Levels And Distribution Characteristics of Microplastics In Water And Sediment of A Typical Shallow Lake In Northern China

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Research Article

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Abstract

Microplastics (MPs), generally found in all environment matrices, have become a hot issue in the world. In this study, a typical shallow lake (Baiyangdian) in Northern China was selected, MPs (0.45 μm-5 mm) in different depth of the water and sediment samples were determined. The abundance of MPs in water samples was 1000-20000 items /m$^3$ (9595 items /m$^3$ in average) and 400-2200 items /kg (1023 items /kg in average) in sediment samples. Since the pollution abatement measures implemented, MPs visible to eyes are generally eliminated, the detected MPs in this study are mainly μm sizes with no more than 3-5 items being mm size for each collected sample. The main forms of MPs are fibrous and fragmented with components mainly being polyamide (PA), polyethylene (PE) and polypropylene (PP). MPs in the water at the garbage transfer station can be ranked as surface water < middle water < bottom water and the sediment contained obviously higher MP fragments indicating the history transferring of garbage can be a main cause of plastic deposition in this place. The content of fibrous MPs in surface water was high, and the fragments were found increasing with the depth of water. The southern area contained less MPs compared with the middle and north part of Baiyangdian lake due to the less human activities. The main sources of MPs in this area are the earlier residents' activities, the running of local plastic factories and the effluent from sewage treatment plant.

1 Introduction

Microplastics (MPs) was first proposed as a new persistent pollutant in marine water and sediments in 2004 and soon attracted widespread attention. MPs are plastic particles and debris with the diameter less than 5 mm (Thompson et al., 2004). According to the global statistics, approximately 300 million tons of plastic materials were produced every year, and it is growing at a rate of 20 million tons annually (Matsuguma et al., 2017; Zhang et al., 2020). MPs main include polyamide fiber (PA), polypropylene (PP), polyethylene (PE), Polyester fiber (PET) etc (Thompson et al., 2004). The shape of MPs is divided into fragments, films, fibrous, granular and foaming. Han (2018) vividly describes MPs as "PM 2.5" in the ocean. MPs from land is proved to be an important source of MPs in the ocean, accounting 80% of plastics in the oceans (Bakir et al., 2012). MPs are widely distributed in environment 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 its small size, MPs are easy (Heim and Nemeroff, 2001) to be ingested by aquatic organisms and not easy to be digested by organisms, which may cause damage to growth and development and even death (Yang and Huang, 2019). At the Second Joint Environment Conference in 2016, it was proposed that MPs have been listed as the second largest scientific problem in the field of environmental and ecological science research and become one of the major global problems (Xia et al., 2019).

Lakes are relatively closed bodies of water. Unlike rivers serving as the main transport route, lakes are more like "oceans" in inland waters and act as sinks of pollutants. MPs can accumulate in lakes, and could have a more direct impact on freshwater organisms, terrestrial organisms and humans themselves (Xiong and Wu, 2021). Both lakes and wetlands are places where MPs accumulate and buffer (Qian et al.,
Duan et al. (2020) found that MPs were widely detected in Yellow River Delta wetland even in the protection area with little human activities and MPs ranged from 136 to 2060 items/kg in soil samples with component being PET (536 to 660 mg/kg) and PC (83.9 to 196 mg/kg). Zhou et al. (2021a) found the average MPs was (558.4±233.3) items/kg in sediment of Fuhe river in Hebei, China with the proportion of fragmentary MPs accounting for 66.1% of the total. Zhou et al. (2021b) studied MPs in the main upstream river flowing to Baiyangdian lake and found that MPs decreased with the increase of sediment depth with the highest content being 1049 ± 462 items/kg in the topmost sediment layer (0-5 cm). PE and PP were the main plastic polymer types in all sediment samples. Cordova et al. (2021) investigated MPs in mangrove sediment, Indonesia, where the average abundance of MPs was 28.09±10.28 items/kg of dry sediment. Foam form was the most dominant in all the samples and was found more abundant on the outside.

As the largest shallow lake in north China Plain, Baiyangdian lake plays an important role in maintaining the balance of ecosystem in northern China (Li et al., 2021; Zhao et al., 2021). Currently, with numerous treatment and construction measures being taken, great changes are taken place here day by day and the environment of Baiyangdian lake has been greatly improved. While the MPs especially with the µm sizes, which can act as carriers of pollutants, is still a problem restricting the development of ecological environment. In view of this situation, this study selected Baiyangdian lake as our research object and carried out experimental research aiming at clarifying the level and distribution characteristics of MPs in the water and sediment of Baiyangdian lake.

2. Materials And Methods

2.1 Study area and sample collection

Due to the multiple sources of MPs into Baiyangdian lake, the sampling area was divided into three habitats (Figure 1). Habitat 1 included the travelling area the water entrance area from Fuhe river where tailwater from sewage treatment plants was discharged; Habitat 2 was mainly villages and there used to existed plastic recycling workshops surrounding the lake area of habitat 3. Surface water, middle water, bottom water as well as the sediment samples were collected in a series of points of these three districts. 2 L of water samples were collected and filtered by a 1800-mesh filter screen (stainless steel), and MP debris on the filter screen were washed into brown glass bottles with pure water, which were brought back to the laboratory for analysis. Sediment samples were wrapped in aluminum foil, sealed and brought back to the laboratory in a self-sealing bag at 4 °C for further experiments.

2.2 Sample treatment and microplastic extraction

The water samples were purified with 50 mL 30% H₂O₂ in a digital water bath thermostatic oscillator (SHY-2A) at 60 °C for 24 h. Then the water samples were filtered by a circulating vacuum pump (SCJ-10) using a 0.45 µm filter membrane. The filter membrane was put in a petri dish and MPs were determine. Sediment samples were weighed and put in the brown glass bottle and add 80 mL saturated NaCl
solution for MPs separation. Then put the sediment sample in the ultrasonic cleaning machine at the frequency of 40 kHz, ultrasonic for 10 min. After ultrasonic, put the sediment sample in the centrifuge at 4000 r/min speed, centrifugation for 10 min. Then the mixed solution was filtered through the 1800 mesh stainless steel membrane by vacuum pump (SCJ-10), and the membrane was washed with 5 mL deionized water, and the rinsed solution was put into a 100 mL glass bottle. Repeat the process and place the second rinse mixture into the glass bottle. 15 mL 30% H₂O₂ were added for purification and passed through a 0.45 µm filter membrane. MPs on the filter membrane in the petri were determined with a biological microscope (NIKON Nanjing Nikon Jiangnan Optical Instrument Co., Ltd.) E200 MW). The size of microplastics was recorded and the morphology of the MPs was observed under the oil mirror. Finally, 100 µm~5 mm particles were analyzed by a Fourier transform infrared spectrometer (FTIR) (Thermer Fisher Science and Technology Co., Ltd Nicolet IS10) to identify the polymer type, and the scan range was from 4000 to 400 cm⁻¹. The FTIR spectra were compared with 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 covered with tin foil when the vessels were not in use. During the experiment, we avoided using plastic products to the greatest extent to avoid the interference. The filtered membrane is placed in a closed space to avoid interference from impurities in the air. Cotton lab clothes were worn when entering the lab and nitrile rubber gloves when doing experiments. The standard recycling method was adopted to ensure the reliability of the experimental data. PP and PE were added into the water sample, and three parallel samples were set. The measured recovery rate of MPs was 90%. It shows that the test process is well controlled and the test data is reliable. Before sample treatment, the digestion solution and ultrapure water were pumped and filtered. Microscopic examination showed that no MP particles were found, which proved that there was no MPs pollution in the laboratory.

3. Results And Discussion

3.1 Levels of MPs

The abundance of MPs in the water of Baiyangdian lake ranged from 1000 to 20000 items /m³ with an average of 9595 items /m³. In sediment samples, MPs ranged from 400 to 2200 items /kg with an average of 1023 items /kg. The highest abundance was found in Quantou Village which may due to the dense population and poor waste management, and the residents’ fishing behaviors such as using foam, wasted plastic bottles as a floating material (Kumar et al., 2021). MPs in the surface water of Fuhe before entering into Baiyangdian lake was relatively high which indicated the upstream tail water of Baoding sewage treatment plants and the domestic sewage of the residents along the river still an important MPs input source of Baiyangdian(Zhou et al., 2021a; Zhou et al., 2021b). As shown in figure 2, the color of MPs is transparent, blue, purple(mostly). The MPs were mainly fibrous (66.85%) followed by fragments 30.0% and the thin film (3.13%) in the water and fibrous (59.0%), fragmentary (37.0%) and film (4.0%) in
sediments (Figure 3). This was consistent with the high content of fragmented and fibrous MPs in domestic wastes and wastewater (Jiang et al., 2019). In addition, the fertilizer woven bags used in agriculture are prone to aging and can break down to form fibrous MPs (Zhou et al., 2021a). Most of the fragmented plastics are small fragments of plastic products cracked under natural conditions, so the fragmented MPs are mainly secondary MPs (Zhang et al., 2015). The film MPs mostly come from discarded plastic bags and agricultural land membrane. The components of MPs were determined by Fourier transform infrared spectroscopy. As can be seen in Figure 4, the spectrogram for MPs in collected samples (fibrous and fragmented) were compared with the standard PA and PP spectrograms. Combining with the elemental analysis results: fibrous samples consist of 65% C, 12% H, 10% N and 13% O and the fragment samples consist of 88% C, 12% H, which is consistent with the element compositions of PA and PP. Thus, the component of fibrous and fragmented MPs from the collected samples can be inferred as PA and PP.

Compared with earlier studies, the MPs in the sediment of Fuhe river (400 items /kg) in this study are relatively lower than the earlier average results (558.4 items /kg) with similar component (PE, PP) and shape (fragment, fiber, film and pellet) (Zhou et al., 2021b). The tiny discrepancy in MPs abundance and shape may come from the variations of sampling locations and extraction methods. Compared with the data from Poyang Lake: 16.2-710 items /m³ in water and 112-334 items /kg in sediment, the abundance of MPs in Baiyangdian lake is obviously higher with similar component (PE, PP) and shapes (particles, fragments, fibers, films) (Liu et al., 2019; Yuan et al., 2019). The higher abundance of MPs in Baiyangdian was due to the multiple input of MPs including the surrounding plastic recycling workshop, the tail water of the sewage treatment plant, fishing behaviors and poor waste management practices. Compared with lakes and rivers in foreign countries, MPs in Baiyangdian Lake was at a high level such as Iran (0.40~4.41 items /m³ and 140~2820 items /kg) (Rasta et al., 2020), African (mean of 705 items /m³ and 116.8 items /kg) (Dahms et al., 2020), Portugal (71–1265 items /m³ and 100–629 items /kg) (Rodrigues et al., 2018), Korea (293-4760 items /m³ and 1970 items /kg) (Eo et al., 2019).

### 3.2 Vertical distribution of MPs

Different form and component of MPs showed different vertical distribution in the surface, middle and bottom water of Baiyangdian Lake. The fibrous MPs in the surface water were higher and with the depth of water, the fragmentary MPs increased. The fibrous MPs are lighter and easy to suspend on the surface which are mainly nylon and polyester. And the fragmentary MPs may be PP and PE, although the density of PP and PE is lower than that of river water, the density of MP may increase due to the attachment and accumulation of organic matter, impurities and biology in the surface of MPs, then they are more likely to settle in the sediments (Wang et al., 2018). As can be seen in Figure 5, the vertical distribution of MPs in Zaozhadian of habitat 1 was affected with the human activities and the water turbulence under wind and temperature. MPs increased with the depth of water in the point with resident living (Zaozhadian-V) while the less disturbed area (Zaozhadian-N) showed a higher abundance of MPs in surface water where the MPs may come from the living areas along with the water turbulence. MPs in the bottom water and sediment of the two points collected from Zaozhadian were at a comparable level. The entrance point of
Baiyangdian Lake linked with Fuhe river showed the highest MPs abundance (surface water, middle water, bottom water) indicating continuous input of MPs in this area. In the area with denser human activities including Quantou, Guangdian, Dizhuang and the traveling area of the Lotus Garden, the MPs tend to be higher in surface and middle water which may influenced by the local residents’ living habits (poor waste management and nearby fishing cages and nets). There existed a plastic floating area between Guandian and Quantou and the MPs are both found with higher abundance in surface, middle and bottom water collected in Dec. 13th, 2020. The floating plastics are daily items including bags, bottles, foams and etc. which may cause a secondary MPs source of this area. The MPs at the garbage station (abandoned) showed a higher MPs in middle and bottom water which may come from the earlier transfer and disposal of wastes. The MPs in the areas with lower MPs abundance in Beitianzhuang, which may be due to the less disturbance in the lake, and easy settlement of MPs, resulting in stratification. It can be seen that the vertical distribution of MPs in water is related to the morphology of MPs, hydrological and geographical conditions, and the activities of surrounding residents (Zhou et al., 2021b).

### 3.3 Horizontal distribution of MPs

MPs was highest at the entrance point from Fuhe and tourism area in the Lotus Garden in habitat 1. The water of this area was found containing higher TN, TP and heavy metals according to earlier studies (Ma et al., 2020; Zhao et al., 2020). Water from the sewage treatment plants are proved to be an important source of MPs (Carr et al., 2016), and the Baoding sewage treatment plant in the upstream of Fuhe River was the main source of MPs at the entrance point and spreading to other area of the lake through water turbulence. Besides the tail water, tourists’ activities and cruise ships, as well as plastic waste generated by tourists can all lead to higher accumulation MPs at the Lotus Garden (Shan, 2021). In habitat 2 where villages are distributed, the abundance of MPs of this area was generally high. The plastic wastes generated by residents partly flowed into the lake due to the poor management of wasted transfer and disposal. It indicated that the abundance of MPs in Baiyangdian District is closely related to the intensity of human activities (Shan, 2021; Zhou et al., 2021a; Zhou et al., 2021b). In habitat 3, MPs was found higher in Dizhuang, Caiputai where the population density was relatively large. The domestic waste generated by residents and the industrial wastewater discharged by surrounding factories caused the high abundance of MPs in Dizhuang and Caiputai, which was consistent with the earlier results that MPs is higher in the areas with denser population and more intense human activities (Cordova et al., 2019; Peng et al., 2018). While for the area with less human and factories (S6, S9), the MPs were relatively low. In addition, there are abundant emergent plants such as lotus in the north of Baiyangdian District, where there are few villages, little human interference and relatively good water quality also showed a lower MPs abundance (Wang et al., 2020). The horizontal distribution of MPs is shown in Figure 6.

### 4. Conclusions
MPs are commonly found in water (9595 items /m$^3$) and sediment (1023 items /kg) of Baiyangdian lake with components mainly being PA and PP. The vertical distribution of MPs in the water was affected by the hydraulic condition at different areas and the size, component of the MPs. The earlier fishing behaviors and poor waste management is the main source of MPs in the lake and the discharge of tail water from Fuhe and the surrounding recycling workshops has also intensified the levels of MPs in the water and sediment. MPs with larger sizes (mm) were generally eliminated along with the currently implemented water quality improvement measures, while the left large amounts of MPs with µm sizes is still an existing problem cannot be ignored. The natural degradation and the carrier effects of left MPs in the lake should also be attentioned in the future.

**Declarations**

Data availability

Data is available upon request.

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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 have a role in data analysis interpretation. Sample treatment was
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Ethics declarations

Not applicable

Declaration of competing interest

The authors declare no competing interests.

Consent for publication

Not applicable

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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

Shape proportions of MPs
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

Distribution of microplastics in Baiyangdian Lake (unit: items/m³ water, items/kg sediment)