Journal of Environmental Management 340 (2023) 118011

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Homogenization of microplastics in alpine rivers: Analysis of microplastic abundance and characteristics in rivers of Qilian Mountain, China

Qian Liu [a,c], Xiong Xiong [a,*], Kehuan Wang [a,c], Hui Wang [a,c], Yiqin Ling [d], Quanliang Li [b], Fengyi Xu [b], Chenxi Wu [a]

[a] State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, 430072, China
[b] Qinghai Service Guarantee Center of Qilian Mountain National Park, Xining, 810000, China
[c] University of Chinese Academy of Sciences, Beijing, 100049, China
[d] China University of Geosciences, Wuhan, 430078, China

ARTICLE INFO

Keywords:
Microplastics
Remote area
Alpine river
Qilian mountain
Qinghai-tibet plateau

ABSTRACT

Microplastics in remote areas has received increasing concern in recent years. However, studies on microplastics in alpine rivers and their affecting factors are still limited. In this study, we investigate the abundance and characteristics of microplastic in the surface water of five alpine rivers in Qilian Mountain, China. Utilizing sieve collection, digestion and density separation, along with microscopy and Raman spectroscopy analyses, microplastics were observed in all the water samples and the average abundance of microplastics was 0.48 ± 0.28 items/L, which was lower than in other freshwaters. Transparent (37.3%) and fibrous (72.1%) microplastics were predominant. Polypropylene (53.8%) was the most frequently identified polymer type. Analysis of similarities (ANOSIM) and linear discriminant analysis (LDA) based on microplastic shape, color, and polymer type showed that there was no significant difference in the microplastic characteristics among rivers of Qilian Mountain. The distance decay models revealed that the similarity in microplastics characteristics was not affected by changes in watershed characteristics, such as geographical distance, elevation, water quality, and land use. This finding suggests that the primary source of microplastics in Qilian Mountain rivers could be from dispersed origins. The results of this study indicated that despite remote alpine rivers suffering limited anthropogenic impacts, they were not immune to microplastics. However, in watersheds with lower intensity of human activity, the abundance and characteristics of microplastics in water bodies may be more uniformly distributed and controlled by diffusion conditions such as atmospheric transport or riverine transport. Our investigation unveils novel understanding of microplastic dispersion in secluded alpine territories, emphasizing the crucial need for managing atmospheric transport of microplastics within conservation areas.

1. Introduction

Every year, millions of tons of plastic are released into the environment and eventually break down into microplastics, which are particles smaller than 5 mm (Ibrahim et al., 2021). Microplastics enter the aqueous environment from other environmental media, undergo transport and vertical migration due to water flow and gravity, and can break down into smaller particles. Thus, the widespread occurrence of microplastics and their potential ecological risks have become a global concern and poses a challenge to the management of microplastic pollution (Galloway et al., 2017; Kumar et al., 2020; Sridharan et al., 2021; Talbot and Chang, 2022). Microplastics in aqueous environment can accumulate through food webs (Ivleva et al., 2017). They also serve as carriers of microorganisms, heavy metals, and organic pollutants in aquatic environments (Mughini-Gras et al., 2021; Selvam et al., 2021; Sharma et al., 2020). Microplastics and other contaminants that coexist with them can adversely affect aquatic organisms and aquatic ecosystems through physical damage and the toxic effects of chemicals (Li et al., 2020). Over the past few decades, the presence of microplastics in aquatic ecosystems, such as oceans, lakes, and rivers, has been a hot topic of research (Alimi et al., 2018; Talbot and Chang, 2022; Wong et al., 2020b). Even in some remote areas, the presence of microplastics

* Corresponding author. State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Donghu South Road #7, Wuhan, 430072, China.
E-mail address: xxiong@ihb.ac.cn (X. Xiong).

https://doi.org/10.1016/j.jenvman.2023.118011
Received 8 March 2023; Received in revised form 16 April 2023; Accepted 23 April 2023
Available online 26 April 2023

in water bodies has still been found (Dong et al., 2021; Free et al., 2014; Yang et al., 2021). Despite the sole origin of microplastics being human-related plastic usage, comprehending the factors that affect microplastic distribution and characteristics in remote environments remains crucial for the effective mitigation of microplastic pollution.

The distribution of microplastics in water bodies is influenced by both anthropogenic activities and physical watershed characteristics (Baraza et al., 2022; Talbot and Chang, 2022). Previous studies have focused on the impacts of anthropogenic factors such as land cover, wastewater treatment plants, and population density on microplastic abundances (Feng et al., 2020; Hou et al., 2021; Kataoka et al., 2019). Additionally, industrial, agricultural, tourism, and fisheries development in the watershed have been linked to the occurrence of microplastics in water bodies (Feng et al., 2021a; Mao et al., 2021; Xiong et al., 2021). Various physical watershed characteristics (e.g., elevation, slope, hydrological characteristics) of rivers, which are related to the processes of microplastic input and distribution also influence the occurrence of microplastic (Baraza et al., 2022; de Carvalho et al., 2021; Zhou et al., 2021). These factors mentioned above can well explain the characteristics of microplastics in densely populated areas. However, the distribution of microplastics in low-intensity anthropogenic areas, particularly those with minimal plastic use, is not well understood. Atmospheric transport is an important pathway for microplastics to reach remote areas from areas of intense human activity due to their light weight and durability (Bullard et al., 2021; Dong et al., 2021). However, after microplastics reach these remote areas, how environmental factors affect their distribution in water bodies still needs further study.

Previous studies have tended to focus more on the factors influencing microplastic abundance. However, the ecological risks of microplastics are also closely related to their characteristics such as particle size, shapes, and polymer types (Thornton Hampton et al., 2022). Smaller particles are more likely to trigger oxidative stress and biological damage (Ding et al., 2020). Fibers or fragments have been found to be potentially more harmful to aquatic organisms than spheres (Qiao et al., 2019). Different polymer types also caused differential effects on reproductive output in Daphnia magna (Zimmermann et al., 2020). Therefore, it is important to assess the influence of environmental factors on microplastic characteristics. Microplastics in the environment are complex particles with varying sizes, shapes, colors, and polymer types, which makes it challenging to generalize the influence of environmental factors on microplastic characteristics (Daily and Hoffman, 2020). To address this challenge, studies have adopted the concept of "microplastic communities" from ecological research (Li et al., 2021a; Yuan et al., 2022). These studies have used community ecology methods to analyze the changing patterns and influencing factors of microplastic characteristics in the environment (Yuan et al., 2022). found that found that microplastic communities in surface water had a higher migration rate than those in sediment and soil. The differences in the sources of microplastics in different environmental mediums can also be analyzed from the perspective of "microplastic communities" (Chen et al., 2022; Li et al., 2021a). (Liu et al., 2023) recently used this concept to distinguish the effects of irrigation on the distribution of microplastics in soil, water, and sediments. Thus, this approach can help us better understand the factors affecting the distribution of microplastics in remote environments.

Qinghai-Tibet Plateau (QTP), known as the "the Third Pole of the World", is characterized by hydrological development in the alpine region and is the origin of many rivers and lakes in Asia (Liu et al., 2021). (Zhang et al., 2016) first reported microplastics in inland lakes in QTP, and subsequent field studies have found that microplastics are widely distributed in surface water and sediments in QTP (Dong et al., 2021; Feng et al., 2021a, 2021b; Jiang et al., 2019a; Liu et al., 2022; Xiong et al., 2018). The concentration of microplastics in most water bodies in QTP was generally low (Feng et al., 2021b; Gong et al., 2022; Liu et al., 2022). Qilian Mountain, located at the northeastern margin of QTP, is a crucial component of China's national park system (Li et al., 2022). It serves as the source of numerous rivers in the endorheic region of northwest China (Sun et al., 2016). The complex geographical features and conservation practices in Qilian Mountain make it an ideal site to study microplastics in remote alpine rivers. This study used the concept of microplastic community to investigate the abundance and characteristics of microplastics in the rivers of Qilian Mountain to understand the occurrence and distribution of microplastics and their driving factors in the surface water of remote alpine rivers. Findings from this study will improve our understanding of microplastics in remote freshwaters and provide guidance for future monitoring and risk assessment of microplastics in areas with fragile and sensitive ecosystems.

2. Materials and methods

2.1. Study area

Located at the boundary of three major plateaus of China, Qilian Mountain (36°43′–39°36′N, 94°25′–103°46′E) spans a terrain that decreases in altitude from northwest to southeast, ranging from 2100 to 5800 m. It has a typical continental alpine climate, characterized by an average annual precipitation of 150–800 mm, mostly falling from May to September (Sun et al., 2016). With increasing altitude, the average annual temperature ranges from 6 to −5 °C (Sun et al., 2016). Rivers are widely distributed in Qilian Mountain, mainly belonging to the endorheic river system in northwest China. Most of these rivers are situated in remote nature reserves, with few areas of human settlement. The Qilian Mountain National Nature Reserve was established in 1988 and was later designated as one of the first pilot national parks in China in the 2010s.

2.2. Sample collection

Considering the limited anthropogenic sources in the survey area, we chose the wet season to investigate microplastics in the region, taking into account the potential transport of precipitation to microplastics in the water column (Wong et al., 2020a). In August 2020, surface water samples were collected from 34 sampling sites across five rivers in the Qilian Mountain. The sampling sites included six sites in the Shule River (SL1-SL6), five sites in the Tuole River (TL1-TL5), eight sites in the Heihe River (H1–H6, BB1-BB2), ten sites in the Datong River (LHS, LHX, DT1-DT6, CMY, SG), and five sites in the Shiyang River (SY1-SY5) (Fig. 1). The geographical locations of the sampling sites are presented in Table S1.

We employed a bulk sampling approach, similar to our previous study to collect water samples (Liu et al., 2022). At each sampling site, we collected 15–60 L of river surface water (up to a volume that could pass through the sieve) using a stainless-steel bucket. The collected water was screened through a stainless-steel sieve with a pore size of 30 μm in situ. The volume of surface water collected at each sampling site is presented in Table S2. Residues on the sieve were rinsed into a clean glass bottle (100 mL) using pure water. All samples were transported to the laboratory and stored at 4 °C until further analysis.

2.3. Extraction of microplastics

Microplastics from the water samples were extracted according to our previous study (Liu et al., 2022). The water samples were dried at 60 °C and then digested with 20 mL 30% H_2O_2 for 24–72 h to ensure full oxidation of organic matter. The residues obtained after digestion were subjected to density separation using a separation funnel containing zinc chloride solution ($\rho = 1.5$ g/mL) for 24 h. The particles that settled in the separation funnel were discarded, and the supernatant was filtered onto a 1.2 μm filter (Millipore S-Pak) using vacuum extraction. All filters were transferred to covered glass Petri dishes and air-dried at room temperature.

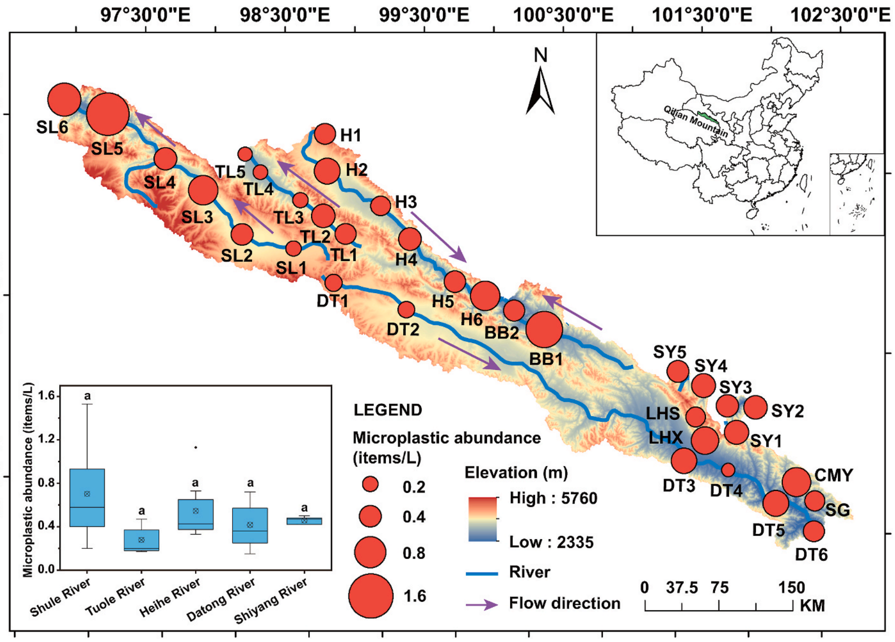

Fig. 1. Geographical location of sampling sites, abundance, and spatial distribution of microplastics in surface waters of rivers in Qilian Mountain.

2.4. Observation and identification of microplastics

Suspected microplastics on the filters were visually identified based on their shape and color (Hidalgo-Ruz et al., 2012) and photographed using a stereomicroscope (SZ61, Olympus, Japan) equipped with a digital camera (DigiRetina 16, Olympus, Japan). The morphological characteristics of the suspected microplastics were classified into different colors and three categories based on their shapes, namely fiber, fragment, and film.

The polymer type of microplastics was identified using a Renishaw inVia Raman microscope (Wotton-under-Edge, Gloucester-shire, UK) with an incident laser of 785 nm. The Raman spectrum ranged from 300 to 3200 cm^{-1}. We randomly selected 238 suspected microplastic particles (approximately 30% of the total suspected microplastic particles) from all samples for Raman analysis, of which 193 particles were identified as microplastics. The obtained Raman spectrums of particles were compared to the instrument's Renishaw Polymeric Materials Database and the Raman spectra of the self-made standard plastic polymers. As microplastics may undergo weathering to varying degrees in the natural environment, a spectrum with a matching index of >70% was considered acceptable.

2.5. Quality assurance and control

Adequate precautions were taken to avoid possible sample contamination. All sampling tools and containers were cleaned with ultrapure water before use. All liquid solutions were filtered through GF/C filter (1.2 μm pore size, Whatman) prior to use. Cotton lab coats, cotton masks, and nitrile gloves were worn during the experiment. All glassware was covered with aluminum foil. Blank controls were conducted to examine microplastic background contamination from laboratory sources. Three blank controls with distilled water were treated synchronously with water samples according to the same processes. The results showed that no microplastics were detected in 3 blank samples (ultrapure water).

2.6. Environmental factors

Land use data for Qilian Mountain region were obtained from the Globeland30 global land cover dataset with a 30-m resolution for the year 2020 (http://www.globallandcover.com, accessed on September 23, 2022). The Globeland30 dataset divides the Qilian Mountain area into ten land use types, including cropland, forest, grassland, shrub, water body, wetland, tundra, building land, bare land, and permanent ice and snow. The proportion of land cover for each sampling site within a 500-m buffer zone was calculated using ArcGIS (v.10.6). To simplify the analysis, we combined some land use types with similar characteristics, such as merging cropland and building land, categorizing shrubs as forest, classifying tundra as grassland, and grouping water bodies with wetlands, while bare land, ice and snow, and glaciers were grouped as barren land (Table S2).

In addition, various water environmental parameters were measured at each sampling site. Water velocity was measured at three random locations (two along the riverbank and one in the center) of each river sampling site using a current meter, and the average value was calculated. Water turbidity was measured using a Hach HQ40D portable multiparameter water quality analyzer (USA). Water samples were collected at each sampling site and analyzed in the laboratory for total nitrogen (TN), total phosphorus (TP), and total organic carbon (TOC) using standard methods (SEPA, 2002).

2.7. Statistical analysis

The abundance of microplastics in surface water was quantified in items/L. Spearman's correlation analysis was used to test the correlation between variables and microplastic abundance. To analyze the difference in microplastic abundance and characteristics among different groups, one-way analysis of variance (ANOVA) was conducted with a 95% confidence level. Analysis of similarities (ANOSIM) was performed to determine the statistical differences in microplastic communities based on the shape, color, and polymer types of microplastics in different groups. Linear discriminant analysis (LDA) was used to further reduce the dimensions of the data to visually observe the differences of microplastic communities between different groups. The Bray-Curtis distance was used to calculate the dissimilarity of microplastic communities between samples, and the distance-decay relationship (DDR) was established to examine the effect of increasing geographical distance, vertical altitude distance, environmental distance, and land use distance on the similarity of microplastic communities. Environmental and land use data were constructed using Euclidean distance, and several environmental variables (TN, TP, TOC, turbidity, and velocity) were selected in this process. Data analyses and plotting were performed in R (v.4.1.2) using packages vegan. Geographical locations and sampling sites were plotted with ArcGIS 10.6. Other figures were plotted using Origin 2021 and *ggplot2* in R.

3. Results

3.1. The abundance of microplastics

Microplastics were detected in all river water samples collected from the Qilian Mountain area, with an abundance range of 0.15–1.53 items/L and a mean value of 0.48 ± 0.28 (means ± SD, the same as below) items/L (Fig. 1, Table S3). The highest abundance of microplastics was observed at site SL5 in the Shule River (1.53 items/L), while the lowest abundance was found at site DT4 in the Datong River (0.15 items/L). The Shule River had the highest microplastic abundance (0.71 ± 0.48 items/L) followed by the Heihe River (0.55 ± 0.27 items/L), the Shiyang River (0.46 ± 0.04 items/L), the Datong River (0.48 ± 0.19 items/L), and the Tuole River (0.28 ± 0.13 items/L) (Fig. 1). However, there was no significant difference in microplastic abundance among the different rivers. Microplastic abundance generally increased downstream in the Shule River, Heihe River, and Datong River (Fig. 1).

3.2. Morphological characteristics and polymer types of microplastics

Fibrous microplastics were found to be the most predominant in all rivers, accounting for an average proportion of 72.1%, followed by fragments (23.4%) and films (4.6%) (Fig. 2A). Typical photographs of microplastics with different shapes under stereomicroscope were presented in Fig. S1. The detection rate of fibrous microplastic in all sites was 100%, and their abundance was significantly higher than that of other shapes of microplastics ($P < 0.05$) (Fig. S2). Transparent was the most common color for microplastics found in the rivers of Qilian Mountain (37.3%), followed by white (26.9%), black (15.6%), and yellow (10.2%). Other colors, including blue, yellow, red, green, and purple accounted for less than 10% (Fig. 2B). Polypropylene (PP) was the most frequently occurring polymer type (53.8%), followed by polyethylene (PE) (35.9%), polyethylene terephthalate (PET) (9.0%), and polyvinyl chloride (PVC) (1.4%) (Fig. 2C). Typical Raman spectra

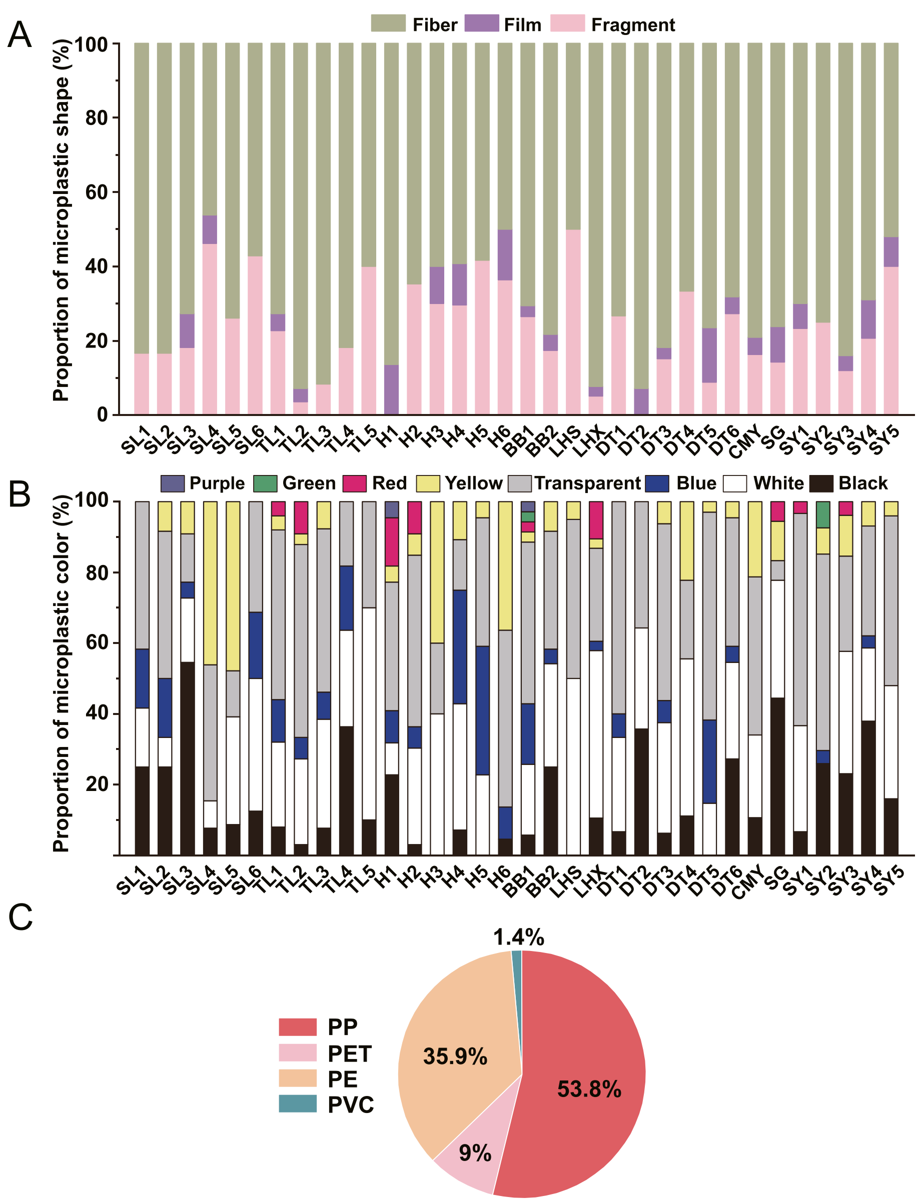

Fig. 2. The shapes (A), colors (B), and polymer types (C) of microplastics in the surface water of rivers in Qilian Mountain.

were provided in Fig. S3.

Microplastic abundance had a significant positive correlation with the concentration of TP in the water, water turbidity, and the proportion of barren land ($P < 0.05$; Fig. 3). However, microplastic abundance significantly decreased with an increase in altitude ($P < 0.05$; Fig. 3). Furthermore, the relative abundance of PE microplastics had a positive correlation with the proportion of cropland and building land ($P < 0.05$; Fig. 3).

3.3. "Microplastic communities" in rivers of Qilian Mountain

The results of ANOSIM based on microplastic characteristics indicated that the similarity of microplastic communities between rivers was not significantly greater than the similarity of microplastic communities within rivers (Fig. 4A). The microplastic community composition of different rivers was not effectively distinguished by LDA, which further indicated a high similarity of microplastic characteristics among rivers (Fig. 4B). The distance decay model indicated that the similarity of microplastic communities was not significantly influenced by geographic distance (Fig. 5A, $R^2 = 0.0003$, $P = 0.663$), altitude (Fig. 5B, $R^2 = 0.0001$, $P = 0.300$), water environment (Fig. 5C, $R^2 = 0.0017$, $P = 0.817$), and land use (Fig. 5D, $R^2 = 0.003$, $P = 0.088$).

4. Discussion

4.1. Abundance of microplastics in the rivers of Qilian Mountain

The abundance of microplastics in the rivers of Qilian Mountain was comparable to other rivers and lakes in QTP (Table 1). However, compared with other freshwater studies with a similar sampling method around the world (Table 1), the abundance of microplastics in this study was 1–3 orders of magnitude lower. The microplastic abundance was usually positively correlated with local population density (Wang et al., 2018). Qilian Mountain was located far away from areas with intensive human activities. Since the establishment of the Qilian Mountain Natural Reserve, human activities in this area have been restricted, and the population density and anthropological land use in this area have shown a declining trend (Li et al., 2022). Common pollutants such as nitrogen, phosphorus, and heavy metals were effectively controlled in the Qilian Mountain area (Wu et al., 2023). The low microplastic abundance in rivers of Qilian Mountain further suggested that conservation efforts in national parks had a positive effect on controlling microplastics. In addition to abundance, the fewer types of microplastic polymers in the rivers and the more common dominant colors also indicate a low intensity of human activities affecting plastic pollution in the Qilian Mountains region.

The lower microplastic abundance in Qilian Mountain rivers, compared to developed areas, can be attributed to lower human activity. However, within the Qilian Mountain region, no significant correlation was observed between microplastic abundance and land use types associated with human activities. Also, there was no significant spatial variation in the microplastic abundances between the rivers in Qilian Mountain. Previous studies have indicated a strong connection between microplastic abundance in water and the intensity of human activity and urbanization (Baraza et al., 2022; Barrows et al., 2018; He et al., 2020). However, the strict local regulations in the reserve effectively control human activity intensity in Qilian Mountain (Gong et al., 2022), thereby reducing differences in microplastic abundance. Additionally, atmospheric deposition of microplastics across the area may have blurred the link between local anthropogenic activities and microplastics (Kaliszewicz et al., 2020). Nevertheless, an increase in microplastic abundance from upstream to downstream was observed in most rivers, consistent with the significant negative correlation between microplastic abundance and altitude. This increase in downstream microplastics could be caused by hydrological dynamics, by which rivers transport microplastics from upstream to downstream (Baraza et al., 2022). Considering that human activities may be more concentrated in downstream areas, in remote mountainous areas, altitude may be a parameter that better reflects human activity intensity than land use.

The positive correlation between the abundance of microplastics and barren land, water turbidity, and TP suggests that the abundance of microplastics in the region may be related to some indicators related to the influence of surface runoff flushing. In alpine rivers of the Qilian Mountain area, which are mainly recharged by precipitation (Sun et al., 2016), an increase in water turbidity is generally associated with input from surface runoff carrying particulate matter (Manseau et al., 2022). Similarly, an increase in TP in unpolluted alpine rivers is generally linked to particulate phosphorus input resulting from precipitation runoff (Huang et al., 2014). It suggests that surface runoff may also be an important factor influencing the abundance of microplastics in the rivers of Qilian Mountain. The positive correlation between barren land and microplastic abundance further suggests that intra-watershed scouring could be the main source of surface microplastics in these rivers. Previous studies have demonstrated the contribution of long-range atmospheric transport to surface microplastics in alpine regions (Dong et al., 2021; Evangeliou et al., 2020), which could bring abundant microplastics to remote areas. The lack of vegetation interception on barren land, permanent snow and ice, and other surfaces could make them more likely to input microplastics (Helcoski et al., 2020).

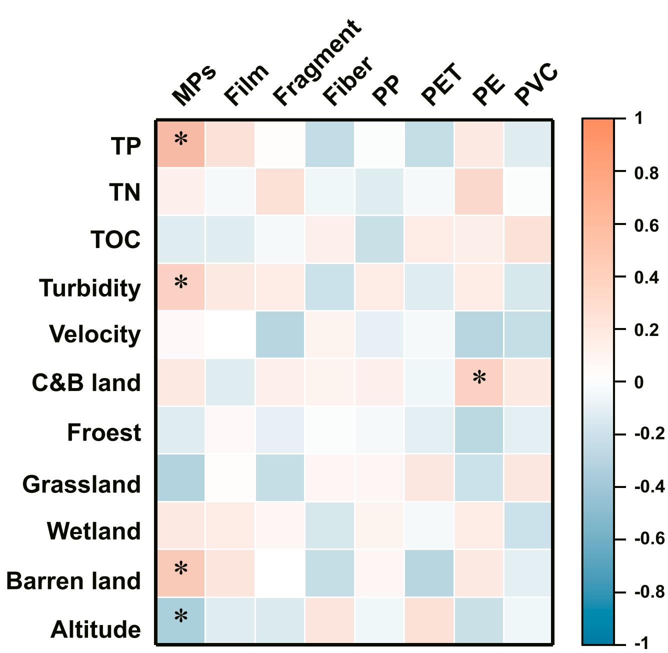

Fig. 3. Spearman's correlations of microplastic abundances (MPs), microplastic characteristics, and polymer types with water nutrient (TP, TN, and TOC), water turbidity, water velocity, land use (cropland and building land (C&B land), forest, grassland, wetland, and barren land), and altitude. *$P < 0.05$.

4.2. Factors affecting the microplastic characteristics in the rivers of Qilian Mountain

Unlike traditional pollutants, the ecological risk of microplastics is not only determined by their abundance but also by their various characteristics, including morphology, particle size, and polymer type (Kumar et al., 2021). These characteristics also influence the suspension-settlement dynamics of microplastics in rivers, which affect their distribution (Daily and Hoffman, 2020). Recent studies suggest that specific characteristics of microplastics could have stronger relationships with environmental factors than their abundance (Baraza et al., 2022; He et al., 2020). (de Carvalho et al., 2021) found the size of microplastics decreased in low hydrological conditions, and the

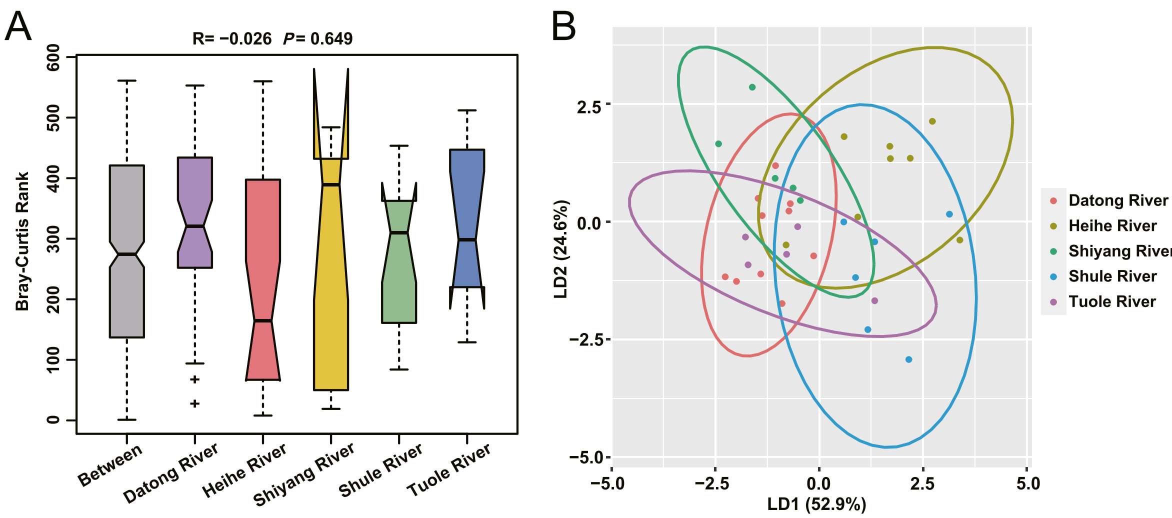

Fig. 4. Differences of microplastic communities in different rivers: (A) ANOSIM was used for variance testing, and the y-axis represents the dissimilarity ranks based on microplastic communities between and within rivers; (B) LDA was used to maximize the differences of microplastic communities.

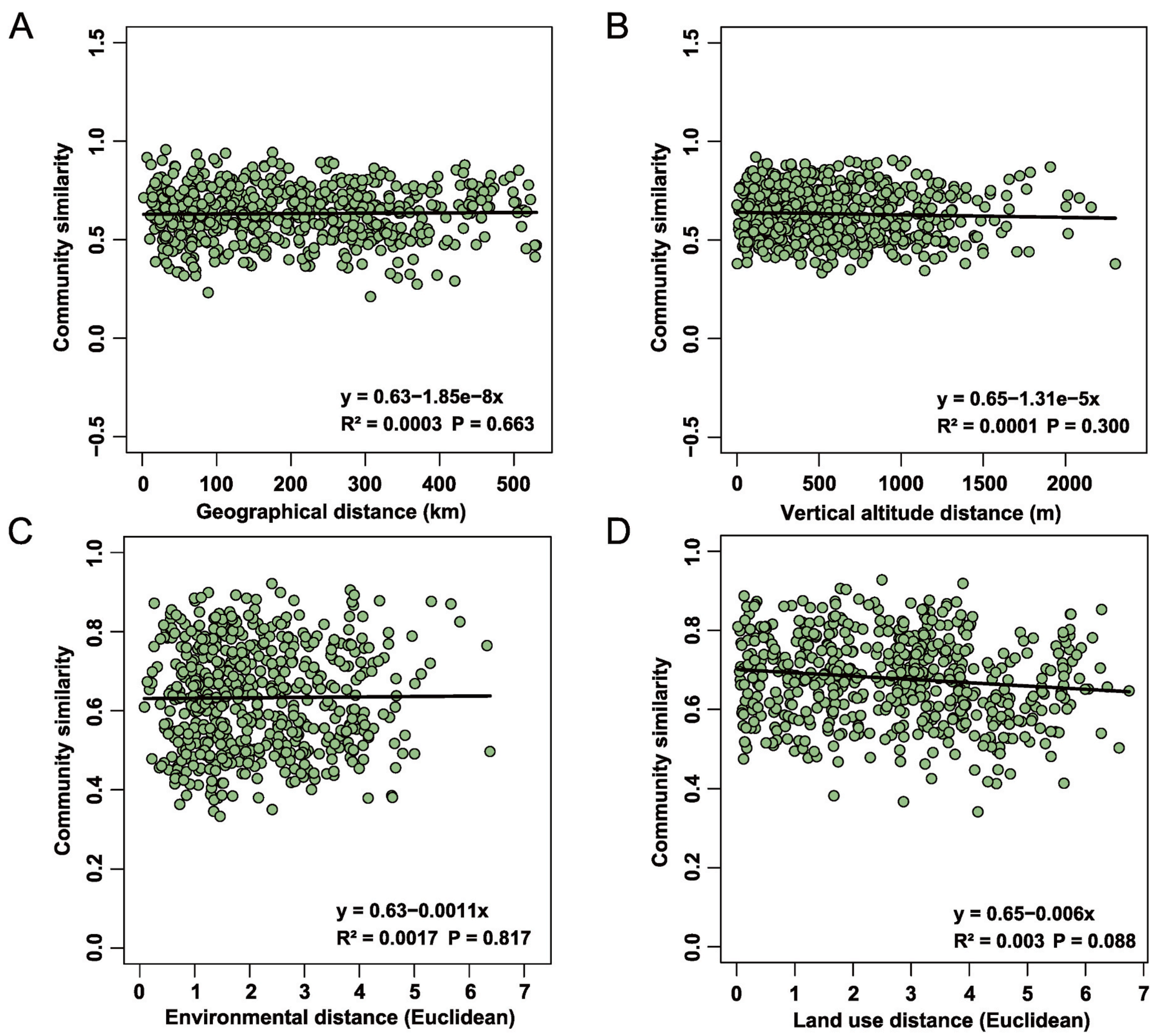

Fig. 5. Relationship between microplastic community similarity and geographical distance (A), vertical altitude distance (B), environmental distance (C), and land use distance (D).

Table 1
Abundance comparison with other freshwater systems (surface water).

Waterbody	Abundance items/L	Characterization methods	Size (mm)	Shapes	Reference
Rivers in the Qilian Mountain	0.48 ± 0.28	Raman	0.03–5	Fiber, fragment, film	This study
Changjiang Estuary	4.14 ± 2.46	FTIR	>0.07	Fiber, fragment, film	Xu et al. (2018)
Chishui River	1.77–14.33	FTIR	>0.75	Fiber, block, foam, film	Li et al. (2021b)
Dongting Lake and Hong Lake	0.9–4.65	Raman	0.05–5	Fiber, granule, film	Wang et al. (2018)
Garonne River	0.15 ± 0.46	FTIR	0.7–5	–	de Carvalho et al. (2021)
Dutch portion of the Rhine	334.67	LDIR	<0.5	–	Mughini-Gras et al. (2021)
Amsterdam canal	48–187	FTIR	0.01–5	Fiber, foil, sphere	Leslie et al. (2017)
Rivers in the Tibet plateau	0.48–0.97	Raman	0.045–5	Fiber, pellet, fragment	Jiang et al. (2019a)
Rivers in the Tibet plateau	0.67–0.73	Raman	0.02–5	Fiber, fragment, film, particle	Feng et al. (2020)
Rivers and lakes in the Tibet plateau	0.62 ± 0.41	Raman	0.02–5	Fiber, fragment, film, ball, foam	Feng et al. (2021b)

proportion of PP was significantly related to river size. However, the microplastic characteristics in the Qilian Mountain rivers did not show significant differences in either dominant species or microplastic community analysis. Given that microplastic characteristics are closely related to their sources (Li et al., 2021a), it suggests that microplastics in the rivers of Qilian Mountain could have a high homology. Combining the results of microplastic abundance analysis and fewer types of plastic polymers in the region, microplastics from non-native sources could be the main contributors to microplastics in rivers of Qilian Mountain. It could consist mainly of microplastics transported by long-range atmospheric transport to alpine regions (Evangeliou et al., 2020). A study in the Pyrenean Mountains showed that microplastics could travel from known anthropogenic sources to remote areas through atmospheric transport and deposition, and that fibers accounted for most of the microplastics from atmospheric deposition (Zhang et al., 2019). The high proportion of fibrous microplastics in rivers of Qilian Mountain also supports this speculation.

The DDR analysis revealed that the similarity of microplastic communities was not associated with geographic distance, elevation, water environment, or land use in the watershed. It is inconsistent with the significant decay of microplastic community similarity with geographic distance in previous studies (Li et al., 2021a; Yuan et al., 2022). The similarity of communities in ecology is influenced by differences in dispersal sources and dispersal capacity (Jiang et al., 2019b; Mouquet and Loreau, 2003), and similar factors may affect the similarity of microplastic communities. As discussed previously, the similarity of microplastic dispersal sources in Qilian Mountain is relatively high. Additionally, the relatively small spatial scale and turbulent hydrologic characteristics of the alpine rivers in this study limited the impact of differences in microplastic dispersal capacity on community characteristics. Due to the difference in the settling capacity of microplastics with different characteristics in water, microplastic communities in the river changed with geographical distance (Yuan et al., 2022). However, intense hydrologic variations of alpine rivers made microplastics less prone to settling or retention in sediments and more likely to be suspended in the water column (Luo et al., 2019). (Li et al., 2021a) suggested that migration and exchange of microplastics were more likely to occur at sampling points close to each other. The relatively small spatial scale of this study also promoted the possibility of microplastic dispersal between sample sites. The differences between the results of different studies highlight the importance of spatial scale in assessing the distribution of microplastic communities.

The effect of land use type on microplastics in water bodies has been found in previous studies (Baraza et al., 2022; Barrows et al., 2018). Artificial surfaces and agricultural land contributed significantly to microplastic pollution, while vegetation would have an interception effect on microplastics (Helcoski et al., 2020; Kataoka et al., 2019). Although the intensity of anthropogenic activities was low in the Qilian Mountain region, some anthropogenic-related land use types still existed. Their influence on microplastic characteristics was most directly manifested in the positive correlation with the proportion of PE. Atmospherically transported fibrous microplastics generally came to be PET fabric fibers, while PE was the more common polymer type used in plastic products for daily use and agriculture (He et al., 2020; Wurm et al., 2020; Yuan et al., 2022).

Our results exclude various factors including geographical distance, elevation, anthropogenic activities, and land use that could affect the microplastic characteristics of the rivers in Qilian Mountain. It further suggests that microplastics in Qilian Mountains rivers may come from similar dispersed sources, and atmospheric transport is certainly the most likely source. However, the distribution of microfibers from dry and wet deposition might vary under the influence of meteorological factors such as wind, rainfall, and relative humidity in different regions (Roblin et al., 2020; Tan et al., 2020). We do not yet have specific data on the atmospheric deposition of microplastics in the region to quantify the role of atmospheric transport on riverine microplastics and the factors influencing it. More event-specific sampling will be needed to trace this pattern of migration.

5. Conclusions

The results of this study indicated that although microplastics still behaved ubiquitously, strict conservation measures and low-intensity anthropogenic activities kept the abundance of microplastics in the rivers of Qilian Mountain at a relatively low level with an average abundance of 0.48 ± 0.28 items/L. There was no significant difference in microplastic abundance among the rivers. ANOSIM and LDA based on microplastic shape, color, and polymer type also showed that there was no significant difference in the microplastic characteristics among rivers. Due to homogeneity in source, hydrodynamic characteristics of alpine rivers, and relatively small spatial scales, the differences in microplastic community characteristics of the rivers in Qilian Mountain were not associated with geographic distance, elevation, water environment, or land use. It further suggested the potential impact of atmospheric transport on riverine microplastics in remote areas. Our study also suggested that the spatial location and spatial scale of watersheds played an important role in studying factors affecting the microplastic characteristics in freshwater environments. The establishment of nature reserves can greatly facilitate the limitation of local microplastic pollution caused by human activities. However, systematic investigation of atmospheric transport of microplastics is necessary to further understand its contribution to microplastics in water bodies in the remote area.

Credit author statement

Qian Liu: Writing – Methodology; Original draft preparation and Visualization. Xiong: Writing – Conceptualization; Review & editing; Project administration. Kehuan Wang: Investigation. Hui Wang: Investigation; Methodology. Yiqin Ling: Methodology. Quanliang Li: Investigation; Project administration. Fengyi Xu: Project administration. Chenxi Wu: Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

This work is supported by the Second Tibetan Plateau Scientific Expedition and Research Program (STEP, 2019QZKK0304), the State Key Laboratory of Freshwater Ecology and Biotechnology, Qinghai Provincial Forestry and Grassland Administration, and the Youth Innovation Promotion Association CAS (2021339). We would also like to appreciate the help provided by Ms. Min Wang for her help in the Raman spectroscopy analysis.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.118011.

References

Alimi, O.S., Farner Budarz, J., Hernandez, L.M., Tufenkji, N., 2018. Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport. Environ. Sci. Technol. 52 (4), 1704–1724. https://doi.org/10.1021/acs.est.7b05559.

Baraza, T., Hernandez, N.F., Sebok, J.N., Wu, C.-L., Hasenmueller, E.A., Knouft, J.H., 2022. Integrating land cover, point source pollution, and watershed hydrologic processes data to understand the distribution of microplastics in riverbed sediments. Environ. Pollut. 311, 119852 https://doi.org/10.1016/j.envpol.2022.119852.

Barrows, A.P.W., Christiansen, K.S., Bode, E.T., Hoellein, T.J., 2018. A watershed-scale, citizen science approach to quantifying microplastic concentration in a mixed land-use river. Water Res. 147, 382–392. https://doi.org/10.1016/j.watres.2018.10.013.

Bullard, J.E., Ockelford, A., O'Brien, P., McKenna Neuman, C., 2021. Preferential transport of microplastics by wind. Atmos. Environ. 245, 118038 https://doi.org/10.1016/j.atmosenv.2020.118038.

Chen, Y., Shen, Z., Li, G., Wang, K., Cai, X., Xiong, X., Wu, C., 2022. Factors affecting microplastic accumulation by wild fish: a case study in the Nandu River, South China. Sci. Total Environ. 847, 157486 https://doi.org/10.1016/j.scitotenv.2022.157486.

Daily, J., Hoffman, M.J., 2020. Modeling the three-dimensional transport and distribution of multiple microplastic polymer types in Lake Erie. Mar. Pollut. Bull. 154, 111024 https://doi.org/10.1016/j.marpolbul.2020.111024.

de Carvalho, A.R., Garcia, F., Riem-Galliano, L., Tudesque, L., Albignac, M., ter Halle, A., Cucherousset, J., 2021. Urbanization and hydrological conditions drive the spatial and temporal variability of microplastic pollution in the Garonne River. Sci. Total Environ. 769, 144479 https://doi.org/10.1016/j.scitotenv.2020.144479.

Ding, J., Huang, Y., Liu, S., Zhang, S., Zou, H., Wang, Z., Zhu, W., Geng, J., 2020. Toxicological effects of nano- and micro-polystyrene plastics on red tilapia: are larger plastic particles more harmless? J. Hazard Mater. 396, 122693 https://doi.org/10.1016/j.jhazmat.2020.122693.

Dong, H., Wang, L., Wang, X., Xu, L., Chen, M., Gong, P., Wang, C., 2021. Microplastics in a remote lake basin of the Tibetan plateau: impacts of atmospheric transport and glacial melting. Environ. Sci. Technol. 55, 12951–12960. https://doi.org/10.1021/acs.est.1c03227.

Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., Stohl, A., 2020. Atmospheric transport is a major pathway of microplastics to remote regions. Nat. Commun. 11 (1), 3381. https://doi.org/10.1038/s41467-020-17201-9.

Feng, S., Lu, H., Tian, P., Xue, Y., Lu, J., Tang, M., Feng, W., 2020. Analysis of microplastics in a remote region of the Tibetan Plateau: implications for natural environmental response to human activities. Sci. Total Environ. 739, 140087 https://doi.org/10.1016/j.scitotenv.2020.140087.

Feng, S., Lu, H., Yao, T., Liu, Y., Tian, P., Lu, J., 2021a. Microplastic footprints in the Qinghai-Tibet Plateau and their implications to the yangtze river basin. J. Hazard Mater. 407, 124776 https://doi.org/10.1016/j.jhazmat.2020.124776.

Feng, S., Lu, H., Yao, T., Xue, Y., Yin, C., Tang, M., 2021b. Spatial characteristics of microplastics in the high-altitude area on the Tibetan Plateau. J. Hazard Mater. 417, 126034 https://doi.org/10.1016/j.jhazmat.2021.126034.

Free, C.M., Jensen, O.P., Mason, S.A., Eriksen, M., Williamson, N.J., Boldgiv, B., 2014. High-levels of microplastic pollution in a large, remote, mountain lake. Mar. Pollut. Bull. 85 (1), 156–163. https://doi.org/10.1016/j.marpolbul.2014.06.001.

Galloway, T.S., Cole, M., Lewis, C., 2017. Interactions of microplastic debris throughout the marine ecosystem. Nat. Ecol. Evol. 1 (5), 116. https://doi.org/10.1038/s41559-017-0116.

Gong, W., Xing, Y., Han, L., Lu, A., Qu, H., Xu, L., 2022. Occurrence and distribution of micro- and mesoplastics in the high-latitude nature reserve, northern China. Front. Environ. Sci. Eng. 16 (9), 113. https://doi.org/10.1007/s11783-022-1534-7.

He, B., Wijesiri, B., Ayoko, G.A., Egodawatta, P., Rintoul, L., Goonetilleke, A., 2020. Influential factors on microplastics occurrence in river sediments. Sci. Total Environ. 738, 139901 https://doi.org/10.1016/j.scitotenv.2020.139901.

Helcoski, R., Yonkos, L.T., Sanchez, A., Baldwin, A.H., 2020. Wetland soil microplastics are negatively related to vegetation cover and stem density. Environ. Pollut. 256, 113391 https://doi.org/10.1016/j.envpol.2019.113391.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ. Sci. Technol. 46 (6), 3060–3075. https://doi.org/10.1021/es2031505.

Hou, L., Kumar, D., Yoo, C.G., Gitsov, I., Majumder, E.L.W., 2021. Conversion and removal strategies for microplastics in wastewater treatment plants and landfills. Chem. Eng. J. 406, 126715 https://doi.org/10.1016/j.cej.2020.126715.

Huang, T., Li, X., Rijnaarts, H., Grotenhuis, T., Ma, W., Sun, X., Xu, J., 2014. Effects of storm runoff on the thermal regime and water quality of a deep, stratified reservoir in a temperate monsoon zone, in Northwest China. Sci. Total Environ. 485–486, 820–827. https://doi.org/10.1016/j.scitotenv.2014.01.008.

Ibrahim, Y.S., Hamzah, S.R., Khalik, W.M.A.W.M., Ku Yusof, K.M.K., Anuar, S.T., 2021. Spatiotemporal microplastic occurrence study of setiu wetland, south China sea. Sci. Total Environ. 788, 147809 https://doi.org/10.1016/j.scitotenv.2021.147809.

Ivleva, N.P., Wiesheu, A.C., Niessner, R., 2017. Microplastic in aquatic ecosystems. Angew. Chem. Int. Ed. 56 (7), 1720–1739. https://doi.org/10.1002/anie.201606957.

Jiang, C., Yin, L., Li, Z., Wen, X., Luo, X., Hu, S., Yang, H., Long, Y., Deng, B., Huang, L., Liu, Y., 2019a. Microplastic pollution in the rivers of the Tibet Plateau. Environ. Pollut. 249, 91–98. https://doi.org/10.1016/j.envpol.2019.03.022.

Jiang, X., Chen, J., Xie, Z., 2019b. Different roles of elevational and local environmental factors on abundance-based beta diversity of the soil Enchytraeidae on the Changbai Mountain. Ecol. Evol. 9 (4), 2180–2188. https://doi.org/10.1002/ece3.4913.

Kaliszewicz, A., Winczek, M., Karaban, K., Kurzydłowski, D., Górska, M., Koselak, W., Romanowski, J., 2020. The contamination of inland waters by microplastic fibres under different anthropogenic pressure: preliminary study in Central Europe (Poland). Waste Manag. Res. 38 (11), 1231–1238. https://doi.org/10.1177/0734242x20938448.

Kataoka, T., Nihei, Y., Kudou, K., Hinata, H., 2019. Assessment of the sources and inflow processes of microplastics in the river environments of Japan. Environ. Pollut. 244, 958–965. https://doi.org/10.1016/j.envpol.2018.10.111.

Kumar, M., Xiong, X., He, M., Tsang, D.C.W., Gupta, J., Khan, E., Harrad, S., Hou, D., Ok, Y.S., Bolan, N.S., 2020. Microplastics as pollutants in agricultural soils. Environ. Pollut. 265 https://doi.org/10.1016/j.envpol.2020.114980.

Kumar, R., Sharma, P., Verma, A., Jha, P.K., Singh, P., Gupta, P.K., Chandra, R., Prasad, P.V.V., 2021. Effect of physical characteristics and hydrodynamic conditions on transport and deposition of microplastics in riverine ecosystem. Water 13 (19), 2710. https://doi.org/10.3390/w13192710.

Leslie, H.A., Brandsma, S.H., van Velzen, M.J.M., Vethaak, A.D., 2017. Microplastics en route: field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. Environ. Int. 101, 133–142. https://doi.org/10.1016/j.envint.2017.01.018.

Li, C., Busquets, R., Campos, L.C., 2020. Assessment of microplastics in freshwater systems: a review. Sci. Total Environ. 707 https://doi.org/10.1016/j.scitotenv.2019.135578.

Li, C., Gan, Y., Zhang, C., He, H., Fang, J., Wang, L., Wang, Y., Liu, J., 2021a. Microplastic communities" in different environments: differences, links, and role of diversity index in source analysis. Water Res. 188, 116574 https://doi.org/10.1016/j.watres.2020.116574.

Li, J., Ouyang, Z., Liu, P., Zhao, X., Wu, R., Zhang, C., Lin, C., Li, Y., Guo, X., 2021b. Distribution and characteristics of microplastics in the basin of chishui river in renhuai, China. Sci. Total Environ. 773, 145591 https://doi.org/10.1016/j.scitotenv.2021.145591.

Li, S., Su, S., Liu, Y., Zhou, X., Luo, Q., Paudel, B., 2022. Effectiveness of the Qilian Mountain nature reserve of China in reducing human impacts. Land 11 (7), 1071. https://doi.org/10.3390/land11071071.

Liu, Q., Hu, H., Xiong, X., Zhao, E., Wang, K., Wu, C., 2022. Urban natural wetland as a sink for microplastics: a case from Lalu Wetland in Tibet, China. Sci. Total Environ. 828, 154399 https://doi.org/10.1016/j.scitotenv.2022.154399.

Liu, R.-p., Dong, Y., Quan, G.-c., Zhu, H., Xu, Y.-n., M Elwardany, R., 2021. Microplastic pollution in surface water and sediments of Qinghai-Tibet Plateau: current status and causes. China Geol 4 (1), 1–7. https://doi.org/10.31035/cg2021011.

Liu, Y., Liu, Y., Li, Y., Bian, P., Hu, Y., Zhang, J., Shen, W., 2023. Effects of irrigation on the fate of microplastics in typical agricultural soil and freshwater environments in the upper irrigation area of the Yellow River. J. Hazard Mater. 447, 130766 https://doi.org/10.1016/j.jhazmat.2023.130766.

Luo, W., Su, L., Craig, N.J., Du, F., Wu, C., Shi, H., 2019. Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. Environ. Pollut. 246, 174–182. https://doi.org/10.1016/j.envpol.2018.11.081.

Manseau, F., Bhiry, N., Molson, J., Cloutier, D., 2022. Factors affecting river turbidity in a degrading permafrost environment: the Tasiapik River, Umiujaq (Nunavik). Arct. Sci. 8 (4), 1202. https://doi.org/10.1139/as-2021-0036.

Mao, R., Song, J., Yan, P., Ouyang, Z., Wu, R., Liu, S., Guo, X., 2021. Horizontal and vertical distribution of microplastics in the Wuliangsuhai Lake sediment, northern

China. Sci. Total Environ. 754, 142426 https://doi.org/10.1016/j.scitotenv.2020.142426.
Mouquet, N., Loreau, M., 2003. Community patterns in source-sink metacommunities. Am. Nat. 162 (5), 544–557. https://doi.org/10.1086/378857.
Mughini-Gras, L., van der Plaats, R.Q.J., van der Wielen, P.W.J.J., Bauerlein, P.S., de Roda Husman, A.M., 2021. Riverine microplastic and microbial community compositions: a field study in The Netherlands. Water Res. 192, 116852 https://doi.org/10.1016/j.watres.2021.116852.
Qiao, R., Deng, Y., Zhang, S., Wolosker, M.B., Zhu, Q., Ren, H., Zhang, Y., 2019. Accumulation of different shapes of microplastics initiates intestinal injury and gut microbiota dysbiosis in the gut of zebrafish. Chemosphere 236, 124334. https://doi.org/10.1016/j.chemosphere.2019.07.065.
Roblin, B., Ryan, M., Vreugdenhil, A., Aherne, J., 2020. Ambient atmospheric deposition of anthropogenic microfibers and microplastics on the western periphery of europe (Ireland). Environ. Sci. Technol. 54 (18), 11100–11108. https://doi.org/10.1021/acs.est.0c04000.
Selvam, S., Jesuraja, K., Venkatramanan, S., Roy, P.D., Jeyanthi Kumari, V., 2021. Hazardous microplastic characteristics and its role as a vector of heavy metal in groundwater and surface water of coastal south India. J. Hazard Mater. 402 https://doi.org/10.1016/j.jhazmat.2020.123786.
SEPA, 2002. Water and Wastewater Monitoring and Analysis Method. Chinese Environmental Science Press, Beijing.
Sharma, M.D., Elanjickal, A.I., Mankar, J.S., Krupadam, R.J., 2020. Assessment of cancer risk of microplastics enriched with polycyclic aromatic hydrocarbons. J. Hazard Mater. 398, 122994 https://doi.org/10.1016/j.jhazmat.2020.122994.
Sridharan, S., Kumar, M., Singh, L., Bolan, N.S., Saha, M., 2021. Microplastics as an emerging source of particulate air pollution: a critical review. J. Hazard Mater. 418 https://doi.org/10.1016/j.jhazmat.2021.126245.
Sun, F., Lyu, Y., Fu, B., Hu, J., 2016. Hydrological services by mountain ecosystems in Qilian Mountain of China: a review. Chin. Geogr. Sci. 26 (2), 174–187. https://doi.org/10.1007/s11769-015-0791-9.
Talbot, R., Chang, H., 2022. Microplastics in freshwater: a global review of factors affecting spatial and temporal variations. Environ. Pollut. 292, 118393 https://doi.org/10.1016/j.envpol.2021.118393.
Tan, J., Fu, J.S., Carmichael, G.R., Itahashi, S., Tao, Z., Huang, K., Dong, X., Yamaji, K., Nagashima, T., Wang, X., Liu, Y., Lee, H.-J., Lin, C.-Y., Ge, B., Kajino, M., Zhu, J., Zhang, M., Liao, H., Wang, Z., 2020. Why do models perform differently on particulate matter over East Asia? A multi-model intercomparison study for MICS-Asia III. Atmos. Chem. Phys. 20 (12), 7393–7410. https://doi.org/10.5194/acp-20-7393-2020.
Thornton Hampton, L.M., Brander, S.M., Coffin, S., Cole, M., Hermabessiere, L., Koelmans, A.A., Rochman, C.M., 2022. Characterizing microplastic hazards: which concentration metrics and particle characteristics are most informative for understanding toxicity in aquatic organisms? Microplastics and Nanoplastics 2 (1), 20. https://doi.org/10.1186/s43591-022-00040-4.
Wang, W., Yuan, W., Chen, Y., Wang, J., 2018. Microplastics in surface waters of dongting lake and hong lake, China. Sci. Total Environ. 633, 539–545. https://doi.org/10.1016/j.scitotenv.2018.03.211.
Wong, G., Löwemark, L., Kunz, A., 2020a. Microplastic pollution of the Tamsui River and its tributaries in northern Taiwan: spatial heterogeneity and correlation with precipitation. Environ. Pollut. 260, 113935 https://doi.org/10.1016/j.envpol.2020.113935.
Wong, J.K.H., Lee, K.K., Tang, K.H.D., Yap, P.-S., 2020b. Microplastics in the freshwater and terrestrial environments: prevalence, fates, impacts and sustainable solutions. Sci. Total Environ. 719, 137512 https://doi.org/10.1016/j.scitotenv.2020.137512.
Wu, X., Sun, W., Huai, B., Wang, L., Han, C., Wang, Y., Mi, W., 2023. Seasonal variation and sources of atmospheric polycyclic aromatic hydrocarbons in a background site on the Tibetan Plateau. J. Environ. Sci. 125, 524–532. https://doi.org/10.1016/j.jes.2022.02.042.
Wurm, F.R., Spierling, S., Endres, H.J., Barner, L., 2020. Plastics and the environment—current status and challenges in Germany and Australia. Macromol. Rapid Commun. 41 (18), 2000351 https://doi.org/10.1002/marc.202000351.
Xiong, X., Liu, Q., Chen, X., Wang, R., Duan, M., Wu, C., 2021. Occurrence of microplastic in the water of different types of aquaculture ponds in an important lakeside freshwater aquaculture area of China. Chemosphere 282, 131126. https://doi.org/10.1016/j.chemosphere.2021.131126.
Xiong, X., Zhang, K., Chen, X., Shi, H., Luo, Z., Wu, C., 2018. Sources and distribution of microplastics in China's largest inland lake – Qinghai Lake. Environ. Pollut. 235, 899–906. https://doi.org/10.1016/j.envpol.2017.12.081.
Xu, P., Peng, G., Su, L., Gao, Y., Gao, L., Li, D., 2018. Microplastic risk assessment in surface waters: a case study in the Changjiang Estuary, China. Mar. Pollut. Bull. 133, 647–654. https://doi.org/10.1016/j.marpolbul.2018.06.020.
Yang, L., Luo, W., Zhao, P., Zhang, Y., Kang, S., Giesy, J.P., Zhang, F., 2021. Microplastics in the Koshi River, a remote alpine river crossing the Himalayas from China to Nepal. Environ. Pollut. 290, 118121 https://doi.org/10.1016/j.envpol.2021.118121.
Yuan, W., Christie-Oleza, J.A., Xu, E.G., Li, J., Zhang, H., Wang, W., Lin, L., Zhang, W., Yang, Y., 2022. Environmental fate of microplastics in the world's third-largest river: basin-wide investigation and microplastic community analysis. Water Res. 210, 118002 https://doi.org/10.1016/j.watres.2021.118002.
Zhang, K., Su, J., Xiong, X., Wu, X., Wu, C., Liu, J., 2016. Microplastic pollution of lakeshore sediments from remote lakes in Tibet plateau, China. Environ. Pollut. 219, 450–455. https://doi.org/10.1016/j.envpol.2016.05.048.
Zhang, Y., Gao, T., Kang, S., Sillanpää, M., 2019. Importance of atmospheric transport for microplastics deposited in remote areas. Environ. Pollut. 254, 112953 https://doi.org/10.1016/j.envpol.2019.07.121.
Zhou, Y., He, G., Jiang, X., Yao, L., Ouyang, L., Liu, X., Liu, W., Liu, Y., 2021. Microplastic contamination is ubiquitous in riparian soils and strongly related to elevation, precipitation and population density. J. Hazard Mater. 411, 125178 https://doi.org/10.1016/j.jhazmat.2021.125178.
Zimmermann, L., Göttlich, S., Oehlmann, J., Wagner, M., Völker, C., 2020. What are the drivers of microplastic toxicity? Comparing the toxicity of plastic chemicals and particles to Daphnia magna. Environ. Pollut. 267, 115392 https://doi.org/10.1016/j.envpol.2020.115392.