Journal of Mining and Earth Sciences

Website: https://jmes.humg.edu.vn

Assessment of the status of microplastic distribution in surface water and water column in the dry season at the Cai river estuary (Khanh Hoa)

Khoi Dang Le Ta [1], Van Thu Thi Vu [2], Ve Van Dam [3], Huong Thu Thi Tran [4,*]

[1] *Center for Advanced Technology Research and Development, NhaTrang University, Vietnam*
[2] *Vietnam Environmental Incident Response Center, Hanoi, Vietnam*
[3] *Northern Center for Environmental Monitoring, Hanoi, Vietnam*
[4] *Hanoi University of Mining and Geology, Hanoi, Vietnam*

ARTICLE INFO

Article history:
Received 18th Apr. 2026
Revised 29th June 2026
Accepted 09th July 2026

Keywords:
Column water,
Distribution,
Estuary,
Microplastic,
Surface water.

ABSTRACT

Microplastics (MPs) pollution has been identified as a significant environmental concern in various ecosystems, including estuarine and coastal waters. In this study, 12 water samples including 06 surface samples (NT_NM) and 06 column water samples (NT_CN) from the Cai River estuary (Khanh Hoa) were collected during the dry season 2024 to analyze and compare. Microplastic distribution status was determined by two methods including Stereomicroscope and FTIR system. Microplastic characteristics are based on quantity, shape, size, color, and polymer composition. Total Microplastic particles abundance in column water (94 MPs/L) was consistently lower than in surface water (105 MPs/L). Microfragments and microfibers of smaller size classes predominated. Green was the most common color with values of 43.13% in surface water and 50.95% in the water column, followed by white, red, black and other colors. The number of polymers was 5 types in surface water samples and 7 types in column water samples. Polyethylene terephthalate (PET) and nylon accounted for the highest proportion of all samples. This result shows that human activities and geographical location characteristics influence the density of microplastic occurrence.

*Corresponding author
E - mail: tranthithuhuong@humg.edu.vn
DOI: 10.46326/JMES.2026.67(4).04

1. Introduction

Plastics are synthetic or semi-synthetic solid materials primarily composed of high-molecular weight polymers, often supplemented with additives to enhance performance and reduce production costs. The plastics industry classifies these materials into major groups such as LDPE, HDPE, PP, PVC, and PET (Besseling, 2018). Owing to their superior properties and low production costs, global plastic production has increased steadily over time. Plastic waste progressively degrades into microplastics that accumulate in water, sediments, and biota, thereby adversely affecting the environment, ecosystems, and ultimately human health (Andrady & Neal, 2009).

According to ECHA (2021) and NOAA (2015), microplastics are plastic particles smaller than 5 mm, originating from various sources such as cosmetics, textiles, packaging, and industrial activities. They are generally classified into primary microplastics, which are directly manufactured for use in products such as textiles, personal care products, and containers (Boucher et al., 2017; Kovochich et al., 2021), and secondary microplastics, which are formed through the degradation of larger plastic items via natural weathering processes after entering the environment.

Rivers play a critical role in transporting plastic waste from land to the ocean, accounting for an estimated 80% of marine debris in Vietnam. It has approximately 112 coastal estuaries from north to south, which act as major pathways for plastic discharge into the ocean and pose potential risks to estuarine ecosystems. In Vietnam, many studies have reported microplastic contamination in aquatic environments (Lahens et al., 2018; Nguyen et al., 2019; Strady et al., 2020). However, research on the microplastic distributin status in coastal estuaries of the South-Central region, particularly in both surface water and the water column, remain limited.

Rivers significantly contribute to microplastic pollution in the oceans due to their connectivity with estuarine and marine systems. Moreover, residential activities along riverbanks and various discharge sources into rivers pose potential risks to ecosystems, facilitating the accumulation of plastics and microplastics in the water environment and subsequently in bottom sediments. Therefore, assessing microplastic contamination in the aquatic environment during the dry season at the Cai River estuary (Khanh Hoa) is necessary to fill current knowledge gaps and provide a scientific basis for environmental management measures.

2. Methodology

2.1. Characteristics of sampling area

Khanh Hoa is a coastal province located in the central South Central Coast region of Vietnam, featuring three major river systems: the Cai River (Nha Trang), the Dinh River (Ninh Hoa), and the To Hap River, along with several smaller independent streams. The Cai River represents the largest interprovincial river basin in Khanh Hoa Province, with a catchment area of 1,732 km^2 and a total length of 84 km. Flowing through areas characterized by diverse socio-economic activities, the river receives substantial quantities of waste with complex composition, which are ultimately discharged into the Cai River estuary. Six sampling poisitions (Figure 1 and Table 1), extending from the Kim Bong River to Nha Trang Bay, were selected at locations characterized by significant discharge sources or activities associated with plastic waste generation and disposal.

2.2. Sampling method

The collection of microplastics in water surface and water column followed established methodologies (Masura et al., 2015). A Neuston net (mesh size: 300 μm) was attached to a collection frame or a Manta trawl (dimensions: 30×30×15 cm) equipped with a flow meter to quantify the volume of water filtered during sampling. Sampling devices were secured to a boat at designated locations, and the collection frame was deployed at the water surface to capture floating materials and particles within the water column, including plastic debris and other suspended solids. The Neuston net was operated for a duration of 30÷60 minutes. Sampling was conducted during the dry season of 2024. Collected samples were preserved at 4^{0}C in amber glass bottles, including 6 surface water (NT_NM) and 6 column water samples (NT-CN) and transported to the laboratory on the same day.

2.3. Analysis method

Figure 1. Area study.

Table 1. Characteristic of sampling position.

No.	Position	Code	Coordinates	Characteristic
1	Near Ngoc Thao Bridge	NT1	12°15'41"N; 109°11'17E"	Urban residential areas on both banks; well-mixed water; confluence flowing into the Cai River.
2	Kim Bong intersects with Cai River	NT2	12°15'35"N; 109°11'10"E	Surrounded by residential areas, receive urban wastewater, water is dark with foul odor.
3	Doan Ket Slope	NT3	12°15'32"N; 109°11'29"E	Residential areas on both banks, one side fishing village, the other a river embankment.
4	Near Tran Phu Bridge	NT4	12°15'37"N; 109°11'52"E	Estuarine zone where the Cai River discharges into Nha Trang Bay.
5	Xom Bong Bridge	NT5	12°15'47"N; 109°11'1744"E	Predominantly residential areas near Ponaga Tower; one bank with embankment, hotels, and housing, the other mainly residential.
6	Cham Pa Bridge	NT6	12°15'46"N; 109°11'34"E	Mixed land use: eco-tourism area on one side and residential area on the other.

The samples transported to the laboratory for analysis. Since this method is yet defined following Vietnam regulations, then we used the analysis method according to the published by Masura et al., (2015). The analytical procedure is summarized in the following diagram Figure 2.

2.4. Statistic

GraphPad 6 and Original 2019 were used statistically analyze and process the data for this study.

3. Results and discussion

3.1. Microplastics distribution by density

The results of total microplastic density at the Cai River estuary (Khanh Hoa), presented in Table 2, indicate the presence of microplastics at all six sampling sites. Overall, microplastic density in surface water samples was higher than in the water column, with values ranging from 94 to 105 MPs/L. The lowest value was recorded at NT1 position for the water column and NT3 for surface water (3 and 7 MPs/L, respectively). The highest density was

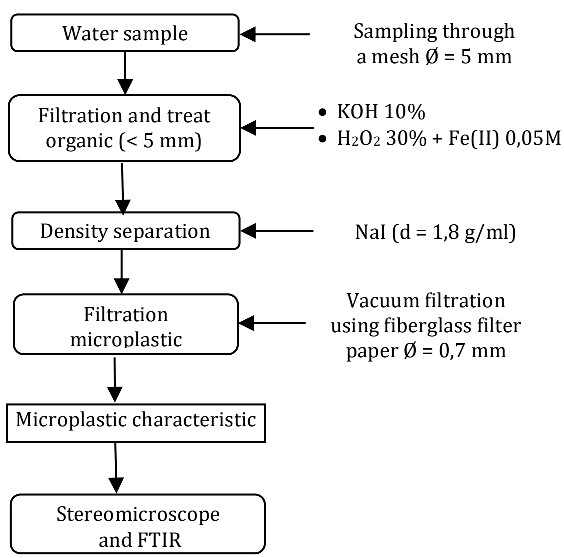

Figure 2. Steps for treating microplastics in water samples.

observed at NT2 position for column water and NT5 for surface water samples, with corresponding values of 36 and 22 MPs/L. The occurrence of microplastics in both group samples at the Cai River estuary (Khanh Hoa) is likely associated with domestic activities and service-related operations along both riverbanks, which contribute to plastic waste discharge into the river.

Table 2. Microplastic density in water samples at Cai River estuary (Khanh Hoa).

No.	Code	Density (MPs/L)	
		NT_NM	NT_CN
1	NT1	19	3
2	NT2	20	36
3	NT3	7	14
4	NT4	18	19
5	NT5	22	7
6	NT6	19	15
	Total	105	94

3.2. Microplastics distribution by size

Size classification results identified five microplastic categories (Masura et al., 2015): <200, 200÷500, 500÷1000, 1000÷1500 and >1500 µm (Table 3). The smallest fraction (<200 µm) was dominant in both sample groups, with density of 47 and 57 MPs/L in surface and water column, respectively. The >1500 µm fraction showed the lowest density in the water column (2 MPs/L), whereas in surface water, the 1000÷1500 µm fraction exhibited the lowest value (5 MPs/L). Microplastic size distribution was heterogeneous, with several sampling sites showing no detectable microplastics in certain size classes.

3.3. Microplastics distribution by shape

Microplastic shapes, including fibers, fragments, pellets, and other forms, were identified in water samples collected from the Cai River estuary. The distribution of shape categories differed notably between the two sample groups. In surface water, four morphotypes were recorded: fibers, fragments, pellets, and others. In contrast, water column samples contain fragments, fibers, and other forms, while pellets were not detected. In surface water, fibers were dominant (49.1%), followed by fragments (40.8%). Similarly, fibers accounted for the highest proportion in the water column (64.97%), whereas fragments represented 34.57%. The remaining categories-pellets and other forms-occurred at much lower proportions, ranging from 0.46% (water column) to 7.7% (surface water) across the two sample types (Figure 3).

Table 3. Number of microplastics in water samples at the Cai River estuary (Khanh Hoa), categorized by particle size.

Code	< 200 µm		200÷500 µm		500÷1000 µm		1000÷1500 µm		> 1500 µm	
	NT-NM	NT- CN	NT-NM	NT-CN	NT-NM	NT-CN	NT-NM	NT-CN	NT-NM	NT-CN
NT1	10	1	3	2	3	0	0	0	3	0
NT2	7	12	6	12	5	7	2	4	0	1
NT3	3	10	0	2	3	1	0	1	1	0
NT4	11	18	6	1	0	0	0	0	1	0
NT5	9	5	6	0	3	1	2	0	2	1
NT6	7	11	2	1	5	3	2	0	3	0
Total	47	57	23	18	19	22	6	5	10	2

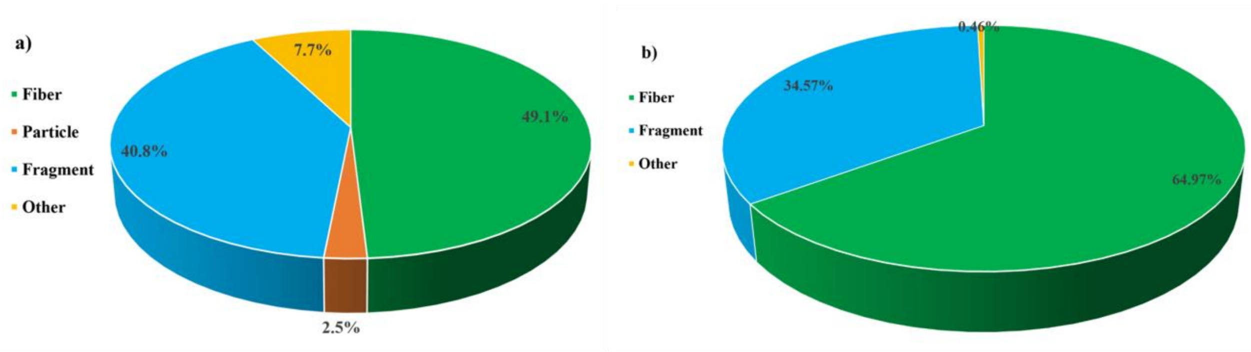

Figure 3. Ratio of microplastic shapes (Fiber, fragment, particle and other) in surface water (a) and column water (b) at Cai River estuary (Khanh Hoa).

3.4. Microplastics distribution by colour

The identified microplastics exhibited a range of colors, including transparent, white, black, green, red, and brown. Among these, white and green were the most prevalent and consistently dominant across all sampling sites. Overall, green accounted for nearly half of the detected particles, representing approximately 43.13% in surface water and 50.95% in the water column. White was the second most abundant color, followed by black, red, and other colors. In surface water samples, the respective proportions were 26.67, 5.87, 3.94, and 19.9%, while in water column samples, they accounted for 27.15, 14.31, 5.55, and 2.51%, respectively (Figure 4).

3.5. Microplastics distribution by polymer

The polymer composition analysis indicated the presence of microplastics at 5 out of 6 sampling positions in surface water samples (no polymers were detected at NT2 position). A total of five polymer types were identified, including PET, Nylon, Polyester, Polyethylene, and Melamine-urea-formaldehyde resin. Among these, Nylon and Polyester were the most abundant. Nylon microplastics were detected at 4 out of 6 positions (NT3, NT4, NT5, and NT6), while Polyester and Melamine-urea-formaldehyde resin were found at 3 out of 6 positions. At NT1 position, only Polyester was detected, whereas at NT4 both Polyester and Nylon were present, with Polyester being more dominant (57.14 and 42.86%, respectively). NT3 position contained three polymer types-PET, Nylon, and Melamine-urea-formaldehyde resin-in equal proportions (33.33%). At the remaining positions (NT5 and NT6), Nylon was dominant, accounting for 64.29 and 50%, respectively (Figure 5).

For water column samples, seven polymer types were identified: PET, Nylon, Polyester, Olefin, Polytetrafluoroethylene, Polypropylene homopolymer, and Cellophane. Nylon was the most frequently occurring polymer, detected at 4 out of 6 positions with the highest overall abundance. Specifically, Nylon accounted for the largest proportion at NT1 and NT3 (50%), while PET dominated at NT2 and NT6, with proportions of 55.56 and 40%, respectively. At NT4 position, two polymer types-Olefin and Polyester-were present in equal proportions (50% each). At NT5 position, only one polymer type (Olefin) was detected in the water column samples (Figure 5).

3.6. Discussion

The results indicate that microplastic distribution status in the riverine aquatic environment varies significantly among sampling sites and between sample types at the Cai River estuary. Similar findings have been reported in previous studies (Manh et al., 2022; Alam et al., 2019). High microplastic abundances have been observed in estuaries worldwide, such as 8,902 MP/m^3 in the Pearl River estuary, China (Hernandez et al., 2017), and 98, 246, and 1,032 MP/m^3 in the Clyde, Bega, and Hunter estuaries, Australia (Yan et al., 2019). Various microplastic morphotypes-including fibers, fragments, pellets, and films-have been reported in estuarine environments, with fibers and fragments typically dominating (Hitchcock & Mitrovic, 2019). Lenaker et al. (2019) also suggested that during transport from emission sources to estuaries, ports, or reservoirs, microplastic concentrations tend to be higher in surface layers compared to the water column (Lenaker et al., 2019).

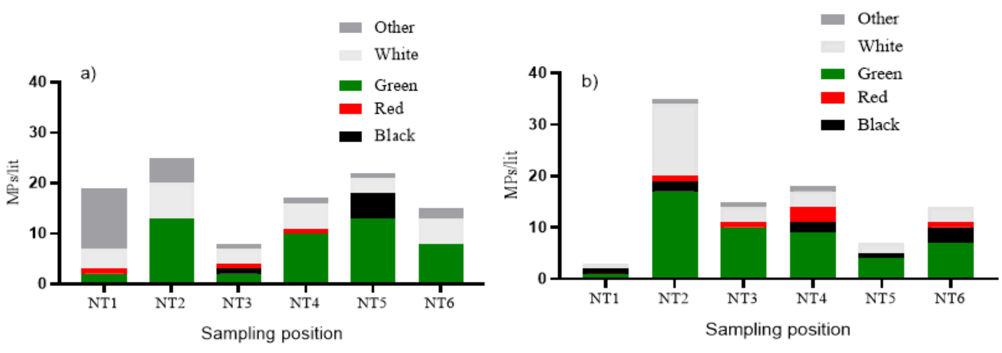

Figure 4. Ratio of microplastic colour in surface water (a) and column water (b) at Cai River estuary (Khanh Hoa).

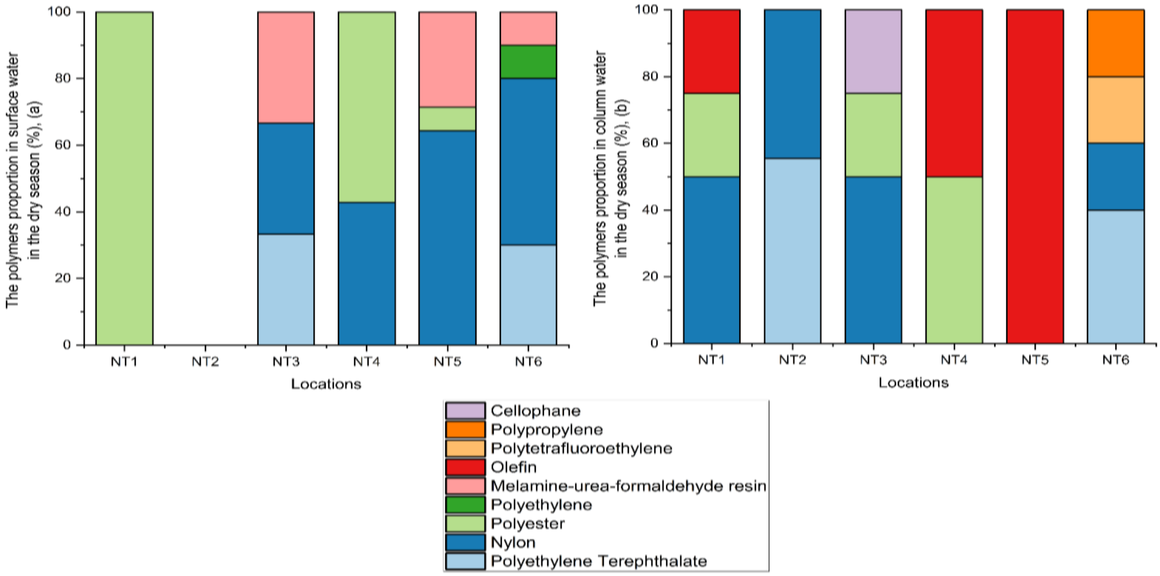

Figure 5. Ratio of microplastic polymer in surface water (a) and column water (b) at Cai River estuary (Khanh Hoa).

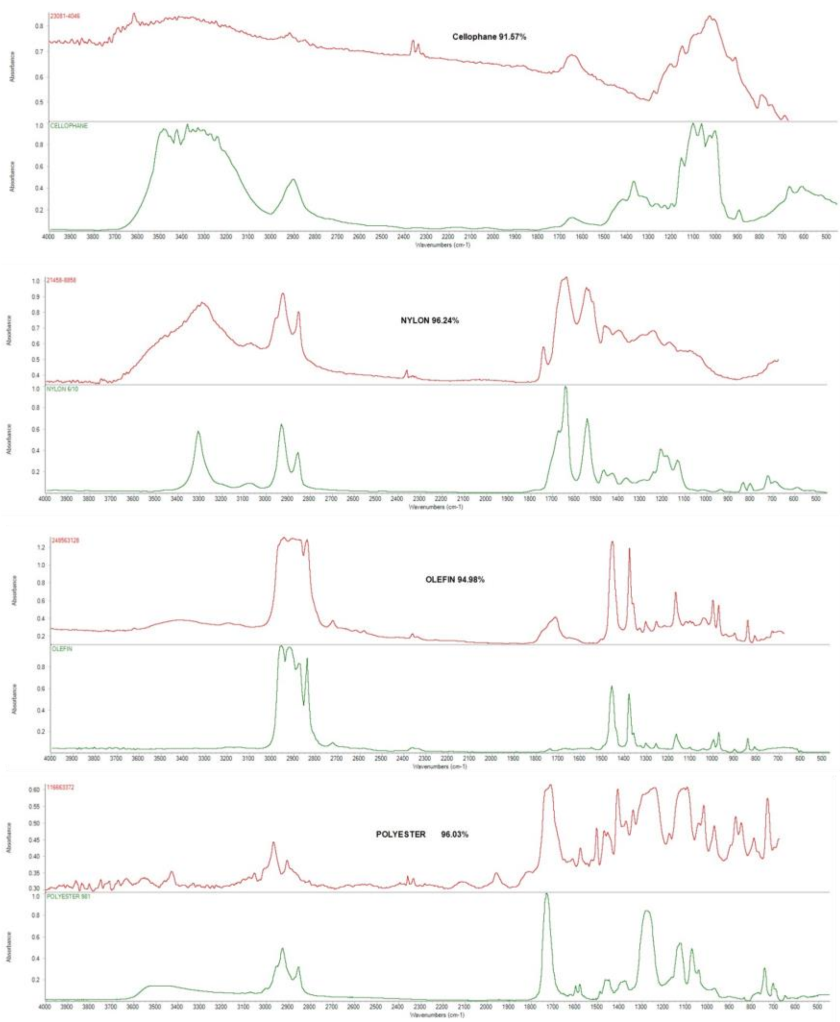

Figure 6. FTIR images of some polymers' appearance in sampling positions.

This heterogeneity may be attributed to factors such as sampling methods, natural conditions (including wind, tides, and hydrodynamics), and anthropogenic activities within the catchment (Alam et al., 2019). The Cai River estuary is directly connected to the sea, and both riverbanks are predominantly occupied by residential areas, hotels, restaurants, tourist facilities, and fishing villages. This indicates that human activities in these areas influence the occurrence of microplastics in the estuarine aquatic environment. Due to their small size, microplastics pose potential threats to aquatic organisms and ecosystems. Compared to larger plastic debris, microplastic particles are more likely to be ingested by organisms as they are often mistaken for food (Lenaker et al., 2019). Moreover, owing to their sorptive properties, plastic debris can interact with biological processes and accumulate contaminants (Cole et al., 2014). Over time, under environmental influences such as solar radiation, wind, and water flow, larger plastic particles can fragment into smaller microplastics. The predominance of smaller size fractions (Table 4) suggests that the study area has been exposed to substantial and prolonged inputs of plastic waste into the aquatic environment.

Because microplastics can be readily mistaken for food by aquatic organisms (Teuten et al., 2009; Lenaker et al., 2019), their color is an important consideration in aquatic environments (Avio et al., 2016). In addition, color may provide preliminary information regarding plastic production sources (Li et al., 2020). In this study, white and green were the dominant colors during the dry season. This result may be explained by the fact that blue microplastics often originate from blue nylon fishing nets (Klein et al., 2015), whereas white particles may derive from fishing gear (e.g., lines and nets) or result from weathering-induced discoloration (Hidalgo-Ruz et al., 2012; Jabeen et al., 2017). Field observations indicated that most restaurants, hotels, residents, and traditional markets along both riverbanks primarily use plastic bags in white, green, or blue, while fishing nets are commonly white and green. The study area is influenced by a semi-diurnal tidal regime with an amplitude of approximately 0.6 m. The river is characterized by a relatively steep gradient, strong flow variability, and low sediment load. During the dry season, reduced upstream discharge lowers water levels and promotes salinity intrusion. Although the area includes dense residential zones, restaurants, hotels, supermarkets, and local markets along the riverbanks-receiving substantial land-based waste inputs during flood events-river discharge decreases markedly in the dry season, which may explain the relatively low microplastic abundances observed during this period.

4. Conclusion

This study assessed the microplastic distribution status in the Cai River estuary (Khanh Hoa) with two sample groups: surface water and column water during the 2024 dry season. The microplastics distribution was analyzed and characterized in terms of density, shape, size, color, and polymer composition. The results showed that microplastics were present in most surveyed positions, with heterogeneity between the two sample types. Small-sized microplastics, with fibrous forms predominate in both sample groups. The predominant colors were green, followed by white, black, red, and other colors. PET and Nylon were the most frequently identified polymers. These findings indicate the presence of plastic debris contamination in estuarine and coastal environments, posing potential risks to recreational activities and local ecosystems.

Author contributions

Khoi Dang Le Ta - Methodology, validation, investigation, data curation, writing - original draft; Van Thu Thi Vu - Methodology, validation, investigation, writing - review & editing; Ve Van Dam - Methodology, investigation, formal analysis, writing - review & editing, visualization; Huong Thu Thi Tran - Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing - original draft, writing - review & editing, visualization, supervision, project administration, funding acquisition.

Acknowledgments

This paper is the result of project KC562, code DTĐL.CN÷53/22 "Research and evaluation of the accumulation and impact of microplastics on the coastal estuary ecosystem of South-Central Vietnam". The authors sincerely thank the Ministry of Science and Technology for providing funding for this project and paper.

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