Applied Environmental Research
- RESEARCH FOR SUSTAINABLE PLANET -

Research Article

Microplastic Contamination in the Coastal Environment: A Case Study from the Mae Klong Estuary, Samut Songkhram

Pattraporn Chaisanguansuk[1], Suphak Ploenbuppa[1], Thitiphan Assawincharoenkij[1,2*], Sumet Phantuwongraj[1,3*], Akkaneewut Jiraphinyakul[1,3]

[1] *Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*
[2] *Applied Mineral and Petrology Special Task Force for Activating Research, Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*
[3] *Center of Excellence in Morphology of Earth Surface and Advanced Geohazards in Southeast Asia, Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*

*Correspondence Email: thitiphan.a@chula.ac.th and phantuwongraj.s@gmail.com

Abstract

The mangrove sediment from the Mae Klong River (MK) and Klong Khon Canal (KK) revealed the microplastics contamination in the Mae Klong Estuary environment. Microplastic analyses were analyzed by using $ZnCl_2$ density separation and H_2O_2 digestion process. The average concentrations of microplastic was 580 and 1690 items kg^{-1} dry weight in the samples from MK and KK. MK sediment contained more coarse grain than KK sediment. The lower microplastic concentration in MK was mainly related to the runoff through the sea. In contrast, the abundant microplastic in KK was possibly caused by the low transportation energy of sediment in the tidal flat that associated with deposition of fine grain. In addition, the microplastics were mainly polyester fiber originating from laundry processes or transport from the vicinity. The contamination in mangrove sediment in this study may encourage communities and the government to be more aware of waste management.

ARTICLE HISTORY

Received: 4 Aug. 2022
Accepted: 15 Jun. 2023
Published: 29 Jun. 2023

KEYWORDS

Microplastics;
Mangrove sediment;
Surface sediment;
Gulf of Thailand

Introduction

Plastic consumption has dramatically increased over the decade [1]. However, its lightweight, highly persistent, and high resistance to degradation make plastic debris a global pollution issue [2]. PlasticEurope [3], for example, reported that 4600 million tons of plastic debris contaminated the environment from 1950 to 2015. It has been estimated that 8 million tons of plastic litter are dumped in the marine, approximately 80% of marine pollution [4-5]. Most plastic litter in the ocean is considered produced in Asian countries due to their fast-growing plastic market [1, 6].

Microplastics generally refer to plastic particles smaller than 5 mm to 1 μm along their longest dimension; smaller particle <1 μm that are called nanoplastic [7]. Microplastics are strong hydrophobicity, stable chemical composition, large specific surface area, and small size [8]. These properties allow them to be readily ubiquitous by wind and water and accumulation in the environments, including remote areas, e.g., the deep sea [9], the Tibetan Plateau [10], and the Arctic sea ice [11]. Microplastics can be classified into primary and secondary microplastics based on their sources [12-14]. Primary microplastics are tiny microbeads produced in the industry for cosmetics and personal care products, e.g., dermal exfoliators and cleaning agents [7]. Although plastic is highly resistant to natural degradation, it can be decomposed by environmental mechanisms, i.e., hydrolysis, photo-, thermo-oxidative, and bio-degradations [15]. These processes can dis-integrate plastic which eventually becomes smaller than 5 mm, called secondary microplastics [12–14].

Microplastics have become the emerging pollution issue not only caused of their ubiquitous and abundant in the environment but also because they possibly affect organisms [16]. The risks of microplastics through

https://doi.org/10.35762/AER.2023009

ingestion and dermal contact are limited and require further research [17]. Microplastic pollution is caused by human activities and related to intensity of human activity in the area [18]. Beach with heavy tourism and recreational activities had higher levels of plastic debris [19]. Although in Thailand, plastic consumption has increased by 7-8% per year, the microplastic studies in Thailand are paucity, making a lack of information on plastic waste management strategy [18, 20-27].

Most of the previous studies of microplastic pollution focused on the ocean including beach, water body, sea floor sediment and sea creatures whereas the study of microplastic pollution in the mangrove ecosystems that biologically more diverse has been infrequently reported [28]. Mangrove forests are buffers between the land and the ocean, specially limited to the tropical and subtropical zone. There is a habitat for numerous amphibious and marine animals. The mangrove forests play a significant role as sediment traps involve other particle or substance from land- or marine-based activities [29]. The Mae Klong Estuary is one of the abundances of mangrove forests and aquatic resources in Thailand. Therefore, this study aims to investigate the microplastic contamination in the coastal area of Samut Songkhram, a high population density area (495 km^{-2} and the 7^{th} in Thailand) [30].

Materials and methods

1) Study area

Samut Songkhram is a part of the central plain of Thailand located 72 km west of Bangkok. The map of the study area has shown in Figure 1. According to a previous geomorphological study, Samut Songkhram is a tidal plain at the mount of the Mae Klong River connected to the upper Gulf of Thailand [31-33]. The river originates from Tenasserim Hills in Kanchanaburi, 200 km northwest of Samut Songkhram. It is one of the four major rivers (i.e., Mae Klong, Tha Chin, Chao Phraya, and Bang Pakong rivers) discharging into the upper Gulf of Thailand. The mean annual runoff of the Mae Klong River is 14,246 million m^3, the highest river runoff in the central plain of Thailand [34]. In Samut Songkhram, the Mae Klong tidal plain is intersected by a hundred tidal canals and water pathways.

Figure 1 The study area shows sampling collection along the Klong Khon tidal canal (KK-1, KK-2, KK-3) and the Mae Klong River (MK-1, MK-2, MK-3).

https://doi.org/10.35762/AER.2023009

In this study, the sediment samples were collected from mangrove forests along the Mae Klong River estuary (MK) and the Klong Khon tidal canal (KK) (Figure 1). MK is a transition zone between fluvial and marine processes near the Mae Klong River mount, including the northeast tidal flat. The Mae Klong River flows through urban area and industrial area. KK is one of the canals dissecting the tidal plain. It is parallel to the Mae Klong River and surrounded by mangrove forests and the giant tiger prawn farm. In addition, these area was located in a site of recognized ecological interest Don Hoi Lot – the Ramsar site [35]. Many studies reported that biota and sediment of the Mae Klong Estuary has been polluted by human activities including trace element heavy metal [36-38].

2) Sediment sampling

Due to dense vegetation in the mangrove forests, we selected three sampling points along MK and KK according to accessibility. At each sampling point, three surface sediments (0-5 cm from the sediment surface) were collected by stainless shovel within a quadrat frame (50x50 cm^2) in September 2020 [26, 39]. Eighteen samples were packed with aluminum foil, transported, and stored in the freezer at the Department of Geology, Chulalongkorn University, until further analysis.

In the laboratory, the subsamples were dried in an oven at 60 °C for 48 h. We divided the samples into two parts for microplastic and grain size analysis. The dried samples were stored in glass desiccator to avoid contamination and moisture proof.

3) Particle size analysis

The dried samples were sieved using a mesh size of 4.75 mm diameter. The 1-2 g of prepared samples were then sent to Scientific and Technological Research Equipment Center, Chulalongkorn University, for analysis of the grain size distribution by laser diffraction technique using a Malvern Mastersizer 3000. The particle size of sediment was classified as a specific sedimentology by using Wentworth scale [40].

4) Microplastic analysis

To avoid any contamination, we used non-plastic laboratory equipment and carefully cleaned them with distilled water many times before use. The 50 g of dried samples were further analyzed by $ZnCl_2$ density separation [41] and subsequently H_2O_2 digestion [42].

Since the density of $ZnCl_2$ is higher than that of plastic, it is frequently applied to microplastic extraction. $ZnCl_2$ was more effective in density separation than other solution [43]. Previous studies improved microplastic density separation, $ZnCl_2$ solution could be reused at least five times maintaining an efficiency above 95% [42, 44]. $ZnCl_2$ solution in this study was reused 3-4 times for maintaining great efficiency.

A solution of $ZnCl_2$ was filtered by a 1.2 µm pore glass microfiber filter to remove impurities in the solution before adding to the dried sediment samples. The prepared samples were stirred with a magnetic stirrer at 500 rpm for 5 min and left to settle for 3 h. Subsequently, the samples were filtered by the 1.2 µm pore glass microfiber filter to extract the floating particles. These processes were repeated three times. It is well known that zinc chloride as a toxic substance to aquatic organisms, researchers were trained by Center of Safety, Health and Environment of Chulalongkorn University (SHECU) and $ZnCl_2$ waste and other toxic substance from laboratory were sent to the Center of Excellence on Hazardous Substance Management (HSM) for proper hazardous waste disposal.

After the $ZnCl_2$ density separation, the H_2O_2 digestion method was introduced to exclude organic matter from the microplastics. The extracted materials were rinsed with a 30% H_2O_2 and heated at 70 °C for 3 h. Afterward, a 30% H_2O_2 solution was added and left overnight to remove all organic matters. The 1.2 µm pore glass microfiber filter filtered an aliquot of each treated subsample. The sample left on the filter was counted and identified under a light binocular microscope. According to laboratory tool, lower size limit of microplastic that examined in this study was 100 µm.

Primary check and identification of microplastic under microscope was tested by hot needle technique [45] and inspected feature including non-cellular structure, equally thick especially in fiber, homogeneous texture [46]. Then, we selected forty samples, which were representative of each microplastic group. These selected were further analyzed by micro-Fourier transform infrared spectroscopy (µ-FTIR) LUMOS II at the Center of Excellence in Environmental Engineering, Faculty of Engineer, Chulalongkorn University, to understand their chemical composition.

Results

1) Sediments grain size analysis

Eighteen samples from MK and KK were analyzed for their grain size distribution using laser diffraction. The samples from MK were composed of approximately 50–25%, 60–40%, and less than 10% of the sand, silt, and clay fractions, respectively (Figure 2). In contrast, the sand content became remarkably decreased or undeterminable in the samples from KK. The grain size analysis demonstrated that the sediment samples collected from KK are generally composed of 70 and 30% of silt and clay fractions (Figure 2). A 5% of sand-fraction was found in KK-3 (Figure 2).

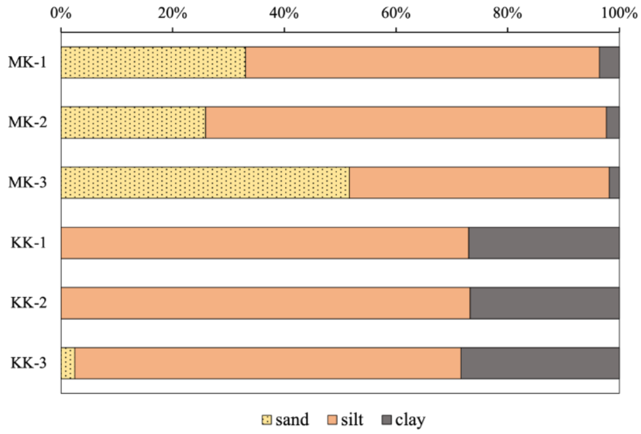

Figure 2 Grain size distribution of the surface sediments from the Mae Klong River (MK) and the Klong Khon tidal canal (KK).

2) Microplastic concentration

Microplastics were found in all the samples obtained from MK and KK, which were 580 and 1690 items kg^{-1} on average, respectively (Tables 1 and 2). The microplastic concentration was comparable to 470 items kg^{-1} dry weight (d.w.) in the MK-1 and MK-2 (Figure 3). They significantly increased and reached 800 items kg^{-1} d.w. in MK-3 (Figure 3). The microplastic concentrations were approximately 2000, 1800, and 1240 items kg^{-1} d.w. in the samples nos. KK-1, KK-2, and KK-3, respectively (Figure 3).

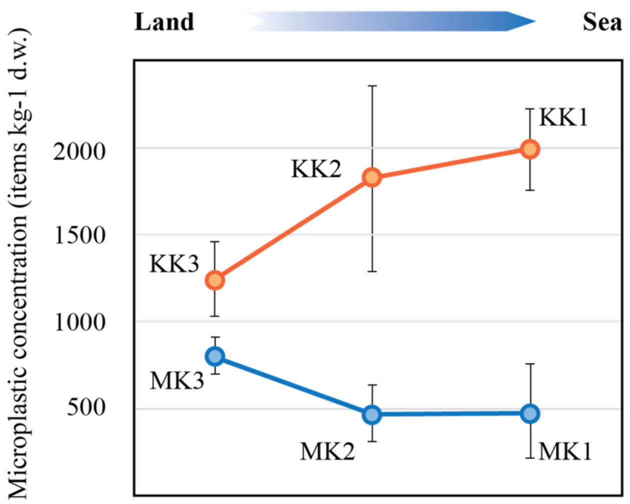

Figure 3 Abundance of microplastic in each sampling site (MK: the Mae Klong River; KK: Klong Khon tidal canal).

3) Physical characteristics of microplastics

The physical characteristics of microplastic, i.e., their size, color, and shape, were identified under a light binocular microscope. An example of microplastic image obtained with the microscope is shown in Figure 4.

Microplastic sizes 1.0–5.0 mm were the most prevailing in the samples from MK that was 53%, and sizes 0.1–1.0 mm at 47%. The color of microplastic is black (43%), colorless (22%), and others (35%). The fiber was the most abundant microplastic, comprised of approximately 73%, followed by fragments at 20% (Figure 5). The plate and stick shapes were meager at less than 10%. However, the foam was undeterminable in the samples from MK (Figure 5).

In the samples from KK, the size 0.1–1 mm was 70% and a dominant proportion, whereas the size 1-5 mm was approximately 20%. Most of these samples were colorless (45%) and purple (24%). The samples from KK mainly consisted of fiber, which was approximately 86%. The plate, foam, and stick fractions were found at 6.3, 3.3, and 4.4%, respectively (Figure 5).

4) Chemical compositions of the microplastics

The samples were classified into five groups based on their shapes, i.e., fiber, foam pellet, plate, stick, and fragment (shapeless). Particle samples have been chosen by their characteristics; shape, color, and size to be a representative of the group. The μ-FTIR analysis further analyzed 40 samples in total, representative samples of each group, to identify the chemical composition of the microplastics. The example of spectra from FTIR analysis has shown in Figure 4. There were 28 samples from MK consisting of 13, 12, 2, and 1 sample of fiber, fragment, plate, and stick shapes, respectively. The samples from KK were 7, 4, and 1 sample of fiber, fragment, and foam, totaling 12 samples. However, among 40 samples, 13 samples were non-plastic or undeterminable by μ-FTIR analysis. Consequently, the particle that had similar characteristics to non-plastic or undeterminable object were deducted from the total number. The polymer frequently found in these samples were polycarbonate (PC), polyethylene (PE), polyester (PES), and polypropylene (PP) (Figure 6).

The fiber obtained from MK was mainly PES (45%), followed by PP (22%) (Figure 6). Each PC, olefin, and rayon was found in only 1 sample. The fragment from MK was comparable to 29% of PC, PE, and PP (Figure 6). The plate and stick samples were polyvinyl chloride (PVC) and olefin. PES was 50% and the most predominant polymer in the fiber from KK (Figure 6). The other fiber samples were PE, polyethylene terephthalate (PET), and combined rayon, nylon, and PES. The fragment and foam samples were PP and polyvinyl acetate.

https://doi.org/10.35762/AER.2023009

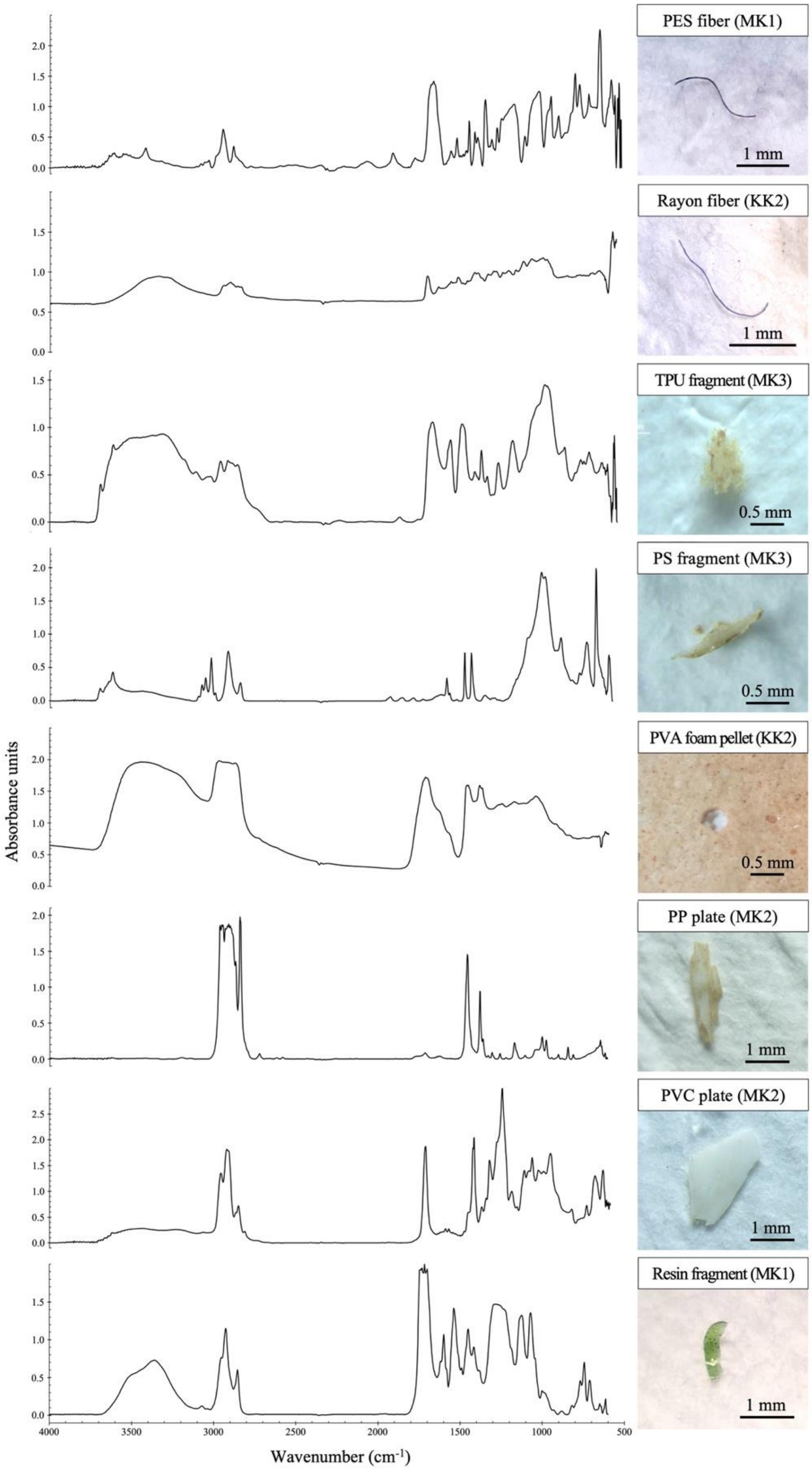

Figure 4 Example of microplastic under microscope and their FTIR spectra from this study.

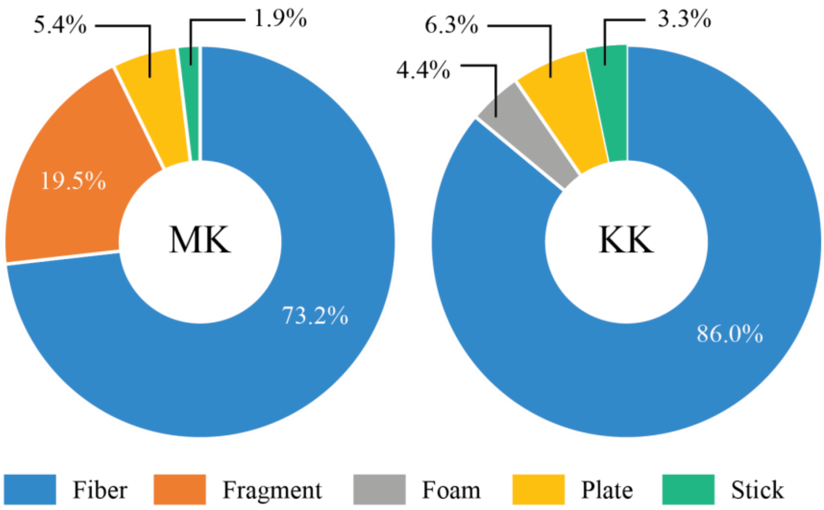

Figure 5 Shape of microplastic in the mangrove sediments from the Mae Klong River (MK) and the Klong Khon tidal channel (KK).

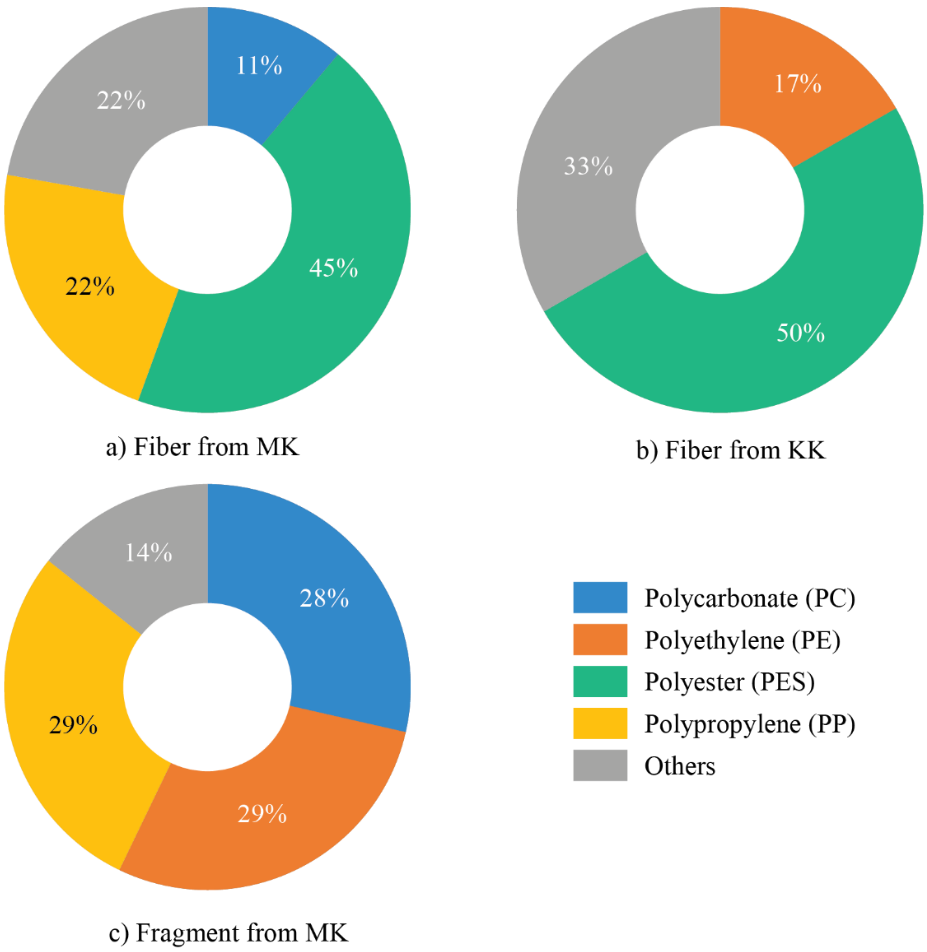

Figure 6 Major chemical composition of fiber and fragment microplastic from the Mae Klong River (MK) and the Klong Khon tidal canal (KK).

https://doi.org/10.35762/AER.2023009

Discussions

The trend of microplastic abundance in MK declined in relation to distance from the headwater, on the other hand, microplastic abundance in KK increased with distance from headwater (Figure 3). MK area with a high population density was lower microplastic abundance than KK area. Anthropogenic and environmental factors affected on the varies of microplastic abundance. Especially, environmental factors (geography, hydrodynamic, environment) play significant role in the accumulation of microplastics [47]. In this study, environmental factor may significantly affect the microplastic deposition. Microplastics consisting of clay fractions were significantly more abundant in the samples from the KK than in the MK (Figures 2). This correspondence could be explained by the similarity of microplastics and fine sediments dispersion [41, 48, 49]. The low transportation energy in the KK tidal plain allowed for a higher sink of clay-sized sediments and microplastics. At KK1 station that surrounded by flat plain with abundantly mangrove forest tended to be a most suitable area for finer grain and microplastic deposition. In contrast, the runoff and marine processes near the Mae Klong River mount prohibited the microplastic deposition in the MK estuary. Especially, MK-1 and MK-2 station located at river mouth that microplastic concentration have been lower than other station. Semi–log graph has shown in Figure 7 that used for demonstrating the result from this study. Log–scale on y–axis has covered a large range of sediment grain size. This explanation is supported by a reverse relationship between grain size distribution and microplastic concentration. The association demonstrated that high microplastic concentration is related to fine sediments (Figure 7). The results from site MK-3 may not fit with the general pattern, possibly caused by the site located near village area (Figure 1).

The samples were collected in the mangrove forests, a complex plant community fringing the tropical coastal shore. The dense vegetation in mangrove forests reduces the transportation energy of tidal flow, wave height, and induced sedimentation. Consequently, mangrove forests were potentially trapping and sinking microplastic [50-51]. The studies on microplastic contamination in sediment in Thailand has shown in Table 2, the microplastic concentration in MK and KK are significantly higher than the sediments from other coastal areas, i.e., Tapi-Phumduang River, Bandon Bay, Bang Yai Estuary, and the Gulf of Thailand [25, 52–53]. However, the maximum number of microplastic in mangrove in this study was much lower than tourists' beach that reported in Thailand [22, 26] and they also became lower than Futian and Pearl River Estuary, China, which is an estuary environment [54–55]. Other studies were classified a microplastic size below 50 µm [29, 54–55] but the cut-off of microplastic size that examined in this study was 100 µm. According to the limitation of microplastic examination under microscope, the total number in this study may be lower than the real number in environment. The microplastic concentration has been generally considered to be varied according to the population density [55]. Therefore, the less contamination of microplastic in this study was possibly caused by three times lower population density along the Mae Klong River than that along the Pearl River [30, 56]. The location that near to the major source of microplastics, for examples, industrial outputs, wastewater treatment plants and densely populated urban areas, tends to accumulated high loads of microplastics [57]. However, since the population density in Samut Songkhram is significantly lower than that in Jakarta, Indonesia, and Singapore, the other factors possibly play a role in the microplastic accumulation.

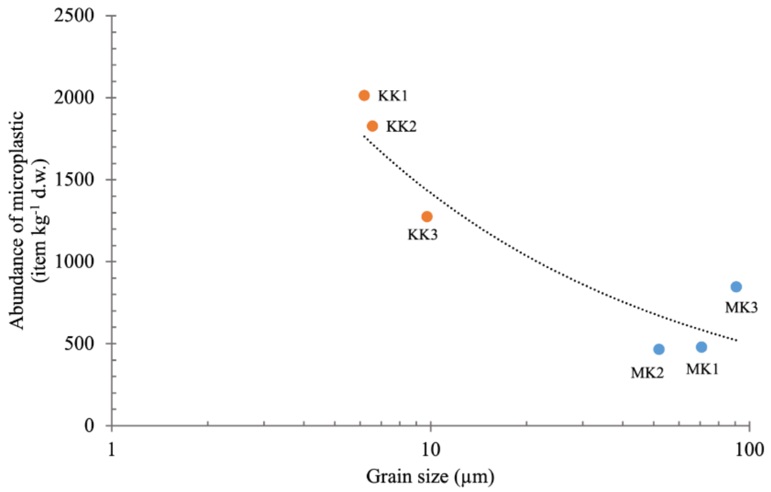

Figure 7 A semi-log plot comparing between abundance of microplastics and mean grain size.

https://doi.org/10.35762/AER.2023009

Table 1 Abundance and characteristics of MPs in mangrove sediment found at Singapore, China, Indonesia, and Thailand

Studied area	Sample depth	Analytical method	Abundance of MPs (items kg^{-1} d.w.)		Dominate shape	Dominate polymer	Reference
			Average ± SD	Range			
Pearl River Estuary, China	Top 5 cm	$NaCl + H_2O_2$	851 ± 177	100 – 7,900	Fiber (70%)	PP, PE	[55]
Futian, China	0 – 5 cm	$ZnCl_2 + H_2O_2$	2,249 ± 747	980 – 3,100	Fiber	PP	[54]
Singapore	Top 3 – 4 cm	Saline solution	36.8 ± 23.6	12 – 62	Fiber (76%)	PP, PVC, Nylon	[29]
Muara Angke River, Indonesia	Top 4 – 8 cm	$NaCl + H_2O_2$	28.1 ± 10.3	11.83 – 47.79	Foam	PS, PP, PE	[58]
Mae Klong River, Thailand	0 – 5 cm	$ZnCl_2 + H_2O_2$	580 ± 87	260 – 880	Fiber (73%)	PES	This study
Klong Khon tidal canal, Thailand	0 – 5 cm	$ZnCl_2 + H_2O_2$	1,687 ± 253	1020 – 2,380	Fiber (86%)	PES	This study

Table 2 Abundance and characteristics of MPs in sediments along shoreline, Thailand

Studied area	Sample depth	Abundance of MPs (items kg^{-1} d.w.)		Dominate shape	Dominate polymer	Reference
		Average±SD	Range			
Gulf of Thailand	0 – 5 cm	150.4 ± 86.2	25.0 – 362.5	Fiber	Rayon, PES	[25]
Eastern beach Gulf of Thailand	Top 5 cm		420 – 24,980 (max. >200,00)			[22]
Western beach Gulf of Thailand	Top 5 cm		20 – 273 (max. 5,741)	Plate (84.54%)		[26]
Tapi-Phumduang River	Top 5 cm	79.0 ± 18.3	55 – 160	Fiber (70%)	Rayon	[52]
Bandon Bay	Top 5 cm	73.0 ± 17.4	15 – 135	Fiber (94%)	Rayon	[52]
Mae Klong River	0 – 5 cm	580 ± 87	260 – 880	Fiber (73%)	PES	This study
Klong Khon tidal canal	0 – 5 cm	1,687± 253	1,020 – 2,380	Fiber (86%)	PES	This study

The most prevalent color of microplastic in MK is black, following colorless and others. In contrast, a black color was not found in KK, whereas a colorless and purple were generally found. The color can be indicating a significant source of microplastic. For example, transparent/white was prevalent color in beach sediment in Eastern Gulf of Thailand but the prevalent color in Western Gulf of Thailand was black [22, 26]. Each area may find a different prominent color depending on the source in those area.

The microplastic size <1 mm was mostly found in mangrove sediments in Asia (Singapore [29], Indonesia [58], and China [54]) and also in KK area. Whereas microplastic size ranging from 0.1 – 1.0 mm and 1.0 – 5.0 mm were equally found in MK. Small microplastics (<1 mm) were prominent in sediment along the Gulf of Thailand [22, 26, 52]. Whatever, all of microplastic size were found in digestive system and soft tissues of marine organism [52, 59]. Its smaller size microplastic tends to more difficult to investigate.

The predominance of fiber microplastic in KK and MK corresponds well with the other studies, e.g., Singapore [29], Futian, and the Pearl River, China [54–55], the Gulf of Thailand [25], the Tapi-Phumduang River [52], and Bandon Bay [52] (Tables 1 and 2). While foam and plate microplastic was abundant in the Muara Angke River, Indonesia [58], and the western part of the Gulf of Thailand [26].

According to Tables 1 and 2, microplastic chemical compositions vary and are possibly associated with nearby or adjacent human activities of their provenance. The prevalent polymers in China and Singapore were PP [29, 54–55]. While rayon was the most abundant polymers along the Gulf of Thailand [25, 52]. Since the most plastic consumption in Thailand is packaging and fishery is the most prominent in Samut Songkhram, PE and PP were initially presumed to be the most dominant microplastics [29]. However, although the textile industry is unavailable in the study area, PES fiber is the most dominant microplastic in the study area (Figure 6). To increase reliability in a qualitative information in further research, determining more FTIR analysis sample may be shown the variety of polymer types of microplastic that close to the current proportion in environment. Many studies found that the provenance of PES fiber in the environment was mainly from sewage in the laundering process, especially from the washing machine [60-62]. However, the synthetic fiber was possibly transported from other areas since it was discussed to contaminated shores on a global scale [60]. Moreover, ropes and nets in aquaculture can release microplastic fragment and fiber into the environment [63]. The synthetic particles are ubiquitous and persistent in the food chain, allowing them to link to the health effect on the people in Samut Songkhram and the other part of Thailand.

Conclusion

To investigate the microplastic contamination in the coastal area of Samut Songkhram, we collected sediment samples from mangrove forests along the Mae Klong River Estuary (MK) and nearby Klong Khon tidal canal (KK). Microplastics were extracted and analyzed for their physical and chemical properties. Microplastic concentrations were 580 and 1690 items kg^{-1} d.w. in the samples from MK and KK. Microplastics were more abundant in the samples from KK, possibly caused by their geomorphology of tidal flat, than from MK. Microplastic abundance was directly proportional to the sediment size distribution related to transportation energy. Moreover, the microplastic concentration collected from the mangrove area was significantly higher than that from the other coastal area in Thailand. The most prominent microplastic in the coastal area in Samut Songkhram was polyester fibers, possibly from either sewage in the laundering process or transportation from the vicinity. These results demonstrated a high abundance of microplastics hint the communities, and the government necessitated being more aware of plastic waste management in the mangrove area. Microplastic may ingest by the estuarine biota that lived in polluted area and finally migrate to human body by trophic transfer.

Acknowledgment

The first author gratefully acknowledges the financial support from the Graduate scholarship at Chulalongkorn University. This research is funded by Thailand Science Research and Innovation Fund Chulalongkorn University (CU_FRB65_dis (15)103_ 23_33). We would like to thank the Department of Geology, Faculty of Science, Chulalongkorn University for support in field and laboratory work and Associate Professor Dr.Sakonvan Chawchai for valuable suggestions. Moreover, we also would like to thank Mr. Phakorn Intassingha and Mr. Kanisorn Kattachan for the support in field.

References

[1] Ritchie, H., Roser, M. Our world in data, 2018. [Online] Available from: https:// ourworldindata.org /plastic-pollution [Accessed 25 July 2022].

[2] Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M.A. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 2009, 364, 1985–1998.

[3] PlasticEurope. PlasticEurope, 2021. [Online] Available from: https://plasticseurope.org/wp-content/uploads/2021/12/Plastics-the-Facts-2021-web-final.pdf

[4] Jambeck Jenna, R., Geyer, R., Wilcox, C., Siegler Theodore, R., Perryman, M., Andrady, A., ..., Law Kara, L. Plastic waste inputs from land into the ocean. Science, 2015, 347(6223), 768–771.

[5] Beaumont, N., Aanesen, M., Austen, M., Bцrger, T., Clark, J., Cole, M., ..., Wyles, K. Global ecological, social and economic impacts of marine plastic. Marine Pollution Bulletin, 2019, 142.

[6] Plastic Debris in the Ocean. Plastic debris in the ocean. The characterization of marine plastics and their environmental impacts, situation analysis report. Gland: IUCN. 2014. [Online] Available from: https://portals.iucn.org/library/

sites/library/files/documents/2014-067.pdf [Accessed 25 July 2022].

[7] Crawford, C.B., Quinn, B. 5 - Microplastics, standardisation and spatial distribution, In: C.B. Crawford and B. Quinn (ed.), Microplastic Pollutants. Elsevier, 2017, 101–130.

[8] Yu, H., Zhang, Y., Tan, W., Zhang, Z. Microplastics as an emerging environmental pollutant in agricultural soils: Effects on ecosystems and human health. Frontiers in Environmental Science, 2022, 10.

[9] Van Cauwenberghe, L., Vanreusel, A., Mees, J., Janssen, C.R. Microplastic pollution in deep-sea sediments. Environmental Pollution, 2013, 182, 495–499.

[10] Yang, L., Kang, S., Wang, Z., Luo, X., Guo, J., Gao, T., ..., Zhang, Y. Microplastic characteristic in the soil across the Tibetan Plateau. Science of the Total Environment, 2022, 828, 154518.

[11] Peeken, I., Primpke, S., Beyer, B., Gьtermann, J., Katlein, C., Krumpen, T., ..., Gerdts, G. Arctic sea ice is an important temporal sink and means of transport for microplastic. Nature Communications, 2018, 9.

[12] Cole, M., Lindeque, P., Halsband, C., Galloway, T.S. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 2011, 62(12), 2588–2597.

[13] Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of the Total Environment, 2017, 586, 127–141.

[14] Akdogan, Z., Guven, B. Microplastics in the environment: A critical review of current understanding and identification of future research needs. Environmental Pollution, 2019, 254, 113011.

[15] Webb, H.K., Arnott, J., Crawford, R.J., Ivanova, E.P. Plastic degradation and its environmental implications with special reference to poly(ethylene terephthalate). Polymers, 2013, 5(1).

[16] Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C. Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). Environmental Science & Technology, 2008, 42(13), 5026–5031.

[17] Prata, J.C., Silva, A.L.P., Walker, T.R., Duarte, A.C., Rocha-Santos, T. COVID-19 pandemic repercussions on the use and management of plastics. Environmental Science & Technology, 2020, 54(13), 7760–7765.

[18] Matsuguma, Y., Takada, H., Kumata, H., Kanke, H., Sakurai, S., Suzuki, T., ..., Newman, B. Microplastics in sediment cores from Asia and Africa as indicators of temporal trends in plastic pollution. Archives of Environmental Contamination and Toxicology, 2017, 73.

[19] Akkajit, P., Thongnonghin, S., Sriraksa, S., Pumsri, S. Preliminary study of distribution and quantity of plastic-debris on beaches along the coast at Phuket Province. Applied Environmental Research, 2019, 54–62.

[20] Apinanwattanakul, N. SCB Economic Intelligence Center's website, 2018. [Online] Available from: https://www.scbeic.com/th/ detail/product/4905 [Accessed 25 July 2022].

[21] Puthcharoen, A., Leungprasert, S. Determination of microplastics in soil and leachate from the landfills. Thai Environmental Engineering Journal, 2019, 33(3), 39–46.

[22] Bissen, R., Chawchai, S. Microplastics on beaches along the eastern Gulf of Thailand – A preliminary study. Marine Pollution Bulletin, 2020, 157, 111345.

[23] Marks, D., Miller, M., Vassanadumrongdee, S. The geopolitical economy of Thailand's marine plastic pollution crisis. Asia Pacific Viewpoint, 2020, 61, 266-282.

[24] Ta, A., Babel, S., Haarstrick, A. Microplastics contamination in a high population density Area of the Chao Phraya River, Bangkok. Journal of Engineering and Technological Sciences, 2020, 52, 534–545.

[25] Wang, Y., Zou, X., Peng, C., Qiao, S., Wang, T., Yu, W., ..., Kornkanitnan, N. Occurrence and distribution of microplastics in surface sediments from the Gulf of Thailand. Marine Pollution Bulletin, 2020, 152, 110916.

[26] Thepwilai, S., Wangritthikraikul, K., Chawchai, S., Bissen, R. Testing the factors controlling the numbers of microplastics on beaches along the western Gulf of Thailand. Marine Pollution Bulletin, 2021, 168, 112467.

[27] Pradit, S., Noppradit, P., Loh, P.S., Nitiratsuwan, T., Le, T.P., Oeurng, C., . . . Wang, J. The Occurrence of microplastics in sediment cores from two mangrove areas in Southern Thailand. Journal of Marine Science and Engineering, 2022, 10(3).

[28] Deng, J., Guo, P., Zhang, X., Su, H., Zhang, Y., Wu, Y., ..., Li, Y. Microplastics and accumulated

heavy metals in restored mangrove wetland surface sediments at Jinjiang Estuary (Fujian, China). Marine Pollution Bulletin, 2020, 159, 111482.

[29] Mohamed Nor, N.H., Obbard, J.P. Microplastics in Singapore's coastal mangrove ecosystems. Marine Pollution Bulletin, 2014, 79(1), 278–283.

[30] Department of Provincial Administration. Registration statistics. 2018.

[31] Thiramongkol, N. Geomorphology of the lower central plain, Thailand. Proceedings of the 3rd Meeting of Working Group on Geomorphology of Rivers and Coastal Plain, 1984, 103-117.

[32] Sinsakul, S. Late Quaternary geology of the Lower Central Plain, Thailand. Journal of Asian Earth Sciences, 2000, 18(4), 415–426.

[33] Tanabe, S., Saito, Y., Sato, Y., Suzuki, Y., Sinsakul, S., Tiyapairach, S., ..., Chaimanee, N. Stratigraphy and Holocene evolution of the mud-dominated Chao Phraya delta, Thailand. Quaternary Science Reviews, 2003, 22(8), 789–807.

[34] Office of the National Water Resources. Office of the National Water Resources' website, 2021. [Online] Available from: http://www.onwr.go.th/?p=10637 [21 March 2022].

[35] Agri-Map Samut Songkhram. [Online] Available from: https://www.ldd.go.th/Agri-Map/Data/C/skm.pdf [Accessed 25 July 2022].

[36] Peebua, P., Kruatrachue, M., Pokethitiyook, P., Kosiyachinda, P. Histological effects of contaminated sediments in Mae Klong River tributaries, Thailand, on Nile tilapia, Oreochromis niloticus. ScienceAsia, 2006, 32.

[37] Pengthamkeerati, P., Kornkanitnan, N., Sawangarreruks, S., Wanichacheva, N., Wainiphithapong, C., Sananwai, N. Assessment of heavy metals in sediments of the Don Hoi Lot area in the Mae Klong estuary, Thailand. Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 2013, 48(11), 1356-64.

[38] Worakhunpiset, S. Trace elements in marine sediment and organisms in the Gulf of Thailand. International Journal of Environmental Research and Public Health, 2018, 15(4).

[39] Heo, N., Hong, S., Han, G., Hong, S., Lee, J., Song, Y., ..., Shim, W. Distribution of small plastic debris in cross-section and high strandline on Heungnam beach, South Korea. Ocean Science Journal, 2013, 48.

[40] Wentworth, C.K. A scale of grade and class terms for clastic sediments. The Journal of Geology, 1922, 30(5), 377–392.

[41] Lo, H.S., Xu, X., Wong, C. Y., Cheung, S.G. Comparisons of microplastic pollution between mudflats and sandy beaches in Hong Kong. Environmental pollution (Barking, Essex: 1987), 2018, 236, 208–217.

[42] Duan, J., Han, J., Zhou, H., Lau, Y.L., An, W., Wei, P., ..., Tam, N.F.Y. Development of a digestion method for determining microplastic pollution in vegetal-rich clayey mangrove sediments. Science of the Total Environment, 2020, 707, 136030.

[43] Coppock, R.L., Cole, M., Lindeque, P.K., Queirys, A.M., Galloway, T.S. A small-scale, portable method for extracting microplastics from marine sediments. Environmental Pollution, 2017, 230, 829–837.

[44] Rodrigues, M., Gonзalves, A., Gonзalves, F., Abrantes, N. Improving cost-efficiency for MPs density separation by zinc chloride reuse. MethodsX, 2020, 7, 100785.

[45] De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., ..., Robbens, J. Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. Marine Pollution Bulletin, 2014, 85(1), 146–155.

[46] Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M. Microplastics in the marine environment: A review of the methods used for identification and quantification. Environmental Science & Technology, 2012, 46(6), 3060–3075.

[47] Hamid, F., Shahul, Bhatti, M., Anuar, N., Anuar, N., Mohan, P., Periathamby, A. Worldwide distribution and abundance of microplastic: How dire is the situation? Waste Management & Research, 2018, 36, 0734242X1878573.

[48] Harris, P.T. The fate of microplastic in marine sedimentary environments: A review and synthesis. Marine Pollution Bulletin, 2020, 158, 111398.

[49] Mendes, A., Golden, N., Bermejo, R., Morrison, L. Distribution and abundance of microplastics in coastal sediments depends on grain size and distance from sources. Marine Pollution Bulletin, 2021, 172, 112802.

[50] Martin, C., Almahasheer, H., Duarte, C.M. Mangrove forests as traps for marine litter. Environmental Pollution, 2019, 247, 499–508.

[51] Martin, C., Baalkhuyur, Valluzzi, Saderne, V., Cusack, M., Almahasheer, H., ..., Duarte, C. Exponential increase of plastic burial in mangrove sediments as a major plastic sink. Science Advances, 2020, 6, 5593.

[52] Chinfak, N., Sompongchaiyakul, P., Charoenpong, C., Shi, H., Yeemin, T., Zhang, J. Abundance, composition, and fate of microplastics in water, sediment, and shellfish in the Tapi-Phumduang River system and Bandon Bay, Thailand. Science of the Total Environment, 2021, 781, 146700.

[53] Jiwarungrueangkul, T., Phaksopa, J., Sompongchaiyakul, P., Tipmanee, D. Seasonal microplastic variations in estuarine sediments from urban canal on the west coast of Thailand: A case study in Phuket province. Marine Pollution Bulletin, 2021, 168, 112452.

[54] Li, R., Yu, L., Chai, M., Wu, H., Zhu, X. The distribution, characteristics and ecological risks of microplastics in the mangroves of Southern China. Science of the Total Environment, 2020, 708, 135025.

[55] Zuo, L., Sun, Y., Li, H., Hu, Y., Lin, L., Peng, J., ..., Xu, X. Microplastics in mangrove sediments of the Pearl River Estuary, South China: Correlation with halogenated flame retardants' levels. Science of the Total Environment, 2020, 725, 138344.

[56] Guangdong Statistics Bureau. Guangdong statistical yearbook. 2018.

[57] Idrus, F., Fadhi, N., Harith, M. Occurrence of Microplastics in the Asian freshwater environments: A review. Applied Environmental Research, 2022, 1–17.

[58] Cordova, M., Ulumuddin, Y., Purbonegoro, T. Characterization of microplastics in mangrove sediment of Muara Angke Wildlife Reserve, Indonesia. Marine Pollution Bulletin, 2021, 163.

[59] Azad, S.M.O., Towatana, P., Pradit, S., Patricia, B.G., Hue, H.T.T., Jualaong, S. First evidence of existence of microplastics in stomach of some commercial fishes in the lower Gulf of Thailand. Applied Ecology and Environmental Research, 2018, 16, 7345–7360.

[60] Browne, M.A., Crump, P., Niven, S., Teuten, E., Tonkin, A., Galloway, T., ..., Thompson, R. Accumulation of microplastic on shorelines worldwide: Sources and sinks. Environmental Science & Technology, 2011, 45, 9175-9.

[61] Napper, I.E., Thompson, R.C. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Marine Pollution Bulletin, 2016, 112(1), 39–45.

[62] Hernandez, E., Nowack, B., Mitrano, D.M. Polyester textiles as a source of microplastics from households: A mechanistic study to understand microfiber release during washing. Environmental Science & Technology, 2017, 51(12), 7036–7046.

[63] Montarsolo, A., Mossotti, R., Patrucco, A., Caringella, R., Zoccola, M., Pozzo, P.D., ..., Tonin, C. Study on the microplastics release from fishing nets. The European Physical Journal Plus, 2018, 133(11), 494.