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Vertical Profiles of Microplastics in the Hyporheic Zone Sediment: A Case Study in the Yangtze River, Nanjing Section

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Abstract: Microplastics are ubiquitous in the river environment, although their abundance in sediment profiles has received little attention. The river hyporheic zone (HZ) sediment is the area influenced by surface and groundwater flow dynamics, and pollutants are more likely to be transported vertically in this area, thus entering the groundwater. Understanding the microplastic abundance and composition in the HZ sediment is crucial for microplastic pollution management. Hence, this study investigated the vertical distribution and characteristics of microplastic in the HZ sediment of the Yangtze River (Nanjing section). The results show that the abundance of microplastics in the HZ sediment ranged from 207 ± 95 to 1817 ± 467 items/kg dry wet in a vertical profile. With the increase of sediment depth, the abundance of microplastics decreased obviously in most sites, whereas the proportions of pellet shapes and smaller sizes of microplastics increased only at S1. No significant variation was found in the microplastic colors between different depth layers. Polypropylene and polyethylene were the dominant polymer types in all sediment samples. These results provided insights into the understanding of the microplastic fates in a river HZ region.

Keywords: microplastic; hyporheic zone; vertical distribution; sediment

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1. Introduction

Due to their excellent properties, plastic products have been ubiquitously used in daily life. The annual production of plastic in 2019 was 460 million tons, which will further reach up to 1.23 billion tons in 2060 [1]. However, only 9% of plastic products were recycled globally [2], representing a large proportion of plastics that were released into the environment. These plastic wastes further fragmented into progressively smaller particle sizes due to various natural weathering and degradation processes, becoming microplastics with a diameter of less than 5 mm [3].

Microplastics have been ubiquitously detected in different natural waters, including seawater, surface water, groundwater, and even drinking water [4]. Due to small sizes, which are similar to phytoplankton, the microplastics in waters can be accidentally ingested by aquatic organisms, and even transferred through the food chain and intergeneration [5]. Moreover, microplastics can also act as carriers to enhance the transport of pollutants, pathogens, and antibiotic resistance genes in waters, causing serious risks to different organisms and ecosystems [6]. Hence, there is a rising concern regarding the occurrence and fate of microplastics in aquatic ecosystems, and microplastics have been regarded as globally emerging contaminants.

Among the aquatic environments, rivers play an important role in the transport of microplastics into the oceans [7]. It is estimated that more than 70% of terrestrial microplastics were transported to the ocean by global rivers [8]. In the Yangtze River Basin, rivers have been regarded as an important transport pathway of microplastics to lakes, including Taihu, Poyang, and Dongting Lakes [9]. The river seems to be heavily polluted by microplastics, especially located in the megalopolises. Once entering rivers, microplastics can transport along the river with water flow. Most of them may settle into the sediment under the influence of the microplastic's gravity and related environmental factors, such as attached algae, microorganisms, and sand [10]. As a result, river sediment becomes a temporary repository of sunken microplastics [11]. Microplastic abundance in surface sediment has been reported to be several orders of magnitude greater than that in surface water. The distribution of microplastics among river water and sediment appears to be different.

The river hyporheic zone (HZ) is the area of river sediment influenced by surface and groundwater flow dynamics, playing an ecologically essential compartment of fluvial ecosystems. Microplastics located in surface sediment are likely to vertically transfer in the HZ following hyporheic exchange flows [12], and then be vertically deposited in the HZ sediment. Recently, microplastics have been detected in different depths of sediment, and the abundance of microplastics located in deep sediment may be much higher than that in surface sediment. For instance, Frei et al. [13] found that the abundances of microplastics between 500–5000 µm extracted from the 40–60 cm sediment in the Roter Main River were higher than that in the surface sediment (0–10 cm). In the karst HZ of urban rivers in Southwest China, Jiang et al. [14] also detected a high abundance of microplastics in sediments, with the abundance ranging from 800 items/kg to 4400 items/kg. The hyporheic exchange in the HZ seems to dominate the transport of microplastics with a small size to deeper depths [15]. In addition to the water exchange, the benthic bioturbation in the HZ sediment may be also responsible for the vertical transport of microplastics [16]. Thus, the total abundance of microplastics in the sediment may be underestimated if their storage in the surface sediment is included only. It is necessary to investigate the vertical distribution of microplastics in the HZ sediment.

The Yangtze River, one of the largest rivers in the world, has been considered one of the largest plastic-export rivers in the world. In recent studies, microplastics have been detected in surface waters and sediments in the Yangtze River, from the Three Gorges Reservoir to the Yangtze Estuary [17,18]. However, research on the distribution of microplastics in the vertical profiles of sediment in this river is rare. For a better understanding of microplastic pollution in the Yangtze River, to the best of our knowledge, this is the first time the vertical distribution of microplastics in the HZ sediment in the lower reaches of the Yangtze River (Nanjing section) has been investigated. The objectives of this study were to: (1) document the abundance of microplastics in different sediment depths; (2) investigate the vertical variation of the microplastic characteristics, and (3) elucidate the spatial change in microplastic pollution in different river sites. Results gained from this study could provide a more comprehensive understanding of the fates of microplastic in rivers.

2. Materials and Methods

2.1. Sampling Sites

Nanjing is a central city in the lower reaches of the Yangtze River with more than 9.42 million permanent residents. The shoreline length of the Yangtze River in the Nanjing section is 186.55 km. The river is undergoing serious deterioration of water quality due to increasing urbanization. Four sampling sites were selected along the Yangtze River (Nanjing section), including three tributary confluences (S1–S3) and one drinking water source (S4). In these sampling sites, S1 was located in the confluences of the Yangtze River and New Qinhuai River, which is an artificial river dug in 1980 with a total length of 16.9 km. S2 was located near the confluences of the Yangtze River and Qinhuai River, which flows across the city center of Nanjing with a high population density of 21,000 people per square kilometer. S3 was located near the confluences of the Yangtze River and Jinchuan River, which receives domestic sewage and industrial wastewater year-round from the Chengbei wastewater treatment plant. S4 was located in the Yanziji drinking water source protection area, supplying 200,000 tons of drinking water per day to Nanjing City. The sampling sites are listed in Figure 1.

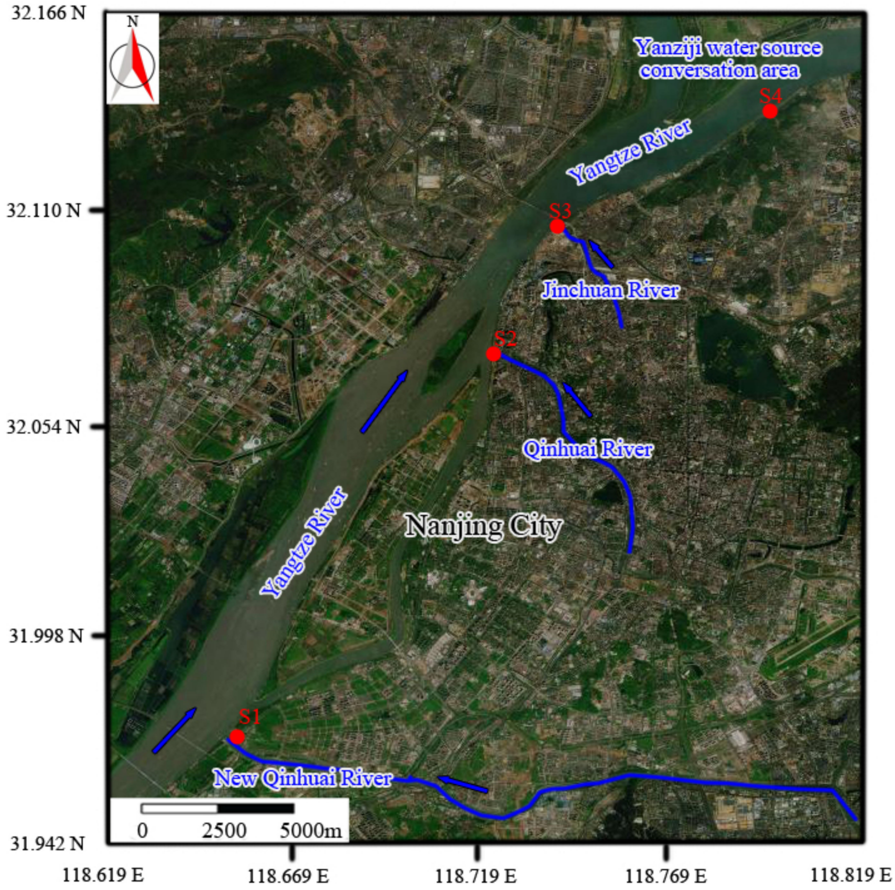

Figure 1. Location of sampling sites in the Yangtze River (Nanjing section).

2.2. Sample Collection

The sediment was sampled at each site on 4 January 2021 located in the low tide of the Yangtze River. The hydrological conditions of the Yangtze River (Nanjing section) were relatively stable during sampling periods. The sediment samples were collected using a push corer with a length of 0.5 m and a diameter of 40 mm with three replicates. The sampling process was kept slow to reduce the sediment compression. The samples were wrapped immediately with aluminum foil and then separated at 10 cm intervals in the sediment depth of 0–50 cm using a sterilized stainless-steel knife. Subsequently, all samples were placed in a portable cooler below 4 °C and transferred to the laboratory.

2.3. Sample Treatment

The separated sediments were freeze-dried for 48 h on a clean aluminum disk. After picking out leaves and other impurities with stainless steel tweezers, microplastics were floated from the sediment by density separation [19]. A total of 50 g dry sediment was transferred into a 1000 mL glass beaker containing saturated NaCl solution (1.20 g/cm^3) for density separation. The supernatant was then poured through a double stainless-steel screen (5 mm and 54 μm). Afterward, a saturated $ZnCl_2$ solution (1.5 g/cm^3) was added to separate high-density microplastics. All floatation procedures were repeated three times. After that, the sieved contents on the 54 μm screen were washed into a glass bottle and then treated with Fenton's reagent (0.05 M Fe (II) + 30% H_2O_2) at room temperature for 24 h to remove the organic substances in the samples. Afterward, the samples were diluted with ultrapure water and filtered with GF/A filter paper (Whatman, 5 μm) under a vacuum. All filter papers were collected for further observation.

2.4. Observation and Identification of Microplastics

The microplastics were observed with an Olympus stereomicroscope (SZX10) with a magnification of up to × 100. The digital images of all microplastics were captured by a camera connected to the stereomicroscope. The microplastics were then classified according to abundance, shape, color, and size. According to the morphological characteristics, the microplastic shapes were divided into fiber, pellet, foam, and fragment. The color of microplastic particles was recorded according to the color of their surface. The size of the microparticles was measured on the longest dimension of the image, and divided into <0.2 mm, 0.2–0.5 mm, 0.5–1.0 mm, and 1.0–5.0 mm. In this study, the microplastic abundance of sediments (dry weight, dw) was represented by the particle number (items/kg dw).

The polymer types of microplastics were determined using the micro-Raman spectrometer (iHR320, Horiba, Kyoto, Japan). Following randomly selected a certain amount of suspected microplastics (10%). For each microplastic sample, three micro-zones were randomly selected and averaged to obtain a final estimate. Due to the unavoidable physical and chemical effects of sediment, the structure of microplastics may be distorted. Hence, the polymer types of microplastics were determined based on a 70% similarity between the measured spectra and the standard spectra database.

2.5. Quality Control

To minimize microplastic pollution from different environments, such as air, clothes, or instruments, some preventive measures were carried out according to the previous study [19]. During the sample processes, nitrile gloves and cotton lab coats were worn. All sampling instruments were rinsed with filtered deionized water before and after use to minimize potential cross-contamination. All reagents, such as ultrapure water, flotation solution, and Fenton reagent, were filtered through 0.45 µm filter papers (GF/C, Whatman) before use. The extraction and observation of microplastics were taken in a fume cupboard to minimize air pollution. In addition, blank controls were also carried out during the processing of microplastics in the laboratory. Only a small abundance of microplastics was detected in blank samples (0.14 items/L), and the experimental data were corrected based on the blank experiment.

2.6. Data Analysis

Data processing and analysis were implemented using SPSS 22.0 software and all results were expressed as mean ± standard deviation. The Shapiro–Wilk and Levene tests were used to determine the homogeneity of variances and normality of data. Afterwards, Dunnett's test in a one-way ANOVA was used to test the significance of the data, and the significance level was $p < 0.05$.

3. Results and Discussions

3.1. Spatial Distribution of Microplastics in the Surface Sediment

In the middle and lower reaches of the Yangtze River, microplastics have been widely detected in waters, including the Three Gorges Reservoir, Wuhan city, and the estuary, and high abundances were usually observed in the reservoirs and cities, especially in the metropolis [9,17,18,20]. These microplastics will be inevitably settled in sediments, leading to a high abundance of microplastics in the sediment of the Yangtze River. In this study, microplastics were detected in all surface sediment samples (0–10 cm) at four sites in the Yangtze River, Nanjing section, with an abundance ranging from 613 ± 121 to 1073 ± 266 items/kg dw (Figure 2). This abundance was comparable to that in the surface sediment of Poyang Lake and Taihu Lake [21,22]. Similar abundances of microplastics were also found in the sediment of the Thames River in the UK and the Bloukrans River in South Africa [8,11]. Compared to the high abundance of microplastics detected in the sediment of Wen-Rui Tang River in China (32,947 ± 15,342 items/kg) [23] and Rhine-Main River in Germany (11,070 ± 600 items/kg) [24], the detected microplastics in this study were much lower. In particular, an extremely high abundance of microplastics in sediments was recorded in urban water in Norway, with the highest abundance of 200,000 items/kg [25]. The different microplastic pollution may be attributed to the different population densities and anthropogenic activities in each region, as reported by Wang et al. [20]. In addition, the standards of life and lifestyle in different regions or cities also control the distribution of microplastics in different environments [26]. Effluent from the nearby sewage treatment plant (STP) might be also an important source of microplastics in these waters which eventually settles into the sediment. In similar urban rivers, the abundance of microplastics in the karst HZ sediments was two times higher than that in this study, since the transport of microplastics in the karst HZ was extremely rapid [14]. However, the low abundance of microplastics in the Qinhuai River in Nanjing City suggests that microplastics in sediment could be effectively removed by dredging [27].

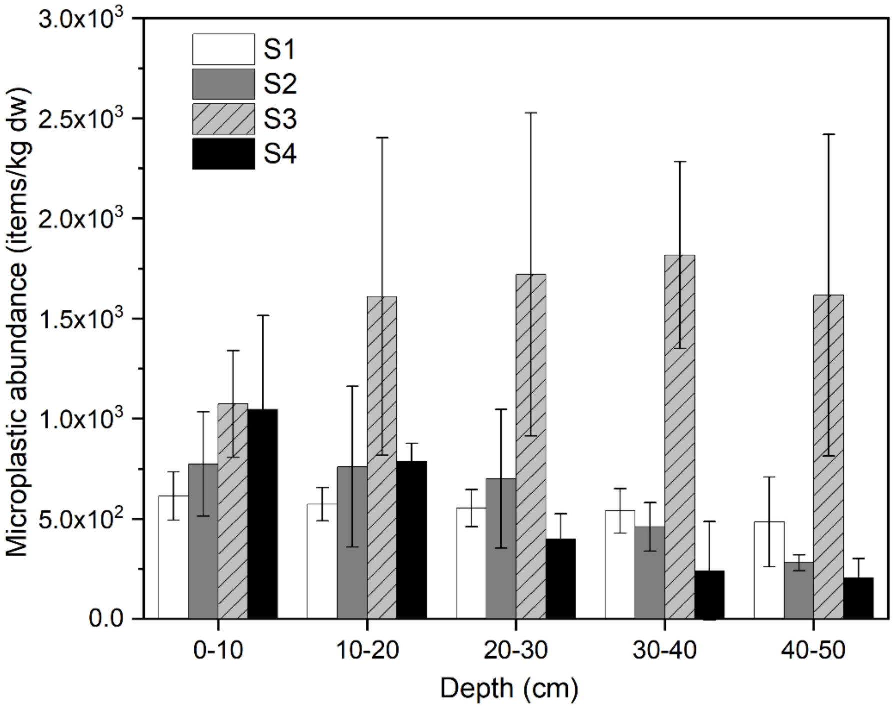

Figure 2. Distribution of microplastics in the hyporheic zone of the Yangtze River (Nanjing section).

Spatially, the distribution profiles of microplastics in the surface sediment generally presented an increasing trend along the river, with the abundance ranging from 613 ± 121 items/kg at S1 located in the upstream area to 1047 ± 469 items/kg at S4 located in the downstream zone (Figure 2). Our previous study also found an increase in the microplastic abundance in the sediment along the Qinhuai River [19]. Indeed, microplastics can be transported by rivers from the upstream to the lower reaches. Meanwhile, microplastics can also sink in the sediment depending on their density, shape, and biofouling [28]. Hence, the downstream sediment of rivers always has a high accumulation of microplastics. In this study, both S1 and S2 are located in the river confluence of the Yangtze River and New Qinhuai River and Qinhuai River, respectively. Since the two rivers have been heavily polluted by microplastics, it is not surprising the high abundance of microplastics in the sediment of the river mouth, and tributaries were considered relevant contributors of microplastics to main rivers. In addition, the Qinhuai River runs through the city of Nanjing, which may bring more microplastics into the Yangtze River due to the extremely high anthropogenic activities and population densities in the urban areas. S3 is located in the confluence of the Yangtze River and Jinchuan River and is dominated by the effluent of the Chengbei STP, Nanjing. Given that STPs have been regarded as the prominent point sources of microplastic pollution in waters [29], it could be inferred that the high abundance of microplastics in the sediment located at S3 may be partly attributed to the discharge from the STPs. In particular, the highest microplastic abundance was observed in the surface sediment at S4, which is located in the water source conservation area with fewer human activities. Hence, the residue of microplastics in this site may be mainly transported from upstream of the Yangtze River, and then deposited in the sediment under the influence of different physicochemical factors. Meanwhile, the spatial distribution of microplastics in the sediment may be also influenced by the water dynamics in rivers, including the water follow and direction. In a previous study, water dynamics have been regarded as the driving forces of plastic transport in waters [30], which may further alter the spatial distribution of microplastics in sediments. In different sampling sites, the water dynamics of the river may be significantly different due to the feed of different tributaries, which may be also responsible for the spatial distribution of microplastics in the sediment. Furthermore, the transport of microplastics in sediments was also dominated by the mean grain size of the hyporheic sediment matrix, as well as the microbenthic and macrobenthic organisms in sediments [31]. Hence, further study should also focus on the composition and bacterial populations of the sediments.

3.2. Vertical Distribution of Microplastics in the HZ Sediment

The vertical distribution profiles of microplastics in the HZ sediment are shown in Figure 2. At S1, S2, and S4, the highest microplastic abundance was generally observed in the upper layer of sediment (0–10 cm), and then decreased as the sediment depth increased. The microplastic abundance in the upper layer accounted for 14–39% of the whole microplastics in all layers (0–50 cm) in the same site. It suggests that the abundance of microplastics in the non-surface sediment (10–50 cm) was significantly higher than that in the surface sediment (0–10 cm). Similar vertical distribution of microplastics in sediment has been reported in different waters. For instance, Wang et al. [32] found that the microplastic abundance in different sediment layers in the South Yellow Sea decreased from 2143 items/kg in the surface sediment to 471 items/kg in the bottom layer. The abundance of microplastics in Ulansuhai Lake also significantly decreased with the increase in sediment depth [33]. Xue et al. [34] demonstrated that the microplastic abundance in the non-surface sediment in the Nanliu Lake was eightfold higher than that in the surface sediment. Given that the age of the sediment in waters always increases with the depth of sediment [35,36], the vertical distribution of microplastics in sediment showed a certain time trend, and its abundance increased with the increase of time. Hence, the vertical microplastic distribution in sediment may be consistent with the settlement ratios of microplastics and the growth rate of plastic production. In addition, the history of human activities' growth and the types of these activities could also affect the long-term deposition of microplastics in sediment, and the sediment dynamic and sediment accumulation rate may also alter the microplastic behavior, which could be clarified through the sediment chronology [37]. Hence, a radiometric dating approach should be used to estimate the sediment chronology in further study. But at S3, the highest abundance of microplastics was detected at a deeper depth of 30–40 cm, which was 1.7-fold higher than that in the surface sediment. Niu et al. [27] also found that microplastics presented vertical profiles in river sediment, and the mean abundance of microplastics increased from the shallow layers to the deep layers of sediment. This may be caused by the influences of hyporheic exchange and benthic bioturbation in the HZ sediment, which led the microplastics to settle vertically from surface sediment into deeper sediment. Previous studies have shown that the transport of particulate pollutants in river sediment could be significantly affected by both water exchange and bioturbation [38,39]. These results suggest that river HZ sediment might be an important pathway to transport microplastics from surface water into groundwater. In addition, the total storage of microplastics in the deeper sediment was 1.6 to 6.3-fold higher than that in the surface sediment, suggesting the distribution of microplastics in deeper sediment may pose a large risk to benthonic organisms and groundwater. Thus, the high microplastic residuals in the bottom sediment could not be neglected.

3.3. Morphological Characteristics of Microplastics along Sediment Depth

3.3.1. Vertical Distribution of Microplastic Shape

According to the visual results, the microplastics in sediment were divided into four shapes, including fiber, pellet, foam, and fragment. The proportions and photographs of each shape in vertical sediment are shown in Figure 3. The average abundance of pellet and foam microplastics in the four sites was the highest in most of the sediment layers, followed by fiber microplastics, whereas fragments were detected sporadically in all sediment layers. Pellet microplastics may mostly come from the industrial raw materials used in daily personal care products and plastic products. The foam microplastics in sediment possibly came from the fragmentation of large packaging boxes by physical and chemical forces [19]. The appearance of fiber microplastics in this study was thin and long, which may come from clothing and fishing [17]. Fragments microplastics were mostly fragmented from woven bags, packaging materials, and plastic containers. Zhou et al. [26] found that the highest content of microplastic in the sediment of the Fuhe River estuary was fragment shape, followed by fiber microplastics. The difference between these studies may be caused by the regional conditions. In these shapes, the pellet and foam are important because they are ovoid or cylindrical, which might have a deeper transport depth in the sediment than the fiber and fragment.

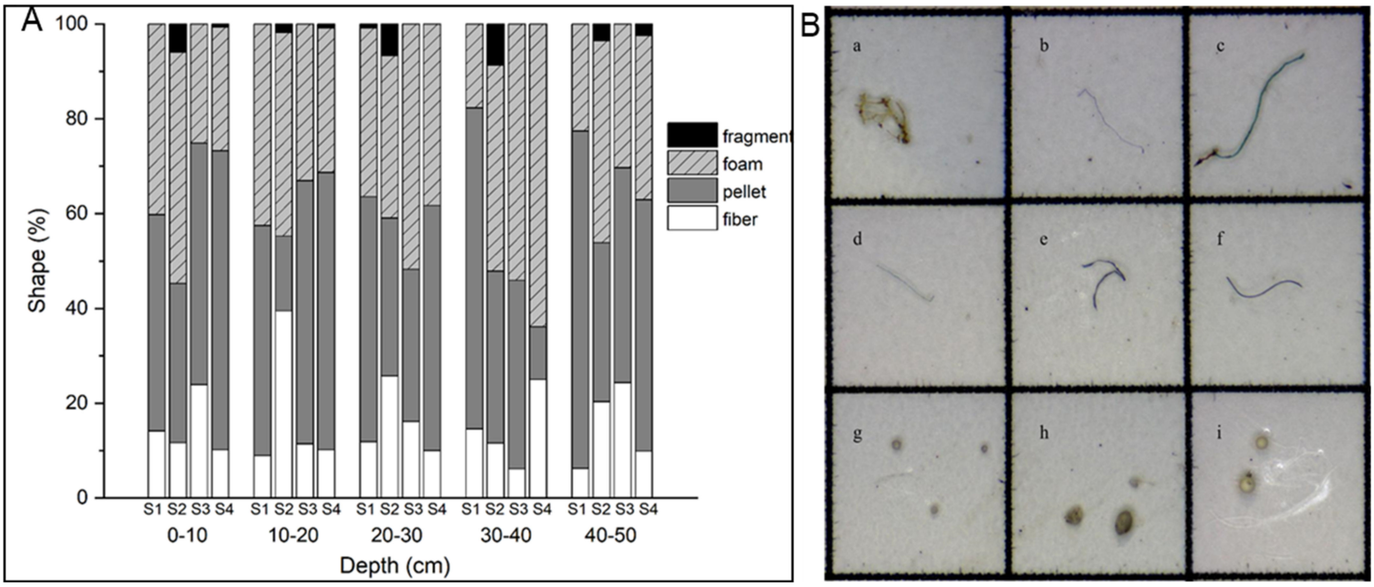

Figure 3. Proportion (**A**) and photograph (**B**) of different microplastic shapes (**a**–**i**) in the hyporheic zone sediment, and the square is 3 mm × 3 mm.

Spatially, the proportions of pellets increased with the increase of depth at S1, with the rates ranging from 45.65% to 71.19%. On the contrary, the abundance of foam microplastics at S1 showed a decreasing manner along sediment depth. At the S2 site, the main microplastics was foam, which was heterogeneously distributed in different sediment layers, as well as the pellet. In addition, the main microplastic shapes at S3 and S4 were also pellet and foam, showing a heterogeneous distribution in the vertical sediment. Given the pellet microplastics were easier to sink and vertically transport in the sediment due to their relatively larger density and ovoid, it is no surprise that this results in high storage in deeper sediment. However, for foam microplastics, which were from expanded lightweight polystyrene, polyethylene, and polyvinyl chloride, their vertical distribution in the sediment may be caused by natural settling. Foam microplastics can have their settling ratio into sediment enhanced by the microorganisms that easily attach to them [28]. In deep sediment, the frequent hyporheic exchange and benthic bioturbation in the HZ sediment would further influence the vertical distribution of microplastics.

3.3.2. Vertical Distribution of Microplastic Color

The observed colors of microplastics in the vertical sediment in this study mainly included white, transparent, yellow, red, blue, and black (Figure 4). Among them, transparent (27.78%~75.00%) and white (17.71%~63.89%) were the dominant colors, with a sum contribution of more than 90%. The high-frequency detection of transparent and white microplastics in the HZ sediment may be related to the large storage of pellet and foam microplastics, which were generally white and transparent. Moreover, the colored microplastics in sediment could fade, which may contribute to the presence of transparent and white microplastics in sediment [19]. Martí et al. [40] also reported that the most abundant colors of plastics in the ocean were white and transparent/translucent (47%), which may be caused by the longer oxidative degradation in nature. A similar result has been confirmed by Dai et al. [41], who found that the white microplastic in the sediment of the Bohai Sea was the dominant color. In addition, other colors were also detected, but the proportion was relatively low (<10%), which may mainly come from the colored fiber and fragment. In the vertical sediment, there was no obvious color distribution in different layers. It is significant to detect the distribution of microplastic colors in aquatic environments. Yan et al. [19] found that the visual characteristics of microplastics could affect their ingestion by fish, especially the color. The discoloration of microplastics may lead to the leaching of the dyes that they contain, which further induced toxicity in *Physalaemus cuvieri* tadpoles [42].

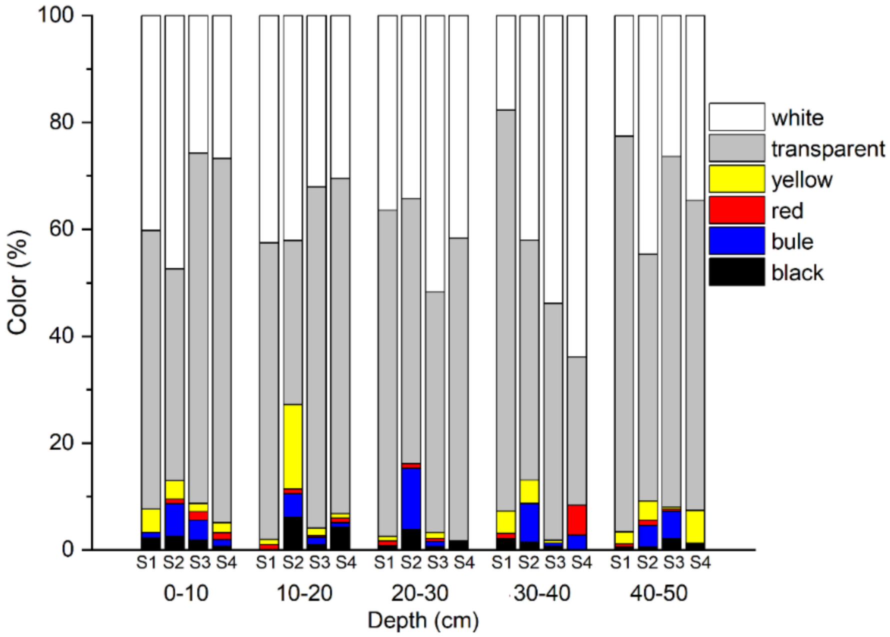

Figure 4. Proportions of microplastic colors in the hyporheic zone sediment.

3.3.3. Vertical Distribution of Microplastic Size

Given that there is no clear standard to classify microplastic size, microplastics in this study were divided into four categories according to previous studies [19,26], and the proportion of each size is shown in Figure 5. Among them, microplastics with a size of less than 0.2 mm accounted for the largest proportion of all sediment samples, with an average level of 80% at each site. After the smallest size, the abundance of 0.2–0.5 mm microplastics only accounted for 4.31–16.74% of the total microplastics. This result is consistent with previous studies, in which the small size of microplastics was also dominant in the sediment [27]. Microplastics with small sizes are especially easy to aggregate with other microplastics and natural colloids, showing an increased possibility of sedimentation [43].

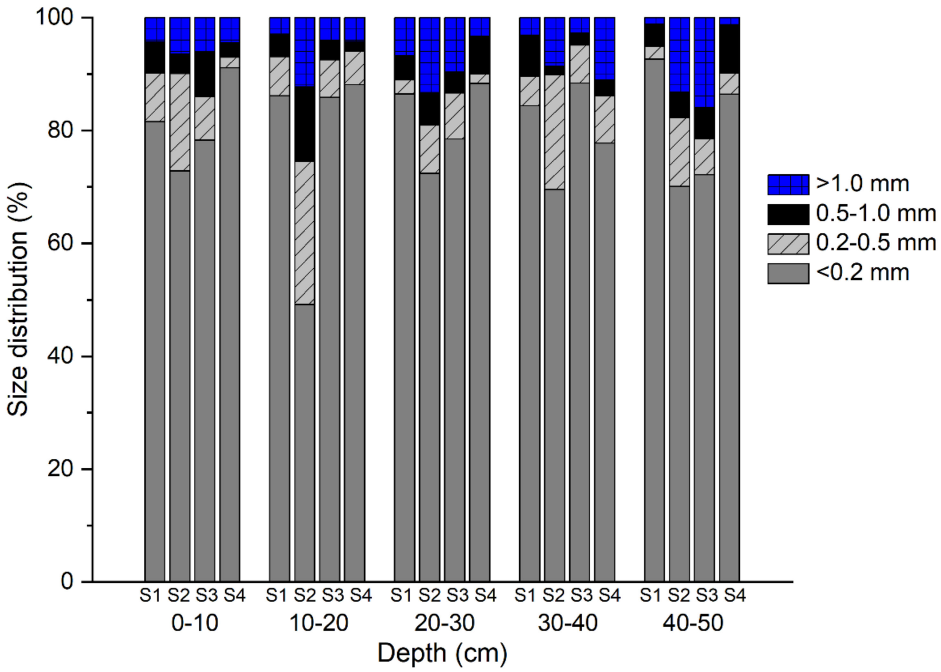

Figure 5. Proportions of particle size of microplastics in the hyporheic zone sediment.

Vertically, the proportion of microplastics with small sizes (<0.2 mm) at S1 increased with the increasing sediment depth, indicating that the deeper sediment at S1 was dominated by microplastics with smaller sizes. Similarly, Niu et al. [27] found that microplastics presented a regular vertical profile in the sediment of the Qinhuai River, and smaller microplastic particles were dominant in deeper layers. The high proportion of microplastics with small sizes in the deep sediment may be mainly related to the long-stay storage of this debris at depth, which could be fragmentized into large ones with small sizes over a long period. However, at site S4, the proportion of microplastics with small sizes decreased with the increase in depth (0–40 cm). This difference may be caused by the distinct hydrological characteristics of the two sites. At S2, the 0.2–0.5 mm microplastics presented a relatively higher proportion in each layer. These findings suggest that the vertical profiles of microplastic sizes in the HZ sediment are complex, which may be related to regional conditions, hydrological characteristics, and benthic activities.

3.4. Polymer Types of Microplastics

Five polymer types of microplastics were observed in the HZ sediment sampled from the Yangtze River (Nanjing section), including polypropylene (PP), polyethylene (PE), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). The proportions of each polymer type and non-plastic based on the Raman spectra are shown in Figure 6. The most common polymer types in sediment were PP and PE, with the sum proportions of 58–64%. A similar composition of microplastics in the sediment has been detected in the Yangtze River [9,17]. PP and PE are common types of plastics in daily life due to their superior stabilities and corrosion resistance and are frequently used in storage containers, plastic bags, and synthetic fibers. In addition, PP and PE pellets are also commonly used in skin care products, toothpaste, and other daily necessities [44]. The large demands of PP and PE inevitably lead to their huge discharge into waters, which may contribute to their high proportion of sediment. Behind PP and PE, PS was one of the common polymers of microplastics (6.64–23.78%). In general, PS is used in disposable foam lunch boxes and personal skin care products. Given the low density of PP, PE, and PS, they are possibly difficult to settle in waters. However, it does not mean the final vertical distribution in sediment. In addition to the density, the settlement of microplastics in waters may be also related to their shapes and surface area [45]. The water flow dynamics and biofilm colonization could also enhance their settlement into sediment [46]. PVC (1.38 g/cm^3) and PET (1.37 g/cm^3) with high density were also detected in the sediment. Their low proportions in the sediment suggest that both PVC and PET may not be produced on a large scale in this area or high removal by STP.

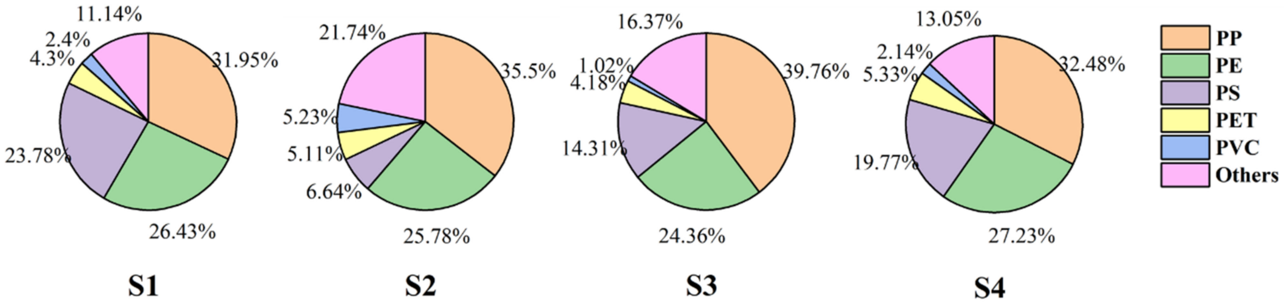

Figure 6. Polymer types of different microplastics in the hyporheic zone sediment.

3.5. Environmental Implication of Vertical Microplastic Distribution

Generally, the vertical distribution of microplastics in sediment is the result of their long-term sedimentation, reflecting the pollution status of microplastics in different periods in the aquatic environment. Since the abundance of microplastics in deeper sediment may be extremely greater than that in surface sediment, it suggests the studies only focus on the microplastics in the surface sediment may underestimate their total storage in sediment. Therefore, more attention should be paid to the vertical distribution of microplastics in different sediment layers.

In addition, the HZ sediment is an important habitat for various invertebrates, and benthic organisms living in this zone may face a much longer exposure time to microplastics due to their long retention in the HZ sediment. Thus, the vertical distribution of microplastics in the HZ sediment may pose a complex risk to benthic organisms. On the other hand, the bioturbation of benthic organisms could also alter the transport of microplastics in the sediment, further influencing their vertical distribution in the HZ sediment. Thus, further research is needed to focus on the interaction between microplastics and benthic organisms in sediment. Moreover, the vertical distribution of microplastics in the HZ sediment is complex and may be influenced by different factors, such as the morphological characteristics of microplastics, the heterogeneous properties of the sediment, and the hyporheic exchange, which needs to be further studied.

4. Conclusions

In this study, the vertical distribution of microplastic in the HZ sediment of the Yangtze River (Nanjing section) was investigated. Microplastics were detected in all sediment layers, with the abundance ranging from 207 ± 95 to 1817 ± 467 items/kg dw. The average abundance of microplastics decreased obviously from the surface layer to the deep layers of sediment in most cases, showing a vertical profile in the HZ sediment. With the increase of sediment depth, the proportions of pellet shapes and smaller sizes of microplastics increased at S1. PP and PE were the dominant polymer types in the river sediment, and the colors were mainly transparent and white. There are no significant differences in the microplastic colors in different depth layers. Tributaries and domestic wastewater were regarded as relevant contributors of microplastics to the sediment, and the benthic bioturbation and hyporheic exchange in the HZ sediment may further influence the vertical profile of microplastics. This study focused on plastic waste in aquatic environments and provided new insight into the challenges relating to the sustainability of plastic. Further studies on the transport of microplastics in the HZ sediment and the related risks are required. Since human activities and sediment dynamics may also influence the vertical distribution of microplastics in sediments, the radiometric dating approach should be included to estimate the sediment chronology in future studies. In addition, there is an existing knowledge gap about plastic waste sources, which plays an important role in plastic waste management projects, strategies, policies, and regulatory frameworks [47,48]. Hence, a depth understanding of regional and sectorial plastic waste is needed. Additionally, a regulatory framework is needed to reduce plastic emissions during chain production [49]. Meanwhile, the transport paths and accumulation points of microplastics should be also addressed in a management effort.

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