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Microplastic pollution in water and sediment in a textile industrial area

Hua Deng [a], Ren Wei [b], Wenya Luo [a], Lingling Hu [a], Bowen Li [a], Ya'nan Di [c], Huahong Shi [a,*]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200241, China
[b] Institute of Biochemistry, University of Greifswald, Felix-Hausdorff-Straße 4, D-17487, Greifswald, Germany
[c] Institute of Marine Biology and Pharmacy, Ocean College, Zhejiang University, Zhejiang 316000, China

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ABSTRACT

Microplastics pollution in the environment is closely determined by the surrounding industrial and human activities. In present study, we investigated microplastics in water and sediment samples collected from a textile industrial area in Shaoxing city, China. The abundance of microplastics varied from 2.1 to 71.0 items/L in surface water samples, and from 16.7 to 1323.3 items/kg (dw) in sediment samples. The polymer type was dominated by polyester both in water (95%) and sediment (79%) samples. The majority of the detected microplastics was predominantly colored fibers smaller than 1 mm in diameter. The high level of microplastic pollution detected in local freshwater and sediment environments was attributed to the production and trading activities of textile industries, for which severe regulations should be envisaged in the future to effectively reduce the local microplastic pollution.

1. Introduction

More than two decades have passed since microplastics (plastic smaller than 5 mm) were recognized as a pollutant of global concern, which have been found in every continent, including the polar regions (Andrady, 2017; Auta et al., 2017; Chen et al., 2018). The ubiquitousness of microplastics raises concerns of their potential risks for organisms, including humans, though debates on their actual ecological influences are still ongoing (Imhof and Laforsch, 2016; Wright and Kelly, 2017; Conkle et al., 2018). Tracking the source of microplastics and the pathways through which they enter the environment is commonly recognized as crucial for tracing their further distribution in the biosphere. Recently, increasing research interest has emerged with respect to the terrestrial sources of microplastic pollution (Anderson et al., 2016; Bordós et al., 2019; Hu et al., 2018). Indeed, the accumulation of microplastics in the oceans has been mainly attributed to terrestrial human activities including industrial manufacturing, agriculture and municipal solid waste landfilling (Driedger et al., 2015; Vandermeersch et al., 2015). While the removal of microplastics from polluted environments is almost impossible, establishing a waste management system including an efficient control of the pollution source is regarded as a proper measure to reduce the risk of microplastic pollution (Anderson et al., 2016; Estahbanati and Fahrenfeld, 2016). Taking the primary microplastics as an example, they are indeed plastic microbeads manufactured as exfoliates in the above-given size range for adding to personal care products (Browne et al., 2011; Wang et al., 2016; Conkle et al., 2018). Monitoring of plastics pellets and the ban on microbeads in "rinse-off" products hence becomes the first wave of new environmental regulations with respect to the control of microplastics (Law and Tompson, 2014; Iñiguez et al., 2017; Law, 2017). However, due to the short implementation time so far, the primary benefit of the ban is still unknown.

In 2016, over 5.4 million tons of synthetic fibers were produced worldwide (Carr, 2017), which can enter the aquatic environment by textile washing processes (Browne et al., 2011). Filed studies have showed that synthetic fibers are the dominant type of polyester microplastics detected in water, sediments and various organisms (Woodall et al., 2014; Lourenço et al., 2017; Abbasi et al., 2018; Halstead et al., 2018). For example, synthetic fibers accounted for over 90% of microplastics in abundance in global coastal environments (Barrows et al., 2018). Wastewater generated by industrial and domestic textile laundry has been attributed to be the

* Corresponding author.
E-mail address: hhshi@des.ecnu.edu.cn (H. Shi).

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major sources of synthetic fibers found in the aquatic environment (Browne et al., 2011). Nevertheless, the contribution of textile industries to the microplastic pollution has been so far rarely studied in the context of a field survey.

The industrial production of textile fibers requires often a large amount of water consumption and discharge. Wastewater released by textile industries contains numerous toxic compounds, such as nonylphenol ethoxylates, benzothiazole, etc., and was thus previously considered as a primary pollution source (Brigden et al., 2012; Avagyan et al., 2015). In contrast to the above-described contaminants which are generally monitored and treated in the textile wastewater effluent system, the release of synthetic microplastic fibers into wastewater systems is currently not sufficiently regulated (Li et al., 2018; Carr, 2017). In addition, washing, packaging and transportation of the textile products are leading to further environmental release of microplastics.

Although a few studies concerning microplastics made of textile fibers have been published (Jemec et al., 2016; Dris et al., 2017), a comprehensive field survey on microplastic pollution is still missing near textile industrial areas and the link between suspected sources of microplastic and microplastic pollution in the environment is still hard to be established. Here we report a comprehensive field survey on microplastic pollution in various waterbodies and sediments near textile industrial areas of Shaoxing County, which is the center of the Chinese textile industry and trading markets. We aimed to provide a quantitative estimation on the correlation between potential sources, including the manufacturing and trading activities, and the factual situation of microplastic pollution in the surrounding environment.

2. Materials and methods

2.1. Study area

The "China Textile City" (CTC) was selected as the target study area since it is the largest textile manufacturing and trading center in Zhejiang Province, China and the largest textile professional market in Asia (Fig. 1). About 120 textile factories and 160 trading markets unevenly distributed in this area were investigated. Over three million tons of various synthetic fibers, nineteen billion meters of printing and dyeing cloth and nearly 300 million pieces of costume are produced here every year, generating an annual export of textile fabrics valuing nearly nine billion dollars (http://www.ctcte.com/autumn/business_020-001.html). No apparent upstream, midstream or downstream could be clearly identified in the local small water bodies of the textile area to serve as reference sites apart from the manufacturing and trading activities. Instead, we selected an agricultural area with similar water body distribution near to Zhejiang Province to set up eleven reference sampling sites (R_1-R_{11}) as shown in Fig. S1 in Supplementary materials.

2.2. Sample collection

Geographical information (i.e. latitude and longitude data) of sampling sites, textile markets and factories were recorded as shown in Table S1 in Supplementary materials. Surface water samples (0−5 cm below the surface) and sediment samples (top 5 cm) were collected from 21 study sites (S_1−S_{21}) during July to October 2018 (Fig. 1). Only surface water samples were collected from 11 reference sites (R_1-R_{11}) in the agricultural area. Samples were collected at different distances to the textile factories and trading markets in CTC to reveal the gradient of microplastic pollutants in the textile area (Fig. 3). At each sampling site, we collected three replicates of 5 L of water and 2 kg of wet sediments using a metal pail shovel and stored at 4 °C until further analysis.

2.3. Isolation of microplastics

The microplastics from water and sediments were isolated as described previously with slight modification (Su et al., 2016, 2018; Hu et al., 2018). Briefly, the particles were filtered using a 20 μm nylon mesh filter (Millipore Nylon NY 2004700) by applying a vacuum after recording the water volume. For the purpose of digesting the organic material, all particles on the filter were rinsed into a flask by using 150 mL of H_2O_2 (30%, V/V) filtered in advance. Each container was covered by metal cap and shaken in a shaking incubator at 65 °C and 80 rpm for almost three days. The solution in the flask was filtered again using a 5 μm nylon filter (PALL Nylon NCG047100). Finally filters were kept in a Petri dish for further study, which was baked at 450 °C previously for 8 h to reduce the contamination of airborne.

The wet sediments were put in a stainless steel can with a cap in

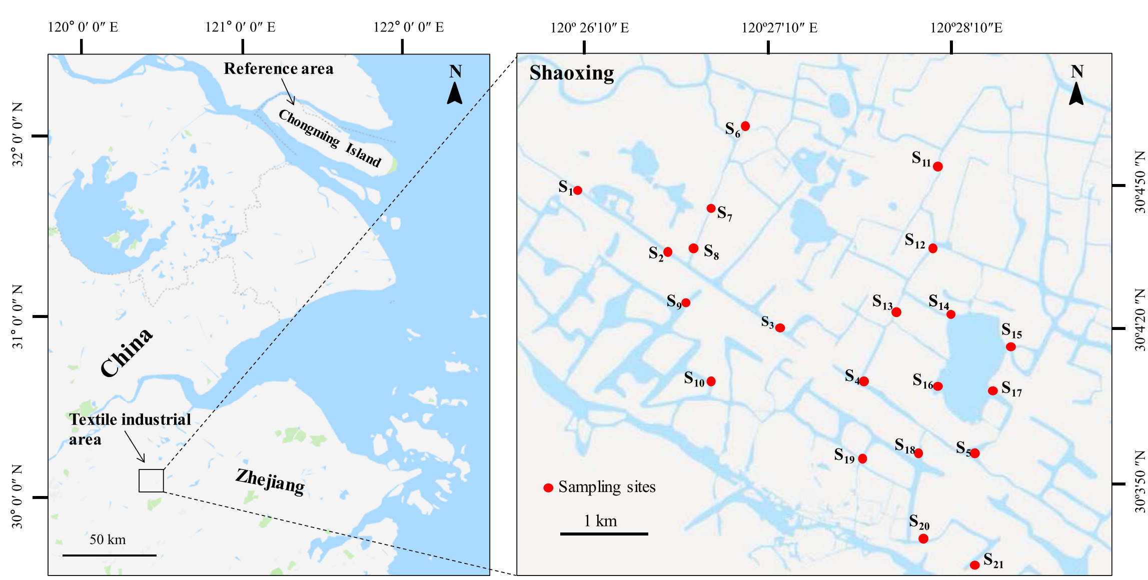

Fig. 1. Locations of sampling areas and sites.

an oven under 65 °C for the purpose of evaporating the water. After 4 days, around 100 g of the dried sediments were weighed and mixed with a saturated saline solution (NaCl) (36%, w/w) filtered slowly in one 2-L glass flask of 30 cm depth. The mixture was stirred and sat quietly overnight. The supernatant without any sediment was filtered through a nylon filter with a pore size of 20 μm. The remaining sediments were mixed with the saturated NaCl solution again, and stirred and sat quietly. Flotation operation was repeated twice. The settle time was 12 h for the second and third cycle. All supernatant were transferred on the same nylon filter. Finally, all particles filtered onto the filter were washed in a glass flask with 150 mL of H_2O_2 filtered prior to digestion. The same method was used to digest and filter the sediment samples. All filters were stored in a Petri dish as described above.

2.4. Observation and validation of microplastic

Dried filters were investigated using a stereo microscope to photograph microplastics by a digital camera. According to our previous research (Luo et al., 2019), particles on filters were classified into four types based on their morphological characteristics: fiber, pellet, film and fragment.

Nine hundred and twenty six particles (55% of all visualized identified particles) selected from water (501 items) and sediment (463 items) samples were identified using a micro-Fourier Transform Infrared spectrometer (μ-FTIR; Thermo, Nicolet iN10). The data was measured under a transmission mode with 16-s scan times. All identified spectra were compared with the library from Thermo Fisher to identify their polymer nature. The spectra matches higher than 70% were accepted. After validation, the number of verified non-plastics was excluded and the amount of microplastics was recalculated.

Sixty blanks were run without water and sediment during the whole procedure to confirm and evaluate background contamination. Sixteen fiber items were observed in blanks totally (5 and 11 items for water and sediment blanks respectively, equal to 5% of the microplastic level in samples). The lower abundances of microplastics were found in the blanks for water (0.24 ± 0.44 items/filter) and sediment (0.28 ± 0.56 items/filter), indicating that the indoor air pollution during the entire experiment process were successfully avoided.

2.5. Data analysis

The obtained results were statistically analyzed and visualized using SPSS 19, OriginPro 9 and GraphPad Prism 5. To assess the data normality, Shapiro-Wilk test was used. Independent sample *t*-test was used to compare the difference in microplastic abundance in surface water between the textile industrial area and the reference area. Non-parametric test (abnormal distribution) was used to judge the differences in numbers and morphological characteristics (such as shape, size and color), followed by Kruskal-Wallis test to analyze the significance. Pearson correlation coefficient was applied to estimate the goodness of fit and the significance of correlation. A significance level of 0.05 was chosen.

3. Results

3.1. Validation and composition of microplastics

In this study, 85% and 90% of the randomly selected particles in water and sediment samples were verified as microplastics in textile area. In total, eleven polymer types were identified (Table 1). The dominant polymer types in water samples were polyester (PES, 65.7%) and rayon (RA, 6.7%) (Fig. 2A, C). Similarly, the dominant polymers were PES (54.8%) and polypropylene (PP, 8.3%) in sediment samples (Fig. 2B, D). Non-plastics such as paper, cotton and cellulose were also identified in both water and sediment samples. Polyester was also the dominant polymer type detected in the reference area.

Table 1
Composition of microplastics identified using μ-FTIR for the particles randomly selected from the samples.

Composition of particles	Water		Sediment	
	No.	%	No.	%
particles measured	446	100	547	100
plastic particles	399	89.5	463	84.6
acrylic	17	3.7	6	1.1
cellophane	5	1.1	1	0.2
ethylene-vinyl acetate (EVA)	0	0	4	0.7
non-plastic	47	10.5	84	15.4
nylon	8	1.7	1	0.2
polyethylene (PE)	4	0.9	27	4.9
polyester (PES)	304	65.7	300	54.8
polyether urethane (PU)	0	0	1	0.2
polypropylene (PP)	30	6.5	100	18.3
polystyrene (PS)	0	0	7	1.3
poly (vinyl chloride) (PVC)	0	0	2	0.4
rayon (RA)	31	6.7	14	2.6

Note: In water or sediment, the percentage of plastic particles = (the numbers of plastic particles) ÷ (the numbers of particles measured). For the percentage of each different types of plastic particles = (the numbers of each different types of plastic particles) ÷ (the numbers of particle particles).

3.2. Abundances of microplastics in water and sediments

The average abundance of microplastics was 6.8 items/L in surface water in the reference area (Supplementary materials Fig. S1). The abundance ranged from 2.1 to 71.0 items/L in water and 16.7–1323.3 items/kg dw (dry weight) in sediments in the textile industrial area (Fig. 3A and B). The average abundance of microplastics in surface water in the textile industrial area (13.3 items/L) was about two times higher than that monitored in the reference area ($p < 0.05$).

Many textile factories are located in the northwestern part of the research area whereas most textile trading markets distribute in the southeastern part of the textile industrial area (Fig. 3). Therefore, we divided this region into two study areas with a textile factory area where textile products are manufactured and processed and a trading market area where the products are stored and sold. In both areas, the abundance of microplastic found in water and sediment samples showed no correlation ($p > 0.05$).

3.3. Sizes, types and colors of microplastics identified

The size of microplastics found in water samples was in the range of 0.017–4.975 mm while the corresponding size range of microplastics found in sediment was from 0.064 to 4.894 mm. The patterns of size distribution of microplastics found in water and sediment samples were similar in the density curve analysis (Fig. 4A). In addition, the average size of microplastics found in water was smaller than those in sediment (Fig. 4B). Nevertheless, the dominant size range of the microplastics was in the range of 0.1–1 mm in both water and sediment samples ($p < 0.05$) collected in the study area, comparable with those (69.9%) in water samples collected in the reference area ($p < 0.05$) (Supplementary materials Fig. S2).

Fiber was the most abundant shape of microplastics found in both water (95%) and sediment (79%) samples collected almost at all sampling sites except for the sediment sample obtained at S_6

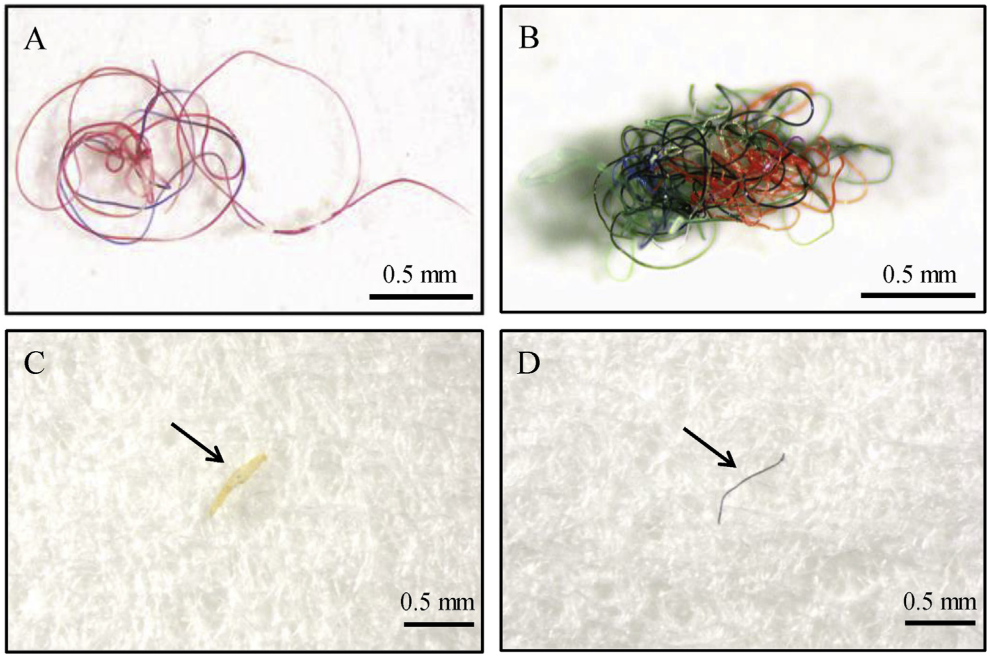

Fig. 2. Tangled of plastic fibers found in water (A and C) and sediment (B and D) in textile area.

where PP fragments were identified at the highest quantity ($p < 0.05$) (Fig. 4C). Similarly, fibers were also most frequently identified in water samples collected in the reference area ($p < 0.05$) (Supplementary materials Fig. S2).

The fraction of blue, red and black microplastics, which were significantly more abundant than other colors ($p < 0.05$), was more than 75% of all microplastics found in water samples (Fig. 4D). By contrast, white, red and black are the dominant colors of microplastics, accounting for 70% of those found in water samples of the reference area (Supplementary materials Fig. S2). In sediment samples collected in the textile industrial area, 60% of microplastics are in black, white or blue, which showed significantly higher abundance than other colors ($p < 0.05$) (Fig. 4D).

4. Discussion

4.1. The level of microplastic pollution in water and sediment

Our study described the characteristics and the spatial distribution of microplastics in water and sediment samples collected from a textile industrial area. Compared with other freshwater systems worldwide, microplastic pollution in this area showed different levels in water and sediment (Supplementary materials Table S2).

The maximum abundance of microplastics (71.0 items/L) was found at S_3 among all the water bodies near the textile industrial area. This abundance was almost 6-fold higher than that monitored in the reference area in this study, 3-fold higher than that (21.5 items/L) in other small water bodies in Zhejiang Province, and 9.6-fold higher than that (7.4 items/L) in Suzhou River which belongs to the same delta as the target sampling area in this study (Hu et al., 2018; Luo et al., 2019). Also, compared with other countries, higher pollution level showed the same situation mostly of microplastic pollution in water (Fischer et al., 2016; Bordós et al., 2019). Nevertheless, our results showed a lower level of microplastic pollution than that measured in raw waste water with a peak value of 900 items/L as well as in extremely polluted natural freshwater with microplastics exceeding 100 items/L (Dris et al., 2017; Leslie et al., 2017).

In contrast to the water sample, microplastic pollution determined in sediment was greatly variable and in the range of a global discovered background (Klein et al., 2015; Horton et al., 2017; Hu et al., 2018). The highest abundance of microplastics in sediment determined in this study was comparable with that (1600 items/kg dw) in freshwater river sediments in Shanghai reported by Peng et al. (2018). However, it was significantly lower than the microplastic pollution level reported in small water bodies (3185.3 items/kg dw) in China (Hu et al., 2018).

The results showed a moderate microplastics pollution level in water and sediment compared with other investigated areas, and it also fell into the range of microplastic pollution in the inland water from China. The source, distribution pathway and fate of microplastics should be taken into account for assessing the influence of inland water from China on microplastic pollution (Zhang et al., 2018).

4.2. The relationship between microplastic pollution level and textile area

At the spatial scale, the highest pollution level of microplastics in water was found in the southern area, followed by the middle place of textile factory area. For example, remarkably high abundances of microplastics were found at S_3 (71.0 items/L), which is located at the downstream of a river according to the direction of water flow as shown in Fig. 3. Microplastic fibers released from textile factories floated down the river and accumulated at the downstream locations. The abundance of microplastics in water in the trading market area was generally lower than in the factory area. Similarly, a low level abundance of microplastics was found in the reference area. Therefore, local microplastic pollution was strongly suspected to originate from the textile industrial wastewater effluent. Xu et al. (2018) reported that the abundance of microfibers, of which 77% were plastics, were 334.1 items/L in the influent and 16.3 items/L in the effluent, respectively, in the wastewater from a textile dyeing wastewater treatment plant (WWTP), suggesting that the release of microplastics could not be

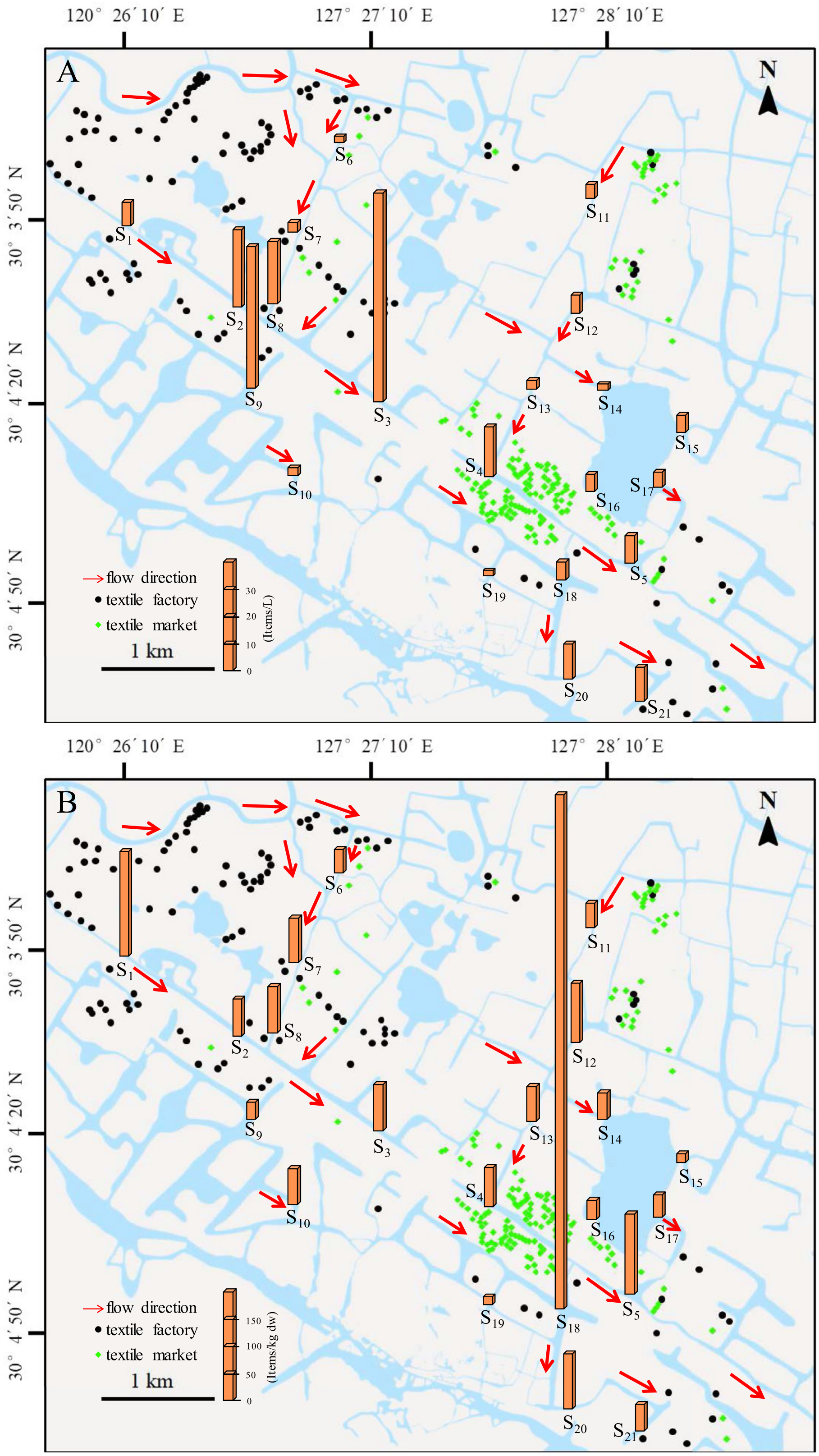

Fig. 3. The abundance of microplastics in water (A) and sediment (B) in textile area. The red arrows represented direction of water flow, black dots represented the location of textile factory and green dots represented the location of textile market (individual dot meant individual factory or market). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

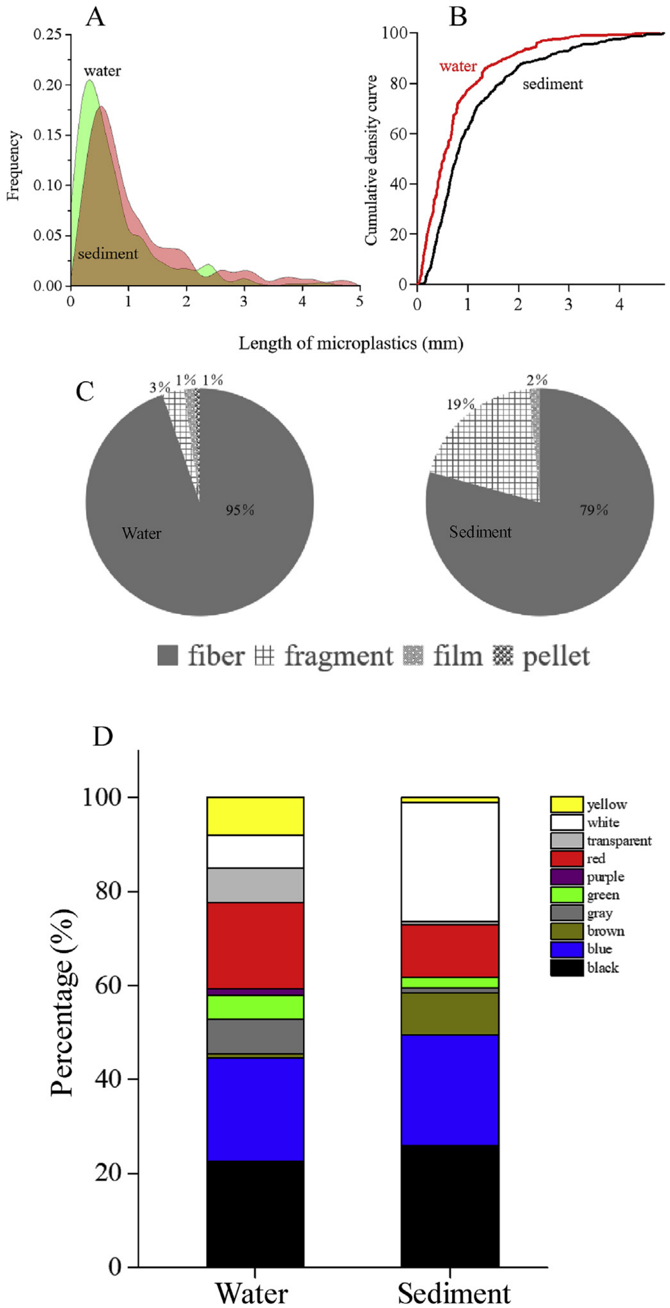

Fig. 4. The distribution of size (A, B) shape (C) and color (D) in water and sediment in textile area. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

ignored in wastewater from WWTP with such a severe microfibers pollution. Within the investigation area, there were numerous textile factories and trading markets, from which microfibers could be released to the water bodies nearby. The lack and inadequacy of sewage systems in some textile factories could cause a low removal efficiency of microplastics (Ziajahromi et al., 2017; Lares et al., 2018). The contribution from atmospheric fallout and rainfall cannot be ignored while microplastics are continuously released by the manufacturing, transportation, packaging of textile products in close vicinity (Dris et al., 2016).

Similarly, the abundance of microplastics in sediment (180.0 items/kg dw) collected at S_1 surrounded by many factories was the highest in textile factory area. As for site S_{18} (1323.3 items/kg dw) located in the trading market area, several textile factories were also found in the neighborhood, which sharpened the microplastic pollution at this site. Due to the fact found in this study revealing fibrous microplastics as dominant pollutants with low mobility in sediment samples, textile factories in the surroundings were suggested as the main source of microfiber pollution in the sediments.

Microplastics found in two areas showed a similar color distribution with dominated dark colors (black and blue), in line with the results determined in textile dyeing wastewater as described previously (Stanton et al., 2019). The morphology and polymer nature of microplastics collected from textile area resembled those from textile dyeing wastewater (Yang et al., 2019a). Most of these dark fibers became the primary sources of microplastics in the field. Polyester and polypropylene were the main polymer types both in our study and in a previous study concerning textile dyeing wastewater (Sun et al., 2019), indicating a clear relationship between the microplastics occurrence and the textile factories. It's essential to trace the sources and identify solutions to reduce their input to the environment by dividing microfibers into primary and secondary microplastics (Talvitie et al., 2017). Unfortunately, it was truly hard to explore the relationship between microplastic pollution and manufactured or sale activities and requires long-term survey. Our results were able to link the potential source of microplastic pollution to its abundance and characteristic based on a serial evidences. Firstly, compared with reference area, the textile area showed pretty high microplastic pollution. Secondly, we found the mass of fibers in water from the textile area, and such mass of microfibers have never been found in reference area or any other area in our previous studies. Finally, a significantly higher amount of agglomerate fiber balls and colorful microplastics was discovered in textile area than in reference area. All together, these findings indicated that manufactured and sale activities might be the main reasons leading to the high microplastic pollution in textile area.

4.3. The source control of microplastics

Compared to plastic pellets and microbeads, synthetic fibers were observed as the dominant microplastic type. The release of microfibers into the ocean increased by 15% in 2 years (Browne et al., 2011). Nevertheless, monitoring of plastic debris and the ban on microbeads in personal care products have previously drawn more public attention (Law and Tompson, 2014; Law, 2017; Iñiguez et al., 2017). By contrast, the primary sources for microfibers including domestic sewage and industrial release in textile manufacturing area have been inadequately investigated (Carr, 2017; Guerranti et al., 2019).

The fate of microplastics i.e. how they move from their terrestrial source region to the open sea or the sediment sink is considered to be affected by multiple factors. Tracing the pollution source of microplastics becomes thus the first step to understand their initial footprint in the environment. In this study, microfibers were found to be the majority of microplastics detected both in water bodies and sediments, suggesting that they originated from industrial wastewater discharge and domestic sewage in the textile industrial area. Multiple factors and activities including manufacturing, distance issues of transportation, packaging and laundry processing of the textile products have been attributed to the release of microplastics into the environments (Fahrenfeld et al., 2019). Therefore, in addition to the distances to the factories and trading markets investigated in this study, other environmental factors could also be taken into account for the microplastic pollution. For example, an extensive water flow might accelerate the microplastics transport and consequently broaden their distribution area. Our investigation sites are located in the main textile industrial area, where complex river systems are present, which allow the rapid transport of microplastic pollution between sampling sites and thus hampering the direct assignment of specified microplastic pollution to a certain sampling site. Some researchers have proven that quantities of microplastics contribute to the discharged sewage under different conditions and in different washing processes (Hartline et al., 2016; Belzagui et al., 2019; Yang et al., 2019b). While the contribution of point pollution sources for microplastics was shown in this study, the equivalent influence of diffuse urban pollution sources (non-point pollution sources) which were neglected in most regional studies deserves obviously further investigation.

The demand of plastic products is increasing as a result of the continuous economic development in China. Accordingly, the increasing risk of microplastic release as well as their influences on natural environments and human health have been recognized. Based on our findings in this study, control of their sources by the production, processing and trading of textile product might be an efficient provision to reduce the amount of microplastic pollution (Henry et al., 2019). In this study, both textile factories and trading markets were identified as point sources of microplastic pollution, which should be steadily monitored for a better pollution control as well as to fill the knowledge gap of the initial footprints of microplastics. Besides, the potential risks of microplastics in textile industrial area should be aroused concern.

5. Conclusion

Microplastics were found as an emerging pollutant accumulating in water and sediment samples collected from a textile industrial area as a consequence of industrial release. A significantly higher microplastic pollution level was found in this industrial area compared with a reference agriculture area. Polyester fibers were found as the most abundant microplastics followed by polypropylene. We described the factual situation of microplastic pollution in a typical textile industrial area, from where the corresponding pollution data has been rarely described. Monitoring and control of the manufacturing and trading activities in this textile industrial area was suggested to be an effective approach to reduce the local microplastic pollution.

Declaration of competing interest

The authors declare no competing financial interest.

CRediT authorship contribution statement

Hua Deng: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing. **Ren Wei:** Writing - review & editing. **Wenya Luo:** Methodology, Validation, Investigation, Resources, Data curation. **Lingling Hu:** Writing - review & editing. **Bowen Li:** Investigation, Resources. **Ya'nan Di:** Writing - review & editing. **Huahong Shi:** Supervision, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2019.113658.

References

Abbasi, S., Soltani, N., Keshavarzi, B., Moore, F., Turner, A., Hassanaghaei, M., 2018. Microplastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. Chemosphere 205, 80–87.

Anderson, J.C., Park, B.J., Palace, V.P., 2016. Microplastics in aquatic environments: implications for Canadian ecosystems. Environ. Pollut. 218, 269–280.

Andrady, A.L., 2017. The plastic in microplastics: a review. Mar. Pollut. Bull. 119, 12–22.

Auta, H.S., Emenike, C.U., Fauziah, S.H., 2017. Distribution and importance of microplastics in the marine environment: a review of the sources, fate, effects, and potential solutions. Environ. Int. 102, 165–176.

Avagyan, R., Luongo, G., Thorsén, G., Östman, C., 2015. Benzothiazole, benzotriazole, and their derivates in clothing textiles—a potential source of environmental pollutants and human exposure. Environ. Sci. Pollut. Res. 22 (8), 5842–5849.

Barrows, A.P.W., Cathey, S.E., Petersen, C.W., 2018. Marine environment microfiber contamination: global patterns and the diversity of microparticle origins. Environ. Pollut. 237, 275–284.

Belzagui, F., Crespi, M., Álvarez, A., Gutiérrez-Bouzán, C., Vilaseca, M., 2019. Microplastics' emissions: microfibers' detachment from textile garments. Environ. Pollut. 248, 1028–1035.

Bordós, G., Urbányi, B., Micsinai, A., Kriszt, B., Palotai, Z., Szabó, I., Hantosi, Z., Szoboszlay, S., 2019. Identification of microplastics in fish ponds and natural freshwater environments of the Carpathian basin, Europe. Chemosphere 216, 110–116.

Brigden, K., Santillo, D., Johnston, P., 2012. Nonylphenol Ethoxylates (NPEs) in Textile Products, and Their Release through Laundering. Greenpeace Research Laboratories Technical Report, pp. 7–9.

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastic on shorelines worldwide: sources and sinks. Environ. Sci. Technol. 45, 9175–9179.

Carr, S.A., 2017. Sources and dispersive modes of micro-fibers in the environment. Integr. Environ. Assess. Manag. 13 (3), 466–469.

Chen, Q., Reisser, J., Cunsolo, S., Kwadijk, C., Kotterman, M., Proietti, M., Slat, B., Ferrari, F.F., Schwarz, A., Levivier, A., Yin, D., Hollert, H., Koelmans, A.A., 2018. Pollutants in plastics within the north Pacific subtropical gyre. Environ. Sci. Technol. 52 (2), 446–456.

Conkle, J.L., Báez Del Valle, C.D., Turner, J.W., 2018. Are we underestimating microplastic contamination in aquatic environments? Environ. Manag. 61, 1–8.

Driedger, A.G.J., Durr, H.H., Mitchell, K., Van Cappellen, P., 2015. Plastic debris in the Laurentian Great lakes: a review. J. Gt. Lakes Res. 41, 9–19.

Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, V., Tassin, B., 2017. A first overview of textile fibers, including microplastics, in indoor and outdoor environments. Environ. Pollut. 221, 453–458.

Dris, R., Gasperi, J., Saad, M., Mirande, C., Tassin, B., 2016. Synthetic fibers in atmospheric fallout: a source of microplastics in the environment? Mar. Pollut. Bull. 104 (1–2), 290–293.

Estahbanati, S., Fahrenfeld, N.L., 2016. Influence of wastewater treatment plant discharges on microplastic concentrations in surface water. Chemosphere 162, 277–284.

Fahrenfeld, N.L., Arbuckle-Keil, G., Naderi Beni, N., Bartelt-Hunt, S.L., 2019. Source tracking microplastics in the freshwater environment. Trends Anal. Chem. 112, 248–254.

Fischer, E.K., Paglialonga, L., Czech, E., Tamminga, M., 2016. Microplastic pollution in lakes and lake shoreline sediments – a case study on Lake Bolsena and Lake Chiusi (central Italy). Environ. Pollut. 213, 648–657.

Guerranti, C., Martellini, T., Perra, G., Scopetani, C., Cincinelli, A., 2019. Microplastics in cosmetics: environmental issues and needs for global bans. Environ. Toxicol. Pharmacol. 68, 75–79.

Halstead, J.E., Smith, J.A., Carter, E.A., Lay, P.A., Johnston, E.L., 2018. Assessment tools for microplastics and natural fibres ingested by fish in an urbanised estuary. Environ. Pollut. 234, 552–561.

Hartline, N.L., Bruce, N.J., Karba, S.N., Ruff, E.O., Sonar, S.U., Holden, P.A., 2016. Microfiber masses recovered from conventional machine washing of new or aged garments. Environ. Sci. Technol. 50 (21), 11532–11538.

Henry, B., Laitala, K., Klepp, I.G., 2019. Microfibres from apparel and home textiles: prospects for including microplastics in environmental sustainability assessment. Sci. Total Environ. 652, 483–494.

Horton, A.A., Svendsen, C., Williams, R.J., Spurgeon, D.J., Lahive, E., 2017. Large microplastic particles in sediments of tributaries of the River Thames, UK – abundance, sources and methods for effective quantification. Mar. Pollut. Bull. 114 (1), 218–226.

Hu, L., Chernick, M., Hinton, D.E., Shi, H., 2018. Microplastics in small waterbodies and tadpoles from Yangtze river delta, China. Environ. Sci. Technol. 52 (15), 8885–8893.

Imhof, H.K., Laforsch, C., 2016. Hazardous or not – are adult and juvenile individuals of Potamopyrgus antipodarum affected by non-buoyant microplastic particles? Environ. Pollut. 218, 383–391.

Iñiguez, M.E., Conesa, J.A., Fullana, A., 2017. Microplastics in Spanish table salt. Sci. Rep. 7, 8620.

Jemec, A., Horvat, P., Kunej, U., Bele, M., Kržan, A., 2016. Uptake and effects of microplastic textile fibers on freshwater crustacean Daphnia magna. Environ. Pollut. 219, 201–209.

Klein, S., Worch, E., Knepper, T.P., 2015. Occurrence and spatial distribution of

microplastics in river shore sediments of the rhine-main area in Germany. Environ. Sci. Technol. 49 (10), 6070–6076.
Lares, M., Ncibi, M.C., Sillanpää, M., Sillanpää, M., 2018. Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. Water Res. 133, 236–246.
Law, K.L., 2017. Plastics in the marine environment. Annu. Rev. Mar. Sci. 9, 205–229.
Law, K.L., Tompson, R.C., 2014. Microplastic in the seas. Science 345, 144–145.
Leslie, H.A., Brandsma, S.H., van Velzen, M.J.M., Vethaak, A.D., 2017. Microplastics en route: field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. Environ. Int. 101, 133–142.
Li, X., Chen, L., Mei, Q., Dong, B., Dai, X., Ding, G., Zeng, E.Y., 2018. Microplastics in sewage sludge from the wastewater treatment plants in China. Water Res. 142, 75–85.
Lourenço, P.M., Serra-Gonçalves, C., Ferreira, J.L., Catry, T., Granadeiro, J.P., 2017. Plastic and other microfibers in sediments, macroinvertebrates and shorebirds from three intertidal wetlands of southern Europe and west Africa. Environ. Pollut. 231, 123–133.
Luo, W., Su, L., Craig, N.J., Du, F., Wu, C., Shi, H., 2019. Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. Environ. Pollut. 246, 174–182.
Peng, G., Xu, P., Zhu, B., Bai, M., Li, D., 2018. Microplastics in freshwater river sediments in Shanghai, China: a case study of risk assessment in mega-cities. Environ. Pollut. 234, 448–456.
Stanton, T., Johnson, M., Nathanail, P., MacNaughtan, W., Gomes, R.L., 2019. Freshwater and airborne textile fibre populations are dominated by 'natural', not microplastic, fibres. Sci. Total Environ. 666, 377–389.
Su, L., Cai, H., Kolandhasamy, P., Wu, C., Rochman, C.M., Shi, H., 2018. Using the Asian clam as an indicator of microplastic pollution in freshwater ecosystems. Environ. Pollut. 234, 347–355.
Su, L., Xue, Y., Li, L., Yang, D., Kolandhasamy, P., Li, D., Shi, H., 2016. Microplastics in taihu lake, China. Environ. Pollut. 216, 711–719.
Sun, J., Dai, X., Wang, Q., van Loosdrecht, M.C.M., Ni, B., 2019. Microplastics in wastewater treatment plants: detection, occurrence and removal. Water Res. 152, 21–37.
Talvitie, J., Mikola, A., Setälä, O., Heinonen, M., Koistinen, A., 2017. How well is microlitter purified from wastewater? – a detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant. Water Res. 109, 164–172.
Vandermeersch, G., Van Cauwenberghe, L., Janssen, C.R., Marques, A., Granby, K., Fait, G., Kotterman, M.J.J., Diogène, J., Bekaert, K., Robbens, J., Devriese, L., 2015. A critical view on microplastic quantification in aquatic organisms. Environ. Res. 143 (Part B), 46–55.
Wang, J., Tan, Z., Peng, J., Qiu, Q., Li, M., 2016. The behaviors of microplastics in the marine environment. Mar. Environ. Res. 113, 7–17.
Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E., Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. R. Soc. Open Sci. 1, 8.
Wright, S.L., Kelly, F.J., 2017. Plastic and human health: a micro issue? Environ. Sci. Technol. 51, 6634–6647.
Xu, X., Hou, Q., Xue, Y., Jian, Y., Wang, L., 2018. Pollution characteristics and fate of microfibers in the wastewater from textile dyeing wastewater treatment plant. Water Sci. Technol. 78 (10), 2046–2054.
Yang, L., Li, K., Cui, S., Kang, Y., An, L., Lei, K., 2019a. Removal of microplastics in municipal sewage from China's largest water reclamation plant. Water Res. 155, 175–181.
Yang, L., Qiao, F., Lei, K., Li, H., Kang, Y., Cui, S., An, L., 2019b. Microfiber release from different fabrics during washing. Environ. Pollut. 249, 136–143.
Zhang, K., Shi, H., Peng, J., Wang, Y., Xiong, X., Wu, C., Lam, P.K.S., 2018. Microplastic pollution in China's inland water systems: a review of findings, methods, characteristics, effects, and management. Sci. Total Environ. 630, 1641–1653.
Ziajahromi, S., Neale, P.A., Rintoul, L., Leusch, F.D.L., 2017. Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics. Water Res. 112, 93–99.