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Assessment of ecological risk from microplastic pollution in sediments: A case study in Han river estuary (Vietnam)

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ABSTRACT

Microplastic (MP) pollution has emerged as a critical environmental concern, posing ecological risks across various aquatic systems. In this study, sediment samples from the Han river estuary (Vietnam) were analyzed during the 2023 rainy season and the 2024 dry season to evaluate the spatial and temporal variations in MP contamination. The characterization of MPs was conducted based on density, morphology (shape and size), color, polymer composition, and pollutant load index (PLI). Results revealed the presence of MPs at all sampling sites, exhibiting clear seasonal and spatial variability. MP concentrations were substantially higher in the rainy season (7,295.3 MPs/kg) compared to the dry season (2371 MPs/kg). Small fragments and fibers (50–150 µm) were predominant, indicating intensive degradation and fragmentation processes. White particles were most abundant during the rainy season, while green particles dominated during the dry season. Seventeen polymer types were identified in the rainy season and ten in the dry season, with polyethylene terephthalate (PET) being the most prevalent polymer (2,828.7 and 792 MPs/kg, respectively). The average PLI value of 2.9 placed the area in pollution group I-representing a low pollutant load. However, the persistence and potential ecological risks associated with MPs warrant further investigation. Future studies should aim to refine the classification of plastic polymers and support the development of comprehensive management strategies to regulate plastic usage in daily life and industrial sectors, thereby mitigating MP pollution in estuarine ecosystems.

Keywords: estuary, microplastics, pollution, pollution load index, sediment.

INTRODUCTION

Microplastics are synthetic or semi-synthetic polymer particles smaller than 5 mm (Sharma et al., 2017). They are classified as primary-manufactured as microbeads, pellets, fibers-or secondary, which result from the breakdown of larger plastics through mechanical, chemical, or microbial processes (Dowarah et al., 2020). Primary particles enter waterways via stormwater, rivers, or wastewater effluent, while secondary particles form in situ as macroplastics degrade (Naidu et al., 2019). Their widespread presence has been documented in rivers and estuaries worldwide, including the Ottawa river (Vermaire et al., 2017), Saigon river (Lahens et al., 2018), Ganges (Singh et al., 2021), Ergene river (Zaynep et al., 2023), and several rivers in China (Wang et al., 2021). Microplastics (MPs) are extensively distributed across both freshwater and marine environments (Lin et al., 2022; Xiong et al., 2022; Matias et al., 2023). Beyond their presence in the water column, MPs tend to accumulate in bottom sediments and are ingested by a wide range of aquatic organisms. Such bioaccumulation facilitates their entry into the food web, ultimately reaching humans through seafood consumption. This pervasive contamination raises growing concern regarding the potential ecological and health risks associated with chronic exposure to microplastics and their associated chemical additives (Horton et al., 2021).

Microplastics have been recognized as emerging contaminants that pose diverse ecological and toxicological risks to aquatic habitats, sediments, and living organisms (Weber et al., 2020; Zhao et al., 2020; Horton et al., 2021). Because the ocean ultimately serves as the final sink for these particles, a substantial portion of scientific investigations has concentrated on their abundance, distribution, and transport dynamics in marine systems. Nevertheless, it is estimated that roughly 80 % of plastic debris found in the sea originates from terrestrial activities, with river networks functioning as the primary conveyance pathways (Lenaker et al., 2019). In Vietnam and globally, nearly half of all plastic products are designed and manufactured for single use and then quickly discarded. Only a fraction of this discarded material is recovered for recycling, while the remainder is either incinerated or disposed of in landfills (MONRE report, 2019a). Consequently, the threat of environmental pollution from unmanaged plastic waste in Viet Nam is escalating. Without effective control measures, plastic pollution will endanger aquatic and marine biodiversity, degrade environmental quality, and exert significant negative impacts on socio-economic sectors such as tourism, transportation, and agriculture.

The 7.2 km-long Han river, formed by the confluence of the Cam Le and Vinh Dien rivers, is one of Da Nang's four principal waterways and flows through the city center to the East Sea. It supports key activities such as fisheries, transport, and recreation, making it vital for the city's socio-economic development. Yet growing plastic consumption and dense settlement along its banks heighten the risk of microplastic contamination. Like many Vietnamese rivers, the Han is increasingly affected by plastic debris, but data on microplastic levels-particularly in its estuarine sediments-remain scarce despite Viet Nam's status as a major contributor to marine plastic pollution. Microplastics in surface waters may settle into sediments or be transported ashore, where high concentrations are often recorded (Martellini et al., 2018). Coastal deposits are strongly influenced by human activities, whereas offshore sediments are shaped by tides, winds, currents, and biofilm development (Wang et al., 2018b). Although large plastic debris is recognized as an environmental hazard (Provencher et al., 2017), the ecotoxicity of microplastics (MPs) remains quite limited (Hartmann et al., 2019). Plastics act as complex contaminant mixtures containing additives, heavy metals, and persistent organic pollutants (Rochman, 2015), which can become bioavailable and pose health risks to organisms upon ingestion (Hartmann et al., 2017). While numerous studies have examined the abundance and polymer composition of MPs across various environments (Veerasingam et al., 2020b), their ecological risk in sediments remain understudied. The aims of this study to (i) assess the distribution characteristics of MP pollution in sediments at the Han River estuary, Da Nang during the 2023 rainy season and 2024 dry season, and (ii) evaluate the associated potential ecological risks.

MATERIALS AND METHODS

Characteristics of study area

Da Nang, the largest city in Central Vietnam, lies at 15°55′–16°14′ N and 107°18′–108°20′ E. The Han river – one of four major rivers (with Vu Gia, Cu De, and Phu Loc rivers) flows through the urban center into Da Nang Bay, supporting socio-economic development and flanked by dense residential, hotel, and restaurant areas. Eight sampling sites were established from Tien Son bridge to Da Nang bay (Table 1 and Figure 1) in zones strongly influenced by wastewater discharge and domestic waste.

The selected sampling stations were strategically distributed along the Han river and extended toward the estuarine area of Da Nang bay to represent varying degrees of anthropogenic influence and hydrodynamic conditions. Stations ĐN1–ĐN4 are located along the urban stretch of the river, characterized by intensive residential, commercial, and recreational activities, which are potential sources of plastic waste input. Station ĐN5 represents a critical point of anthropogenic discharge, receiving municipal wastewater directly from Da Nang City. In contrast, ĐN6–ĐN8 are positioned near the river mouth and within Da Nang Bay, reflecting areas with relatively lower direct human impact but influenced by hydrological mixing processes between riverine and marine systems. This spatial arrangement allows for a comprehensive assessment of microplastic distribution patterns and accumulation tendencies across the river estuary-bay continuum.

Sampling method

The microplastic in sediment is collected by the method according to Lenaker et al., (2019). Micropalstic samples in the surface layer (0–25 cm) will be taken with the standard dandruff of the Ekman Bottom Grab standard size 20 × 20 × 35 cm. The sample bucket will be anchored into the boat in sampling locations. The sample will be collected at each location in the rainy season in 2023 and the dry season in 2024. Mix the sample and put in the glass bottle and pack with aluminum paper, store it at 4 °C in dark bottles and transport it to the laboratory. Sediments are collected and stored in clean glass jars and frozen in -10 °C to use for the next analysis.

Analysis method

Sediment microplastics were analyzed following Masura et al. (2015). Samples were thawed to room temperature, their drying coefficient determined according to Vietnamese Standard 6648:2000, then dried and sieve through a sieve 0.3–5.0 mm. 100 g dry sample was placed in a 500 ml beaker, oven-dried at 60 °C for 20–24 h, cooled overnight, and re-weighed to obtain dry mass. The microplastic-impurity mixture underwent by wet oxidation mehtod with H_2O_2 and Fe(II) to remove organics. Finally, microplasic is observed with a stereomicroscope and a FTIR system to determine the shape, size and micropalstic density (Figure 2).

Calculate the pollution load index

To assess the level of MPs pollution in the sediment samples, the pollutant load index (PLI) was applied according to the method of Tomlinson et al. (1980) and Ranjani et al. (2021). The PLI allowing to classify the risk of microplastic pollution is presented in Table 2 and calculated by the following equation:

$$PLI_{Si} = \sqrt{\frac{C_{si}}{C_0}} \quad (1)$$

Table 1. Characteristics of survey locations in the study area

No.	Sampling station	Code	Characteristics
1	Under Tien Son Bridge	ĐN1	This site is situated beneath Tien Son Bridge, where both riverbanks are densely populated residential areas belonging to My An and Hoa Cuong Wards of Ngu Hanh Son District.
2	Under Tran Thi Ly Bridge	ĐN2	Located beneath Tran Thi Ly Bridge, this station is surrounded by residential zones and local restaurants near the Green Island Villa area, including the vicinity of Dinh Tien Hoang Primary School in Binh Thuan Ward.
3	Under Dragon Bridge	ĐN3	The area beneath Dragon Bridge is characterized by dense residential development and numerous restaurants along both sides of the river within Hai Chau Wards.
4	Under Han River Bridge	ĐN4	This station is positioned where Hai Chau and Son Tra Districts intersect; both sides feature hotels, restaurants, eateries, and supermarkets, reflecting intense urban activities.
5	City Wastewater Discharge Point	ĐN5	Located near the main municipal wastewater discharge outlet of Da Nang City, this site lies adjacent to the old Da Phuoc fishing port in Thuan Phuoc Ward, where effluents are directly released into the Han River.
6	Under Thuan Phuoc Bridge	ĐN6	This station lies close to the Thuan Phuoc Lighthouse; both banks host hotels and restaurants but lack residential settlements, representing a semi-urban waterfront area in Nai Hien Dong Ward.
7	Da Nang Bay 7	ĐN7	Positioned near the confluence where the Han River meets Da Nang Bay, approximately 700 meters downstream of Thuan Phuoc Bridge, this site reflects a transition zone between riverine and marine environments.
8	Da Nang Bay 8	ĐN8	This site is about 800 m from DN7, no residential area, located on Da Nang Bay.

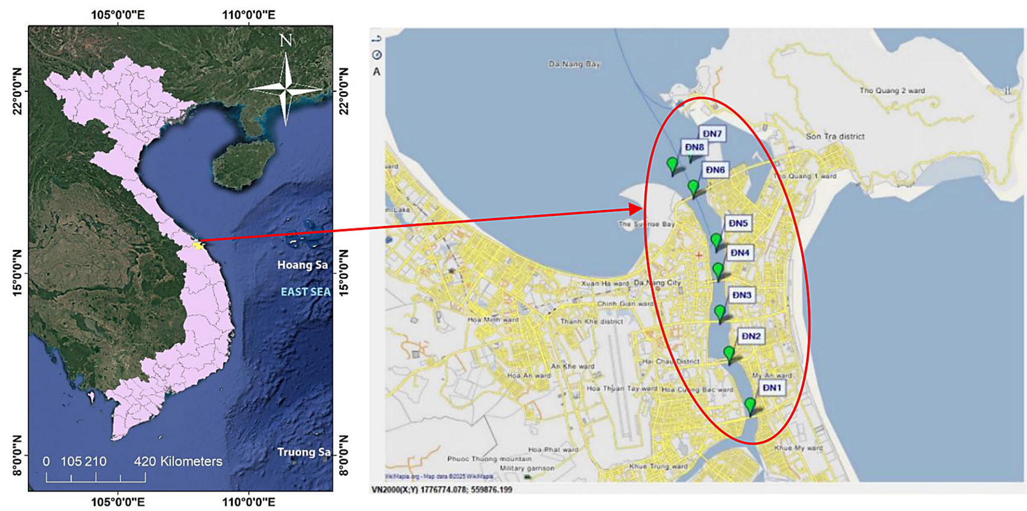

Figure 1. Sampling locations

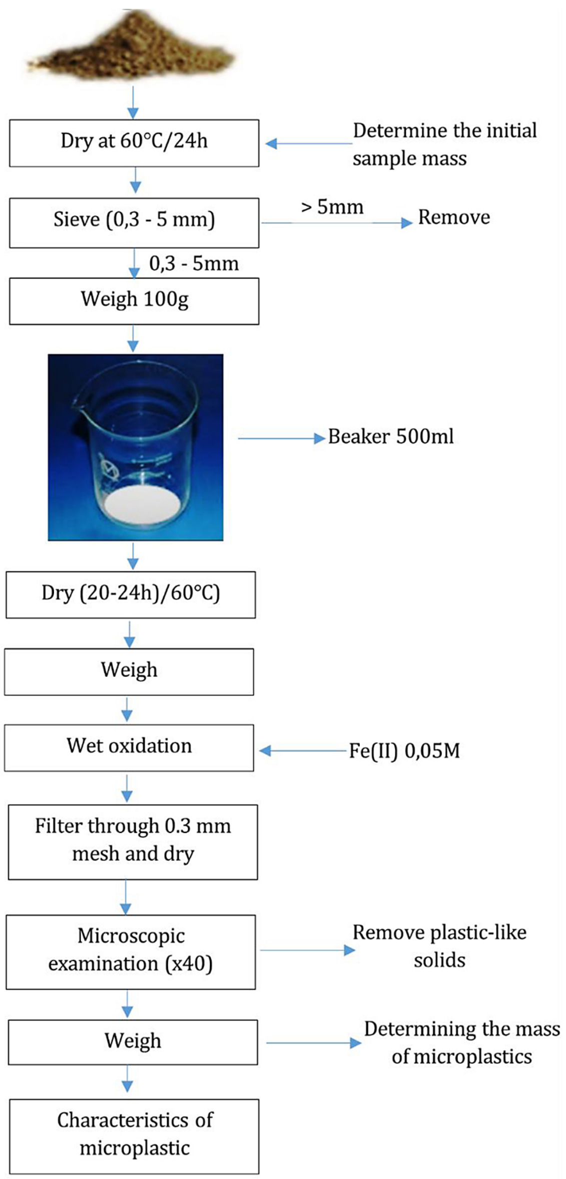

Figure 2. The analysis method of microplastics in sediment

$$PLI_{local} = \sqrt[n]{PLI_{S1.}\ PLI_{S2} \ldots .\ PLI_{Sn}} \quad (2)$$

In this equation, "Csi" denotes the concentration of MPs measured at a specific sampling site, while "C_0" corresponds to the minimum MP concentration observed throughout the study, representing unpolluted conditions since there is no absolute reference value of zero.

Statistical analysis

The data in this study were processed using GraphPad Prism 6 and Origin 2019b software to ensure statistical accuracy and reliability. Sediment mass, measured via a calibrated flowmeter, was recorded to support subsequent quantitative analyses. The density of MPs was calculated according to the method described by Do et al. (2022), using the following formula:

$$C = n / V \quad (3)$$

where: C denotes the density of microplastics, n is the total number of MP particles identified within the sample, and V represents the dry mass of sediment (in kilograms) that passed through the analytical mesh.

RESULTS AND DISCUSSION

Status of microplastic pollution by density

Figure 3 presents total microplastic density in Han river estuary sediments across two seasons. microplastics were detected at nearly all sites in

Table 2. Classification table for microplastic pollution according to PLI (Tomlinson et al., 1980; Ranjani et al., 2021)

PLI	Pollution classification
< 10	Low risk
10–20	Medium risk
20–30	High risk
> 30	Very high risk

both seasons, except ĐN4 during the dry season. In the rainy season, the microplastics density in 8 sediment samples fluctuated greatly, reaching 7295.3 MPs/kg and from 348.2 to 3567.8 MPs/kg (mean = 911.94 MPs/kg). ĐN1 location had a significantly higher microplastics density compared to the remaining locations (3567.8 MPs/kg), higher than the average value of 3.91 times, while the remaining locations had lower than the average value. ĐN6 location had the lowest value with a value of 348.2 MPs/kg (Figure 3a). In the dry season, the microplastics density decreased significantly, reaching only 2371 MPs/kg and from 0 to 600 MPs/kg (mean = 296.37 MPs/kg). ĐN8 location had the highest value compared to the remaining locations (600 MPs/kg), and ĐN6 location had the lowest value with 97 MPs/kg, and no microplastics were found at ĐN4 (Figure 3b). Some microplastics images in sediments at the Han river estuary (Da Nang) showed in Figure 4.

The data in Figure 3 indicate significant spatial and seasonal differences in microplastic density within Han river estuary sediments. During the rainy season, density decline progressively from the upstream location (ĐN1) toward the river mouth (ĐN8), whereas in the dry season this gradient is not evident. Overall, total MP levels in the dry season remain consistently lower than those in the rainy season. Rivers act as primary conduits carrying land-based microplastics to the ocean (Tanju et al., 2024), so MP occurrence here is likely linked to waste inputs from services, industry, and residential areas. The findings of this study are consistent with some previous studies in the estuary area (Li et al., 2020; Diana et al., 2022). For example, Li et al. (2020) reported that 10–60 MPs/kg dry weight in Yangtze River estuary sediments, with amounts decreasing from the estuary toward offshore islands. Likewise, Diana et al. (2022) observed higher densities in the Sado River estuary, Portugal (1,042.8 ± 430.8 MPs/kg) compared with coastal sediment samples (52.9 ± 31.9 MPs/kg).

The survey results showed that microplastic density increases upstream from the estuary, reflecting the influence of daily human activities along both riverbanks. In this study, the three downstream locations (ĐN6-ĐN8) contained relatively low and relatively similar microplastic density, consistent with their setting: sparsely populated riverbanks and very few service and production activities. In contrast, microplastic density in dry season varies irregularly among locations, reflecting the influence of weather, tidal patterns, rainfall, and localized flooding. Da Nang's coastal waters experience a semi-diurnal tide of about 0.6 m, while the Han river has a unique flow direction from South to North and flows into Da Nang bay. The river is short and steep, with large flow fluctuations and low sediment loads. During the rainy season, brief but intense floods occur, whereas in the dry season reduced upstream input lowers water levels and

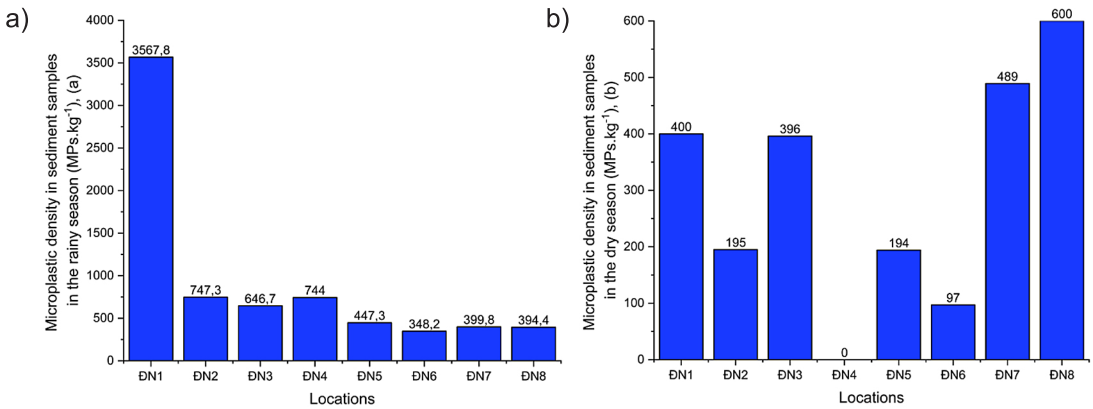

Figure 3. The microplastics density in sediments at the Han River estuary (Da Nang) in the two seasons: a) rainy season; b) dry season

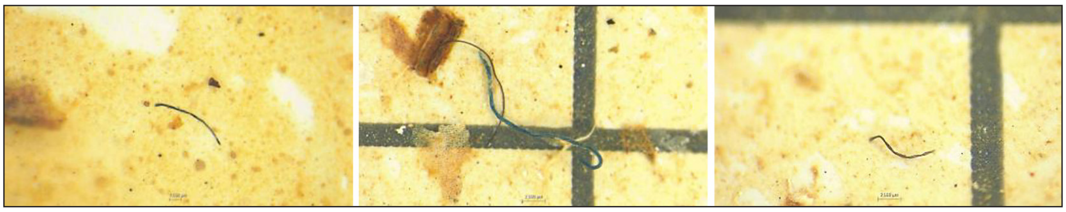

Figure 4. The microplastics images in sediments at the Han river estuary (Da Nang)

leads salinization. Extensive residential zones, together with numerous restaurants, hotels, markets, and a fishing port near the river mouth contribute terrestrial waste. Flood events transport this waste into the river, explaining the higher MP densities observed in the rainy season compared with the dry season.

Status of microplastic pollution by shape and size

The analysis results revealed three microplastic shapes in sediment samples at the Han river estuary including: fiber, fragment and particle. During the rainy season, fibers dominated with 4068 MPs/kg (55.8%), followed by fragments of 3029.4 MPs/kg (41.5%) and particles shape is 198.4 MPs/kg (2.7%) (Figure 5a). In the dry season, only fibers and fragments were detected with fibers again prevailing of 1283 MPs/kg (54.1%) over fragments of 1088 MPs/kg (45.9%), particles shape was absent (Figure 5b).

There are 5 size groups of microplastic including 20–50 µm, 50–150 µm, 100–300 µm, 300–500 µm and >500 µm identified in sediment samples at the Han river estuary – Da Nang (Table 3). In the rainy season, microplastics with small sizes (50–150 µm) accounted for the highest proportion with a value of 2532 MPs/kg, followed by >500 µm group (2034.2 MPs/kg), while 300–500 µm group were least abundant (595.9 MPs/kg). In the dry season, sizes varied by location, but 50–150 µm particles remained most common (887 MPs/kg), 300–500 µm ranked second (495 MPs/kg), and size group of 20–50 µm accounted for the smallest proportion, reaching only 199 MPs/kg (Table 3).

The dataset reveals considerable variation in MP size and shape within Han River estuary sediments. Across all eight sites and both seasons, fragments and fibers were the dominant forms, while particles appeared only during the rainy season. Most MPs measured under 150 µm (Table 3), and some locations lacked certain size groups altogether, indicating that microplastic pollution had occurred in the survey area over a long period. Over time, microplastics with small sizes are readily transported by wind and water, leading to gradual accumulation in sediments. This pattern aligns with previous findings that plastic debris persists and fragments progressively under environmental forces such as sunlight, wind, and water flow (Mato et al., 2001; Teuten et al., 2009; Hernandez et al., 2017; Alam et al. (2019). Because plastics adsorb pollutants and interact with biological processes, prolonged environmental exposure further promotes the breakdown of larger particles into smaller fractions, reinforcing the dominance of fine MPs recorded in this study.

According to Pushan et al. (2022), the morphology of microplastics in Han river estuary sediments displayed distinct seasonal and

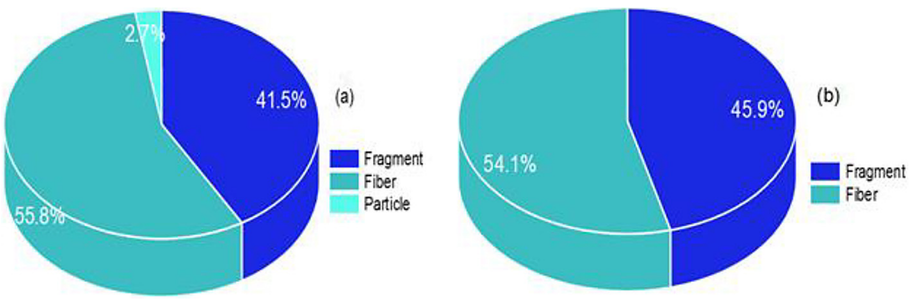

Figure 5. The microplastics shape in sediments at the Han River estuary (Da Nang) in the two seasons: a) rainy season; b) dry season

Table 3. The microplastics size in sediment samples at Han river estuary in both seasons

Code	20–50 µm		50–150 µm		150–300 µm		300–500 µm		>500 µm	
	Rainy (MPs/kg)	Dry (MPs/kg)	Rainy (MPs/kg)	Dry (MPs/kg)	Rainy (MPs/kg)	Dry (MPs/kg)	Rainy (MPs/kg)	Dry (MPs/kg)	Rainy (MPs/kg)	Dry (MPs/kg)
ĐN1	446	0	892	0	545	200	297.3	100	1387.9	100
ĐN2	348.7	0	199.3	0	-	195	49.8	0	149.5	0
ĐN3	49.7	99	597	99	-	0	-	99	-	99
ĐN4	99.2	0	396.8	0	148.8	0	49.6	0	49.6	0
ĐN5	248.5	0	99.4	97	49.7	0	49.7	97	-	0
ĐN6	-	0	99.5	0	-	0	99.5	97	149.2	0
ĐN7	100	0	100	391	-	0	50	0	150	98
ĐN8	-	100	148	300	98.6	100	-	0	148	100
Total	1292.1	199	2532	887	842.1	495	595.9	393	2034.2	397

site-specific patterns shaped by hydrological conditions and water movement, making MPs an important indicator of pollution. Fibrous microplastics were dominant in both seasons with 55.8 and 54.1% in the rainy and dry seasons, followed by fragments with 41.5 and 45.9%, respectively. Particles accounted for only 2.7% in the wet season and were absent in the dry season (Figure 4). The predominance of fibrous microplastics may be due to surface runoff and hydrodynamic forces (e.g., heavy rainfall, turbulent flow) that break up larger plastics, consistent with findings in Da Nang (Nguyen et al., 2020; Do et al., 2022) and other Vietnamese estuaries (Nguyen et al., 2020; Nguyen et al., 2021; Luu et al., 2020; Truong et al., 2020). Much of this debris originates from packaging, cleaning products, cosmetics, and plastic containers (Wu et al., 2019) and is transported downstream during floods, where mechanical action accelerates degradation. In contrast, when river flow is weaker in the dry season, fibers derived mainly from discarded fishing gear (Montarsolo et al., 2018) persist because lower turbulence reduces physical breakdown. Although present in smaller amounts, other forms such as foam and granules remain ecologically significant due to their potential toxicity to aquatic life (Tanaka and Takada, 2016).

Status of microplastic pollution by color

Microplastics in sediment samples have a variety of colors such as white, black, blue, red... During the rainy season, white color microplastics predominate in all surveyed locations with 49.8%, followed by blue with 38%; green 8.73%; red 2.76% and finally some other colors accounting for 0.67%. (Figure 6a). In contrast, during the dry season, green color microplastics account for the largest proportion of 47.6%. Next is white with 43.4%; black 7.2%; red 1.4% and finally some other colors accounting for 0.4% (Figure 6b).

The color microplastics can offer useful clues about the original raw plastic materials and potential sources (Klein et al., 2015). Previous research reported a predominance of white particles, Corcoran et al. (2015) found that white MPs were markedly more abundant than other colors, followed by pink and purple. While Li et al. (2020) documented that white accounted for 64.7% of all MPs in sediments of the Yangtze river estuary in China, blue, transparent, yellow, black, red, brown, and green occurring in smaller proportions. In the Han River estuary, a significant seasonal difference in dominant colors was observed (Figure 6). The white and blue microplastic prevailed in rainy season, whereas white and green dominated in dry season. Blue microplastic is likely derived from nylon fishing nets commonly used in local fisheries, whereas white microplastic can originate from fishing lines and nets (Jabeen et al., 2017) and may also appear as faded particles due to weathering and photodegradation (Hidalgo-Ruz et al., 2012). Field surveys support these interpretations: many restaurants, hotels, households, and traditional markets along the riverbanks primarily use white, green, or blue plastic bags, while local fishing gear is typically white or green. These results suggest that both land-based consumer waste and fishing activities are key contributors to the observed color distribution of microplastic in Han River sediments.

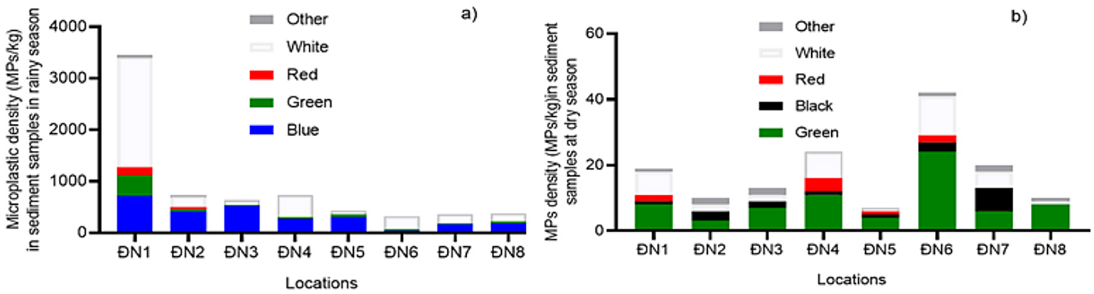

Figure 6. The microplastics colors in sediments at the Han river estuary (Da Nang) in the two seasons: a) rainy season; b) dry season

Status of microplastic pollution by polymer

FTIR analysis identified 17 microplastic polymer types in Han River estuary sediments during the rainy season, totaling 7,295.5 MPs/kg across eight samples. PET and nylon were dominant, comprising 38.8% and 12.9%, respectively (Figure 7a). In the dry season, 10 polymer types were detected with 2.371 MPs/kg in seven of eight locations (no microplastics at ĐN4 location), PET and nylon were still the two polymers with the highest proportions of 33.4 and 24.8%. Other polymers occurred unevenly with low proportions in both seasons and locations (Figure 7b).

FTIR spectroscopy offered confirmation of the microplastic pollution patterns previously reported for estuarine and coastal sediments. In the Han River estuary, 17 different polymer types were detected in rainy season, while only 10 were identified in dry season, highlighting the influence of seasonal hydrodynamics on polymer diversity (Figure 7). Polyethylene terephthalate (PET) remains the most prevalent polymer in aquatic and sedimentary environments worldwide. For example, Li et al. (2020) found PET and polypropylene (PP) of 37.3% and 28.6% in the Yangtze river estuary (China), respectively. While Diana et al. (2022) documented PET at 41% in Portugal's Sado River estuary. Sediments from Rhine–Main river (Germany) were also found to contain up to 75% PET, PP, and PS (Klein et al., 2015). Consistent with these global observations, PET dominated across all seasons and sample types in this study, reaching 2,828.7 MPs kg^{-1} in rainy-season sediments and 792 MPs kg^{-1} in the dry season. Polyester and nylon followed during the rainy season, with concentrations of 1,834.8 and 943.9 MPs kg^{-1}, respectively. In contrast, nylon ranked second in the dry season at 588 MPs kg^{-1}, a result likely linked to the widespread use of nylon bags and fishing gear in commercial and household activities along both sides of the Han River. Several minor polymers including olefins, Teflon, and phenolic resins were also identified, indicating multiple sources of plastic input. Olefins, for instance, may originate from fuel leaks or mechanical wear associated with cruise ships, fishing vessels, and naval operations near the river mouth. These findings emphasize the complex and diverse origins of MP pollution in the estuary.

Ecological risk index PLI

The ecological risk index is widely applied to evaluate MP impacts in diverse ecosystems including coastal sediments, estuaries, soils, mangroves, and the atmosphere (Tomlinson et al., 1980; Barletta et al., 2016; Deng et al., 2021; Pegado et al., 2021; Nishitha et al., 2022). Following this approach, the PLI was used to assess microplastic pollution risk in Han river estuary sediments (Figure 8). PLI values across all locations indicated low contamination, ranging from 1.4 (at DN6 loaction in the dry season) to 8.5 (at DN1 location in the rainy season) (Figure 8a). The results of PLIlocal index calculations showed that the study area had low pollution load, with an average PLI value of 2.9 (Figure 8b), classified as "Hazard Level I" (<10 on the risk classification scale – Table 2).

Although the overall pollution load was rated low, microplastics can still harm estuarine ecosystems. They pose risks to aquatic organisms by causing gastrointestinal blockage, reducing nutrient absorption, and releasing toxic additives. Such impacts may lead to population declines of key species and disrupt ecological balance. Microplastic can also act as carriers for other pollutants, including persistent organic pollutants (POPs) and heavy metals, thereby amplifying

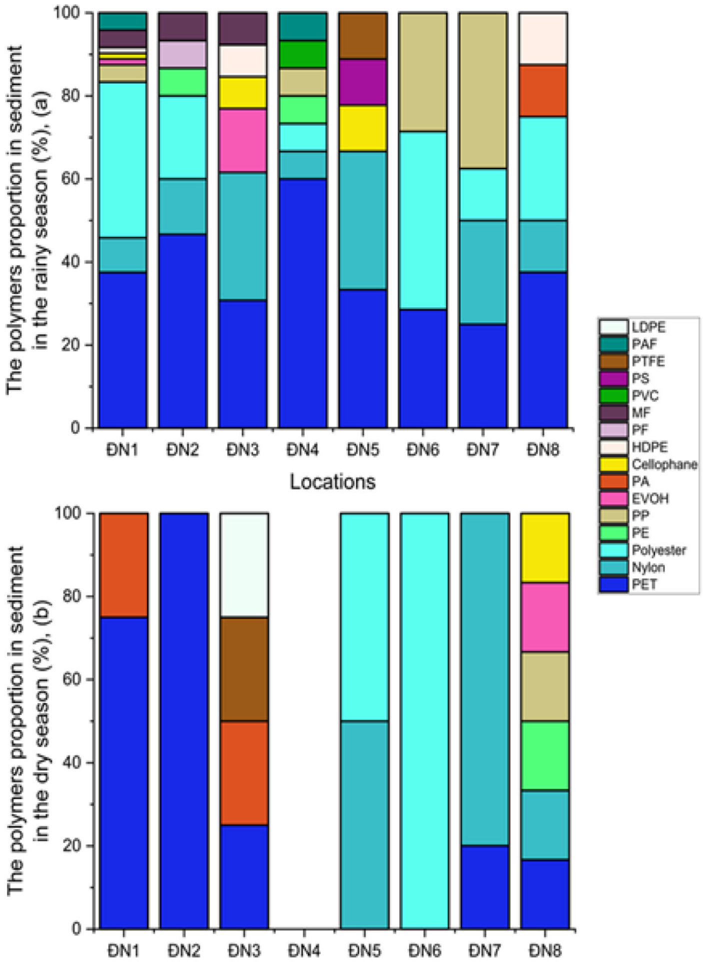

Figure 7. The microplastics polymer proportion in sediments at the Han river estuary (Da Nang) in the two seasons: a) rainy season; b) dry season. In while: Low density Polyethylene_LDPE; Perfluoroalkoxy_PAF; Polytetrafluoroethylene_PTFE; Polystyren _PS; Polyvinyl chloride_PVC; Melamine-urea-formaldehyde-resin_MF; Phenol resin_PF; High density Polyethylene_HDPE; Polyacrylamide_PA; Evoh Eval Film_EVOH; Polypropylen_PP; Polyethylene_PE; Polyethylene teraphalate_PET

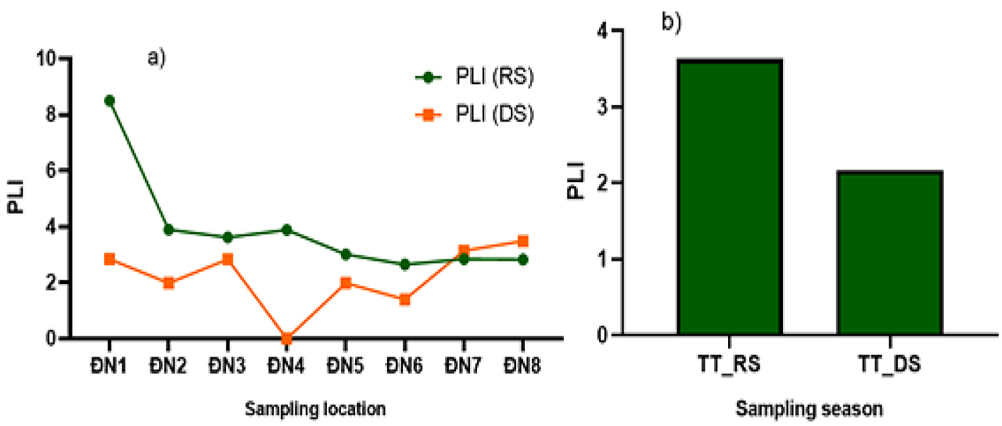

Figure 8. The microplastic PLI value in sediments in the 08 locations and two seasons: a) sampling location; b) samling season. PLI (RS)_pollution load index in rainy season and PLI(DS)_ pollution load index in dry season

ecological and toxicological risks. Ultimately, these contaminants can enter the food web and threaten human health when local communities consume affected aquatic species.

CONCLUSIONS

This study showed that microplastics occurred at all sites, with densities in the rainy season (7295.3 MPs/kg) higher than dry season (2372 MPs/kg). Small fragments and fibers dominate, mainly white and green. Seventeen polymers were identified in the wet season and ten in the dry, with PET most abundant, followed by PS and nylon, with PET accounted for 2,828.7 and 792 MPs/kg, respectively. Spatial differences reflected human activity along the river. These results provide baseline data for south central coast estuaries and highlight potential ecological impacts, even though the pollutant load index indicated a low "Hazard Level I" risk.

Therefore, it is recommended that these activities be monitored to minimize MPs emissions and prevent increases in PLI concentrations, which could result in increasingly harmful effects on the environment and local populations in the future. Overall, the results demonstrate a clear seasonal influence on microplastic form distribution, with fragments dominating during high-flow conditions, and fibers becoming more prevalent under low-flow conditions. Vertical variation also suggests differential transport, sinking behavior, and sources of microplastics, emphasizing the need for stratified sampling and seasonal monitoring in aquatic ecosystems. The widespread presence of microplastics across water highlights the critical importance of distribution and accumulation data for ecological risk assessments. Consequently, further research is warranted to classify plastic types more precisely, and the development of effective policies is needed to manage the use of plastic products in everyday life, transportation, and other sectors to mitigate microplastic pollution within ecosystems.

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