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Distribution of Microplastics along Mai Khao Coastline, Phuket

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Highlights:

- Microplastics were found in beach sediments with an average abundance of 154.7 ± 44 items kg^{-1}.
- White color (44.94%) and fiber shape (95%) were dominant characteristics.
- Polyethylene terephthalate (94.7%) was the most abundant plastic type.

Abstract. The distribution of microplastics at Mai Khao beach, Phuket, Thailand was studied. A total of 12 samples from four sample sites with 0.5 m x 0.5 m quadrats were taken at the intertidal zone during March and July, 2020, and sorted into two size classes (>300 µm and 20 to 300 µm). The mean abundance of microplastics at Mai Khao beach ranged from 44.08 to 68.7 items kg^{-1} d.w. for >300 µm and from 90.6 to 106.1 items kg^{-1} d.w. for the 20 to 300 µm range. White (44.94%) and blue (23.60%) colors, and fiber shape (94.5%) were dominant in particle counts; and based on µFTIR analysis the dominant polymer type was polyethylene terephthalate (94.7% by number count), with considerable fractions of cotton and cellophane. The microplastic characteristics suggest anthropogenic activities as possible sources. Notably, the abundance of microplastic found in the study area was definitely higher than at other sites investigated along the west coast or Phuket. Significant differences in the abundances of the two microplastic size classes were observed ($p < 0.05$), indicating that the microplastics in Mai Khao beach can accumulate in the marine food chain and transfer up along the trophic levels. Therefore, urgent attention should be given to the contamination problem, with a proper management system and a public awareness campaign, to reduce the effects of microplastic on organisms and ecosystems.

Keywords: *beach sediment; Mai Khao; microplastics; plastic waste; Phuket.*

1 Introduction

Plastics are purposefully manufactured for various target applications, such as personal care products, electronics, or food and beverage packaging, etc. The contamination of the marine environment by plastic is a major environmental concern and has recently been the subject of an increasing number of studies [1-

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3]. Microplastics are small pieces of plastic less than five millimeters in diameter, coming from a variety of sources, including larger plastic debris that degrades into smaller and smaller pieces [4]. When microplastics are introduced into the coastal environment, they can be transported over long distances, and they are now considered a serious hazard to the marine environment [5]. The transfer of microplastics to aquatic organisms and their impact on marine organisms has been widely reported [6-9].

Phuket is the largest island in Thailand, located on the west coast of southern peninsular Thailand, and is known as a tourism hub with more than 13 million visitors annually [10] in normal pre-Covid times. Phuket has the most beautiful beaches, certified by many international awards [11], therefore tourism has been one of the mainstays of the local economy, giving Phuket its solid reputation as a vacation destination. Most beaches on the west coast of Phuket are used mainly for harbor activities, while on the east coast there are popular locations for tourist activities with hotels, resorts, restaurants, and shopping centers. Mai Khao beach is located on the northwest coast of Phuket and is considered a highly productive zone with rich biodiversity that includes mole crabs and seagrasses. Mai Khao is located very close to Phuket International Airport and is part of Sirinat National Park. It is clean and natural, and is one of the few Phuket beaches where nesting sea turtles can be found using it as a breeding ground [12]. Recent studies have reported on the occurrence and distribution of microplastics in beach sediments in Phuket [5,13,14] but still little is known about the distribution of microplastics along the Mai Khao coastline. Much of the plastics used in the tourism industry contribute to plastic waste, especially in coastal areas. The large emissions of plastic debris from tourist activities along the Mai Khao coastline can cause environmental degradation, especially in the marine environment. The problem of plastic waste (or any waste in Phuket) needs to be addressed for sustainable tourism, which is the main local source of income.

Therefore, the aim of this study was to determine the distribution of microplastics in beach sediment from the Mai Khao coastline, to provide preliminary data that can be used in formulating management strategies for reducing the impact of microplastics on the marine environment, and secondarily on human health through seafood consumption. Understanding the abundance and size of microplastics in a coastal sea area is a key aspect of their spatial distribution. In this study, microplastics in two size ranges, 20 to 300 μm and above 300 μm in size, were studied, as these size fractions are similar to the sizes of mesoplankton and microplankton that are important organisms in the marine food chain [15]. The present study reports, for the first time, microplastics in beach sediment samples from the Mai Khao coastline, in Phuket Province. Then, the potential routes for bioaccumulation of microplastics through trophic transfer can be identified, and the impact of bioaccumulation on the coastal ecosystem as a whole can be further assessed.

2 Methodology

2.1 Study Area

Phuket is located in the Andaman Sea and is globally known as a holiday destination. Tourism is the major local source of income and is crucially important to the local economy [11]. Mai Khao is the longest stretch of sandy beach on the northwest coast of Phuket, being over 11 km long. A map of Mai Khao and the sampling stations is shown in Figure 1. Beach sediment samples were collected from four locations, 2.5 km apart and labeled as M1 (8.185843º N, 98.288460º E), M2 (8.160862º N, 98.294388º E), M3 (8.160862º N, 98.294388º E), and M4 (8.111573º N, 98.301735º E). These were selected to represent the coastline of Mai Khao. M1 is located almost at the northernmost point of Phuket, which has a steep slope at the shore and is not suitable for swimming activities. M2 and M3 are open areas without residences, but with a 5-star hotel located nearby M3. M4, or the airplane view point, is located right at Phuket International Airport and is a very popular location for tourists to take pictures of planes landing and taking off.

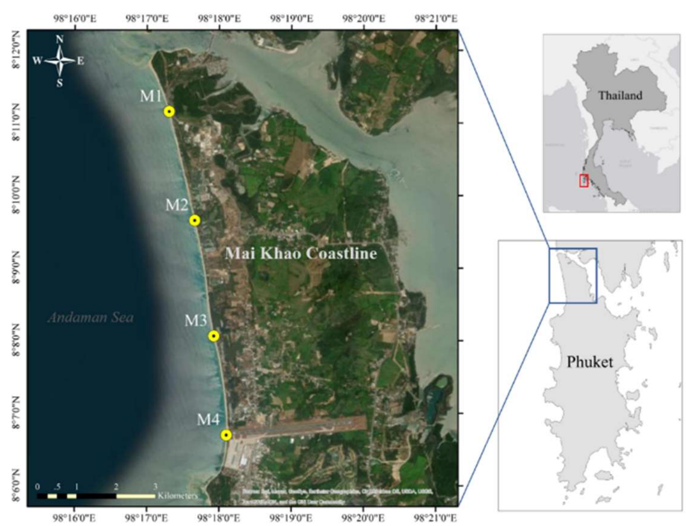


Figure 1 Map of the sampling sites.

2.2 Sampling Method

In this study, beach sediment samples were collected during March (dry season) and July (rainy season) of 2020 at low tide. The beach sediment samples were taken from the intertidal zone and three replicate sediment samples were taken at each site. A 50 cm × 50 cm square frame was placed within the established area and the sediment was taken from within the top 5 cm of the surface with a metal spoon. Approximately three kilograms of beach sediment was taken and pooled together from each station and then immediately shipped back to the laboratory. In the laboratory, the beach sediment samples were oven-dried at 60 ºC to complete dryness before further analysis [4-5].

2.3 Microplastic Analysis

Four hundred grams by dry weight (d.w.) of sediment from each sampling site was mixed with 300 mL of a concentrated salt solution NaCl (~300 g L^{-1}) for density separation. The mixture was shaken for 3 min and allowed to settle for 2 hours. After settling, the supernatant was filtered using two nets with mesh sizes of 300 µm and 20 µm, using a Rocker 300C oil-free vacuum pump. The extraction and digestion of microplastics from the beach sediments were adopted from NOAA [4] with modifications. Wet peroxide oxidation was performed with 20 mL of aqueous 0.05 M Fe(II) solution ($SO_4 \cdot 7H_2O$) in a beaker containing microplastic debris with 20 mL of 30% hydrogen peroxide (H_2O_2) at room temperature for five minutes. The process was continued on a hot plate at 75 °C; an additional aliquot of 20 ml hydrogen peroxide was added when remaining organic matter was evident. Then the solution was filtered through a glass microfiber filter (GF/C Whatman, 47 mm diameter; 1.2 µm porosity) and the particles retained on the filter were subjected to color and shape analysis.

After filtration, suspected microplastics on the filter paper were identified and quantified under a stereomicroscope (HumaScope Stereo Trinocular 110-250V/50-60Hz). All microplastics were counted and categorized by shape into fibers, fragments, spheres, and film; and by color (red, green, yellow, blue, black, and white) visually under a stereomicroscope. A Micro Fourier Transform Infrared Spectrometer (µFT-IR) (Jasco FT/IR-6600) was used in this study for the characterization of the polymer types of suspected microplastics, by spectrum measurement in the range from 4000 to 600 cm^{-1}. In the statistical analysis, the differences in quantities of microplastics at different sampling stations, also by microplastic size range, were assessed using t-test and one-way analysis of variance (ANOVA) ($p \leq 0.05$) by SPSS software (24.0). For quality control, all laboratory equipment and glassware were rinsed with double distilled water several times and covered with aluminum foil prior to laboratory analysis. Cotton lab coats and gloves were worn at all times during analysis, and blank control with deionized water samples was used for correction of potential procedural contamination.

3 Results and Discussion

3.1 Abundances of Microplastics in Beach Sediment at Mai Khao Beach

The quantity and distribution of microplastics (in two size ranges, 20 to 300 μm and >300 μm) found in sediment samples from Mai Khao beach are given in Table 1. Based on the results of all sampling stations and all sampling periods, microplastics were found in beach sediments from every sampling site (n = 793 items), from 20 to 73 items of the >300 μm microplastic, and from 29 to 99 of the 20 to 300 μm microplastic. The highest mean microplastic numbers were observed at S1 (n = 249 items) and S4 stations (n = 235 items). The mean abundance of microplastic ranged from 44.08 to 68.7 items kg^{-1} d.w. for >300 μm and from 90.6 to 106.1 items kg^{-1} d.w. for the 20 to 300 μm size range. The two size ranges of microplastic showed significant differences in the amounts of microplastic ($p < 0.05$), with the greater amount in numbers for the smaller microplastic. It is known that microplastic ingestion by organisms depends on their abundance and particle size [16]. High abundances of the smaller microplastic size class indicate the opportunity of microplastic accumulation in the marine food chain and transfer up along the trophic levels due to this size range being similar to the sizes of mesoplankton and microplankton, which are important organisms in the food chain. The digestion of microplastic mixed in zooplankton occurs because microplastic and zooplankton are of similar dimensions [17]. The small microplastic fraction is significant and potentially available to a wide range of organisms via ingestion, with potential for adverse effects if present in higher concentrations [18].

In this study, no variation in microplastic abundance was observed between the different seasons ($p < 0.05$) (n = 408 and 385 items for T1 and T2, respectively). Season and rainfall may play important roles in the variation of microplastic abundance and in the offloading of plastics from land-based sources into the sea. However, tourism activities on the beach during the dry season can also increase the abundance of marine debris; in this case no significant difference in microplastic abundance was observed. The results of this study are consistent with [19], which found no seasonal variability in marine debris in Manado Bay, Indonesia. However, the quantity and distribution of microplastic in beach sediment were attributed to different land uses and anthropogenic activities. Microplastic abundance was notably higher on the beaches at S1 and S4, which are used for tourist activities, such as a resting area for tourists with street food trucks, and the airplane viewpoint. The sources of microplastic in this study may include land-based input of water discharges through sewer pipes observed at S4, and some may be returned to the beach through intertidal effects. In addition, the tidal ocean currents and winds can contribute greatly to the migration, distribution and concentration of microplastics in the ocean, with deposition affected by intertidal effects.

Table 1 Quantity (item count) and abundance (items kg^{-1} d.w.) of microplastics.

Season	Station	>300-µm microplastics		20-300-µm microplastics	
		Quantity (items)	**Abundance (items kg^{-1} d.w.)**	**Quantity (items)**	**Abundance (items kg^{-1} d.w.)**
T1 (Dry season)	M1	73 ± 6.4	113.9	63 ± 7.55	98.3
	M2	36 ± 8.5	56.2	29 ± 3.51	45.6
	M3	24 ± 1.0	37.5	70 ± 10.02	109.2
	M4	43 ± 4.2	67.1	70 ± 4.51	109.2
Total numbers of MPs		**n = 408 items**			
T2 (Rainy season)	M1	30 ± 2.6	46.8	83 ± 12.42	129.5
	M2	20 ± 2.5	31.2	40 ± 8.62	62.4
	M3	40 ± 5.5	62.4	50 ± 2.52	78.0
	M4	23 ± 4.0	35.9	99 ± 20.7	154.5
Total numbers of MPs		**n = 385 items**			

Notably, the microplastic abundance in beach sediments found in this study area was definitely higher than at other sites investigated previously along the west coast of Phuket [5,13]. Akkajit, *et al.* [5] found microplastic at the most popular beaches of Patong, Kalim, and Tri Trang, ranging from 22.8 to 82.2 items kg^{-1} d.w. for >300 µm and from 22.9 to 69.7 items kg^{-1} d.w. for the size range of 20 to 300 µm. This may be because those popular beaches on the West coast of Phuket have good waste management practices, including beach clean-up campaigns, that the local administrative office must follow in order to keep a good image for international tourism. In addition, the influence of high waves, rip tides and very strong currents at Mai Khao beach may cause the flushing of plastic debris back to the beach through intertidal effects, increasing the microplastic abundance relative to other beaches on the west coast of Phuket. In comparison, microplastic in beach sediments from other parts of Thailand had higher concentrations than in the current study. For example, the microplastic abundance in beach sediments along the eastern Gulf of Thailand, at Chonburi, Rayong, Chanthaburi and Trat provinces, ranged within 420 to 200,000 items kg^{-1} d.w. [19]; while microplastics at Suchada, Saeng Chan and Laem Charoen beaches in the Rayong province, Eastern Thailand were at 568.33 ± 153.05 items kg^{-1} d.w. [20]; and at 150.4 ± 86.2 items kg^{-1} d.w. in the Gulf of Thailand [21].

3.2 Characteristics of Microplastics

3.2.1 Color of Microplastics

For microplastic debris management along the coastal area, characteristics such as color, shape, and polymer type of microplastics are also important for identifying microplastic sources, their distribution patterns, and the potential for marine ingestion. In this study, color classification of microplastics in the Mai Khao beach included white, black, yellow, blue, red, and green as the categories, as illustrated in Figure 2. According to the results, the rank orders for the two microplastic size ranges in this study are: white (44.94%) > blue (23.60%) > black (14.61%) > yellow (10.11%) > red (6.37%) > green (0.37%). White items contributed almost half of all the detected plastic particles; white has been reported as the most common color of microplastics in marine environments, which may be caused by the discoloration of microplastics during weathering and exposure to sunlight [22,23]. Blue plastics can be from fishing lines and fishing nets used by local people at Mai Khao beach. The results of this study are consistent with the previous study of Akkajit, *et al.* [5,13], who showed white/transparent as the most common microplastics color in the coastline of Phuket.

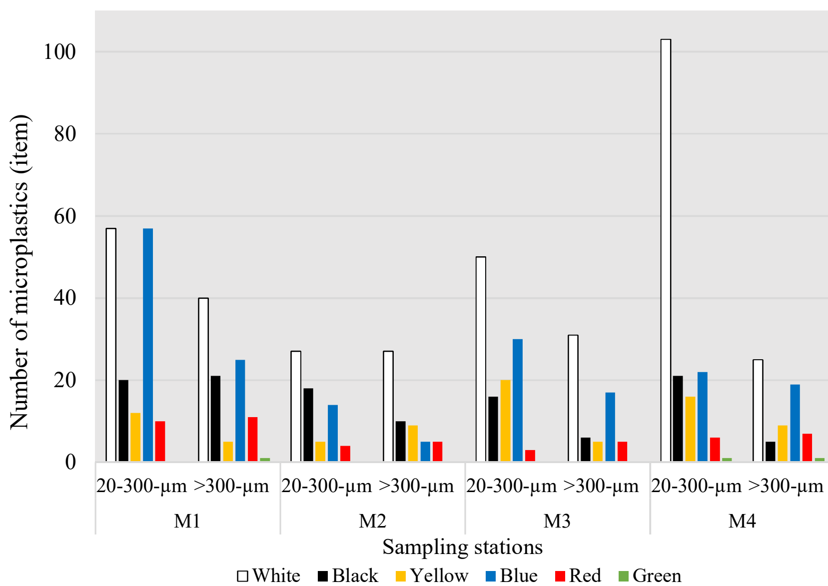


Figure 2 Color distributions by counts of microplastics.

3.2.2 Shapes of Microplastics

Differences in microplastic shape may affect the dispersion of microplastic to different compartments of the aquatic environment. All particles identified as microplastic in this study were assessed for their shapes. The four categories by shape of microplastic from the Mai Khao coastline were: fiber, fragment, film, and sphere (Figure 3).

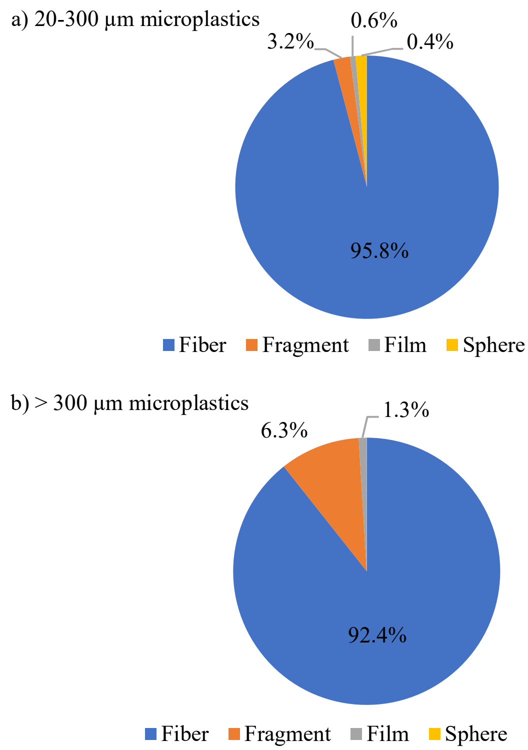


Figure 3 Shape distributions of microplastics.

The results showed that fibers significantly dominated among the identified microplastic types at the four sample sites (M1-M4) for both microplastics size ranges (95.83% and 92.38% for 20 to 300 µm and >300, respectively). The results on microplastic contamination in this region were consistent with previous studies, which have shown a large proportion of fibrous microplastics at the west and east coasts of Phuket, attributed to the washing of synthetic clothing, pieces of rope, broken safeguard lines, and all fishing materials [5,13].

Figure 4 shows microscopic photos as examples of the detected microplastic particles. On the Mai Khao coastline, microplastic fibers found in the beach sediments are directly linked to effluent from washing clothing, from safeguard lines, fishing lines, or from sewer pipes. Large numbers of synthetic fibers were also observed in prior studies, for example in beach sediment from the Gulf of Thailand [19, 21], from the Andaman Sea [24], in Da Nang beach, Vietnam [25], the coastal areas of Lamongan regency, Indonesia [26], and in beach sediments from selected coastal sites in Virginia and North Carolina, USA [27].

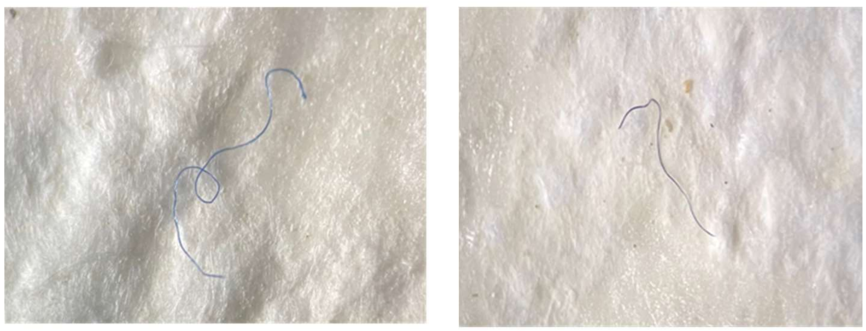


Figure 4 Microsgraphs of fibrous microplastic samples.

3.2.3 Polymer Type Microplastics

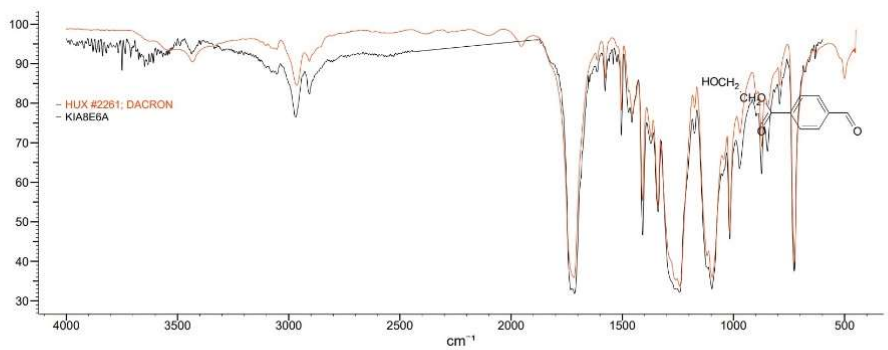
The identification of polymer type microplastics was based on µFTIR with the spectral database used by the Bio-Rad Spectroscopy Software. Visually detected plastic-like particles in the samples were selected randomly (n = 68 items), and the FTIR confirmed 53% of them as microplastics (Table 2). In total, three polymer types from the µFTIR analysis were identified, namely polyethylene terephthalate (PET), polyamide (PA), and polyether urethane (PU) (Table 2). According to the results, PET constituted the majority among the polymer types in this study, at 94.7% (n = 36), followed by PA (n = 1) and PU (n = 1). These observed three polymers are widely used for many different applications. For example, PET is a thermoplastic polymer that is commonly used in packaging applications and electronic devices [22,28-29]. PET is a material widely used to manufacture many different products that are prevalent in tourism related activities, like water bottles, drink bottles, and microwave packaging. PU in its turn is used in the manufacture of high-resilience foam seating, and is commonly used as cushioning in a variety of consumer and commercial products, such as foam insulation panels, spray foam, in surface coatings and sealants, and in hard plastic parts for electronic instruments [30]; and PA, commonly known as nylon, is widely used in application segments such as electronic applications, packaging applications, fishing lines, toothbrush bristles, or tubing [31].

Table 2 μFTIR analysis of the detected microplastic particles.

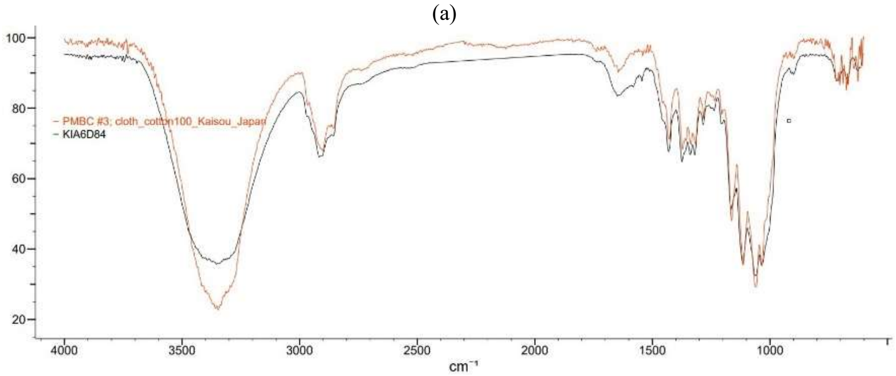
Polymer types	items	%
Plastic:		
Polyethylene terephthalate (PET)	36	94.74
Polyamide (PA)	1	2.63
Polyether Urethane (PU)	1	2.63

The large portion of non-plastics detected by μFTIR analysis included cloth cotton (n = 25) and cellophane (n = 5) (Figure 5). Cotton is not plastic but was also detected in this study; it may originate from tourist activities, including the washing of synthetic clothing, or just clothing worn by tourists at the beaches. Cellophane is cellulose made from wood or cotton, and comes in a variety of transparent plastic films used mostly for packaging. The shedding of clothing fibers during recreational activities and in laundry water from nearby hotels or from cosmetics and personal care products can be considered the major source of these materials in the beach sediments. In addition, the results on polymer type in this study are consistent with the observed microplastic shapes. Fibers include a diverse group of synthetic plastic polymers, such as PET, natural cellulose, and/or synthetic cellulose.

The high proportion of PET fibers in this study indicates a correlation between the contribution of these materials and tourist activities. Inefficient waste management and the lack of a proper understanding of the sorting process and disposal of waste can cause waste generation in coastal areas, so that it is more likely to contribute to marine debris. Management of coastal and marine environments in Thailand has been conducted with several efforts and legal frameworks to manage and tackle marine plastic litter [33]. In Phuket, waste management is largely the responsibility of local administrative organizations led by the Phuket governor. Many campaigns, for example, promoting the use of environmentally-friendly packaging and reduction of single-use plastic carryout bags have been adopted. However, the government needs to establish a more efficient waste management system to support continuous implementation in order to strengthen the co-ordination between various government organizations, and to raise people's awareness about proper waste disposal behavior.



(a)



(b)

Figure 5 μFT-IR spectra of (a) polyethylene terephthalate, and (b) cloth cotton.

4 Conclusions

This study provided the first baseline data for the presence of microplastics in beach sediments along the Mai Khao coastline of Phuket island, Thailand, which were found to contain a significant amount of microplastic particles, especially of the small-sized microplastics fraction (20 to 300 μm). Plastics on Mai Khao beach can accumulate in the marine food chain and transfer up along the trophic levels, from land to sediment, seawater to zooplankton, potentially negatively impacting marine organisms. Therefore, a proper management system with appropriate laws and regulations, and public awareness campaigns are important to reduce the effects of microplastic on marine organisms and their ecosystem. Further research is needed to understand the mechanisms influencing microplastic transport, deposition, and interactions with biota, in order to ensure sustainable tourism development and management at Mai Khao.

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