Textural and Chemical Characteristics of Microplastics in Coastal Sediments along the Southeast Coast of Sri Lanka: Implications for Possible Sources

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RESEARCH ARTICLE

Textural and Chemical Characteristics of Microplastics in Coastal Sediments along the Southeast Coast of Sri Lanka: Implications for Possible Sources

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Abstract

At present Microplastics (MPs) have been recognized as one of the most critical and emerging sources of marine pollution with a significant impact on marine and coastal biota. The current study aimed to comprehend MP pollution along the Southeastern coast of Sri Lanka by investigating their spatial distribution, morphology, composition and possible sources. For the study, 23 coastal sediment samples were collected from straight beaches and 8 samples were collected from lagoon areas of the Southeast coast extending from Kalmunai to Panama. About 5 kg of surface sediments were collected from the wrack line to the berm zone at each sampling site. The MPs were isolated by density separation using 1.20 g/ml NaCl solutions. The amount, shape, and colour of isolated MPs were analyzed on the petrographic microscope. The Scanning Electron Microscope (SEM) and Fourier Transform Infrared (FTIR) Spectroscope were employed to investigate their morphology and chemical composition respectively. The results indicated the presence of both mesoscopic- and microscopic-sized plastics in the studied sediments. The MPs occurred in five morphological categories; fibers (86.77%), flakes (6.61%), fragments (3.58%), foams (1.93%), and films (1.10%), and nine various colours. The SEM images demonstrated the presence of different weathering surfaces such as scratches, pores, protrusions, grooves, pits, and scales in these MPs. These weathered surfaces may have been formed due to mechanical abrasion, chemical reactions, photodegradation, and microbial degradation. The FTIR analysis revealed that the main polymer compositions of MPs are polyethylene and polystyrene. The distribution of MPs along the coast varied greatly (from 0 to 45 MPs 500 g^{-1}) and shows the highest amount in lagoon environments (>20 MP 500 g^{-1}) indicating land-derived sources of MPs. An in-depth textural and compositional characterization of MPs, and their spatial distribution investigations will advance the understanding of MP pollution in the Southeastern coast of Sri Lanka.

Keywords: Microplastics, Coastal sediments, Marine biota, Surface morphology

1. Introduction

Microplastics (MPs), plastic particles smaller than 5 mm in size, are one of the emerging environmental threats across the globe as a consequence of their non-biodegradability and bioaccumulation [1][2][3][4][5]. The MPs can either originate as primary MPs, which are commonly produced in cosmetics, pharmaceutical industries, synthetic textiles, and plastic pellets used in plastic industries or secondary MPs, which result as a consequence of physical, chemical, and biological fragmentation of macro-plastics [6][7][8].

A considerable fraction of MPs is lower in density than seawater, causing them to float on aquatic bodies and accumulate rapidly in the oceans. [1][9][10]. Therefore, at present MPs have been recognized as one of the most critical sources of marine pollution with a significant impact on marine and coastal biota [11][10][12]. As a recent example, numerous tons of primary MPs were released into the marine environment of Sri Lanka as a result of the X-Press Pearl incident, which resulted in serious environmental damage and the deaths of marine organisms [13]. The MPs associated with marine environments are called Marine Microplastics (MMPs). These MMPs are readily accessed by a variety of aquatic organisms and eventually transferred along the food chain [14][11][10][15]. The accumulation of MMPs in marine organisms' cells and tissues causes long-term biological impacts such as inhibition of growth and development, changes in behaviour and feeding, genetic damage, and reproductive and immunological toxicities [16][4]. Also, they cannot be easily removed from the marine environment because of their small size [10]. Therefore, the raised MP concentrations in seawaters cause numerous health impacts on marine creatures at all scales. Moreover, alternate ingestion of MP has the potential to harm human beings by altering chromosomes and increasing the risk of health issues such as cancer, obesity, and infertility [11].

The detection and identification of MPs are challenging and require various techniques. Advancements in analytical techniques such as Fourier-Transform Infra-Red (FTIR) spectroscopy, Raman microscopy, and pyrolysis gas chromatography have improved the process [17][18]. MPs' physical properties impact their hazard potential and ecological fate, making it crucial to quantify and characterize them. [11][10][15][19]. The first indication of MP pollution in Sri Lanka was reported in 2017 in beach sand from Negombo. Since then, Sri Lanka has advanced with numerous research on MPs mostly along its western and southern coasts [20][21][22]. Although during the last two decades, urbanization, coastal tourism and fishing activities have been proliferated along the Southeast Coastline of Sri Lanka, this area has not been paid much attention by researchers for research based on MP pollution and its consequences.

The current study reports the first investigation of the occurrence, spatial distribution, morphology and composition of MPs in sediments from the Southeast coastline of Sri Lanka. In this contribution, we attempted to identify the shape, colour, surface morphology and chemical composition of MPs, and subsequently interpret the possible sources of coastal MPs pollution.

Study Area

The studied coastal stripe lies on the Southeast coastline of Sri Lanka between the beaches of Kalmunai to Panama ranging from 6°52'59.4"N to 7°23'21.7"N and 81°50'38.4"E to 81°50'44.7"E in Ampara district (Fig. 1). The investigated beaches are flat, straight beaches and comprise several coastal lagoons namely Periya Kalappu, Korai Kalappu, Komari, Arugam, Pottuvil and Panama Lagoons, which are retreated by local channels [23][24]. In addition, the smaller bays, sandy spits and rocky headlands are common [25]. The major rivers, which bring sediments from hilly areas and dump them along the studied beach stripe are Ambalam Oya, Karanda Oya, Heda Oya and Wil Oya [26][24][27]. Climatologically, the area falls under a dry climatic zone in Sri Lanka and receives high precipitation during the Northeast monsoon period (750 mm) from October to February with an average yearly temperature of 29.25 ^{o}C. The majority of this studied coast is covered by sand-sized sediments yielding some places such as ilmenite and garnet [27].

The Kalmunai to Panama coast is being used by local people for various activities such as fishing, settlements (housing schemes and individual houses) and recreational activities [28][29]. The beach stripe from Kalmunai up to Korai Kalapu is highly populated and consequently, the anthropogenic influences on this beach stripe are increased towards Kalmunai. Therefore, this area is vulnerable to the accumulation of plastic waste due to the disposal of garbage along with plastics by local people. In contrast, from Korai Kalapu to Panama, the only populated township found is Pottuvil and the rest is mostly covered by dry evergreen forests. Arugam Bay, a world-famous surf tourism center based on geo-tourism is the main commercial city in this area.

2. Methodology

2.1 Field investigations and sampling

The field investigations were carried out along the Southeast coastline of Sri Lanka covering the beach stripe from Kalmunai to Panama (Fig. 1) considering freshwater inputs (river mouths/channels), lagoon inlets and polluted areas specially to study the effects of seawater interactions and human activities on the horizontal distribution of MPs. Sampling sites were identified by areas of macroplastic deposition as shown in Figure 2. The sampling was carried out in a total of 31 locations along the wretch line to the berm zone of the straight beaches (23) and lagoon outlets (8). Out of the samples collected from straight beaches most are within the 3 km from freshwater outlets. The surface sediment samples were collected within a 30 cm x 30 cm quadrant using a metal shovel, and ~5 cm surface layers were collected [30]. In order to prevent contamination, these samples were kept in foil containers.

2.2 Sample preparations

During sample preparations, the standard procedures were followed to minimise laboratory contaminations [30]. All the collected sediments were dried at 60 °C for 72 hours to obtain dry sediments for further analyses. The dried sediment samples were spread on metal trays and macroscopic plastic pieces were handpicked and separated for further characterization. Non-plastic debris such as shells, moss, and pebbles in sand samples were also removed.

The MPs were isolated by employing the density flotation method as described by Mohsen et al. in 2019. In this method, 500 g of dried sediment sample was mixed with 1500 ml NaCl solution ($\rho = 1.20$ g/ cm^{-3}) in a glass beaker for 10 minutes followed by settling for 15 minutes at room temperature. The visible floating items were picked using metal forceps and stored in Petri dishes for further analysis.

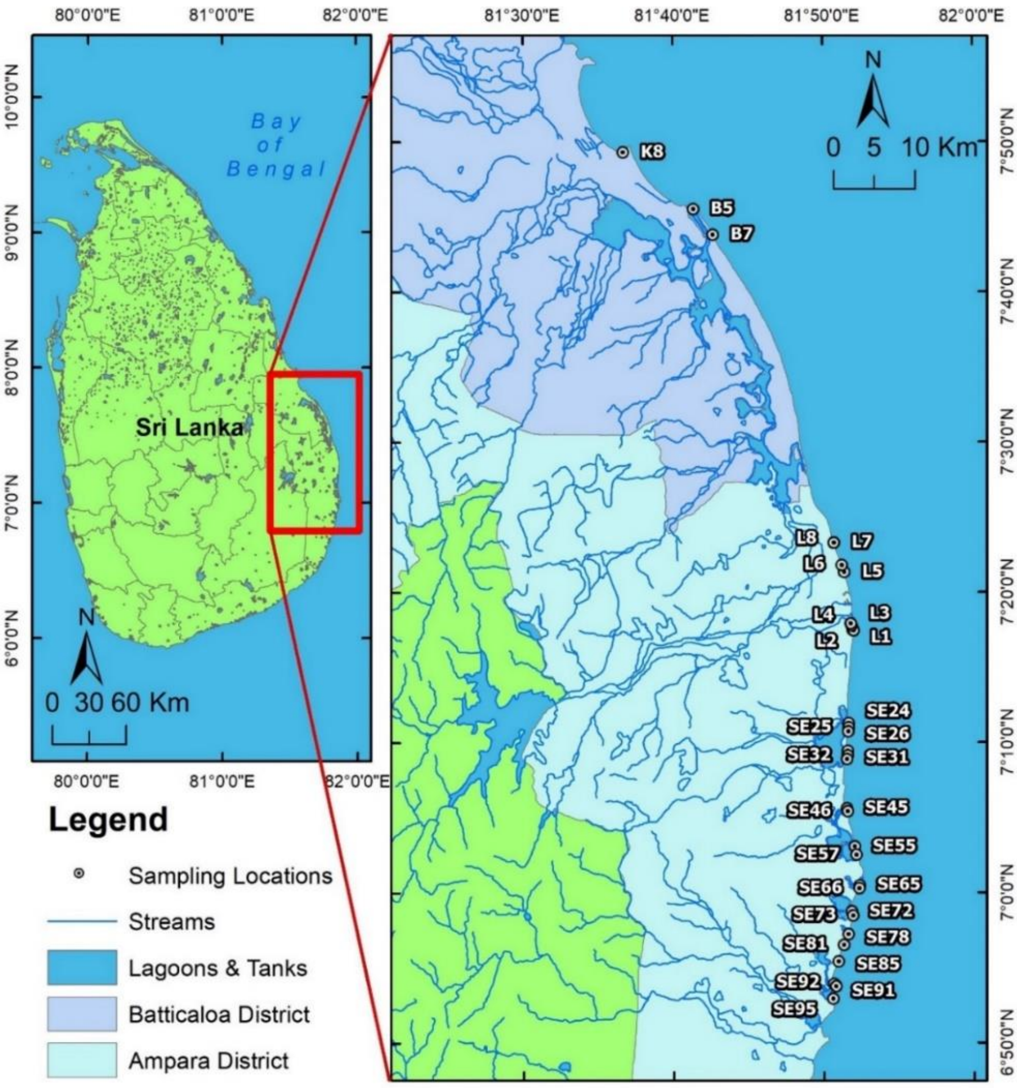

Fig. 1. A map showing the study area and sediment sampling sites

Then the supernatant was transferred into a second glass beaker. A volume of 15 ml H_2O_2 (30%) was added and stirred. After 24 hours, the supernatant was filtered using a vacuum filtration method. Then the filtrate was kept in the petri dish for further analysis. The two replications were carried out for each sampling location. A laboratory blank was carried out by applying the same protocol similar to the sediment samples.

2.3 Light Microscopic and Scanning Electron Microscopic Analyses

The colour, shape and quantity of MPs were observed under the light microscope available at the Earth Science Laboratory, Faculty of Applied Sciences, South Eastern University of Sri Lanka, Sammanthurai, Sri Lanka. The surface morphology of MPs was observed by using a Scanning Electron Microscope (SEM) (ZEISS EVO LS15) available at the Department of Geology, University of Peradeniya. Peradeniya, Sri Lanka. The samples were studied under magnification from x 100 to x 5000.

2.4 Compositional analyses

The polymer types of MPs were characterized by using the Fourier Transform Infrared (FTIR) spectrometer (PerkinElmer FT-IR C95033) equipped with MIRacle ATR (Attenuated Total Reflectance) and a ZnSe crystal available at Science Research Center, Faculty of Applied Science, South Eastern University of Sri Lanka, Sammanthurai, Sri Lanka. The MPs were scanned at a resolution of 4 cm^{-1} and a spectral wavelength range of 4000 to 400 cm^{-1}.

3. Results and Discussion

3.1 Field relations

During the field investigations, several domestic and urban waste dumping sites, fish waste sites, and stagnant polluted water bodies were observed. Plastic debris such as discarded foam floats (rigifoam), plastic bottles and polythene bags were observed in wastewater accumulations in lagoons, channels from the urban areas and river mouth environments (Figs. 2a, 2b and 2c).

Because of this accumulated waste and some illegal encroachments, the most of lagoon waters in the study area were stagnant leading to water being retained for prolonged periods (Fig. 2d). Consequently, it can upsurge the formation of MPs in such stagnant waters and resulting sinking of denser MPs to the river or lagoon bottoms and subsequent addition to the sediment load as there is no effluent [31].

Therefore, river and lagoonal beds can serve as temporary sinks for plastic that can be re-suspended and moved further downstream as denser plastic can sink, especially in less dense freshwater [32]. Ultimately, at high discharge time, this riverine and lagoonal sediment load with plastic debris merges with the marine sediments [31]. As per the most recent findings, the highest fraction of marine plastics enters the ocean through rivers [33][34][35].

Similarly, the discarded plastic bottles, and plastic and polythene bags with erratically dumped domestic waste were frequently observed along the beaches in most of the highly populated areas (Figs. 2a, 2b and 2c). The plastic materials related to fisheries such as discarded foam floats, nylon ropes and fishing nets were also evident in random places on many of the beaches. These plastics can be moved offshore through wind and/or tidal currents, and ultimately circulate the entire globe with ocean currents [36][37]. Therefore, it is evident that most plastics are land-derived while natural rivers and manmade channels from the urban areas are major pathways to transport plastic waste from inland areas to the studied coastal stripe.

Fig. 2. Field photographs showing plastic availability along different types of coastal environments. (a) accumulation of plastics along the wreck line to the berm zone of straight beaches; (b) accumulation of plastics with organic matter; (c) accumulation of organic debris with considerable plastic debris after a rainfall; d) stagnant water accumulation at a mouth of a canal at Karativu Coast showing floating plastics with organic matter

3.2 Macroscopic characteristics

Macro-plastic fragments showing various colours, sizes and shapes could be observed with the brownish organic matter after spreading the collected dried sediment samples on metal trays (Fig. 3a). Debris of rigifoam (Fig. 3b), fishing nets (Fig. 3d), ropes and coloured hard plastic fragments (Fig. 3c) could be identified with the naked eye. The mechanical abrasions of fishing nets and ropes during their use may produce fiber plastic waste [38]. However, in any of the samples, the lighter plastics such as debris from polythene bags could not be observed. These lighter plastic debris can be easily blown off from sediments through wind and tidal currents whereas denser polymers tend to accumulate in the sediment layers [39]. The presence of various plastic debris in studied sediment samples indicates that the studied beaches are polluted with various types of plastics. The morphology and the content of macro-plastic availability are mostly controlled by the proximity to the pollutant sources and the availability of fishing areas.

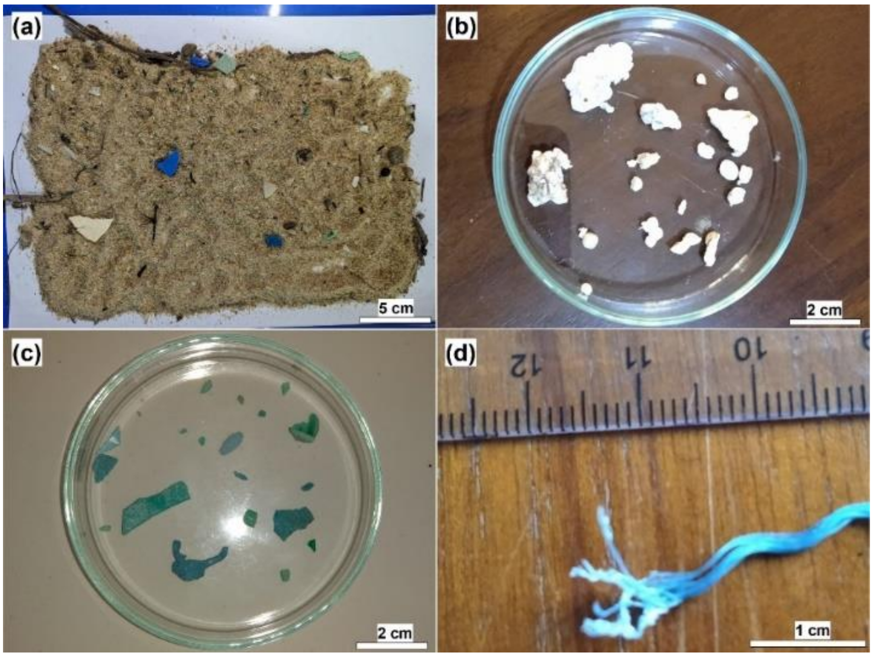

Fig. 3. Example macro-plastic fragments commonly found in straight beaches of urbanized areas. a) varieties of macro-plastic fragments in a spread sediment sample; b) handpicked macro-sized weathered rigifoam; c) coloured fragments of macro-plastics; d) blue-coloured fiber fragment detached from a fishing net

3.3 Quantity and spatial distribution of MPs

The number of MPs in each sample (no. of MP particles 500g-1 dry sediment) was counted under a light microscope (Fig. 4a). According to these data, the highest number of MPs is found in sample SE 25, which was obtained from Sinnamuhattuvram delta point in Periya Kalappu (lagoon). On the contrary, the samples SE 26, SE 46, SE 65 and SE 91 have relatively higher amounts of MPs [(i.e., more than 20 MP per 500g of beach sediments) Fig. 4a]. Except for sample SE 65, the other four samples (SE 25, SE 26, SE 46, SE 91) have been collected from coastal lagoon areas. Therefore, it indicated that lagoons have high loads of MPs. The water renewal in coastal lagoons takes place at a very slow rate and the plastics/MPs entering into this ecosystem remain for a longer time leading to a high concentration of MPs in coastal lagoons [40][41]. The only exception is SE 65 has a high number of MPs because this sample was collected from the straight beach near the Sangamankanda lighthouse, where significant plastic dumping is taking place (direct discharge of solid waste). On the other hand, sample L6 (near Karaitivu bridge) doesn’t contain any MPs. Field observations confirmed that the waste dumping on the banks of this canal is recent. Therefore, it can be suggested that the discarded plastics at this waste site have not had sufficient time to break into smaller MPs. Nevertheless, all the other sediment samples were collected near old dumping sites, coastal lagoons, fishing areas and areas with greater human populations. Therefore, the frequent sources of MP pollution in the studied coastal environments are due to the direct disposal of waste to beaches, and the discharge of waste to rivers and channels, which consequently enter the marine environment through river mouths and lagoons [42][33][40].

3.4 Textural characteristics of MPs

The shapes of MPs were identified by following the shape categories given in recent research [43][44]. Five shape categories of MPs, which were identified in sediments collected from this study are given in Figure 4a. According to these analyses, fibers were the most abundant shape type of MPs (86.77%) and were observed in all the investigated locations. The second most common shape type is flakes (6.61%) and it is also found in most of the studied samples. Except that fragments (3.58%), foams (1.93%) and films (1.10%) were found in low quantities. However, such morphological types were limited to a few locations.

The sources of MPs could be predicted by using their shapes [3][45][43][46]. Most of such morphological features of MPs are directly related to human activities on the beach such as fishing, the tourism industry and waste disposal [3][45][47]. Fiber-shaped MPs are mostly derived from fishing nets and ropes [1][48]. Since most ropes and nylon fishing nets are constructed of strands, these strands tend to elongate and develop fibrous shapes as they break down [49]. Also, a considerable fraction can be produced during the washing of textiles specially by using washing machines [14][50]. The fishing activities and direct domestic dumping to streams, manmade canals and lagoons observed in the studied coastal environment could contribute to such fiber-shaped MPs.

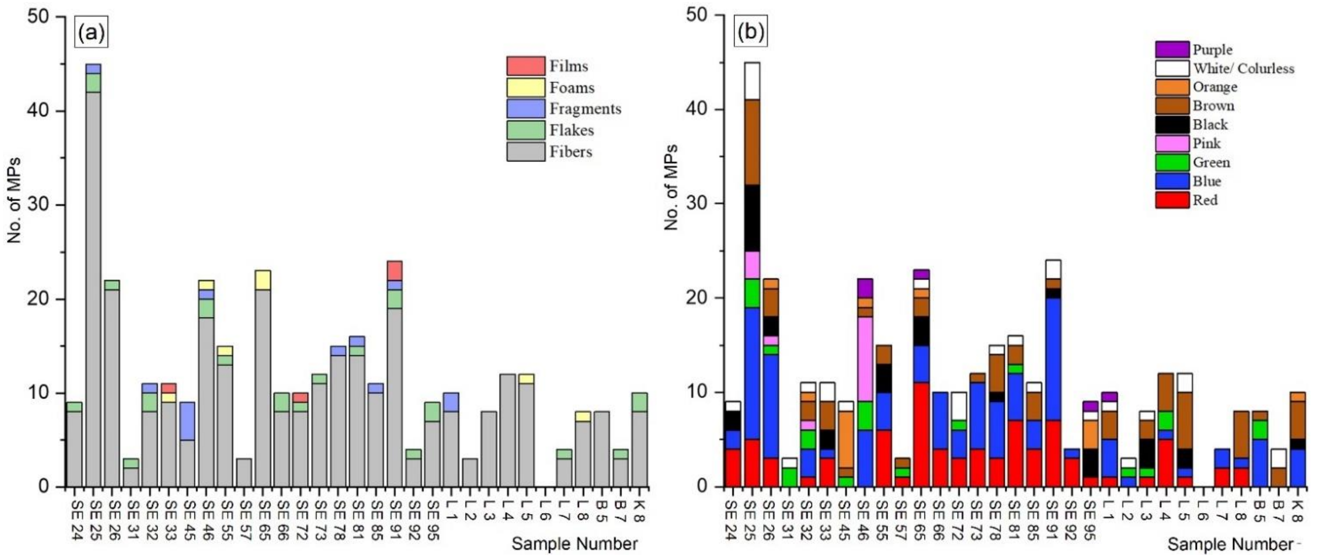

Fig. 4. Quantities of MP particles extracted from 500g of dry sediment samples from each studied location. (a) different morphological categories of MPs, films, foams, fragments, flakes and fibers; (b) different colour varieties of MPs; purple, white/colourless, orange, brown, black, pink, green, blue and red.

Conversely, the flakes are mainly derived from plastic and polythene bags [50]. Fragments and films originated from plastic bags and mulching films. Most of the foams, films and fragments are derived from the breakdown of large plastic debris in coastal and marine environments [45][43][44][51].

Fig. 5. Microscopic images of isolated MP particles showing different morphological and colour varieties. (a), (b), (c), (d) and (e) show different morphological varieties of fiber, flake, fragment, foam and film respectively; (f), (g), (h) and (i) show variously coloured MP fibers.

Figure 4b summarizes nine various colours observed in MPs. In terms of overall abundance, blue-coloured MP particles (29.75%) were dominant followed by red (22.60%), brown (17.08%), black (8.26%), white/colourless (7.44%), green (5.80%), orange (3.85%), pink (3.85%) and purple (1.37%) colours. This colour variation indicates the multiple sources of MPs and the high consumption of coloured plastic products in everyday life [52][53]. As being synthetic polymers primary plastics may show various colours [52][53]. Further, discolouration and fading of colour could be seen in some MPs and could be indicative of their weathering due to exposure to sunlight and hydraulic effects [54][55].

3.5 Surface morphology and weathering conditions of MPs

The different shape categories of MPs observed under SEM demonstrated the presence of various surface morphologies (Fig. 6 and 7). The surfaces of fibers showed degradation marks of scratches, pits, grooves and protrusions of different sizes (Fig. 6). The flakes showed small scratches with jagged corners whereas foams exhibited scaly protrusions and irregular pores on their surfaces (Fig. 7). Moreover, the surface layers of foams appeared to be separated from the underlying layers (Fig. 7).

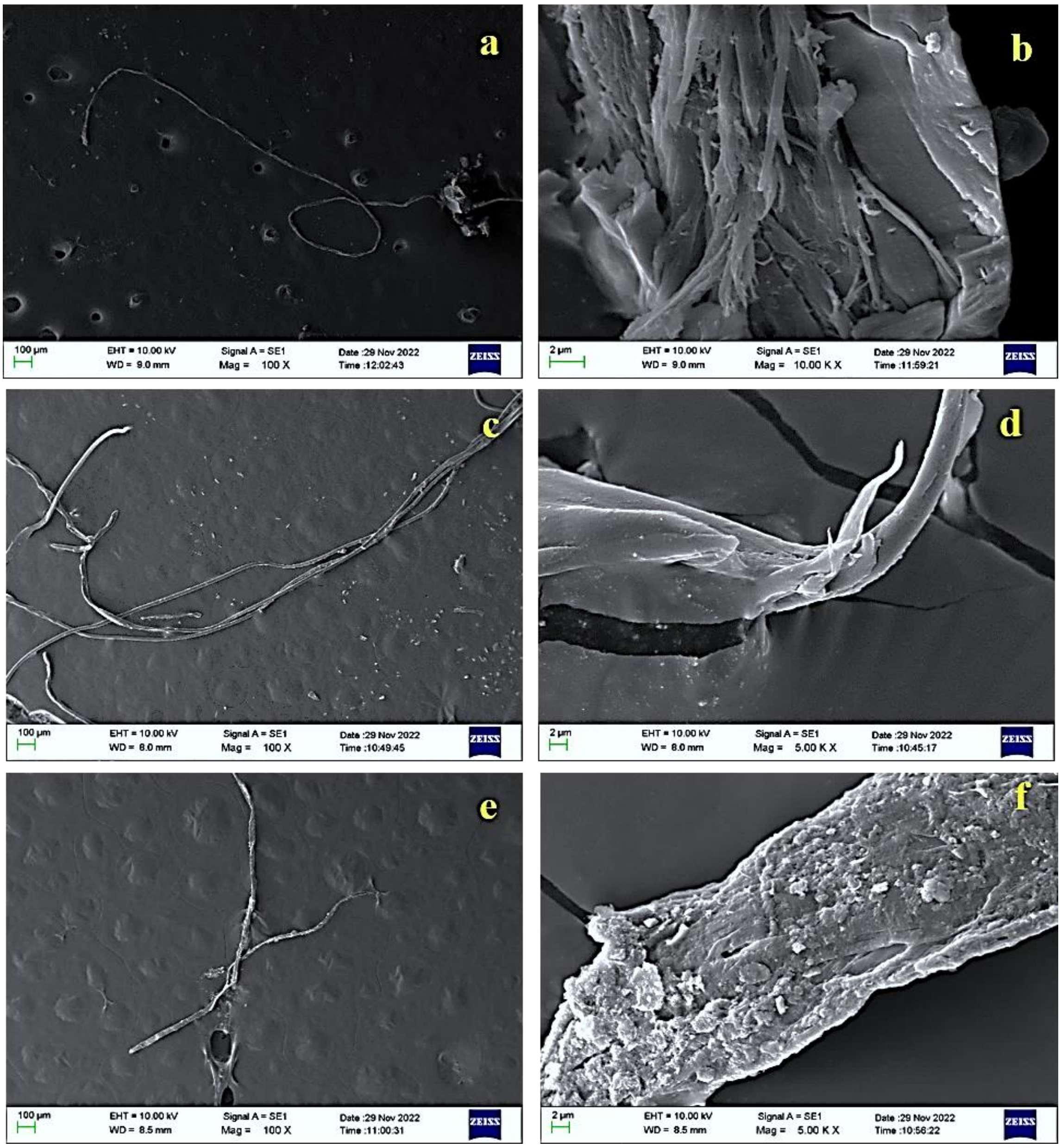

Fig. 6. SEM images of (a) fiber A at Mag = 100× (b) fiber A at Mag = 10.00 K× (c) fiber B at Mag = 100× (d) fiber B at Mag = 5.00 K× (e) fiber C at Mag = 100× (f) fiber C at Mag = 5.00K×.

The most possible weathering processes of MPs include mechanical degradation due to abrasion by sands, chemical degradation due to the interaction of MPs with seawater, photodegradation due to solar radiation (UV light) and biodegradation due to microorganisms [56][54][55]. As a result of wave and tidal actions along the coastline, most of the MPs have physically degraded forming scratches, pores and protrusions on their surfaces. Moreover, extreme beach surface temperature might be the reason for the thermal degradation of the MPs [7]. Apart from possible hydraulic action in the lagoon, river and canals, the disintegration of MPs also occurs due to prolonged exposure to heat and ultra-violet light [56][54][55]. The climate of the studied area is tropical monsoon with an average yearly temperature of 29.25 °C, which could be ideal for such degradation. Therefore, SEM analysis indicated that almost all MPs had been weathered due to the combined effect of environmental conditions prevailing along the studied coastal stripe. Further, since weathering can alter the MPs' colour, shape, and sorption capacity, marine species can readily consume them and experience health issues [57].

3.6 Chemical composition of MPs and possible sources

The resulted FTIR profiles of relatively large-sized MP flakes and foams are shown in Fig. 8. The FTIR spectrum of the flake (Fig. 8a) shows major IR peaks at 2917, 2847, 1411 and 718 cm^{-1} corresponding to CH_2 asymmetric stretch, CH_2 symmetric stretch, CH_3 umbrella bending and CH_2 rocking vibration respectively indicating the presence of polythene [58]. Fig. 8b shows the FTIR spectrum of foam and the major IR peaks at 3026, 2918/2846, 1643/1492/1451 and 756/698 cm^{-1} corresponding to C-H aromatic stretch, methylene C-H stretch, C=C aromatic stretch and C-H bending confirming that this foam consists of polystyrene. The stretching vibration absorption of O-H is represented by the absorption peaks at wave number 3432 cm^{-1}, indicating the presence of hydroxyl from water [59]. Because polystyrene and polyethylene have larger surface areas and contain benzene rings, respectively, they have greater sorption capabilities to chemical pollutants compared to other polymer types. As a result, these MP polymers serve as carriers of these pollutants along food chains [60].

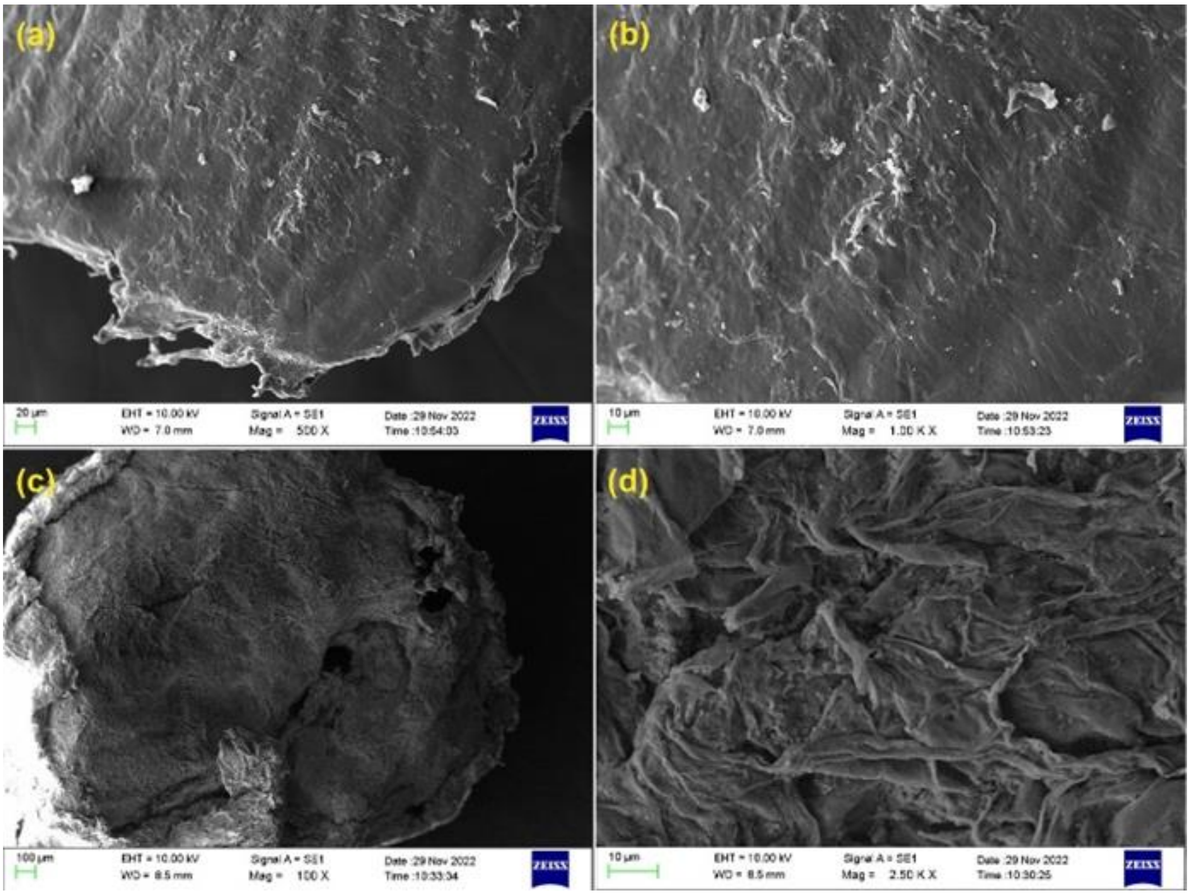

Fig. 7. SEM images of a flake under (a) Mag = 500× (b) Mag = 1.00K× and a foam under (c) Mag = 100× (d) Mag =2.00K×.

To determine the changes in IR spectra due to weathering, a normal regiform particle and an eroded rigid foam particle collected from location L8 (Sainthamaruthu beach) were analyzed under the FTIR spectrometer (Fig. 8c). Both eroded and normal rigifoam particles show FTIR spectra corresponding to polystyrene. However, the intensity of the weathered particle was lower than that of the normal rigifoam particle. Therefore, this indicates that weathering and degradation of the surface of plastics have a significant impact on their molecular vibrations. The surface of a normal polystyrene sample is neat and smooth [61]. However, when the surface is eroded, the polystyrene chain breaks and forms cracks, causing serious damage to the surface. Due to these structural changes, molecular vibrations alter IR spectra [61].

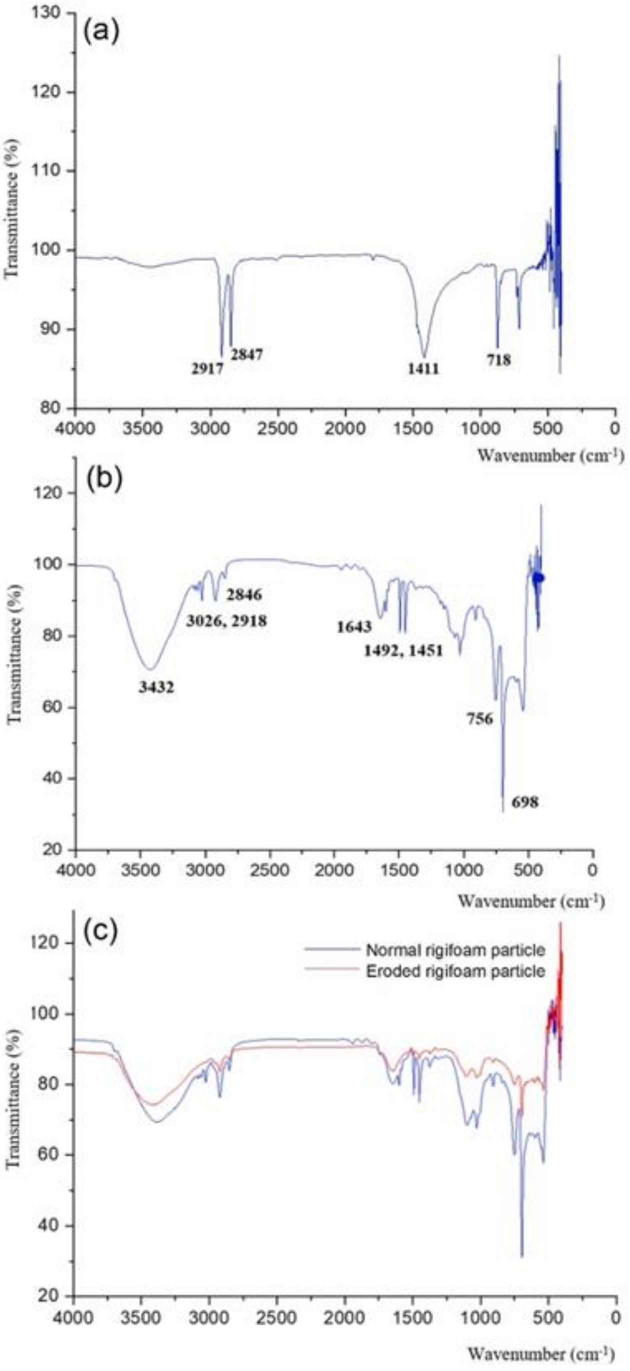

Fig. 8. FTIR spectra of randomly selected MP particles. (a) the spectrum of a flake with characteristics peaks at 2917, 2847, 1411 and 718 cm-1 corresponding to CH2 asymmetric stretch, CH2 symmetric stretch, CH3 umbrella bending and CH2 rocking vibration respectively indicating the presence of polythene; (b) the spectrum of foam with characteristics peaks at 3026, 2918/2846, 1643/1492/1451 and 756/698 cm-1 corresponding to C-H aromatic stretch, methylene C-H stretch, C=C aromatic stretch and C-H bending respectively indicating presence of polystyrene and (c) spectra of the fresh rigid foam particle and weathered rigifoam particle

4. Conclusion

The studied beach area is contaminated with MPs comprising of five shapes and nine colour varieties. Most of the investigated MPs are secondary in origin and indicative of land-derived sources. Also, these MPs are polyethylene and polystyrene in composition implying the anthropogenic sources, specifically from domestic and fishery waste. The various surface morphologies present in these MPs revealed their prolonged exposure to hydraulic actions and consequent mechanical degradation. The distribution of MPs along the coast is highly variable with lagoon environments having the highest amount and is influenced by fishing activities and the direct dumping of waste into surface water bodies. A further comprehensive investigation is needed to be carried out for a better understanding of the river influx of MPs, distribution and migration of MPs on the Southeastern coast.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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