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Baseline

Seasonal microplastic variations in estuarine sediments from urban canal on the west coast of Thailand: A case study in Phuket province

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ABSTRACT

To improve knowledge of the relationships of human activities with microplastic pollution in the urban estuary in Phuket province, which has a densely populated city on the western coast of Thailand, a total of 463 plastic-like items from 24 sediment samples in the dry and the rainy seasons were identified by micro-Fourier transform infrared spectroscopy. The microplastic abundance ranged in 300–900 and 33–400 items/kg dry weight in the dry and the rainy seasons, respectively, indicating that the estuary is moderately contaminated with microplastics. The most abundant polymer types were rayon and polyester with colored fibers, suggesting that the microplastics deposited in this area originate mainly from washing effluents. Additionally, our findings show that the microplastic distribution is significantly governed by hydrodynamic energy in the estuary. This provides basic information for a better understanding of the fate of microplastics within estuary, and for management actions to address microplastics in urban estuary.

1. Introduction

The use of plastics in daily life has sharply increased from the 1.5 million tons produced in the 1950s to more than 348 million tons in 2017 (PlasticsEurope, 2018; Zhou et al., 2018). Some of these plastics become litter distributed to the environment (e.g., to lakes, rivers, lagoons, and oceans) (Thompson et al., 2004; Vianello et al., 2013; Jambeck et al., 2015; Zhao et al., 2015; Wen et al., 2018). Under the influence of physicochemical factors, large-sized plastic wastes are degraded and fragmented into small-sized particles: broken products with diameters below 5 mm are known as secondary microplastics (Ryan et al., 2009; Efimova et al., 2018). In contrast, the primary microplastics are particles of less than 5 mm size manufactured for commercial use, including microbeads, capsules, fibers, or pellets (GESAMP, 2016). Formations of biofilm and organic carbon on microplastic polymers can be caused by an increase in microplastic density (Lobelle and Cunliffe, 2011; Enders et al., 2019), and these combined microplastic polymers will deposit onto and get buried in marine sediments (Andrady, 2011; Eriksen et al., 2014; Näkki et al., 2019). Thus, marine sediments play an important role as the ultimate sinks for microplastic particles that pollute the marine environment (Cozar et al., 2014; Woodall et al., 2014; Harris, 2020).

Due to their small size, microplastic particles in sediments can absorb/adsorb chemical substances and they are available for ingestion to organisms, causing physical and chemical harm to their bodies (Robinson et al., 2010; Cole et al., 2013; Wright et al., 2013; Van Cauwenberghe and Janssen, 2014). Moreover, several studies show evidence on microplastic particles occurring in benthic food webs (Powell et al., 2010; Van Cauwenberghe et al., 2015; Taylor et al., 2016). This problem has negative impacts on biological and estuarine ecosystems; thus, it is essential to observe microplastic particles in sediments to assess current and future effects in the habitats and ecosystems. Also, there can be microplastic management plans in the future.

Recently, the contamination of the marine environment in Thailand by microplastics has become an issue of increasing concern (Wang et al., 2020; Bissen and Chawchai, 2020; Chinfak et al., 2021). Most of these studies focused on beaches and marine organisms (Bissen and Chawchai, 2020; Klangnurak and Chunniyom, 2020). However, studies of the degree of microplastic contamination in estuarine sediments from urban areas that have a relatively high concentration of microplastics (e.g., Qiu

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et al., 2015; Abidli et al., 2018; Wen et al., 2018; Li et al., 2020) are rare in Thailand and the current status remains unclear. This knowledge gap needs to be addressed, to assess the fate of microplastics from urban rivers entering the marine environments, especially in an urban estuary that is a tremendous economic resource but under negative influences of human activities.

It is well-known that Phuket province is one of the most popular tourist destinations in Thailand. Phuket is the largest island on the west coast of Thailand in the Andaman Sea. The island has an area of 576 km^2. Its population was 249,446 in 2000, rising to 525,709 in the 2010 decennial census. Additionally, the annual count of tourist visitors increased from 9,467,248 in 2011 to 13,493,273 in 2016. Accordingly, the island has the most densely populated city in southern Thailand. In Phuket province, the Bang Yai canal catchment is home for ~116,000 people, recorded in 2017 (Phuket Provincial Administration Office, 2020). Bang Yai canal originates at Kathu waterfall, passing through large parts of an urban area in Phuket Town, and finally enters the Andaman Sea on the west coast of Thailand. Bang Yai canal is also the main receiving water body for domestic sewage and industrial wastewater and may be a source of many pollutants introduced into the sea (Regional Environment office 15, 2012). Moreover, the mouth of the Bang Yai canal is close to the wastewater treatment plant and the landfill (Fig. 1).

To better understand the relationship of human activities with microplastics pollution in the marine environment, microplastics deposited in estuarine sediments in urban areas must be assessed. Here, the abundances, compositions, and polymer types of microplastics in the surface sediments of urban areas in the Bang Yai canal mouth both in the dry and the rainy seasons were observed. This study might provide useful knowledge for developing long-term plastic management plans in estuarine environments and could possibly point out specific dominant sources of microplastics in the urban estuary in Phuket province.

2. Materials and methods

2.1. Sample collection

In this study, estuarine sediments were collected from Bang Yai canal mouth in May 2020 (dry season) and in September 2020 (rainy season) from 12 sampling sites (Fig. 1), for a total of 24 samples. Three sediment samples were collected around each sampling site by using a stainless-steel Ekman bottom grab. Approximately 600 g of surface sediments (0–5 cm) from these samples were homogenized and were wrapped in aluminum foil. All the surface sediments were kept on ice in a cooler box in the field and during transport to the laboratory. In the laboratory, these sediment samples were stored at 2 °C in a refrigerator until analysis.

2.2. Analytical methods

All surface sediment samples were subjected to grain-size analysis. Due to the agglutination of organic matter, it is necessary to remove organic matters from sediments before analysis (Loring and Rantala, 1992; Beuselinck et al., 1998). Bulk sediments were sequentially reacted with 10% H_2O_2 at 60 °C in a shaking water bath for 3 h, and with 0.5% HCl, to remove organic matters and carbonate, respectively (Jiwarungrueangkul et al., 2019). After rinsing with deionized water, grain size distributions of siliciclastic fractions were determined by using a Mastersizer 3000 laser particle size analyzer at Phuket Marine Biological Center, with a measurement range of 0.4–2000 μm. The repeated measuring error was within 2%. The percentage contribution of each fraction to cumulative volume was calculated. The grain sizes were classified as follows: clay (<4 μm), silt (4–63 μm), and sand (>63 μm).

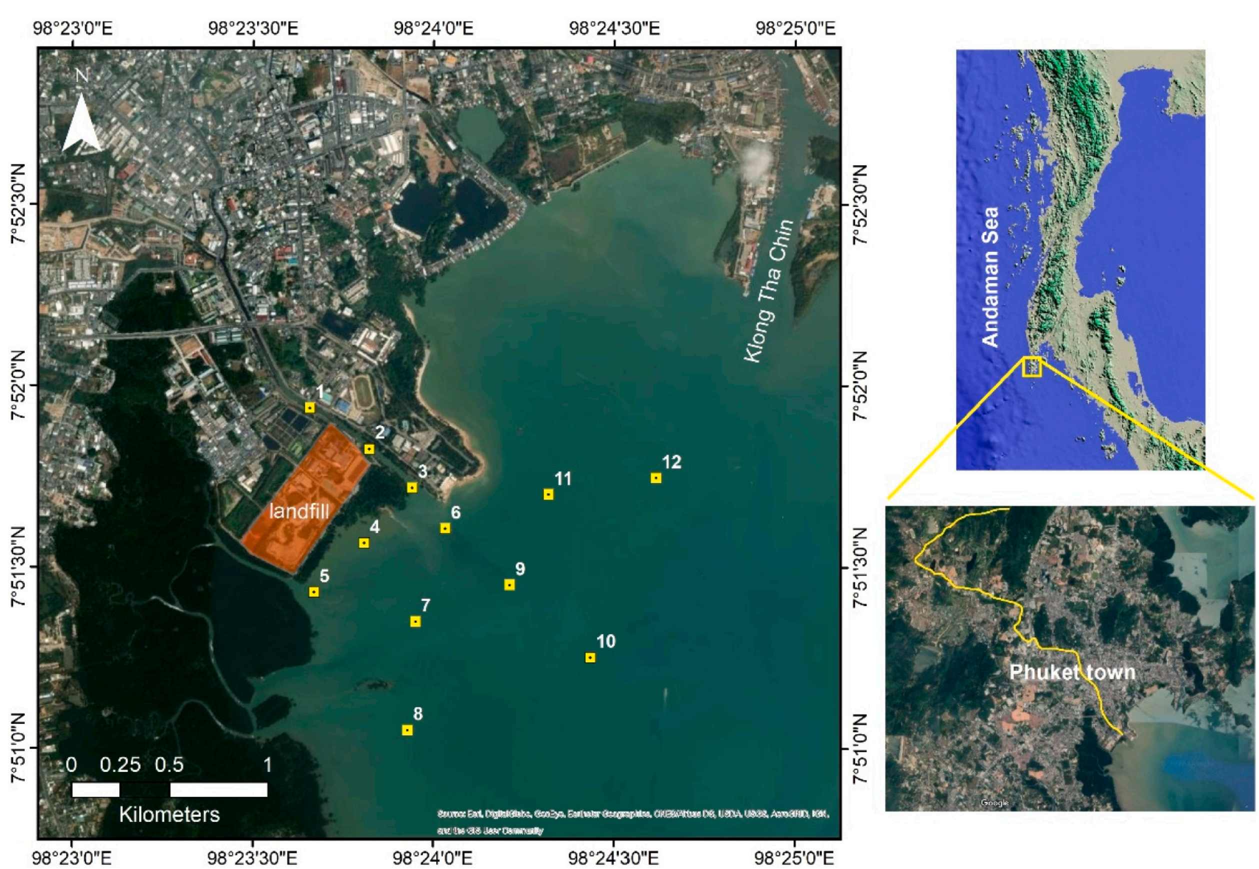

Fig. 1. Sampling sites of surface sediments in Bang Yai canal mouth, Phuket province, Thailand.

2.3. Microplastic isolation

The collected sediment samples were dried at 40 °C in an oven for 24 h. Saturated NaCl (density 1.20 g/cm^3) solution was used to separate microplastics from the sediments, based on the method of Wang et al. (2020) with some minor changes. A saline solution was prepared by dissolving 337 g of NaCl (Analytical Reagent; KEMAUS) in 1 l of distilled water. Several previous studies have shown that the NaCl method has a high extraction rate, and it has been widely used to separate microplastics from sediments (e.g., Fries et al., 2013; Vianello et al., 2013; Bissen and Chawchai, 2020; Li et al., 2020; Wang et al., 2020). Additionally, NaCl is inexpensive and environmentally friendly (Wang et al., 2020). Firstly, 40 g of homogenized sediment was accurately weighed and transferred into a 500 ml clean glass beaker (washed with deionized

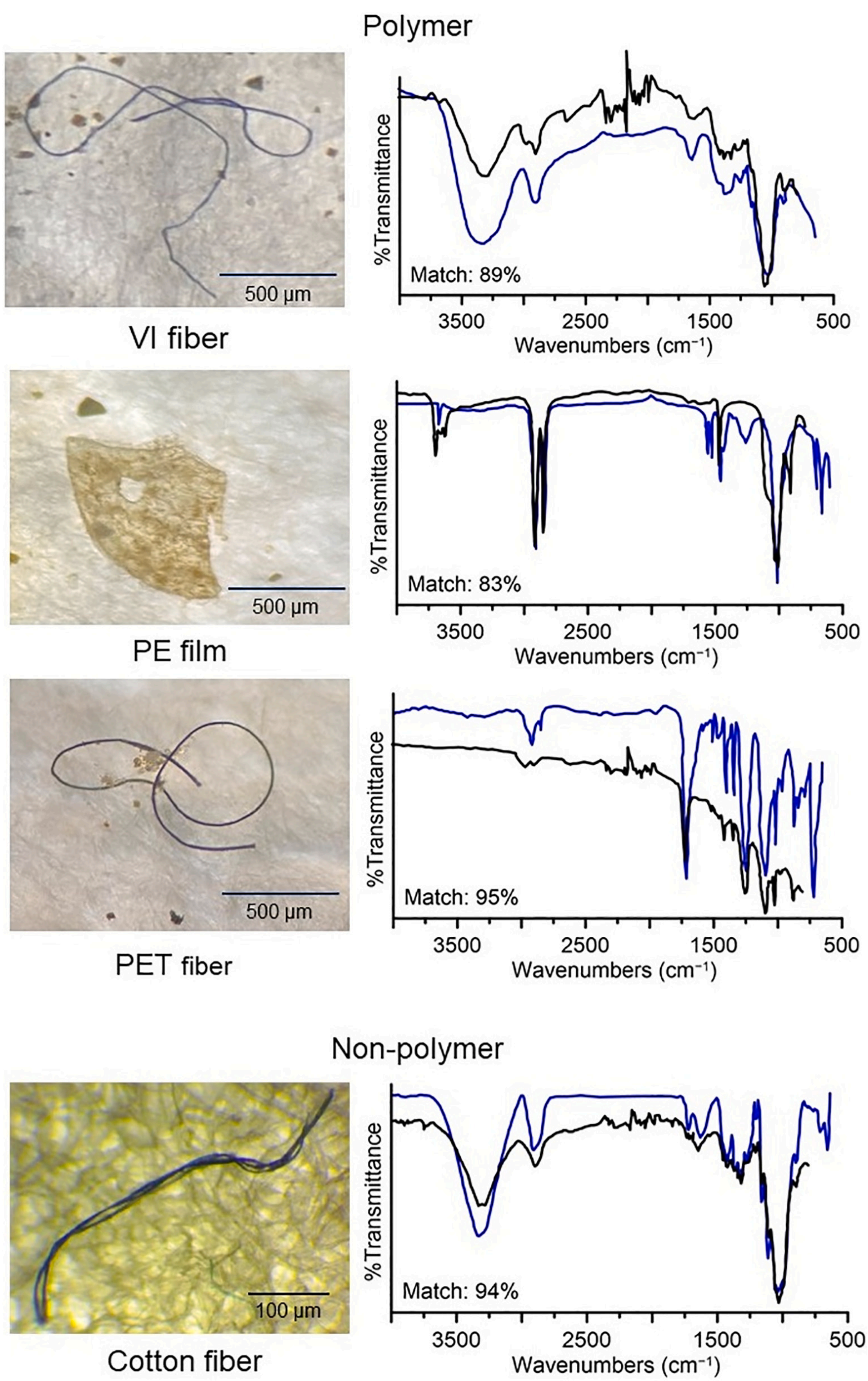

Fig. 2. Examples of FT-IR spectra and microscope images of dominant polymer and non-polymer materials found in surface sediments of Bang Yai canal mouth. The polymer materials are viscose rayon (VI), polyethylene (PE), and polyethylene terephthalate (PET). The blue curve is the FTIR spectra of standard polymers in spectral libraries, and the black curve is the FTIR spectra of microplastics samples. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

water). To remove the organic matter, approximately 100 ml of 20% H_2O_2 was added, and the beaker was covered with aluminum foil for 24 h. After 24 h, the sample was added 10 ml of 30% H_2O_2 and manually stirred in a water bath at 80 °C to increasingly digest the organic matter. Then, 500 ml of the filtered NaCl solution was introduced and stirred for 5 min. After settling for 4 h, the suspension was decanted in a 150 ml beaker. The supernatant was filtered under vacuum through a nylon filter (20 μm pore size; 47 mm diameter). While the samples were still standing, the glass beakers were covered with aluminum foil. The procedure of adding filtered NaCl solution and filtering was repeated three times. The microplastics with the filter were then dried in an oven at 40 °C with coving an aluminum foil (Vianello et al., 2013). Finally, they were kept in a desiccator for further analysis. In this study, two blank samples were used for pre-extraction to estimate the background contamination.

2.4. Polymer identification

After drying, the plastic-like items were firstly counted and identified by color and shape, using a stereomicroscope (Olympus CX31, 60× magnification). Optical images of plastic particles were taken with a digital camera. The size range of plastics examined in this study was between 0.1 and 5 mm. The lower size limit of 0.1 mm represented the size of the plastic particles that can be collected for identifying their polymer types. It was noted that the plastic-like items were re-inspected by observers before identifying polymer process, especially fiber. To identify the microplastics, all plastic-like particles (463 items) were analyzed using a micro-Fourier transform infrared spectroscope (Spectrum Two with Spotlight 200i, PerkinElmer) in the reflection mode with 30 × 30 μm aperture size, using 24 scans and spectral resolution of 4 cm^{-1}. Spectra were produced with wavenumbers 600–4000 cm^{-1} at the Department of Marine Science, Faculty of Fisheries, Kasetsart University. The polymer types of microplastics were identified by comparing the spectra libraries processed by PerkinElmer Spectrum IR Version 10.6.2. The polymer that appeared in the first top 10 list of detected compounds was chosen with a high match value (Fig. 2).

2.5. Contamination and mitigation

To avoid microplastic contamination, lab coats and gloves were always worn throughout the microplastic analysis and the gloves were changed between steps in sample treatments. The workplace was cleaned with 70% alcohol before analyzing any samples and all glassware were rinsed three times with distilled water and covered with aluminum foil to prevent contamination with airborne dust. Inspection for microplastic contamination from ambient air was performed by exposing filters to the air in the laboratory, whenever samples were open to the laboratory environment. The exposing filters were carefully checked for any type of particles under the stereomicroscope. Both distilled water and saturated NaCl solution used in this study were filtered by a vacuum pump with WHATMAN® GF/C filter (1.2 μm pore size; 47 mm diameter). We evaluated for possible microplastic contamination during microplastic extraction using blank tests. This performed using 500 ml of filtered saturated NaCl solution without sediments, following the extraction procedure detailed above. This was repeated for each set of microplastic extraction. These blank samples were filtered by the GF/C filter. The dried filters were then observed under the stereomicroscope. No microplastics were found in these exposing filters and blank test filters, indicating that microplastic contamination from airborne dust or reagent solutions was negligible.

3. Results

3.1. Identification of microplastics

All 463 plastic-like items (from both the dry and the rainy seasons) were identified by using a micro-Fourier transform infrared spectroscope. The results showed that only 234 items were polymer items, which accounted for 50.5% of the total detected plastic-like items (Table 1). Polymer materials found in the surface sediments of Bang Yai canal mouth were categorized into ten types, including polypropylene, low-density polyethylene, polyethylene, polytetrahydrofuran, polystyrene, polyamide (nylon), polymethyl methacrylate (acrylic), polyvinyl chloride, polyester, polyethylene terephthalate, and viscose rayon. In contrast, the other items that were not synthetic polymers contributed 49.5% of the total plastic-like items (Table 1). The non-polymers were identified as cotton, cellulose, and silica fragments. These non-polymer items are very similar to the polymers, which makes it difficult to distinguish them under a stereo microscope, and easy to confuse with microplastics (Fig. 2 and Fig. S1). Because of this, an insufficient sample volume for identification may give unreliable results. We suggest that the identification of all plastic-like items is an important tool for studying microplastic pollution, helping avoid overestimates of microplastic abundance.

As presented in Fig. 3a, the sediments of the Bang Yai canal mouth were contaminated with ten polymer types. In general, viscose rayon was found from all sampled sites in the dry season, in the range from 30% to 100%. Meanwhile, polyester was observed from almost all the sampled sites in the rainy season, contributing between 25% and 100%. Polypropylene, polyethylene, and polyethylene terephthalate were the next most abundant plastic types in both seasons, accounting for 4.5–57.1%, 11.0–100.0%, and 7.4–33.3%, respectively. Other polymer types were only present in minor abundances, namely polytetrahydrofuran, low-density polyethylene, polystyrene, polyamide, polymethyl methacrylate, and polyvinyl chloride. These could be observed only from some sampling sites, and most of these were generally found only in the dry season, not in the rainy season (Fig. 3a).

3.2. Microplastic abundance

The number of abundances of microplastic items found in 24 sediment samples from 12 sampling sites in Bang Yai canal mouth, both in the dry and the rainy seasons, are shown in Fig. 4. Statistical analysis showed that the average microplastic concentration in the dry season (450 ± 196 items/kg dry weight) was significantly higher than that in the rainy season (200 ± 105 items/kg dry weight). In the dry season, the highest abundance of microplastic items at 900 items/kg dry weight was observed at sampling site BY-2, while the lowest accumulation was observed at sampling sites BY-5, BY-6, BY-8, BY-10, and BY-11 at about

Table 1
Identification results of all plastic-like particles by using a micro-Fourier transform infrared spectroscope.

Density (g/cm^3)	Identification	Plastic-like particles	
		Items	%
Polymer			
0.89–0.92	Polypropylene	34	7.3
0.91–0.92	Low-density polyethylene	6	1.3
0.95	Polyethylene	32	6.9
0.98	Polytetrahydrofuran	2	0.4
1.01–1.09	Polystyrene	3	0.6
1.14	Polyamide (nylon)	1	0.2
1.12–1.17	Polymethyl methacrylate (acrylic)	1	0.2
1.10–1.47	Polyvinyl chloride	1	0.2
1.35	Polyester	58	12.5
1.37–1.38	Polyethylene Terephthalate	20	4.3
1.50	Viscose rayon	76	16.4
	Total	234	50.5
Non-polymer			
1.54	Cotton	91	19.7
1.50	Cellulose	93	20.1
	Silica fragment	45	9.7
	Total	229	49.5

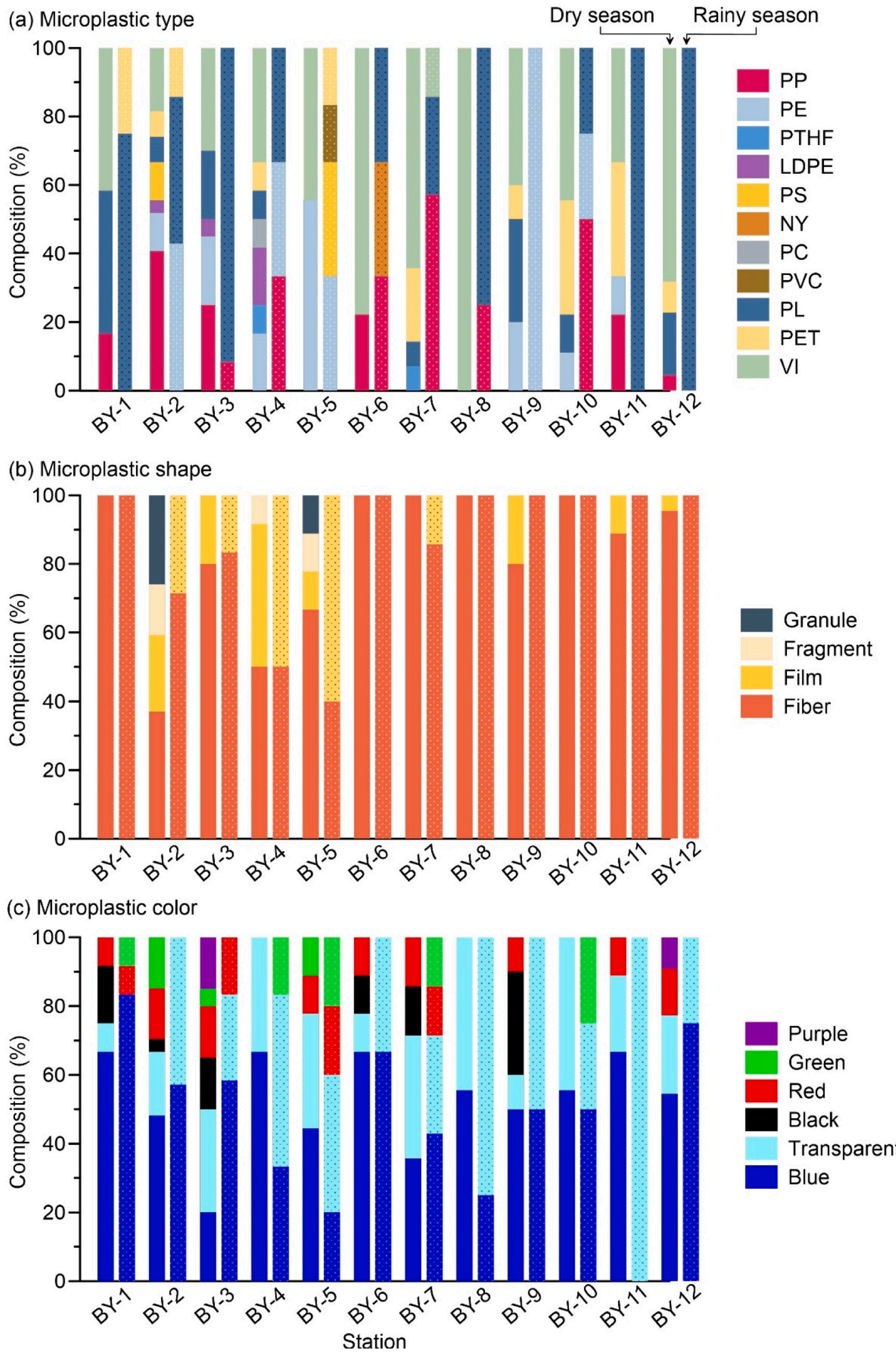

Fig. 3. Seasonal variation in relative compositions of microplastics collected from sediments of 12 sampling sites in Bang Yai canal mouth, according to type (a), shape (b), and color (c). Solid bar and solid bar with dot indicate the dry and the rainy season. Polymer materials include polypropylene (PP), low-density polyethylene (LDPE), polyethylene (PE), polytetrahydrofuran (PTHF), polystyrene (PS), polyamide (nylon: NY), polymethyl methacrylate (acrylic: PC), polyvinyl chloride (PVC), polyester (PL), polyethylene terephthalate (PET), and viscose rayon (VI).

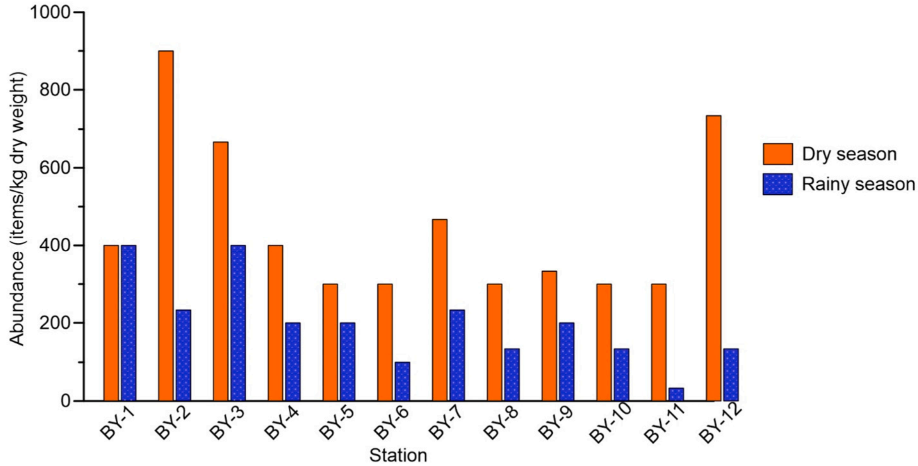

Fig. 4. Seasonal variation in microplastic abundances of sediments from 12 sampling sites in the Bang Yai canal mouth.

300 items/kg dry weight. The abundance at each sampling site varied by season. The sediments in the rainy season with the greatest microplastic abundances were from sampling sites BY-1 and BY-3 (400 items/kg dry weight), while sampling site BY-11 (33 items/kg dry weight) was the least contaminated site in this study (Fig. 4). Our results show that the sediments of the Bang Yai canal mouth were widely contaminated with microplastics with seasonal variations.

3.3. Shape and color of microplastics

The microplastics deposited in this estuary both in the dry and the rainy seasons varied in morphological characteristics, including fibers, films, fragments, and granules (Fig. 3b). Fibers were observed from all sampling sites and they significantly dominated among plastic shapes from sampling sites BY-1, BY-3, and BY-6 to BY-12, contributing up to 80%. Films were the second most common type of microplastic, with high contents (average 50.6%) at sampling sites BY-4 and BY-5 (except in the dry season). Fragments and granules were the least frequent shape and could be found only in the dry season at sampling sites BY-2, BY-4, and BY-5, accounting for <20% (Fig. 3b).

Six colors of microplastics were observed, namely blue, black, red, green, purple, and transparent (Fig. 3c). Blue and transparent particles were most common in the sediments from all sampling sites, contributing about 49.7% and 34.9%, respectively. Meanwhile, black, red, green, and purple particles were characterized by low contents and most of them were found in the dry season, not in the rainy season (i.e., sampling sites BY-1, BY-2, and BY-3) (Fig. 3c).

3.4. Siliciclastic grain size

The grain size distributions of all samples are shown in Fig. 5. The sediments in the study area are mainly sand (17.9–85.6% and 15.3–96.7% in the dry and rainy seasons, respectively) and silt (13.3–71.5% and 3.1–68.9% in the dry and rainy seasons, respectively), with a minor content of clay (<12.4% and <18.0% in the dry and rainy seasons, respectively). The mean grain size of sediments in the dry season ranged from 31.1 to 127.0 μm with an average value of 75.9 μm, whereas it varied between 21.2 and 211.0 μm with an average value of 81.1 μm in the rainy season. Generally, the sediments in sampling sites BY-1 to BY-5 had a high proportion of silt, whereas sampling sites BY-6 to BY-12 were dominated by sand (Fig. 5).

4. Discussion

4.1. Microplastic contamination and distribution in the Bang Yai canal mouth

All sediment samples in this study contained microplastics, indicating that the sediments of the Bang Yai canal mouth in both the dry and the rainy seasons are contaminated with plastics (Fig. 4). The microplastic abundances in the surface sediments vary within the ranges 300–900 and 33–400 items/kg dry weight in the dry and the rainy seasons, respectively. Since a direct comparison in microplastic abundances with published research is problematic because different methods and size definitions were applied (Besley et al., 2017; Zhao et al., 2018; Li et al., 2020), we selected published research that used similar extraction and identification methods for consistency of data comparison (Table 2). It is important to note that when concordance size range in comparison with previous studies will be more reasonable. This study focused on the microplastic in the size range of 0.1–5 mm; thus, the comparison result presented here may be limited. However, it could provide preliminary information for performing an environmental risk assessment of microplastic pollution in the study area (e.g., Ballent et al., 2016; Zhao et al., 2018; Wang et al., 2020; Bissen and Chawchai, 2020; Chinfak et al., 2021). As reported in Table 2, the microplastic abundances in the estuarine sediments collected from the Bang Yai canal mouth are lower than those from the eastern Gulf of Thailand (Bissen and Chawchai, 2020), the marine sediments from Wanning, China (Qiu et al., 2015), the intertidal sediments of Scapa Flow, Orkney (Blumenröder et al., 2017), and the lagoon of Venice, Italy (Vianello et al., 2013); and higher than those from Bandon Bay, Thailand (Chinfak et al., 2021), Southern Yellow Sea, China (Zhao et al., 2018), Changjiang Estuary, China (Peng et al., 2017), and Singapore's coastline (Mohamed Nor and Obbard, 2014). Therefore, our results suggested that the estuarine sediments in the Bang Yai canal mouth could be moderately contaminated with microplastics. Besides, it is observed that the microplastic abundances in the Bang Yai canal mouth are significantly higher than that in the Gulf of Thailand far from the coastline (Wang et al., 2020; Table 2). It can be inferred that the urban estuarine sediments located on the Thai coastline can trap microplastics and retain them. This needs to be considered when assessing the fate of microplastics between sea and land in Thai waters.

At the Bang Yai canal mouth, the microplastic abundances in estuarine sediments in the rainy season are lower than those in the dry season (Fig. 4), which may be caused by the runoff flux effects on microplastic input (Kang et al., 2015; Cheung et al., 2016; Fan et al., 2019; Li et al., 2020; Sukhsangchan et al., 2020). Based on data of mean total rainfall between 1981 and 2010 in Phuket on the western coast of

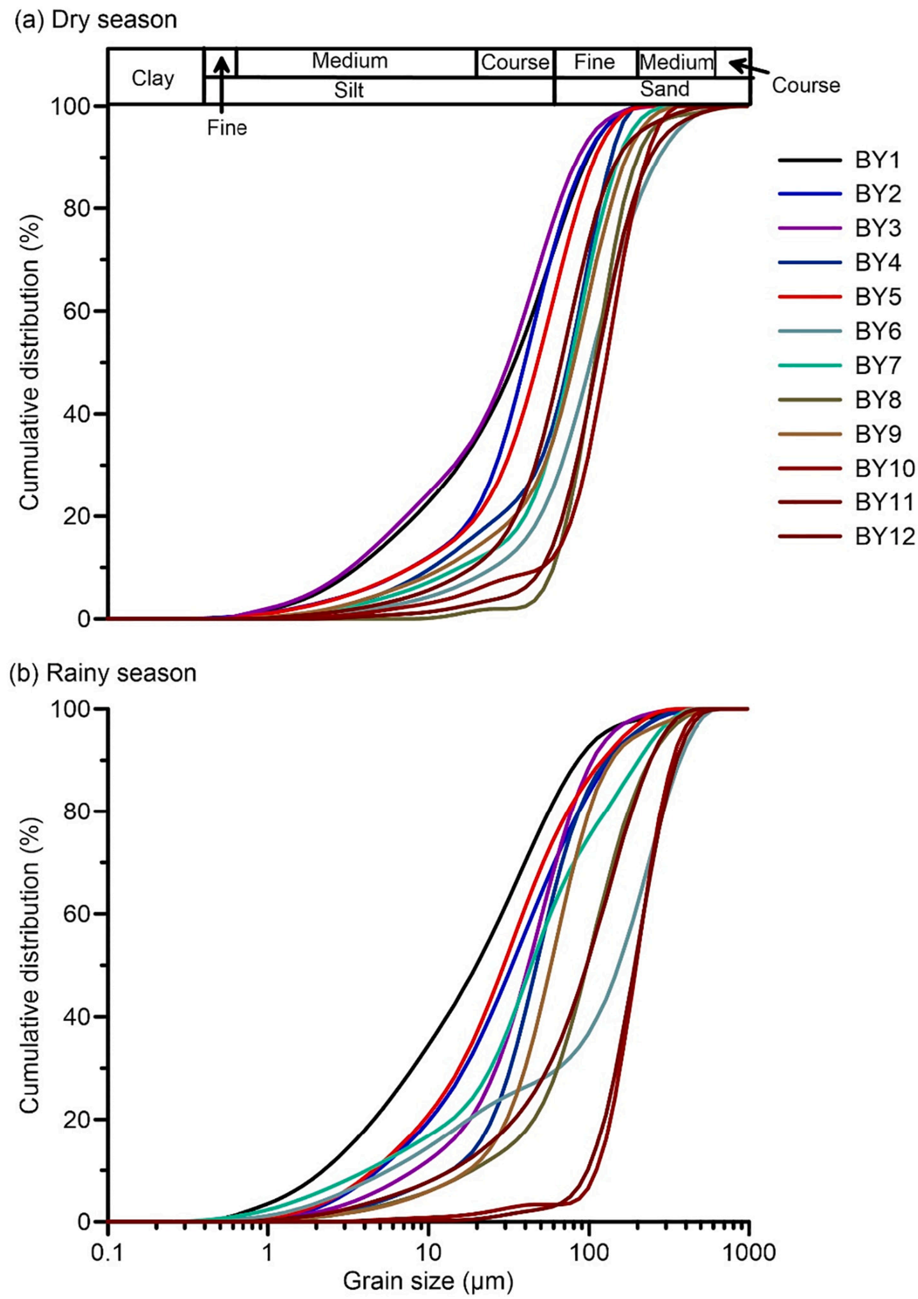

Fig. 5. Grain-size distributions of the sediments in Bang Yai canal mouth in the dry season (a), and in the rainy season (b).

Thailand, the mean rainfall could reach about 253 mm in the rainy season, whereas it is only 66 mm in the dry season (Thai Meteorological Department, 2012). Although high runoff flux in the rainy season can bring suspended microplastics into the lakes and estuaries (Kang et al., 2015; Fok and Cheung, 2015; Liu et al., 2019), the stronger hydrodynamic forces may make the deposition of microplastics into sediments difficult (Vermeiren et al., 2016; Krelling et al., 2017). This leads to a lesser amount of microplastics deposition in the rainy season. This highlights the seasonal variations in microplastic abundance in estuarine sediments. Consequently, caution should be used when monitoring the microplastic abundance in estuarine sediments to account for seasonal variations.

There is significant variation in the distribution of microplastics (Fig. 4). In general, the abundances of microplastics in sampling sites BY1 to BY4 (inner river mouth) are higher than at sampling sites BY5 to BY12 (outer river mouth) in both seasons, excluding the sampling site BY-12 in the dry season. This might be due to the hydrodynamic forces (waves, tides, and currents) in aquatic systems (Browne et al., 2011; Vermeiren et al., 2016; Besseling et al., 2017; Krelling et al., 2017; Fan et al., 2019). To understand the distribution in estuarine sediments, the relationships between microplastic abundances and grain sizes are considered. As seen in the C-M diagram (Fig. 6) that can show depositional processes associated with energy in the environmental conditions (Passega, 1964), all sampling sites of the inner river mouth fall in the uniform suspension pattern, while most sampling sites of the outer river mouth are classified to rolling, with some grains transported in suspension and graded suspension and some grains transported by rolling, graded suspension. This indicates that the sediments in the inner river mouth are characterized by a low-dynamic area; thus, microplastics could have been easily deposited on the sediments in the inner river mouth. This can explain the higher microplastic abundances that can be found in the inner river mouth, rather than at the outer river mouth.

Table 2
Microplastic abundance in coastal sediments of different countries. All studies are based on the density separation method (NaCl 1.2 g/cm^3) for microplastic extraction.

Location	Abundance (items/kg dw.)	Size definition (mm)	Quantification	Reference
Eastern Gulf of Thailand	420–>200,000	<0.5–4	Visually counted and verified with a micro-Raman spectrometer	Bissen and Chawchai (2020)
Wanning, China	8714	<1–<5	Visually counted/ polymer identification (Nicolet™ iN10 FTIR)	Qiu et al. (2015)
Scapa Flow, Orkney, Scotland	730–2300	<5	Visually counted/ polymer identification (PerkinElmer Spectrum 100 FTIR)	Blumenröder et al. (2017)
Lagoon of Venice, Italy	672–2175	0.03–2.4	Visually counted/ polymer identification (Nicolet™ iN10 FTIR)	Vianello et al. (2013)
Phuket province, Thailand (dry season)	300–900	0.1–5	Visually counted/ polymer identification (PerkinElmer Spectrum Two with Spotlight 200i FTIR)	This study
Phuket province, Thailand (rainy season)	33–400	0.1–5	Visually counted/ polymer identification (PerkinElmer Spectrum Two with Spotlight 200i FTIR)	This study
Changjiang Estuary, China	121 ± 9	<5	Visually counted/ polymer identification (Nicolet™ iN10 FTIR)	Peng et al. (2017)
Gulf of Thailand, Thailand	150	<0.1–>2	Visually counted/ polymer identification (Nicolet™ iN10 FTIR)	Wang et al. (2020)
Bandon Bay, Thailand	15–135	<1–5	Visually counted/ polymer identification (PerkinElmer Frontier™ FTIR)	Chinfak et al. (2021)
Southern Yellow Sea, China	72	<1–5	Visually counted/ polymer identification (Nicolet™ iN10 FTIR)	Zhao et al. (2018)
Mangrove, Singapore	12–63	<0.02–5	Visually counted/ polymer identification (Varian 3100 FTIR Excalibur Series)	Mohamed Nor and Obbard (2014)

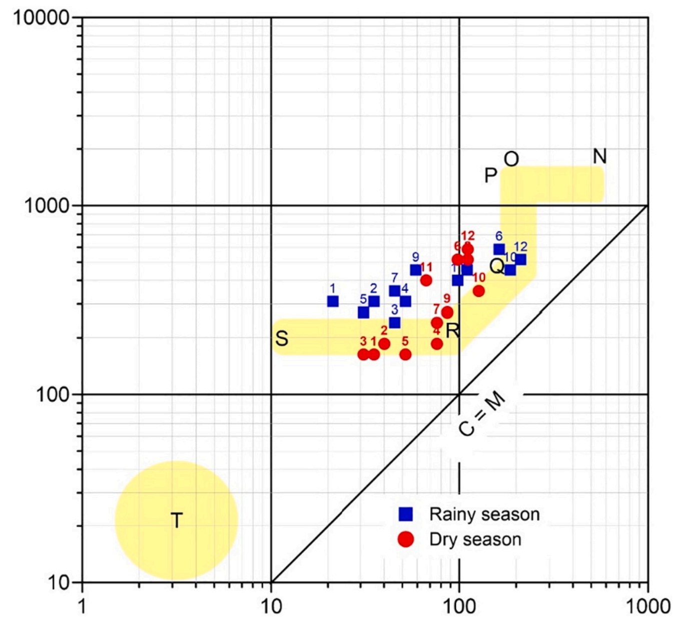

Fig. 6. Depositional processes visualized in a CM diagram (Passega, 1964) for sediments in the Bang Yai canal mouth. Tractive currents: rolling (NO), rolling with some grains transported in suspension (OP), graded suspension with some grains transported by rolling, graded suspension (QR), and uniform suspension (RS). Non-tractive currents: pelagic suspension (T).

Accordingly, we suggest that microplastic distribution in estuarine sediments is significantly controlled by the energy of hydrodynamic conditions in an estuary system.

According to the sedimentology hypothesis, different densities of each microplastic type could lead to different deposition and distribution (e.g., Klein et al., 2015; Ballent et al., 2016). The densities of polypropylene and polyethylene are lower than that of seawater (~1.03 g/m^3). Meanwhile, polyethylene terephthalate, polystyrene, polyamide, and polyvinyl chloride have a higher density than that of seawater (Table 2). In fact, in the concept of deposition hypothesis, both polypropylene and polyethylene are expected to be not found at sampling sites of the outer river mouth section where the water density increases due to higher salinity because they should float due to lower densities (e.g., Ballent et al., 2016; Yang et al., 2021). However, they are present in both the inner and outer river mouth (Fig. 4). It is therefore unlikely that the different density by microplastic type was an important factor in the microplastic distribution in estuarine sediments.

Note the high microplastic concentration at the sampling site BY-12 in the dry season, with 900 items/kg dry weight (Fig. 4). This might occur due to the microplastic input from Klong Tha Chin that is also an urban canal (Fig. 1) since the distance between Klong Tha Chin and the sampling site BY-12 is short. This apparently promotes microplastic deposition at this sampling site in the dry season, when the water velocity is comparatively low. It, therefore, appears reasonable that the sediments at sampling site BY-12 have high microplastic concentrations despite the outer river mouth section.

4.2. Main source of microplastics in the Bang Yai canal mouth

As demonstrated in Fig. 7b, large spatial variations are observed in the synthetic fiber concentrations both in the dry season (79.0%) and in the rainy season (84.5%), indicating that synthetic fibers are the major sources of microplastics in the studied estuarine. Fibrous microplastics are the most common shape in several estuaries, for example, Changjiang Estuary (Peng et al., 2017), Jiaojiang, Oujiang, Minjing Estuaries (Zhao et al., 2015), and Yangtze Estuary (Zhao et al., 2014). Due to the fiber pollution from washing clothes, municipal wastewater has been regarded as a primary source of fibrous plastics in several urban areas (McCormick et al., 2014; Henry et al., 2019; Cesa et al., 2020). The Bang

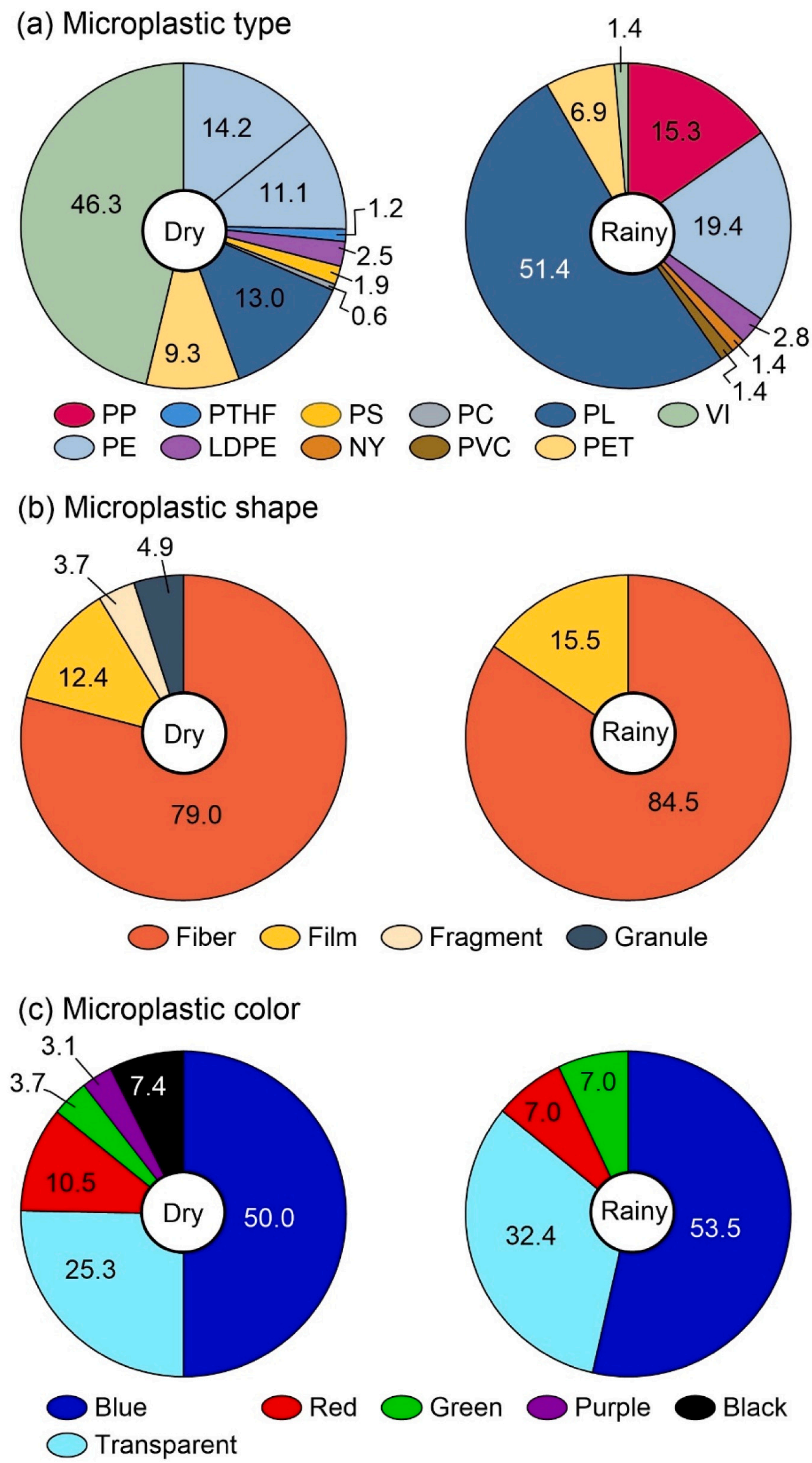

Fig. 7. Seasonal percentages of microplastic abundances found in the sediments in Bang Yai canal mouth, according to type (a), shape (b), and color (c). Data of microplastic types as in Fig. 3.

Yai canal that also runs through a large part of the urban area in Phuket town can be accredited as potentially the main origin of fibrous microplastics in the canal.

Identification also showed that the majority of microplastics in these estuarine sediments are viscose rayon (46.3% for the dry season) and polyester (51.4% for the rainy season) (Fig. 7a). Generally, these two materials are the most common textile materials found in fashion items (Sandin and Peters, 2018; Zambrano et al., 2019). Rayon is quite popular in drapery, clothing, athletic wear, and silky clothing, etc. Meanwhile, polyester has a variety of uses in fashion, including outdoor apparel, bags, and backpacks, etc. Therefore, it can be inferred that the main microplastics in the studied area came from clothes (e.g., Sandin and Peters, 2018; Wang et al., 2019; Zambrano et al., 2019; Sait et al., 2021),

The microplastics reported here are mostly colored particles (>70% for both seasons; blue, red, green, black, and purple) (Fig. 7c), which is consistent with other studies on microplastics (Mohamed Nor and Obbard, 2014; Zhao et al., 2014; Zhao et al., 2015). Coloring is a common practice to enhance the market appeal of plastic products (Thetford et al., 2003). The dominance of colored plastics in our study is consistent with the fact that most microplastics here commonly originate from consumer products (e.g., clothes, plastic bags, plastic containers, and plastic caps).

Considering all main microplastic characters in the sediments (Fig. 7), it can be inferred that most of the microplastics in the estuarine sediments of the study area could mainly come from colored clothes and enter this area in effluents from washing machines in the urban area. The developing or less developed countries tend to discharge home laundry effluents directly into the environment (Boucher and Friot, 2017). Additionally, it is noted that a large number of tourist visitors in Phuket province may promote an increase in textile laundering and it may contribute microplastics to the estuary. The knowledge gained from this study is crucial for microplastic management purposes in the urban estuary because the control strategies of microplastics distributed in environments should differ according to the main microplastic source (Arthur et al., 2009). Here, an urgent need for a strategy to mitigate this problem is the developing a suitable method for trapping the microplastics from an effluent pipe of the washing machine.

5. Conclusions

This is the first study to report the seasonal variations in microplastic abundances of surface estuarine sediments in the Bang Yai canal mouth on the west coast of Thailand. The major conclusions are as follows:

1) The microplastic abundances (0.1–5 mm size) in the surface sediments vary within the ranges 300–900 and 33–400 items/kg dry weight in the dry and the rainy seasons, indicating that the estuary is moderately contaminated with microplastics compared with estuaries worldwide.
2) Microplastic distribution is significantly controlled by hydrodynamic energy conditions in the estuary system.
3) The majority of microplastics were of viscose rayon in the dry season and of polyester in the rainy season; and most of them are fibers with colored items, suggesting that the microplastics deposited in the study area mainly originated from clothes to effluents from washing machines in the urban area.
4) This preliminary study can inform policymakers of Phuket province for concerning microplastic pollution and a suitable microplastic management system in this province is required.

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CRediT authorship contribution statement

Thanakorn Jiwarungrueangkul: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing, Supervision. **Jitraporn Phaksopa:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Penjai Sompongchaiyakul:** Conceptualization, Investigation, Writing – review & editing. **Danai Tipmanee:** Data curation, Writing – review & editing.

Declaration of competing interest

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

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