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Temporal and Spatial Distribution Characteristics of Microplastics and Their Influencing Factors in the Lincheng River, Zhoushan City, China

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Abstract: Microplastics (MPs), a new type of pollutant, pose a significant threat to the environment at high concentrations. One of the primary sources of MPs in the ocean is river runoff, highlighting the need to investigate the spatial and temporal variations of MPs in rivers that flow into the sea, as well as their contributing factors. In this study, we analyzed MPs distribution and their influence factors in the Lincheng River, China. The Lincheng is the second largest river in Zhoushan island that directly flows into the ocean. MPs in the river water and sediments were detected during the wet season (July 2021), the dry season (November 2021) and the typhoon season (September 2021), and MPs were present in all reaches of the river. The abundance of MPs in the river was moderate compared to other studies, with the river water exhibiting a concentration of 15 $\pm$ 2.64 n/L and the sediment containing 318.24 $\pm$ 49.53 n/kg of MPs. In surface water, the most commonly found MP was blue man-made cellulose (CE), while the sediment contained mostly fragments of polypropylene (PP) and polypropylene polyethylene blends (PP + PE) in blue and green colors. The abundance of MPs showed significant seasonal differences, with higher abundance during the wet season compared to the dry season and typhoon period. Furthermore, local construction activities may contribute to higher MP abundance. To explore the influence factors of MPs, the Basin Development Index (BDI) was proposed, and a positive correlation between BDI and MP abundance was founded. This correlation indicates that the increase in land use for construction highly contributes to the MP pollution. In conclusion, future long-term monitoring of the abundance of MPs in the Lincheng River is necessary.

Keywords: basin development index; microplastics; river entering the ocean; spatial and temporal variation

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1. Introduction

Since the 1950s, there has been a significant increase in global plastic production, and the worldwide production of plastic was predicted to exceed 25 billion tons in 2050 [1]. Plastics exposed to the environment will degrade and fragment into small plastic particles, with sizes less than 5 mm classified as microplastics (MPs) [2]. Due to their large specific surface area, MPs can easily adsorb pollutants, such as persistent organic pollutants and heavy metals [3,4]. The feeding capacity, reproductive capacity and immune characteristics of organisms may be influenced when exposed to MPs, and even their survival may be affected [5]. In addition, MPs can spread through the food chain [6], and the adhered heavy metals and other pollutants can accumulate in human bodies [7], posing significant risks to human health. Recently, researchers have discovered that microorganisms can degrade MPs, which may help alleviate microplastic pollution [8,9].

In the global oceans, plastic accounts for approximately 60% to 80% of all marine debris [10], with most of it originating from rivers that flow into the sea, from marine fishing and from transportation [11]. Although the average abundance of MPs in the Yangtze River water is only 157.2 ± 75.8 n/m^3, due to its huge flow, an average of 798.1 × 10^9 m^3 of water enters the East China Sea every month. Therefore, a large amount of MPs enters the East China Sea from the Yangtze River, making the Yangtze River a major source of pollution for the East China Sea [12]. The abundance of MPs in rivers and the factors affecting their concentration have become a focus of attention as an important pathway for terrestrial MPs to enter the oceans. Previous research has shown that human activity has a significant impact on microplastic abundance in rivers, as observed in four river estuaries in the Chesapeake Bay by Yonkos et al. [13], where the concentration of MPs was positively correlated with population density and the proportion of urban or suburban development in the watershed. Zhao et al. [14] also found that the economic structure of a city influences the level of microplastic pollution. For example, the high abundance of MPs in the Jiaojiang River estuary is likely due to the presence of over 10,000 plastic companies located in Taizhou City, which the river flows through.

In recent years, numerous researchers have investigated the abundance of MPs in rivers flowing into the sea, including the Mekong River [15], Yibei River [16], and Minjiang River [14]. However, most of these studies only focused on exploring the spatial variation of microplastic abundance, while continuous observations at the same location were lacking. Therefore, it is imperative to conduct spatiotemporal studies on the distribution characteristics of microplastic abundance in these rivers. Such studies can provide insights into the variation patterns of microplastic abundance in both temporal and spatial dimensions, thereby enhancing our understanding of the impact of rivers on marine microplastic pollution.

Zhoushan, a small island city situated adjacent to the Zhoushan fishing ground, has a relatively lower industrial development level compared to other cities, and the rivers on the island generally have low flow. Therefore, human activities are the main source of MPs in this area, but little research has been conducted on the abundance levels of MPs and their influencing factors in the rivers. To address this knowledge gap, the Lincheng River located on Zhoushan Island was selected as the study site. MPs in the surface water and sediment samples were collected in typical seasons to study the spatiotemporal variation of MPs and analyze the influencing factors of microplastic pollution in the Lincheng River. This research is crucial for assessing microplastic pollution, calculating the inflow flux of MPs into the sea, and MP pollution control and treatment.

2. Materials and Methods

2.1. The Study Site

The Lincheng River is situated in Zhoushan and originates from the Dong'ao Reservoir (Figure 1), which is a drinking water source and releases an average of 1000–2000 m^3 of water daily only from June to September, so rainwater collected from pipes serves as the primary source of water for the river. The river has a total length of 8.38 km, an average width of 20.78 m, and a basin area of 2.83 km^2. At the river mouth, there is a sluice that functions as a tide-blocking and drainage gate, opening and closing based on the incoming water flow. In 2021, the gate was opened 74 times during the wet season, with a flow rate ranging from 0.02–29.99 m^3/s and a water level in front of the gate of −0.37–1.38 m. During the dry season, the flow rate ranged from 0–9.42 m^3/s, and the water level in front of the gate was between −0.03–0.99 m. The river reaches its peak flow rate when the gate is open. The Lincheng River is the second largest river in Zhoushan, flowing through the Lincheng New District, with the rising population, human activity in the region has increased. Additionally, there are many rainwater outlets along the riverbank, and the collected rainwater flows directly into the river.

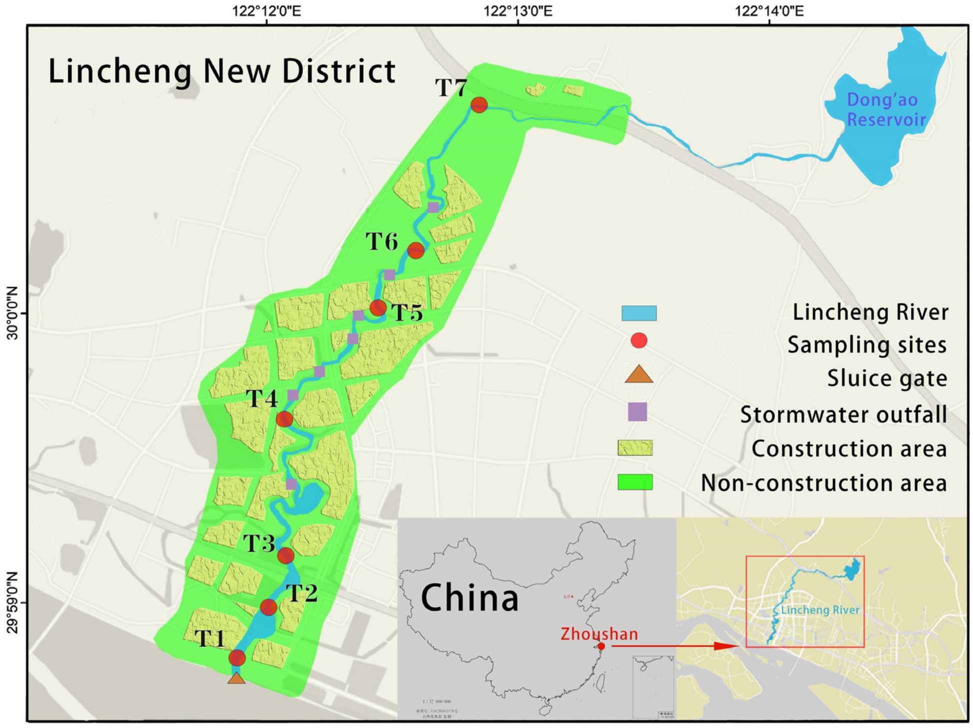

Figure 1. Sampling sites in the Lincheng River.

2.2. Sample Point Settings

This study established a total of seven sampling sites (T1–T7) along the Lincheng River, from its mouth to its source, as illustrated in Figure 1. T1, located at the mouth of the river, was greatly influenced by the Tianluozhi water gate. T2 was primarily surrounded by office buildings, while T3, T4, and T5 were situated near densely populated residential areas. T6 was surrounded by wasteland and new construction projects were underway nearby during the dry season. T7, located at the upstream source, had a lower population density. To minimize water disturbance during sampling, most sites were located at the intersection of roads and bridges. However, due to sediment conditions on the riverbed, no sediment was collected at T2, T3, and T5.

2.3. Sample Collection and Processing

Sampling work for this study was conducted in the Lincheng River in July, September, and November 2021. The July sampling was conducted during the wet season and the November sampling during the dry season, while the September sampling took place on the first day after a typhoon, which marks the typhoon season. Sample collection included surface water and sediment. Water samples were directly extracted using a stainless-steel bucket, and 1 L of the water sample was measured by a measuring cylinder and filtered with a vacuum filtration device through a 3 μm filter membrane (Xinya Company, Shanghai, China) on-site. A total of three water samples were collected, with volumes of 300 mL, 300 mL, and 400 mL, respectively. Then, the filtered samples were labeled and prepared for further testing in the laboratory.

The identification of MPs involved two main steps. Firstly, a preliminary identification was carried out by moving the filter membrane in a "zigzag" pattern under a microscope (SMZ25, Nikon Corporation, Tokyo, Japan) and visually identifying microplastic particles based on their shape, color, gloss, and surface structure. Secondly, all suspected MPs were removed using anti-static forceps and subjected to spectral detection with Fourier-transform infrared microscopy (Nicolet iN10, Thermo Fisher Scientific, Waltham, MA, USA). The obtained spectra were compared with the standard spectral library of polymers, and if the similarity was greater than 70%, the polymer type was confirmed.

The collection and processing of sediment samples followed the procedure by Cao et al. [17] for Yangtze River soil samples. The sediment samples were collected by a Petersen grab and transferred to aluminum boxes with a stainless-steel shovel. It should be noted that only one sediment sample was collected due to poor substrate conditions. After drying, the soil samples were weighed for further calculation of microplastic abundance. The separation of MPs from soil samples was achieved by exploiting the difference in density between MPs and the solution. Firstly, 10 g of soil samples were placed in a 45 mL centrifuge tube, followed by the addition of saturated NaCl (National Pharmaceutical Group Corporation, Beijing, China) solution (1.2 g/cm^3) that was mixed thoroughly to prevent soil particles from aggregating and compromising the experimental results. After proper mixing, the centrifuge tube was spun at 4000 rpm for 5 min (SF-TDL-5A, Feiqia'er, Shanghai, China), and the supernatant was collected. This step was repeated three times until the supernatant had no apparent floating particles. Next, the supernatant was treated with 30% hydrogen peroxide solution for over 24 h to eliminate any interference from plant fibers during the subsequent microscopic examination. Finally, the supernatant was filtered using a filtration device (filter membrane 3 μm), and the filter membrane was carefully preserved for microscopic examination. The detection method employed was the same as the water sample processing method.

2.4. Quality Control

To reduce contamination, distilled water was utilized in all steps. For filtration, the beaker was rinsed with distilled water at least three times, so that MPs adhered to the walls of the beaker could be washed onto the filter membrane, resulting in a reduction of experimental errors. During digestion, the beaker was covered with aluminum foil to prevent airborne MPs from entering the sample. In order to minimize the impact of fiber shedding on clothing, the experimenters wore cotton lab coats and masks during the experiment. Furthermore, to reduce experimental variability, all sample processing was performed by the same person. To ensure accuracy, three experiments were conducted in the blank group while processing the samples, and no MPs were found.

2.5. Method for Analysis of River Basin Construction

To fully illustrate the impact of urban development on MP abundance, this study introduces the concept of the Basin Development Index (BDI). For each sampling site, BDI was calculated as the ratio of constructed land area ($\text{Area}_{\text{construction}}$) to the total area of the basin ($\text{Area}_{\text{total}}$) between the upstream of the sampling point and the next sampling point (for T7, BDI was calculated between the upstream of T7 and the dam spillway).

$$\text{BDI} = \frac{\text{Area}_{\text{construction}}}{\text{Area}_{\text{total}}} \tag{1}$$

The constructed land area and total basin area were both calculated using Google Earth. A higher BDI indicates a larger proportion of constructed land in the basin and a higher level of urbanization, while a lower BDI indicates a smaller proportion of constructed land in the basin and a lower level of urbanization.

2.6. Data Processing

We created a map of the sampling point distribution using ArcGis 10.2 software and generated related graphs using Origin 2019b and Excel 2019. The abundance of MPs in water samples was expressed as "n/L," and the abundance of MPs in sediment samples was expressed as "n/kg," where "n" represents the number of MPs, and "kg" denotes the dry weight of sediment.

3. Results

3.1. Abundance Distribution of MPs

The abundance of MPs at different sampling points and times is presented in Figure 2. The results indicate that MPs were widely distributed throughout the river, including in water and sediment. The abundance of MPs in water was 15 ± 2.64 n/L (3–49 n/L) and exhibited temporal and spatial variations. The mean abundance during wet season, typhoon season, and dry season was 19 ± 6.37 n/L, 14 ± 3.41 n/L, and 12 ± 2.60 n/L, respectively. The highest abundance of MPs in water (49 n/L) was observed at T1 during the wet season, whereas the lowest abundance was found at T7 during the wet season and T2 during the dry season (both 3 n/L). Overall, during the typhoon season, the abundance of MPs in water generally increased downstream, whereas during the dry season, it was higher in the middle reaches and relatively lower in the upper and lower reaches.

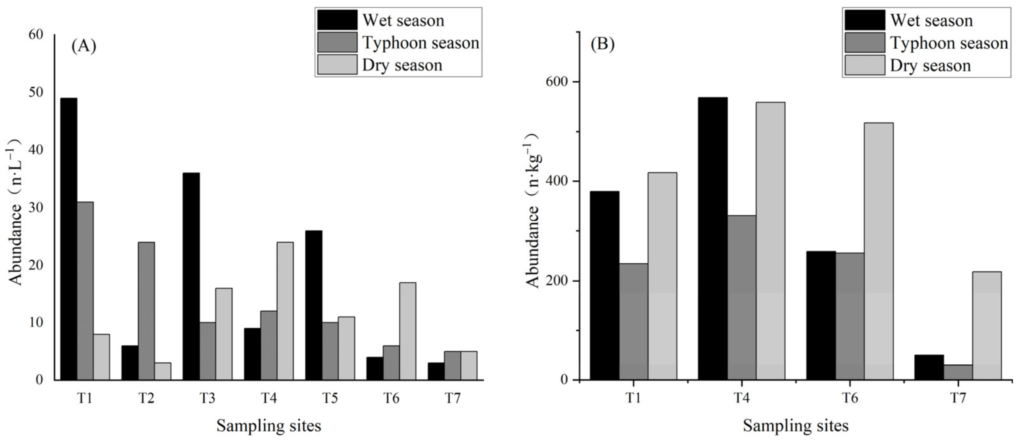

Figure 2. Abundance of MPs in different seasons. (**A**) denotes water sample, while (**B**) represents sediment sample.

The abundance of MPs in sediment was determined to be 318.24 ± 49.53 n/kg (29.77–568.45 n/kg), with average values of 314.26 ± 94.02 n/kg, 212.64 ± 55.79 n/kg, and 427.82 ± 65.84 n/kg during the wet, typhoon, and dry seasons, respectively. The T4 sampling point showed the highest abundance of MPs at different sampling times, with the peak abundance of 568.45 n/kg occurring during the wet season. Conversely, the T7 sampling point located at the headwaters of the river exhibited the lowest abundance of MPs in sediment, with a value of only 29.77 n/kg during the typhoon season.

3.2. Morphological Characteristics of MPs

According to microscopic inspection results, MPs were classified into three categories: fibers, fragments, and films, with specific shapes illustrated in Figure 3. The statistical analysis of MPs with different shapes is presented in Figure 4. The predominant shapes of MPs were different between water and sediment. Fibers were the most prevalent shape of MPs in water, with average proportions of 67.67%, 89.80%, and 92.86% during the wet, typhoon, and dry seasons, respectively. However, in sediment, the average proportion of fibers was only 19.63%, 25.00%, and 38.82% during the same seasons, respectively. Fragments were the most dominant shape of MPs in sediment, with average proportions of 72.60%, 67.50%, and 57.24% during wet, typhoon, and dry seasons, respectively. In water, the average proportions of fragments were 7.52%, 8.16%, and 5.95% during the same seasons, respectively.

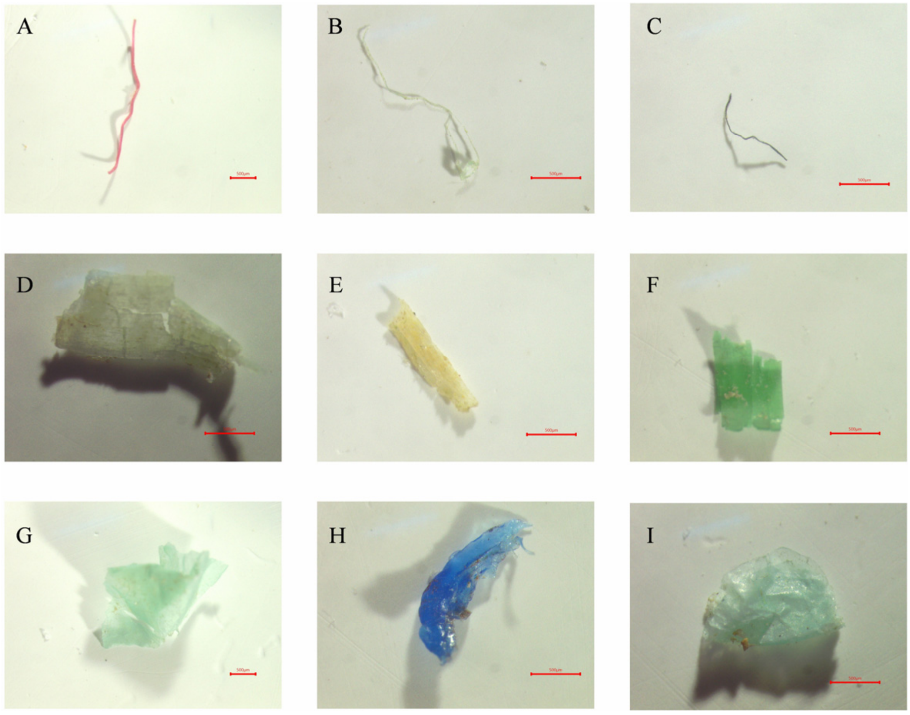

Figure 3. Micrographs of typical microplastics. (**A**–**C**) are fibers, (**D**–**F**) are fragments, (**G**–**I**) are film.

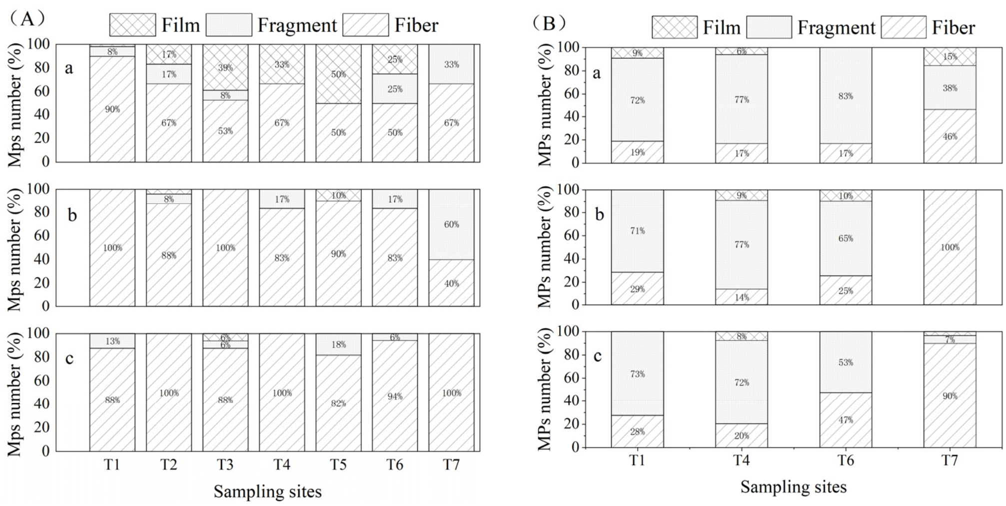

Figure 4. The proportion of microplastic shapes in different seasons. (**A**) denotes a water sample, while (**B**) represents a sediment sample. Proportions of various microplastic shapes in wet, typhoon, and dry seasons are represented by a, b, and c, respectively.

The color distribution of MPs in the Lincheng River is shown in Figure 5, mainly consisting of red, green, and blue. In water, the average proportion of blue MPs was the highest, reaching 57.89%, 73.47%, and 71.43% during the wet, typhoon, and dry seasons, respectively. Most of these blue MPs were fiber shaped. In sediment samples, green (35.53–66.67%) and blue (20.55–46.05%) MPs were the main colors, and they mostly appeared in the form of fragments.

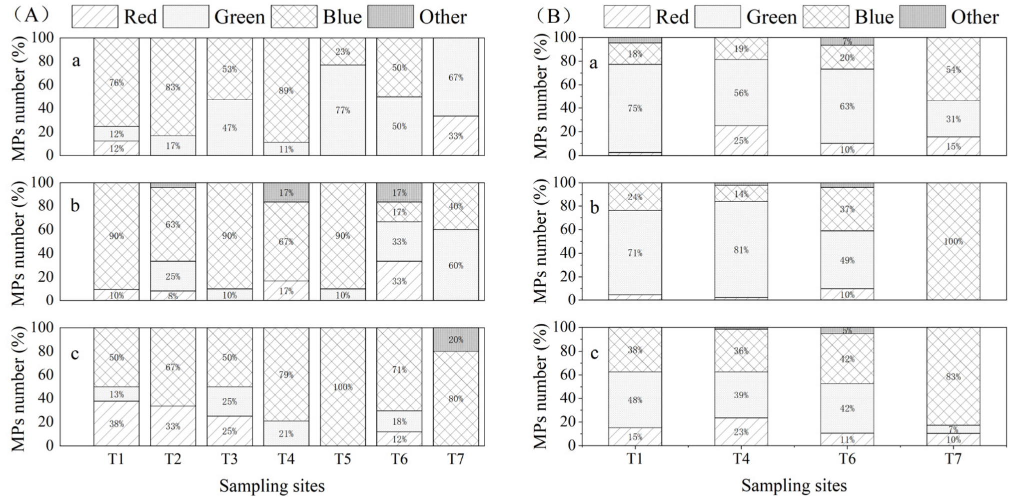

Figure 5. The proportion of microplastic color in different seasons. (**A**) denotes a water sample, while (**B**) represents a sediment sample. Proportions of various microplastic colors in the wet, typhoon, and dry seasons are represented by a, b, and c, respectively.

3.3. Main Components of MPs

The main microplastic types found in the Lincheng River included polypropylene (PP), polyethylene (PE), polypropylene-polyethylene blends (PP + PE), cellulose (CE), as well as small amounts of polyester, polystyrene (PS), polyethylene terephthalate (PET), and nylon (PA). Infrared spectra of some of these materials are shown in Figure 6. The proportions of microplastic components were analyzed across different sampling periods and locations and are presented in Figure 7. CE was the most abundant component in water, accounting for 54.89–78.57% of total MPs and mainly present as blue fibers. PP was the primary component in sediment samples during wet and typhoon seasons, comprising 45.00–78.02% of MPs, while PP + PE was the primary component during the dry season, accounting for 50.66% of MPs. The main shapes of PP and PP + PE were blue or green fragments.

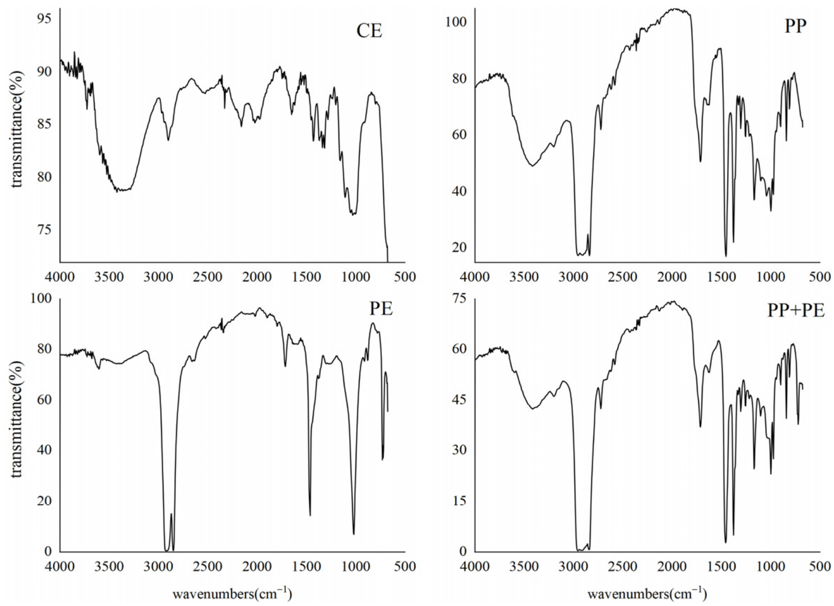

Figure 6. Infrared spectroscopy of typical microplastics in the Lincheng River.

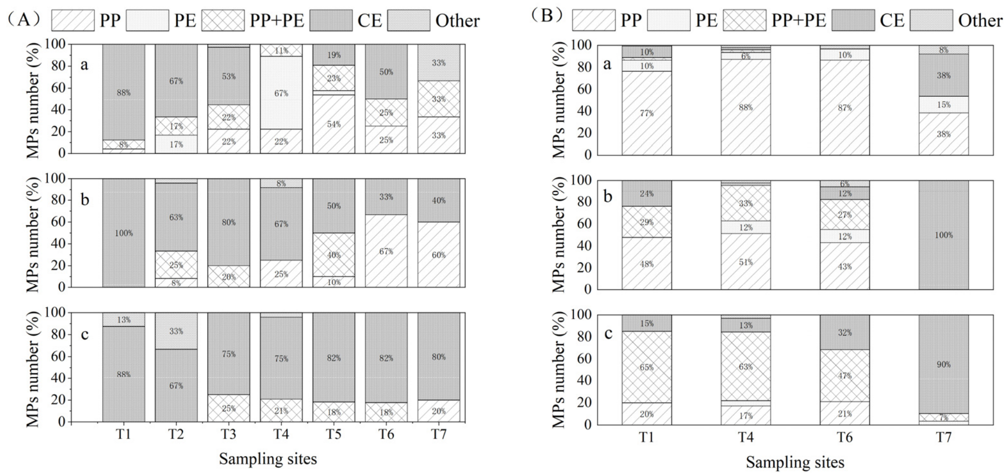

Figure 7. The proportion of microplastic components in different seasons. (**A**) denotes a water sample, while (**B**) represents a sediment sample. Proportions of various microplastic components in the wet, typhoon, and dry seasons are represented by a, b, and c, respectively.

4. Discussion

4.1. Temporal and Spatial Variation Characteristics of MP Abundance in the Lincheng River

The Lincheng River originates from the Dong'ao Reservoir and flows through several community streets before joining the ocean. The basin contains numerous rainwater sewage outlets, and rainwater is collected through pipelines and eventually flows into the river. Studies indicated that rainfall contributes 24–77% of MPs in stormwater runoff, with 72% of MPs in rainfall being fiber MPs [18]. The river is an important pathway for terrestrial MPs to enter aquatic environments, migrating from land to surface water with rainwater runoff [19,20]. Currently, numerous scholars have researched MPs in freshwater environments. According to Table 1, the abundance of MPs in both the La Chaux River [21] and Douro River [22] is at a relatively high level. The MP levels in the La Chaux River may be due to the presence of nearby landfill sites, while for the Douro River it may be related to wastewater treatment plants and shipbuilding factories. Microplastic abundance in the Lincheng River was higher than that in the Xiangxi River, Koshi River, Beiyun River and Chubut River, but lower than that in the upstream Chongqing section of the Yangtze River and freshwater rivers of Shanghai, primarily due to environmental conditions on both sides. The Xiangxi River [23] and the Koshi River [24] are both mountainous rivers, and the population density surrounding the Chubut River [25] is low. Although the Beiyun River [26] is located in Beijing, the main areas on both sides are farmland, resulting in a relatively low abundance of MPs in both water and sediment. The upstream Chongqing section of the Yangtze River [27] and freshwater rivers of Shanghai [28] have a high population density and developed industry, resulting in a very high abundance of MPs. The banks of the Brisbane River [29] and the Vistula River [30] are primarily residential and commercial areas, similar to the Lincheng River, resulting in a comparable level of microplastic abundance in the sediment of both rivers. Additionally, in the Plankenburg River [31], Nakdong River [32], and West River [33], the abundance of MPs in the water is lower than that in the Lincheng River, but the abundance of MPs in sediment is higher than that in the Lincheng River. Overall, this study concludes that the microplastic abundance in the water and sediment of the Lincheng River is at a moderate level, based on a comparison with microplastic abundance in typical freshwater environments.

Table 1. Microplastic abundance in some typical freshwater basins.

Freshwater Basins	Microplastic Abundance in Water Samples/($n \cdot L^{-1}$)	Microplastic Abundance in Sediments ($n \cdot kg^{-1}$)	Reference
La Chaux River	412.00 ± 432.00 (Average)	-	[21]
Douro River	<1.00–350.00	-	[22]
Xiangxi River	1.50–11.50	130.00–830.00	[23]
Koshi River	0.04–0.36	12.00–143.00	[24]
Chubut River	0.80–11.50	175.40 ± 63.50 (Average) 516.00 (Maximum)	[25]
Beiyun River	1.74–9.94	109.00–299.00	[26]
Yangtze River	46.70–204.00	100.00–583.00	[27]
Six Freshwater Rivers of Shanghai	-	802.00 ± 594.00 (Average)	[28]
Brisbane River	-	10.00–520.00	[29]
Vistula River	1.60–2.55	190.00–580.00	[30]
Plankenburg River	6.87–9.25	455.94–3031.48	[31]
Nakdong River	0.21–10.00	1971 ± 62 (Average)	[32]
West River	2.99–9.87	2560.00–10,240.00	[33]
Lincheng River	3.00–49.00	29.77–568.45	This study

- denotes that this data is not available in the literature.

Microplastic abundance displays distinct seasonal variations. In the Xiangxi River [23], microplastic abundance in both water and sediment was higher during the wet season than during the dry season, while the opposite trend was observed in the hydro-fluctuation belt. In the Lincheng River, microplastic abundance in water was higher during the wet season than during the dry season, but in sediment, it was higher during the dry season. During the wet season, abundant rainfall carried MPs from the surface and atmosphere into the river via runoff, resulting in a higher abundance of MPs in the river water. Conversely, during the dry season, slower water flow and less rainfall caused MPs from point sources to settle in place, leading to a higher abundance of MPs in sediment samples. Ding et al. [34] also reported that low water flow facilitates microplastic deposition. Additionally, during typhoon periods, water body disturbance led to the lowest abundance of MPs in sediment samples among all sampling periods. At sampling point T7 in the headwaters of the river, microplastic abundance during the dry season was much higher than during the wet season and typhoon period. During the sampling process, it was discovered that the T7 sediment sample was primarily composed of fine sand. Asadi et al. [35] have reported that the content of MPs in sand and gravel was significantly lower than that in sticky clay. The larger the particle size of the substrate, the smaller the frictional force per unit volume of sediment on MPs, allowing them to easily migrate with the water flow [23]. During the wet season and typhoon period, there was an increase in rainfall, and upstream reservoirs release water. At T7, the originally narrow river channel collected a large amount of water flow in a short period, resulting in a much faster water flow in the river compared to during the dry season, causing greater erosion of the riverbed by the water flow. MPs attached to the fine sand were more easily washed away by the water flow, resulting in a much lower microplastic abundance at this point compared to in the dry season.

Microplastic abundance exhibited certain differences among various sampling points during the same sampling period. During wet and typhoon periods, MPs increased in water abundance due to a rise in water flow and were transported downstream [36]. In the wet season and typhoon period, the sluice gate downstream was not opened for two days before sampling. Consequently, MPs tend to accumulate in front of the sluice gate, as observed in previous studies where dams [37], weirs [38], and closed sluice gates [39] act as potential sinks for river MPs, extending their residence time at those locations. As a result, the abundance of MPs reached a maximum level at the mouth of the river's sampling point T1 during the wet season and typhoon period. During the dry season, the lower microplastic abundance observed in the water samples at T1 and T2, compared to other sampling points at the same time, except for T7, may be attributed to the gate being opened to release water on the morning of the sampling day, followed by the sampling work. As a result, some MPs in the water were carried away with the water flow and entered the ocean, causing a decrease in the microplastic abundance in the water samples. During the dry season, the abundance of MPs in water and sediment suddenly increased at sampling point T6, which was previously a wasteland. Construction sites started working nearby in October, and wastewater from construction and domestic sources was directly discharged into the river. Consequently, the water sample was significantly turbid compared to other areas, and both construction and domestic wastewater contained MPs, which resulted in short-term accumulation of MP abundance in the area. Furthermore, a considerable amount of dust was generated during the construction process, and Zhang et al. [40] reported that the average microplastic content in dust near construction sites in the Northwest Aibi Lake Basin was 28.61 ± 1.13 mg/kg. MPs in dust were the first to affect the land and rivers near the construction site after natural settling or atmospheric transport. After rainfall, MPs originally deposited on the land will further accumulate in the river, leading to an aggravation of microplastic pollution in the river.

Human activities along river coasts were a key factor influencing the spatiotemporal distribution of MPs [26]. Population density in the study area shows a strong correlation with the degree of microplastic pollution [41]. During the wet season and typhoon periods, the rapid water flow carries MPs released from residential areas downstream, resulting in insignificant effects on microplastic abundance at nearby sampling points. In line with prior research, Gao et al. [42] also observed a considerable quantity of MPs that migrated with the water body during the rainy season. However, during the dry season, when river flow was smaller, human activities on both sides of the river posed a greater impact on microplastic abundance. At sampling point T4 during the dry season, the abundance of MPs in both water and sediment samples was the highest among all sampling points during the same period, and it was also the most densely populated area among all sampling points. Human activities were an important source of MPs in the aquatic environment of the study area [43]. Huang et al. [33] found a spatial correlation between the distance to the city center and the abundance of MPs in surface water and sediment downstream of the Xijiang River in southern China, where the closer to the city center, the more severe the microplastic pollution in the river.

4.2. Relationship between BDI and MPs Abundance

Yuan et al. [44] investigated the abundance of MPs in the Yangtze River Basin and found that it was highest near construction sites, followed by farmland, grassland, and forests. The study suggested that microplastic abundance was linked to the proportion of construction land area in the basin, and therefore, introduced the concept of BDI. Xiong et al. [45] reported that the microplastic abundance in sediments in Wuhan was higher than that in downstream Shanghai, indicating that most MPs sink into local sediments rather than being transported downstream by the river. Furthermore, MPs in sediments were less likely to be disturbed than those in water, making them a better indicator of the relationship between BDI and microplastic abundance near sampling points. Therefore, this study analyzed microplastic abundance in sediments during the wet, typhoon, and dry seasons only. Sediment samples were collected at T1, T4, T6, and T7 due to the influence of riverbed sediment conditions, and BDI was calculated for each of the four sampling points, resulting in values of 0.51, 0.63, 0.26, and 0.06, respectively. Correlation analysis between microplastic abundance in sediment and BDI in the Lincheng River Basin is shown in Figure 8. The correlation coefficients (r) between microplastic abundance in sediments during the wet, typhoon, and dry seasons and BDI were 0.9821, 0.8707, and 0.7537, respectively, all of which were greater than 0.7, indicating a strong correlation. The results suggest that an increase in the proportion of construction land area in the basin is associated with an increase in microplastic abundance.

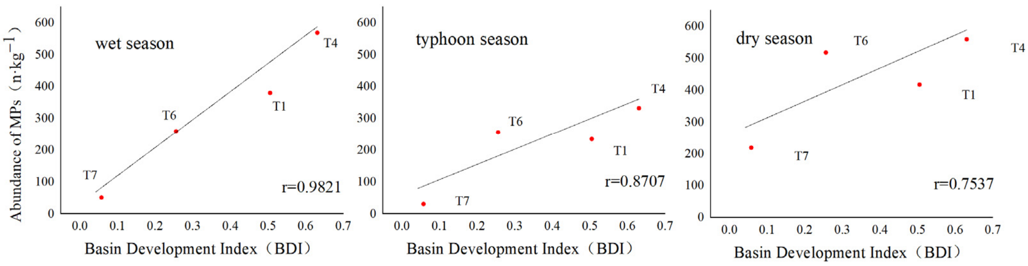

Figure 8. Correlation analysis between microplastic abundance and BDI.

4.3. Main Sources of MPs in the Lincheng River

After testing all suspected MPs in the water samples, it was found that artificial cellulose was the most abundant polymer. Similarly, Su et al. [46] found that synthetic cellulose was the most prevalent polymer in water samples from Taihu Lake. Synthetic cellulose, commonly derived from textiles, is a primary material in environmental samples [47]. Previous studies have detected artificial cellulose in both indoor and outdoor air, and Dris et al. [48] observed large amounts of fibers, including natural and artificial fibers, in apartment and office environments. Cai et al. [49] detected suspected MPs in atmospheric deposition samples in Dongguan, of which 73% were cellulose. These artificial celluloses are transported into rivers through runoff after rainfall, resulting in an increased concentration of artificial cellulose in rivers. Although there was no significant source of artificial cellulose released in the area, T7 contained mainly artificial cellulose polymers. Microplastic pollutants can travel long distances through the atmosphere and settle in remote areas [50,51]. Therefore, it is speculated that the artificial cellulose found in T7 may have been transported there by wind from other areas containing artificial cellulose in the atmosphere. During field investigations, a large number of rainwater pipe openings were discovered on both sides of the Lincheng River. Sang et al. [52] confirmed that there were numerous MPs in the rainwater pipes, and the fiber microplastic content in residential area rainwater pipes was higher than that in other areas due to the frequent use of synthetic fiber products by residents. In the study area, the residential area is relatively large, and during rainfall, fiber MPs scattered near the residential area will enter the river through the rainwater pipes, exacerbating MP pollution in the river. These findings provide important insight into the sources and transport pathways of MPs in rivers and the surrounding environment.

The study area sediment was found to have the highest proportion of PP or PP + PE polymer types, which are widely used due to their exceptional characteristics. PP and PE are the most produced plastics globally and are commonly utilized in various daily life products [53], including food packaging, toys, and agricultural films. Additionally, they are the most common polymers found in the Yangtze River Basin [44]. During the detection process, the identified PP or PP + PE polymers were mainly green or blue fragments, with thicker fragments potentially from food packaging or plastic labels and thinner fragments from disposable plastic bags. Furthermore, plastic fragments are brittle [54], and larger ones readily disintegrate into smaller fragments under natural conditions. The detection process revealed numerous PP or PP + PE fragments with morphological similarities within the same sample, indicating that these fragments may originate from the same plastic type.

Comparing the microplastic abundance at the same sampling point before and after construction, it was found that a significant amount of MPs were released during construction activities. In Wang's study of the Shanghai urban river network [55], construction activities were identified as the main source of abnormal increase of MPs at some measurement sites. Comparing the composition of MPs detected at T6 during the dry season, it was found that the content of artificial cellulose and PP + PE in the river increased significantly after construction. As workers live on construction sites and discharge their wastewater directly into the river, this leads to an increase in the content of artificial cellulose in the river. The increase in PP + PE may be due to some construction plastic waste not being properly disposed of. PP + PE with superior performance can be produced by modifying the brittleness of PP through the addition of PE [56]. This material finds widespread use in applications such as wire and cable insulation, hoses, roofing films, and water pipes due to its versatility and high-performance characteristics [57,58]. In addition, some mineral water bottles and food plastic bags discarded at construction sites may also be potential sources of microplastic pollution in the area.

5. Conclusions

MPs were widely distributed in the Lincheng River of Zhoushan Island and the abundance was at a moderate level. In water, the main shape of MPs was fiber and the main polymer type was CE. While in sediments, fragment was the highest proportion, and PP and PP + PE were the main polymer type. Based on the analyses, we conclude the following:

(1) Human activities played an important contribution to MPs in the Lincheng River, since the MP abundance in sediments was highly correlated with BDI. Rainwater pipes and discarded plastic products were the main sources of MPs in the river.
(2) Local construction activities can lead to an increase in the abundance of MPs.
(3) The abundance of MPs varied significantly with time. During the wet season, the abundance of MPs in water was higher than during the dry season, while in sediment, it was higher during the dry season.

High levels of MPs will have negative impacts on the health of organisms. Therefore, during special periods, the abundance of MPs in water should be monitored to avoid ecological impacts. In addition, when calculating the flux of MPs into the sea, the time periods should be fully considered.

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