MICROPLASTICS IN MANGROVE SEDIMENTS AT MAEKLONG RIVER MOUTH, SAMUT SONGKHRAM PROVINCE

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น.ส.พัตราพร ไชยสงวนสุข

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พัตราพร ไชยสงวนสุข : ไมโครพลาสติกในตะกอนป่าชายเลนบริเวณปากแม่น้ำแม่กลอง จังหวัดสมุทรสงคราม. (MICROPLASTICS IN MANGROVE SEDIMENTS AT MAEKLONG RIVER MOUTH, SAMUT SONGKHRAM PROVINCE) อ.ที่ปรึกษาหลัก : ผศ. ดร.สุเมธ พันธุวงค์ราช, อ.ที่ปรึกษาร่วม : ผศ. ดร.ฐิติพรรณ อัศวินเจริญกิจ

ไมโครพลาสติกเป็นสิ่งปนเปื้อนที่ปัจจุบันสามารถพบแพร่กระจายอยู่ในสิ่งแวดล้อม สามารถก่อให้เกิดผลกระทบต่อสิ่งมีชีวิตต่างๆ ได้ งานวิจัยนี้ศึกษาการสะสมตัวของไมโครพลาสติกในบริเวณพื้นที่ป่าชายเลนซึ่งเป็นบริเวณที่มีการเคลื่อนที่ของตะกอน อินทรียวัตถุและสสารต่างๆ มาสะสมตัวจากทั้งบกและทะเล บริเวณพื้นที่ศึกษาคือบริเวณปากแม่น้ำแม่กลอง จังหวัดสมุทรสงคราม ซึ่งเป็นบริเวณที่มีป่าชายเลนอุดมสมบูรณ์และเป็นแหล่งประมงสำคัญแห่งหนึ่งของประเทศไทย การเก็บตัวอย่างตะกอนที่ใช้ในการศึกษาวิจัยประกอบด้วย (1) ตัวอย่างตะกอนพื้นผิว จากจุดศึกษาบริเวณแม่น้ำแม่กลองจำนวน 3 จุดศึกษาและ (2) ตัวอย่างตะกอนจากแท่งตะกอนบริเวณปากแม่น้ำแม่กลอง 2 จุดศึกษา โดยนำตัวอย่างตะกอนไปวิเคราะห์คุณลักษณะของตะกอน คือ ขนาดตะกอน และปริมาณสารอินทรีย์ และวิเคราะห์การปนเปื้อนของไมโครพลาสติก ผลการศึกษาตะกอนพื้นผิวป่าชายเลนบริเวณปากแม่น้ำแม่กลองพบว่า มีไมโครพลาสติกสะสมในตะกอนเฉลี่ย 580 ± 87 ชิ้นต่อกิโลกรัม โดยตัวอย่างตะกอนจากจุดศึกษาที่อยู่ใกล้บริเวณปากแม่น้ำแม่กลองมีการสะสมของไมโครพลาสติกน้อยกว่าเนื่องจากได้รับอิทธิพลของกระแสน้ำจากแม่น้ำและคลื่นจากทะเล และเมื่อนำข้อมูลจากงานวิจัยนี้ไปประมวลผลร่วมกับข้อมูลปริมาณการสะสมตัวของไมโครพลาสติกในบริเวณคลองโคน พบว่าตะกอนพื้นผิวจากบริเวณแม่น้ำแม่กลองมีการสะสมตัวของไมโครพลาสติกน้อยกว่าบริเวณคลองโคน เนื่องด้วยลักษณะทางภูมิศาสตร์เป็นสายน้ำที่ขนาดใหญ่และมีกระแสน้ำที่แปรปรวนมากกว่า จากแท่งตะกอนบริเวณแม่น้ำแม่กลองพบว่า มีไมโครพลาสติกสะสมตั้งแต่ 0 – 5,200 ชิ้นต่อกิโลกรัม และสามารถพบไมโครพลาสติกที่ระดับความลึก 142 เซนติเมตรจากระดับพื้นผิวได้ โดยมีแนวโน้มของการสะสมตัวลดลงตามระดับความลึก ตำแหน่งที่ตั้งและขนาดของตะกอนในพื้นที่มีผลต่อการสะสมของไมโครพลาสติกในตะกอน พบว่าขนาดของไมโครพลาสติกส่วนใหญ่ที่อยู่ในช่วง 0.1 – 1 มิลลิเมตร รูปร่างแบบเส้นใยเป็นรูปร่างที่พบมากที่สุดและชนิดของไมโครพลาสติกที่พบส่วนใหญ่เป็นชนิดโพลีเอสเตอร์ซึ่งเกี่ยวข้องกับแหล่งที่มาที่เกิดจากการหลุดรุ่ยของเส้นใยสิ่งทอจากการซักล้าง แล้วจึงปนเปื้อนลงสู่น้ำทิ้งจากครัวเรือนสะสมในสิ่งแวดล้อม รวมถึงกิจกรรมทางการประมงหรือการเพาะเลี้ยงสัตว์น้ำ เช่น การใช้อวน แห เป็นต้น การตรวจสอบการสะสมตัวของไมโครพลาสติกในสิ่งแวดล้อม จึงสามารถบ่งบอกถึงที่มาและทำให้ตระหนักถึงการป้องกันและเฝ้าระวังการนำเข้าไมโครพลาสติกเข้าสู่สิ่งแวดล้อมได้

สาขาวิชา ธรณีวิทยา ลายมือชื่อนิสิต .....

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Microplastics are omnipresent in our environment. Living organisms were affected by microplastic pollution. This study was investigated microplastic in mangrove environments because there are accumulated various substances from land and sea. Moreover, mangrove is an important ecosystem that is a habitat for marine life and benthic organism. Our study area is the Maeklong River mouth, Samut Songkhram Province, Thailand. Surface sediments from 3 stations were collected from the Maeklong River area and 2 core sediments were collected from the Maeklong River mouth and the Queen Sirikit Park. Sediment samples were analyzed by Loss on ignition (LOI) and grain size distribution. Microplastics were digested and observed their characteristics. Surface sediments from the Maeklong River mouth were found microplastic with average 580 ± 87 item per kilogram. The abundance of microplastic at far away site from river mouth was lower amount than at river mouth site. Previous studies in the Klong Khon tidal canal showed that the number of microplastic from the Klong Khon was higher than the Maeklong River. According to the Maeklong River flow are turbulent that affected on sediment also other particle to accumulate. 142 cm core was found microplastic ranging from 0 – 5,200 items per kilogram that concentration was decreasing with more depth. Location and grain size had an influence in the accumulation of microplastic in sediment. The most common microplastics that found in this study were 0.1 – 1.0 mm in size. The fiber was the abundance shape of microplastic. Polyester is the prevalent type of plastic in this study, the result refers to the source that can generate microplastic into environment such as wastewater from washing process and material from fishing.

Field of Study: Geology

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Student's Signature .....

Advisor's Signature .....

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Pattraporn Chaisanguansuk

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1
INTRODUCTION

1.1. Background

Plastic debris has become a severe problem of this century, as plastic consumption has quadrupled over the past 30 years (Ritchie & Roser, 2018). In 2015, only 9% of plastic waste was recycled, while 79% had accumulated in landfills or the environment. It is a major source of plastic pollution worldwide (Geyer et al., 2017). The debris is derived from land-based sources such as urbanization, industrial development, and shipping. When plastic debris sizes are smaller than 5 mm, it can call microplastics. Microplastics originated from two sources: primary sources and secondary sources. Primary source, produced as a small particle, used for commercial product such as microbeads (health and beauty products), microfiber (cloth and fishing net). Secondary microplastics, breaking down of larger plastic items, resulted from environmental factors - sun's radiation and/or ocean waves (Cole et al., 2011; Ng & Obbard, 2006).

Microplastics have been found worldwide, even in the most remote and deepest place on earth: the arctic and the deep ocean (Courtene-Jones et al., 2020; Peeken et al., 2018; Peng et al., 2018). Human activity is one factor that causes microplastic pollution because of improper management of plastic debris. Besides, the abundance of microplastics in the environment can refer to the increase in global plastic production (Claessens et al., 2011). Microplastics are not only found in visible size but also in micron size that can preserve in clay sediment. Consequently, this tiny particle can be ingested by marine life such as fish, mussel, and plankton (Browne et al., 2008; Wright et al., 2013). It may be caused harm to an organism by its being an obstacle to the body system. Moreover, when it transfers to an organism by ingestion, microplastics can move through the food chain. Microplastic surfaces can absorb chemicals from the environment such as toxic metals, and persistent organic pollutants (POPs). These chemicals cause impairment of key body functions (Teuten et al., 2009).

Microplastics are omnipresent in our environment for long time. Many researchers found the evidence of historical changes in microplastic deposition. Sediment cores are providing insight long-term microplastic record in ocean (Matsuguma et al., 2017; Uddin et al., 2021), lacustrine (Dong et al., 2020; Turner et al., 2019), coastal (Asadi et al., 2019), estuary (Willis et al., 2017), and mangrove (Luu Viet et al., 2021). Especially, Mangrove forest have an potential for trap marine litter (Martin et al., 2019). Because mangrove plant aerial roots can trap a suspending particle from land and sea. Moreover, the smaller sediment size in mangrove environment are suitable for microplastic accumulation (Martin et al., 2020). Sediment record can be used as a geological proxy that human activity effected the global environment - Anthropocene (Brandon et al., 2019; Sun et al., 2021). Increased plastics loading in sediment cores tends to associated with global plastic production (Dong et al., 2020). It can refer that microplastic accumulated in environment and showed the strong resistance of plastic characteristic.

Microplastics have become an interesting topic in Thailand for a decade. Microplastics were found in many places such as the Chao Phraya River, Bandon Bay, and beaches along the eastern Gulf of Thailand, the studies revealed that the anthropogenic activities were related to the concentration of microplastics in the area (Bissen & Chawchai, 2020; Chinfak et al., 2021; Thepwilai et al., 2021). The studies on microplastic contamination in Thailand mostly emphasized marine organism, surface sediment and surface water (Bissen & Chawchai, 2020; Chinfak et al., 2021; Jiwarungrueangkul et al., 2021; Thepwilai et al., 2021). On the other hand, there are a few studies on determining microplastic accumulation at depth and associate with mud deposit - fine grain sediment such as clay and silt.

This study aimed to quantify microplastic and identify type of microplastic in mangrove area by using the data from sediment surface and sediment core sampling. The study area is the Maeklong River mouth in Samut Songkhram Province, Thailand. This site is unique because there is the habitat of many shells such as razor clam (Solen regularis), undulated surf clam (Paphia undulata), tongue shell (Lingula anatina), cockle (Cardiidae), etc. In addition, the site has been registered as Ramsar site number 1099 in 2001 – Don Hoi Lot (Department of Marine and Coastal

Resources, 2018). Accordingly, the study about microplastics in sediment, the habitat for marine life, can declare the distribution of microplastics that contaminate in environment. In addition, the results from this study will be interpreted with the results in Klong Khon tidal canal from Ploenbuppa (2021) for understanding current microplastic contamination status in Samut Songkhram Province.

This thesis combined 2 publications which have been published in the international journals. These publications worked with different kinds of sediment sampling. Firstly, the study on surface sediment was conducted to investigate microplastic accumulation in mangrove sediment from two different waterways which has been shown in Chapter 4, entitled "Microplastic contamination in the coastal environment: a case study from the Maeklong Estuary, Samut Songkhram Province". Lastly, sediment cores from two mangrove areas were examined for vertical distribution of microplastic in mangrove environment which presented in Chapter 5, entitled "Preliminary Study on Microplastic Abundance in Mangrove Sediment Cores at Maeklong River, Upper Gulf of Thailand".

1.2. Research Objectives

This research focuses on microplastic that accumulated in mangrove sediment from the Maeklong River mouth, Samut Songkhram Province. The analysis of sediment feature also be carried out.

(1) To investigate a contamination of microplastics in mangrove sediments at the Maeklong River mouth.

(2) To identify polymer type of microplastic that found in mangrove sediments at the Maeklong River mouth.

1.3. Scope of Study

The study area was located around the Maeklong River mouth (13° 22' to 13° 22'N and 99° 59' to 100° 02'E) (Figure 1). Sediment surface samples were collected from three locations along the shore of the Maeklong River mouth (Figure 1) and compiled with near important waterways, Klong Khon tidal – the data from Ploenbuppa (2021) (Figure 1). For vertical profile sampling, sediment cores were

collected from the mangrove forest at the Maeklong River mouth and Queen Sirikit Park - the intertidal area (Figure 1). Both of sediment cores were selected for further study by microplastic analysis, loss on ignition (LOI), and grain size analysis at 1, 2, and 5-cm interval, respectively. For the microplastic analysis, there are two steps to separate microplastic from sediment: floating method by using $ZnCl_2$ solution (density 1.6-1.7 g ml^{-1}) and digestion method by using H_2O_2 solution.

Figure 1 Study area map showing location of the Maeklong River and Klong Khon tidal canal in Samut Songkhram Province.

1.4. Expected Outcomes

This study will provide evidence of microplastic accumulated in sediment in the mangrove environment at the Maeklong River mouth.

The expected results are as follows:

(1) The abundance and characteristics of microplastics in mangrove surface sediments.

(2) The distribution and characteristics of microplastics in mangrove core sediments.

CHAPTER 2
LITERATURE REVIEW

This chapter describes the background of microplastic and the study area – Maeklong estuary, Samut Songkhram Province.

2.1. Microplastics

2.1.1. Source of microplastics

Microplastics are divided into two types - primary microplastic and secondary microplastic. Microplastic was defined as primary microplastic originally manufactured to a small size such as microbeads in cosmetic products or plastic pellets for the thermoplastic process. The secondary microplastic was a small piece of plastic that fragmented from a larger plastic item. The plastic was broken by environmental factors such as sunlight, wave, and wind, etc. (Crawford & Quinn, 2017; Koehler et al., 2015).

Microplastic pollution is caused by human activity. Accordingly, investigated the occurrence and distribution of microplastics in the Belgian coast from different locations (coastal harbors, beaches, and sublittoral areas). The harbor found the greatest quantity of microplastics. There is popular human activity such as shipping and tourism (Claessens et al., 2011). Moreover, household activity can generate a large of microplastic in the environment. Microfibers from clothes are released during washing and dumped into wastewater. A proper wastewater treatment can flite small particles uncovered in all areas (De Falco et al., 2019).

2.1.2. Identification and characterization of microplastics

Microplastics have the same quality as normal plastic: durable, flexible, lightweight, and low-cost. There are many points to study microplastic characteristics in the research that are upon to objective of the research. The general characteristics such as shape, length, and color were normally identified under stereomicroscopic.

Size

Microplastics are a plastic particle with a size below 5 mm but there is currently no standardized size-range of microplastic. Many studies normally ranged from below 5 mm to 1 μm (Figure 2) (Crawford & Quinn, 2017; Frias & Nash, 2019).

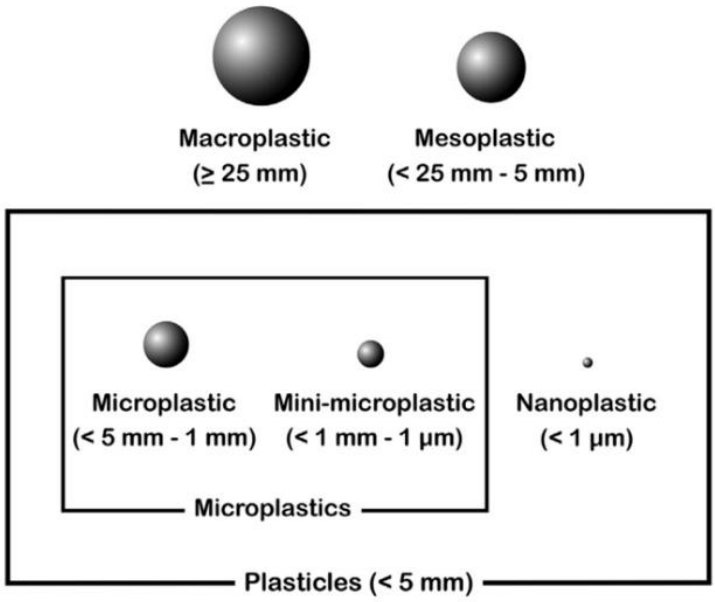


Figure 2 The standardized size categories of a piece of plastic (Crawford & Quinn, 2017).

Polymer type

Thermoplastic is currently used extensively. The variety of thermoplastic is produced in various ways to offer a wide range of consumer use (Figure 3) (Gilbert, 2017). There are various polymer types of plastic that used in individual products. For example, packaging was made from various types of polymers such as linear low density polyethylene (LLDPE), low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), and Polyethylene terephthalate (PET) (Figure 4) (PlasticEurope, 2021).

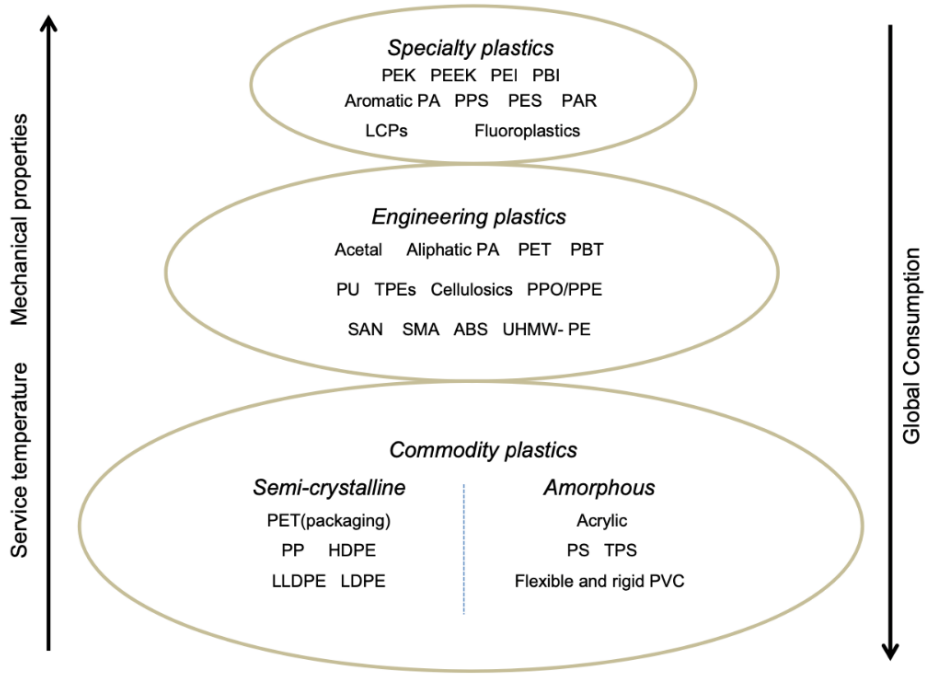


Figure 3 Schematic diagram of thermoplastic classifications (Gilbert, 2017)

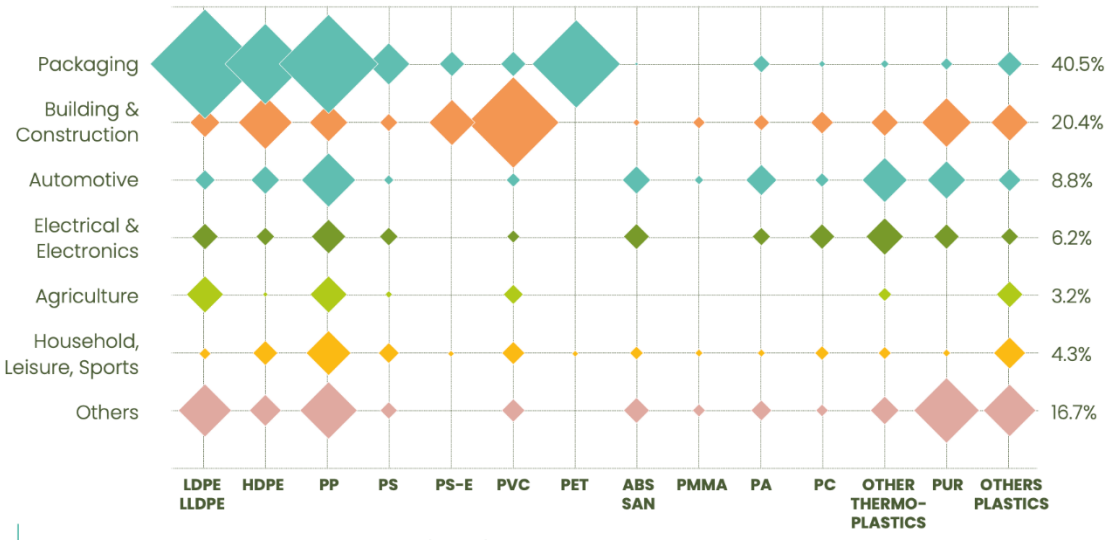


Figure 4 Market segments and polymer types of European plastics demand in 2021 (PlasticEurope, 2021).

2.2. Microplastic Analysis

2.2.1. Density separation

Density separation, namely flotation method, uses the differentiation of specific gravity of a substance. Original method used NaCl or seawater (specific gravity = 1.2 g/ml) to separate microplastic from sediment. The specific gravity of plastic has shown in Table 1. However, the higher specific gravity polymers (specific gravity > 1.2 g/ml) such as polyvinyl chloride (PVC), poly (ethylene terephthalate) (PET), and polyester must be in effective by using NaCl. Therefore, Lo et al. (2018) developed flotation method by using $ZnCl_2$ (specific gravity 1.6-1.7 g/ml) that heavier liquid than NaCl solution allowed the particle that specific gravity less than solution floating up into suspension.

Table 1 Densities and common applications of plastics found in the marine environment (Koehler et al., 2015)

Resin type	Common applications	Specific gravity
Polyethylene	Plastic bags, storage containers	0.91-0.95
Polypropylene	Rope, bottle caps, gear, strapping	0.90-0.92
Polystyrene (expended)	Cool boxes, floats, cups	0.01-1.05
Polystyrene	Utensils, containers	1.04-1.09
Polyvinyl chloride	Film, pipe, containers	1.16-1.30
Polyamide or Nylon	Fishing nets, rope	1.13-1.15
Poly(ethylene terephthalate)	Bottles, strapping	1.34-1.39
Polyester resin + glass fibre	Textiles, boats	>1.35
Cellulose Acetate	Cigarette filtters	1.22-1.24

2.2.2. Digestion method

Upon to organic matter in the sample that features like plastic and is hard to classify, the acid was used to dispose of the organic substance in the sample. Duan et al. (2020) investigated the efficiency method that uses H_2O_2 solution with controlling heat to catalyze the reaction (Figure 5). 30% H_2O_2 solution washed

the particle from the flotation method and boiled the solution for increasing reaction rate. There are three stage digestions to ensure that vegetal litter was removed from the sample and only remained microplastic in the last process. First, filter paper was rinsed by 200 ml H_2O_2 solution (30% w/w) for wash process and then the solution was heated at 70℃ for 1 h. The following stages required to raise the temperature from 70℃ to 100℃ and heated for 3 h. Finally, the 200 ml H_2O_2 was added and heated for 7 h. After digestion method, filter papers were dried in oven at 60℃ for 24 h. Microplastics were picked up under stereo microscope and identified by FT-IR spectroscopy.

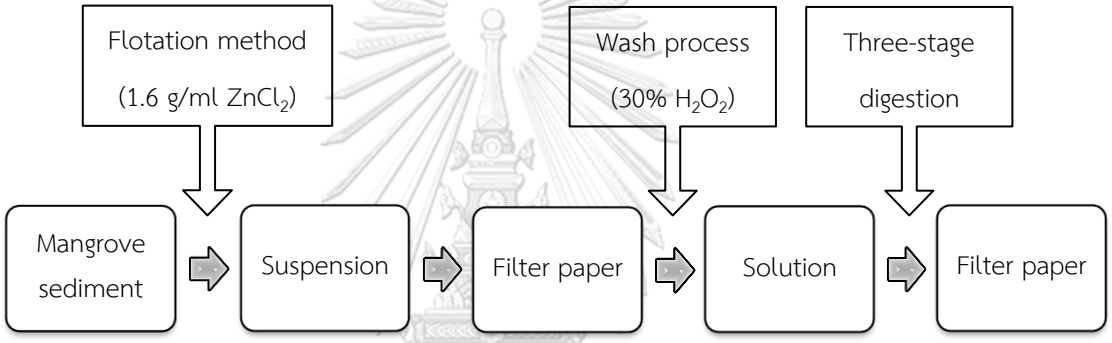


Figure 5 Microplastic analysis including flotation method and digestion method.

2.2.3. Polymer type identification

Infra-red (IR) or Raman are two spectroscopy techniques that are used for identifying polymer types of specimens. FT-IR spectroscopy is counted on the absorption of electromagnetic radiation by vibrational states of molecules. IR technique is broadly used for identifying various substances ranging from food, cosmetics, agriculture, geology, and medicine.

Raman technique depends on the shift in energy by inelastic light scattering that photons interact with molecules bringing them to virtual energy states and scattering back. Raman technique is also used for identifying various samples ranging from food to medicine.

The suitable techniques for analyzing samples rely on various factors such as particle size, sample placement, and cost (Colthup et al., 1990). Microplastic polymer

type was generally identified via developing IR techniques - micro-Fourier transform infrared (μ-FTIR) spectroscopy. The FTIR spectra will match the reference database that refers to the polymer type (Figure 6).

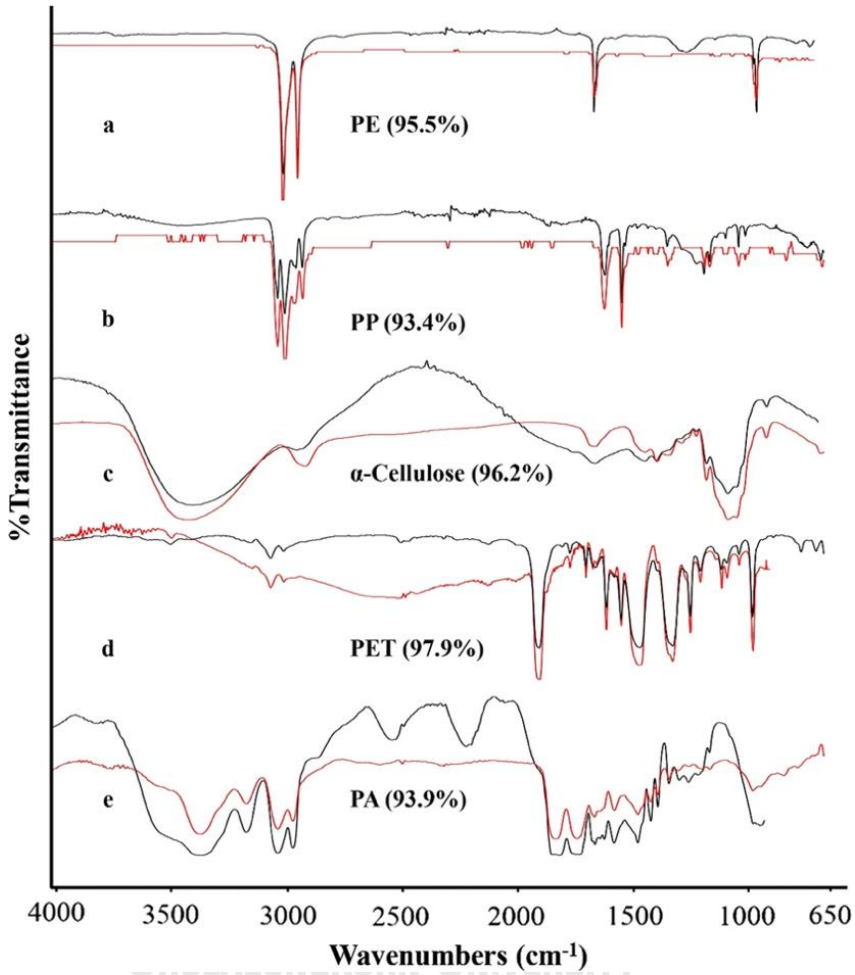


Figure 6 FT-IR spectra and match degrees of selected items. Red curves are FTIR spectra of standard polymers in spectral libraries, and black curves are FTIR spectra of microplastic samples (Y. Li et al., 2020).

2.3. Microplastic in Sediment

Studies on microplastic had lately become more popular over the past decade. Microplastics have been detected in various environments such as the water column, sublittoral zone, and beach sediments worldwide. Microplastics have been dispersed across continents (Figure 7).

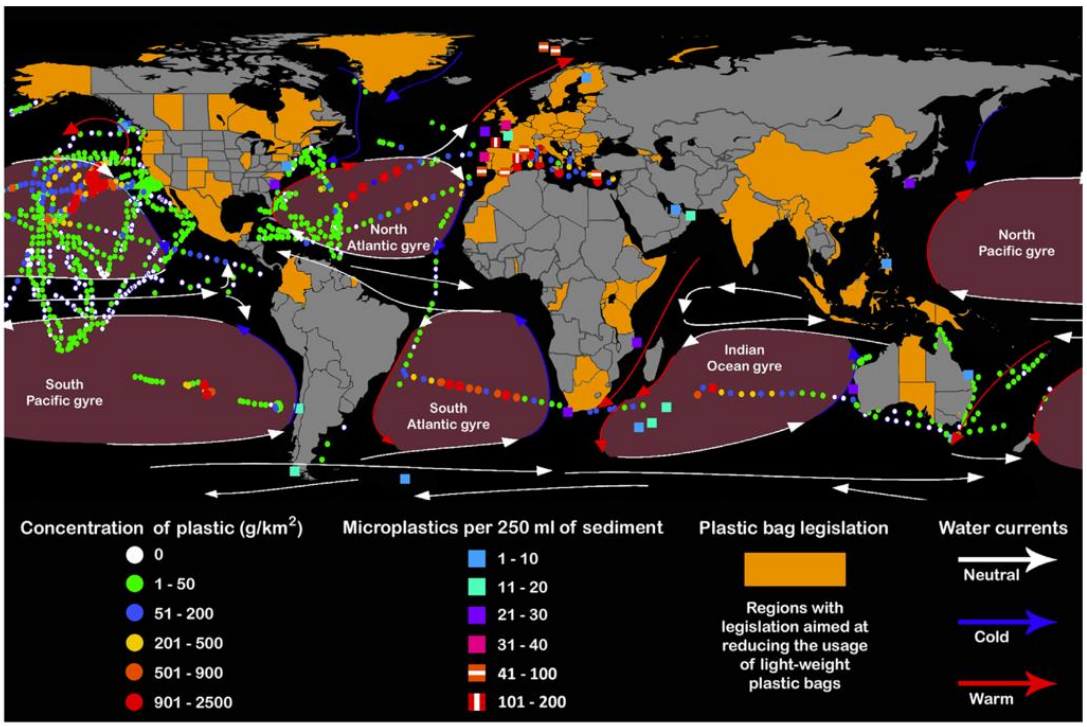


Figure 7 The map showing global abundance of plastics in surface waters and sediment in the marine environment (Crawford & Quinn, 2017).

Plastics contributed to and are widely used by humans. Plastic can be fragmented into small pieces less than five millimeters long. Small plastic pieces can be accumulated with other particles in the surrounding (Crawford & Quinn, 2017). A deposition is a geological process in which matter, usually particles of sediment, rocks, organic matter, or dissolved material has been eroded and transported by a natural process, then accumulated together (Nichols, 2009). Sediment has been considered to be a potential sink of microplastic (Graca et al., 2017; Matsuguma et al., 2017). A potentially important source of microplastics emitted into the environment was freshwater rivers (Claessens et al., 2011). In addition, Microplastic has been more associated with finer grain size (Enders et al., 2019). The factors affecting microplastic accumulation in sediment are tidal currents, winds, and tides (Zhang et al., 2019).

Early studies on microplastic in sediment found plastic particles in the pelagic zone and sedimentary habitats. According to small size particles, microplastics

have been harmful to an organism by mistake ingestion (Thompson et al., 2004). High-density microplastics are likely to sink into the ground. A benthic organism may be ingested microplastics that caused uncertain consequences for the health of the organism (Wright et al., 2013). Blue mussels (filter feeder) and sandworms (deposit feeder) were found microplastic in their tissue (Van Cauwenberghe et al., 2015). Many studies demonstrated that the contamination of microplastic in sediment has an impact on the ecosystem (Hamid et al., 2018). Microplastics have been carried contaminants such as pesticides, pharmaceuticals, metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) (Gallo et al., 2018). Microplastic that absorbed and concentrated toxic organic substances on their surface got into the aquatic organism by accidental intake. According to trophic levels, microplastic and toxic can be transferred from food to the human body (Mohamed Nor et al., 2021). Further research showed that microplastics cause neurotoxic effects, and lipid oxidative damage in wild fish and may impact human health risks (Barboza et al., 2020).

Several studies have shown that microplastics have been contaminating the environment for a long time though. The marine sediment cores collected from Japan, Asia, and Africa have revealed that microplastics have been polluted in the environment since the 1950s and increasingly accumulated in sediment toward the surface layer (Matsuguma et al., 2017). In the same way, microplastics were found in sediment cores from an estuary in Tasmania, Australia. The evidence indicated that the trend of microplastic abundance gets along with global plastic production and coastal population growth (Willis et al., 2017). Many studies in sediment cores supported the upward increase of microplastic abundance associated with growing plastic production and increasing coastal populations (Brandon et al., 2019; Fan et al., 2019). Even in remote areas, marine slopes, there are the same trend of microplastic accumulation (Kukkola et al., 2022). Microplastics contaminated in the environment may be used as an indicator of geological proxy – Anthropocene (Brandon et al., 2019; Dong et al., 2020). Moreover, the shape and type of microplastic found in the area can indicate the source of the microplastic. Microplastics that are released into the environment were directly generated

by human activities. Polyester and rayon fibers found in an urban lake in Wuhan city, China signified that the microplastics most likely originated from textiles (Dong et al., 2020). Washing process and wastewater management have been the main potential sources of microplastic contamination in the environment (Šaravanja et al., 2022; Vassilenko et al., 2021).

Microplastic contamination in mangroves now appears as one of the global pollution issues. The mangrove environment that is a buffer between land and sea has been contaminated by pollution (Deng et al., 2021). The mangrove forests play a significant role as sediment traps involve other particles or substances from land- or marine-based activities (Mohamed Nor & Obbard, 2014). Many pathways can be possible sources of microplastic accumulated in mangrove ecosystems such as wastewater, runoff, and tourism as shown in Figure 8 (Deng et al., 2021). The study in the Red Sea and Arabian Gulf has shown that mangrove sediment acted as a major sink of microplastic. Because of mangrove trees, sediment or particle were trapped by their complex aerial root structure. The mangrove forests generally support high sedimentation efficiently accumulating plastics in their sediments (Martin et al., 2020).

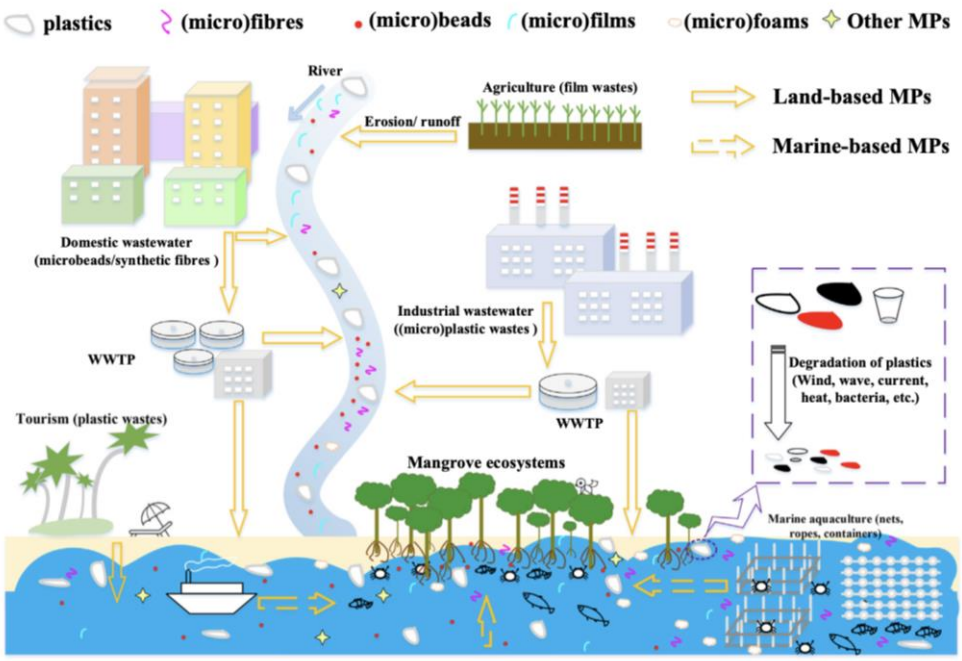


Figure 8 Possible sources and pathways of microplastic in mangrove ecosystems (Deng et al., 2021).

2.4. Plastic Pollution in Thailand

Department of Marine and Coastal Resources (2018) revealed that 10 million tons of plastic litter accumulated in the coastal area of 23 provinces around the Gulf of Thailand in 2015. Most of the plastic litter found in the coastal area is single-use items like plastic bags, plastic bottles, and plastic straws. Eighty percent of Thai marine plastic debris is led by inland human activity such as wastewater, landfill, port, and tourism. Another 20% is led by offshore activities such as shipping, fishing, and marine tourism (Pollution Control Department, 2019). The major source of dumping plastic into the marine environment is the river. In the upper Gulf of Thailand, the river mouth releasing plastic wastes, including hard and soft plastics, was the Chao Phraya River and followed by the Maeklong River, Tha Chin River, Bang Pakong River, and Bang Tabun River, respectively (Marine and Coastal Resources Research and Development Center The Upper Gulf of Thailand, 2019).

Marine and Coastal Resources Research and Development Institute and Burapha University (2014) reported originally microplastic studies in Thailand. The results showed that microplastic was found contaminated in tourism beaches, sediments, and bivalves in Chanthaburi Province in the east of Thailand. Fibers were the most common shape and white was the most common color of microplastics. Moreover, the evidence in commercial marine fish from the Lower Gulf of Thailand found plastic debris in the stomach that was microplastics (79.52%) (<5 mm) and mesoplastics (20.48%) (5-25 mm). Plastic debris affected marine organisms and food chains, and would seriously affect human health (Azad et al., 2018). The coastal area in the eastern and western Gulf of Thailand was investigated, microplastics were found ranging from 420 to 24,980 and from 20 to 273 items per kg dry sediment in the eastern coast and the western coast of the Gulf of Thailand, respectively. A factor that affected the number of microplastic was not only human activity but also other factors such as surface circular direction, geomorphology, sunlight, and coastal erosion structure (Bissen & Chawchai, 2020; Thepwilai et al., 2021). From the studies on surface sediment in estuary zone, the abundance of microplastic ranged in 300–900 and 33–400 items per kg dry weight in the dry and the rainy seasons, respectively. Rayon and polyester were dominant polymer type

and fibers were dominate shape in Bang Yai estuary in Phuket Province (Jiwarungrueangkul et al., 2021). Similarly to the result from Tapi-Phumduang River and Bandon Bay, the most abundant shape was fiber and the abundant polymer type was rayon (Chinfak et al., 2021). In addition, microplastic had accumulated in a deeper layer of sediment than 50 cm depth, the evidence from the mangrove sediment core in Pattani Bay and Songkhla Lagoon, Southern Thailand (Pradit, Noppradit, et al., 2022). Recent papers exploring the microplastic presence in pumice stone along the coast of Thailand. Microplastic entered the hole of the stone and come along with the stone floating from the South China Sea to the Gulf of Thailand (Pradit, Puttapreecha, et al., 2022).

2.5. Study Area

Samut Songkhram Province located in the west of the central plain is the smallest province in Thailand with a total area of 416.7 km^2. The climate of Samut Songkhram Province had dominated by southwest monsoon (mid-May to mid-October) and northeast monsoon (mid-October to mid-February) (Thailand Meteorological department, 2015, 2020). The Maeklong River is mainstream of this area as also Maeklong Basin originating in Kanchanaburi Province. The Maeklong River in Samut Songkhram Province is intersected by hundreds of canals and waterways including the famous canal - Klong Khon tidal canal. The Maeklong River mouth is part of Maeklong River basin that ends up in the sea. There are four major rivers (i.e., Maeklong, Tha Chin, Chao Phraya, and Bang Pakong Rivers) discharging into the upper Gulf of Thailand. The Maeklong River is not extensive as the Chao Phraya River, but the Maeklong River is the highest river runoff in the central region of Thailand with a mean annual runoff of 14,246 million m^2 (Office of the National Water Resources, 2021). There are two main storage dams which are the Srinagarind Dam and Vajiralongkorn Dam. According to watershed areas of the basin, water management in this area is available for using in domestic and industrial, generating hydroelectric power, and controlling salinity (Khalil et al., 2018). At the Maeklong River mouth, there is plenty of benthic in muddy area. Don Hoi Lot – Ramsar site is located at the Maeklong River mouth that unique area consisted of such as razor

clams (*Solen regularis*), undulated surf clams (*Paphia undulata*), tongue shells (*Lingula anatina*), cockle (*Cardiidae*), etc. The abundant mangrove ecosystem in this province was supervised by governments and also citizens. Figure 9 showed the area of marine and coastal resources of Samut Songkhram Province. Rhizophora is a dominant genus of the most widespread mangrove ecosystem around this area including *Rhizophoraapiculata, Avicenniaalba,* and *Xylocarpusgranatum* (Department of Marine and Coastal Resources, 2018). There are the Mangrove Forest Conservation Learning Center and embroidering bamboo coastal erosion structure that It is a barrier length of more than 1,800 meters along the coast.

Land use of this area consisted of agricultural, residential, forest, and others. Samut Songkhram Province is an agrarian society whose economy is based on producing and maintaining crops and aquacultures. Figure 10 and Table 2 showed the land use map and the definition of Samut Songkhram Province. The northern part of the province is an area of the cultivated zone. The many uses of the area along waterways and coastal include artisanal and commercial fisheries, aquaculture, human settlements, and mangrove forests (Land Development Department, 2019, 2021).

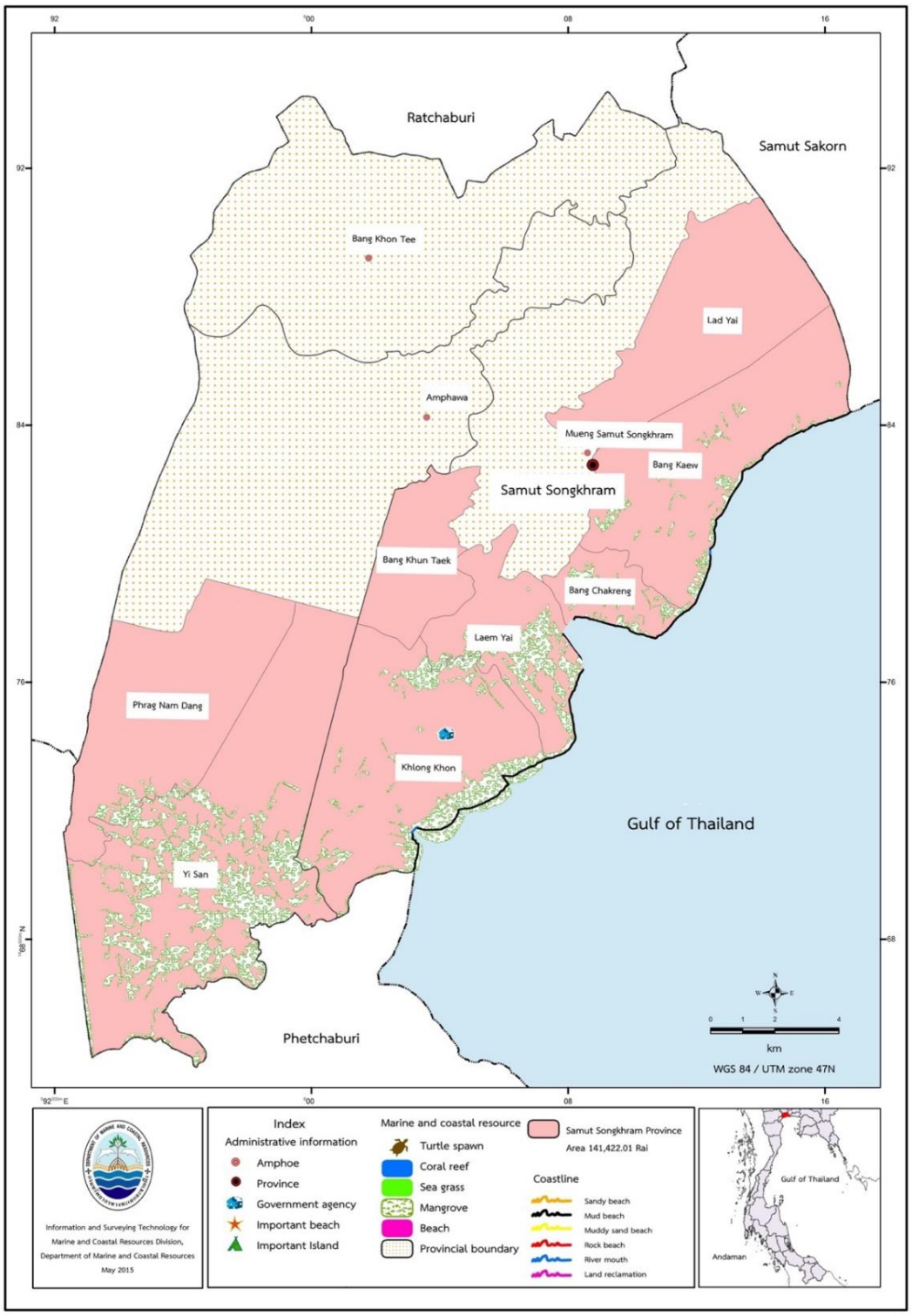


Figure 9 Marine and coastal resources map of Samut Songkhram Province (Department of Marine and Coastal Resources, 2020)

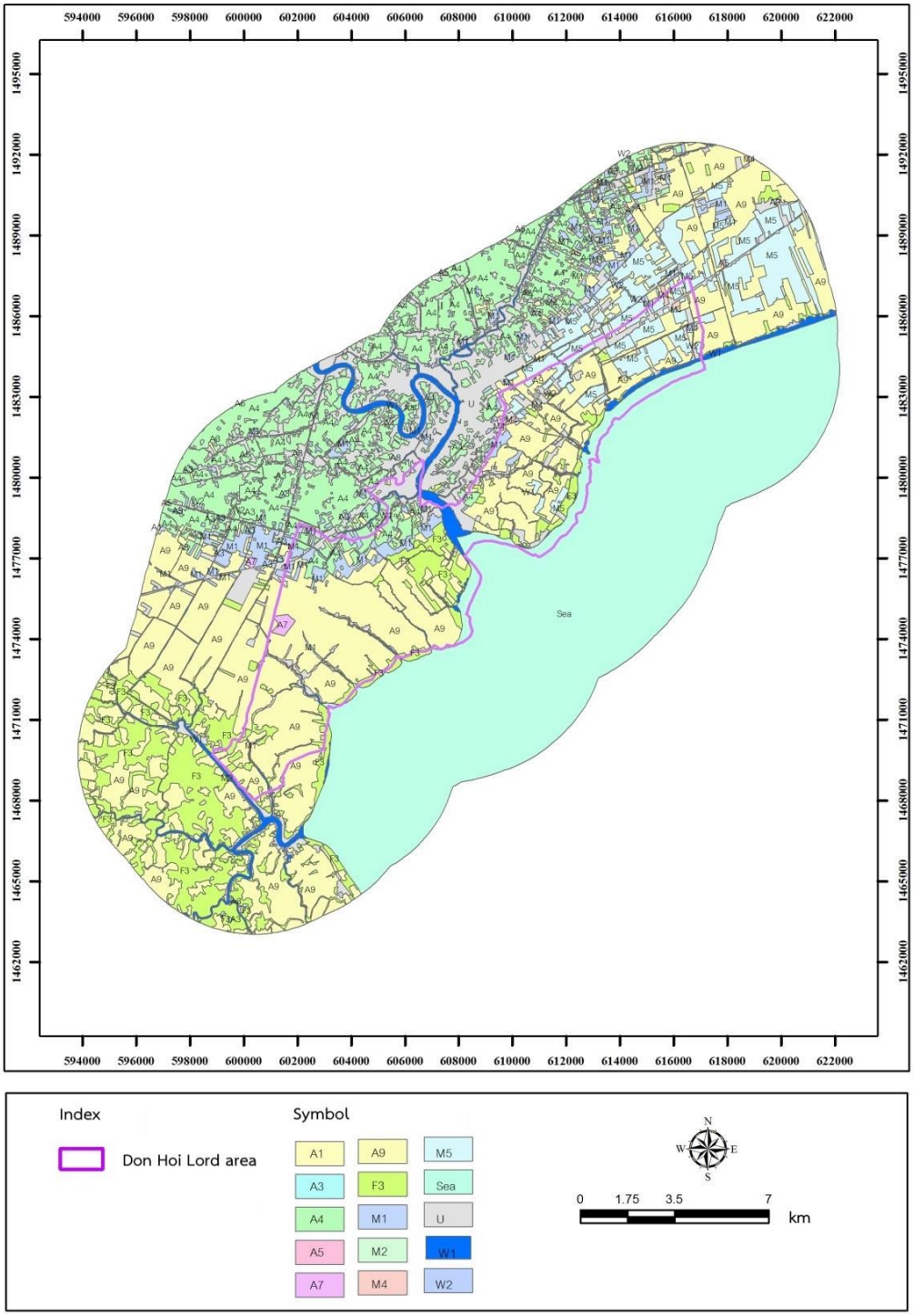


Figure 10 Land use map of Samut Songkhram Province that the detail of the symbol has shown in Table 2 (Land Development Department, 2019)

Table 2 Land use in Don Hoi Lord area modified from Department of Marine and Coastal Resources (2015)

Symbol	Land use	Area (Rai unit)	Proportion (%)
A1	Rice field	9	0.00
A3	Fruit trees	341	0.12
A4	Perennial	36,736	12.51
A5	Agriculture	110	0.04
A7	*Animal husbandry*	368	0.13
A9	Aquaculture	82,369	28.05
F3	Mangrove	23,428	7.98
M1	Grass	9,235	3.15
M2	Marshland	11	0.00
M4	Reclamation area	244	0.08
M5	Salt field	15,636	5.33
Sea	Sea	88,287	30.07
U	Community	28,339	9.65
W1	Waterway	8,437	2.87
W2	Pond	73	0.02
Sum		293,623	100.00

CHAPTER 3

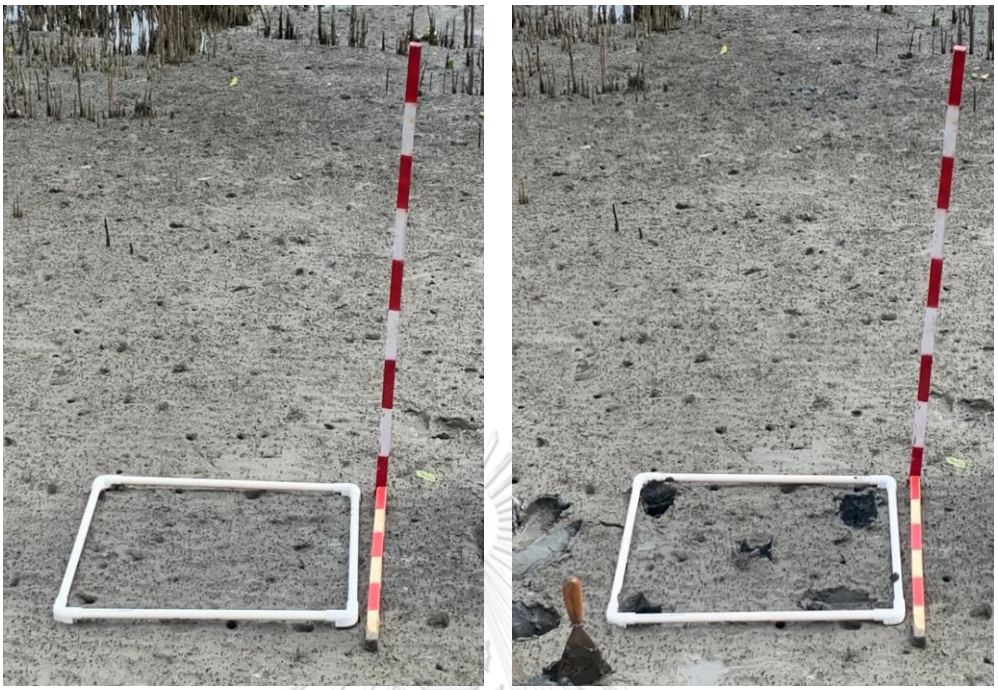
METHODOLOGY

3.1. Sediment Sampling

In this study, sediment surface samples were collected from three location along the shore of the Maeklong River estuary namely MK1, MK2, and MK3. The sediment samples were collected in mangrove zone that area between land and sea (Figure 11). Top 5 cm surface was grabbed by stainless shovel within quadrat pattern (50x50 cm^2), 3 samples per site (Heo et al., 2013; Thepwilai et al., 2021), the pattern has shown in Figure 12. Subsequently, sediment cores were collected from the mangrove forest at the Maeklong River mouth and Queen Sirikit Park. Russian corer (100 cm length and 8 cm in diameter) was used for collecting the sediment profile. An overlap sediment cores at Queen Sirikit Park namely CP1 were collected that total length profile 142 cm. At river mouth site, namely S1 was only collected total length 52 cm in depth.

The samples were stored in aluminum containers and sent to the laboratory. Every step must be considered plastic contamination. The distilled water and the solution were filtered through glass microfiber filter GF/C, 1.2-µm pore. The tools were made from non-plastic material and rinsed with distilled water before use. During processing, the beaker glass or other equipment should be covered away from airborne contamination.

Figure 11 Sampling location of MK2 station that located in mangrove zone.



(a) (b)

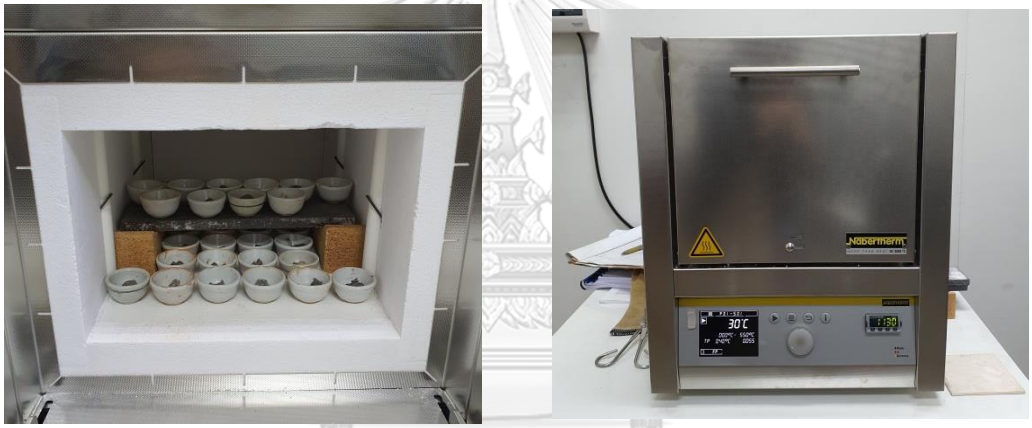
Figure 12 Collecting pattern by using a quadrat (a) before sampling and (b) after sampling by stainless shovel.

3.2. Sample Preparation

This research focuses on microplastic that accumulated in mangrove sediment thus microplastic and sediment were analyzed for understanding integration in mangrove environment. Surface sediment weighed approximately 2 kg at each sample was collected and dried in an oven at 60℃ for 48 h. Dried sediment was stored in desiccator for further analysis. On the part of sediment core, lithofacies were observed and classified on the basis of their color, texture, the lithology of clastic particles. The sample was subdivided a sediment core into slices which 1 cm interval sub-samples. The core sub-samples were divided into two parts: microplastic analysis and sediment analysis. For preparing sediment, each half of sub-sample sediment core was dried at 60°C in an oven for 48 h and stored in desiccator until further analysis.

3.3. Sediment Analysis

For sediment analysis in surface sample, sediment's particle size was analyzed. While core sediment sample at 2 and 5-cm interval were examined by loss on ignition (LOI) testing and grain size analysis, respectively. Each consecutive 2-cm interval wet sediment from core profile were investigated by LOI testing which drying in an oven at 105°C for 12 h and heating at 550°C for 6 h (Figures 13a-b). LOI testing was performed at Department of Geology, Faculty of Science, Chulalongkorn University. Dried sediment was sent to the Scientific and Technological Research Equipment Centre, Chulalongkorn University for sediment's particle size analysis by using a laser diffraction machine (Malvern 3000) (Figure 14).



(a) (b)

Figure 13 LOI testing (a) sediment sample in ceramic pot and (b) high temperature muffle furnace.

Figure 14 Laser particle size distribution analyzer - MALVERN Mastersizer 3000 (STREC Chula) that used for grain size analysis.

3.4. Microplastic Analysis

Dried sediment was sieved through mesh No.4 (4.76 mm) for removing macroparticle that bigger than 5 mm. For the microplastic analysis, there are three steps to separate microplastic from sediment: density separation or floating method by using $ZnCl_2$ solution (density 1.6 - 1.7 g ml^{-1}), digestion method by using 30% H_2O_2 solution and identification. In this study, there are two types of samples, surface sample and core sample. Consequently, the experiments were performed differently in the following ways.

3.4.1. Surface sample

Microplastics were separated from 50 g dried sediment by using 200 ml $ZnCl_2$ density separation method following Lo et al. (2018). Then, the impurities were disposed by using H_2O_2 solution and catalyzed by heat that method from Duan et al. (2020). The flow chart of microplastic analysis for surface sample has shown in Figure 15.

3.4.2. Core sample

Microplastic analysis for core sample in this study was modified from Lo et al. (2018) and Duan et al. (2020). 5 g dried sediment was blended with 50 ml $ZnCl_2$ solution at 500 rpm for 5 min and then settled aside for 3 h (Figure 16). The supernatant was contained with particle that their density less than 1.6 g ml^{-1} including microplastic, organic matter, and other microparticle. To digest microplastic, 30% H_2O_2 solution was used to remove organic material. The GF/C glass microfiber filter with 1.2 µm pore and 70 mm diameter was used in the laboratory (Figures 17a-b). After poured the supernatant through GF/C glass microfiber filter by using vacuum filter (Figure 18a), the residuals on filter were leached by 50 ml H_2O_2 solution (Figure 18b). Next, solution was heated at 70°C (Figure 19) and settled in room temperature overnight. Finally, the solution was filtered through GF/C glass microfiber filter, the filter was preserved in glass petri dish and leave dry at room temperature for further analysis.

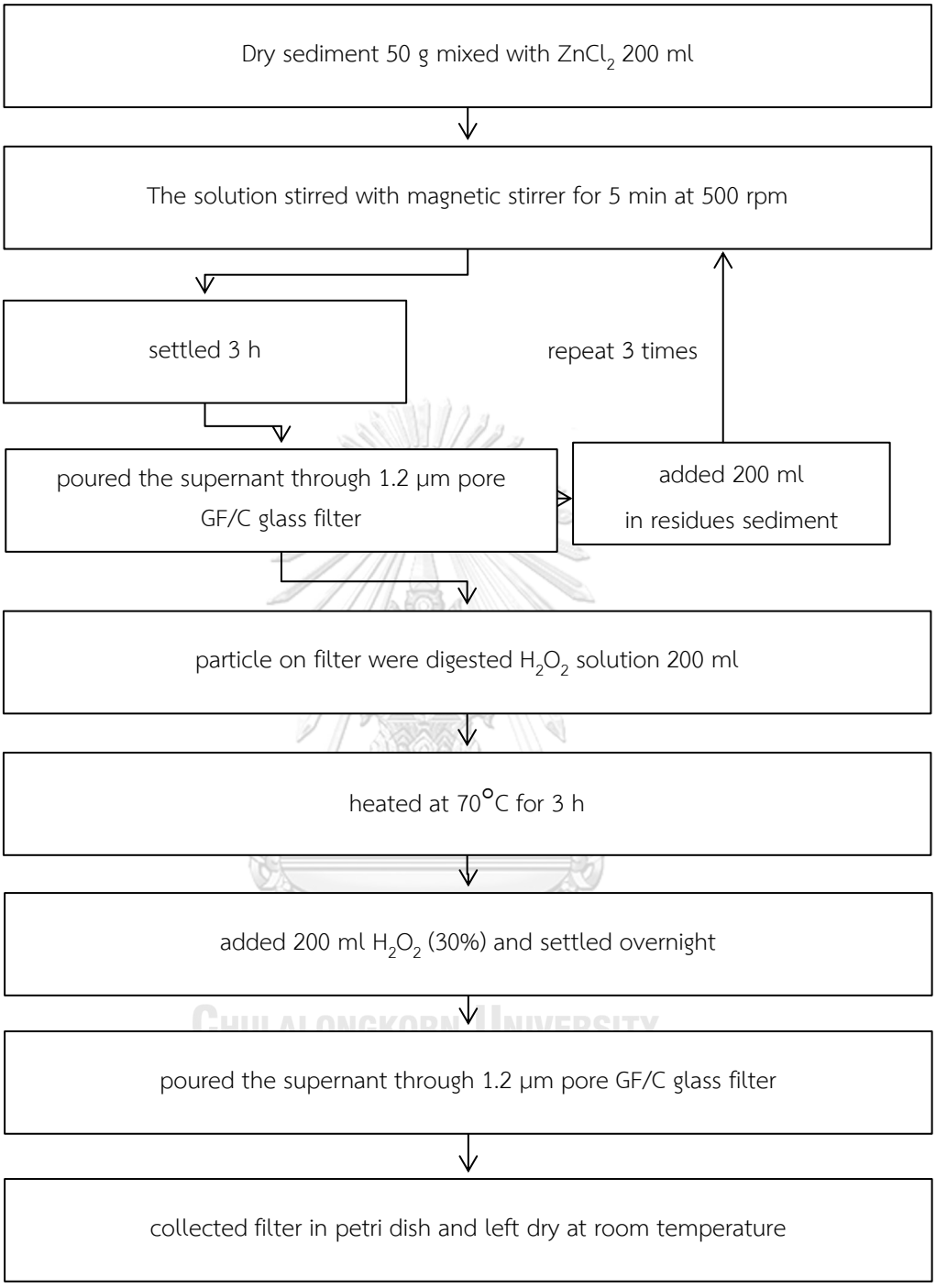


Figure 15 Flow chart showing the floatation method following Lo et al. (2018) and the digestion method from Duan et al. (2020).

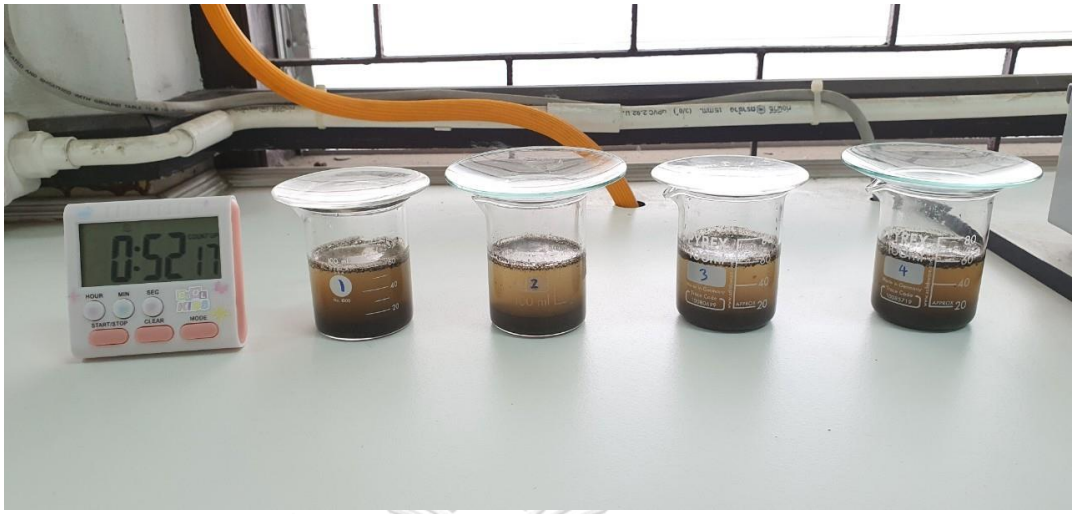


Figure 16 The solution settled aside for 3 h during the precipitation process.

(a) (b)

Figure 17 Equipment used for micro-filter: (a) GF/C glass microfiber filter and (b) filter in the funnel.

(a) (b)

Figure 18 (a) filtering process by using vacuum pump and (b) washing process by using H_2O_2 solution.

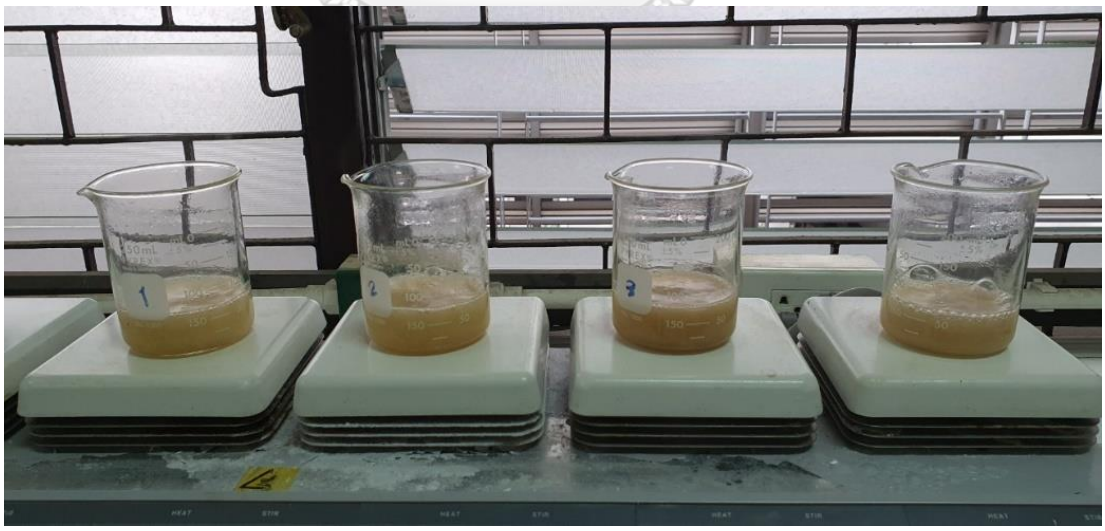
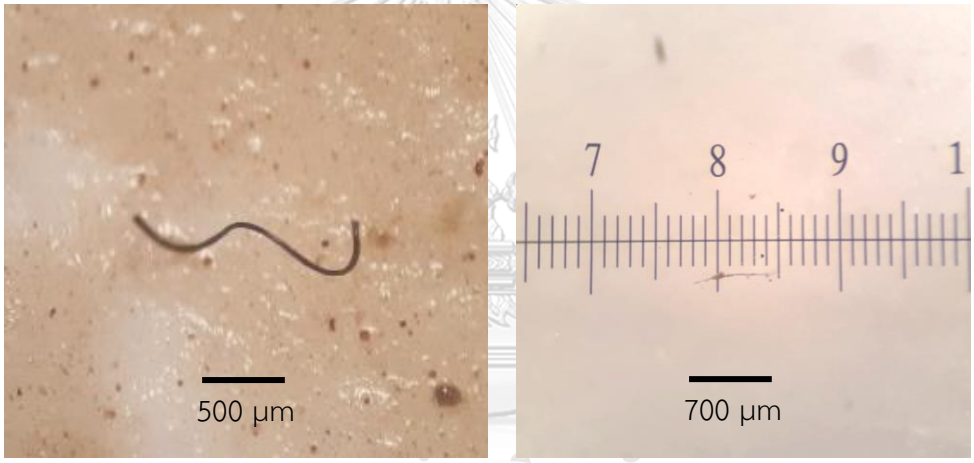


Figure 19 The solution during heating process by using laboratory hot plate.

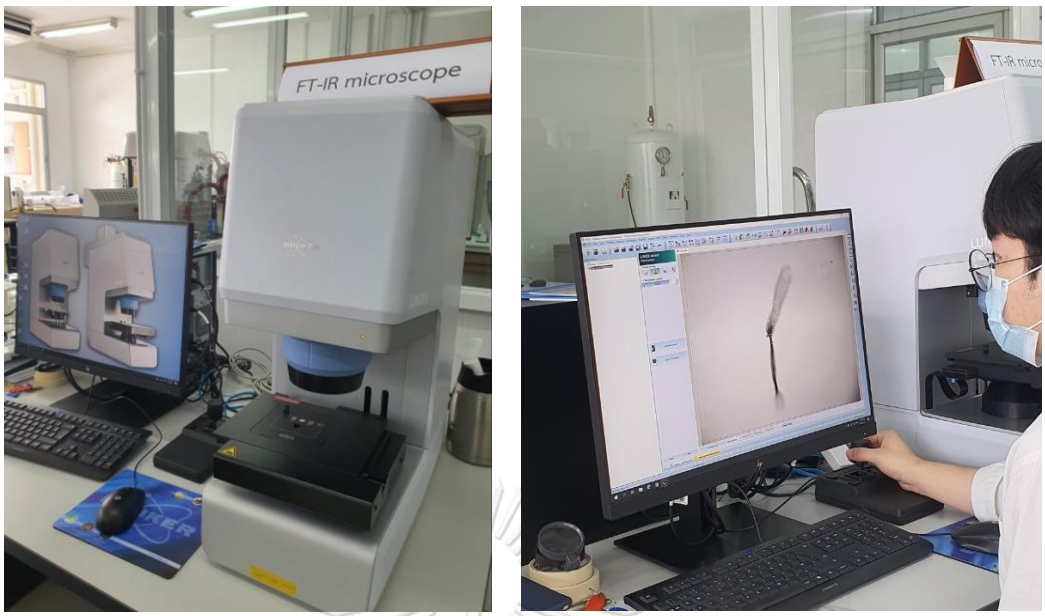
3.5. Microplastic Identification

After microplastic digestion, microparticles on the filter (Figure 20a) including microplastic and other were identified under microscope in order to identification criteria that is shape, color, and size (Figure 20b). Then, microparticles that representative of the group was analyzed polymer type by using micro-Fourier transform infrared (μ-FTIR) spectroscopy LUMOS II at the Professor Aroon Sorathesn Center of Excellence in Environmental Engineering, Faculty of Engineering, Chulalongkorn University (Figures 21a-b). FTIR spectroscopy detected infrared spectrum of absorption or emission of particle and resulted graph that can interpret band spectra with a proper literature.



(a) (b)

Figure 20 Microplastic under stereo microscope (45x) (a) microplastic on the filter and (b) particle size measurement by micron scale.



(a) (b)

Figure 21 Identification process using FTIR spectroscopy (a) FTIR spectroscopy LUMOS II at Faculty of Engineering and (b) monitor showed microparticle under FTIR spectroscopy.

CHAPTER 4

PRELIMINARY STUDY ON MICROPLASTIC ABUNDANCE IN MANGROVE SEDIMENT CORES AT MAEKLONG RIVER, UPPER GULF OF THAILAND

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Abstract

Microplastics have polluted our environment, particularly mangrove ecosystems, the barriers between land and sea that trap sediments and pollutants. The abundance of microplastics has increased in microplastic deposition and tends to rise in the future. There were significant changes in the abundance of microplastics in relation to the sediment particle size ($p < 0.05$). The difference in location between the Queen Sirikit Park and Maeklong River mouth sites was significant ($p < 0.01$). In this study, mangrove sediment cores were collected from the Maeklong River mouth and Queen Sirikit Park (shoreline), Samut Songkhram Province. The microplastics were analyzed using a modified flotation method, then recasted and removed organic matter. Fiber microplastics is composed of 92% and 82% of the total microplastics that found in the Maeklong River mouth and Queen Sirikit Park, respectively. The accumulation of microplastics in the sediments was influenced by grain size and location. The polymer types of microplastics were those normally used in textiles, indicating human activity. Moreover, micro-Fourier transform infrared (μ-FTIR) spectroscopy analysis identified compounds of other small particles, including tire rubber, pigment, paint, dyes, and flame retardant. These results imply that microplastics and microparticles have polluted the mangrove sediment in the Maeklong River basin, which is an important fishery area in the upper Gulf of Thailand.

Keywords: microplastic, mangrove, core sample, organic sediments, μ-FTIR

4.1. Introduction

Plastic is used globally for producing packages and components of consumer goods and other devices. It was invented in the 1900s and has been dramatically deployed since the 1950s (Gilbert, 2017) because of its features, such as durability, low production cost, flexibility, and chemical and water resistance. However, although plastic durability is an outstanding feature, plastic waste requires centuries to degrade. Thus, plastic is broken down into smaller pieces that become microplastics, whose particle size is smaller than 5 mm. Microplastics can be spread and accumulated in the environment for a long time (Claessens et al., 2011; Van Cauwenberghe et al., 2013).

Microplastics have extensively polluted the environment, as shown by historical microplastic records, including lake and marine sediments, ice sheets, and peat sequences. The evidence reveals that microplastics have accumulated in the environment from the late 1950s to now. Microplastics have been found in ice sheets (cores), for example, from the Arctic Ocean and Antarctic Sea ice (Kanhai et al., 2020; Kelly et al., 2020). They were also found in lake sediment areas, such as a dated-lake sediment core in the North London Lake (Turner et al., 2019), a dated sediment core in Japan, and the Donghu Lake in China (Dong et al., 2020). Meanwhile, microplastic sedimentation in China's Donghu Lake has increased 10 times over the past 60 years. Lake sediment potentially hosts great amounts of microplastics produced by human activities (Turner et al., 2019). Moreover, microplastics are omnipresent in the marine environment. For example, the ocean is the destination of plastic waste generated on land and transported via rivers or coastlines (Jambeck Jenna et al., 2015). Furthermore, microplastics are also found in deep-sea sediment cores, such as the Rockall Trough, North Atlantic Ocean (Abel et al., 2022), and the Kuril Kamchatka Trench, Pacific Ocean (Abel et al., 2022).

Studies about microplastics in mangrove areas reveal that plastic has been buried across the Red Sea and the Arabian Gulf since the 1930s and has exponentially increased since the 1950s in line with global plastic production (Martin et al., 2020). Moreover, microplastics were found in core samples from Thailand, Malaysia, and South Africa (Matsuguma et al., 2017). Previous studies

showed the occurrence of microplastics on land, especially in the boundary line between land and mangrove areas. Mangrove areas have a high sinking potential for sediment load and microplastics because of their plant root systems and low-energy environments (Mohamed Nor & Obbard, 2014). Moreover, the investigation of undated sediment cores from mangrove areas in southern Thailand showed that microplastics occurred in greater amounts in mangrove areas than that in outside areas because of the trapping potential of mangrove roots (Pradit, Noppradit, et al., 2022). In addition, there was a significant amount of microplastics in the shelter of wetlands and the surrounding community area, whereas there was a lower amount in open sea-facing areas, the Gulf of Thailand, and the outer community area (Pradit, Noppradit, et al., 2022).

Rivers are pathways that release plastic waste from land to the ocean (Meijer et al., 2021). Plastic waste ends up in the sea through various paths, including runoff, wastewater, rubbish dumping, and soil erosion (Zhang et al., 2018). In this regard, Thailand was ranked sixth in terms of mismanaged plastic waste among 192 coastal countries in 2010 (Jambeck Jenna et al., 2015). Nowadays, Thailand has also been listed as one of the top 20 countries in terms of annual plastic emissions into the ocean (Meijer et al., 2021). Because of improper waste management in Thailand, plastic debris is released into the sea. Most of the plastic debris in the ocean is caused by land activities, including wasteland, drain water, urban areas, and tourism, and a further 20% of the plastic waste is generated by marine activities, including commercial boats, fishing boats, shipping freight, and ocean tourism (Pollution Control Department, 2019). Plastic debris in the environment is eventually turned into microplastics by natural wind, tides, ocean currents, and UV radiation.

Microplastics can enter an organism's body through ingestion (Wright et al., 2013). Previous studies showed that microplastics have been detected in bivalve tissues (Ding et al., 2021). Clams, oysters, mussels, and scallops can potentially receive suspended particles in the water, including microplastics. Microplastics can obstruct and damage an organism's tissues (Deng et al., 2017; Ding et al., 2021). In addition, the microplastic surface can absorb heavy metals and toxic chemicals that may be accumulated in the body and cause diseases (Gallo et al., 2018).

Don Hoi Lot, listed as the Ramsar site under the Ramsar Convention, is Thailand's most distinct wetland ecosystem in the Maeklong River. This deep mangrove area is along the shoreline east of the Maeklong River mouth (Pumijumnong, 2014). The Maeklong River flows through Kanchanaburi, Ratchaburi, and Samut Songkhram Province and ends up in the upper Gulf of Thailand. This river is surrounded by urban and aquaculture areas and is thus an important place for fisheries and for rearing clams, mussels, and giant tiger prawns (Department of Marine and Coastal Resources, 2018).

Many studies have been conducted to study environmental changes, human activities related to the environment, and toxic metal elements in Samut Songkhram Province. As a result of a growing city, human activities cause environmental pollution (Klangnurak & Chunniyom, 2020; Punwong et al., 2018; Qiao et al., 2015). Meanwhile, the mangrove environment is a significant ecosystem providing young ocean animals with food and habitat. In this regard, one study collected and analyzed coastal sediments in Singapore and provided evidence of environmental change in the country (Mohamed Nor & Obbard, 2014). However, studies in this regard on Thailand's core and mangrove sediments are limited. Thus, this study focused on a mangrove area that has potential microplastic sedimentation. This study estimated microplastic contamination in core sediments from the Maeklong River's mouth mangrove ecosystem.

4.2. Material and Method

4.2.1. Study area

Sediment core CP1 and S1 were collected from mangrove area. This study was conducted at a mangrove area along the Maeklong River mouth, Samut Songkhram Province, Thailand (Figure 22a). This area is part of the upper Gulf of Thailand. The S1 site was located at the river mouth near Don Hoi Lot (Figure 22b). Meanwhile, the CP1 site was situated in Queen Sirikit Park (Figure 22c), known as a mangrove conservation area. The Maeklong River estuary area's unique characteristic, known as Don Hoi Lot, covers 4 km wide at the Maeklong River mouth. A mudflat area consisting of sand and mud was smoothly plain with less than

1% slope. According to the location of CP1 site surrounding the exuberant mangrove ecosystem, this site has been an important resource for inhabiting aquatic species. Moreover, bamboo walls along the shore of Samut Songkhram Province protected the mangrove area from coastal erosion (Figure 22c).

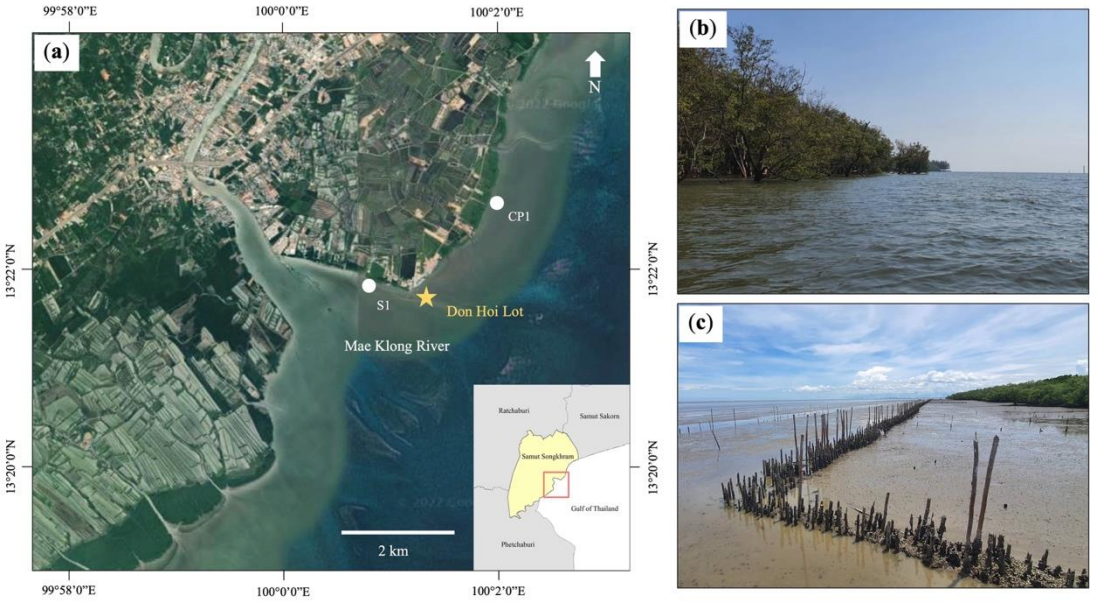

Figure 22 Study area: (a) Location of the Maeklong River mouth on the upper Gulf of Thailand. (b) Landscape of the S1 site located near Don Hoi Lot. (c) Landscape of the CP1 site located on the east side of the Maeklong River mouth.

4.2.2. Core sampling

Considering plastic contamination in the field and laboratory, the use of a plastic-made tool was avoided, and the spoon, blade, and glass bottle were rinsed with distilled water before use. The equipment should be sealed or covered away from airborne microplastic contamination. Two sediment cores were collected from two sites in front of the mangrove area at the Maeklong River mouth. The samples were picked up at the border of the mangrove forest to prevent root disruption. The sediment cores were taken using a Russian corer (100 cm in length and 8 cm in diameter). The CP1 core (Queen Sirikit Park) was collected from the overlap sediment core, and the total length of the site was 142 cm in depth. A 52-cm core was collected at the S1 site (near Don Hoi Lot). After returning to the laboratory,

the core samples were sliced into 1-cm-thick pieces using a stainless blade and individually stored in a container for further analysis.

4.2.3. Sediment analysis

Each consecutive 2-cm interval sample was used to estimate the qualitative changes in organic matter of sediments through loss on ignition (LOI). The samples were dried in an oven at 105°C for 12 h and then combusted at 550°C for 6 h. The organic content was calculated from the weight loss percentage (Heiri et al., 2001).

The sediment's particle size was analyzed using a laser diffraction machine (Malvern 3000). Each consecutive 5-cm interval core sediment was dried in an oven at 60°C for 48 h. Then, 1–2 g of dried sediment was sieved through a No.4 mesh (4.75 mm) and sent to the Scientific and Technological Research Equipment Centre, Chulalongkorn University.

4.2.4. Microplastic analysis

Microplastic abundances were determined for each consecutive 1-cm slice of the core. Wet sediment was dried in an oven at 60°C for 48 h. First, the floating method was used to separate particles using a $ZnCl_2$ solution (density 1.6–1.7 g ml^{-1}). The $ZnCl_2$ solution allowed sediments with higher density than that of the solution to sink to the bottom while plastics and some organics floated up in the supernatant. All solutions were filtered using 1.2 µm mesh size filter paper before use to avoid MPs contamination. Next, 5-g dry-weight sediment was mixed with $ZnCl_2$ (50 ml) at 500 rpm for 5 min and allowed to settle for 3 h. The supernatant containing particles less dense than 1.6 g ml^{-1} was poured through a Millipore filter (glass microfiber filter GF/C, 1.2-µm pore, 70-mm diameter, Whatman) using vacuum filtration. The floating method was repeated three times (modified from Lo et al. (2018)). Next, 30% hydrogen peroxide was used to remove the organic substance associated with microplastics. The filter containing microplastics and organic substances was rinsed using 50 ml of H_2O_2. The solution was heated at 70°C for 1 h and allowed to settle overnight (modified from Duan et al. (2020)).Then, Microplastics were counted and observed under a stereomicroscope. Their characteristics and plastic properties were primary checked by hot needle

technique test and appearance inspection including non-cellular structure, equally thick especially in fiber, homogeneous texture (De Witte et al., 2014; Hidalgo-Ruz et al., 2012). The limitation of the identification process was that microplastics smaller than 0.1 mm (100 μm) were hard to observe under the microscope. Finally, the representative microplastic sample was identified polymer type by using micro-Fourier transform infrared (μ-FTIR) spectroscopy LUMOS II at the Professor Aroon Sorathesn Center of Excellence in Environmental Engineering, Faculty of Engineering, Chulalongkorn University.

4.2.5. Pollution load index (PLI)

To understand the contamination level in core sediment at each site from Maeklong River estuary, an integrated pollution load index (PLI) was calculated based on Tomlinson et al. (1980). PLI at each site is related to microplastic concentration factor (CF_i) (Eqs. 4.1 and 4.2) as given below:

$$CF_i = \frac{C_i}{C_{oi}} \quad (4.1)$$

$$PLI = \sqrt{CF_i} \quad (4.2)$$

At each site, CF_i is the quotient of the microplastic concentration at surface (0-5 cm) (C_i) and the background microplastic concentration (C_{oi}). The microplastic concentration at the bottom of the sediment core was considered as a background value.

4.3. Result

4.3.1. Sediment analysis

Sediment from each consecutive 5-cm depth interval was measured using a laser diffraction machine (Malvern 3000). The sediment sample from the CP1 site (Queen Sirikit Park) had high concentrations of silt (0.002–0.05 mm) and sand (0.06–2.0 mm), whereas the sample from the S1 site (the Maeklong River mouth) was silt dominated. The average grain size from each 5-cm depth interval ranged from 38.9 to 166.0 and 21.4 to 65.7 μm in the CP1 and S1 sites, respectively. The lithostratigraphy and grain size proportion of the sediment cores are shown in

Figure 23. LOI was analyzed by combusting the sediment sample from each consecutive 2-cm interval. LOI reflects the water, organic, and carbonate contents contained in the sediment sample. Lithostratigraphy and grain size proportion of CP1 core (Figures 24a-b) are performed with microplastic abundance graph and LOI percentage graph in Figure 24. The LOI value in the 142-cm core from the CP1 site was high at the top of the core and had a slightly decreasing trend from top to bottom of the core (Figure 24d). The result showed that the levels of organic substances contained at the top of the core sample were higher than that at the bottom of the core. Meanwhile, the LOI value had no difference in the 52-cm core from S1. Organic matter in each depth was equally accumulated at the S1 site.

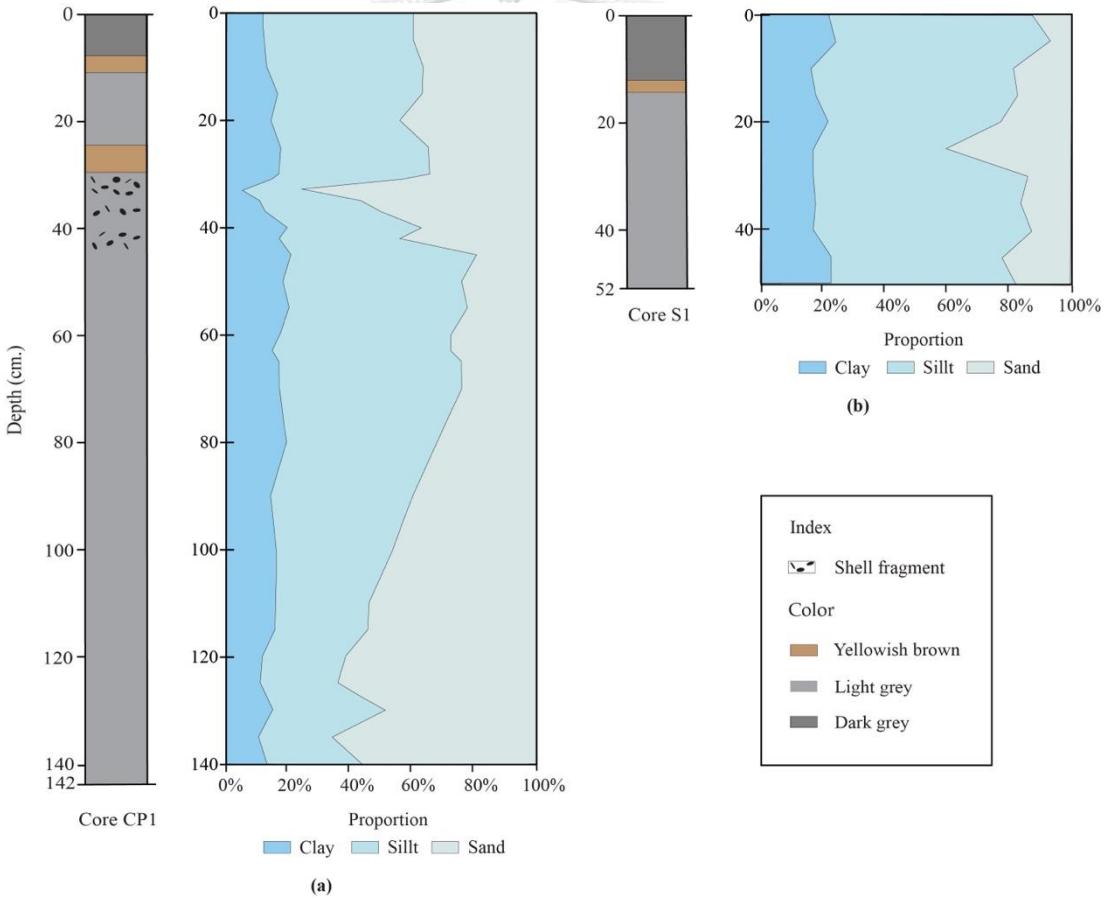

Figure 23 Lithostratigraphy and grain size proportion from top to bottom of (a) the CP1 core and (b) the S1 core.

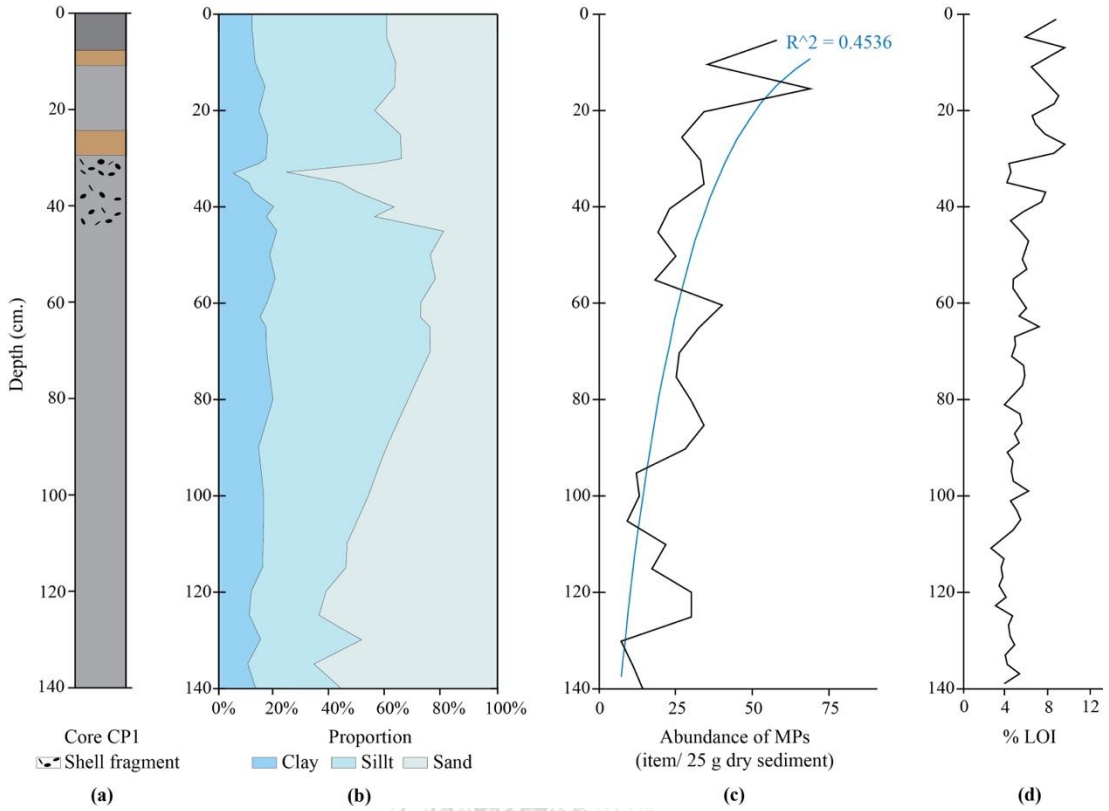

Figure 24 Sediment core CP1: (a) lithostratigraphy of core CP1; (b) percentage proportions of the size of sediment in the CP1 core; (c) microplastic abundance in the CP1 core; (d) LOI percentage of sediment in the CP1 core.

4.3.2. Microplastic analysis

Microplastic abundance

Microplastics were found in almost the entire depth length of the CP1 and S1 core samples. A total of 794 and 63 microplastics were identified in the CP1 and S1 cores, respectively. Microplastics in each 1-cm depth interval in the sediment cores ranged from 0 to 5200 items per kilogram of sediment, with an average of 1102 items per kilogram for the CP1 site and from 0 to 1400 items per kilogram in dry sediment, with an average of 426.9 items per kilogram for the S1 site. The microplastic abundance decreased with increasing sediment depth in the CP1 core; conversely, the abundance of microplastics in each depth had no trend in the S1 core. In addition, pollution load index (PLI) was evaluated by microplastic

concentration at each site. The PLI values of CP1 and S1 site were 2.04 and 1.22, respectively.

Characteristic of the microplastics

Four different shapes of microplastics (i.e., fiber, fragment, stick, and plate) were observed under a microscope. Examples of the microplastics found in this study are shown in Figure 25 At Queen Sirikit Park (CP1 site), most microplastics were in fiber shape (92%), followed by fragment (5%) and stick (3%), respectively. The plate shape was not found at the CP1 site. At the Maeklong River mouth (S1 site), the common shape was also fiber (82%). The other shapes were fragment (11%), plate (4%), and stick (3%), respectively (Figure 26). Meanwhile, fiber was the only shape found at the deeper part of the CP1 core (118- to 142-cm depth).

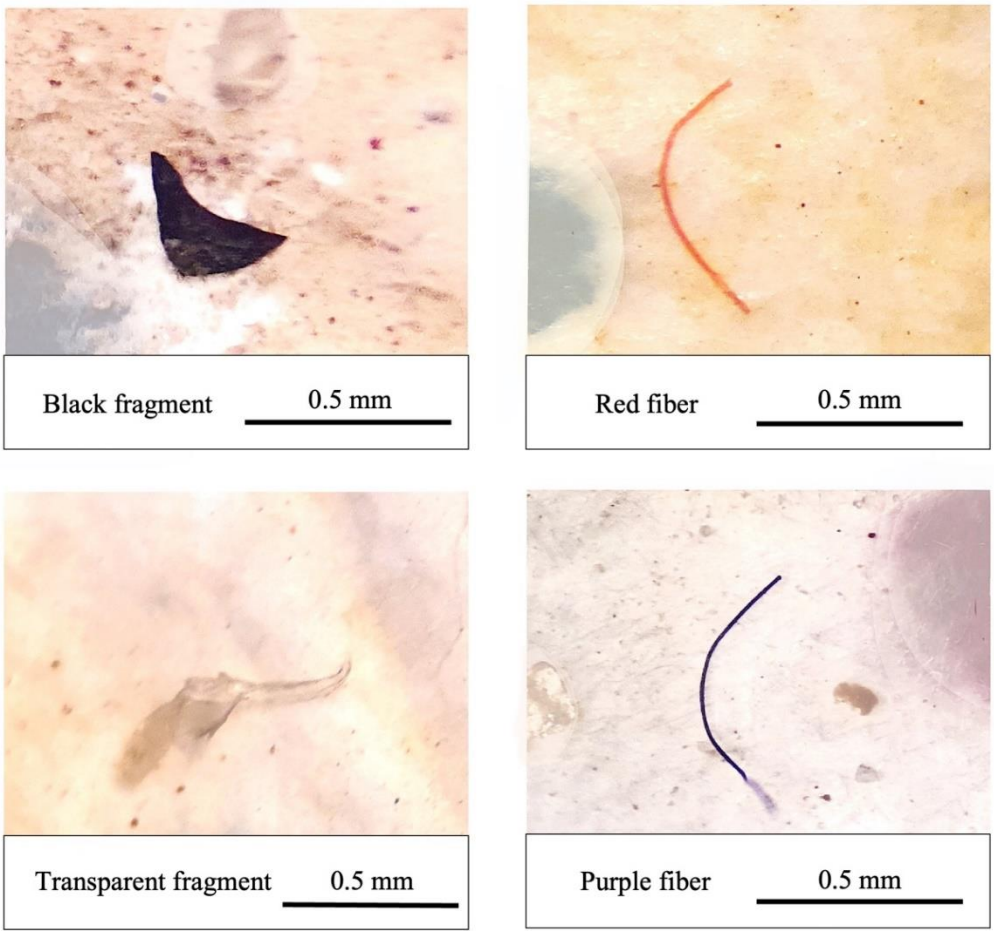

Figure 25 Examples of microplastics found in this study (from the top left in the clockwise direction): black fragment, red fiber, purple fiber, and transparent fiber.

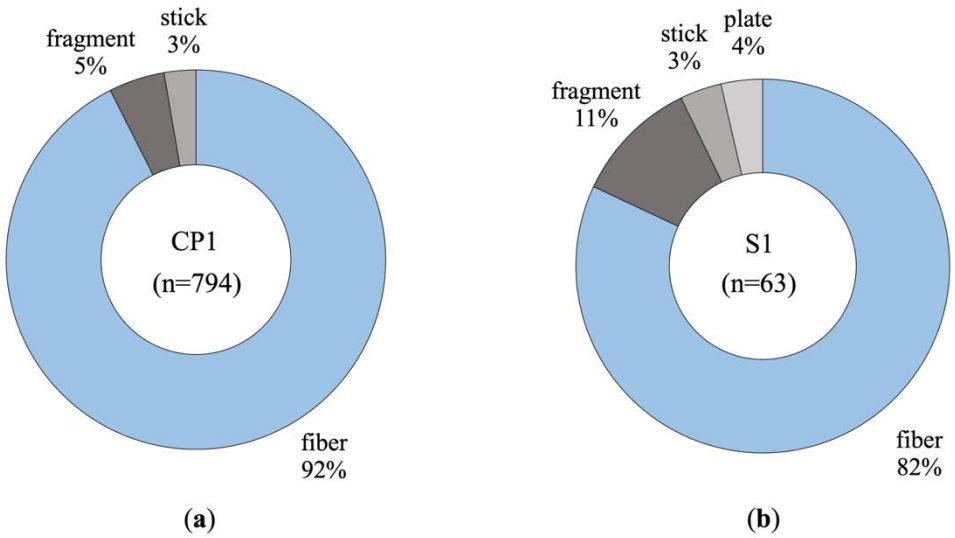

Figure 26 Shapes of microplastics in the sediment cores. Percentage proportions of shape categories of microplastics in (a) the CP1 sample and (b) the S1 sample.

For color identification, multiple microplastic colors were detected, including black, colorless, green, red, white, and brown. The CP1 site had all these colors, whereas the S1 site had all colors except brown. The most prevalent colors from the two sediment cores were equally black and colorless.

The total microplastics found in this study were generally 1.0–5.0 mm in size. Microplastics with sizes ranging from 0.1 to 1.0 mm (62%) and 1.0 to 5.0 mm (38%) were found at the CP1 site. As in the S1 site, microplastics 0.1–1 mm in length (55%) constituted a dominant proportion. The residual part comprised microplastics 0.1–1 mm in length (45%) (Figure 27). Microplastics in the CP1 site accumulated with silt–sand sediment size (0.002–2.0 mm), whereas the S1 site had more silt-size sediment and a smaller microplastic proportion (0.1–1.0 mm) than that in the CP1 site (Figure 27).

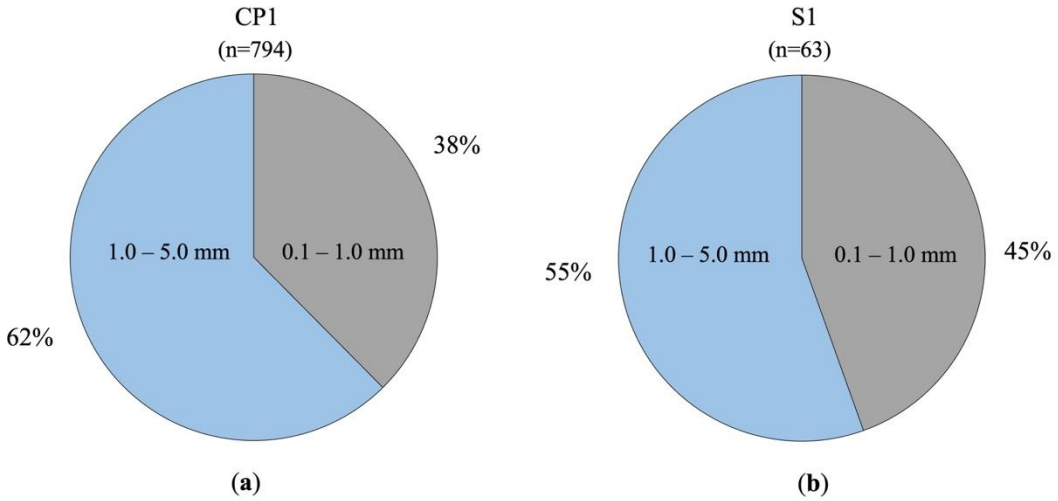

Figure 27 Sizes of microplastics in the sediment cores: percentage proportions of microplastic size in (a) the CP1 sample and (b) in the S1 sample.

Polymer type of microplastic

The μ-FTIR analysis analyzed a total of 38 suspected particles. 8 samples were non-plastic including natural dyes and cotton. Consequently, the particle with the same characteristic as non-plastic were deducted from the total number of microplastic. As the spectra of μ-FTIR can analyze the surface of the sample, coatings or contaminations on the surface can influence the spectra. Moreover, the fiber shape mostly found in this study was pretty hard to analyze because of the limited area for detection. 17 suspected particles were analyzed as a plastic component. The polymer types of the microplastics from the two mangrove sediment cores consisted of rayon, polyester (PES), polyamide (PA), polyethylene (PE), polybutylene terephthalate (PBT), polypropylene (PP), and polycarbonate (PC). An example of a polymer type spectrum of these microplastics is shown in Figure 28. The fiber was detected in various commercial names, including rayon, olefin, spandex, and nylon, which differed depending on the polymer type. In addition, this study detected other microparticles (14 suspected particles of a total suspected particles) that contaminated sediments, such as

pigment, tire rubber, paint, dyes, and flame retardant material. An example of a microparticle's spectrum is shown in Figure 29.

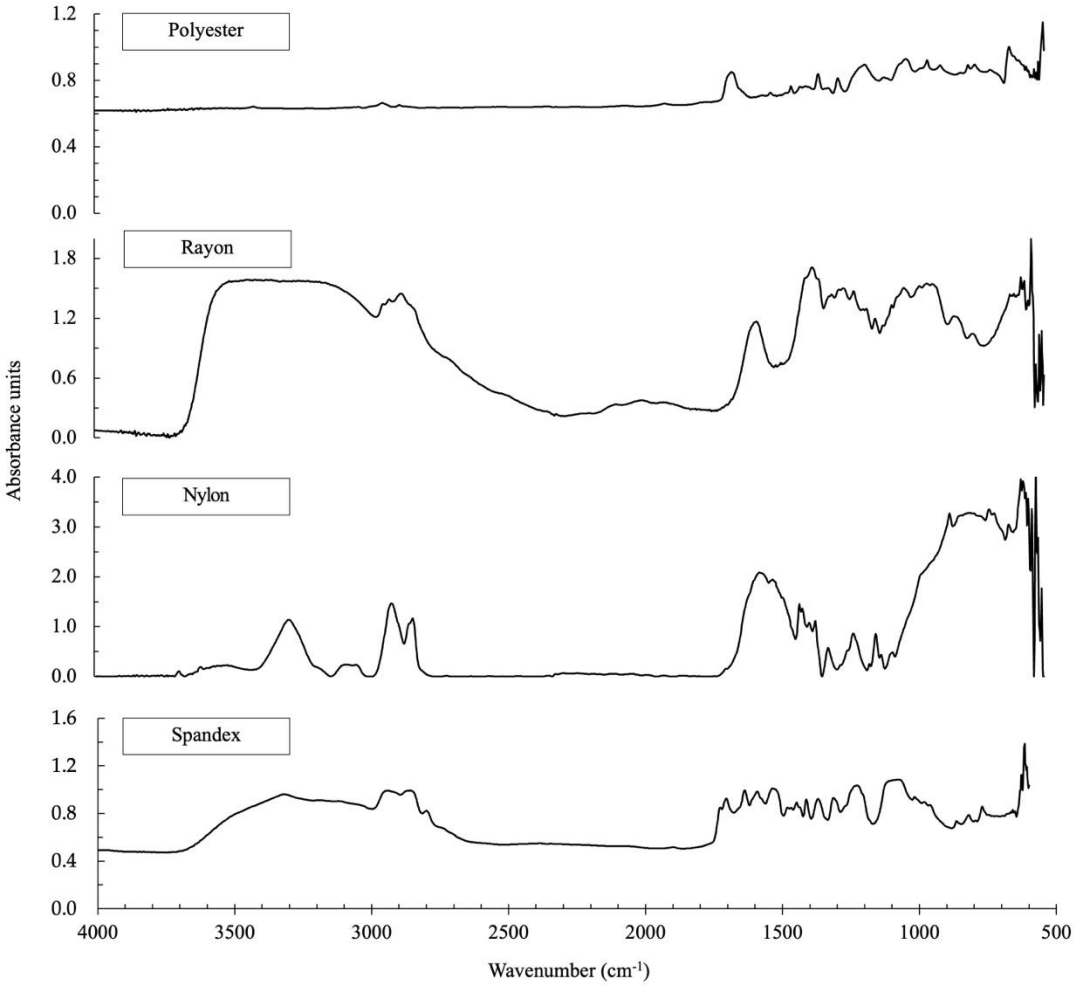

Figure 28 The spectrum from the FTIR analysis in this study. The FTIR spectra showing polymer type of microplastic (e.g., polyester, rayon, nylon, and spandex).

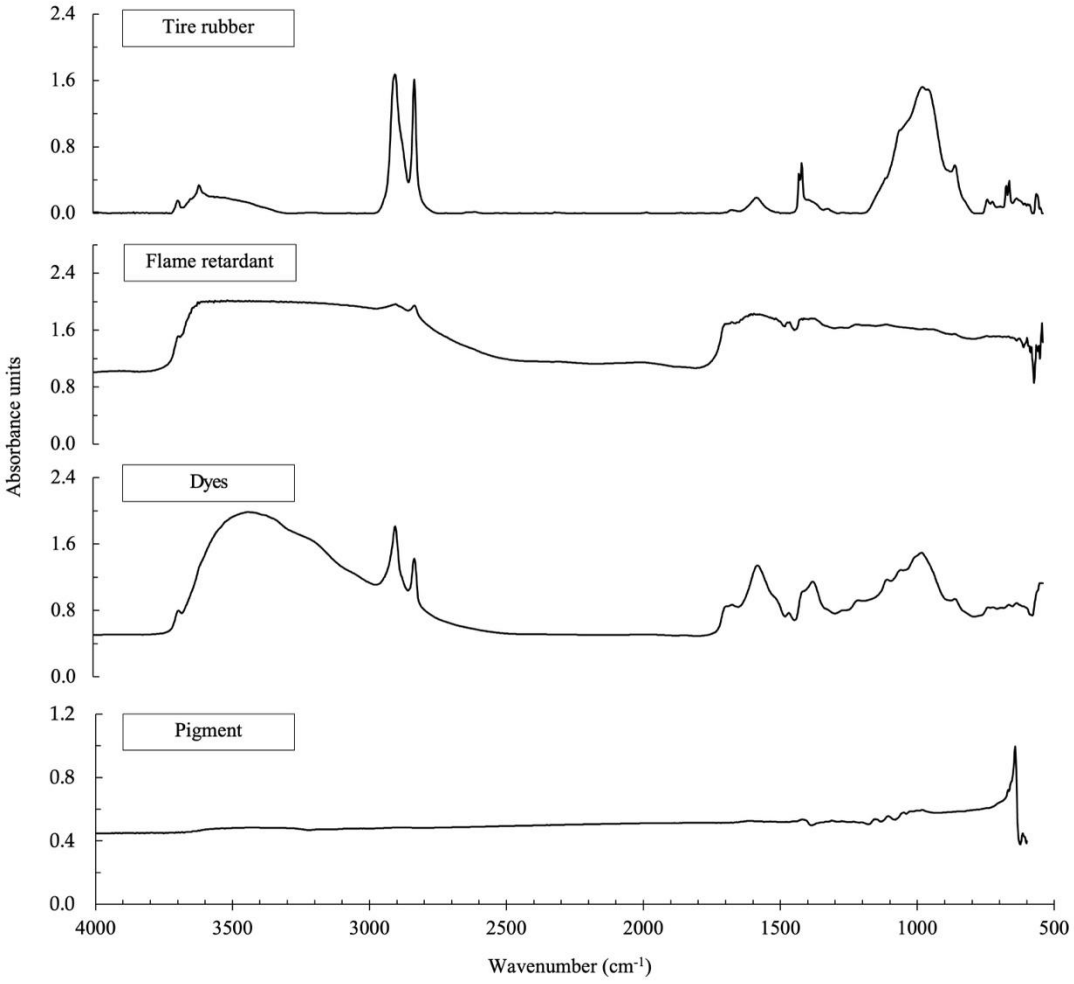

Figure 29 FTIR spectra showing types of micromaterials found contaminating the sediment sample from this study (e.g., tire rubber, flame retardant, dyes, and pigment).

4.4. Discussion

The 142-cm core from the CP1 site and the 52-cm core from the S1 site were analyzed in detail. The results demonstrated that microplastics polluted the mangrove sediment even at a 142-cm depth. A comparison of the findings from this study with those of previous studies in selected regions is shown in Table 1. The microplastic abundance in the mangrove sediment cores from the Samut Songkhram Province was approximately equal to those in Tokyo Bay, Japan, and the Red River Delta, Vietnam. Meanwhile, the abundance of microplastics in

this study was higher than that in other areas in Thailand. Microplastic accumulation and distribution are influenced by environmental parameters such as geography, location, hydrodynamics, environmental pressure, and time (Das, 2016). Because the mangrove area where the CP1 and S1 sites are located is dominated by Pneumatophores (respiratory roots), which enhance the deposition of plastic particles on sediment, the mangrove sediment is a suitable plastic sink (Martin et al., 2020).

Table 3 The abundance of microplastic in sediment cores from this study and selected regions.

Country	Location	Ecosystem	Total Microplastics (item/ kg dry sediment)	Reference
Japan	Tokyo Bay	Bay	1845 – 5385	(Matsuguma et al., 2017)
Thailand	Gulf of Thailand	Bay	83 – 165	(Matsuguma et al., 2017)
	Songkhla Lagoon	Mangrove forest	106 – 413	(Pradit, Noppradit, et al., 2022)
	Pattani Bay	Mangrove forest	108 – 180	(Pradit, Noppradit, et al., 2022)
	Maeklong River	Mangrove forest	0 – 5200	This study
China	Jiaozhou Bay	Bay	3 – 28	(Zheng et al., 2020)
	Hangzhou	Salt marsh	40 – 480	(Jingjing Li et al., 2020)
	Pearl River	Estuary	140 – 820	(Fan et al., 2019)
Indonesia	Baluran National Park	Coastal	116 ± 81	(Asadi et al., 2019)

Country	Location	Ecosystem	Total Microplastics (item/ kg dry sediment)	Reference
Vietnam	Tien Yen Bay	Mangrove forest	0 – 815	(Luu Viet et al., 2021)
	Red River Delta	Mangrove forest	0 – 4941	(Luu Viet et al., 2021)

The number of microplastics detected at every layer from the S1 site was lower than that detected in CP1. The difference in location between the CP1 and S1 sites is significant ($p < 0.01$) (Mann–Whitney U test). Geomorphologically, S1 is located at the river mouth and is thus tide-dominated, whereas CP1 is located near the shoreline and is under coastal protection behind bamboo walls (see Figure 22). Thus, CP1, located at a low-wave energy area, is a more favorable sink for particles and microplastics (Lo et al., 2018).

The sedimentary grain size analysis showed that the particle size of the CP1 and S1 sites ranged from very coarse silt to fine sand and from coarse silt to very fine sand, respectively. Consequently, the sediment samples from S1 had a grain size finer than that of the sediments from CP1. The environment at the S1 site was suitable for silt domination, and fine-grained sediment has accumulated in the Maeklong River mouth. Meanwhile, estuarine environments accumulate various ranges of sediment sizes, but finer grains dominate most estuaries (Das, 2016). In addition, there were significant changes in the abundance of microplastics and the particle sizes of the sediments from the two core samples, with a significance of 0.022 ($p < 0.05$) (Pearson correlation). Moreover, there was a linear relationship between the number of microplastics and the grain sizes of the sediment.

The abundance of microplastics negatively decayed exponentially with deeper depths of sediment core CP1 ($r = 0.6734$; $p < 0.05$). The trend is shown in Figure 24c. This relation was also found in the sediment profile in Kuwait Bay (Aba et al., 2014) and the UK's continental shelf and slope (Kukkola et al., 2022).

The results concluded that the number of microplastic accumulations decreased with increasing sediment depth. Accordingly, the trends of plastic consumption from the past and microplastic accumulation in the core were in the same direction. Pollution load index was normally evaluated the level of pollution in each area. According to this study, PLI value is applied to evaluate the contamination level in microplastic at each depth in core sediment. PLI value from CP1 site (2.04) had greater than S1 site (1.22). Both PLI values were less than 10. Consequently, Hazard level at Maeklong River estuary indicated Hazard level I that refers to hazard category by Lithner et al. (2011). This result may imply that microplastic contamination from past to present has minor risk.

The microplastics found in this study were mostly in fiber form, as in previous studies in mangrove core sediments in southern Thailand, Hangzhou Bay, China, and Northern Vietnam (Jingjing Li et al., 2020; Luu Viet et al., 2021; Pradit, Noppradit, et al., 2022). Moreover, many previous studies also suggested that the fiber type is detected as a major shape of microplastics in mangrove environments (biota: (Hastuti et al., 2019; Klangnurak & Chunniyom, 2020), sediments: (Mohamed Nor & Obbard, 2014; Wang et al., 2020; Zuo et al., 2020)). Synthetic fiber is usually used for clothing, carpets, and various other products made from polymer-based materials such as nylon (PA), spandex (polyether–polyurea copolymer), and rayon (generated cellulose) (Loasby, 1951). Synthetic fiber can release microfibers into the environment during its manufacturing or washing process (Šaravanja et al., 2022). With microfibers dumped into wastewater, some microfibers slip through water filtration systems and finally enter the environment (Vassilenko et al., 2021).

Accordingly, the microplastics found in this study can be implied as sourced from households around the study area. Besides the microplastics found in mangrove sediment cores from Pattani and Songkhla Province, southern of Thailand, rubber and paint have been reported (Pradit, Noppradit, et al., 2022). Other synthetic particles were also discovered associated with plastic polymers in this study, and the μ-FTIR analysis identified compounds of small particles, tire rubber, pigment, paint, dyes, and flame retardant. Currently, tire rubber is made from a mixture of natural and synthetic rubbers. Wear and tear from car tires can generate tire wear

particles recognized as microplastics resulting from the mechanical abrasion between tires and road surfaces (Kole et al., 2017; Wagner et al., 2018). Meanwhile, pigments, dyes, paints, and flame retardants are normally used in coating materials or as additives in polymers to improve the polymers' properties (Ambrogi et al., 2017). According to a study in the United Kingdom, synthetic dyes were found contained in fiber (Turner et al., 2019). Moreover, paint partially made from plastic polymer contribute microplastics into the ocean and waterways. Plastic leakage from paint is heavier than other sources of microplastic leakage (textile fibers and tire dust) (Paruta et al., 2022). The size of the synthetic materials in this study (tire rubber, pigment, paint, dyes, and flame retardant) was less than 5 mm. Synthesis materials and chemicals also play a role in microparticle contamination in the environment.

The 1950s was the period of widespread plastic use (Chalmin, 2019). In this regard, many studies have revealed long-term evidence records of microplastic accumulation in sediments. For example, dated sediment cores from Kuwait represented about 60 years of record with a 59-cm sediment depth. Microplastics were detected at the bottom of the core since 1951 (Aba et al., 2014). Similarly, microplastic contamination started in the 1950s and increased toward the surface layer in a dated sediment core from Tokyo Bay, Japan (Matsuguma et al., 2017). In the Gulf of Thailand, microplastics were detected at 10- to 12-cm depths in an undated sediment core sampling near the Chao Phraya River, but the deeper part of the core had no microplastics (Mohamed Nor & Obbard, 2014). Moreover, the notable core sampling 8 km away from the Maeklong River mouth only found microplastics at the top sediment layer (0–6 cm) (Matsuguma et al., 2017).

The core samples from this study were not dated, but the data from the sediment record in the Klong Khon subdistrict, Samut Songkhram province, provided a sedimentation rate of 0.6 cm per year using OxCal v4.10 (Punwong et al., 2018). According to evidence from the CP1 core, the 33- to 42-cm depths were filled with sand-size grains and shell fragments that may have been interrupted by a strong event. The strong event that brought coarse-grain deposition in this mangrove area was assumed to be typhoon Vae, which attacked the upper Gulf of Thailand in 1962 (Suphat, 2007). The depth from the top to the marked layer (33–42 cm; see

Figure 24) and the period of occurrence of the Vae typhoon were calculated, and the rate of sedimentation was approximately 0.57 cm per year. This study's result is similar to the sedimentation rate at the Klong Khon subdistrict (Punwong et al., 2018) located west of the Maeklong River, Samut Songkhram Province.

Microplastics found in the deep layers may have accumulated before the industrial age in the 1950s. According to a previous study in Turkey, microplastics contaminated estuary sediments before the 1950s (Belivermiş et al., 2021). In this study, microplastics found in the deep layers are supposed to be from microplastic infiltration (Figure 30). Microplastic infiltration, which transports microplastics into deeper areas, is affected by various factors, such as microplastic properties, soil texture, current flow, and biota disruption (Dong et al., 2022; Guo et al., 2022). Accordingly, tidal flat areas are influenced by tides and consist of unconsolidated sediments that typically have high porosity (Semeniuk, 2005). Thus, in this context, microplastics move inside soil cracks or are transported from surfaces to deep layers through leaching or bioturbation (Jia Li et al., 2020). Moreover, as mangrove environments have a great diversity of biota, including aerial root plants and benthic organisms, microplastics are transported into deeper sediment layers by benthic invertebrates (Näkki et al., 2017). Moreover, microplastics that contaminate mangrove sediments may be ingested by organisms in this area. Many studies revealed that microplastics were found in living organisms in mangrove ecosystems (Hamid et al., 2020; Zhang et al., 2021).

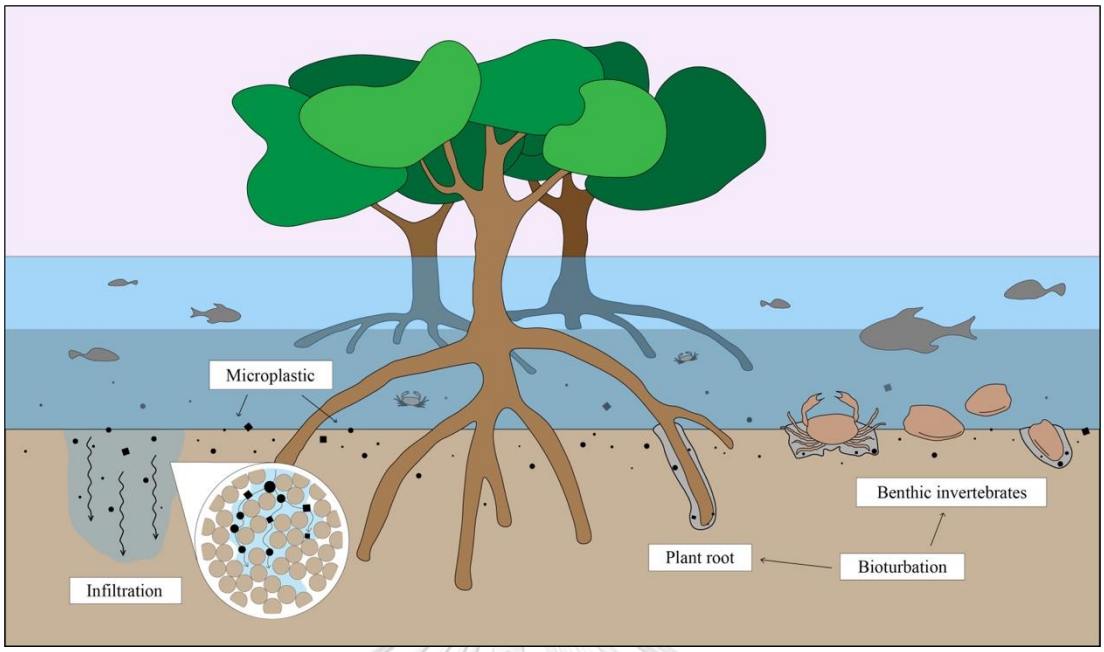

Figure 30 Graphic showing how bioturbation transports microplastics deep into the mangrove environment.

4.5. Conclusion

Microplastics were more abundant in the CP1 core possibly because of the geomorphology of the shoreline area, given that the S1 core is located in the Maeklong River mouth area. The microplastic abundance corresponded to the sediment size distribution and location related to transportation energy. Microplastics were found at a 142-cm depth and have accumulated in deep sediment layers in association with microplastic infiltration and biota distribution. The abundance of microplastics increased from the deep toward the surface. This trend is expected to rise in the future. Microplastic types in this area were implied as due to human activity - waste from households, daily products, and fishing. As mangrove ecosystems are the habitat of diverse species, microplastics in these areas may affect living organisms. Thus, microplastic pollution in mangrove ecosystems should be a great concern.

CHAPTER 5

MICROPLASTIC CONTAMINATION IN THE COASTAL ENVIRONMENT: A CASE STUDY FROM THE MAEKLONG ESTUARY, SAMUT SONGKHRAM

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(Chaisanguansuk, Ploenbuppa, et al., 2023)

Abstract

The mangrove sediment from the Maeklong River (MK) and the Klong Khon canal (KK) revealed the microplastics contamination in the Maeklong estuary environment. Microplastic analysis 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} d.w. 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.

Keywords: Microplastics, Mangrove sediment, Surface sediment, Gulf of Thailand

5.1. Introduction

Plastic consumption has dramatically increased over the decade (Ritchie & Roser, 2018). However, its lightweight, highly persistent, and high resistance to degradation make plastic debris a global pollution issue (Barnes et al., 2009). PlasticEurope (2021), 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 (Beaumont et al., 2019; Jambeck Jenna et al., 2015). Most plastic litter in the ocean is considered produced in Asian countries due to their fast-growing plastic market (Ritchie & Roser, 2018; Thevenon et al., 2014).

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 (Crawford & Quinn, 2017). Microplastics are strong hydrophobicity, stable chemical composition, large specific surface area, and small size (Yu et al., 2022). 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 (Van Cauwenberghe et al., 2013), the Tibetan Plateau (Yang et al., 2022), and the Arctic sea ice (Peeken et al., 2018). Microplastics can be classified into primary and secondary microplastics based on their sources (Akdogan & Guven, 2019; Cole et al., 2011; Horton et al., 2017). Primary microplastics are tiny microbeads produced in the industry for cosmetics and personal care products, e.g., dermal exfoliators and cleaning agents (Crawford & Quinn, 2017). Although plastic is highly resistant to natural degradation, it can be decomposed by environmental mechanisms, i.e., hydrolysis, photo-, thermo-oxidative, and bio-degradations (Webb et al., 2013). These processes can disintegrate plastic which eventually becomes smaller than 5 mm, called secondary microplastics (Akdogan & Guven, 2019; Cole et al., 2011; Horton et al., 2017).

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 (Browne et al., 2008). The risks of microplastics through ingestion and dermal contact are limited and require further research (Prata et al., 2020).

Microplastic pollution is caused by human activities and related to intensity of human activity in the area (Matsuguma et al., 2017). Beach with heavy tourism and recreational activities had higher levels of plastic debris (Akkajit et al., 2019). 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 (Apinanwattanakul, 2018; Bissen & Chawchai, 2020; Marks et al., 2020; Matsuguma et al., 2017; Pradit, Noppradit, et al., 2022; Puthcharoen & Leungprasert, 2019; Ta et al., 2020; Thepwilai et al., 2021; Wang et al., 2020).

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 (Deng et al., 2020). 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 (Mohamed Nor & Obbard, 2014). The Maeklong 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 Province, a high population density area (495/km^2 and the 7th in Thailand) (Department of Provincial Administration, 2018).

5.2. Materials and Methods

5.2.1. Study area

Samut Songkhram Province 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 5.1. According to a previous geomorphological study, Samut Songkhram Province is a tidal plain at the mount of the Maeklong River connected to the upper Gulf of Thailand (Sinsakul, 2000; Tanabe et al., 2003; Thiramongkol, 1984). The river originates from Tenasserim Hills in Kanchanaburi Province, 200 km northwest

of Samut Songkhram Province. It is one of the four major rivers (i.e., Maeklong, Tha Chin, Chao Phraya, and Bang Pakong Rivers) discharging into the upper Gulf of Thailand. The mean annual runoff of the Maeklong River is 14,246 million m^3, the highest river runoff in the central plain of Thailand (Office of the National Water Resources, 2021). In Samut Songkhram Province, the Maeklong tidal plain is intersected by a hundred tidal canals and water pathways.

In this study, the sediment samples were collected from mangrove forests along the Maeklong River estuary (MK) and the Klong Khon tidal canal (KK) (Figure 31). MK is a transition zone between fluvial and marine processes near the Maeklong River mount, including the northeast tidal flat. The Maeklong River flows through urban area and industrial area. KK is one of the canals dissecting the tidal plain. It is parallel to the Maeklong 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 (Land Development Department, 2021). Many studies reported that biota and sediment of the Maeklong estuary has been polluted by human activities including trace element heavy metal (Peebua et al., 2006; Pengthamkeerati et al., 2013; Worakhunpiset, 2018).

Figure 31 The study area shows sampling collection along the Klong Khon tidal canal (KK1, KK2, KK3) and the Maeklong River (MK1, MK2, MK3).

5.2.2. 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 (Heo et al., 2013; Thepwilai et al., 2021). 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.

5.2.3. 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 (Wentworth, 1922).

5.2.4. 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 and subsequently H_2O_2 digestion.

Since the density of $ZnCl_2$ is higher than that of plastic, it is frequently applied to microplastic extraction. ZnCl2 was more effective in density separation than other solution (Coppock et al., 2017). Previous studies improved microplastic density separation, $ZnCl_2$ solution could be reused at least five times maintaining an efficiency above 95% (Duan et al., 2020; Rodrigues et al., 2020). $ZnCl_2$ 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 lab were sent to 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 (De Witte et al., 2014) and inspected feature including non-cellular structure, equally thick especially in fiber, homogeneous texture (Hidalgo-Ruz et al., 2012). 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.

5.3. Results

5.3.1. Sediment grain size and 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 32). 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 32). A 5% of sand-fraction was found in sample no. KK3 (Figure 32).

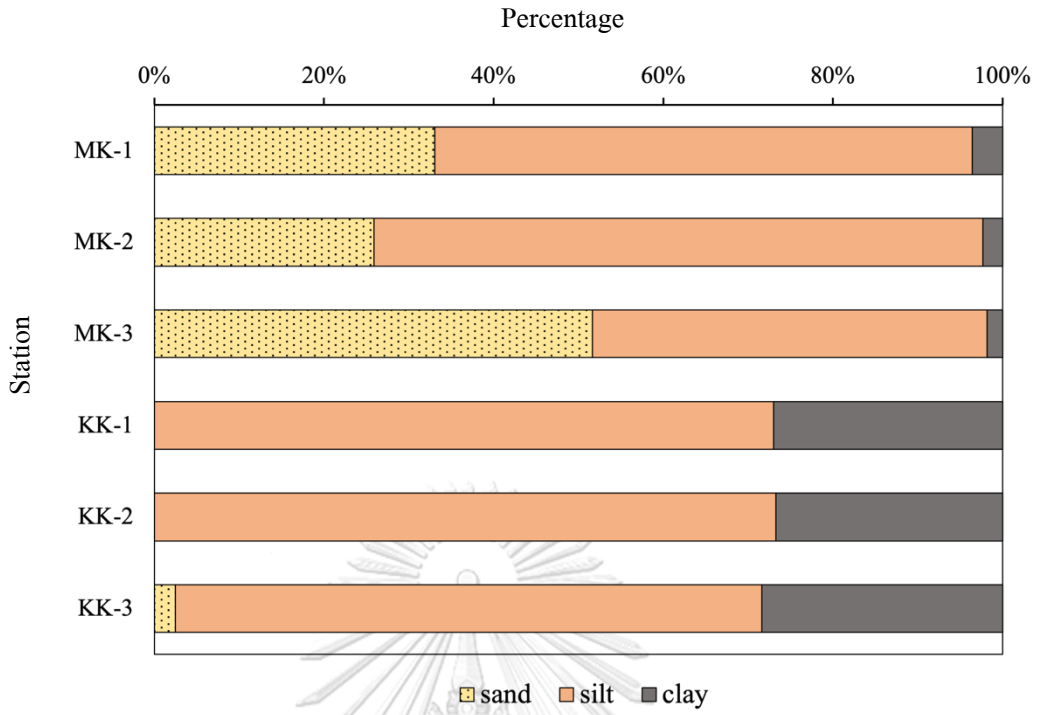

Figure 32 Grain size distribution of the surface sediments from the Maeklong River (MK) and the Klong Khon tidal canal (KK).

5.3.2. 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 4-5). The microplastic concentration was comparable to 470 items kg^{-1} dry weight (d.w.) in the sample no. MK1 and MK2 (Figure 33). They significantly increased and reached 800 items kg^{-1} d.w. in sample no. MK3 (Figure 33). The microplastic concentrations were approximately 2000, 1800, and 1240 items kg^{-1} d.w. in the samples no. KK1, KK2, and KK3, respectively (Figure 33).

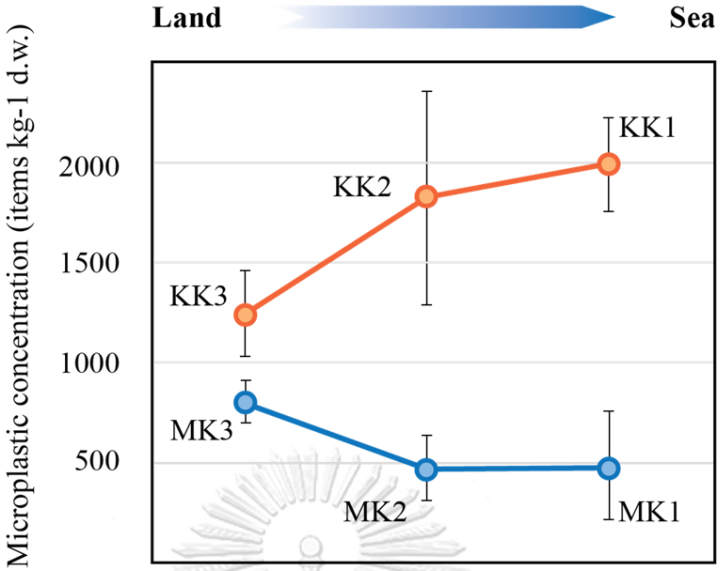

Figure 33 Abundance of microplastic in each sampling site (MK: the Maeklong River; KK: the Klong Khon tidal canal).

5.3.3. 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 34.

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 35). The plate and stick shapes were meager at less than 10%. However, the foam was undeterminable in the samples from MK (Figure 35).

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 35).

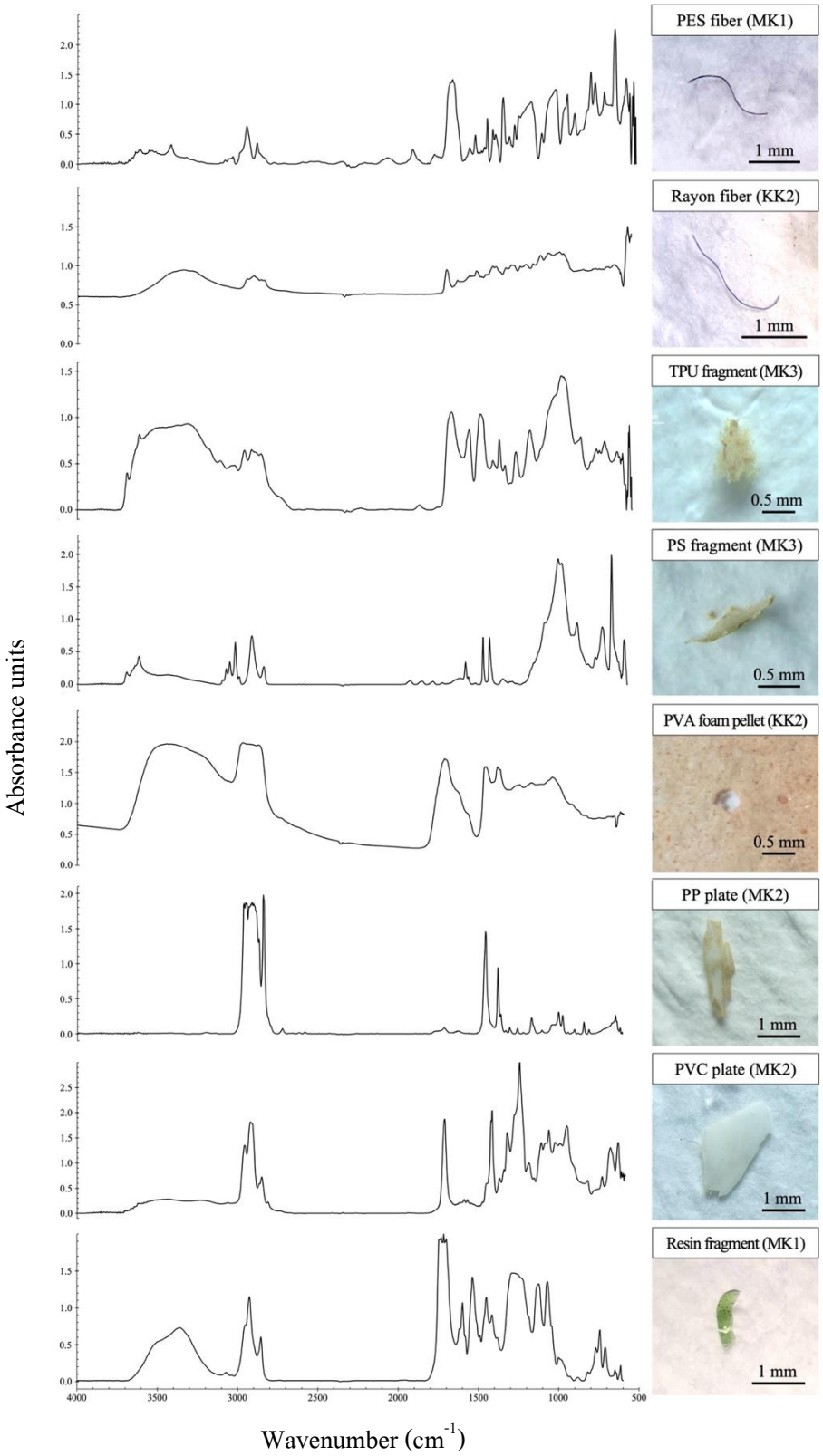

Figure 34 Example of microplastic from this study expressing their image microscope and FTIR spectra.

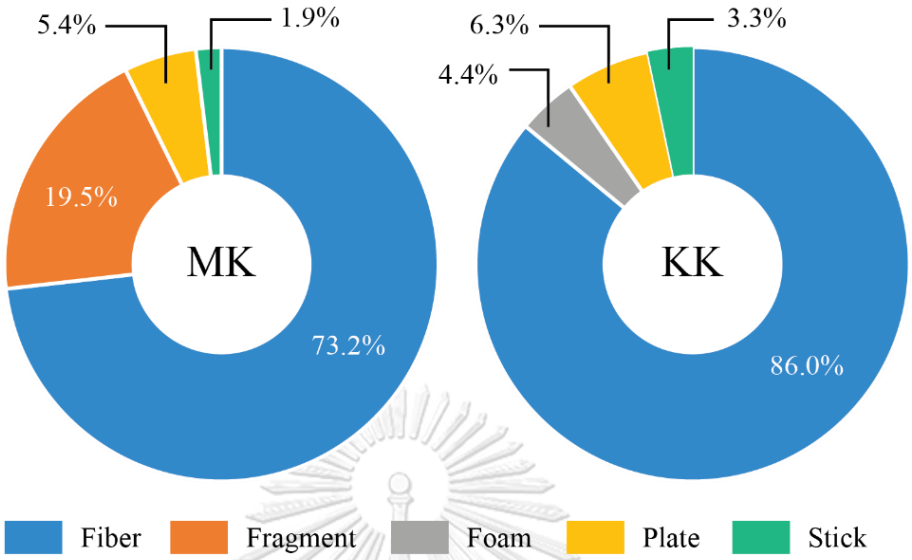

Figure 35 Shape of microplastic in the mangrove sediments from the Maeklong River (MK) and the Klong Khon tidal canal (KK).

5.3.4. 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 34. 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 36).

The fiber obtained from MK was mainly PES (45%), followed by PP (22%) (Figure 36). 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 36). 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 36). 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.

5.4. Discussion

The trend of microplastic abundance in MK declined in relation to distance from the sea. On the other hand, microplastic abundance in KK increased with distance from headwater (Figure 33). 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 (Hamid et al., 2018). 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 32). This correspondence could be explained by the similarity of microplastics and fine sediments dispersion (Harris, 2020; Lo et al., 2018; Mendes et al., 2021). 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 Maeklong River mount prohibited the microplastic deposition in the MK estuary. Especially, MK1 and MK2 station located at river mouth that microplastic concentration have been lower than other station. Semi–log graph has shown in Figure 37 that used for demonstrating the result from this study. Log–scale on y–axis has covered a large range of sediment grainsize. 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 37). The results from site MK3 may not fit with the general pattern, possibly caused by the site located near village area (Figure 31).

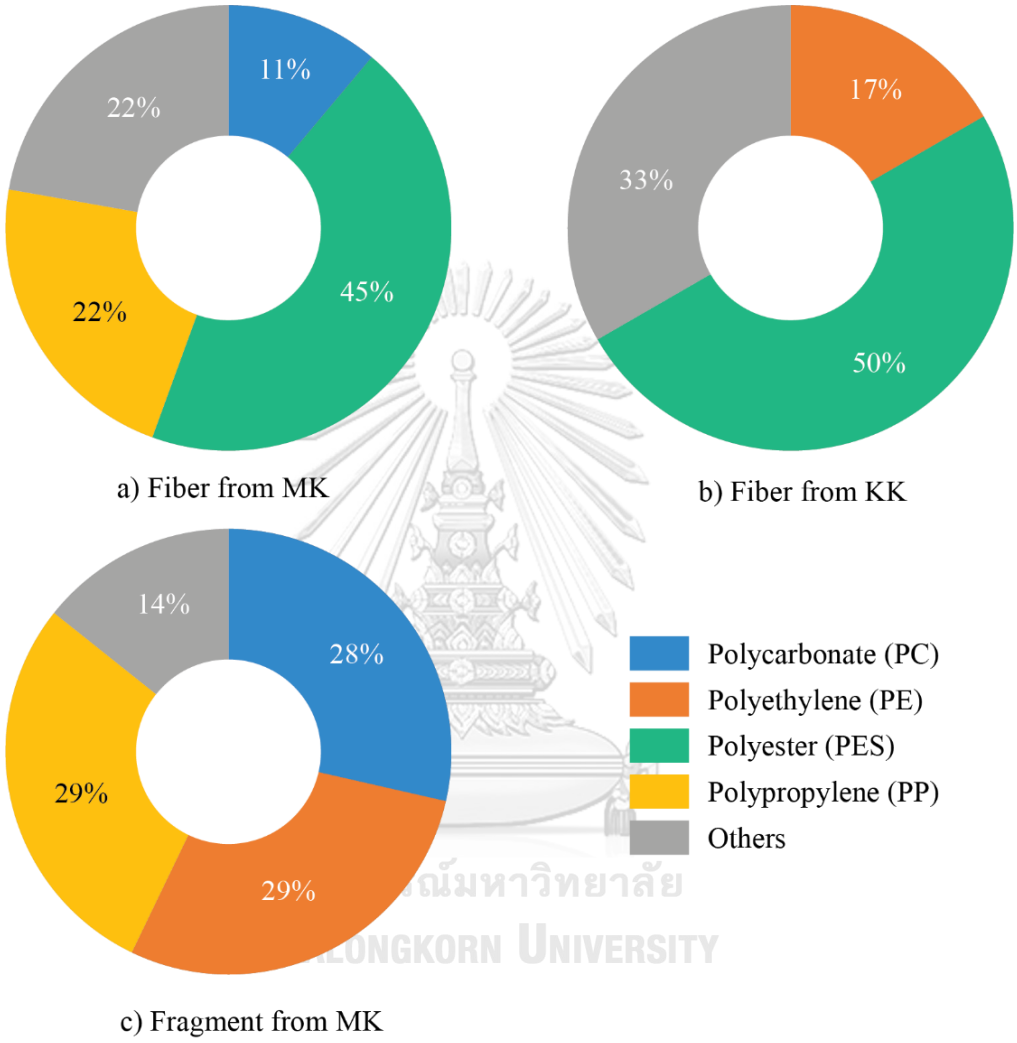

Figure 36 Major chemical composition of fiber and fragment microplastic from the Maeklong River (MK) and the Klong Khon tidal canal (KK).

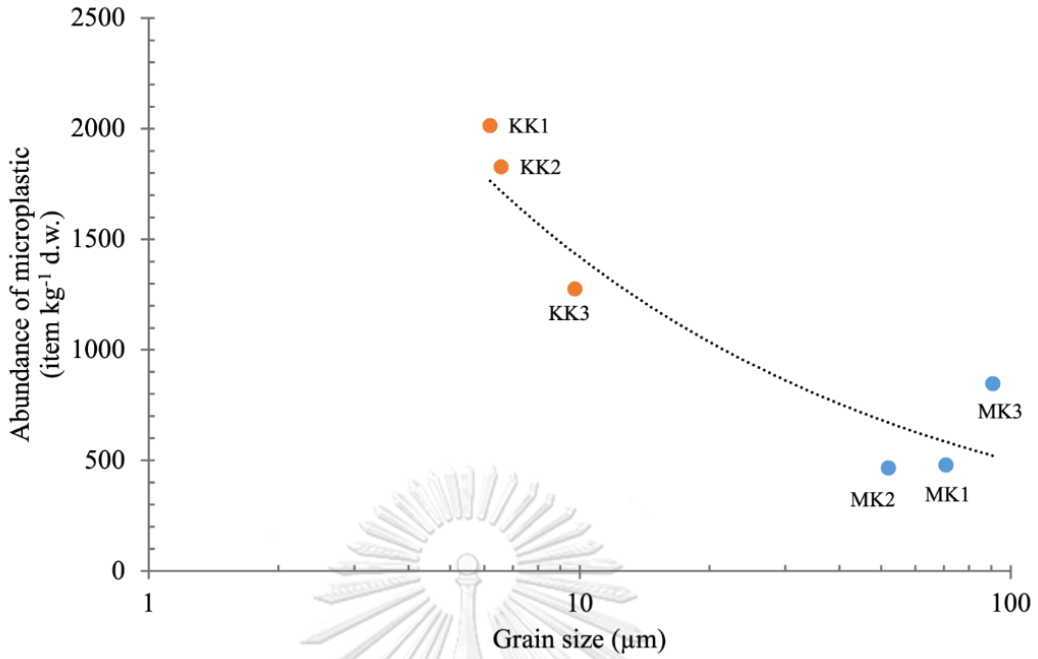

Figure 37 A semi-log plot comparing between abundance of microplastics and mean grain size.

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 (Martin et al., 2019; Martin et al., 2020). The studies on abundance and characteristics of MPs in mangrove sediment found in Asia zone including Singapore, China, Indonesia, and Thailand has shown in Table 4. The studies on microplastic contamination in sediment in Thailand has shown in Table 5, 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 (Chinfak et al., 2021; Jiwarungrueangkul et al., 2021; Wang et al., 2020). However, the maximum number of microplastic in mangrove in this study was much lower than tourists' beach that reported in Thailand (Bissen & Chawchai, 2020; Thepwilai et al., 2021) and they also became lower than Futian and Pearl River estuary, China, which is an estuary environment (R. Li et al., 2020; Zuo et

al., 2020). Other studies were classified a microplastic size below 50 μm (R. Li et al., 2020; Mohamed Nor & Obbard, 2014; Zuo et al., 2020) 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 (Zuo et al., 2020). Therefore, the less contamination of microplastic in this study was possibly caused by three times lower population density along the Maeklong River than that along the Pearl River (Department of Provincial Administration, 2018; Guangdong Statistics Bureau, 2018). 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 (Idrus et al., 2022). However, since the population density in Samut Songkhram Province is significantly lower than that in Jakarta, Indonesia, and Singapore, the other factors possibly play a role in the microplastic accumulation.

Table 4 Abundance and characteristics of MPs in mangrove sediment found at Singapore, China, Indonesia, and Thailand.

Studied area	Sample depth	Analytical method	Abundanceof 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 – 7900	Fiber (70%)	PP, PE	(Zuo et al., 2020)
Futian, China	0 – 5 cm	$ZnCl_2$ + H_2O_2	2249 ± 747	980 – 3100	Fiber	PP	(R. Li et al., 2020)
Singapore	Top 3 – 4 cm	Saline solution	37 ± 24	12 – 62	Fiber (76%)	PP, PVC, Nylon	(Mohamed Nor & Obbard, 2014)
Muara Angke River, Indonesia	Top 4 – 8 cm	NaCl + H_2O_2	28 ± 10	12 – 48	Foam	PS, PP, PE	(Cordova et al., 2021)
Maeklong 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	1687 ± 253	1020 - 2380	Fiber (86%)	PES	This study

Table 5 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 ± 86	25 – 363	Fiber	Rayon, PES	(Wang et al., 2020)
Eastern beach Gulf of Thailand	Top 5 cm		420 – 24,980 (max. >200,00)			(Bissen & Chawchai, 2020)
Western beach Gulf of Thailand	Top 5 cm		20 – 273 (max. 5741)	Plate (85%)		(Thepwilai et al., 2021)
Tapi-Phumduang River	Top 5 cm	79 ± 18	55 – 160	Fiber (70%)	Rayon	(Chinfak et al., 2021)
Bandon Bay	Top 5 cm	73 ± 17	15 – 135	Fiber (94%)	Rayon	(Chinfak et al., 2021)
Maeklong River	0 – 5 cm	580 ± 87	260 – 880	Fiber (73%)	PES	This study
Klong Khon tidal canal	0 – 5 cm	1687 ± 253	1020 – 2380	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 (Bissen & Chawchai, 2020; Thepwilai et al., 2021). 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 (Mohamed Nor & Obbard, 2014), Indonesia (Cordova et al., 2021), and China (R. Li et al., 2020) 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 (Bissen & Chawchai, 2020; Chinfak et al., 2021; Thepwilai et al., 2021). Whatever, all of microplastic size were found in digestive system and soft tissues of marine organism (Azad et al., 2018; Chinfak et al., 2021). 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 (Mohamed Nor & Obbard, 2014), Futian, and the Pearl River, China (R. Li et al., 2020; Zuo et al., 2020), the Gulf of Thailand (Wang et al., 2020), the Tapi-Phumduang River (Chinfak et al., 2021), and Bandon Bay (Chinfak et al., 2021) (Tables 4 and 5).While foam and plat microplastic was abundant in the Muara Angke River, Indonesia (Cordova et al., 2021), and the western part of the Gulf of Thailand (Thepwilai et al., 2021).

According to Tables 4 and 5, 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 (R. Li et al., 2020; Mohamed Nor & Obbard, 2014; Zuo et al., 2020). While rayon was the most abundant polymers along the Gulf of Thailand (Chinfak et al., 2021; Wang et al., 2020). Since the most plastic consumption in Thailand is packaging and fishery is the most prominent in Samut Songkhram Province, PE and PP were initially presumed to be the most dominant microplastics (Mohamed Nor & Obbard, 2014).

However, although the textile industry is unavailable in the study area, PES fiber is the most dominant microplastic in the study area (Figure 36). To increase reliability in a qualitative information in further research, determining more FTIR analysis sample may be shown the variety of polymer type 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 (Browne et al., 2011; Hernandez et al., 2017; Napper & Thompson, 2016). However, the synthetic fiber was possibly transported from other areas since it was discussed to contaminated shores on a global scale (Browne et al., 2011). Moreover, ropes and nets in aquaculture can release microplastic fragment and fiber into the environment (Montarsolo et al., 2018). The synthetic particle are ubiquitous and persistent in the food chain, allowing them to link to the health effect on the people in Samut Songkhram Province and the other part of Thailand.

5.5. Conclusion

To investigate the microplastic contamination in the coastal area of Samut Songkhram Province, we collected sediment samples from mangrove forests along the Maeklong River estuary (MK) and nearby the 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 Province 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.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The objectives of this research are (1) to investigate the contamination of microplastics in mangrove sediments at the Maeklong River mouth and (2) to identify polymer type of microplastics that is found in mangrove sediments at the Maeklong River mouth. Sediments were represented sediment deposition at that time, during the wet season and high water levels. Sediments including surface and core samples that were collected from mangrove ecosystem in the Maeklong River mouth area abundantly contaminated with microplastics. The number, shape, and polymer types of microplastics from surface sediment samples were identified. Accordingly, the conclusion of this study has been separated into two parts as follows:

6.1.1. Part I: Microplastics in surface sediment

The result showed that the average microplastic density in mangrove ecosystem in this study was higher than other countries in southeast Asia such as Singapore and Indonesia. The data from the Maeklong River cooperating with the data from Klong Khon tidal canal was analyzed together. The correlation between an average microplastics abundance and sediment grain size suggests an increasing grain size of sediment link to the lower number of plastic depositions. Because of the location of Klong Khon tidal canal that proper for fine sediment and also other particle, microplastics abundance in Klong Khon tidal canal was higher than the Maeklong River. FTIR analysis revealed that many polymer types of microplastics found in this area: PES, PC, PE, PP, and others. Polyester fiber was the most abundant microplastics in this study area.

6.1.2. Part II: Microplastics in core sediment

A 142-cm long sediment core from a mangrove area at the Queen Sirikit Park (CP1) revealed that sediment favorable accumulated with microplastics because at bottom depth of sediment core was still found microplastics. The trend

of the number of microplastics in core sediment assumed with the plastic production from past to nowadays tends to grow in the same direction. The microplastics abundance was significantly related to the grain size. There was a statistically significant difference in location between CP1 site and the Maeklong River mouth (S1) site. Many factors including location and grain size affected the microplastics accumulation in sediment. Microfiber was the most prevalent shape that found in core profile. According to microplastics accumulation in deep layer, this could be due to reason that (1) gathering with sediment from the past or (2) transporting by bioturbation process. In addition, microparticle that also polluted the environment found in the sediment sample such as tire rubber, pigment, flame retardant.

6.1.3. Overall situation

From the result of this study, microplastics abundance related to grain size of sediment as well as microplastics abundance had significant correlated to sediment size. Moreover, the location that is suitable for sediment accumulation is associated with transportation energy. Microplastics fibers, also known as microfibers, numerically dominate in this study. 73% of microplastics from the surface sample and 91% of microplastics from the core sample were fiber. The polymer type analysis demonstrated that polyester is the prevalent type of plastic. In addition, the dominant shape – fiber has belonged to polyester, rayon, nylon, and spandex which refer to the source of plastic generating microplastics in the environment such as the washing process.

6.2. Recommendation

6.2.1. Sample properties

FTIR analysis is limited by sample properties (thickness, transparency, coating, etc.). Especially, fiber shape was sometimes difficult to investigate under FTIR analysis due to small width part. Having a large number of samples allows researchers to repeat an experiment. The greater number of samples, the greater the precision of results will be.

6.2.2. Microfiber

Due to the fact that fiber was the most prevalent microplastics found in mangrove sediment, human activity such as washing process and aquaculture may be sources of contamination in the environment. Untreated sewage or sewage without proper treatment was discharged into rivers and coast thus government should be concerned about wastewater management. Micro-filtration and proper disposal may reduce the amount of unintentionally released microplastics into the environment.

REFERENCES

Aba, A., Uddin, S., Bahbahani, M., & Al-Ghadban, A. (2014). Radiometric dating of sediment records in Kuwait's marine area. *Journal of Radioanalytical and Nuclear Chemistry*, *301*(1), 247-255. https://doi.org/10.1007/s10967-014-3140-z

Abel, S. M., Primpke, S., Wu, F., Brandt, A., & Gerdts, G. (2022). Human footprints at hadal depths: interlayer and intralayer comparison of sediment cores from the Kuril Kamchatka trench. *Science of The Total Environment*, *838*, 156035. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.156035

Akdogan, Z., & Guven, B. (2019). Microplastics in the environment: A critical review of current understanding and identification of future research needs. *Environmental Pollution*, *254*, 113011. https://doi.org/https://doi.org/10.1016/j.envpol.2019.113011

Akkajit, P., Thongnonghin, S., Sriraksa, S., & Pumsri, S. (2019). Preliminary Study of Distribution and Quantity of Plastic-debris on Beaches Along the Coast at Phuket Province. *Applied Environmental Research*, 54-62. https://doi.org/10.35762/AER.2019.41.2.5

Ambrogi, V., Carfagna, C., Cerruti, P., & Marturano, V. (2017). 4 - Additives in Polymers. In C. F. Jasso-Gastinel & J. M. Kenny (Eds.), *Modification of Polymer Properties* (pp. 87-108). William Andrew Publishing. https://doi.org/https://doi.org/10.1016/B978-0-323-44353-1.00004-X

Apinanwattanakul, N. (2018). การเปลี่ยนแปลงของบรรจุภัณฑ์พลาสติกไทย กับโอกาสของผู้ผลิตไทยในกระแสการเติบโต. Economic Intelligence Centre (EIC). Retrieved 25 July 2022 from https://www.scbeic.com/th/detail/product/4905

Asadi, M., Ritonga, Y., Yona, D., & Hertika, A. (2019). Vertical Distribution of Microplastics in Coastal Sediments of Bama Resort, Baluran National Park, Indonesia. *Nature Environment and Pollution Technology*, *18*(4), 1169-1176.

Azad, S. M. O., Towatana, P., Pradit, S., Patricia, B. G., Hue, H. T. T., & Jualaong, S. (2018). First evidence of existence of microplastics in stomach of some commercial fishes in the lower Gulf of Thailand. *Applied Ecology and Environmental*

Research, *16*, 7345-7360. https://doi.org/10.15666/aeer/1606_73457360

Barboza, L. G. A., Lopes, C., Oliveira, P., Bessa, F., Otero, V., Henriques, B., Raimundo, J., Caetano, M., Vale, C., & Guilhermino, L. (2020). Microplastics in wild fish from North East Atlantic Ocean and its potential for causing neurotoxic effects, lipid oxidative damage, and human health risks associated with ingestion exposure. *Science of The Total Environment*, *717*, 134625. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.134625

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. A. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*, 1985 - 1998.

Beaumont, N., Aanesen, M., Austen, M., Börger, T., Clark, J., Cole, M., Hooper, T., Lindeque, P., Pascoe, C., & Wyles, K. (2019). Global ecological, social and economic impacts of marine plastic. *Marine Pollution Bulletin*, *142*. https://doi.org/10.1016/j.marpolbul.2019.03.022

Belivermiş, M., Kılıç, Ö., Sezer, N., Sıkdokur, E., Güngör, N. D., & Altuğ, G. (2021). Microplastic inventory in sediment profile: A case study of Golden Horn Estuary, Sea of Marmara. *Marine Pollution Bulletin*, *173*, 113117. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.113117

Bissen, R., & Chawchai, S. (2020). Microplastics on beaches along the eastern Gulf of Thailand – A preliminary study. *Marine Pollution Bulletin*, *157*, 111345. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111345

Brandon, J. A., Jones, W., & Ohman, M. D. (2019). Multidecadal increase in plastic particles in coastal ocean sediments. *Science Advances*, *5*(9), eaax0587. https://doi.org/doi:10.1126/sciadv.aax0587

Browne, M. A., Crump, P., Niven, S., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. *Environmental Science & Technology*, *45*, 9175-9179. https://doi.org/10.1021/es201811s

Browne, M. A., Dissanayake, A., Galloway, T. S., Lowe, D. M., & Thompson, R. C. (2008). Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel, Mytilus edulis (L.). *Environmental Science & Technology*, *42*(13), 5026-

5031. https://doi.org/10.1021/es800249a

Chaisanguansuk, P., Phantuwongraj, S., Jirapinyakul, A., & Assawincharoenkij, T. (2023). Preliminary study on microplastic abundance in mangrove sediment cores at Mae Klong River, upper Gulf of Thailand [Original Research]. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/fenvs.2023.1134988

Chaisanguansuk, P., Ploenbuppa, S., Assawincharoenkij, T., Phantuwongraj, S., & Jiraphinyakul, A. (2023). Microplastic Contamination in the Coastal Environment: A Case Study from the Mae Klong River, Samut Songkhram. *Applied Environmental Research*, *45*(2). https://doi.org/10.35762/AER.2023009

Chalmin, P. (2019). The history of plastics: from the Capitol to the Tarpeian Rock. *Field Actions Science Reports. The Journal of Field Actions.* , 6-11. http://journals.openedition.org/factsreports/5071

Chinfak, N., Sompongchaiyakul, P., Charoenpong, C., Shi, H., Yeemin, T., & Zhang, J. (2021). 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*, *781*, 146700. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.146700

Claessens, M., Meester, S. D., Landuyt, L. V., Clerck, K. D., & Janssen, C. R. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin*, *62*(10), 2199-2204. https://doi.org/https://doi.org/10.1016/j.marpolbul.2011.06.030

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*, *62*(12), 2588-2597. https://doi.org/https://doi.org/10.1016/j.marpolbul.2011.09.025

Colthup, N. B., Daly, L. H., & Wiberley, S. E. (1990). CHAPTER 1 - VIBRATIONAL AND ROTATIONAL SPECTRA. In N. B. Colthup, L. H. Daly, & S. E. Wiberley (Eds.), *Introduction to Infrared and Raman Spectroscopy (Third Edition)* (pp. 1-73). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-08-091740-5.50004-1

Coppock, R. L., Cole, M., Lindeque, P. K., Queirós, A. M., & Galloway, T. S. (2017). A

small-scale, portable method for extracting microplastics from marine sediments. *Environmental Pollution*, *230*, 829-837. https://doi.org/https://doi.org/10.1016/j.envpol.2017.07.017

Cordova, M., Ulumuddin, Y., & Purbonegoro, T. (2021). Characterization of microplastics in mangrove sediment of Muara Angke Wildlife Reserve, Indonesia. *Marine Pollution Bulletin*, *163*. https://doi.org/10.1016/j.marpolbul.2021.112012

Courtene-Jones, W., Quinn, B., Ewins, C., Gary, S. F., & Narayanaswamy, B. E. (2020). Microplastic accumulation in deep-sea sediments from the Rockall Trough. *Marine Pollution Bulletin*, *154*, 111092. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111092

Crawford, C. B., & Quinn, B. (2017). 5 - Microplastics, standardisation and spatial distribution. In C. B. Crawford & B. Quinn (Eds.), *Microplastic Pollutants* (pp. 101-130). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809406-8.00005-0

Das, G. K. (2016). Sediment Grain Size. In M. J. Kennish (Ed.), *Encyclopedia of Estuaries* (pp. 555-558). Springer Netherlands. https://doi.org/10.1007/978-94-017-8801-4_148

De Falco, F., Di Pace, E., Cocca, M., & Avella, M. (2019). The contribution of washing processes of synthetic clothes to microplastic pollution. *Scientific Reports*, *9*(1), 6633. https://doi.org/10.1038/s41598-019-43023-x

De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., & Robbens, J. (2014). Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. *Marine Pollution Bulletin*, *85*(1), 146-155. https://doi.org/https://doi.org/10.1016/j.marpolbul.2014.06.006

Deng, H., He, J., Feng, D., Zhao, Y., Sun, W., Yu, H., & Ge, C. (2021). Microplastics pollution in mangrove ecosystems: A critical review of current knowledge and future directions. *Science of The Total Environment*, *753*, 142041. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.142041

Deng, J., Guo, P., Zhang, X., Su, H., Zhang, Y., Wu, Y., & Li, Y. (2020). Microplastics and accumulated heavy metals in restored mangrove wetland surface sediments at Jinjiang Estuary (Fujian, China). *Marine Pollution Bulletin*, *159*, 111482.

https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111482

Deng, Y., Zhang, Y., Lemos, B., & Ren, H. (2017). Tissue accumulation of microplastics in mice and biomarker responses suggest widespread health risks of exposure. *Scientific Reports*, *7*(1), 46687. https://doi.org/10.1038/srep46687

Department of Marine and Coastal Resources. (2018). *Information on marine and coastal resources in Samut Songkhram Province*. Information and Surveying Technology for Marine and Coastal Resources Division. Retrieved 3 March from www.dmcr.go.th/detailLib/3763

Department of Marine and Coastal Resources. (2020). *Marine and coastal resources map of Samut Songkhram Province* https://bigdata.dmcr.go.th/download-map?1=MQ%3D%3D&page=2

Department of Provincial Administration. (2018). Registration statistics. https://stat.bora.dopa.go.th/stat/statnew/statyear/#/

Ding, J., Sun, C., He, C., Li, J., Ju, P., & Li, F. (2021). Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. *Science of The Total Environment*, *782*, 146830. https://doi.org/10.1016/j.scitotenv.2021.146830

Dong, M., Luo, Z., Jiang, Q., Xing, X., Zhang, Q., & Sun, Y. (2020). The rapid increases in microplastics in urban lake sediments. *Scientific Reports*, *10*(1), 848. https://doi.org/10.1038/s41598-020-57933-8

Dong, S., Yu, Z., Huang, J., & Gao, B. (2022). Chapter 9 - Fate and transport of microplastics in soils and groundwater. In B. Gao (Ed.), *Emerging Contaminants in Soil and Groundwater Systems* (pp. 301-329). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-824088-5.00001-X

Duan, J., Han, J., Zhou, H., Lau, Y. L., An, W., Wei, P., Cheung, S. G., Yang, Y., & Tam, N. F.-y. (2020). Development of a digestion method for determining microplastic pollution in vegetal-rich clayey mangrove sediments. *Science of The Total Environment*, *707*, 136030. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.136030

Enders, K., Käppler, A., Biniasch, O., Feldens, P., Stollberg, N., Lange, X., Fischer, D., Eichhorn, K.-J., Pollehne, F., Oberbeckmann, S., & Labrenz, M. (2019). Tracing

microplastics in aquatic environments based on sediment analogies. *Scientific Reports*, *9*(1), 15207. https://doi.org/10.1038/s41598-019-50508-2

Fan, Y., Zheng, K., Zhu, Z., Chen, G., & Peng, X. (2019). Distribution, sedimentary record, and persistence of microplastics in the Pearl River catchment, China. *Environmental Pollution*, *251*, 862-870. https://doi.org/https://doi.org/10.1016/j.envpol.2019.05.056

Frias, J. P. G. L., & Nash, R. (2019). Microplastics: Finding a consensus on the definition. *Marine Pollution Bulletin*, *138*, 145-147. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.11.022

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., Nadal, A., & Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. *Environmental Sciences Europe*, *30*(1), 13-13. https://doi.org/10.1186/s12302-018-0139-z

Geyer, R., Jambeck, J., & Law, K. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*, e1700782. https://doi.org/10.1126/sciadv.1700782

Gilbert, M. (2017). Chapter 1 - Plastics Materials: Introduction and Historical Development. In M. Gilbert (Ed.), *Brydson's Plastics Materials (Eighth Edition)* (pp. 1-18). Butterworth-Heinemann. https://doi.org/https://doi.org/10.1016/B978-0-323-35824-8.00001-3

Graca, B., Szewc, K., Zakrzewska, D., Dołęga, A., & Szczerbowska-Boruchowska, M. (2017). Sources and fate of microplastics in marine and beach sediments of the Southern Baltic Sea—a preliminary study. *Environmental Science and Pollution Research*, *24*(8), 7650-7661. https://doi.org/10.1007/s11356-017-8419-5

Guangdong Statistics Bureau. (2018). Guangdong Statistical Yearbook. http://stats.gd.gov.cn/gdtjnj/index.html

Guo, Z., Li, P., Yang, X., Wang, Z., Lu, B., Chen, W., Wu, Y., Li, G., Zhao, Z., Liu, G., Ritsema, C., Geissen, V., & Xue, S. (2022). Soil texture is an important factor determining how microplastics affect soil hydraulic characteristics. *Environment International*, *165*, 107293. https://doi.org/https://doi.org/10.1016/j.envint.2022.107293

Hamid, B. S. F., Jia, W., & Zakaria, R. B. M. (2020). Microplastics Abundance and Uptake by Meretrix lyrata (Hard Clam) in Mangrove Forest. *Journal of Engineering and Technological Sciences*, *52*, 436-448.

Hamid, F., Shahul;, Bhatti, M., Anuar, N., Anuar, N., Mohan, P., & Periathamby, A. (2018). Worldwide distribution and abundance of microplastic: How dire is the situation? *Waste Management & Research*, *36*, 0734242X1878573. https://doi.org/10.1177/0734242X18785730

Harris, P. T. (2020). The fate of microplastic in marine sedimentary environments: A review and synthesis. *Marine Pollution Bulletin*, *158*, 111398. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111398

Hastuti, A. Y. U., Lumbanbatu, D. T. F., & Wardiatno, Y. (2019). The presence of microplastics in the digestive tract of commercial fishes off Pantai Indah Kapuk coast, Jakarta, Indonesia. *Biodiversitas*, *20*, 1233-1242. https://doi.org/10.13057/biodiv/d200513

Heiri, O., Lotter, A. F., & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*, *25*(1), 101-110. https://doi.org/10.1023/A:1008119611481

Heo, N., Hong, S., Han, G., Hong, S., Lee, J., Song, Y., Jang, M., & Shim, W. (2013). Distribution of small plastic debris in cross-section and high strandline on Heungnam beach, South Korea. *Ocean Science Journal*, *48*. https://doi.org/10.1007/s12601-013-0019-9

Hernandez, E., Nowack, B., & Mitrano, D. M. (2017). Polyester Textiles as a Source of Microplastics from Households: A Mechanistic Study to Understand Microfiber Release During Washing. *Environmental Science & Technology*, *51*(12), 7036-7046. https://doi.org/10.1021/acs.est.7b01750

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environmental Science & Technology*, *46*(6), 3060-3075. https://doi.org/10.1021/es2031505

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics

in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of The Total Environment*, *586*, 127-141. https://doi.org/https://doi.org/10.1016/j.scitotenv.2017.01.190

Idrus, F., Fadhi, N., & Harith, M. (2022). Occurrence of Microplastics in the Asian Freshwater Environments: A Review. *Applied Environmental Research*, 1-17. https://doi.org/10.35762/AER.2022.44.2.1

Jambeck Jenna, R., Geyer, R., Wilcox, C., Siegler Theodore, R., Perryman, M., Andrady, A., Narayan, R., & Law Kara, L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-771. https://doi.org/10.1126/science.1260352

Jiwarungrueangkul, T., Phaksopa, J., Sompongchaiyakul, P., & Tipmanee, D. (2021). Seasonal microplastic variations in estuarine sediments from urban canal on the west coast of Thailand: A case study in Phuket province. *Marine Pollution Bulletin*, *168*, 112452. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.112452

Kanhai, L. D. K., Gardfeldt, K., Krumpen, T., Thompson, R. C., & O'Connor, I. (2020). Microplastics in sea ice and seawater beneath ice floes from the Arctic Ocean. *Scientific Reports*, *10*(1), 5004. https://doi.org/10.1038/s41598-020-61948-6

Kelly, A., Lannuzel, D., Rodemann, T., Meiners, K. M., & Auman, H. (2020). Microplastic contamination in east Antarctic sea ice. *Marine Pollution Bulletin*, *154*, 111130. https://doi.org/10.1016/j.marpolbul.2020.111130

Khalil, A., Rittima, A., & Phankamolsil, Y. (2018). Seasonal and Annual Trends of Rainfall and Streamflow in the Mae Klong Basin, Thailand. *Applied Environmental Research*, *40*(3), 77-90. https://doi.org/10.35762/AER.2018.40.3.8

Klangnurak, W., & Chunniyom, S. (2020). Screening for microplastics in marine fish of Thailand: the accumulation of microplastics in the gastrointestinal tract of different foraging preferences. *Environmental Science and Pollution Research*, *27*(21), 27161-27168. https://doi.org/10.1007/s11356-020-09147-8

Koehler, A., Anderson, A., Andrady, A., Arthur, C., Baker, J., Bouwman, H., Gall, S., Hidalgo-Ruz, V., Koehler, A., Law, K., Leslie, H., Kershaw, P., Pahl, S., Potemra, J., Ryan, P., Shim, W., Thompson, R., Takada, H., Turra, A., & Wyles, K. (2015).

SOURCES, FATE AND EFFECTS OF MICROPLASTICS IN THE MARINE ENVIRONMENT: A GLOBAL ASSESSMENT. https://doi.org/10.13140/RG.2.1.3803.7925

Kole, P. J., Löhr, A. J., Van Belleghem, F., & Ragas, A. M. J. (2017). Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. *Int J Environ Res Public Health*, *14*(10). https://doi.org/10.3390/ijerph14101265

Kukkola, A. T., Senior, G., Maes, T., Silburn, B., Bakir, A., Kröger, S., & Mayes, A. G. (2022). A large-scale study of microplastic abundance in sediment cores from the UK continental shelf and slope. *Marine Pollution Bulletin*, *178*, 113554. https://doi.org/https://doi.org/10.1016/j.marpolbul.2022.113554

Land Development Department. (2019). *Land use of Smaut Songkhram Province*. http://www1.ldd.go.th/web_OLP/Lu_62/Lu62_C/SKM2562.htm

Land Development Department. (2021). *Agri-Map Samut Songkhram*. https://www.ldd.go.th/Agri-Map/Data/C/skm.pdf

Li, J., Huang, W., Xu, Y., Jin, A., Zhang, D., & Zhang, C. (2020). Microplastics in sediment cores as indicators of temporal trends in microplastic pollution in Andong salt marsh, Hangzhou Bay, China. *Regional Studies in Marine Science*, *35*, 101149. https://doi.org/https://doi.org/10.1016/j.rsma.2020.101149

Li, J., Song, Y., & Cai, Y. (2020). Focus topics on microplastics in soil: Analytical methods, occurrence, transport, and ecological risks. *Environmental Pollution*, *257*, 113570. https://doi.org/https://doi.org/10.1016/j.envpol.2019.113570

Li, R., Yu, L., Chai, M., Wu, H., & Zhu, X. (2020). The distribution, characteristics and ecological risks of microplastics in the mangroves of Southern China. *Science of The Total Environment*, *708*, 135025. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.135025

Li, Y., Lu, Z., Zheng, H.-Y., Wang, J., & Chen, C. (2020). Microplastics in surface water and sediments of Chongming Island in the Yangtze Estuary, China. *Environmental Sciences Europe*, *32*. https://doi.org/10.1186/s12302-020-0297-7

Lithner, D., Larsson, Å., & Dave, G. (2011). Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Science of The Total Environment*, *409*(18), 3309-3324. https://doi.org/https://doi.org/10.1016/j.scitotenv.2011.04.038

Lo, H. S., Xu, X., Wong, C.-Y., & Cheung, S. G. (2018). Comparisons of microplastic pollution between mudflats and sandy beaches in Hong Kong. *Environmental pollution (Barking, Essex : 1987)*, *236*, 208-217. https://doi.org/10.1016/j.envpol.2018.01.031

Loasby, G. (1951). THE DEVELOPMENT OF THE SYNTHETIC FIBRES. *Journal of the Textile Institute Proceedings*, *42*(8), P411-P441. https://doi.org/10.1080/19447015108663852

Luu Viet, D., Huu Duc, T., Linh, L., Ly, T., Duong, H., & Hao, N. (2021). Depth Profiles of Microplastics in Sediment Cores from Two Mangrove Forests in Northern Vietnam. *Journal of Marine Science and Engineering*, *9*, 1381. https://doi.org/10.3390/jmse9121381

Marine and Coastal Resources Research and Development Center The Upper Gulf of Thailand. (2019). *Plastic waste in the river mouth, the Upper Gulf of Thailand*. Retrieved 25 october from https://www.dmcr.go.th/detailLib/4547

Marine and Coastal Resources Research and Development Institute and Burapha University. (2014). *Investigatation and indentification of marine waste - microplastic* [Full report]. https://www.dmcr.go.th/detailLib/3095

Marks, D., Miller, M., & Vassanadumrongdee, S. (2020). The geopolitical economy of Thailand's marine plastic pollution crisis. *Asia Pacific Viewpoint*, *61*, 266-282. https://doi.org/10.1111/apv.12255

Martin, C., Almahasheer, H., & Duarte, C. M. (2019). Mangrove forests as traps for marine litter. *Environmental Pollution*, *247*, 499-508. https://doi.org/https://doi.org/10.1016/j.envpol.2019.01.067

Martin, C., Baalkhuyur, Valluzzi, Saderne, V., Cusack, M., Almahasheer, H., Krishnakumar, P., Rabaoui, L., Qurban, M., Arias-Ortiz, A., Masqué, P., & Duarte, C. (2020). Exponential increase of plastic burial in mangrove sediments as a major plastic sink. *Science Advances*, *6*, 5593. https://doi.org/10.1126/sciadv.aaz5593

Matsuguma, Y., Takada, H., Kumata, H., Kanke, H., Sakurai, S., Suzuki, T., Itoh, M., Okazaki, Y., Boonyathumanond, R., Zakaria, M., Weerts, S., & Newman, B. (2017). Microplastics in Sediment Cores from Asia and Africa as Indicators of Temporal Trends in Plastic Pollution. *Archives of environmental contamination and*

toxicology, *73*. https://doi.org/10.1007/s00244-017-0414-9

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, *7*(18), eaaz5803. https://doi.org/doi:10.1126/sciadv.aaz5803

Mendes, A., Golden, N., Bermejo, R., & Morrison, L. (2021). Distribution and abundance of microplastics in coastal sediments depends on grain size and distance from sources. *Marine Pollution Bulletin*, *172*, 112802. https://doi.org/10.1016/j.marpolbul.2021.112802

Mohamed Nor, N. H., Kooi, M., Diepens, N. J., & Koelmans, A. A. (2021). Lifetime Accumulation of Microplastic in Children and Adults. *Environmental Science & Technology*, *55*(8), 5084-5096. https://doi.org/10.1021/acs.est.0c07384

Mohamed Nor, N. H., & Obbard, J. P. (2014). Microplastics in Singapore's coastal mangrove ecosystems. *Marine Pollution Bulletin*, *79*(1), 278-283. https://doi.org/https://doi.org/10.1016/j.marpolbul.2013.11.025

Montarsolo, A., Mossotti, R., Patrucco, A., Caringella, R., Zoccola, M., Pozzo, P. D., & Tonin, C. (2018). Study on the microplastics release from fishing nets. *The European Physical Journal Plus*, *133*(11), 494. https://doi.org/10.1140/epjp/i2018-12415-1

Näkki, P., Setälä, O., & Lehtiniemi, M. (2017). Bioturbation transports secondary microplastics to deeper layers in soft marine sediments of the northern Baltic Sea. *Marine Pollution Bulletin*, *119*(1), 255-261. https://doi.org/https://doi.org/10.1016/j.marpolbul.2017.03.065

Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*, *112*(1), 39-45. https://doi.org/https://doi.org/10.1016/j.marpolbul.2016.09.025

Ng, K. L., & Obbard, J. P. (2006). Prevalence of microplastics in Singapore's coastal marine environment. *Marine Pollution Bulletin*, *52*(7), 761-767. https://doi.org/https://doi.org/10.1016/j.marpolbul.2005.11.017

Nichols, G. (2009). *Sedimentology and Stratigraphy* (2nd ed.). Wiley-Blackwell.

Office of the National Water Resources. (2021). *22 basins in Thailand*. Retrieved 21 March 2022 from http://www.onwr.go.th/?p=10637

Paruta, P., Pucino, M., & Boucher, J. (2022). *Plastic Paints the Environment*. EA-Environmental Action.

Peebua, P., Kruatrachue, M., Pokethitiyook, P., & Kosiyachinda, P. (2006). Histological Effects of Contaminated Sediments in Mae Klong River Tributaries, Thailand, on Nile tilapia, Oreochromis niloticus. *ScienceAsia*, *32*. https://doi.org/10.2306/scienceasia1513-1874.2006.32.143

Peeken, I., Primpke, S., Beyer, B., Gütermann, J., Katlein, C., Krumpen, T., Bergmann, M., & Gerdts, G. (2018). Arctic sea ice is an important temporal sink and means of transport for microplastic. *Nature Communications*, *9*. https://doi.org/10.1038/s41467-018-03825-5

Peng, X., Chen, M., Chen, S., Dasgupta, S., Xu, H., Ta, K., Du, M., Li, J., Guo, Z., & Bai, S. (2018). Microplastics contaminate the deepest part of the world's ocean. *Geochemical Perspectives Letters*, *9*, 1-5. https://doi.org/10.7185/geochemlet.1829

Pengthamkeerati, P., Kornkanitnan, N., Sawangarreruks, S., Wanichacheva, N., Wainiphithapong, C., & Sananwai, N. (2013). Assessment of heavy metals in sediments of the Don Hoi Lot area in the Mae Klong estuary, Thailand. *J Environ Sci Health A Tox Hazard Subst Environ Eng*, *48*(11), 1356-1364. https://doi.org/10.1080/10934529.2013.781881

PlasticEurope. (2021). *Plastics – theFacts 2021*. https://plasticseurope.org/wp-content/uploads/2021/12/Plastics-the-Facts-2021-web-final.pdf

Ploenbuppa, S. (2021). *Contamination of microplastics in clayey mangrove sediments at Khlong Khon tidal channel, Mueang Samut Songkhram District, Samut Songkhram Province* [Senior Project, Chulalongkorn University].

Pollution Control Department. (2019). *Booklet on Thailand State of Pollution 2018*. S.Mongkon Press Limited Partnership. Retrieved 3 March from https://www.pcd.go.th/publication/3657

Pradit, S., Noppradit, P., Loh, P.-S., Nitiratsuwan, T., Le, T. P., Oeurng, C., Mohamed, C. A., Lee, C. W., Lu, X., Anshari, G. Z., Kandasamy, S., & Wang, J. (2022). The

Occurrence of Microplastics in Sediment Cores from Two Mangrove Areas in Southern Thailand. *Journal of Marine Science and Engineering*, *10*(3). https://doi.org/10.3390/jmse10030418

Pradit, S., Puttapreecha, R., Noppradit, P., Buranaprateprat, A., & Sompongchaiyakul, P. (2022). The first evidence of microplastic presence in pumice stone along the coast of Thailand: A preliminary study [Brief Research Report]. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.961729

Prata, J. C., Silva, A. L. P., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2020). COVID-19 Pandemic Repercussions on the Use and Management of Plastics. *Environmental Science & Technology*, *54*(13), 7760-7765. https://doi.org/10.1021/acs.est.0c02178

Pumijumnong, N. (2014). Mangrove Forests in Thailand. In I. Faridah-Hanum, A. Latiff, K. R. Hakeem, & M. Ozturk (Eds.), *Mangrove Ecosystems of Asia: Status, Challenges and Management Strategies* (pp. 61-79). Springer New York. https://doi.org/10.1007/978-1-4614-8582-7_4

Punwong, P., Sritrairat, S., Selby, K., Marchant, R., Pumijumnong, N., & Traiperm, P. (2018). An 800 year record of mangrove dynamics and human activities in the upper Gulf of Thailand. *Vegetation History and Archaeobotany*, *27*(4), 535-549. https://doi.org/10.1007/s00334-017-0651-x

Puthcharoen, A., & Leungprasert, S. (2019). Determination of microplastics in soil and leachate from the Landfills. *Thai Environmental Engineering Journa*, *33*(3), 39-46.

Qiao, S., Shi, X., Fang, X., Liu, S., Kornkanitnan, N., Gao, J., Zhu, A., Hu, L., & Yu, Y. (2015). Heavy metal and clay mineral analyses in the sediments of Upper Gulf of Thailand and their implications on sedimentary provenance and dispersion pattern. *Journal of Asian Earth Sciences*, *114*. https://doi.org/10.1016/j.jseaes.2015.04.043

Ritchie, H., & Roser, M. (2018). *Plastic Pollution*. Retrieved 25 July 2022 from https://ourworldindata.org/plastic-pollution

Rodrigues, M., Gonçalves, A., Gonçalves, F., & Abrantes, N. (2020). Improving cost-efficiency for MPs density separation by zinc chloride reuse. *MethodsX*, *7*,

100785. https://doi.org/10.1016/j.mex.2020.100785

Šaravanja, A., Pušić, T., & Dekanić, T. (2022). Microplastics in Wastewater by Washing Polyester Fabrics. *Materials (Basel)*, *15*(7). https://doi.org/10.3390/ma15072683

Semeniuk, V. (2005). Tidal Flats. In M. L. Schwartz (Ed.), *Encyclopedia of Coastal Science* (pp. 965-975). Springer Netherlands. https://doi.org/10.1007/1-4020-3880-1_317

Sinsakul, S. (2000). Late Quaternary geology of the Lower Central Plain, Thailand. *Journal of Asian Earth Sciences*, *18*(4), 415-426. https://doi.org/https://doi.org/10.1016/S1367-9120(99)00075-9

Sun, Y., Xiong, H., Lee, M.-T., Brodie, C., & Zong, Y. (2021). Geochemical dynamics and depositional history from mangrove sediments within the Pearl River estuary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *584*, 110701. https://doi.org/https://doi.org/10.1016/j.palaeo.2021.110701

Suphat, V. (2007). Impacts of Typhoon Vae and Linda on wind waves in the Upper Gulf of Thailand and East Coast. *Songklanakarin Journal of Science and Technology*, *29*.

Ta, A., Babel, S., & Haarstrick, A. (2020). Microplastics Contamination in a High Population Density Area of the Chao Phraya River, Bangkok. *Journal of Engineering and Technological Sciences*, *52*, 534-545. https://doi.org/10.5614/j.eng.technol.sci.2020.52.4.6

Tanabe, S., Saito, Y., Sato, Y., Suzuki, Y., Sinsakul, S., Tiyapairach, S., & Chaimanee, N. (2003). Stratigraphy and Holocene evolution of the mud-dominated Chao Phraya delta, Thailand. *Quaternary Science Reviews*, *22*(8), 789-807. https://doi.org/https://doi.org/10.1016/S0277-3791(02)00242-1

Teuten, E. L., Saquing, J. M., Knappe, D. R., Barlaz, M. A., Jonsson, S., Björn, A., Rowland, S. J., Thompson, R. C., Galloway, T. S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P. H., Tana, T. S., Prudente, M., Boonyatumanond, R., Zakaria, M. P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., & Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philos Trans R Soc Lond B Biol Sci*, *364*(1526), 2027-2045. https://doi.org/10.1098/rstb.2008.0284

Thailand Meteorological department. (2015). *The climate of Thailand 2015*. Retrieved 3 March from https://www.tmd.go.th/en/archive/thailand_climate.pdf

Thailand Meteorological department. (2020). ภูมิอากาศจังหวัดสมุทรสงคราม. http://climate.tmd.go.th/data/province/กลาง/ภูมิอากาศสมุทรสงคราม.pdf

Thepwilai, S., Wangritthikraikul, K., Chawchai, S., & Bissen, R. (2021). Testing the factors controlling the numbers of microplastics on beaches along the western Gulf of Thailand. *Marine Pollution Bulletin*, *168*, 112467. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.112467

Thevenon, F., Carroll, C., & Sousa, J. (2014). *Plastic Debris in the Ocean. The Characterization of Marine Plastics and their Environmental Impacts, Situation Analysis Report* Plastic Debris in the Ocean). IUCN. https://portals.iucn.org/library/sites/library/files/documents/2014-067.pdf

Thiramongkol, N. (1984). Geomorphology of the lower central plain, Thailand. *Proceedings of the 3rd Meeting of Working Group on Geomorphology of Rivers and Coastal Plain*, 103-117. (Dept of Geology, Chulalongkorn University, Bangkok.)

Thompson, R., Olsen, Y., Mitchell, R., Davis, A., Rowland, S., John, A., McGonigle, D. F., & Russell, A. (2004). Lost at Sea: Where Is All the Plastic? *Science (New York, N.Y.)*, *304*, 838. https://doi.org/10.1126/science.1094559

Tomlinson, D. L., Wilson, J. G., Harris, C. R., & Jeffrey, D. W. (1980). Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen*, *33*(1), 566-575. https://doi.org/10.1007/BF02414780

Turner, S., Horton, A. A., Rose, N. L., & Hall, C. (2019). A temporal sediment record of microplastics in an urban lake, London, UK. *Journal of Paleolimnology*, *61*(4), 449-462. https://doi.org/10.1007/s10933-019-00071-7

Uddin, S., Fowler, S. W., Uddin, M. F., Behbehani, M., & Naji, A. (2021). A review of microplastic distribution in sediment profiles. *Marine Pollution Bulletin*, *163*, 111973. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.111973

Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M. B., & Janssen, C. R. (2015). Microplastics are taken up by mussels (Mytilus edulis) and lugworms (Arenicola

marina) living in natural habitats. *Environmental Pollution*, *199*, 10-17. https://doi.org/https://doi.org/10.1016/j.envpol.2015.01.008

Van Cauwenberghe, L., Vanreusel, A., Mees, J., & Janssen, C. R. (2013). Microplastic pollution in deep-sea sediments. *Environmental Pollution*, *182*, 495-499. https://doi.org/https://doi.org/10.1016/j.envpol.2013.08.013

Vassilenko, E., Watkins, M. J., Chastain, S., Mertens, J., Posacka, A., Patankar, S., & Ross, P. (2021). Domestic laundry and microfiber pollution: Exploring fiber shedding from consumer apparel textiles. *PloS one*, *16*, e0250346. https://doi.org/10.1371/journal.pone.0250346

Wagner, S., Hüffer, T., Klöckner, P., Wehrhahn, M., Hofmann, T., & Reemtsma, T. (2018). Tire wear particles in the aquatic environment - A review on generation, analysis, occurrence, fate and effects. *Water Research*, *139*, 83-100. https://doi.org/https://doi.org/10.1016/j.watres.2018.03.051

Wang, Y., Zou, X., Peng, C., Qiao, S., Wang, T., Yu, W., Khokiattiwong, S., & Kornkanitnan, N. (2020). Occurrence and distribution of microplastics in surface sediments from the Gulf of Thailand. *Marine Pollution Bulletin*, *152*, 110916. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.110916

Webb, H. K., Arnott, J., Crawford, R. J., & Ivanova, E. P. (2013). Plastic Degradation and Its Environmental Implications with Special Reference to Poly(ethylene terephthalate). *Polymers*, *5*(1). https://doi.org/10.3390/polym5010001

Wentworth, C. K. (1922). A Scale of Grade and Class Terms for Clastic Sediments. *The Journal of Geology*, *30*(5), 377-392. http://www.jstor.org/stable/30063207

Willis, K. A., Eriksen, R., Wilcox, C., & Hardesty, B. D. (2017). Microplastic Distribution at Different Sediment Depths in an Urban Estuary [Original Research]. *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00419

Worakhunpiset, S. (2018). Trace Elements in Marine Sediment and Organisms in the Gulf of Thailand. *Int J Environ Res Public Health*, *15*(4). https://doi.org/10.3390/ijerph15040810

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. *Environmental Pollution*, *178*, 483-492. https://doi.org/https://doi.org/10.1016/j.envpol.2013.02.031

Yang, L., Kang, S., Wang, Z., Luo, X., Guo, J., Gao, T., Chen, P., Yang, C., & Zhang, Y. (2022). Microplastic characteristic in the soil across the Tibetan Plateau. *Science of The Total Environment*, *828*, 154518. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.154518

Yu, H., Zhang, Y., Tan, W., & Zhang, Z. (2022). Microplastics as an Emerging Environmental Pollutant in Agricultural Soils: Effects on Ecosystems and Human Health [Review]. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.855292

Zhang, C., Zhou, H., Cui, Y., Wang, C., Li, Y., & Zhang, D. (2019). Microplastics in offshore sediment in the Yellow Sea and East China Sea, China. *Environmental Pollution*, *244*, 827-833. https://doi.org/https://doi.org/10.1016/j.envpol.2018.10.102

Zhang, K., Shi, H., Peng, J., Wang, Y., Xiong, X., Wu, C., & Lam, P. K. S. (2018). Microplastic pollution in China's inland water systems: A review of findings, methods, characteristics, effects, and management. *Science of The Total Environment*, *630*, 1641-1653. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.02.300

Zhang, S., Sun, Y., Liu, B., & Li, R. (2021). Full size microplastics in crab and fish collected from the mangrove wetland of Beibu Gulf: Evidences from Raman Tweezers (1–20 μm) and spectroscopy (20–5000 μm). *Science of The Total Environment*, *759*, 143504. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.143504

Zheng, Y., Li, J., Cao, W., Jiang, F., Zhao, C., Ding, H., Wang, M., Gao, F., & Sun, C. (2020). Vertical distribution of microplastics in bay sediment reflecting effects of sedimentation dynamics and anthropogenic activities. *Marine Pollution Bulletin*, *152*, 110885. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.110885

Zuo, L., Sun, Y., Li, H., Hu, Y., Lin, L., Peng, J., & Xu, X. (2020). Microplastics in mangrove sediments of the Pearl River Estuary, South China: Correlation with halogenated flame retardants' levels. *Science of The Total Environment*, *725*, 138344. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.138344

APPENDICES

APPENDIX A - LOCATIONS

Table 6 Surface locations of MK and KK

Surface sample name	Latitude	Longitude	UTM (WGS) 47P	
			X	Y
MK-1	13.37820818	100.03681085	612266	1479196
MK-2	13.36758057	100.00424313	608744	1478006
MK-3	13.38097933	99.98825811	607007	1479481
KK-1	13.32672400	99.97608100	605712	1473475
KK-2	13.34140300	99.95117300	603008	1475088
KK-3	13.34908900	99.93859000	601642	1475933

Table 7 Core locations of MK1 and S1

Core sample name	Latitude	Longitude	UTM (WGS)	
			X	Y
MK1	13.37820818	100.03681085	612266	1479196
S1	13.36337900	100.01618400	610039	1477546

APPENDIX B - STRATIGRAPHIC COLUMN

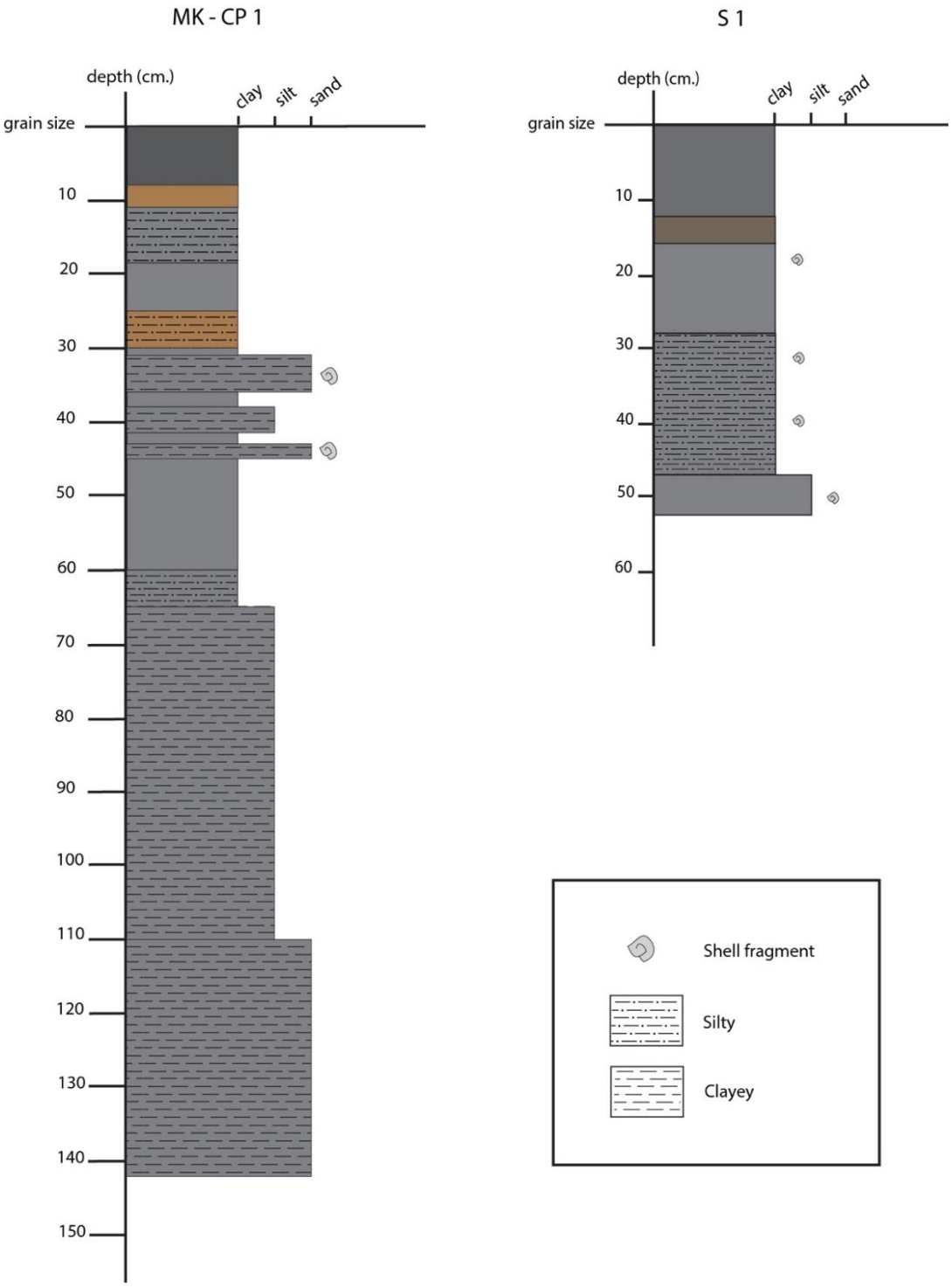

Figure 38 Stratigraphic column of CP1 and S1

APPENDIX C - LOSS ON IGNITION

Table 8 Loss on ignition data of CP1

Sample No.	Depth (cm) below the surface	DW_{105}	DW_{550}	LOI_{550}
#1	1-2	23.079	23.028	8.600
#3	3-4	23.587	23.549	7.379
#5	5-6	22.547	22.464	7.764
#7	7-8	25.595	25.534	8.379
#9	9-10	23.447	23.395	11.207
#11	11-12	24.912	24.847	7.956
#13	13-14	23.036	22.980	6.804
#15	15-16	26.148	26.091	8.028
#17	17-18	25.996	25.930	15.172
#19	19-20	23.836	23.784	7.750
#21	21-22	23.949	23.903	8.156
#23	23-24	26.149	26.087	6.710
#25	25-26	23.235	23.168	7.605
#27	27-28	22.494	22.434	8.487
#29	29-30	26.563	26.485	11.001
#31	31-32	25.160	25.095	6.385
#33	33-34	23.880	23.826	5.299
#35	35-36	25.576	25.548	4.000
#37	37-38	22.595	22.528	8.365
#39	39-40	22.908	22.847	7.722
#41	41-42	26.132	26.068	6.830
#43	43-44	24.735	24.684	6.050
#45	45-46	23.820	23.770	4.608
#47	47-48	24.124	24.069	5.506
#49	49-50	24.562	24.513	5.568
#51	51-52	24.757	24.701	4.188

Sample No.	Depth (cm) below the surface	DW_{105}	DW_{550}	LOI_{550}
#53	53-54	24.177	24.123	5.643
#55	55-56	26.343	26.277	4.922
#57	57-58	23.629	23.577	5.113
#59	59-60	25.889	25.836	5.730
#61	61-62	25.301	25.235	5.651
#63	63-64	24.412	24.341	5.487
#65	65-66	22.989	22.929	5.484
#67	67-68	27.573	27.502	4.890
#69	69-70	24.196	24.144	4.896
#71	71-72	24.851	24.792	4.731
#73	73-74	26.065	26.009	5.157
#75	75-76	24.358	24.296	5.586
#77	77-78	26.519	26.453	5.419
#79	79-80	26.762	26.689	5.892
#81	81-82	24.060	24.011	4.702
#83	83-84	24.419	24.364	4.493
#85	85-86	25.130	25.071	5.700
#87	87-88	26.128	26.063	4.844
#89	89-90	24.143	24.094	4.871
#91	91-92	24.226	24.171	5.102
#93	93-94	26.855	26.802	4.281
#95	95-96	24.696	24.647	4.712
#97	97-98	25.831	25.776	4.850
#99	99-100	25.311	25.229	6.231
#101	101-102	26.196	26.133	4.532
#103	103-104	26.880	26.800	5.118
#105	105-106	24.591	24.513	5.536
#107	107-108	24.655	24.574	4.784
#109	109-110	25.384	25.299	3.763

Sample No.	Depth (cm) below the surface	DW_{105}	DW_{550}	LOI_{550}
#111	111-112	25.183	25.136	2.605
#113	113-114	26.263	26.174	4.064
#115	115-116	25.715	25.639	3.600
#117	117-118	26.182	26.108	3.826
#119	119-120	27.146	27.055	3.417
#121	121-122	25.638	25.554	4.183
#123	123-124	25.074	25.016	3.176
#125	125-126	27.501	27.413	4.814
#127	127-128	26.634	26.563	4.356
#129	129-130	24.992	24.909	4.474
#131	131-132	25.223	25.135	4.883
#133	133-134	25.498	25.402	4.066
#135	135-136	26.435	26.337	4.197
#137	137-138	27.334	27.238	5.418
#139	139-140	24.071	23.986	3.926

Table 9 Loss on ignition data of S1

Sample No.	Depth (cm) below the surface	DW_{105}	DW_{550}	LOI_{550}
#2	1-2	25.470	25.408	7.990
#4	3-4	22.736	22.653	6.598
#6	5-6	24.633	24.542	6.449
#8	7-8	22.661	22.605	6.385
#10	9-10	23.304	23.248	8.421
#12	11-12	23.040	22.990	7.657
#14	13-14	22.411	22.347	8.926
#16	15-16	24.617	24.530	7.067
#18	17-18	23.908	23.832	7.623

Sample No.	Depth (cm) below the surface	DW_{105}	DW_{550}	LOI_{550}
#20	19-20	25.657	25.528	7.057
#22	21-22	27.271	27.176	6.700
#24	23-24	23.582	23.488	7.402
#26	25-26	25.169	25.048	7.620
#28	27-28	27.101	26.999	7.424
#30	29-30	24.005	23.935	5.410
#32	31-32	25.416	25.326	6.267
#34	33-34	23.514	23.428	7.783
#36	35-36	23.531	23.472	7.421
#38	37-38	26.191	26.098	6.638
#40	39-40	23.280	23.186	11.520
#42	41-42	24.219	24.122	7.835
#44	43-44	26.457	26.379	7.558
#46	45-46	24.063	23.996	7.478
#48	47-48	23.860	23.757	18.934
#50	49-50	23.392	23.312	7.707
#52	51-52	25.421	25.330	7.132

APPENDIX D - GRAIN SIZE DISTRIBUTION DATA

Table 10 Grain size distribution data of surface sediment sample

Area	Station	grain size (μm)	result	Clay (%)	Silt (%)	Sand (%)
Mae klong	MK-1	84.8	very fine sand	11.8	48.66	39.53
	MK-2	82.3	very fine sand	12.86	50.82	36.3
	MK-3	76	very fine sand	16.39	46.96	36.63
Klong Khon	KK-1	86.7	very fine sand	14.17	41.88	43.95
	KK-2	72.6	very fine sand	17.51	47.92	34.61
	KK-3	72.1	very fine sand	16.73	49.07	34.2

Table 11 Grain size distribution data of CP1 core

Sample No.	Depth (cm) below the surface	grain size (μm)	result	Clay (%)	Silt (%)	Sand (%)
#1	5	84.8	very fine sand	11.8	48.66	39.53
#2	10	82.3	very fine sand	12.86	50.82	36.3
#3	15	76	very fine sand	16.39	46.96	36.63
#4	20	86.7	very fine sand	14.17	41.88	43.95
#5	25	72.6	very fine sand	17.51	47.92	34.61
#6	30	72.1	very fine sand	16.73	49.07	34.2
#7	31	87.9	very fine sand	14.34	42.18	43.48
#8	33	166	fine sand	4.83	19.29	75.88
#9	35	128	fine sand	10.8	32.68	56.54
#10	37	99.7	very fine sand	12.56	37.26	50.19
#11	40	73	very fine sand	19.73	43.35	36.91
#12	42	133	fine sand	16.75	39.13	44.13
#13	45	38.9	very coarse silt	20.87	60.17	18.95

Sample No.	Depth (cm) below the surface	grain size (μm)	result	Clay (%)	Silt (%)	Sand (%)
#14	50	47.6	very coarse silt	18.12	58.02	23.86
#15	55	38.7	very coarse silt	20.2	57.67	22.11
#16	60	53.8	very coarse silt	17.15	55.48	27.33
#17	63	60.6	very coarse silt	14.52	58.06	27.4
#18	65	49.3	very coarse silt	16.88	59.33	23.82
#19	70	50.1	very coarse silt	16.99	59.07	23.99
#20	80	68.1	very fine sand	19.21	48.89	31.91
#21	90	81.5	very fine sand	14.07	46.2	39.73
#22	100	95.4	very fine sand	16.14	37.5	46.34
#23	110	106	very fine sand	15.86	30.13	53.99
#24	115	106	very fine sand	15.43	30.25	54.31
#25	120	121	very fine sand	11.48	26.96	61.57
#26	125	127	very fine sand	10.59	25.24	64.17
#27	130	90.5	very fine sand	14.92	36.36	48.74
#28	135	133	fine sand	10.08	23.96	65.97
#29	140	101	very fine sand	12.95	30.83	56.22

Table 12 Grain size distribution data of S1 core

Sample No.	Depth (cm) below the surface	grain size (μm)	result	Clay (%)	Silt (%)	Sand (%)
#1	5	21.4	coarse silt	23.86	69.36	6.77
#2	10	38.8	very coarse silt	16.2	65	18.78
#3	15	35.9	very coarse silt	17.65	65.15	17.18
#4	20	43.3	very coarse silt	21.42	56	22.57

Sample No.	Depth (cm) below the surface	grain size (μm)	result	Clay (%)	Silt (%)	Sand (%)
#5	25	65.7	very fine sand	16.91	42.82	40.25
#6	30	33.2	very coarse silt	16.76	69.37	13.88
#7	31	34.8	very coarse silt	17.57	66.43	16.01
#8	33	32.1	very coarse silt	16.96	70.16	12.87
#9	35	42.5	very coarse silt	22.87	55.47	21.68
#10	37	38.2	very coarse silt	22.99	59.41	17.57

APPENDIX E - MICROPLASTIC DISTRIBUTION DATA

E.1. Microplastic distribution of sediment sample

Table 13 Microplastic distribution of surface sediment

Area	Station	Abundance (items)	Abundance (items/kg. dry wt.)	Average (items/kg. dry wt.)
Maeklong	MK1	13	260	473.33
	MK1	39	780	
	MK1	19	380	
	MK2	31	620	466.67
	MK2	25	500	
	MK2	14	280	
	MK3	42	840	800.00
	MK3	44	880	
	MK3	34	680	
Klong Khon	KK1	90	1800	1933.33
	KK1	96	1920	
	KK1	113	2260	
	KK2	119	2380	1826.67
	KK2	90	1800	
	KK2	65	1300	
	KK3	62	1240	1240.00
	KK3	51	1020	
	KK3	73	1460	

Table 14 Microplastic distribution of core sediment

Depth (cm) below the surface	Station CP1		Station S1	
	Abundance (items)	Abundance (items/kg. dry wt.)	Abundance (items)	Abundance (items/kg. dry wt.)
1	16	3200	4	800
2	10	2000	4	800
3	17	3400	1	200
4	11	2200	3	600
5	4	800	2	400
6	6	1200	1	200
7	10	2000	-	-
8	10	2000	3	600
9	3	600	3	600
10	6	1200	3	600
11	10	2000	4	800
12	18	3600	1	200
13	26	5200	1	200
14	10	2000	3	600
15	5	1000	4	800
16	6	1200	1	200
17	12	2400	2	400
18	4	800	1	200
19	5	1000	3	600
20	12	2400	3	600
21	6	1200	1	200
22	6	1200	7	1400
23	5	1000	-	-
24	5	1000	1	200
25	5	1000	2	400
26	7	1400	2	400
27	6	1200	-	-

Depth (cm) below the surface	Station CP1		Station S1	
	Abundance (items)	Abundance (items/kg. dry wt.)	Abundance (items)	Abundance (items/kg. dry wt.)
28	8	1600	3	600
29	8	1600	1	200
30	4	800	5	1000
31	11	2200	-	-
32	6	1200	2	400
33	6	1200	3	600
34	4	800	5	1000
35	7	1400	1	200
36	2	400	2	400
37	7	1400	1	200
38	6	1200	2	400
39	7	1400	5	1000
40	3	600	4	800
41	6	1200	-	-
42	4	800	2	400
43	3	600	-	-
44	4	800	1	200
45	6	1200	1	200
46	7	1400	2	400
47	2	400	5	1000
48	6	1200	1	200
49	4	800	1	200
50	6	1200	1	200
51	5	1000	1	200
52	4	800	-	-
53	3	600		
54	2	400		
55	4	800		

Depth (cm) below the surface	Station CP1		Station S1	
	Abundance (items)	Abundance (items/kg. dry wt.)	Abundance (items)	Abundance (items/kg. dry wt.)
56	7	1400		
57	7	1400		
58	8	1600		
59	8	1600		
60	10	2000		
61	9	1800		
62	5	1000		
63	3	600		
64	11	2200		
65	4	800		
66	8	1600		
67	6	1200		
68	6	1200		
69	3	600		
70	3	600		
71	6	1200		
72	4	800		
73	5	1000		
74	4	800		
75	6	1200		
76	3	600		
77	10	2000		
78	8	1600		
79	5	1000		
80	4	800		
81	5	1000		
82	6	1200		
83	4	800		

Depth (cm) below the surface	Station CP1		Station S1	
	Abundance (items)	Abundance (items/kg. dry wt.)	Abundance (items)	Abundance (items/kg. dry wt.)
84	5	1000		
85	14	2800		
86	6	1200		
87	4	800		
88	4	800		
89	8	1600		
90	6	1200		
91	3	600		
92	1	200		
93	3	600		
94	3	600		
95	2	400		
96	1	200		
97	2	400		
98	3	600		
99	3	600		
100	4	800		
101	3	600		
102	-	-		
103	-	-		
104	2	400		
105	4	800		
106	-	-		
107	2	400		
108	8	1600		
109	8	1600		
110	4	800		
111	3	600		

Depth (cm) below the surface	Station CP1		Station S1	
	Abundance (items)	Abundance (items/kg. dry wt.)	Abundance (items)	Abundance (items/kg. dry wt.)
112	5	1000		
113	2	400		
114	5	1000		
115	2	400		
116	3	600		
117	5	1000		
118	10	2000		
119	6	1200		
120	6	1200		
121	2	400		
122	14	2800		
123	6	1200		
124	5	1000		
125	3	600		
126	2	400		
127	2	400		
128	1	200		
129	1	200		
130	1	200		
131	2	400		
132	3	600		
133	1	200		
134	4	800		
135	1	200		
136	6	1200		
137	2	400		
138	1	200		
139	1	200		

Depth (cm) below the surface	Station CP1		Station S1	
	Abundance (items)	Abundance (items/kg. dry wt.)	Abundance (items)	Abundance (items/kg. dry wt.)
140	4	800		
141	7	1400		
142	4	800		
mean	5.37	1074.48	2.13	426.92

E.2. Microplastic distribution sort by size

Table 15 Microplastic distribution of surface sediment

Area	Station	<0.1 mm	0.1-1.0 mm	1.0-5.0 mm
Maeklong	MK1	-	8	6
	MK1	-	22	17
	MK1	-	9	10
	MK2	-	16	15
	MK2	-	11	15
	MK2	-	8	5
	MK3	-	18	28
	MK3	-	18	29
	MK3	-	12	22
Klong Khon	KK1	-	62	28
	KK1	2	67	32
	KK1	-	82	31
	KK2	-	89	30
	KK2	-	64	26
	KK2	-	48	17
	KK3	-	36	27
	KK3	-	39	13
	KK3	-	53	23

Table 16 Microplastic distribution of core sediment

Area	Station	<0.1 mm	0.1-1.0 mm	1.0-5.0 mm
Maeklong	CP1	-	292	485
	S1	-	49	60

E.3. Microplastic distribution sort by shape and color

Table 17 Microplastic distribution of Maeklong surface sediment sort by shape and color

No.	Shape	Color	Station MK1			Station MK2			Station MK3			Sum
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
1	fiber	black	5	11	7	11	11	2	16	14	12	89
2	fiber	transparent	-	4	5	2	2	4	4	13	7	41
3	fiber	green	2	3	1	1	-	-	5	6	2	20
4	fiber	clear green	-	3	2	-	2	2	1	3	2	15
5	fiber	red	-	3	-	-	1	-	2	1	1	8
6	fiber	clear red	-	-	-	-	-	1	3	1	-	5
7	fiber	opaque white	-	-	-	-	-	-	-	1	4	5
8	fiber	white	1	-	-	2	-	-	1	-	-	4
9	fiber	purple	-	-	-	1	1	-	-	-	-	2
10	fiber	clear orange	-	-	-	-	1	1	-	-	-	2
11	fragment	black	1	11	-	8	1	-	-	1	-	22
12	fragment	transparent	1	3	1	-	-	2	1	1	2	11
13	fragment	white	-	-	-	2	-	-	1	1	-	4
14	fragment	opaque white	-	-	1	1	-	-	2	-	1	5
15	fragment	clear orange	-	-	-	-	-	1	3	-	1	5
16	fragment	clear green	-	-	1	-	-	1	-	-	1	3

No.	Shape	Color	Station MK1			Station MK2			Station MK3			Sum
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
17	fragment	brown	-	-	-	-	-	-	1	-	-	1
19	stick	white	-	-	-	-	-	-	1	1	-	2
20	stick	opaque white	-	-	-	-	-	-	1	-	-	1
21	stick	clear red	-	-	-	-	-	-	-	-	1	1
22	stick	black	-	1	-	-	-	-	-	-	-	1
23	plate	transparent	3	-	1	-	1	-	-	-	-	5
24	plate	opaque white	-	-	-	-	2	-	-	-	-	2
25	plate	white	-	-	-	3	2	-	-	1	-	6
26	plate	clear orange	-	-	-	-	1	-	-	-	-	1
	sum	11	13	39	19	31	25	14	42	44	34	261

Table 18 Microplastic distribution of Klong Khon surface sediment sort by shape and color

No.	Shape	Color	Station KK1			Station KK2			Station KK3			Sum
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
1	fiber	transparent	50	45	58	39	37	20	27	24	25	325
2	fiber	purple	12	16	16	28	19	6	12	10	22	141
3	fiber	clear purple	5	7	8	2	1	3	3	2	6	37
4	fiber	blue	3	6	12	9	-	3	4	-	1	38
5	fiber	clear blue	7	3	2	10	6	2	5	2	2	39
6	fiber	red	1	3	3	3	1	-	3	-	-	14
7	fiber	clear red	2	1	6	4	4	1	4	-	-	22
8	fiber	green	-	-	1	1	4	-	-	2	1	9
9	plate	white	4	7	1	4	2	2	2	6	2	30

No.	Shape	Color	Station KK1			Station KK2			Station KK3			Sum
			1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
10	plate	green	-	1	-	1	1	1	-	1	1	6
11	plate	red	2	4	2	-	-	-	-	2	-	10
12	stick	red	2	3	3	-	5	1	1	2	3	20
13	stick	white	2	-	-	-	-	-	1	-	1	4
14	foam	white	-	-	-	11	8	13	-	-	-	32
	sum	10	90	96	112	112	88	52	62	51	64	727

Table 19 Microplastic distribution of core sediment sort by shape and color

No.	Shape	Color	Station CP1	Station S1
1	fiber	black	305	48
2	fiber	transparent	296	14
3	fiber	brown	13	1
4	fiber	green	85	8
5	fiber	red	20	9
6	fiber	purple	11	-
7	fiber	opaque white	3	2
8	fiber	blue	-	1
9	fiber	white	4	4
10	fragment	black	3	-
11	fragment	transparent	15	5
12	fragment	brown	2	-
13	fragment	green	2	-
14	fragment	red	3	1
15	fragment	white	13	8
16	fragment	blue	-	1
17	stick	transparent	-	4
18	stick	brown	1	-

No.	Shape	Color	Station CP1	Station S1
19	stick	black	1	-
20	plate	transparent	-	1
21	plate	white	-	2
		sum	777	109

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