

Review

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Pollution status of microplastics in the freshwater environment of China: a mini review

Haoran Zhao¹, Yanting Zhou¹, Ye Han¹, Yue Sun¹, Xiuna Ren¹, Zengqiang Zhang¹, Quan Wang^{1,2}

¹College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, Shaanxi, China.

²Key Laboratory of Plant Nutrition and the Agrienvironment in Northwest China, Ministry of Agriculture, Yangling 712100, Shaanxi, China.

Correspondence to: Dr. Quan Wang, College of Natural Resources and Environment, Northwest A&F University, No.3 Taicheng Road, Yangling 712100, Shaanxi, China. E-mail: quanwang_1990@163.com

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Abstract

In the last few years, the pollution of microplastics in freshwater environments such as rivers, lakes, and reservoirs has aroused widespread concerns. In this review, rich and appropriate data on microplastics, in the freshwater ecosystem of China, was collected. Following this microplastics in surface waters, sediments, and biota, of the freshwater system, were thoroughly analyzed. The results show that microplastics are widespread in the freshwater environment of China. At the same time, the abundance of microplastics is positively correlated with both intensive human activities and urbanization. The risk index of microplastics is relatively high in the water of Yellow River (654 items/L), Yangtze River (9.20×10^5 items/km²), and Pearl River regions (7571 items/m³). The prevalent shapes of microplastics, in water and sediments, are fragments and fibers. Moreover, the particle size of microplastics is mainly less than 2 mm. In fact, PP and PE are found to be the main polymer types in the freshwater environment of China. Bivalves and freshwater fish are the main research objects of microplastics pollution in China. In parallel to that, the abundance of microplastics, in each aquatic organism, varied from a few to a dozen. Additionally, the characteristics of microplastics in organisms are mainly fibers smaller than 1 mm. Fundamentally, the key two sources of microplastics, in the freshwater environment of China, are wastewater discharge and surface runoff. It is noteworthy that microplastics, in a freshwater environment, does not only cause environmental pollution but harms aquatic organisms, too. Finally, microplastics can reach the human body, through the food chain, causing potential health issues.



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Keywords: Microplastics, freshwater, China, source, biota

INTRODUCTION

Plastic has been widely used in industry due to its unique properties such as low price, lightweight, high strength, and durability^[1]. Since the 1950s, more than 8.3 billion metric tons of plastic have been manufactured, which makes it world-recognized garbage and pollutant. Statistically, the global plastic production was 368 million tons in 2019, and China occupied 31% of the total production^[2]. Every year, more than 8 million tons of plastic waste enter the freshwater and marine environment worldwide^[3].

Large pieces of plastic would break down into microplastics which are emerging pollutants. Microplastics, defined as plastic debris with a particle size of less than 5 mm, can be divided into primary and secondary microplastics according to the origin of microplastics^[4]. Basically, primary microplastics are manufactured into small-size plastics (e.g., microbeads, plastic pellets, and microfibers), while secondary microplastics are originated from large plastics through physical, chemical, and biological degradation^[5]. Microplastics, as a global pollutant, are widely presented in aquatic, terrestrial, and atmospheric ecosystems, even they were discovered in remote Antarctic and Arctic regions^[6,7]. Meanwhile, the microplastics that were detected in the environment include various types [e.g., polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET)], shapes (e.g., fiber, fragment, pellet, film, and foam), and colors (e.g., black, colored, and white)^[4,8].

Microplastics have a large specific surface area and hydrophobic properties, therefore can adsorb persistent organic pollutants (e.g., PCBs, PAHs, and PBDEs) and heavy metals, enhancing their transportation in terrestrial and aquatic ecosystems^[9]. Recently, many studies have studied microplastic pollution in aquatic ecosystems. Microplastics are easily ingested by aquatic organisms like zooplankton, fish, and bivalves causing a decreased reproduction rate, mechanical injuries, and low growth rate of these aquatic organisms^[10]. Moreover, plasticizers or toxic additives, released from microplastics, are transferred to water, sediments, and biota which aggravate the pollution of the freshwater environment^[9]. Meanwhile, microplastics carrying toxic pollutants may be transferred to higher nutritional levels, through the food chain, reaching the human body and causing various health issues^[11].

The majority of early microplastics research focused on their abundance and pollution in the marine environment, including seawater, seabed sediments, and marine biota^[12]. Unlike the ocean, freshwater (e.g., river, lake, and reservoir) is a vital resource for human life. Simultaneously, it is essential for human reproduction providing drinking water source, food production water, permitting freshwater aquaculture, and playing an important role in sanitation, purification, and stabilization of the coastline^[13]. Consequently, more researchers gradually started to investigate the microplastic pollution in the freshwater ecosystem in developed and developing countries. For example, Eriksen *et al.*^[14] (2013) showed that the average abundance of microplastics was approximately 43,000 particles/km² in the surface water of the Laurentian Great Lakes in the United States. At the same time, He *et al.*^[15] (2020) demonstrated that the microplastics varied between 0.18 and 129.20 mg kg⁻¹ in Brisbane River sediments, Australia. Similarly, Buwono *et al.*^[16] (2021) found that the abundance of microplastics, in the water of the Brantas River in Indonesia, ranged from 133 to 5467 particles/m³.

Obviously, China, as one of the largest countries, are regarded as the largest plastic producer and consumer in the world^[10]. Every year, a huge number of microplastics enters the freshwater environment of China through surface runoff, rainfall, and sewage discharge, causing serious microplastics pollution in surface

water, sediments, and biota of the freshwater environment^[5,17,18]. Hence, there have been progressively more studies investigating the distribution and abundance of microplastics in the freshwater environment (e.g., water, sediments, and biota) of China in the recent years^[5,8,19]. For example, Huang *et al.*^[19] (2020) and Pan *et al.*^[20] (2020) clearly described the abundance, shape, chemical composition, and size distribution of microplastics in the Zhangjiang River and West River. Wang *et al.*^[5] (2020) not only evaluated the microplastics in Beijiang surface water but also detected microplastics in fish samples. In parallel to that, Li *et al.*^[21] (2021) and Mao *et al.*^[22] (2020) studied microplastic pollution in both the Yulin River and Chishui River.

Thus far, the microplastics pollution in the freshwater environment has attracted a great attention. Although, the current research generally focuses on the abundance, sources, and characteristics of microplastics in rivers and lakes in a single region. It ignores the freshwater environment, especially the microplastics pollution in China, which is not conducive to follow-up research and policy research for controlling the microplastic pollution. Hence, the main purpose of this review is twofold: (1) to summarize the abundance and characteristics of microplastics in freshwater environments (e.g., rivers, lakes, sediments, and biota) of China; and (2) to introduce the source and impact of microplastics in freshwater ecosystems of China.

DATA COLLECTION

Since 2017, the issue of microplastics, in the freshwater environment of China, has gradually attracted more attention. Hence, this review focuses on the research papers that were published between 2017 and 2021. Several combination of keywords such as “microplastics”, “freshwater”, “China”, “lakes”, and “rivers” were used to initiate search queries for the articles in the database of Web of Science and Science Direct. Following this procedure, 62 articles were initially selected. In this review, we mainly focus on the major freshwater environments of China including rivers, lakes, and reservoirs which are closely related to human community. After the final screening, based on the distribution of major rivers, lakes and reservoirs in China, a total of 29 (water = 24, sediment = 13, and biota = 11) research articles were carefully chosen.

MICROPLASTIC POLLUTION IN THE FRESHWATER OF CHINA

In the last few years, risk assessment of microplastic, in the freshwater environment of China, has become a hotspot. We counted 29 studies to analyze the presence of microplastics in freshwater, sediments, and biota. Moreover, the following attributes such as the abundance, size, shape, type, and identification of microplastics were also described in [Tables 1-3](#).

Water

The location of the study water samples is shown in [Figure 1](#). The existing literature, about the microplastic pollution in the freshwater of China reveals that trawl nets, pumps, and water collectors were the main sampling methods for collecting the microplastics as indicated in [Table 1](#). On the other hand, these dissimilar sampling methods led to the variances in the expression of microplastic abundance. For surface water of river or lake sampled by trawl, noting that the commonly used unit is “items/ km²”. By contrast, the unit for pump sampling or bulk volume sampling is “items/L” or “items/m³”. The abundance range of microplastics in Chinese freshwater (e.g., river, lake, and reservoir) is 0.03×10^5 - 81.2×10^5 items/km² in the trawl samples as can be seen from [Table 1](#). According to the volume sampling method, the abundance range of microplastics in Chinese freshwater is 16.67 to 24798 items/m³ and 1.7 to 1392 items/L as detailed in [Table 1](#). The expression methods of different units may not be conducive to the subsequent evaluation and research of microplastics. For a better evaluation, it is recommended to unify the units of measure in future research. Although the sampling methods are different, the main shapes of the microplastics in the

Table 1. The abundance and characteristics of microplastics in water

Water Location	Abundance (average)	Size	Sampling	Shape	Color	Polymer types	Identification	Ref.
Beijiang River	400-8400 items/m ³ (3183 items/m ³)	< 0.5 mm (77%)	Trap	-	White (49%), yellow (16%), blue (10%), black (9%), red (8%), green (8%)	-	Microscope	[5]
The Pearl River	2400-18200 items/m ³ (7571 items/m ³)	< 0.5 mm (86%) 2-4 mm (3%)	Trap	Fragment (67%), Fiber (21%), film (3%), spheres (9%)	White (49%), yellow (16%), blue (10%), black (9%), red (8%), green (8%)		Microscope	
Dafeng River (rainy season)	3 × 10 ⁻⁴ -2.5 × 10 ⁻³ items/L 7 × 10 ⁻⁴ -0.12 items/m ²	1-5 mm (dominant)	Trawl net	Fiber (dominant)	-	PET (dominant)	Microscope; FTIR	[8]
Dafeng River (dry season)	4 × 10 ⁻⁵ -9 × 10 ⁻⁴ items/L 2 × 10 ⁻³ -2.8 × 10 ⁻² items/m ²		Trawl net				Microscope; FTIR	
West River (lower)	2.99-9.87 items/L	< 0.5 mm (dominant)	Stainless steel drum	Fiber (dominant), pellet, fragment and film	-	PP (40%), PE (29%), PS (20%)	Microscope; FTIR	[19]
Zhangjiang River	50-725 items/m ³ (246 items/m ³)	0.3-0.5 mm (20.6%) 0.5-1 mm (32.8%) 1-2.5 mm (31%) 2.5-5 mm (15.7)	Steel bucket	Fragment (42.9%), fiber (18.5%), pellet (17.6%), line (13.8%), film (4.1%), and foam (3.1%).	White (55.5%), black (14.4%), yellow (14.0%), grey (6.2%), clear (5.3%), and blue (3.4%)	PP (51.7%), PE (23.1%), PE-PP (7.0%), PES (6.7%), PS (6.1%), PET (5.3%)	Microscope; Raman	[20]
Chishui River	1.77-14.33 items/L	500-1000 μm (63.9%)	Stainless-steel bucket	Fiber (59.4%)	White (including transparent) (41.3%) and polychromatic (44.1%)	PE (36%), PP (31%), PS (25%), PVC(2%)	Microscope; FTIR	[21]
Yulin River	0.70 × 10 ⁻² -1.70 × 10 ⁻² items/L (1.3 × 10 ⁻² items/L)	< 250 μm (dominant)	Teflon pump	Line/fiber, pellet/foam (dominant)	-	PE (39%), PP (31%), PS (23%)	Microscope; SEM; Raman	[22]
Minjiang River (Chengdu)	6.11-44.08 items/L (15.88 ± 3.13 items/L)	< 300 μm (44.1%) 300-1000 μm (46.55) > 1000 μm (9.5%)	Iron drum	Particle (10.3%), fragment(44.8%), fiber (44.9%)	-	PP (26%), PE (15%), RA (20%), PA, PS, PP-PE, PVC	Microscope; FTIR	[23]
Taihu Lake (lake water)	1.7-8.5 items/L (5.67 ± 1.92 items/L)	< 0.1 mm (28%) 0.1-0.2 mm (42%)	Pump	Fragment (58%), fiber (25%), film (12%), pellet (4%) and piece	-	PVC and PE (dominant), PS, PP	Microscope; FTIR; SEM	[24]
Taihu Lake	(6.31 ± 4.36 items/L)	< 0.1 mm	Pump	Fragment (58%), fiber (25%), film		PVC and PE (dominant),	Microscope; FTIR;	

(river water)	inflow) (4.05 ± 1.06 items/L outflow)	(28%) 0.1-0.2 mm (42%)		(12%), pellet (4%) and piece		PS, PP	SEM	
Yangtze River	(1.62 ± 0.61) × 10 ⁵ - (4.25 ± 3.87) × 10 ⁶ items/km ² (9.20 × 10 ⁵ items/km ²)	300 μm-1 mm (69.6%) 1-2.8 mm (19.8%) 2.8-5 mm (10.6%).	Trawling sample	Fragment (47.9%), fiber (32.1%), foam (17.4%), pellet (2.6%)	Transparent (36.1%), white (34.6%), red (6.6%), blue (6.3%), yellow (5.4%), green (4.9%), black (0.9%) and others (5.2%)	PP (43%), PE (29%), PS (14%)	Microscope; FTIR	[25]
	(800.0 ± 300.0)- (3088.9 ± 330.6) items/m ³ (1635 items/m ³)	< 0.5 mm (47.4%) 0.5-1 mm (27.5%) 1-2 mm (9.0%) 2-3 mm (8.3%) 3-4 mm (4.9%) 4-5 mm (2.9%)	Stainless steel bucket	Fiber (63.4%), fragment (29.4%), pellet (4.6%), foam (2.6%)	Transparent (21.5%), blue (15.4%), green (14.8%), red (13.9%), white (13.4%), yellow (8.0%), black (1.9%) and others (11.0%)	PP (54.8%), PE (35.5%), PS (3.2%)	Microscope; FTIR	
Yellow River (lower)	380-582 items/L (wet) (430 items/L) 623-1392 items/L (dry) (654 items/L)	< 200 μm (87.9%)	Stainless steel bucket	Fiber, fragment particles (dominant)	-	PP, PE, PS	Microscope; FTIR	[26]
Qiantang River	50-3233 items/m ³ (dry) (1607 items/m ³) 221-6517 items/m ³ (wet) (889 items/m ³)	< 5 mm	Stainless steel bucket	Fiber (53.2%), fragment (29.5%), granule (8.4%), film (8.5%), foam (0.4%)	White (45%), black (23.4%), transparent (14.6%)	PET, PA, PES (dominant)	Microscope; FTIR	[27]
Qinghai-Tibet Plateau	247-2686 items/m ³	20 μm-5 mm	Water collector	-	-	-	Microscope; Raman	[30]
Poyang Lake	(289 ± 40-1064 ± 90 items/m ³)	< 2 mm (dominant)	Stainless-steel bucket	Fiber (dominant), film, foam, fragment	-	PP, PVC, PE, PS	Microscope; FTIR; SEM	[31]
Qinghai Lake (lake water)	0.05 × 10 ⁵ -7.58 × 10 ⁵ items/km ²	0.1-0.5 mm (dominant)	Trawl net	Fiber and sheet (dominant), fragment, foam	-	PP and PE (dominant), PS, PET	Microscope; Raman	[32]
Qinghai Lake (river water)	0.03 × 10 ⁵ -0.31 × 10 ⁵ items/km ²	0.1-0.5 mm (dominant)	Trawl net					
Dongting Lake	900-2800 items/m ³ (1191.7 items/m ³)	< 2 mm (dominant)	Teflon pump	Fiber (dominant), granule, film	Colored (71.3%), transparent (28.7%)	PP and PE (dominant), PS, PVC	Microscope; SEM; Raman	[33]
Hong Lake	1250-4650 items/m ³	< 2 mm (dominant)	Teflon pump	Fiber (dominant), granule, film	Colored (77.9%), transparent (22.1%)	PP and PE (dominant), PS, PVC	Microscope SEM Raman	

	(2282.5 items/m ³)							
Danjiangkou Reservoir	530-24798 items/m ³ (7205 items/m ³)	75-200 μm (10%) 200-500 μm (61.4%) 500-1000 μm (20.7%) 1000-5000 μm (7.9%)	Stainless-steel water sampler	Fragment (dominant), fiber, film, pellet, microbead	Transparent (42.8%), brown (40.9%), black (5.9%), green (3.7%), gray (3.3%)	PA (24.8%), PE (24%), PP (17.1%)	Microscope; Raman	[36]
Three Gorges Reservoir	1597-12611 items/m ³ (4703 ± 2816 items/m ³)	< 0.5 mm (dominant)	Teflon pump	Fiber (dominant), fragment, pellet, film, and Styrofoam	Transparent (dominant)	PS (38.5%), PP (29.4%), PE (21%), PC, PVC	Microscope; Raman; SEM	[37]
Qin River (lower)	16.67-611.11 items/m ³ 0.1-5.6 items/m ³	1-5 mm (80.3%) 1-5 mm (84.4%)	Teflon pump 75 μm plankton nets	Fiber (88%), sheet and fragment Fiber (49.6%), line, sheet, fragment, and foam	White, black, green, and blue(dominant) White, black, green, and blue(dominant)	PP (39%), PE (28%), PET, PS	Microscope; FTIR	[79]
Lijiang River	0.1-4.6 items/m ³ (67.5 ± 65.6 items/m ³) (0.15 ± 0.15 items/m ³) (0.67 ± 0.41 items/m ³)	1-5 mm (88.9%) 0.3-1 mm (dominant) 1-5 mm (dominant) 1-5 mm (dominant)	300 μm plankton nets Teflon pump 75 μm plankton net 300 μm plankton net	Fiber (38.2%), line, sheet, fragment, and foam Flake and fiber (dominant), film Flake and fiber (dominant), film, granule, line, string, and foam Flake and fiber (dominant), film, granule, line, string, and foam	White, black, green, and blue (dominant) Blue, red, green, and white (dominant) Blue, red, green, and white (dominant) Blue, red, green, and white (dominant)	PP/PE (37.6%), PE (32.2%), PP (19.1%), PVC, PS, PET, PA, PES	Microscope; FTIR	[80]
Wei River	3.67-10.7 items/L	< 0.5 mm (dominant)	Pump	Fiber and film (dominant)	-	-	Microscope; SEM	[81]
Tuojiang River	911.57 ± 199.73-3395.27 ± 707.22 items/m ³	0.5-1 mm (dominant)	Steel sampler	Fiber (dominant), film, fragment, foam	White and multicolor (dominant)	PP (34%), PE (29%), PS (23%)	Microscope; FTIR	[82]

freshwater of China are similar, mostly fibers and fragments that account for more than 60% of the total microplastics. The main source of fiber and fragments is the decomposition of plastic containers such as plastic bags, fishing nets, and lines^[22-24]. At the same time, the size of most of the microplastics, in the freshwater of China, is smaller than 1 mm as shown in Table 1. Furthermore, transparent, white, black, and colored (e.g., red, blue, green, and gray) microplastics were detected in the freshwater of China. In general, white and transparent account for the majority. In addition, the main types of polymers detected in surface water of China are PP, PE, PS, and PET. In parallel to this, the PP and PE microplastics account for the most proportion as described Table 1.

Table 2. The abundance and characteristics of microplastics in sediments

Sediment	Location	Abundance	Size	Sampling	Shape	Color	Polymer types	Identification	Ref.
	Dafeng River	9.4-50.3 items/kg (dry weight) 0.0-21.3 items/kg	< 1 mm (dominant)	Van Veen grab	Fiber (dominant)	-	PET (dominant)	Microscope; FTIR	[8]
	West River (lower)	2560-10,240 items/kg	< 0.5 mm (dominant)	Grab bucket	Fiber (dominant), pellet, fragment, and film	-	PP (38%), PE (27%), PS (16%), PET (4%), PVC (6%)	Microscope; FTIR	[19]
	Minjiang River (Chengdu)	573.84-2878.97 items/kg	< 5 mm	CN-200 piston column mud	Particle (5.1%), fragment (65.7%) and fiber (29.3%)	-	PP (26%), PE (21%), RA (16%)	Microscope; FTIR	[23]
	Taihu Lake	460-1380 items/kg	< 100 µm (70%)	Peterson grab	-	-	PVC and PE (dominant), PS, PP	Microscope; FTIR; SEM	[24]
	Poyang Lake	(821 ± 100-1936 ± 121 items/kg)	< 5 mm	Stainless-steel shovel	Fragment (dominant), fiber, film, foam	-	PP, PVC, PE, PS, and PVA	Microscope; FTIR; SEM	[31]
	Qinghai Lake	50-1292 items/m ²	< 5 mm	Stainless-steel shovel	Fiber, sheet	-	PP, PE (dominant), EVA, PVC, PC	Microscope; Raman	[32]
	Danjiangkou Reservoir	708-3237 items/kg	< 200 µm (21.7%) 200-500 µm (35.2%) 500-1000 µm (23.4%) > 1000 µm (19.6%)	Van Veen grab	Fiber (52.8%), fragment (42.3%), film (3.87%), pellet (1.2%),	Transparent (51.4%) and brown (33.0%)	-	Microscope; Raman	[36]
	Three Gorges Reservoir	25-300 items/kg	0.5-5 mm	Van Veen grab	Fiber (dominant), fragment, pellet, film and foam	Transparent (dominant)	-	Microscope; Raman; SEM	[37]
	Pearl River	80-9597 items/kg	0.02-1 mm (65.3%) 1-2 mm (29.5%) 2-3 mm (7.6%) 3-4 mm (3.3%) 4-5 mm (1.6%)	Van Veen grab	Fiber (54.7%), fragment (43.3%)	White (65.5%), red, black, blue, yellow, green, and transparent	PE (47.6%) and PP (26.2%)	Microscope; FTIR	[42]
	Yongfeng River	5-72 items/kg, (26 ± 23 items/kg)	< 1 mm (dominant)	Peterson gravity sampler	Film (64.4%), fiber (33.9%)	Transparent and green (dominant)	PP (24%), PE (61%), PET (8%)	FTIR; SEM	[56]
	Qin River	0-97 items/kg	1-5 mm (76%)	Grab dredge	Fiber (30.9%), sheets (62.8%), fragment (6.3%)	White (30%), blue (27.6%), green (18.3%), red (18.5%), black (1.5%),	PP (55.3%), PET (21.3%), and PE (17.0%)	Microscope; FTIR	[79]
	Wei River	360-1320 items/kg	< 0.5 mm (dominant)	Garb	Fiber and film (dominant)	-	-	Microscope; SEM	[81]
	Fuhe River	212 ± 14-1049 ± 212 items/kg	0.1-1 mm (dominant)	Columnar sampler	Fragment and fiber (dominant), film, pellet	Transparent (dominant)	PET, PP, PE, PA	Microscope; FTIR	[83]

In this review, we counted the microplastic pollution in 13 rivers including the Yangtze River, the Yellow River, the Pearl River, and the Qiantang River. In the river of China, the main shapes of microplastics are fibers and fragments, and the size of most microplastics is less than 1 mm. The main polymer types of microplastics are found to be PP and PE. This could be the case because of the excellent yield and wide utilization of PP and PE in our daily lives, such as plastic bottles, bags, films, lids, and containers^[2]. Though transparent and white colors are the main colors of the detected microplastics in Chinese rivers. As shown in [Table 1](#), the abundance of microplastics in the Yellow River, Yangtze River, and Pearl River Delta, which are the three main rivers in China, is significantly higher than the abundance of the Qiantang River, Minjiang River, and other rivers^[5,23,25-27]. The surrounding population of these three rivers is dense, and the degree of urbanization and economic development is higher than other regions of China, indicating the microplastic pollution could be closely related to the society and economy of the freshwater neighborhood. Similarly, Eo *et al.*^[28] (2019) and Alam *et al.*^[29] (2019) found that microplastic pollution in densely populated areas is equally serious. Besides this, microplastics were also found in the surface waters of the Chinese remote Qinghai-Tibet Plateau, such as the Yarlung Zangbo River, Tongtian River, and Nu River. This indicates that the microplastics have become the ubiquitous pollutant^[30]. Similarly, microplastics were detected in the freshwater of the Antarctic Special Reserve^[6]. These findings disclose that microplastic pollution has spread all over the world, and in the absence of monitoring, microplastics may transfer and spread under the impact of monsoons, runoffs, and other factors.

To study lakes, we selected the four largest lakes in China (e.g., Poyang Lake, Taihu Lake, Dongting Lake, and Qinghai Lake) and Honghu Lake^[24,31-33]. In conclusion, the particle size of microplastics in Chinese lakes is mainly less than 2 mm as demonstrated in [Table 1](#). Similar to rivers, fibers and fragments are found to be the main shapes of microplastics in lakes. At the same time, PP and PE are the main polymer types as shown in [Table 1](#). The reason behind this phenomenon could be linked to the transportation of microplastics to lakes along with rivers^[24]. The examination of the lake flowing through the river found that the abundance of microplastics in the inflow river is, generally, lower compared to the one found in the outflow river^[24]. Among all lakes, Honghu Lake (2282.5 items/m³) has the highest abundance of microplastics, followed by Dongting Lake (1191.7 items/m³), and Poyang Lake (289 ± 40-1064 ± 90 items/m³)^[31,33]. There is also a high abundance of microplastics in Qinghai Lake (0.05 × 10⁵-7.58 × 10⁵ items/km²) and Taihu Lake (5.67 ± 1.92 items/L)^[24,32]. Hong Lake is adjacent to Dongting Lake. However, compared with Dongting Lake, Hong Lake is more closed and has a smaller water surface area. Consequently, these could be the reasons for its high abundance^[33]. On the other hand, Qinghai Lake is different from other lakes, there is no industry in the Qinghai Lake basin, and the population is also low. However, it has a plenty of tourism resources, which are the primary cause of the observed high abundance of microplastics^[32]. At the same time, large amounts of microplastics have been found in lakes in other countries, such as Red Hills Lake in India (5900 items/m³) and three subalpine lakes in Italy (43,000 items/km²)^[34,35].

In China, microplastics are not just detected in rivers and lakes but also in reservoirs. The Three Gorges Reservoir and Danjiangkou Reservoir are the main reservoirs in China. The characteristics of the microplastics in these two reservoirs are like other freshwater environments, mainly transparent fibers and fragments. The particle size of most microplastics is less than 1 mm as shown in [Table 1](#). Considering the function of the reservoir, the reservoir may be a potential area for the accumulation of microplastics. The abundance of microplastics in the Three Gorges Reservoir (4703 ± 2816 items/m³) and Danjiangkou Reservoir (7205 items/m³) is much higher than Poyang Lake (289 ± 40-1064 ± 90 items/m³), Hong Lake (2282.5 items/m³), and Dongting Lake (1191.7 items/m³)^[31,33,36,37]. Meanwhile, the amount of microplastics in the Three Gorges Reservoir is one hundred thousand times that in the Feilaixia Reservoir (0.56 ± 0.45 items/m³). It might be because the larger the total intake capacity of the reservoir, the higher the

Table 3. The abundance and characteristics of microplastics in biota

Biota	Location	Identification	Average abundance (range)	Size	Shape	Ref.
Wild Freshwater fish	Beijiang River	Microscope	1.0-15.0 items/individual (average 5.6)	< 0.5 mm (> 50%)	Fragment and fiber (> 90%)	[5]
Wild Freshwater fish	Pearl River Delta	Microscope	1.0-14.0 items/individual (average 4.8)	< 0.5 mm (> 50%)	Fragment and fiber (> 90%)	
Wild fishes	Dafeng river	Microscope FTIR	8×10^3 - 5.7×10^4 items/kg (0.3-6.7 items/individual digestive tract) 2×10^3 - 1.7×10^4 items/kg (0.1-3.0 items/individual gill)	0.5-5 mm (dominant)	Fiber (dominant)	[8]
Gymnocypris przewalskii	Qinghai Lake	Raman	2-15 items/individual	-	Fiber, sheet	[32]
Asian clam (Corbicula fluminea)	Middle-Lower Yangtze River	FTIR	0.4-5.0 items/individual (0.3-4.9 items/g)	0.021-4.83 mm 0.25-1 mm (dominant)	Fiber (60%-100%)	[43]
Wild crucians (Carassius auratus)	Poyang Lake	Microscope; Raman	0-18 items/ individual	> 0.5 mm (82.1%)	Fiber (dominant)	[46]
Wild fishes (4 species)	Lijiang River	FTIR	0.6 ± 0.6 items/individual	> 1 mm (60%-100%)	Fiber (dominant)	[80]
Wild organisms	Liaohe Estuary	Stereomicroscope FTIR	0.83 ± 0.99 - 3.87 ± 2.18 items/individual	< 1 mm (dominant)	Fiber (dominant), fragment, pellet	[82]
Reed	Dongting Lake	Microscope FTIR	0-14 items/individual	< 0.5 mm (56%-68%) 0.5-1 mm (24%) 1-3 mm (10%) 3-5 mm (3%)	Fiber (59%-100%) (average value of 89%)	[84]
Tilapia	North and west rivers of Guangdong province	Microscope	0-18.0 items/individual (0-0.116 items/g)	< 1 mm (> 72.5%)	Fragment and fiber (dominant)	[85]
Mud carp	North and west rivers of Guangdong province	Microscope	0-14.0 items/individual (0-0.385 items/g)	< 1 mm (> 72.5%)	Fragment and fiber (dominant)	

opportunities to collect microplastics^[38].

The freshwater resources of rivers, reservoirs, and lakes are generally used to regulate water supply, agricultural irrigation, and aquaculture^[5]. Water with a high abundance of microplastics, used for agricultural irrigation, might aggravate the microplastics pollution in soil and cause potential harm to crops^[39]. In parallel to that, aquaculture in waters, containing a high abundance of microplastics, does not only affect the growth and development of aquatic organisms extremely, but also allows the microplastics to reach the human body, through the food chain, causing various health issues^[40].

Sediments

Sediment is an important accumulation pool of microplastics in rivers, lakes, and reservoirs^[41]. According to the findings of many previous studies, a lot of microplastics were accumulated in the sediment of rivers, lakes, and reservoirs. Basically, sediment sampling is generally carried out with grab buckets, stainless steel shovels, and cylindrical samplers to take the upper layer (usually 0 to 20 cm) sediment as demonstrated in Table 2. The average abundance of microplastics in the sediment of freshwater were ranging between 460 and 10240 items/kg or 0 to 1292 items/m² as can be seen from Table 2. More severe microplastics pollution levels were found in the sediments of West River, Pearl River, Danjiangkou Reservoir, and Minjiang (Chengdu)^[19,23,36,42]. Similar to water, the main shapes of microplastics in sediments are fragments and fibers as shown in Table 2. On the other hand, the main shape of microplastics in the sediment of Qin River is



Figure 1. Distribution map of study locations.

sheet. Additionally, the main types of microplastics in sediments of the freshwater environment in China are PP and PE. Among all sediments of freshwater in China, the pollution of microplastics in the sediments of the Pearl River system is the most critical one as depicted in Table 2. The abundance of microplastics in the downstream sediments in the West River, which is the longest river in the Pearl River Basin, is much higher compared to other water bodies. The high abundance of microplastics observed in West River, was likely due to two reasons, the first downstream industries being well developed and the other sampling areas including commercial and industrial areas, which are significantly affected by humans^[19]. Meanwhile, the abundance of microplastics in the sediments of Danjiangkou Reservoir is higher compared to other water bodies (except the Pearl River Basin). This might be due to the low flow velocity of Danjiangkou Reservoir which reduces the loss of microplastics^[36]. Generally, the microplastics in the sediments can be ingested by benthic organisms and affect their physiological activity and metabolism^[43]. Furthermore, it can be transported to high-trophic organisms along the food chain. The status of microplastics in the sediments of the freshwater environment in China is similar to other countries. For example, Mani *et al.*^[44] (2019) found that the range of microplastics in the sediments of the Rhine River in Germany was 260 ± 10 to $11,070 \pm 600$ items/kg. On contrary, the range of microplastics in Ciwalingke River sediments in Indonesia is only 30.3 ± 15.9 items/kg^[29].

Biota

Microplastics in water bodies and sediments can easily reach aquatic organisms. Therefore, aquatic organisms can be used as an indicator to the level of microplastic pollution in the region^[45]. Previous biological studies were mostly concentrating on the tropical and subtropical regions of southern China. At the same time, all biota samples were directly from sampling or purchasing. Studies reported that some aquatic plants, bivalves (e.g., Asian clams) and fish (e.g., *Oreochromis niloticus*, *Cirrhinus molitorella*, and *Carassius auratus*) all contained microplastics. The abundance range of microplastics in aquatic organisms was 0 to 18 items/individual, with the highest concentrations in Poyang Lake and north and west rivers of Guangdong province. Among them all, the abundance of microplastics in wild fish, in the Lijiang River, was significantly lower than others. It is an indication that the Lijiang River was less polluted by microplastics. Basically, the characteristics of microplastics in aquatic organisms are like the ones in water and sediments. The shape of the microplastics in the aquatic organisms is mainly fiber, and the particle size of most microplastics is less than 1 mm as shown in Table 3. This might be so because fish ingesting microplastic fibers as plant fibers. The researchers found that the type of fish, feeding pattern, and habitat all can affect the level of microplastic enrichment. For example, fish may accumulate microplastics in the different tissues through diverse feeding methods such as swallowing, sucking, and filter feeding^[46,47]. In Beijiang and Pearl River Deltas of China, the microplastic abundances of carnivorous fish were 3.5 and 3 items/individual, respectively. Similarly, the microplastic abundances of omnivorous fish were 6.8 and 6.2 items/individual, respectively^[5]. The result revealed that omnivorous fish are more likely to accumulate microplastics than carnivorous fish. In parallel to this, Zheng *et al.*^[48] (2019) found that benthic fish, generally, accumulate more microplastics than other fishes in the water. The contamination status of microplastics in freshwater organisms, in China, is consistent with those of other countries. In Bangladesh, the abundance range of microplastics for fish is 2 to 6 items/individual^[49]. At the same time, the abundance range of microplastics in freshwater fishes, in southwestern Germany, is 1 to 4 items/individual^[50]. Although, the abundance and type of microplastics in biota of freshwater environments, in China, have been investigated in recent years, more studies should be carried to comprehensively evaluate the MP pollution in freshwater ecosystem of China.

MICROPLASTICS SOURCE IN THE FRESHWATER ENVIRONMENT

Microplastic pollution of the freshwater environment is associated with geographical location, human activities, and other factors^[5]. Exploring the source of microplastics can help us reduce the pollution of microplastics in the freshwater environment. Essentially, the distribution of microplastics is closely related to population, industry, and the degree of urbanization. For example, in the densely populated and economically developed Pearl River Delta, the middle, and lower reaches of the Yangtze River, microplastics pollution is more severe compared to other regions^[5,25].

Chinese freshwater environment is mainly polluted by microplastics through the following channels: domestic wastewater, surface runoff, atmospheric transportation, and aquaculture^[51]. Domestic wastewater is the main source of microplastics in the water body, near the urban regions. In the city, sewage treatment plants are concentrated areas for the collection and treatment of domestic sewage. Although the sewage treatment plant can process up to 99% of microplastics, a considerable amount of microplastics passes through this system and is discharged into the water body along with the sewage^[52-54]. Although the four sewage treatment plants in Guilin, Guangxi have high removal efficiency, each sewage treatment plant discharges 2 to 78 million items of microplastics into the receiving water body every day^[52]. In the underdeveloped countryside of China, sanitary sewage is discharged directly into the water environment with simple or no treatment causing serious microplastics pollution. Likewise, landfills transport microplastics to the environment through the leaching of landfill leachate^[54]. Meanwhile, rainwater runoff (especially during periods of heavy rainfall) is also an essential way for the terrestrial ecosystem to transport microplastics to the aquatic ecosystem. On the banks of the river, lake, and reservoir, there are plastic

containers (e.g., plastic bags), fishing nets, and lines that are randomly discarded which increase the risk of microplastic pollution when these plastics are weathered^[51]. Furthermore, Li *et al.*^[55] (2020) indicated that inappropriate management of these waste plastics is the principal reason behind the microplastic pollution in the water of the Yangtze River Estuary. At the same time, some agricultural activities produce microplastics in the soil then transfer them to the water environment by means of surface runoff^[56]. Additionally, rainfall and atmospheric deposition are one of the primary sources of microplastics in some remote areas^[57]. Either, in cities or rural areas, aquaculture is one of the core sources of microplastics for lakes^[58,59]. Moreover, tourism is also a fundamental source of microplastics in some areas, such as Qinghai and the Qinghai-Tibet Plateau^[32,60].

IMPACTS OF MICROPLASTICS ON THE FRESHWATER ENVIRONMENT

The impact of microplastics on the freshwater ecosystem can be divided into physical and chemical impacts, with the chemical one being the dominant. Basically, the physical impact, of microplastics on the environment, primarily depends on particle characteristics. There are two main reasons for the chemical pollution of microplastics to the freshwater environment. First, the additives released from microplastics that aggravate the pollution of the water environment and second the toxic pollutants adsorbed in microplastics that increase its harm to organisms. Plastics usually contain various additives, such as plasticizers, heat stabilizers, colorants, foaming agents, and heavy metals^[61]. It is considered to be carcinogenic and can damage the endocrine system. Once these additives leached from microplastics do not only pollute the water environment but cause potential harm to aquatic organisms^[62]. For example, lead (Pb) released from PVC affects the gene expression in zebrafish^[63]. Moreover, microplastics would adsorb persistent organic pollutants (e.g., PCBs, PAHs, DDTs, and PBDEs) and heavy metals (e.g., Cr, Cu, Ni, Pb, Cd, and Zn) due to their larger specific surface area and hydrophobicity^[64-67] thus increasing the toxicity of microplastics. At the same time, persistent organic pollutants and heavy metals can cause secretion disorders, mutations, and cancer in organisms. Later, these pollutants can reach high-nutrient organisms through the food chain^[68].

In addition to indirectly affecting aquatic organisms by affecting the water environment, microplastics can directly cause physical and chemical damage to organisms through ingestion^[69]. The ingestion of microplastics, by fish and benthic organisms, may cause abrasions, ulcers, and blockages of the digestive tract. This, in turn, affects the growth and metabolism of these organisms^[10,70]. Fish ingesting microplastics might cause liver poisoning and inflammation^[71]. Furthermore, Jin *et al.*^[72] (2018) and Park *et al.*^[73] (2022) indicated that the PE microplastics could cause inflammation of zebrafish, damage to the liver, and microbiota to crucian carp. Microplastics do not only affect the development of fish embryos but also influence their gene expression^[74]. For example, Umamaheswari *et al.*^[75] (2020) found that PE microplastics affect genes (e.g., cat, sod1, gpx1a, gstp1, hsp70l, ptgs2a, and ache) expression in zebrafish. Moreover, microplastics could change the natural habitat, disturb the bacterial community, disrupt the development of species, and adversely affect the ecological functions of the aquatic ecosystem^[76]. For example, the existence of microplastics reduced the chlorophyll content of algae, thereby decreasing the efficiency of photosynthesis and inhibiting the growth of algae^[77]. Inhibition of algae growth represents a decrease in primary consumers in the environment, which may have an impact on the nutrient cycle in the aquatic ecosystem^[78].

PROSPECTIVE AND SUGGESTIONS

Microplastic pollution, in the freshwater environment of China, is associated with both natural and human factors. Different regions have different distribution characteristics of microplastics and even the same freshwater area showed different results, of the microplastics abundance, due to different sampling methods,

extraction methods, identification methods and units expression. These factors are not conducive to the follow-up evaluation and treatment of microplastics pollution. Therefore, in the future, a unified standard unit representation, sampling, and detecting methods are suggested to better measure and evaluate the status of microplastics.

Furthermore, the sources of microplastics in water are extremely wide, and the control methods are also diverse. Domestic wastewater is one of the principal sources of microplastics in freshwater, thus improving the treatment efficiency of microplastics in wastewater treatment plants can help to effectively control the input of microplastics. Meanwhile, increasing the recovery of the discarded plastics, effectively disposing them in agricultural activity, raising the public awareness of microplastics, and reducing the random discard of plastic products are all of a great significance. In addition to that, tourism is considered the main source of microplastics in remote regions such as Qinghai and Qinghai-Tibet Plateau. Consequently, strengthening supervision and management in this area are one of the key methods to reduce microplastic pollution.

Although some experiments have been done to explore the harm of different microplastics and particle size to organisms of freshwater environment, the comprehensive impact of microplastics on organisms, in the ecosystem, is still unknown. Therefore, exploring microplastics fate in the freshwater environment and evaluating the impact of microplastics on the biota, especially their potential harm to human health, should be brought to the forefront.

CONCLUSION

Microplastic pollution in the freshwater environment of China has become widespread. The abundance of microplastics in areas with intensive human activity (e.g., Pearl River Region) is much higher compared to remote areas (e.g., the Qinghai-Tibet Plateau). The shape of microplastics in the freshwater environment is mainly fragments and fibers, and the types are essentially PP and PE. At the same time, the key sources of microplastics are sewage discharge, surface runoff, and aquaculture. The aquatic organisms, in the freshwater of China, are also polluted by microplastics, especially the bivalves and fishes, which aggravate the accumulation of microplastics in the human body. Although microplastics have been attracting more attention and turned into a trending topic in the last few years, there is still a lack of in-depth research on the sources of microplastics and the harm to the human body. To prevent microplastic pollution, governments, of all countries, should issue relevant policies and regulations, as soon as possible, to reduce their pollution.

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Authors' contributions

Made substantial contributions to conception and design of the study and performed data analysis and interpretation: Zhao H, Zhou Y, Han Y

Performed data acquisition, as well as provided administrative and technical support: Sun Y, Ren X, Zhang Z

Supervision, project administration and writing-review & editing: Wang Q

Availability of data and materials

Not applicable.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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