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Microplastics pollution in selected rivers from Southeast Asia

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ABSTRACT

Microplastics have been found in all hemispheres of the world. However, studies on microplastics are mainly conducted in Europe, North America, and East Asia. Few studies are reported in the Southeast Asian region, where a large number of plastic waste is disposed of improperly into the water. This study investigated the abundance and characteristics of microplastics in the surface water of the Chao Phraya River (Thailand), Citarum River (Indonesia), and Saigon River (Viet Nam). Samples were collected at urban and estuary zones of these rivers. The numbers of microplastics at the urban zones were 80±60, 12±6, and 68±20 items/m^3 at the Chao Phraya, Citarum, and Saigon River, respectively. At the estuary zones, the numbers of microplastics were 48±8, 0±0 (0.08±0), and 42±5 items/m^3 at the Chao Phraya, Citarum, and Saigon River, respectively. Microplastics with morphologies of fragments and fibres were mainly found in the rivers. Polypropylene and polyethylene particles were the most abundant in all collected samples. Since the selected rivers play important roles in water supply and aquaculture activities, the presence of microplastics in these rivers may negatively impact aquaculture and human health. Potential plastic management strategies to minimize microplastic problems in the selected rivers were also proposed in this study.

KEYWORDS

Microplastics, Chao Phraya River, Citarum River, Saigon River

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HIGHLIGHTS

- Microplastics were found in samples collected from Chao Phraya, Citarum and Saigon rivers.
- Number of microplastics in urban zones are much higher than in estuary zones.
- Abundance of microplastics increases with increasing population.
- Most microplastics were polypropylene (PP) and polyethylene (PE), with the predominance of fragments and fibres.
- Policies on waste separation at source and ban on single-use plastic products are suggested.

1. INTRODUCTION

Southeast Asia (SEA) region remains the world's most vulnerable region to water insecurity. Countries in the region are growing, and their water management is a matter of concern (Strazzabosco, 2020). Along with long-standing problems, recent concerns are growing on the abundance of microplastics (MPs) in the water environment. MPs have been found in all hemispheres of the world (Mishra, Singh, & Mishra, 2021). However, studies on MPs are mainly conducted in the Northern Hemisphere (Europe, North America, and East Asia). Few studies are reported in SEA countries where a large number of plastic wastes are improperly disposed into the water.

Previous studies have found 5 countries in the SEA region as the top countries that have mismanaged plastic waste (Lebreton & Andrady, 2019; Jambeck et al., 2015). Thailand, Indonesia, and Viet Nam are the main contributors of ocean plastic waste, with 0.15–1.29 million tonnes per year (Jambeck et al., 2015). Also, a study by Meijer, Van Emmerik, Lebreton, Schmidt, and Van Der Ent (2019) estimated that rivers (including the Chao Phraya River, Citarum River, and Saigon River) in these countries are the top rivers in the world emitting plastics into oceans. However, knowledge on the occurrence of MPs in these rivers is insufficient (based on the literature search on Clarivate's ISI Web of Science).

The Chao Phraya River is a major river in Thailand, with a length of about 372 km flowing through 9 provinces and exits in the Gulf of Thailand. The river is also the major raw water supply for water treatment plants that provide tap water for more than 10 million residents. However, the Pollution Control Department of Thailand (PCD) reported that the water quality of the river has seriously deteriorated in the past decade due to the discharge of wastes from urban activities. The Citarum River is in Majalaya Basin, West Java, Indonesia. This river plays a vital role in the water supply, agriculture, electricity, fishery, and industries of the region. However, this river is listed as the most polluted river in the world (Sembiring, Fareza, Suendo, & Reza, 2020). As the Citarum River supplies several cities with their raw water supply, it is essential to understand the occurrence and distribution of MPs on this river. The Saigon River is the longest in Ho Chi Minh City, with a length of 256 km. This river is also an essential source of water for water treatment plants and agricultural and industrial activities. Nevertheless, recent reports found that 882 to 1,552 tonnes of plastic wastes were collected from the Saigon River each day (No. 3 Enterprise 2016).

Based on the above situation, this study investigated the occurrence of MPs in the Chao Phraya

River (Thailand), Citarum River (Indonesia), and Saigon River (Viet Nam). The main objective is to monitor the status of MPs in surface water of these rivers in urban and estuary zones. Characteristics and polymer types of MPs were also investigated for tracking their origin. Since these rivers play important roles in the economy and society in their own countries, study results will provide baseline data about MPs pollution for further studies and management strategies.

2. METHODOLOGY

2.1. Study area

Study sites were selected at urban and estuary zones of major rivers in selected developing countries (Thailand, Indonesia, and Viet Nam) of the SEA region. At the Chao Phraya River, samples were collected at the Tha Pra Chan and Pak Nam zones on September 19 and May 18, 2019. For the Citarum River, samples were collected at the Oxbow Dayeuhkolot and Muara Gembong zones on October 8 and 13, 2020, respectively. At the Saigon River, samples were also collected near the mouth of Nhieu Loc—Thi Nghe canal (urban zone) and Giong Ong To Creek (estuary zone) to the Saigon River in August 24 and October 10, 2019, respectively.

2.2. Sampling

The methods used in this study were consistent between three research partners. The methods for collecting samples in this study were adopted from Ta and Babel (2020). At the Chao Phraya River, samples were collected and analyzed by researchers at Sirindhorn International Institute of Technology, Thammasat University. For the Citarum River, samples were collected and analyzed by researchers at the Bandung Institute of Technology, and at the Saigon River, samples were collected and analyzed by researchers at Van Lang University.

Water samples at these three rivers were collected by manta trawls. These trawls were fabricated with the same design, which included a rectangular aluminium frame (20 cm high x 50 cm wide) and a 2-m long net. The net with an aperture size of 300 μm was connected with a cod-end (25 cm high x 10 cm diameter). Trawling tracks were recorded via Global Positioning System (GPS) devices. The trawling speed was from 5 to 12 km/h, depending on the river currents. The volume of filtered water was measured by a flow meter mounted at the manta trawl opening. The trawled area and volume were calculated by multiplying the recorded distance with the width and height of the manta opening, respectively.

2.3. Sample analysis

A procedure designed for the analysis of MPs concentration in the marine environment by Masura, Baker, Foster, Arthur, and Herring (2015) was adopted with modifications for this study. Water samples were first sieved through stainless steel aperture sizes of 0.05, 0.3, 0.5, 1.0 and 5.0 mm. All solids were transferred to sieves and rinsed with deionized water. In sieves of 5.0 mm, organic materials such as leaves, bugs, larger algae and wood were carefully rinsed with deionized water and removed from the samples with tweezers. This procedure resulted in size fractions: 0.05–0.3 mm, 0.3–0.5 mm, 0.5–1.0 mm and 1.0–5.0 mm. The fractions containing particles larger than 0.5 mm (i.e., retained in sieves with aperture sizes of 0.5 and 1.0 mm) could be examined visually without instruments. Therefore, suspected plastic debris in this size range were placed on Petri dishes using stainless steel tweezers. The total mass for these particles was determined by drying them in an oven at 60°C for 24 hours. Suspected plastics were inspected by an optical microscope. Under the microscope, MPs were inspected for the number, morphology and colour. After visual sorting, all particles were inspected by an attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy (Thermo Fisher Scientific). Polymer types of MPs were confirmed based on comparison with the standard spectra on the OMNIC™ Specta Software. The match factor threshold was set to 70% to identify the accuracy of the polymer.

The fractions containing particles smaller than 0.5 mm (i.e., retained on sieve aperture sizes of 0.05 and 0.3 mm) were transferred into different beakers by deionized water. Fractions in these size ranges are difficult to examine visually because they carry much sediment and organic debris. Thus, hydrogen peroxide (30%) with iron (II) as a catalyst was used to remove organic material. Moreover, sodium iodide (NaI) with a density of 1.5 g/cm^3 was also used to remove sediment and some organics from the samples in these size ranges. The remaining solids after density separation were filtered on cellulose nitrate membrane filters (0.45 μm, cellulose nitrate, Whatman) by vacuum filtration and dried in an oven at 60°C. After drying, the size fraction of 0.3–0.5 mm was inspected by an optical microscope and FTIR, similar to the particles larger than 0.5 mm.

3. RESULTS AND DISCUSSION

3.1. Number of MPs

3.1.1. MPs in urban zones

At the Chao Phraya River, samples were collected in downtown Bangkok (Tha Pra Chan area), which is the largest city in Thailand. The study site is highly populated, along with many tourist attractions located nearby. Figure 1 (A) shows sampling points and the surrounding area at the urban zone of the Chao Phraya River. In the study area, MPs were found in all collected samples. The numbers of MPs at the site are presented in Table 1. The number of MPs in water samples are 48±11, 38±30, and 155±16 items/m^3 for bank 1, bank 2, and the middle position, respectively. The mean number of MPs in all water samples at the study area is 80±60 items/m^3. This difference in MPs numbers at these positions may be explained by the turbulence and morphology of the river in the study area (Ta & Babel, 2020). As shown in Figure 1 (A), before the sampling points, the river has a curve that affects the river flow. Moreover, the busy activities of boats at the banks may also make materials flow into the middle position of the river. However, further studies are needed to confirm and explain the differences in MPs concentrations at different positions in the river.

At the Citarum River, samples were collected in the urban zone of Oxbow Dayeukolot. The abundance of MPs in this area is associated with population density and the resident's activity. The tributaries flow from denser residential and industrial areas. At Oxbow, there is a flood control channel, and the shape is like a horseshoe. In this channel, the water is stagnant; thus, it can trap the MPs. The sampling points on the Citarum River is shown in Figure 1 (B). The concentration of MPs on the left, centre and right sides from the urban zone were 16 items/m^3, 15 items/m^3, and 4 items/m^3, respectively. The mean number of MPs in the study area was 12±6 items/m^3(Table 1).

At the urban zone of the Saigon River, the width of the river is about 322 m, with a buffer zone of trees on the left bank and right bank, including Tan Thuan port, residential areas, along with small and medium industrial facilities. The sampling points of the Saigon River are shown in Figure 1 (C). The concentration of MPs on the left, centre and right banks from the urban zone were 60 items/m^3, 53 items/m^3, and 90 items/m^3, respectively. The mean number of MPs was 68±20 items/m^3. The number of detected MPs was the highest at the right bank of the river. The reason is that raw sewage from the central districts of Ho Chi Minh City drains via combined sewers and by Doi—Te canal to the Saigon River at the right bank. While the left bank of the river is a buffer zone with trees thus, the number of MPs in the left bank was lower than the right bank. The Saigon River is one of the main waterway transportations of Ho Chi Minh City and the South of Viet Nam. Also, this study site is nearby the Tan Thuan Port, with many ships carrying large tonnage are moving in the middle of the river. So, the water stream often tends to be pushed into two banks carrying suspended solid/particulate to the banks. Thus, the number of MPs at the two banks was found higher than at the middle stream.

3.1.2. MPs in estuary zones

At the Chao Phraya River, sampling points at the estuary zone are shown in Figure 1 (A). The total surface area of the river estuary is about 37.8 km^2. As shown in the figure, in this area, most land on bank 1 is used for aquaculture, while bank 2 is used for small industrial and residential zones.

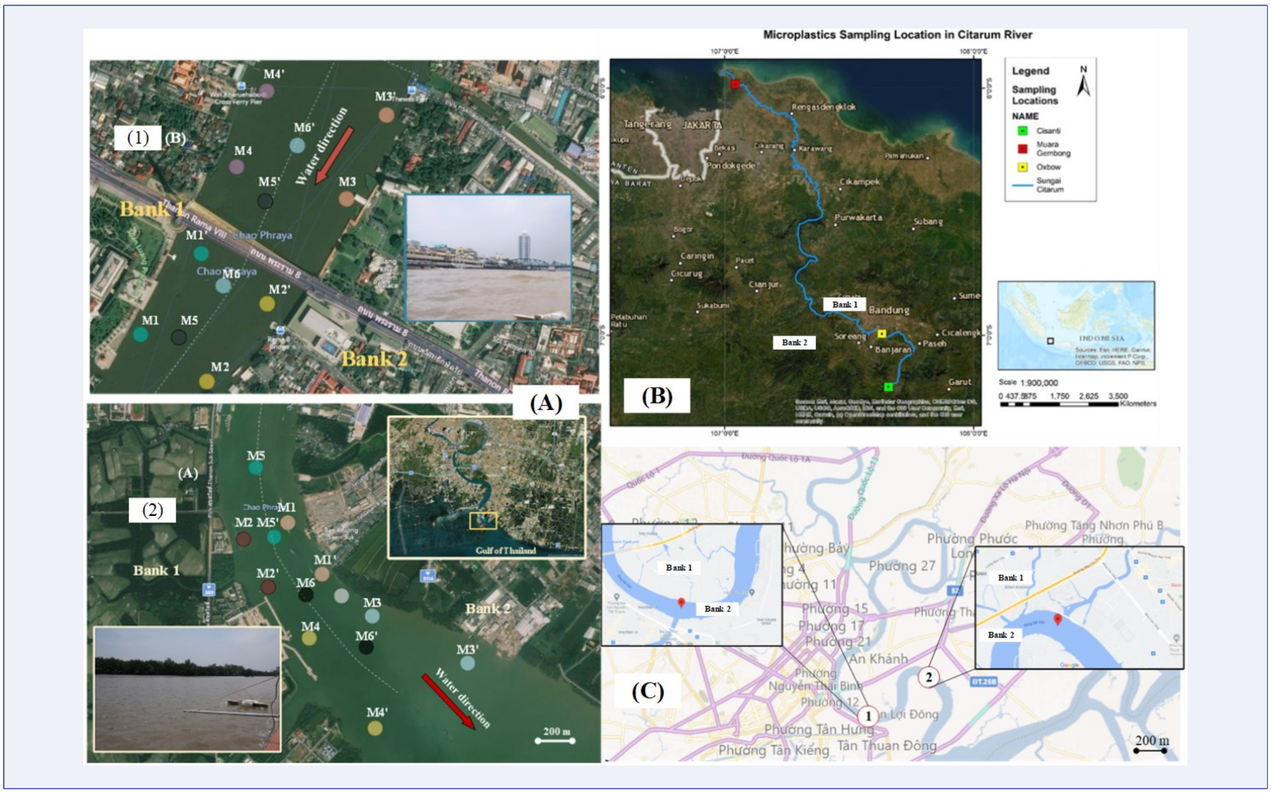

FIGURE 1. Sampling sites at selected rivers: (A) the Chao Phraya River, Thailand: (1) Bangkok (Tha Pra Chan area), (2) Pak Nam, Samut Prakan; (B) Citarum River, Indonesia, (C) Saigon River, Viet Nam: (1) urban zone, (2) estuary zone.

MPs were found in all water samples collected from the estuary zone of the Chao Phraya River (Pak Nam, Samut Prakan). In total, about 5,000 particles were counted, photographed, and categorized in all water samples for the two sampling times. The numbers of MPs in water samples are 46±5, 35±5, and 63±12 items/m^3 for the bank 1, bank 2, and middle position, respectively. The mean number of MPs in all water samples at the study area is 48±8 items/m^3 (Table 1).

At the Citarum River, samples were collected at the estuary zone of the Muara Gembong area. The number of MPs found in this study site was much lower than that of the urban zone. The number of MPs on the left, centre and right banks is 0.098, 0.086 and 0.046 items/m^3, respectively. The mean number of MPs in all water samples at the study area is 0.08±0 items/m^3. The source of plastic and microplastics in Muara Gembong is mainly from industries, fisheries and fish harvesting on the banks of the river. In this location, waste management and wastewater treatment are lacking. Nearby housing and community tend to dump their waste directly into the river. This behaviour was also found from the middle stream to downstream areas of the Citarum River.

At the estuary zone of the Saigon River, the river is about 380 m wide which is the most expansive site among all study sites. At the site, the river receives water from the Giong Ong To Creek, which contains wastewater from residential areas of the urban zone. The left bank river is new residential zones with a low population density and a part of agricultural areas. The number of MPs on the left, centre and right banks are 46.3, 42.9, and 37.1 items/m^3, respectively. The mean number of MPs in all water samples at the study area is 42±5 items/m^3. The number of MPs at the left bank was higher than that of the right bank and middle stream of the river. This may be due to the influence of canal water of the Giong Ong To Creek, which partly carried raw sewage and flows to the left bank at the study site.

When comparing the three rivers, the number of MPs was found in the same trend. The number of MPs found in urban zones was higher than that of the estuary zones. This demonstrated that the

Number of MPs (items/m^3)	**Thailand** (Chao Phraya River)	**Indonesia** (Citarum River)	**Viet Nam** (Saigon River)
Urban zones	80±60	12±6	68±20
Estuary zones	48±8	0±0 (0.08±0)	42±5

TABLE 1. Mean number of MPs in surface water samples at three selected rivers.

abundance of MPs increases with the increase of the urbanization rate. Also, the number of MPs found at the Chao Phraya River (Thailand) and the Saigon River (Viet Nam) is comparable. However, the number of MPs at the Citarum River (Indonesia) is much lower than the Chao Phraya and Saigon River in both urban and estuary zones (Table 1).

3.2. Characteristics of MPs

3.2.1. Size of MPs

The percent distribution of MPs by size was computed using the numbers of MPs. For surface water samples, the percent distribution of MPs by size is not significantly different between the urban and estuary zones of the Chao Phraya River. The size distribution of MPs was similar at all study zones with the predominance of 0.05–0.3 mm. However, it can be realized that the percentage of MPs with the size range of 0.05–0.3 mm in the urban zone is lower than in the estuary zones. According to Boyle and Örmeci (2020), the size of MPs decreases with the time that plastic has been exposed to the natural environment. Control experiments by Song et al. (2017) showed that polymers of PP, PE and EPS need about 2 to 12 months to degrade into MPs smaller than 0.3 mm. Thus, the lower percentage of large MPs (>0.3 mm) in the urban zone of the Chao Phraya River indicates that the plastic debris in this zone may be exposed to the environment for a shorter time than that of estuary zones. Therefore, plastics do not have enough time to degrade into smaller sizes.

At the Citarum River, the size distribution of MPs at the urban (Oxbow) and estuary zones (Muara Gembong) is not significantly different. The most dominant size of MPs was 1.0–5.0 mm at these two study sites with the percentages of 42%–85%. MPs with the size of 0.3–0.5 mm account for the lowest percentages of 3%–17%. As shown in Figure 4 , MPs with the size of 0.3–1.0 mm at the estuary zone were much higher than that of the urban zone.

At the Saigon River, the size distribution of MPs was not very different between the urban and estuary zone. Small sizes of MPs were predominant in all collected samples at the river. At the urban zone, MPs with the size of 0.05–0.3 mm were found with the highest percentage (27%). However, the variation between size ranges was not much different. At the estuary zone, MPs with the size of 0.3–0.5 mm were predominant in all samples (37%). As shown in Figure 4, the size distribution of MPs at the Chao Phraya (Thailand) and Saigon (Viet Nam) is comparable. At these rivers, MPs with small sizes were predominant in urban and estuary zones. However, at the Citarum River, MPs were mainly found with the size of 1.0–5.0 mm in all study zones.

3.2.2. Polymer types

At the Chao Phraya River, the proportion of polymer types is similar in the urban and estuary zones. Polypropylene (PP) was the most abundant polymer type in all surface water samples ranging from 44% to 67%. Polyethylene (PE) (ranging from 26%–36%) was the second abundant polymer at all study zones. PP-PE copolymer was observed with a smaller amount. Moreover, other polymers such as polyester (PES), polyurethane, cellophane, and polybutylene were detected with a total proportion of less than 5%.

At the Citarum River, MPs found in Oxbow and Muara Gembong areas were also mainly PP and PE. The source of MPs in these study sites may come from daily-use plastic, food packaging, and industrial waste in these locations. The high concentration of MPs is related to the high population and resident activities on the land (Alam, Sembiring, Muntalif, & Suendo, 2019). These findings emphasize the urgency to mitigate the MPs contamination of the aquatic environment in the near future.

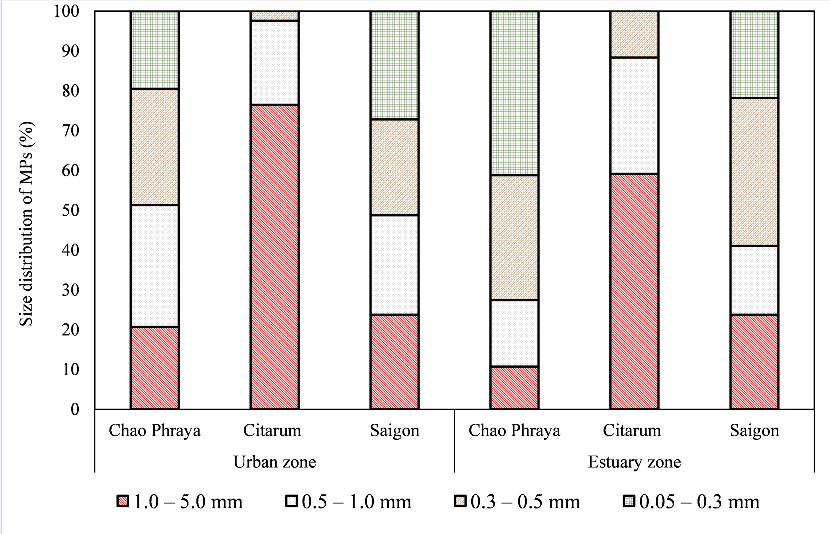

FIGURE 2. Variability of MP sizes at the Chao Phraya River (Thailand), Citarum River (Indonesia), Saigon River (Viet Nam) in urban and estuary zones.

At Saigon River, polymer types of MPs were also similar between urban and estuary zones. MPs at the study sites were mainly detected with four polymer types, including PP, PE, polystyrene (PS), and polyethylene terephthalate (PET). PP was found with the highest percentage (65%–70%), followed by PE (24%–37%). PET was found with the lowest percentage.

The high abundance of PP and PE in the surface water of the Chao Phraya River, Saigon River, and Citarum River could be due to their higher consumption in Thailand, Viet Nam, and Indonesia (Wichai-Utcha & Chavalparit, 2019; VPAS, 2019). These polymers are commonly used to produce consumer products such as containers, bottles, plastic bags, and tableware (Cole, Lindeque, Halsband, & Galloway, 2011). PP and PE polymers are also used in personal care and cosmetics products (Leslie, 2014). According to Plastics Europe (2018), PP and PE are the most widely produced polymers around the world and are also the most frequently detected MPs in the marine and freshwater environment (Wu, Zhang, & Xiong, 2018). Moreover, the densities of the two polymers are lower than water (PP: 0.91 g/cm^3, PE: 0.95 g/cm^3), which makes them float easily on the surface water. The existence of denser polymers such as PES (1.40 g/cm^3) in the surface water can be explained by the following reasons. First, the weathering process can decrease the density of these MPs. According to Guo and Wang (2019), weathering changes the crystallinity of MPs by reducing the density. Moreover, the molecular weight of plastic would decrease due to polymer chain cleavage and oxidation during the weathering process (Lv, Huang, Kong, Yang, & Li, 2017). Second, the higher surface-to-volume ratio enabled the MPs to be suspended in the surface water. In addition, the tides and waves could resuspend the dense MPs from the bottom sediment.

3.2.3. Morphology of MPs

Morphologies of MPs were categorized into fibres, fragments, pellets, and films. In brief, pellets are spherical, ovoid, disk-shaped, or cylindrical particles. Fibres are thin and long items, films are thin pieces of plastic debris, and fragments are unidentified morphology. As shown in Figure 4, morphologies of MPs were not significantly different between the Chao Phraya and Citarum River with the predominance of fragments. However, at the Saigon River, fibre was found with the highest percentage. In general, the morphology of MPs is related to their origins. Fibres may be generated from textile materials, fishing gear, and the deposition of airborne matter (Cesa, Turra, & Baruque-Ramos, 2017). Plastic bags and packaging

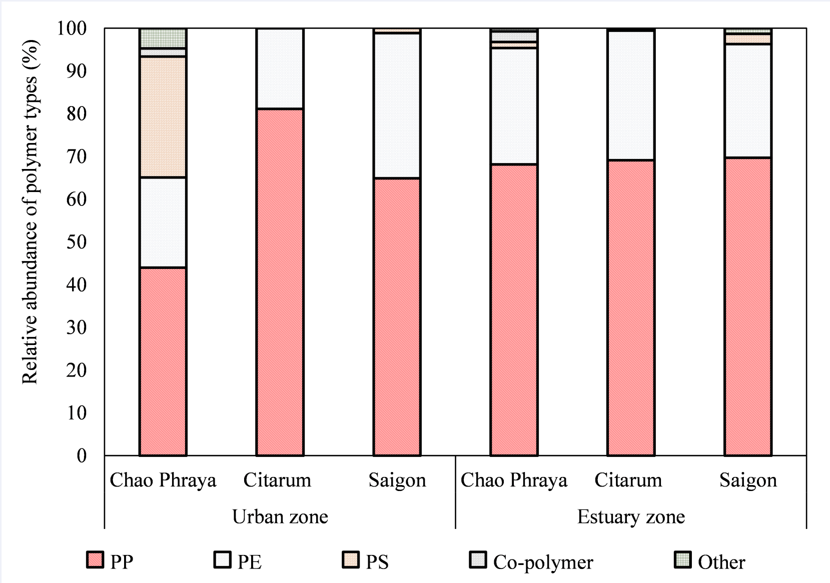

FIGURE 3. Variability of MP polymers at Chao Phraya River (Thailand), Citarum River (Indonesia), Saigon River (Viet Nam) in urban and estuary zones.

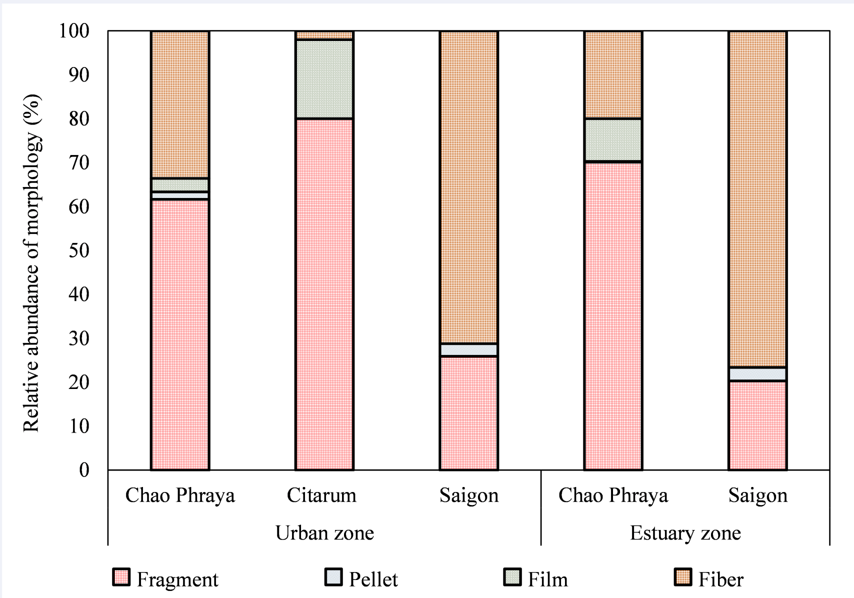

FIGURE 4. Variability of morphology at Chao Phraya River (Thailand), Citarum River (Indonesia), Saigon River (Viet Nam) in urban and estuary zones.

materials, which are thinner and softer, are the primary sources of film-shaped MPs. Pellets can be derived from plastic resin or microbeads in personal care products (Ta & Babel, 2020). Fragments are likely degraded from larger plastic goods (i.e. plastic containers, tableware, furniture, and toys) through mechanical and UV radiation (Horton, Walton, Spurgeon, Lahive, & Svendsen, 2017). Thus, the higher percentage of fragments in this study indicates that MPs found in the Chao Phraya, Citarum, and Saigon River are mainly secondary MPs.

3.2.4. Comparison to other studies

Since the standards for the collection, identification, and evaluation of MPs are still not developed, the units of MPs abundance vary among the studies. Therefore, the results in this study are only compared with studies using the same units. A comparison of MPs levels between the Chao Phraya River, Citarum River, Saigon River and other rivers in the world is presented in Table 2. These studies are classified based on the land-use functions such as urban and estuary zones.

Urban zone

As presented in Table 2, the MPs numbers in the surface water of the Chao Phraya River (Bangkok), Citarum River (Oxbow Dayeukolot), and Saigon River (Nhieu Loc—Thi Nghe) are lower compared to other urban zones. The level of MPs in these studied rivers is comparable with the urban zone of Tamsui River (Taiwan) (Wong, Löwemark, & Kunz, 2020) and Milwaukee River (USA) (Lenaker et al., 2019). Most of the studies on rivers in China, such as the Suzhou River (Luo et al., 2019) and the Hanjiang River (Wang, Ndungu, Li, & Wang, 2017), have higher MPs than the Chao Phraya, Citarum and Saigon River. In the Nakdong River (South Korea), the number of MPs was 293±83–4760±5242 items/m^3 (Eo, Hong, Song, Han, & Shim, 2019), which is much higher than that of the studied rivers. Table 2 also depicted the number of MPs in urban zones of rivers in North America and European countries, such as the Ottawa River (Canada) (Vermaire, Pomeroy, Herczegh, Haggart, & Murphy, 2017) and Danube River (Austria) (Lechner et al., 2014) and have lower numbers of MPs than this study. According to Lambert and Wagner (2018), waste management practices and high population density are directly related to the high level of MPs pollution in regions. Therefore, the number of MPs in this study and other studies may demonstrate the level of waste management systems in each study area. Moreover, the data also highlight the unsound waste management systems in Asian countries compared to European countries (Wu et al., 2018).

Estuary zone

In comparison to other studies using the same metrics, the abundance of MPs in the estuary zone of the Chao Phraya River (Samut Prakan), Citarum River (Muara Gembong) and Saigon River (Giong Ong To Creek) are among the lowest recorded for estuaries. As shown in Table 2, the abundance of MPs in this study is comparable to the Clyde Estuary of Australia. It has similar activities of land uses as in the current study (Hitchcock & Mitrovic, 2019). However, it is lower than that in most estuaries globally. For example, MPs abundance in the Yangtze Estuary (Zhao, Zhu, Wang, & Li, 2014) and Bohai Bay (Wu et al., 2019) of China and the Hunter Estuary of Australia (Hitchcock & Mitrovic, 2019) are found to be 8 to 300 times higher than this study. The significant differences in MPs levels among this study and others may be due to the following reasons. Firstly, the sampling areas in the current study are suburban zones, where land is used for aquaculture, factories and residential zones. Other studies were conducted in densely populated areas with activities of industry, tourism, commerce and recreation. For example, the Yangtze Estuary, estuaries in Bohai Bay and Hunter Estuary are in the metropolitan areas of Shanghai, Tianjin, and Newcastle, respectively. Secondly, different methodologies for sampling and analysis of MPs are applied in the studies. In the Yangtze Estuary and Bohai Bay of China, MPs from the surface water were collected by pumps (Wu et al., 2019). The study at the South Carolina estuaries used a sea surface microlayer collection apparatus with a 2-mm stainless steel mesh to collect MPs samples (Gray, Wertz, Leads, & Weinstein, 2018). The study at Hunter Estuary used a plankton net with a mesh size of 37 mm (Hitchcock & Mitrovic, 2019).

3.3. Potential plastic management strategies to minimize MPs problem in the selected rivers

As mentioned above, Thailand, Indonesia and Viet Nam were the top countries that have mismanaged plastic waste and are the main contributors of ocean plastic waste (Jambeck et al., 2015; Lebreton & Andrady, 2019). With the presence of MPs found in the Chao Phraya River, Citarum River and Saigon River, plastic management strategies are necessary to minimize MPs pollution problems. The following strategies are suggested to reduce MPs levels in the

Location	Abundance (items/m^3)	Reference
Urban zones		
Hanjiang River, China	933±305.5	Wang et al. (2017)
Suzhou River and Huangpu River, China	1,800–2,400	Luo et al. (2019)
Tamsui River, Taiwan	10.1–70.5	Wong et al. (2020)
Nakdong River, South Korea	293±83–4,760±5,242	Eo et al. (2019)
Ottawa River, Canada	0.71–1.99	Vermaire et al. (2017)
Milwaukee River, USA	0.54–11.6	Lenaker et al. (2019)
Danube River, Austria	0.317±4.665	Lechner et al. (2014)
Chao Phraya River, Thailand	80±60	Present study
Citarum, Indonesia	12±6	
Saigon, Viet Nam	68±20	
Estuary zones		
Yangtze Estuary, China	4,137.3±2,461.5	Zhao et al. (2014)
Jiaojiang Estuary	955.6±848.7	Zhao et al. (2015)
Oujiang Estuary	680.0±284.6	
Minjiang Estuary, china	1,245.8±531.5	
Changjiang Estuary	231±182	Xu et al. (2018)
Yondingxinhe River	788.0±464.2	Wu et al. (2019)
Haihe River, China	1,333.3±782.1	
Hunter Estuary	1,032	Hitchcock & Mitrovic (2019)
Clyde Estuary, Australia	98	
Chao Phraya River, Thailand	48±8	Present Study
Citarum, Indonesia	0.08±0	
Saigon, Viet Nam	42±5	

TABLE 2. Abundance of MPs in the selected rivers as compared to other rivers in the world by their land use.

selected rivers.

3.3.1. Policy

- Regarding domestic solid waste management, the main aspect being considered is solid waste separation at source, including establishing legal documents to serve programs on solid waste separation at source: (1) Regulation on classification and storage at source, (2) Collection from source, (3) Transit and transport, (3) Reuse and recycle, and (4) Treatment and recycle.
- Develop policies to reduce single-use plastic products (having regulation on single-use plastics) and plastic bags.
- The governments of the three countries should promulgate policies encouraging recycling plastic waste, especially invaluable plastic waste, and support funding to improve existing recycling facilities or invest in recycling facilities with advanced technologies.
- Develop policies to limit the import, production, and supply of non-degradable plastic bags.

3.3.2. Database building and scientific research

- Strengthen monitoring and investigations of plastic waste and MPs in the canal and river systems.
- Establishing a database system on domestic solid waste, including plastic and MPs waste.
- Strengthening scientific research on recycling single-use or invaluable plastic waste (plastic bags).

3.3.3. Human resources

- Develop human resources for urban solid waste management, especially plastic waste.
- Organize a monitoring group for the classification of solid waste at source and indiscriminate disposal of waste in the local community.

- Decentralization of solid waste management, where local authorities (community level) are responsible for enforcing solid waste separation at source and controlling littering in the environment.

3.3.4. Tax and fee tools

- Increase environmental protection tax on plastic bags and bring single-use plastic products into the category subject to environmental protection tax.
- Deposit refund system: For some plastic packaging, the buyer will be refunded the deposit when returning packaging to the store after using the product.

3.3.5. Propaganda, education to raise awareness

The public plays a vital role in increasing effective plastic waste management. Thus, participation of public sectors and communities in solid waste separation at source is critical to minimizing plastic waste and MPs in the aquatic ecosystem. The following activities and campaigns are recommended to increase public participation and awareness on plastic waste and MPs problems.

- Organize activities to raise awareness amongst the population about the negative impacts caused by improper plastic waste management and leakage in the environment at all levels by propaganda programs, which should be carried out continuously and regularly in various forms to attract public participation.
- Activities to increase people's awareness of behaviour and habits of using single-use plastic products and non-degradable plastic bags and littering habits in communities.
- Communication education on the harmful effects of plastic waste and MPs should be conducted in communities and schools (at all levels).
- Strengthen training programs for staff at public and private agencies on plastic waste, MPs, and their harmful effects.
- Television and radio programs should devote time to propagate about plastic waste, MPs and their harmful effects on human health, biota and the environment.

3.3.6. Domestic wastewater treatment

The government of the selected countries should plan a roadmap to treat all domestic wastewater generated from urban zones of the rivers with advanced technologies, taking into account the pollutant component of MPs.

4. CONCLUSION

MPs were detected in all surface water samples collected from the Chao Phraya (Thailand), Citarum (Indonesia), and Saigon River (Viet Nam). Variation of MPs levels was found to depend mainly on land use around rivers. The number of MPs at urban zones was higher than that of estuary zones. This demonstrated that the abundance of MPs increases with the increase of the urbanization rate. Also, the number and size of MPs at the Chao Phraya River and Saigon River were comparable at both urban and estuary zones. However, at the Citarum River, the number of MPs was much lower and the size much larger than the two other rivers. For the morphologies of MPs, fragments and fibres were predominant types at all rivers. Polymer types of PP and PE were the most abundant in all collected samples from the three rivers. The selected rivers in this study play important roles in water supply and aquaculture activities in their countries. Thus, the occurrence of MPs in these rivers can create harmful impacts on humans, biota and ecosystems. This study also provides important background data to bridge the knowledge gap for MPs pollution in rivers from the Association of Southeast Asian Nations (ASEAN) region. Also, potential plastic management strategies to minimize MPs problems in the selected rivers are suggested in this study. Solid waste separation at the source needs to be legally implemented in all three countries. Policies to control single-use plastic and encourage plastic recycling waste are required. Awareness and education on the impacts of plastics and MPs for public sectors and communities are also essential to minimize plastic waste and MPs in the aquatic environment.

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