Marine Pollution Bulletin 173 (2021) 112933

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Horizontal variation of microplastics with tidal fluctuation in the Chao Phraya River Estuary, Thailand

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ARTICLE INFO

Keywords:
Microplastics
Estuary
River discharge
Tidal fluctuation
Thailand

ABSTRACT

Microplastic (MP) pollution in estuarine environments is poorly characterized globally, although they are extensive buffer regions between terrestrial, freshwater and seawater environments. This research aims to investigate MP pollution levels and variations of MPs abundance with tidal fluctuation. Fourteen samples were collected from the surface water of the Chao Phraya River Estuary, Thailand using the Manta net at flood and ebb tides. The average abundance of microplastics at flood tide was 5.16×10^5 particles/km^2 and at ebb tide was 3.11×10^5 particles/km^2. The abundance of microplastics in the estuary was directly related to the tidal fluctuation, creating an accumulation of microplastics in the study area. Polypropylene, polyethylene, and polystyrene were the most common polymers. The findings provide important information on the pollution status of microplastics in the Chao Phraya River Estuary and the variation of suspended microplastics with tidal fluctuation should be considered in future estuarine microplastic studies.

Mismanaged plastic debris in the aquatic environment is an emerging ecological threat to ecosystems nowadays (Thompson et al., 2004). Under the influences of UV irradiation, mechanical abrasion, and biodegradation, large amounts of plastic waste in the oceans could be degraded into microplastics (Alimi et al., 2017). Due to their large surface-to-volume ratio, microplastics (MPs) provide substrata for adsorption of various contaminants including persistent organic pollutants (POPs), metals (e.g., Cu, Pb), and pathogenic species (Frias et al., 2010; Kirstein et al., 2016; Ta and Babel, 2020). MPs are therefore considered to be hazardous waste because hydrophobic toxic pollutants in the water could be adsorbed and concentrated on the MPs while they transverse through the environment. The common additives in MPs such as phthalates, polybrominated diphenyl ethers (PBDEs), and constituent monomer bisphenol A also impact ingesting organisms and the connected food chain (Barnes et al., 2009). Moreover, ingestion of MPs causes a variety of consequences to the ingesting biota, such as reduction of stomach storage capacity and may cause internal wounds in the gastrointestinal tract leading to death (Hämer et al., 2014; Murray and Cowie, 2011).

MP pollution in estuarine environments is poorly characterized globally, although an estuary is an extensive buffer region between terrestrial, freshwater, and seawater environments. Furthermore, estuaries are identified as MP hotspots due to the discharge of mismanaged plastic waste transported along with the river discharge. The Chao Phraya River flows through the most heavily populated regions of Thailand. As a result, large quantities of domestic and industrial wastes are discharged into the Gulf of Thailand by the river. The purpose of the current research is to investigate MP pollution levels and variations of MPs abundance with tidal fluctuation in the study area.

The Chao Phraya River is the largest river in Thailand, originating from four rivers in the northern mountains which combine to form the main river. The river flows south through the central plain passing Bangkok Metropolis and several other large cities as it flows toward the Gulf of Thailand. The drainage area is about 177,000 km^2 (McLaren et al., 2004). The Chao Phraya River basin is one of the most heavily populated regions of Thailand, where agricultural and industrial activities have been developed. As a result, large amounts of domestic and industrial waste are carried by the river to the upper Gulf of Thailand

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https://doi.org/10.1016/j.marpolbul.2021.112933
Received 21 March 2021; Received in revised form 31 August 2021; Accepted 2 September 2021
Available online 14 September 2021

through its estuary. The upper Gulf of Thailand is a large shallow semi-enclosed sea, tides are both mixed (two uneven magnitude tides a day) and diurnal (one flood and ebb tide each day) (Saramul and Ezer, 2014). The mean depth of the estuary is shallow with an average depth of 15 m (Sirirattanachai and Utoomprurkporn, 2005). The Chao Phraya River estuary is relatively close to Bangkok and heavily affected by a variety of anthropogenic activities.

Sample collections were performed consecutively over four days in the dry season (February 2020) with flood and ebb tide conditions. Seven sampling points, R1, R2, R3 (first transect), L1, L2, L3, and L4 (second transect), were selected in the navigation channels to collect representative samples of river discharge flow in the estuary as shown in Fig. 1. Samples were collected one transect per day to identify the variation of MPs with tidal fluctuation using a Manta net with 335 μm mesh size (Hydro-Bios, Germany), rectangular metal mouth opening (30 × 15 cm), from the water surface to a depth of 10 cm. It was attached to the vessel (Samut Prakan 220) and trawled for about 25 to 30 min at constant speed (approximately 3 knots) to obtain uniform inflow (Fig. 2). The effect of the vessel wake decreases the quantity of floating debris on the surface water including MPs therefore the distance between the vessel and net was maintained at 1.4 m to avoid that effect (Kooi et al., 2016). The trawl distance was measured during samplings with a mechanical flow meter (pitch 0.3 m/revolution; model 438110; HYDRO-BIOS, Germany) installed at the bottom of the metal frame aperture. At the end of each trawl, the collected debris in the detachable filter bag at the cod-end was transferred to a 1.5 L sealable glass jar, and placed in an ice-box with ice packs, then brought back to the Water Quality Engineering Laboratory (Mahidol University) for further analysis. GPS coordinates for the start and stop of samplings were recorded from the Garmin GPS tracker (eTrex Legend Cx).

Samples were wet sieved in the laboratory through a 5 mm stainless-steel sieve to separate large debris and aquatic organisms. The organic matter in sieved samples was digested with 30% hydrogen peroxide (H_2O_2) for 24 h at room temperature. Density separation with saturated sodium chloride solution (5 M, density 1.2 g/cm^3) was performed overnight in a density separator funnel to separate putative MPs from

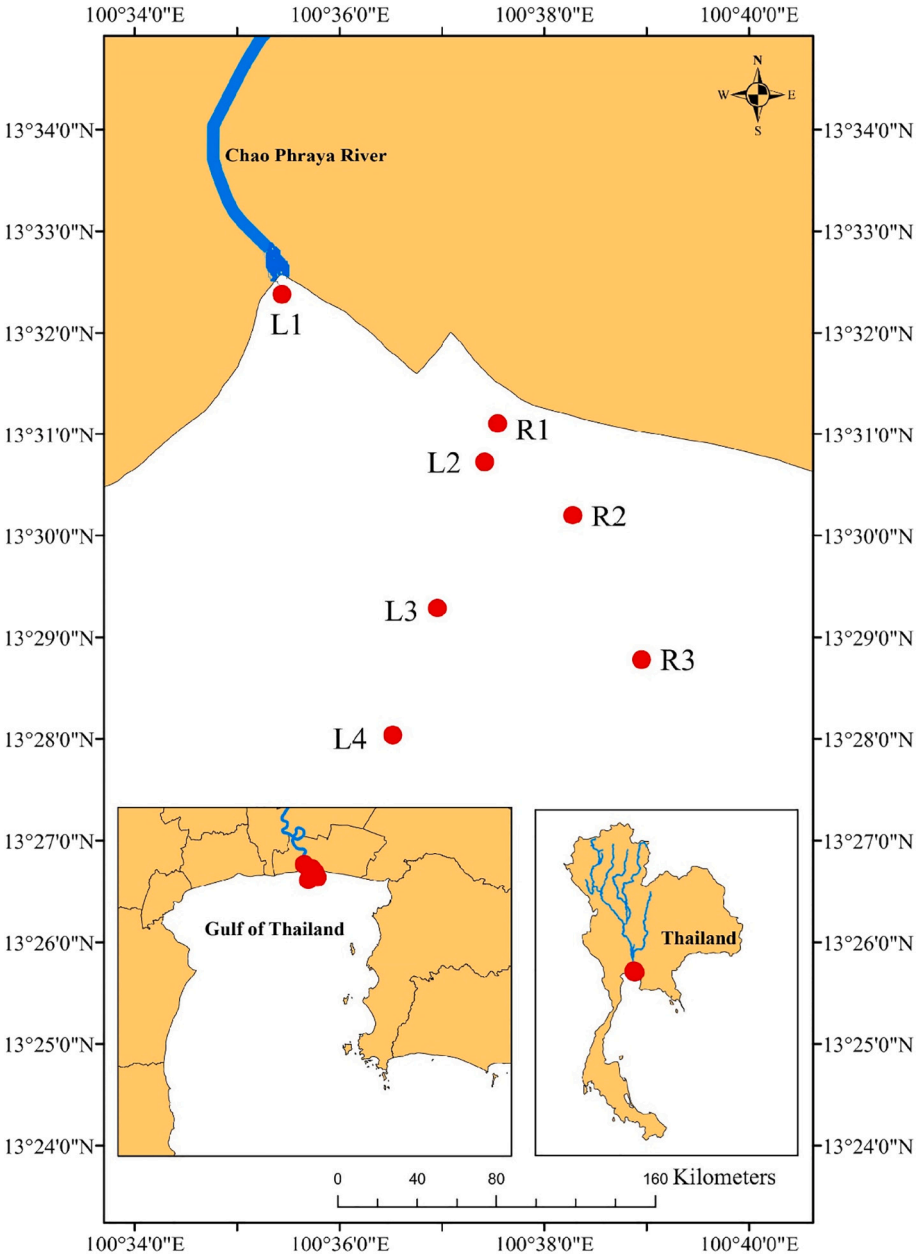

Fig. 1. Sampling stations in the Chao Phraya River Estuary, Thailand.

Fig. 2. Sampling of microplastics by the Manta net.

the digested sample. The floated particles were collected and categorized into four different size ranges (335–515 μm, 516–990 μm, 991–2030 μm, 2031–5000 μm) with stacked stainless-steel sieves. The categorized particles were transferred to prepared glass petri dishes (rinsed with DI water and dried at 40 °C in an oven) and then weighed with a precision balance (5 decimal places, 0.00001 g).

The categorized particles were quantified and identified using a stereomicroscope and Motic Images Plus 3 software (Motic Asia, Hong Kong) to classify physical features (size, shape, and color). All particles from the two large size ranges were analyzed, but the two smaller size ranges were picked using quadrants (approximate 25% by total weight) for analysis. To identify the chemical composition of the polymers, Fourier Transform Infrared Spectroscopy (FTIR, Thermo Fisher, USA) was applied in Attenuated Total Reflectance (ATR) mode to collect the spectra of the putative MPs. FTIR was operated in single reflection mode and analyzed 32 scans per particle to obtain the resolution of 4 cm^{-1} between the Infrared (IR) range of 600 to 4000 cm^{-1}. The collected spectrum was compared to the reference spectra of the OMNIC polymer database provided by Thermo Fisher. Particles with higher than 70% similarity index were accepted as MPs and below 70% were assumed to be non-plastic (Frias et al., 2016).

In order to prevent possible contamination when sampling, the Manta net was installed at the windward side of the vessel and the net was rinsed thoroughly from outside to confirm that all debris were collected by the detachable filter bag at the cod-end after each trawl to avoid cross contamination. To avoid contamination during sample processing, the apparatus and glassware were thoroughly rinsed three times with deionized water and then dried before use. All materials used during the experiment (forceps and glassware) were placed in the cabinet and covered with aluminum foil when they were not in use. Furthermore, all beakers and funnels were covered with aluminum foil after use during the experiments. Moreover, the settled debris from density separation was also passed through the sieve and inspected for the presence of high-density polymers. The efficiency of MP recovery by the sample extraction process was ascertained by spiking water collected from the estuary during the sampling trip with twenty-five primary MPs of 350 μm (Goodfellow Cambridge Ltd., England). The same procedure was then conducted with five replicates to ensure the recovery rate of MPs extraction from the samples. The resulting MP recovery rates ranged from 84% to 90.4%.

MPs were detected in all sampling stations of the Chao Phraya River estuary. The average abundance of MPs at flood tide was 5.16×10^5 particles/km^2 (5.16 particles/m^3) and at ebb tide was 3.11×10^5 particles/km^2 (3.11 particles/m^3). The abundance at flood tide ranged from 1.28 to 10.39×10^5 particles/km^2 (Fig. 3-A). At ebb tide this was from 2.23 to 4.43×10^5 particles/km^2 (Fig. 3-B). These results indicate that the abundance at flood tide was considerably higher than at ebb tide. A possible explanation for this might be that this is caused by some debris that leaves the estuary on the ebb tide re-entering the estuary during flood tide and conversely leaving again on the ebb tide, especially near the river mouth. These results are consistent with the findings from Tamar estuary (England) where the abundance of MPs was also higher in flood tide than ebb tide (Sadri and Thompson, 2014). The station with the highest abundance at flood tide of 10.39×10^5 particles/km^2 (R1) was near the river mouth and at ebb tide was 4.43×10^5 particles/km^2 (L1) at the river mouth. The abundance gradually decreased in the seaward direction (Fig. 3). These results also indicate that the source of MP emissions was from the river discharge (Rech et al., 2014). It is also consistent with the findings from the survey of MPs in surface sediments from the Gulf of Thailand (Wang et al., 2020).

When comparing the abundance of MPs in this study and other estuaries from different parts of the globe, the abundance in the Chao Phraya River estuary was lower than most of the estuaries in China, but higher than the Pearl River estuary (China) and Goiania estuary (Brazil) (Table 1). These figures reveal that MP pollution levels in the estuaries of China were much higher than the Chao Phraya River estuary. The most important thing to note is that these studies applied fine mesh sizes such as 32 μm in the Yangtze estuary, 48 μm in Haihe and Yondingxinhe estuary, and 60 μm in Changjiang estuary. That could increase the number of collected MPs (Kang et al., 2015). On the other hand, almost the same mesh size was applied in the Pearl River estuary (335 μm) and Goiania estuary, Brazil (300 μm), but the abundances were lower than this study. The selection of mesh size of the sampling net significantly affects the abundance of collected MPs (Kang et al., 2015). Although the abundance of MPs was investigated by the researchers in different regions of the globe, direct comparison is impractical as different methods were applied for sampling, sample pre-treatment, and analysis in the different studies. However, the comparison provides qualitative information on the severe threat of MPs to organisms in the respective areas.

When compared with our previous study, the abundance of MPs at flood tide in the rainy season was 2.3×10^5 particles/km^2 (Oo et al., 2020) and in the dry season was 5.16×10^5 particles/km^2 (this study).

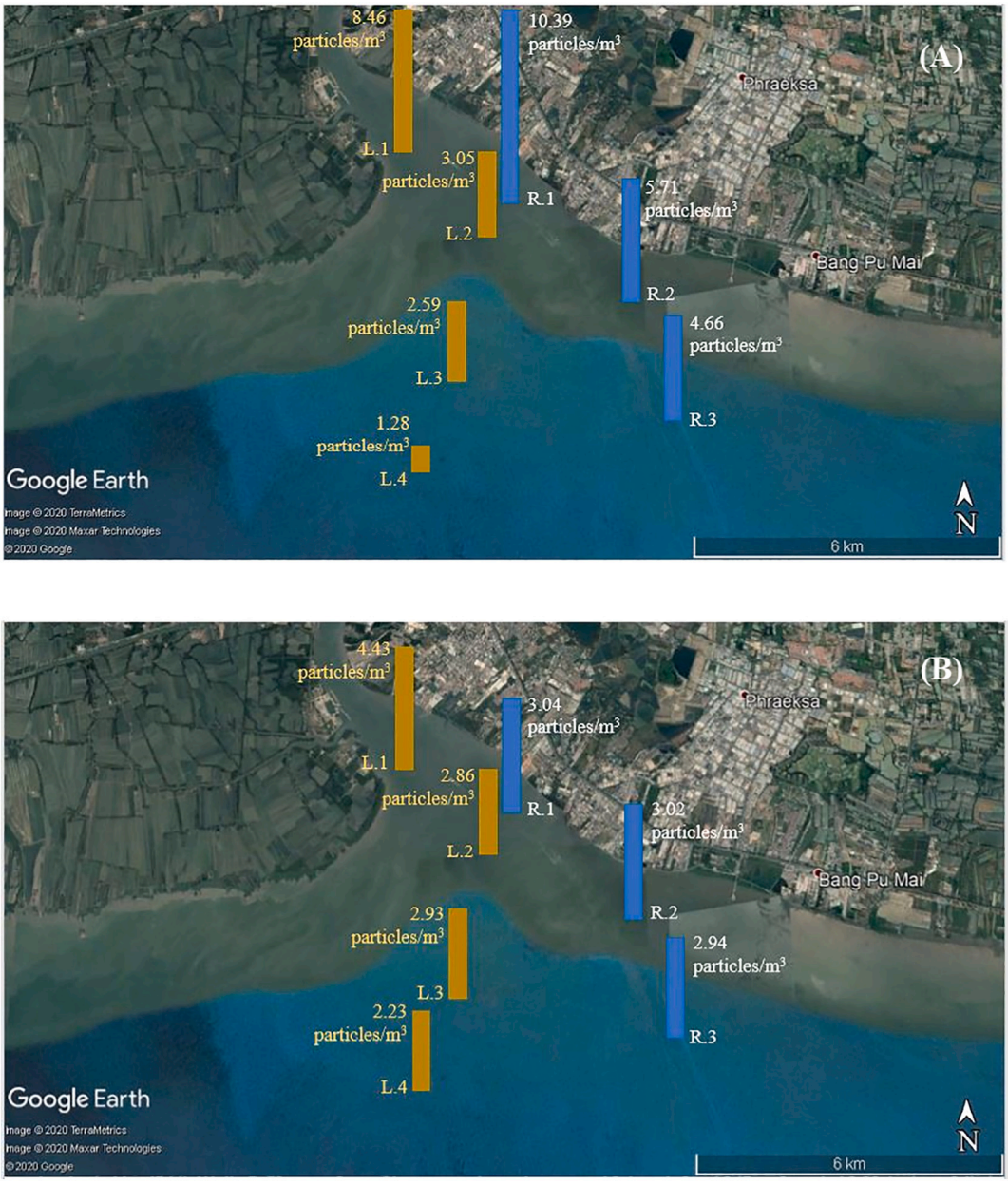

Fig. 3. Abundance of microplastics with tidal fluctuation in the study area at flood tide (A); at ebb tide (B).

The results indicate that the abundance of MPs in the dry season was twofold higher than in the rainy season. The study from Banderas Bay (Mexico) stated that the abundance of MPs was significantly higher in the wet season than the dry season due to the surface runoff that transported plastic debris from the land to the study area and the abundance of plastic debris was positively related to the rainfall data (Pelamatti et al., 2019). However, their study was in the biggest bay of Mexico, therefore there was a different nature in the estuary such as the discharge flow of the river. The results of our research revealed that the abundance of MPs in the estuary was directly related to the tidal current as it is typically strong and predominantly influences the residence time and transport of floating objects within the estuary. MPs could be discharged to the sea along with the river discharge on the ebb tide. However, MPs could re-enter the estuary at the flood tide because of the tidal current. Biofouling changed the density of MPs leading to sinking of low-density MPs (Kooi et al., 2017; Song et al., 2018). Tides and waves may support the resuspension of benthic particles (Sadri and Thompson, 2014). The accumulation of MPs in the estuary increased the residing time causing biofouling, settling, and resuspension leading to a high threat to the aquatic organisms in the study area and the connected food chain.

Collected MPs were categorized into four size ranges (335–515 μm, 516–990 μm, 991–2030 μm, 2031–5000 μm) to indicate a clearer distribution pattern of MPs in the study area (Fig. 4). The smallest size range (335–515 μm) had the most abundance and comprised more than 50% of collected MPs. The second smallest range (516–990 μm) was the second most abundant with almost 30% of MPs in the study area. These results were consistent with the findings from three urban estuaries in China that also stated that small size MPs (<1 mm) were the most abundant size in the estuaries (Zhao et al., 2015). Most of the MP surveys stated that the small and medium size ranges were the most collected MPs from the respective area. The size of MPs influenced the potential effect on biota in the ecosystem (Aliabad et al., 2019). Tiny MPs have a larger effective surface area than large MPs. As a result, they can adsorb more organic pollutants (e.g., antibiotics, heavy metals) on the surface which could increase the threat to ingested organisms and the

Table 1
Comparison of estuarine microplastics abundance in Asia.

Area	Sampling equipment	Abundance	Reference
Yangtze Estuary	12 V DC Teflon pump at a depth of 1 m (32-μm steel sieve)	4137.3 ± 2461.5 particles/m^3	(Zhao et al., 2014)
Nakdong River Estuary, Korea	Manta net (330 μm)	0.62–57 particles/m^3	(Kang et al., 2015)
Goiania Estuary, Brazil	Plankton net (300 μm)	0.26 particles/m^3	(Lima et al., 2014)
Pearl River Estuary, Hong Kong	Manta net (335 μm)	3.627 particles/m^3	(Cheung et al., 2018)
Haihe Estuary, China	12 V DC Teflon pump at a depth of 30 cm (48 μm steel sieve)	1485.7 ± 819.9 particles/m^3	(Wu et al., 2019)
Yondingxinhe Estuary, China		788.0 ± 464.2 particles/m^3	
Changjiang Estuary, China	Screw pump at 30 cm depth (60 μm steel sieve)	157.2 ± 75.8 particles/m^3	(Zhao et al., 2019)
Chao Phraya River Estuary, Thailand	Manta net (335 μm)	5.16 particles/m^3 (flood tide) 3.11 particles/m^3 (ebb tide)	This study

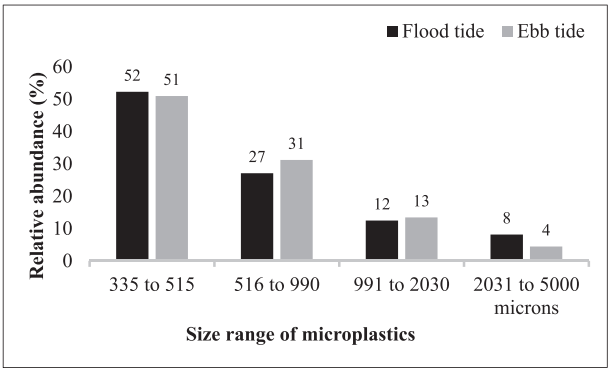

Fig. 4. Size distribution of microplastics with tidal fluctuation.

ecosystem. Therefore, the toxicity of the MP is directly related to its size. Moreover, the size of MPs influences potential bioavailability to the marine organisms as smaller MPs have high potential for mistaken ingestion by diverse organisms (Auta et al., 2017). Microorganisms such as pathogenic bacteria could colonize on MPs and be transferred to non-native habitats that cause threats to biodiversity and coastal environments (De Tender et al., 2015; Peilin et al., 2018). Ingestion of MPs could also lead to an impact on the digestion system and cause damage to internal organs (Klein et al., 2015).

Physical identification of observed colors showed that 62% of total MPs were white followed by transparent (17%), blue (9%), brown (6%), black (4%), and red (2%) on the flood tide. 61% of total MPs were white followed by transparent (22%), blue (9%), brown (3%), black (3%), and red (2%) on the ebb tide (Fig. 5). According to these results, white and transparent MPs were the dominant colors (almost 80%) of total MPs and the rest (about 20%) were colored MPs. White and transparent colors were easily ingested by aquatic organisms such as fish and oysters, therefore an abundance of MPs with these colors could increase the risk of exposure to the organisms in the estuary (Li et al., 2018). Colored MPs could also increase the misidentification as food by organisms because of the similar appearance of plastics and prey (Aliabad et al., 2019).

Microscopic identification of MPs could support determining their origin, such as primary or secondary MPs. Fragments, foam, and film are products of degradation and with the breakdown of larger pieces of plastic waste therefore they are secondary microplastics. Fibers are also considered as secondary microplastics derived from the wastewater of

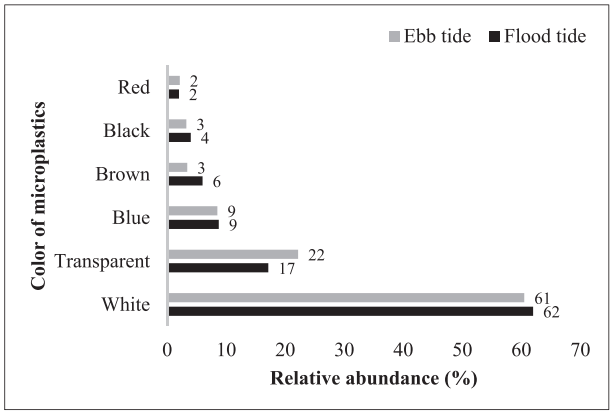

Fig. 5. Color distribution of microplastics with tidal fluctuation.

washing machines and degradation of fishing nets. Pellets are likely to be considered as primary microplastics which are mostly used as industry feedstock for plastic material productions. Microbeads are also primary microplastics which are mostly derived from personal care products.

Shape analysis of collected MPs indicated that fragments were the most dominant with almost 80% of collected MPs, followed by foam, film, pellets, fiber, and microbeads (Fig. 6). The abundance of fragments indicated that MP pollution in the estuary is principally from the fragmentation of large plastic debris. Although plastics have resistance to degrading, physical forces such as wave action and wind, and UV light increase their fragmentation in the environment after a certain period of exposure (Andrady, 2011; Laglbauer et al., 2014). Fragments with varying sizes and cracked surfaces also indicate that such MPs were derived from fragmentation of larger plastic pieces. As a small piece of plastic debris degrades, it could generate several tiny fragments in the environment.

Based on the chemical identification by ATR-FTIR, polypropylene (PP) was the most abundant type followed by polyethylene (PE), polystyrene (PS), and low-density polyethylene (LDPE) in the study area (Fig. 7). The high proportion of PE and LDPE (over 60% of collected MPs) was not surprising as these are the polymer types most produced by the plastics industry globally and are commonly found in consumer products such as plastic bags, bottles, caps, film, and containers (Cole et al., 2011; Geyer et al., 2017). PP is also commonly used in fishing applications (Wang et al., 2018). Moreover, when MPs are impacted by weathering effects, MP particles of PP have a higher sorption rate of heavy metal than other polymers in laboratory and field tests (Gao et al., 2019). Therefore, the abundance of PP creates a high threat to ingested organisms and connected food chains.

This study revealed that MPs were detected in all sampling stations of

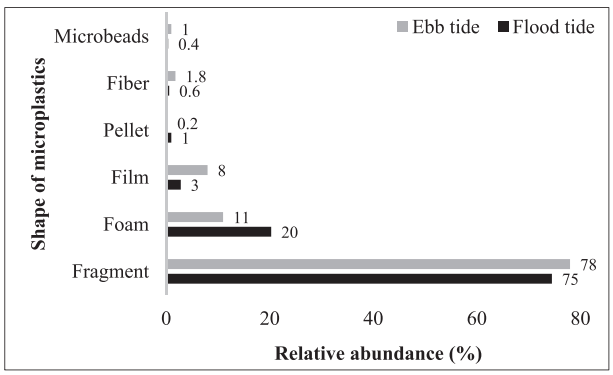

Fig. 6. Shape distribution of microplastics with tidal fluctuation.

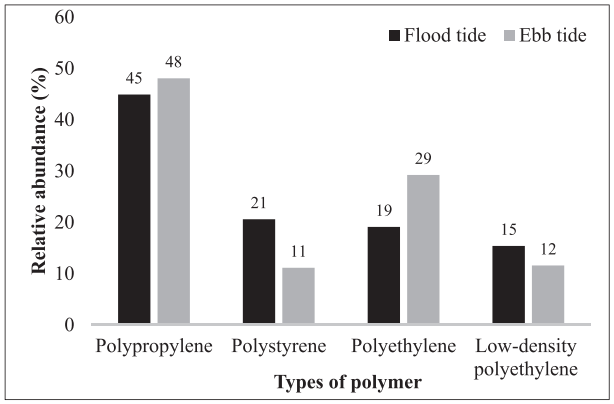

Fig. 7. Polymer distribution of microplastics with tidal fluctuation.

the Chao Phraya River estuary with an average abundance of MPs at flood tide of 5.16×10^5 particles/km^2 (5.16 particles/m^3) and ebb tide of 3.11×10^5 particles/km^2 (3.11 particles/m^3). MP pollution levels in the Chao Phraya River estuary were higher than found in other estuary studies that used a similar mesh size. The stations with the highest abundance were located around the river mouth indicating that the source of MPs emission was from the river discharge. The abundance of MPs in the estuary was directly related to the tidal fluctuation, which also created an accumulation of MPs in the study area. The smallest size range (335–515 μm) was the most abundant and comprised more than 50% of collected MPs which increased its potential bioavailability to the diverse marine organisms. White and transparent were dominant colors in collected MPs. The abundance of fragments revealed that these were derived from degradation of larger plastic waste. Polypropylene, polyethylene, and polystyrene were the most abundant polymers. The findings of this study provide important information on the pollution status of microplastics, the threat to aquatic organisms in the Chao Phraya River estuary, and the variation of suspended microplastics with tidal fluctuation which should be considered in future estuarine microplastic studies.

Data availability

The data and materials of this study will be available from the corresponding author on reasonable request.

Ethics approval

This manuscript has not been published or presented elsewhere in part or in entirety.

Consent to participate

Not applicable.

Consent for publication

All authors agreed to publish this article in Marine Pollution Bulletin.

CRediT authorship contribution statement

Phyo Zaw Oo: material preparation, sample collection, sample analysis, data analysis, and writing the original manuscript. Suwanna Kitpati Boontanon: funding acquisition, filed investigation, data analysis, review, editing and supervision. Narin Boontanon: sampling method optimization, review and editing. Shuhei Tanaka and Shigeo Fujii: review, editing and supervision.

Declaration of competing interest

The authors declare no competing interests.

Acknowledgements

The author would like to express sincere thanks to the Head of the Regional Harbor Office (Samut Prakan Branch), officers and staff for providing the required documents and the marine vessel. This study was supported by the On-site Laboratory Initiative of the Graduate School of Global Environmental Studies, Kyoto University. We would like to thank Graham K. Rogers for editing and reviewing this manuscript for English language.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at https://doi.org/10.1016/j.marpolbul.2021.112933. These data include the Google map of the most important areas described in this article.

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