

# Abundance and distribution of microplastics in water and sediment of Baiyangdian Lake, Northern China

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## Research Article

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# Abstract

Microplastics (MPs) have been found in all environment matrices and have become an issue of concern worldwide. In this study, Baiyangdian Lake in Northern China was investigated for the presence of MPs ( $0.45\text{ }\mu\text{m}-5\text{ mm}$ ) in sediment and at different water depths. MPs were found at  $1,000-20,000\text{ pieces/m}^3$  (average 9,595) in water and at  $400-2,200\text{ pieces/kg}$  (average 1,023) in sediment. Since the implementation of pollution abatement measures, visible MPs have been nearly eliminated; the MPs found in this study were mainly in the micrometer range, with no more than 3–5 pieces greater than 1 mm per sample. The main forms of MPs were fibrous and fragmented, and the main components were polyamide, polyethylene, and polypropylene. MPs found in water near a garbage transfer station showed the following abundance of MPs: surface water < middle water < bottom water. The sediment contained a higher amount of MP fragments, indicating that the historical transfer and disposal of garbage was a main source of plastic deposition in this area. There was a high content of fibrous MPs in surface water, while the abundance of fragmented MPs increased with the depth of water. The main sources of MPs in the study area were residential activities, local plastic factories, and the treated effluent from a sewage treatment plant.

## 1. Introduction

Microplastics (MPs) were first proposed as a persistent pollutant in marine water and sediment in 2004 and soon gained widespread attention. MPs are plastic particles and debris with a diameter of less than 5 mm (Thompson et al., 2004). Approximately 300 million tons of plastic material is produced every year and is growing at a rate of 20 million tons annually (Matsuguma et al., 2017; Zhang et al., 2020). MPs mainly consist of polyamide (PA), polypropylene (PP), polyethylene (PE), and polyester (PET) (Thompson et al., 2004). MPs can be classified by their shape as fragments, films, fibers, granules, and foams. Han (2018) described some MPs found in the ocean as "PM 2.5". MPs transferring from land to the ocean is an important source of marine MPs, accounting for 80% of plastics in the ocean (Bakir et al., 2012). MPs are widely distributed in environmental matrices, including rivers (Peng et al., 2020), lakes (Yuan et al., 2019), wetlands (Jian et al., 2018; Yu et al., 2021), soils (Henseler and Gallagher, 2021), and air (MeralYurtsever. et al., 2018). Because of their small size, MPs can be easily ingested by aquatic organisms (Ha and Yeo, 2018), but they cannot be easily digested and can compromise growth and development, and even result in death (Yang and Huang, 2019). At the Second Joint Environment Conference in 2016, MPs were listed as the second-largest scientific problem in the field of environmental and ecological science research and were acknowledged as a major global problem (Xia et al., 2019).

Lakes are relatively closed bodies of water. Unlike rivers, which serve as the main transport routes of pollutants, lakes can function as "inland oceans" and act as sinks of pollutants. MPs can accumulate in lakes and thus can have a direct impact on freshwater and terrestrial organisms, including humans (Xiong and Wu, 2021). MPs can accumulate in lakes and wetlands and become entrapped (Qian et al., 2021). Duan et al. (2020) widely detected MPs in the Yellow River Delta wetland even in protected areas with little human activity; the MPs ranged from 136 to 2,060 pieces/kg in soil samples, with the primary

components being PET (536–660 mg/kg) and Polycarbonate (PC) (83.9–196 mg/kg). In sediment from the Fuhe River in Hebei, China, Zhou et al. (2021a) found the average abundance of MPs is  $558.4 \pm 233.3$  pieces/kg, with fragmentary MPs accounting for 66.1% of total MP particles. Zhou et al. (2021b) studied MPs in the main upstream river flowing into Baiyangdian Lake and found that MPs decreased with increasing sediment depth, with the highest content being  $1,049 \pm 462$  pieces/kg in the topmost sediment layer (0–5 cm). PE and PP were the main plastic polymer types in the sediment samples. Cordova et al. (2021) investigated MPs in mangrove sediment in Indonesia and found the average MPs abundance of  $28.09 \pm 10.28$  pieces/kg of dry sediment. Foam MPs were the predominate type found in that study, and they were more abundant in samples collected from the ground surface.

As the largest shallow lake in the North China Plain, Baiyangdian Lake plays an important role in maintaining the balance of the ecosystem in Northern China (Li et al., 2021; Zhao et al., 2021). Several treatment and construction measures have been enacted in this area, and the environment of Baiyangdian Lake has greatly improved. However, MPs, especially those in the micrometer range, can act as carriers of pollutants. This continues to be a problem that hinders the improvement of the ecological environment. In view of this situation, this study investigated the abundance and distribution of MPs in the water and sediment of Baiyangdian Lake.

## 2. Materials And Methods

### 2.1 Study area and sample collection

On the basis of the multiple sources of MPs in Baiyangdian Lake, the sampling area was divided into three habitats (Figure 1). Habitat 1 included a tourist area and the area at which water from the Fuhe River enters Baiyangdian Lake. This area is also near where treated effluent from a sewage treatment plant is discharged. Habitat 2 mainly comprised villages. Habitat 3 comprised an area that formerly hosted plastic recycling workshops. Surface water, middle water, bottom water, and sediment samples were collected in a series of vertical points at sampling locations in these three habitats. For each water sample, 2 L of water was collected and filtered through an 1800-mesh stainless steel screen. The MP debris on the filter screen was washed into a brown glass bottle with pure water and then transferred to the laboratory for analysis. Sediment samples were wrapped in aluminum foil, sealed, and transferred to the laboratory in a self-sealing bag at 4 °C for analysis.

### 2.2 Sample treatment and microplastic extraction

The water samples were purified by adding 50 mL of 30% H<sub>2</sub>O<sub>2</sub> to each sample and putting in a thermostatic water bath shaker (SHY-2A) at 60 °C for 24 h. The samples were then filtered through a 0.45 µm filter membrane using a circulating vacuum pump (SCJ-10). The filter membrane was placed in a Petri dish for MPs determination. The sediment samples were weighed and transferred to a brown glass bottle along with 80 mL of saturated NaCl solution for MPs separation. The samples were placed in an ultrasonic cleaning machine and sonicated at 40 kHz for 10 min. After ultrasonication, the samples were centrifuged at 4,000 r/min for 10 min. The resulting pellets were filtered through an 1800 mesh stainless

steel screen using a vacuum pump (SCJ-10). The material on the screen was then washed into a 100 mL glass bottle using 5 mL of deionized water. This was repeated, and the material from the second rinse was added to the bottle. Next, 15 mL of 30% H<sub>2</sub>O<sub>2</sub> was added for purification, and the mixture was passed through a 0.45 µm filter membrane. The filter membrane was placed in a Petri dish, and MPs were identified under a biological microscope (Nanjing Nikon Jiangnan Optical Instrument Co., Ltd., E200 MW). The sizes of the MPs were recorded, and the morphologies were observed under an oil mirror. Finally, particles ranging from approximately 100 µm to 5 mm were analyzed by Fourier transform infrared spectroscopy (FTIR) (Thermo Fisher, Nicolet IS10) to identify the polymer type, using a scan range of 4,000 to 400 cm<sup>-1</sup>. The FTIR spectra were compared to those in the Hummel Polymer and Additives Library.

## 2.3 Quality assurance and quality control

The glass vessels were cleaned three times with deionized water before each procedure and were covered with tin foil when not in use. During the experiments, we avoided using plastic products as much as possible to avoid contaminating the samples with MPs. The filter membranes were stored in a closed space to prevent contamination from MPs in the air. Cotton lab coats were worn when in the lab, and nitrile rubber gloves were worn when conducting experiments. Standard controls were analyzed to ensure the reliability of the experimental data. For this, PP and PE MP standards were added to water samples, and three parallel samples were tested. The measured recovery rate of the control PP and PE MPs was 90%. This finding shows that the test process was functioning well and the experimental data are reliable. Before sample treatment, the digestion solution and ultrapure water were filtered. Microscopic examination of the solutions used in the experiment revealed no MP particles, which proved that there was no MP pollution from the laboratory.

## 3. Results And Discussion

### 3.1 MPs abundance

The abundance of MPs in the water of Baiyangdian Lake ranged from 1,000 to 20,000 pieces/m<sup>3</sup> with an average of 9,595 pieces/m<sup>3</sup>. In sediment samples, MPs ranged from 400 to 2,200 pieces/kg with an average of 1,023 pieces/kg. The highest abundance was found in Quantou Village, which may have resulted from the dense population, poor waste management practices, and the fishing activities of residents, who often use foam and waste plastic bottles as the floatation material (Kumar et al., 2021). The abundance of MPs in the surface water of Fuhe River before it flows into Baiyangdian Lake was relatively high. This indicates that treated effluent discharged from the Baoding sewage treatment plant and from the domestic sewage of residents living along the river remains an important source of MPs to Baiyangdian Lake (Zhou et al., 2021a; Zhou et al., 2021b). As shown in Figure 2, the MPs were often purple, but some were transparent or blue. In the water samples, most MPs were fibers (66.85%), followed by fragments (30.0%) and thin films (3.13%). In the sediment samples, most MPs were fibers (59.0%), fragments (37.0%), or films (4.0%) (Figure 3). These results were consistent with the high content of

fragmented and fibrous MPs found in domestic waste and wastewater (Jiang et al., 2019). In addition, the woven bags used to contain fertilizer for agriculture use are prone to aging and break down to form fibrous MPs (Zhou et al., 2021a). Most fragmented plastics are small fragments of plastic products that have broken down under natural conditions; therefore, fragmented MPs are mainly secondary MPs (Zhang et al., 2015). Film MPs mostly arise from discarded plastic bags and sheeting used on agricultural land. In the current study, the components of the MPs were determined by FTIR. The spectrograms of the MPs in the collected samples (fibers and fragments) were compared with standard PA and PP spectrograms (Figure 4). Along with the elemental analysis results, the results showed that the fibrous MPs consisted of 65% C, 12% H, 10% N, and 13% O, and the fragment MPs consisted of 88% C and 12% H. These results are consistent with the element compositions of PA and PP. Thus, the fibrous and fragmented MPs in the collected samples were inferred to be composed of PA and PP.

The abundance of MPs found in the Fuhe River sediment (400 pieces/kg) in this study was slightly lower than in a previous study (558.4 pieces/kg), but they had similar components (PE, PP) and shapes (fragments, fibers, films, and pellets) (Zhou et al., 2021b). The small change in MP abundance and shape may have arisen from differences in the sampling locations and extraction methods. Compared with data from Poyang Lake (16.2–710 pieces/m<sup>3</sup> in water and 112–334 pieces/kg in sediment), the abundance of MPs in Baiyangdian Lake was higher, but they had similar components (PE, PP) and shapes (particles, fragments, fibers, and films) (Liu et al., 2019; Yuan et al., 2019). The higher abundance of MPs in Baiyangdian Lake resulted from the multiple sources of MPs, including nearby plastic recycling workshops, treated effluent from sewage plants, fishing activities, and poor waste management practices. When compared with lakes and rivers in other countries, MPs in Baiyangdian Lake were at high levels and comparable to those found in Iran (0.40–4.41 pieces/m<sup>3</sup> and 140–2,820 pieces/kg) (Rasta et al., 2020), Africa (mean of 705 pieces/m<sup>3</sup> and 116.8 pieces/kg) (Dahms et al., 2020), Portugal (71–1,265 pieces/m<sup>3</sup> and 100–629 pieces/kg) (Rodrigues et al., 2018), and Korea (293–4,760 pieces/m<sup>3</sup> and 1,970 pieces/kg) (Eo et al., 2019).

## 3.2 Vertical distribution of MPs

The different forms and components of MPs showed different vertical distributions in Baiyangdian Lake. Fibrous MPs in the surface water were more abundant at shallower water depths, while fragmentary MPs increased with depth. Fibrous MPs are lighter and can more easily be suspended on the surface, and they were mainly composed of nylon and polyester. Fragmentary MPs were often composed of PP and PE. Although the densities of PP and PE are lower than that of freshwater, the density of MPs can increase when organic matter and other material attaches and accumulates on the MP surface, in which case they are more likely to settle into the sediment (Wang et al., 2018). Figure 5 shows the vertical distribution of MPs in Zaozhadian Lake, located in habitat 1. The abundance of MPs in this area was likely affected by human activities and water turbulence due to wind and temperature. MPs increased with the depth of water at the sampling location near residences (Zaozhadian-V), while the less disturbed area (Zaozhadian-N) showed a higher abundance of MPs in the surface water. In this area, the MPs may have been affected by residential activities in addition to water turbulence. Comparable levels of MPs were

found in the bottom water and sediment of the two Zaozhadian Lake sampling locations. The point at which the Fuhe River enters Baiyangdian Lake showed the highest MPs abundance (surface water-middle water-bottom water), indicating the continuous input of MPs to this area. In areas with denser human activity, including Quantou, Guangdian, Dizhuang, and the Lotus Garden tourism area, the MPs tended to be more abundant in surface water and middle water, which might be influenced by local residential activities (i.e., poor waste management and nearby fishing cages and nets). There is an area of floating plastic debris located between Guandian and Quantou, and MPs were found with high abundance in surface, middle, and bottom water collected in this area on December 13, 2020. The floating plastics consisted of daily items such as bags, bottles, and foams; this debris is probably a source of secondary MPs in this area. Samples taken near an abandoned garbage station had high MPs abundance in middle and bottom water, which may have come from previous waste transfer and disposal activities. Areas in Baiyangdian Lake with lower MPs abundance may have experienced less lake disturbance, allowing the MPs to settle and resulting in stratification. A previous study found that the vertical distribution of MPs in water is related to MPs morphology, hydrological and geographical conditions, and local human activities (Zhou et al., 2021b).

### 3.3 Horizontal distribution of MPs

The highest abundance of MPs was found where the Fuhe River enters the lake and near the Lotus Garden tourism area in habitat 1. Previous studies found that water in this area contained high level of Total Nitrogen (TN), Total Phosphorus (TP), and heavy metals (Ma et al., 2020; Zhao et al., 2020). Water from sewage treatment plants is an important source of MPs (Carr et al., 2016). The Baoding sewage treatment plant located along the Fuhe River upstream of Baiyangdian Lake is the main source of MPs at the river's entry point into the lake; the MPs then spread to other areas of the lake through water turbulence. In addition to the treated effluent from the sewage plant, tourist activities and cruise ships can lead to the higher accumulation of MPs in the Lotus Garden area (Shan, 2021). The abundance of MPs was generally high in habitat 2, which contains several villages. Plastic waste generated by residents can flow into the lake because of poor waste management practices. This indicates that the abundance of MPs in Baiyangdian District is closely related to the intensity of human activity (Shan, 2021; Zhou et al., 2021a; Zhou et al., 2021b). In habitat 3, MPs were most abundant in Dizhuang and Caiputai, where there is a relatively high population density. Domestic waste generated by residents and industrial wastewater discharged by surrounding factories led to the high abundance of MPs in this area, which is consistent with previous studies showing that MPs are more abundant in areas with denser populations and more intense human activity (Cordova et al., 2019; Peng et al., 2018). In the area with less human activity and fewer factories (S6 and S9), the MPs abundance was relatively low. In addition, in the north of Baiyangdian District, there was much more plant life (such as lotuses), few villages, little human interference, and relatively good water quality, and this area had a low MP abundance (Wang et al., 2020). The horizontal distribution of MPs is shown in Figure 6.

## 4. Conclusions

MPs were commonly found in the water (9,595 pieces/m<sup>3</sup>) and sediment (1,023 pieces/kg) of Baiyangdian Lake, with the main components being PA and PP. The vertical distribution of MPs in the water was affected by the hydraulic conditions of the lake and by the size and components of the MPs. Previous fishing activities and poor waste management practices are the main source of MPs in the lake. The discharge of treated effluent from the Baoding sewage treatment plant located on the Fuhe River and nearby recycling workshops has also intensified the level of MPs in the water and sediment. MPs with larger sizes (millimeters) have been nearly eliminated owing to water quality improvement measures; however, the large amount of micrometer-sized MPs continues to be a problem that cannot be ignored. The natural degradation of MPs and carrier effects in the lake should be further investigated.

## Declarations

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### Competing Interests

The authors declare no competing interests.

### Author Contributions

Ruonan Hu, Xiufeng Hu, Yu Wang, and Yanyan Fang are from the College of Ecology and Environment, Hebei University.

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All authors contributed to the study conception and design. Ruonan Hu, Xiufeng Hu, and Yu Wang designed the research project and contributed to data analysis and interpretation. Yiding Guo analyzed

the samples. Wei Liu and Lihong Wei prepared materials. Yanyan Fang is the corresponding author. All authors have read and approved the final manuscript.

### **Compliance with Ethical Standards**

Not applicable

### **Consent for publication**

Not applicable

### **Data availability**

Data is available upon request.

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## Figures

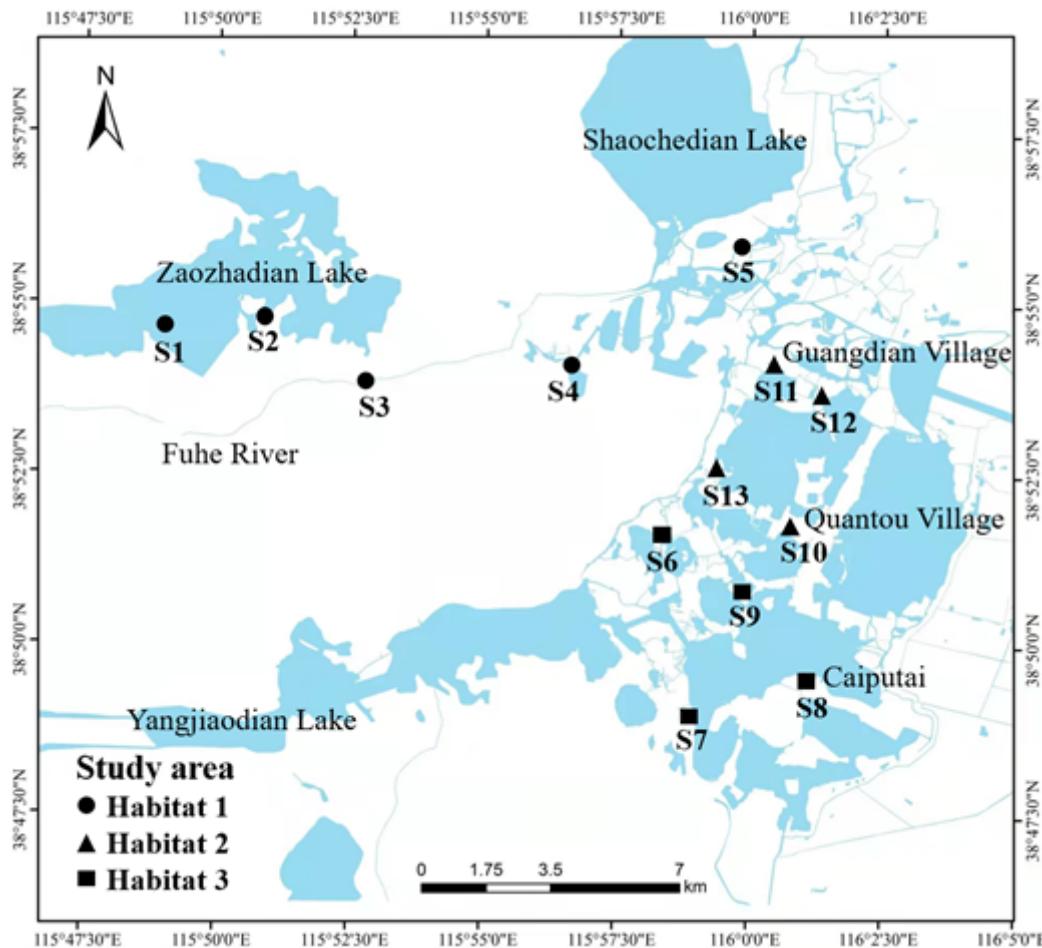
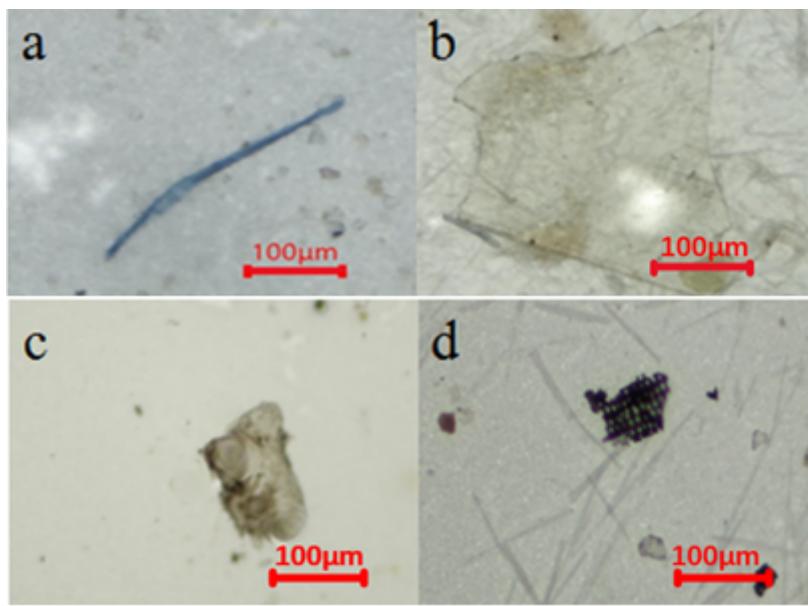


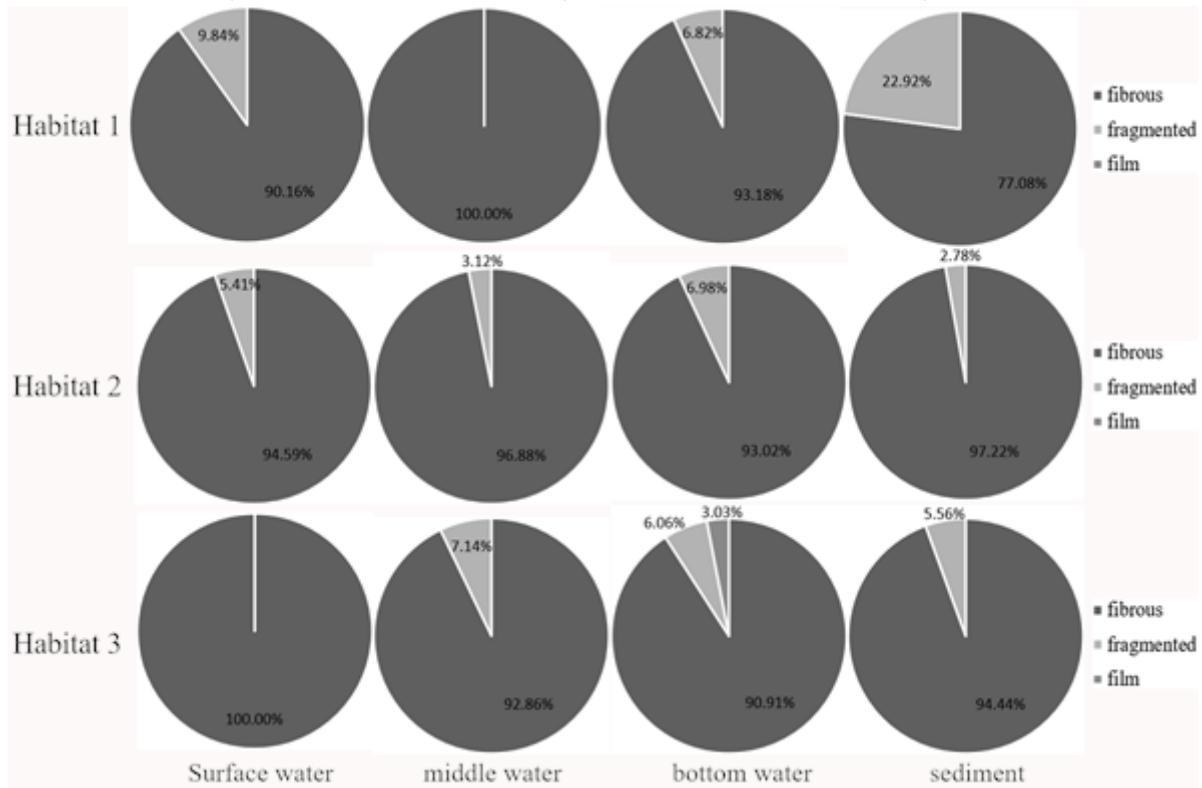
Figure 1

Sampling sites layout



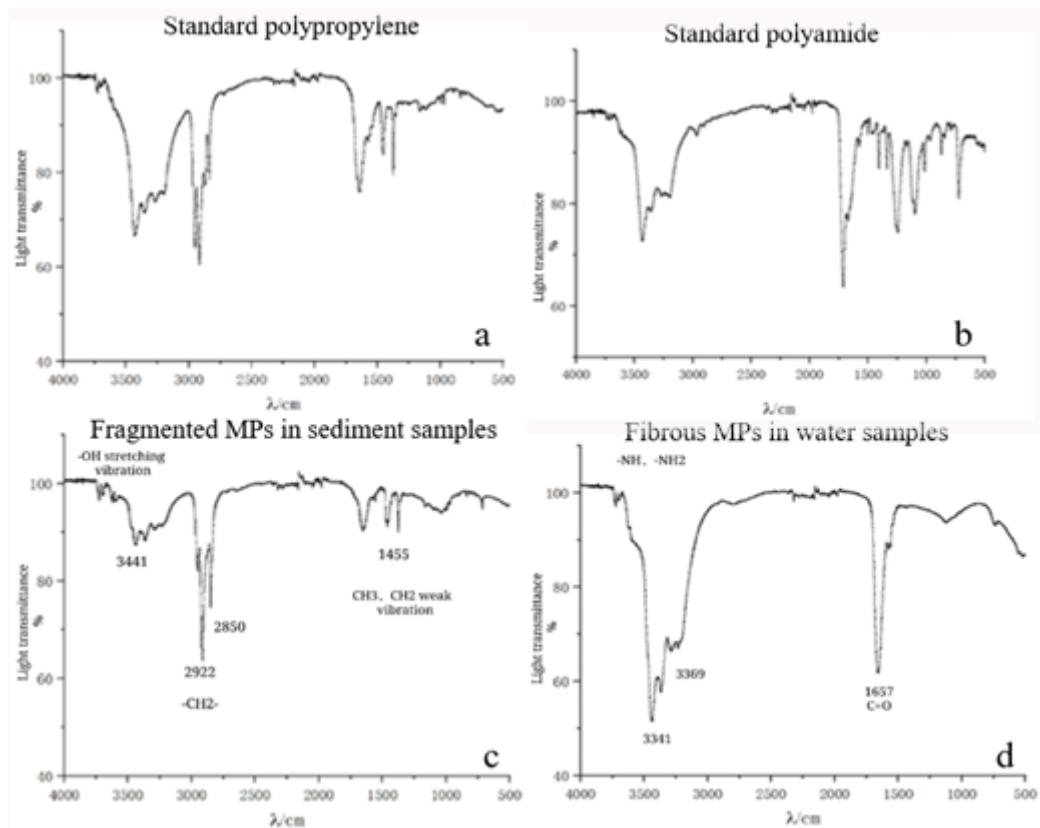
**Figure 2**

The shape of microplastics: a) Fragmentary microplastics; b) Fibrous microplastics; c) thin film microplastics; d) Fibrous microplastics(Suspected of fishing nets)



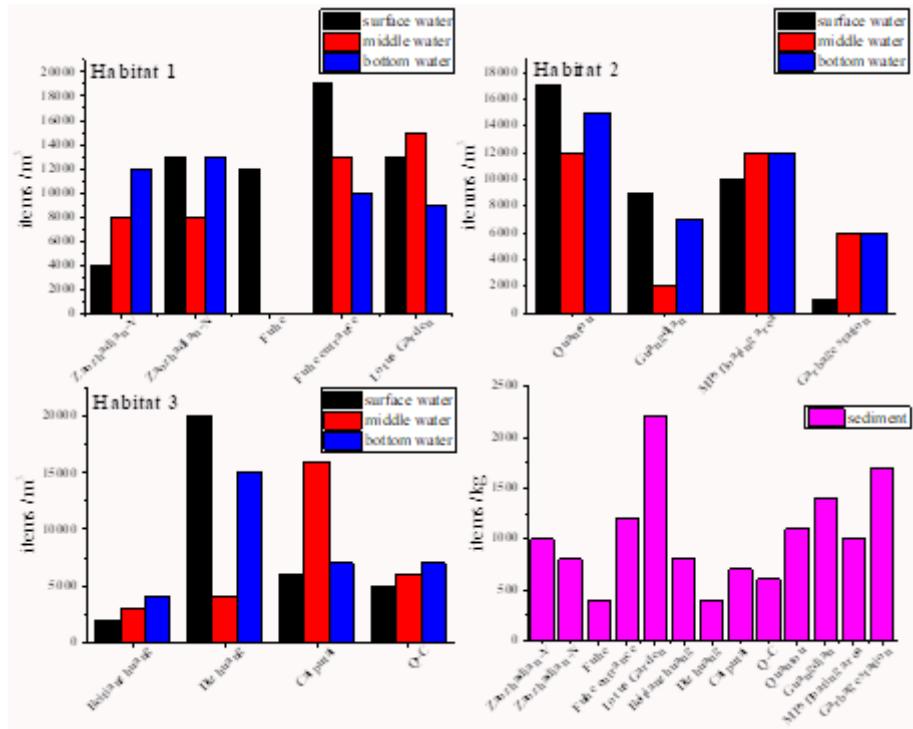
**Figure 3**

Form proportion of microplastics in habitat 1×2×3



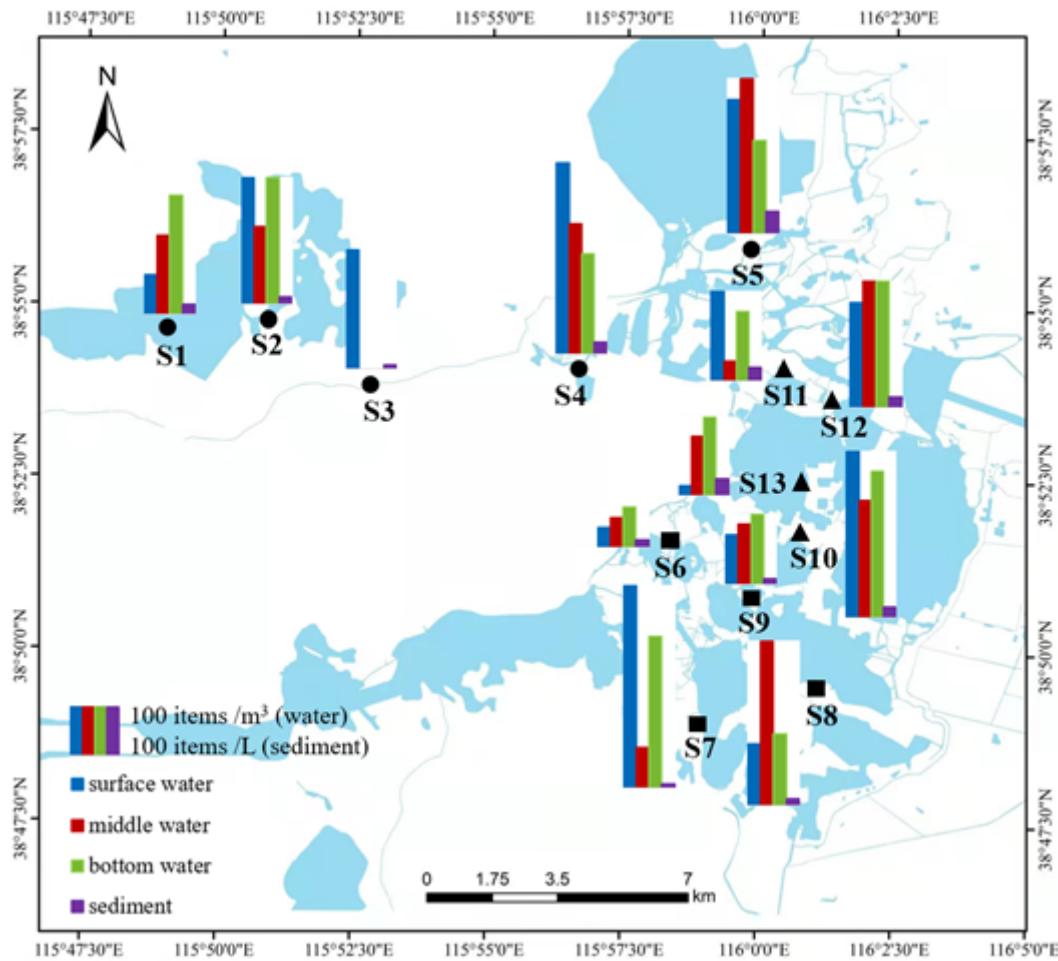
**Figure 4**

Fourier transform infrared spectroscopy  
**a** Standard polypropylene  
**b** Standard polyamide  
**c** fragmented microplastics  
**d** fibrous microplastics



**Figure 5**

## Microplastics in surface, middle, bottom water and sediment of the study section



**Figure 6**

Horizontal distribution of microplastics in Baiyangdian Lake (unit: items /m<sup>3</sup> water/items /kg sediment)