



# Occurrence and risk assessment of microplastics in the Lhasa River—a remote plateau river on the Qinghai-Tibet Plateau, China

Amei Zhou · Yuhong Zhao · Minxia Liu ·  
Bongkotrat Suyamud · Wenke Yuan · Yuyi Yang

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**Abstract** Microplastics (MPs) are ubiquitous in the aquatic environment and have received widespread attention worldwide as emerging pollutants. Urbanization and anthropogenic activities are the main sources of MPs in rivers; however, the MPs in plateau rivers with less human activities are not well understood. In this study, the pollution of MPs in the surface water and shore sediment of the Lhasa River from the Qinghai-Tibet Plateau was investigated, and

a risk assessment was conducted. The abundance of MPs in the surface water and shore sediment of Lhasa River were 0.63 n/L and 0.37 n/g, respectively. MPs in surface water were mainly dominated by films (43.23%) and fibers (31.12%) in shape, transparent (54.25%) in color, and 0–0.5 mm (75.83%) in size, while MPs in the shore sediment were mainly fibers (43.69%) and fragments (36.53%), transparent (71.91%), and 0–0.5 mm (60.18%). PP and PE were the predominant polymer types, accounting for 44.55% and 30.79% respectively in the surface water and 32.51% and 36.01% respectively in the shore sediment. More notably, the polymer pollution index (*H*) of MPs in the Lhasa River was at hazard level III due to the high risk caused by PVC, but the pollution

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Amei Zhou and Yuhong Zhao make equal contributions to this manuscript.

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A. Zhou · Y. Yang  
Research Center for Ecology and Environment  
of Qinghai-Tibetan Plateau, Tibet University,  
Lhasa 850000, China

A. Zhou · Y. Yang  
College of Science, Tibet University, Lhasa 850000, China

A. Zhou · B. Suyamud · W. Yuan (✉) · Y. Yang  
Key Laboratory of Aquatic Botany and Watershed  
Ecology, Wuhan Botanical Garden, Chinese Academy  
of Sciences, Lumo Road No.1, Wuchang District,  
Wuhan 430074, China  
e-mail: yuanwenke@wbgcas.cn

Y. Zhao  
Tibet Agricultural and Animal Husbandry University,  
Nyingchi 860000, China

M. Liu  
College of Forestry, Shanxi Agricultural University,  
Taigu County 030801, China

B. Suyamud  
Department of Environmental Engineering,  
Faculty of Engineering, Chulalongkorn University,  
Bangkok 10330, Thailand

W. Yuan · Y. Yang  
University of Chinese Academy of Sciences,  
Beijing 100049, China

W. Yuan · Y. Yang  
Danjiangkou Wetland Ecosystem Field Scientific  
Observation and Research Station, the Chinese Academy  
of Sciences & Hubei Province, Wuhan 430074, China

load index (*PLI*) was low at hazard level I. This study reveals that the remote river in the Qinghai-Tibet Plateau are polluted by MPs, and their potential risks to the vulnerable ecosystem deserve attention.

**Keywords** Microplastic pollution · Plateau river · Freshwater environment · Risk assessment

## Introduction

Due to their low cost and chemical stability, plastics are widely used in our daily lives (Andrady, 2011). Since being put into mass production in the 1950s, the global production of plastics has been on an exponential growth trend, rising to 367 million tons by 2020 (PlasticsEurope, 2021). Unfortunately, plastics can persist in the environment for hundreds to thousands of years due to their durability and resistance to degradation (Barnes et al., 2009). These plastics are cracked under the action of ultraviolet radiation and external mechanical force to form MPs, which accumulate, migrate, and diffuse in the environment (Thompson et al., 2004; Ziccardi et al., 2016). MPs are plastic particles with a particle size of less than 5 mm (Arthur et al., 2009). As emerging environmental pollutants, MPs are widely spread worldwide, posing great potential risks to biota in the environment and human health (Lagarde et al., 2016; Miloloža et al., 2021). MPs are widely found in the global water environment, such as lakes (Yu et al., 2019), rivers (Wang et al., 2020), estuaries (Zhao et al., 2015), and oceans (Cincinelli et al., 2021). Under the action of ocean currents and wind, plastic waste can be transported long distances to remote or unpolluted areas, including polar regions (Waller et al., 2017), deep-sea areas (Van Cauwenberghe et al., 2013), and plateau regions (Jiang et al., 2019).

Rivers are important pools for MPs discharged from the urban and rural areas. In a recent study, big cities (e.g., Wuhan and Shanghai) along the Yangtze River were found to be the critical places for MPs management (Yuan et al., 2022). The abundance of MPs in rivers was detected with a wide variation, presenting several orders of magnitude differences (Kumar et al., 2021; Wang et al., 2021c). For example, MPs in water from Snake River were detected with a low abundance from 0 to 0.014 n/L (Kapp & Yeatman, 2018), while a high abundance of MPs could be found in Pearl River

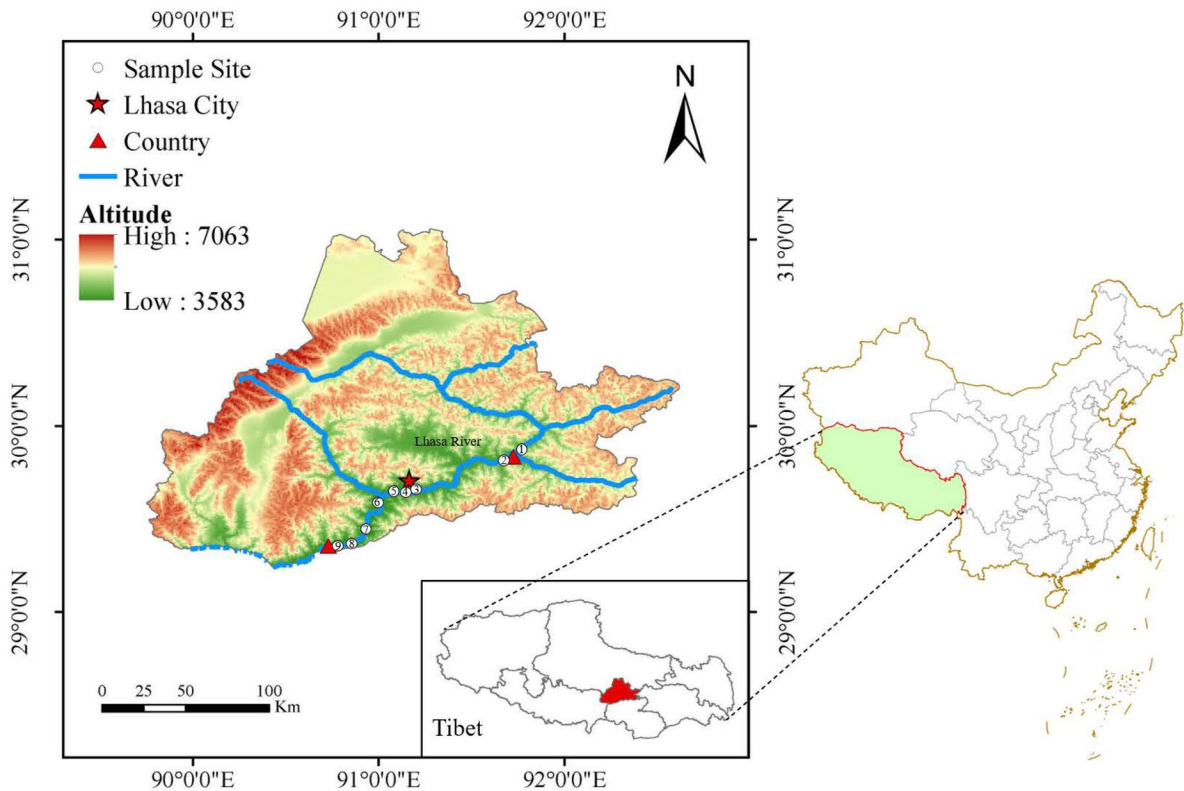
(19.8 n/L) (Yan et al., 2019). Polypropylene (PP) and polyethylene (PE) were the main polymers of MPs in the Beiji River, accounting for 52.3% and 27.4% (Tan et al., 2019). PP, PE, and polyamide (PA) were the three main polymer types found in the Brisbane River sediments (He et al., 2020). Water and sediment also displayed different characteristics of MP pollution in rivers. In the German river Elbe, a higher MP abundance and diversity were found in sediments compared to the water (Scherer et al., 2020). In the Yangtze River, sediments also showed higher abundance, diversity, and more small-sized fractions of MPs than water (Yuan et al., 2022). Therefore, the MP pollution in riverine systems depends on the compartments, pollution sources, and human activities.

In Qinghai-Tibet Rivers, the abundance of MPs was detected with a wide variation (0.25–2.69 n/L) (Liu et al., 2021). The MP pollution in Brahmaputra River, Tongtian River, Lancang River, and Nujiang River from Qinghai-Tibet Plateau has been studied (Jiang et al., 2019). Lhasa River Basin only accounts for 2.7% of the total area of the Tibet Autonomous Region, while the population and arable land in the basin account for about 15% of the entire Autonomous Region. It is an area where Tibetan industry, agriculture, and animal husbandry are concentrated. However, the occurrence and risk of MPs in the surface water and shore sediment of Lhasa River have not been well understood. Hence, the Lhasa River basin was selected as a research object to analyze the pollution characteristics and potential risks of MPs. The results of this study will enrich the data on MP pollution in plateau rivers and provide a reference basis for further studies.

## Methods and materials

### Sampling sites

The Lhasa River basin, the longest of the Yarlung Tsangpo tributaries, drains an area of 32,471 km<sup>2</sup>. The river flows through the south of the Tibet Autonomous Region of China, with a length of about 450 km. In September 2019, surface water and shore sediment samples were collected from nine sites in the Lhasa River (Fig. 1). Sites 1 and 2 are located in Maizhokunggar County, with an average altitude of over 4000 m. Livestock and mining are the main



**Fig. 1** Geographical location of sampling sites for surface water and shore sediment in the Lhasa River

human activities in this region. Sites 3–6 are along the reaches of Lhasa City. Sites 3 and 4 are in the old part of the city, while sites 5 and 6 are in the development zone with a high degree of economic activities and a dense population. Sites 7–9 are located along the reaches of Qushui County, a key grain-producing area. A total of 50 L of surface water was collected at each sampling site using buckets and filtered through a 45  $\mu\text{m}$  stainless steel screen. After filtration, the residue in the sieve was rinsed with filtered water (0.45  $\mu\text{m}$ ) into sample bottles for cryopreservation for further analysis. The shore sediment (0–5 cm) was sampled at each sampling site using a stainless steel shovel; three replicates were collected and each sample was spaced 5 m apart at the same sampling site, after which the three replicates were mixed into one sample in order to obtain a homogenized composite sample, which they were transferred to stainless steel containers and cryopreserved.

### Separation of MPs

In the laboratory, all surface water samples were spiked with 30%  $\text{H}_2\text{O}_2$  in conical flasks to ablate the organic matter, according to our previous study (Yuan et al., 2022). The samples were then filtered onto 0.45  $\mu\text{m}$  filter membranes (GF/F, 47 mm  $\varnothing$ , Whatman) using a vacuum pump and placed in clean dishes awaiting microscopic observation. The shore sediment samples were dried in an oven at 70  $^\circ\text{C}$  until constant weight. A 50 g dry weight sample was also weighed and 30%  $\text{H}_2\text{O}_2$  was also added to the sample and placed in a 50  $^\circ\text{C}$  oven for 48 h to dissipate the organic matter, after which 30 mL saturated NaCl solution (density 1.2  $\text{g}/\text{cm}^3$ ) was added, and the supernatant was transferred to a new conical flask and repeated twice until the supernatant was completely transferred. Then, the rest of the procedure was similar to the aqueous sample.

## Microscopic imaging and Raman analysis

All samples were observed under a motorized body microscope imaging system (SMZ25, Japan), and all images of MPs were also taken by the camera in the microscope. Suspected particles were identified according to their morphology, and the shape, color and particle size of the MPs were recorded. MP shapes were classified as fragment, film, foam, pellet, and fiber. The colors are categorized into transparent, blue, red, green, yellow, and black. The particle sizes were grouped as <1 mm, 1–2 mm, 2–3 mm, 3–4 mm, and 4–5 mm. Fiber particles exceeding 5 mm were not recorded in the MPs during the testing process. Afterwards, suspected particles were selected, washed with alcohol, and then re-filtered through a vacuum pump onto a new 0.45 µm filter membrane and placed on a laser confocal Raman spectrometer (DXR2, Thermo, USA) for validation. All spectra were compared with a database to verify the polymer type of individual particles.

## Quality control measures

To avoid contamination of samples, masks, nitrile gloves, and lab coats were worn throughout the experiments. All liquids to be used in the experiments were filtered through a vacuum pump under a 0.45 µm filter membrane before use, and if not used, all containers were covered with aluminum foil. An additional blank group was conducted and demonstrated that the estimated background contamination could be neglected.

## Risk assessment

This study estimated the possible risk of MPs in surface water and shore sediment samples from the Lhasa River according to previous studies (Lithner et al., 2011; Pan et al., 2021; Xu et al., 2018). The chemical toxicity of MP polymers is used as an important indicator to assess their ecological hazard based on the type of polymer and its hazard score (Lithner et al., 2011; Xu et al., 2018). The following equation was used.

$$H = \sum P_n \times S_n \quad (1)$$

$H$  is the polymer risk index caused by MPs,  $P_n$  is the percentage of MP polymer types collected at each sampling site, and  $S_n$  is the MP polymer hazard score (Supplementary materials Table S1).

The pollution load index ( $PLI$ ) was also used to assess the ecological risk of MP concentration load (Tomlinson et al., 1980).  $PLI$  is usually used to assess the level of pollution in an estuary and could be considered a standardized rule to monitor the pollution level between different areas (Angulo, 1996). The formula used is as follows.

$$CF_i = C_i / C_{oi} \quad (2)$$

$$PLI = \sqrt{CF_i} \quad (3)$$

$$PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \dots \times PLI_n} \quad (4)$$

where the MP concentration factor ( $CF_i$ ) is the quotient of the microplastic abundance ( $C_i$ ) at each site with the minimum MP concentration ( $C_{oi}$ ).  $C_{oi}$  is a defined value and in this study the lowest concentrations of 0.17 n/L and 0.20 n/g were used to represent (Isobe et al., 2014; Wang et al., 2021b; Xu et al., 2018). The  $PLI$  of the Lhasa River ( $PLI_{zone}$ ) is obtained from the  $n$ -root of the  $n$ - $PLI$  obtained from all stations. Risk level criteria for MP pollution were shown in Supplementary materials Table S2.

## Statistical analysis

The abundance of MPs in surface water and shore sediment was expressed in n/L and n/g (dry weight, dw), respectively. Figures were made using Origin 2021b. Pearson correlation analysis was used to analyze the correlation between MPs by Rstudio. Maps of the sampling locations were generated using ArcGIS based on GPS coordinates.

## Results

### Abundance of MPs in the Lhasa River

Contamination was prevented during sample processing, and the blank control values were negligibly low. MPs were ubiquitous in all samples from the Lhasa

River. The mean abundance of MPs in surface water was 0.63 n/L with a range of 0.17–1.30 n/L. In shore sediment, the mean abundance of MPs was 0.37 n/g with a range of 0.20–0.57 n/g (Fig. 2). There was no significant Pearson correlation between the abundance of surface water and shore sediment ( $p > 0.05$ ). This result indicated that the abundance of MPs in surface water and shore sediment was not consistent, probably because of the lagged change of MPs in shore sediment. To better analyze the distribution of MPs, the sampling sites were divided into three parts: Maizhokunggar County (1–2), Lhasa City (3–6), and Qushui County (7–9). The mean abundance of MPs in surface water was higher in Qushui County (0.96 n/L) than in Maizhokunggar County (0.26 n/L) and Lhasa City (0.56 n/L). In addition, the higher MP abundance at site 3, located in the old city of Lhasa, was mainly due to the higher intensity of human activities. Site 8 and 9 in Qushui County also exhibited a high abundance of MPs because of the use of mulch in the surrounding grain-producing area and a cultivation industry.

### Morphology of MPs in the Lhasa River

#### Shape

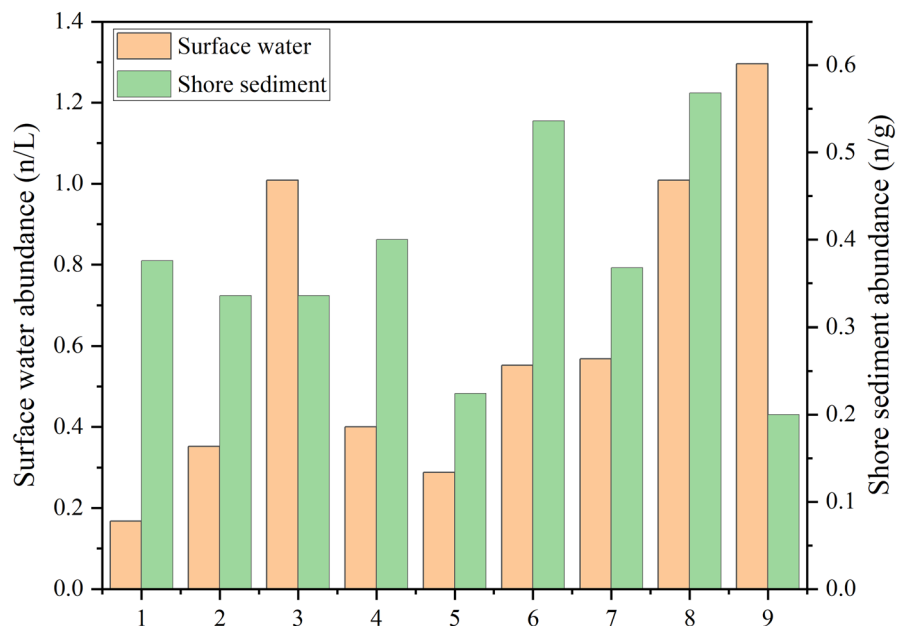
The typical shapes of MPs in the surface water and shore sediment from the Lhasa River were obtained

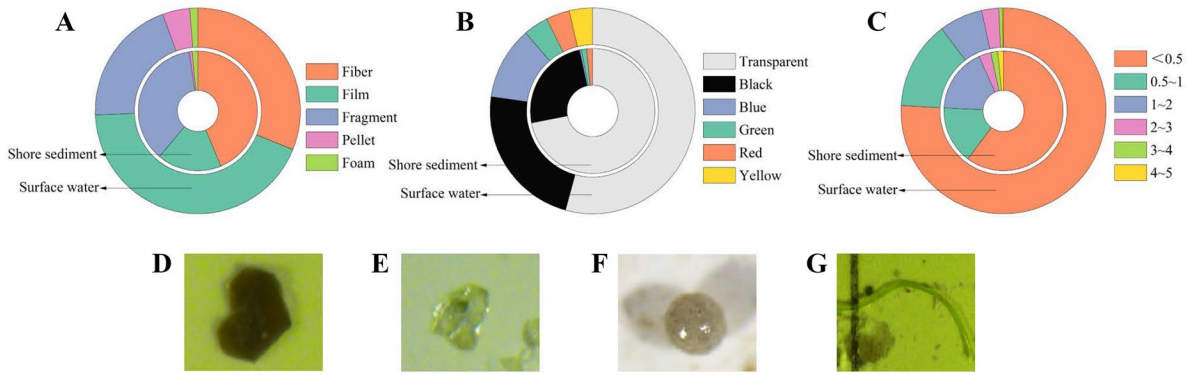
from the camera in the microscope imaging system (Fig. 3), including fragments, film, pellet, and fiber. Figure 3A shows the percentage of different shapes for MPs in surface water and shore sediment at each sampling site. Thin films and fibers were the dominant shapes in surface water with 43.23% and 31.12%, respectively. In comparison, the main shapes in the shore sediment were fibers and fragments with 43.69% and 36.53%, respectively. The film content was relatively low at 17.46%, less than surface water. Pellets (4.3% and 1.28%) and foams (1.53% and 0.79%) were also found in surface water and shore sediment.

#### Color and size

Transparent was the dominant color in all sampling sites, accounting for 54.25% and 71.91% of MPs in surface water and shore sediment, respectively. Other colors in surface water such as black, blue, green, red, and yellow accounted for 22.95%, 11.5%, 3.89%, 3.72%, and 3.69%, respectively. Black, red, green, and blue in the shore sediment accounted for 24.69%, 1.56%, 1.35%, and 0.5% of MPs, respectively (Fig. 3B). For the size of MPs, <0.5 mm was the most abundant in surface water and shore sediment, accounting for 75.83% and 60.18%, respectively,

**Fig. 2** MP abundance in the surface water and shore sediment of Lhasa River





**Fig. 3** Morphological characteristics of MPs in the surface water and shore sediment of Lhasa River. **A** The percentage of MP shapes in surface water and shore sediment. **B** The per-

centage of MP colors in surface water and shore sediment. **C** The percentage of MP particle sizes (mm) in surface water and shore sediment. **D** fragment, **E** film, **F** pellet, **G** fiber

followed by 0.5–1 mm with 13.88% and 15.65%, respectively (Fig. 3C).

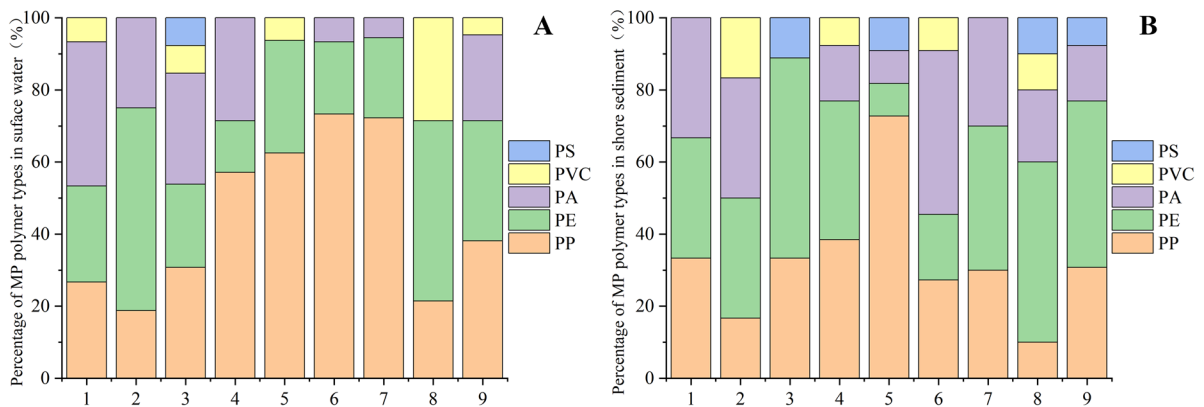
surface water samples and 22.44%, 4.83%, and 4.21% in shore sediments, respectively.

*Polymer type*

Risk assessment of MPs in the Lhasa River

The polymer type of MPs in surface water and shore sediment from the Lhasa River was identified by Raman spectroscopy (Fig. 4A and B). And the Raman spectra of typical MPs were shown in Fig. S1. PP and PE were the most common MPs types in all samples. PP and PE accounted for 44.55% and 30.79% of surface water samples, respectively. In shore sediment, PP and PE accounted for 32.51% and 36.01%, respectively. Other polymeric types of MPs included PA, PVC, and PS with 17.82%, 5.99%, and 0.85% in

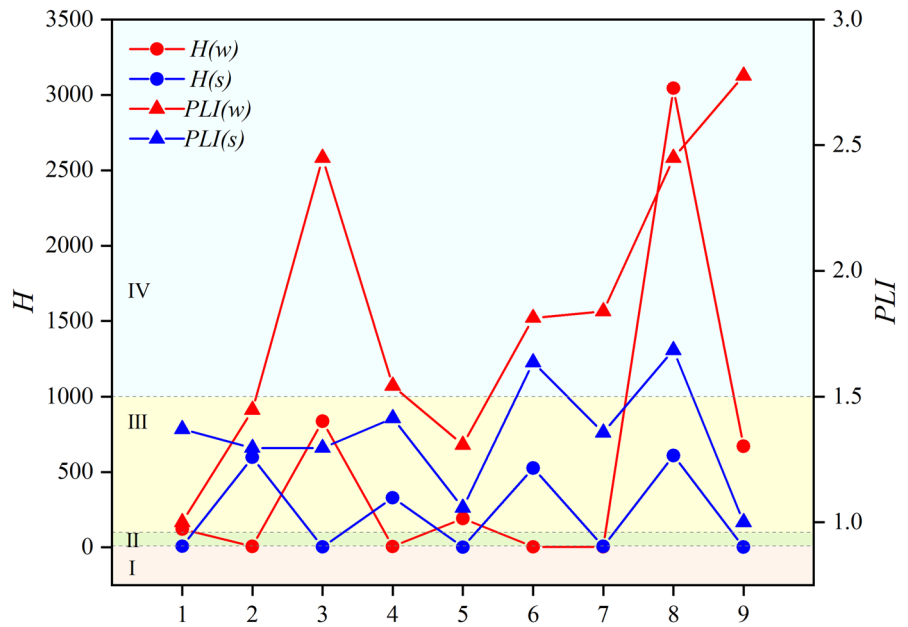
Based on the polymer risk index (*H*) and the pollutant load index (*PLI*), this study presents a preliminary assessment of the ecological danger posed by MPs (Supplementary materials Table S3; Fig. 5). The risk index of *H* in surface water and shore sediment was mostly at hazard level I or III. However, at site 8 of surface water, the risk reached hazard level IV due to the high percentage of PVC with a high risk level in the surface water at this site. The *PLI* value at all sampling sites was less than 10, and the risk belonged



**Fig. 4** Polymer types of MPs in the surface water and shore sediment of Lhasa River. **A** Percentage of MP polymer types in the surface water. **B** Percentage of MP polymer types in the shore sediment



**Fig. 5** Risk and pollution loading indices of MPs pollution. *H*: the polymer risk index. *PLI*: the pollution load index. *w*: the surface water samples. *s*: the shore sediment samples



to hazard level I. Overall, the values of *H* and *PLI* in the surface water of the Lhasa River were 542.82 and 1.76, respectively, with hazard levels III and I, respectively. In the shore sediment, the values of *H* and *PLI* were 231.74 and 1.33, respectively, and the hazard levels were III and I, respectively.

**Discussion**

Comparison of MPs abundance in different rivers

The MPs in the Lhasa River, covering the most area of intensive human activities in Tibet, were investigated in this study, which is a strong supplement for MP pollution in remote plateau rivers. MPs were ubiquitous in all samples from the Lhasa River. The MP abundance in different rivers was significant and detected with a wide variation (Supplementary materials Tables S4 and S5), which may be due to the geographic conditions, human activities, hydrodynamic conditions, sampling methods, and so on (Fan et al., 2022; Gray et al., 2018; Prata et al., 2019). In surface water, the MPs abundance of Lhasa River was 0.17–1.30 n/L, which was 3–4 orders of magnitude lower than that of the lower Yellow River mouth (Han et al., 2020) sampled by the same method and at a relatively low level compared to other rivers, such

as Wei River (Ding et al., 2019), Chishui River (Li et al., 2021), and Xijiang River (Mai et al., 2021). In shore sediments, the abundance of MPs in the Lhasa River ranged from 0.20–0.57 n/g, also at a relatively low level of contamination compared to Shahe River (Zhang et al., 2022), Wujiang River (Wu et al., 2022), and West River (Huang et al., 2021). Although most areas of intensive human activities in Tibet are in the Lhasa River basin, the intensity of human activities in the studied area is still obviously lower than those in Eastern and Central China. Urbanization and human activities were the main factors influencing MP pollution (Huang et al., 2020). So, it is not surprising that the MP pollution in the surface water and shore sediment of the Lhasa River was detected at a relatively low level.

Potential sources of MPs

The polymer type and shape of MPs in the surface water and shore sediment and their surrounding environment provided important information about the sources. Sites 7–9, located in the grain-producing area, are detected with a higher proportion of films (47.91%). The MP fragment is mainly from the breakage of plastic products. Therefore, the mulch used in agricultural activities in this county could be an important source of MPs (Zhang et al., 2020).

Fibers are probably discharged from domestic sewage containing clothing fibers (Claessens et al., 2011). Fibers were also the main form of MPs in the Lhasa River. Pellets and foams were also found in surface water and shore sediment from the Lhasa River, which may be generated from personal care products, and packaging materials. These results indicated that daily activities (e.g., personal care products, clothing fibers, and domestic wastewater), as well as agricultural activities, were the main sources of MP pollution in the Lhasa River (Wang et al., 2021a; Zhang et al., 2020).

Differences in MP pollution between surface water and shore sediment (shape, color, and size)

The highest percentage of films in the surface water could be mainly attributed to the use of agricultural mulch. The decrease in the proportion of film in the shore sediment may be because the film is less dense and more inclined to float on the water surface. In addition, the fiber content was higher in both surface water and shore sediment at 31.12% and 43.69%, respectively. The higher fiber in the shore sediment may be related to the high fiber concentration in the surface water.

Transparency is the predominant color in the surface water and shore sediments of the Lhasa River, which may be attributed to the widespread use of transparent colors in everyday life (e.g., disposable plastics, agricultural mulch). In addition to this, most of the plastics produced in the world of application are white, and the fading of colored plastics due to environmental factors may also be potential reasons for transparent being the dominant color (Davis et al., 1983). The black color also accounted for a large portion of MPs in the samples, which may be due to the black mulch used in agricultural production processes.

MPs of small size (<0.5 mm) accounted for the largest proportion of all samples. This is consistent with the results of the Xiangjiang river (Yin et al., 2022), West River (Huang et al., 2021), and Liangfeng River (Xia et al., 2021). The high proportion of small size MPs may be due to the decomposition of large plastic particles due to environmental and anthropogenic factors. Smaller sizes tend to lead to more serious environmental pollution problems due to their larger specific surface area and stronger adsorption properties (Covernton et al., 2019).

Risk assessment of MPs

PVC is the most hazardous polymer in this study, and once it enters the environment, it can release additives such as carcinogenic monomers and plasticizers, which can have a fatal impact on the ecological environment (Green et al., 2016). The value of *PLI* was related to the abundance of MPs, which was higher when the abundance of MPs was high, unlike *H*, which may also be high due to the presence of polymers with a high-risk hazard level, despite the low abundance of MPs at the site. Compared with Dongshan Bay, the values of *PLI* in this study were lower than Dongshan Bay ( $PLI_{estuary} = 17.34$ ), while the values of *H* were significantly higher than Dongshan Bay ( $H_{estuary} = 12.94$ ) (Pan et al., 2021), which may be attributed to the presence of MPs in the high hazard class polymer in this study. Due to the lack of a systematic and standardized model, the risk assessment of MPs in this study is largely at a preliminary stage and does not provide a good and complete assessment of its true ecological risk. Therefore, a better model may be followed to assess the true risk assessment of MPs (Koelmans et al., 2022).

## Conclusion

MPs were ubiquitous in the surface water and shore sediment of the Lhasa River, with ranges from 0.17–1.30 n/L and 0.20–0.57 n/g, respectively, but the MP pollution was at a relatively low level compared to other rivers in China. Fibrous, transparent, and small-sized MPs dominated the surface water and shore sediment. PP and PE were the dominant polymer types of MPs. Domestic water discharge, domestic waste, and the use of agricultural films may be the main sources of MPs in the Lhasa River. The polymer risk index (*H*) in the surface water and shore sediment of the Lhasa River indicated MP pollution was hazard level of III. Considering the potential impact of MPs on the fragile ecosystems and specific biota in the Qinghai-Tibet Plateau, the existence of MPs in the plateau rivers needs more attention.

**Author contribution** Minxia Liu and Bongkotrat Suyamud contributed to the study conception and design. Material preparation and sample collection were performed by Yuhong Zhao and Yuyi Yang. Data analyses were performed by Amei Zhou and Wenke Yuan. The first draft of the manuscript was written



by Amei Zhou and Yuhong Zhao, and they make equal contributions to this manuscript. All authors commented on previous versions of the manuscript and approved the final manuscript.

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**Data availability** Data generated or analyzed during this study are included in the article and further details will be made available upon request.

**Declarations**

**Ethical approval and consent to participate** Not applicable.

**Consent for publication** All authors have read and agreed to the publication of the manuscript.

**Competing interests** The authors declare no competing interests.

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