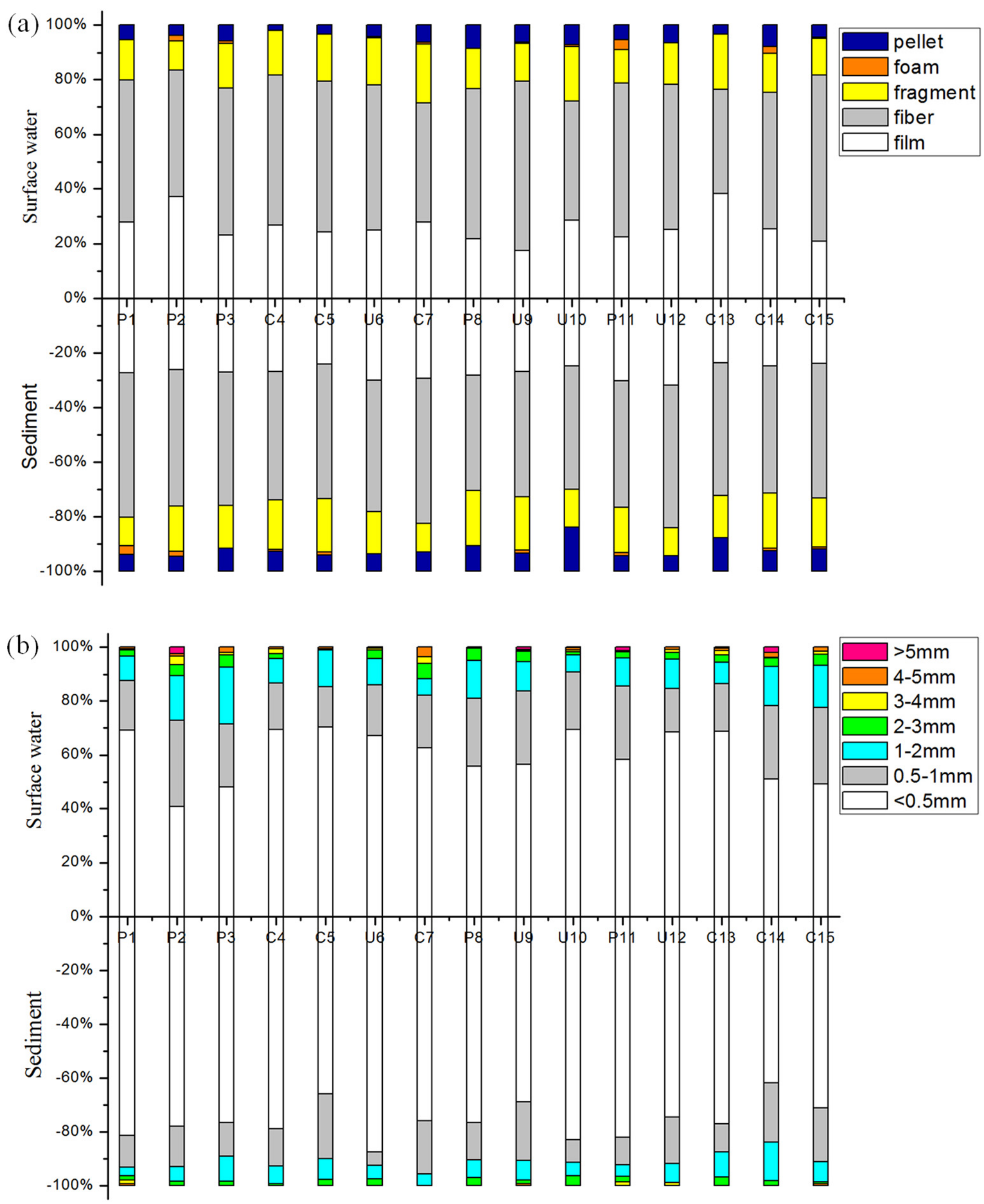

Fig. 4. Type distribution (a) and size distribution (b) of microplastics collected from the Wei River.

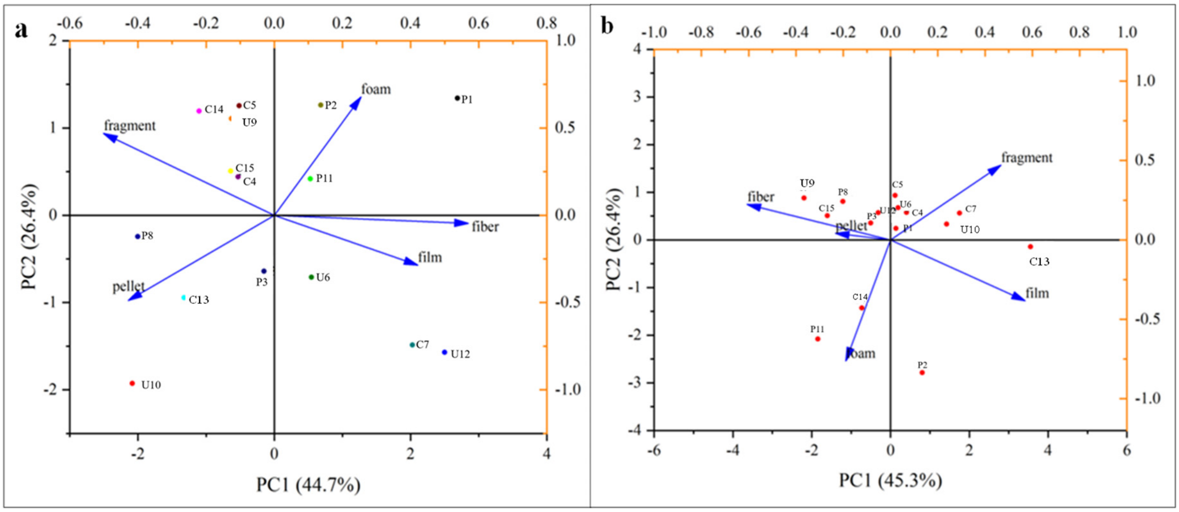

Fig. 5. Principal component analysis of microplastic species in Wei River (a. surface water and b. sediment).

are an important source of microplastics in the Wei River (Wang et al., 2018a). Moreover, the developed farming and agricultural activities also increase the presence of film in the water and sediments, which could be recognized as a source of microplastics in the Wei River. Fragments were found in the surface water (accounting for 10.6% to 21.7%) and sediment (accounting for 10.2% to 20.3%), which may come from the decomposition of many plastic wastes, such as agricultural tools, plastic packaging materials, plastic woven bags and plastic seed bags (Antunes et al., 2013). Although the quantity was relatively small, pellets were also found in sediment samples (accounting for 5.6% to 16.1%) and water samples (which occupied 0.4% to 7.8%). Many personal care products and manufactured plastic products can cause pellet pollution. Therefore, industrial manufacturing and domestic sewage may be potential sources of microplastic (Di and Wang, 2018b). The foams collected from the Wei River were fewer than the other four categories. The total foam found in water samples from nine points ranged from 0.25% to 3.5% and the foam observed in eight sediment samples ranged from 0.7% to 3.5%; this material may be generated from packaging materials and plastic containers (Mohamed Nor and Obbard, 2014). Therefore, the types of microplastics are related to agricultural activities and industrial manufacturers, which could be important sources of microplastics in the Wei River.

Because of the proportion of different plastic types at different sampling sites, using PCA can be more intuitive for observing the distribution of the microplastic. The PCAs of the 5 variables describing the distributions of microplastic types in the surface water and sediment from the Wei River are shown in Fig. 5, which demonstrated the significant separation by distributions (Cai et al., 2017). Among them, the 5 variables are the different types of microplastics for each sampling site. The results revealed that different sampling sites are dominated by different types of microplastics. In addition, PCA can also make a statistical analysis of the distribution of microplastics types at sampling points. Fig. 4a shows the PCA of the 5 variables in the surface water, in which the first component showed strong contributions from fiber (44.7%), and the second component was dominated by fragments (26.4%). It can be observed that fiber was the dominant types in surface water. Besides, fibers and films are mainly distributed in site U6,site C7and site U12, which were almost located the confluence of tributaries and main stream areas. Fragments are more widely distributed than fibers and were almost located in countryside. Human activities may lead to the production of large amounts of fibers, fragments and films. These wastes are discarded or flowed into the river to cause pollution. Foams are distributed in extensive agricultural planting areas, which are produced by agricultural activities. In Fig. 4b, the first component of the sediments showed strong contributions from fibers (45.3%)which are observed in sediment of many sites. It indicate that fibers were widely present in Wei river. The second component was dominated by films (26.4%), but films has less distribution, which were almost located agricultural planting areas. The distribution characteristics can show that the main source of films is agricultural activities. The results of this investigation indicate that fiber is the primary microplastic type in the Wei River, which was in accordance with the other studies on freshwater systems (Peng et al., 2017; Zhang et al., 2016). In addition, the distribution characteristics of different types of microplastics are closely related to agricultural and human activities in regional characteristics.

Microplastics were classified into seven categories (<0.5 mm, 0.5–1 mm, 1–2 mm, 2–3 mm, 3–4 mm, 4–5 mm and >5 mm) based on their size, and their relative proportions in different samples is presented in Fig. 4b. The microplastics in group 1 (<0.5 mm) were the most abundant in all the samples and accounted for 40.8% to 68.8% in all the samples, followed by group 2, which occupied 15.1%–27.1% and 8.35%–24.2% of the surface water and sediment. In the other classifications, the proportion of microplastics decreased successively along with the size enlargement. These trends were similar to data from Lake Garda (Imhof et al., 2016), Three Gorges (Di and Wang, 2018a), and Qinghai Lake, China (Xiong et al., 2018). The high number of small-sized microplastics may be because larger plastic wastes could be decomposed into small particles. The small-sized microplastics were likely attributed to the effects of sand in the Wei River. The sand dramatically accelerates the weathering of plastics. In addition, surface runoff may also increase the efflorescence of the microplastics. Therefore, the waste plastics may have undergone intense weathering and sand abrasion in the river.

4. Conclusions

Microplastics were found in all the water and sediment samples from the Wei River. Moreover, the abundances of microplastics in the surface water and sediments are relatively high. However, this study shows that the microplastics in the water samples from the Wei River Basin are lower than the microplastics in the sediments. The result demonstrates that the low water flow and high sand content rate give rise to the accumulation and distribution of microplastics. In addition, the microplastic sources in the Wei River Basin are closely related to agricultural activities. Therefore, we recommend that people focus on the management of agricultural waste. More work should be performed to assess the risks of microplastic pollution in the Wei River.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.02.332.

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