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Spatiotemporal distribution of microplastic debris in the surface beach sediment of the southeastern coast of Bangladesh

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A R T I C L E I N F O

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SEM

A B S T R A C T

This study undertakes a spatiotemporal analysis of microplastic pollution in surface beach sediments, covering 7 coastal beaches in Bangladesh and two seasons-monsoon and winter. The concentration of microplastics extracted from the surface beach sediment is 242.86 particles/kg dw. The results showed both significant seasonal (p value = 0.001) and spatial (p value = 0.004) variation. The abundance and polymer types were significantly higher (57 %) in winter than in the monsoon season (43 %). Touristic and commercial beaches showed higher levels of microplastic pollution than the non-touristic beaches. Polyethylene (28.8 %) and Polypropylene (27.6 %) were the most abundant polymer. The most dominant coloration of microplastics was white (42.6 %). The majority of the microplastics were fibers (33.5 %). Smallest particles measuring <1 mm constituted nearly half of the total microplastics load (48.5 %). This baseline data can be useful in terms of coastal zone management for the southeastern coastal beaches of Bangladesh.

1. Introduction

Microplastic pollution has become an increasing *trans*-boundary, complex, socioeconomic and environmental issue of the 21st century, with there being few attainable solutions, meaning it poses a threat to marine biodiversity and also to mankind worldwide. Microplastics can be described as small pieces of plastic less than 5 mm in size [1]. The prevalence of microplastics in the oceans was first reported by scientists in the early 1970s [2], and almost 13.2 % of the mass of the global marine plastic debris and 92.4 % of the number of global plastic particles represent microplastics [3].

Both land and sea-based activities are particularly responsible for 75 %–90 % and 10 %–25 % of the plastic in the marine and coastal environment, respectively, resulting from mismanaged wastes disposal [4–6]. Land-based sources include personal care products, textile, agriculture, packaging, construction, tourism, ship dismantling etc., while sea-based sources include fisheries, aquaculture, offshore industries, maritime tourism etc.

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Microplastics differ from one another and can be classified based on their heterogeneous characteristics such as size, shape, colour, chemical composition, density etc. (Bergmann et al., 2015). With progressive residence time in the environment, plastic debris undergoes different types of fragmentation processes including photodegradation, thermal degradation, chemical degradation, or biological degradation influenced by various drivers like UV radiation, oxygen and seawater, or mechanical forcing [4,7–13].

Microplastics are a pollutant of critical concern due to their persistence, ubiquity and role as vectors for pathogens and chemical toxicants like additives, Persistent Organic Pollutants (POPs), heavy metals etc., and also for transferring them through various trophic levels causing severe physical, carcinogenic, genotoxic, endocrine-disrupting impacts [14,15]. Pollution from microplastics has increased in Bangladesh due to poor waste and wastewater management, industrial/domestic sewage and effluents, accidental losses, and illegal dumping of plastic debris. Microplastic fragments can get carried away to the shoreline or beach from the land and sea-based sources by the terrestrial or river runoff, precipitation, aeolian input, tidal currents, storm surges etc. and get accumulated along the wreck line of the shore in various concentrations depending on the coastal geography and watershed area [16]. Microplastic concentrations on beaches can be an important indicator of pollution in the adjacent ocean as the pollutants are eventually transported to the sea [17]. A very limited number of studies focusing on only the spatial observation and a short stretch of study area regarding microplastic pollution has been conducted till date in Bangladesh confirming microplastic abundance in the beach sediment with an average of 368.68 ± 10.65 items kg^{-1} [18,19].

It is evident that with the exception of anthropogenic pressure, weather and seasonal conditions like wind, precipitation, and ocean currents also affect microplastic abundance and distribution in the coastal zone and open ocean [20,21]. The present study focuses on the microplastic pollution between two seasons-monsoon and winter in 7 different beaches of the two major coastal districts- Chattogram and Cox's Bazar of Bangladesh lying beside the Bay of Bengal. This study is the first of its kind in Bangladesh to report baseline data on both spatial and seasonal variation of microplastic abundance over a long stretch of sampling locations in the southeastern coastal area.

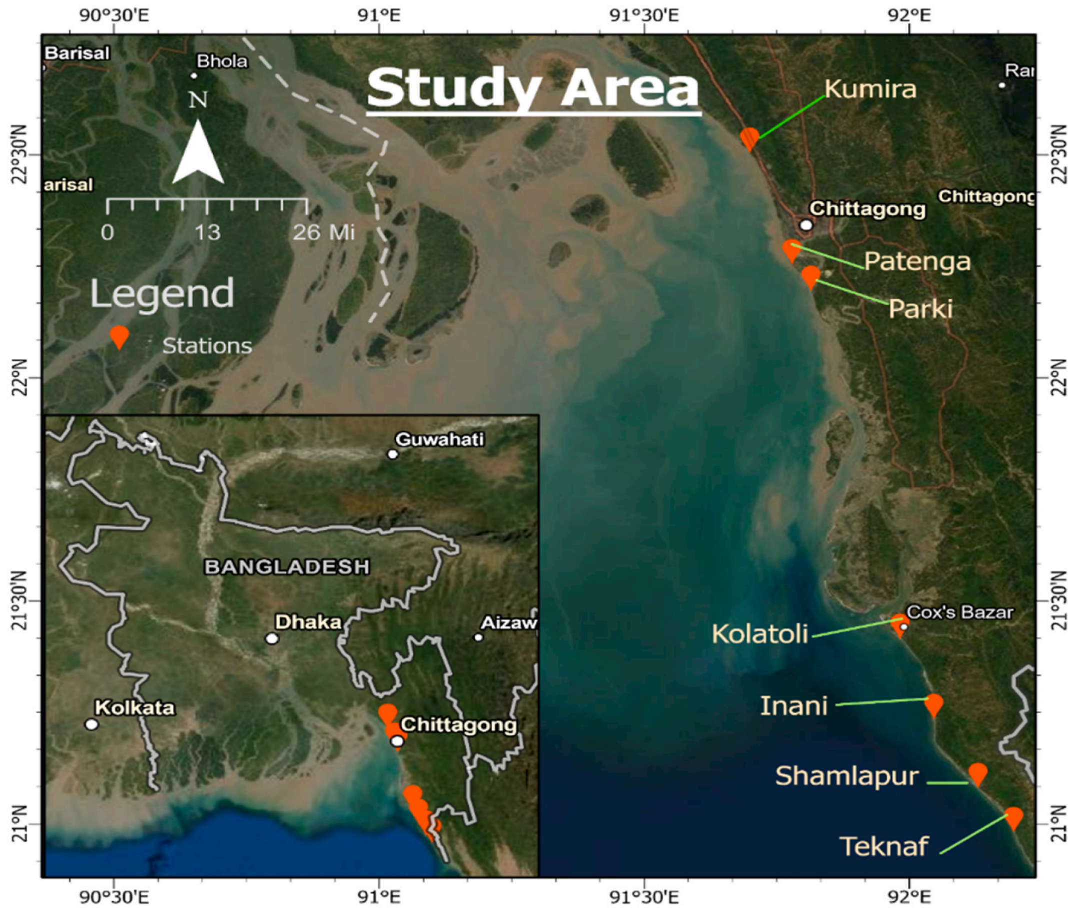

Fig. 1. Map of sampling stations.

2. Materials and methods

2.1. Study area

Chattogram and Cox's Bazar are suffering from an excessive number of expanding maritime industries such as tourism, aquaculture, shipping, ship breaking, Exclusive Economic Zone (EEZ) establishment etc., making these two areas vulnerable to environmental and ultimately microplastic pollution. The native flora and fauna of these coastal regions such as phytoplankton, zooplankton, seaweed, algae, crab, shrimp, oysters, marine fish, seabirds, sea turtles and marine mammals are also under severe ecotoxicological threat due to potential microplastic pollution. Seven different coastal beaches were selected for the study from the Chattogram and Cox's Bazar area covering 240 km from Kumira to Teknaf coast. The weather features of these areas are almost similar while geomorphological settings and anthropogenic uses of the beaches differ from one another. Kumira includes the famous ship breaking yard; Patenga, Parki, Kolatoli and Inani are famous tourist attractions, Shamlapur represents a local isolated beach and Teknaf is a renowned fishing site. The sampled beach's locations are shown in Fig. 1.

2.2. Monsoon and winter characteristics of Bangladesh

The dominant climatic trait of Bangladesh is monsoon, with approximately 80 % of the yearly rainfall occurring from June to October. The rains are more frequent along the southeastern coast reaching 750 mm in Chattogram, to 900 mm in Cox's Bazar, and to as high as 1000 mm in Teknaf. The winter season is typically dry, and less than 4 % of the total annual rainfall of Bangladesh occurs in this season from October till March. The average rainfall is less than 20 mm in the western and southern regions of the country during this season [22].

These two seasons were chosen by their distinctiveness in weather characteristics. During the monsoon season, a monsoon wind and a high amount of rainfall prevails, which may wash off the beach sediment surface and carry away deposited microplastics and other debris in the shallow coastal ocean. Thus, it is expected that there will be a reduction in microplastic abundance in the surface sediment during the monsoon. On the other hand, in the winter season there is relatively cool and dry weather. This scenario may in turn promote an increased abundance of microplastic in the surface beach sediments, as there is less stormwater runoff due to lower amounts of precipitation.

2.3. Field sampling

Sand samples from seven different beaches in Chattogram and Cox's Bazar were collected in two phases over two seasons. Monsoon sampling was conducted from 5th to 7th September 2019. Consecutive winter sampling was conducted from 21st to 23rd February 2020.

Microplastic has a patchy distribution on the sandy beach. It mostly accumulates along the high tide line in the intertidal area or along the wreck line with other organic and inorganic debris. Sand samples were collected from the intertidal area, for example 1 m seaward from the high tide line. All the samples were collected during low tide. A 30 $\times$ 30 cm square stainless-steel quadrat was placed on the sampling location. As only the surface microplastic samples were targeted, sand samples were collected from the surface to 5 cm depth using a stainless-steel scoop. The samples were filtered in the field using a stainless-steel sieve with a mesh size of 5 mm to reduce the sample volume and to discard debris that are larger than 5 mm. Later, the sieved samples were collected and wrapped in an aluminum foil to reduce contamination in the samples. The foil packaging was sealed until further analysis to protect the samples.

2.4. Sample pretreatment

During sample preparation, the pre-treatment took place in 4 steps-I) Drying, II) Deflocculation III) Density separation and IV) Digestion.

In the drying step, collected beach sediment samples were both purified and prepared for further instrumental analysis and identification of microplastics. The samples were air dried in a cleaned laboratory room with negligible contamination at room temperature for 2–3 days. Then an 100 gm sediment sample was taken in a 500 ml beaker for each station and each season.

For deflocculation, sodium hexametaphosphate was used to prevent small microplastic particles to adhere to fine sand or clay particles in suspension to form flocs and thus facilitates the separation of smaller size microplastics. A solution of sodium hexametaphosphate was prepared using 1 L of deionized water and 51 gm of sodium hexametaphosphate powder in an electronic mixer at 700 rpm for 15–20 min. From that mixture, 500 ml was taken and mixed with the sample and was kept in the same electronic mixer until the sample was well combined with the solution. This mixture was kept in a hot air oven at 65 °C for 3 days until the texture was considered muddy enough [23].

For density separation, a saturated solution of NaCl (1.2 g cm^{-3}) was used as it is both economically feasible and does not pose any toxic chemical properties. A 1-L beaker containing sample mixture was placed inside a 3-L beaker. A brine solution of NaCl was poured in the mixture slowly through a separatory funnel until the inner beaker had overflown, and the water level of the outer beaker was equal to the mouth of the inner beaker. The beaker was kept at rest for 3/4 days until microplastics floated to the surface or stayed in a suspended condition, while heavier particles such as sand, clay, silt or biogenic material settled to the bottom of the beaker. The separation process was repeated 3 times per sample to ensure the maximum degree of removal of microplastics from the sediment samples.

Finally, during the digestion procedure, the supernatant from the density separation mixture was screened with a 212 μm sieve. The sieve was washed carefully with deionized water and the washed water was passed completely through a 47 μm nylon filter paper carefully to deposit microplastics with floating debris. Finally, the filter paper was washed in a beaker with 10 % H_2O_2 solution for 24 h making the organic matters fragile, digested or dissolved. The solution was then passed through a new 47 μm filter paper and it was rested for half a day. Then the filter paper was ready for further counting and analysis.

2.5. Quantification and characterization of microplastics

Microplastic abundance was measured using a Leica stereo microscope as a visual aid to count the microplastic particles on the filter papers at 5.0-megapixel image capture resolution and up to 40× magnification. The microplastic particles were systematically counted up to the size range 0.2–5 mm. The morphological types such as fiber, fragment, foam, pellet, film and colour were also recorded during this visual inspection [24]. The total microplastic particles were divided into three size classes of 5–3 mm, 3-1 mm and <1 mm. Residues were carefully visually inspected to avoid misidentification of the microplastic particles focusing on homogenous colour and thickness thorough the entire length for fibers and sharp edges for the fragments [25].

In this study, a PerkinElmer FT-IR/NIR Spectrometer Frontier with ATR adapter was used to understand the chemical composition and chemical bonds present in the microplastic particles. The operating range was (650–4000) cm^{-1} with 4 scans and a resolution of 4 cm^{-1}. Identification was based on the transmittance frequencies for specific chemical bonds and comparison of each spectrum with standard references of polymer spectra. The software used for this operation is named Spectrum 10.4.4. To evaluate the surface texture of microplastic particles, Carl Zeiss EVO 18 Scanning Electron Microscope was used. In X-ray geometry, the LaB_6 high brightness source upgrade path was used for a better level of performance. SmartSEM software was used in the analysis for processing. Click or tap here to enter text. In this study, EHT (electron high tension) of 15 kV, working distance of 9.0 mm and sample magnification of up to 5 k times were performed.

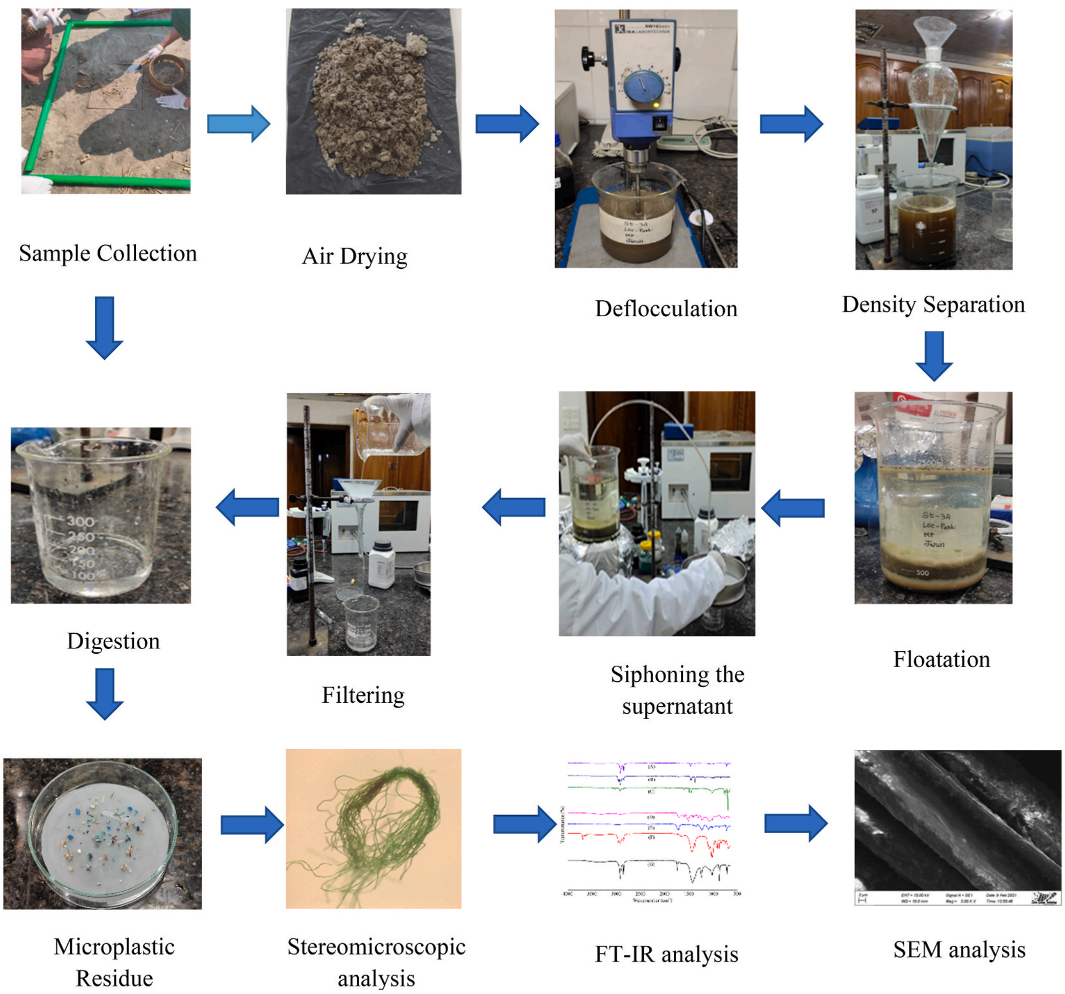

Fig. 2. Sample collection, laboratory analyses, quantitative and qualitative investigations.

The microplastic extraction procedures, quantitative and qualitative analysis steps are presented in Fig. 2.

2.6. Quality control and quality assurance

The sampling instruments and all filter meshes were carefully cleaned with deionized water before use. During field sampling, the collected samples were immediately covered and wrapped with aluminum foil and were transferred to a sealed airtight bag. During laboratory treatment, a dress code of non-plastic materials including a lab coat, gloves and head cover was maintained. Prior to analysis, the laboratory platform was thoroughly cleaned to get rid of dirt and other impurities. All the analytical and measuring devices were cleaned and covered before and after use. A laboratory blank test was performed to investigate air contamination with 500 ml of deionized water stored in a beaker, and this was treated the same as the field samples. No plastic was found on the filters, indicating that contamination from the laboratory air, containers or processing was negligible [26,27].

2.7. Data analysis

The abundance of microplastics in each sediment sample was represented as the number of particles per kilogram dry weight (number particles/kg dw). In the present study, a paired sample *t*-test was used to compare the seasonal variability, as samples were collected from the same locations in two seasons, and the Analysis of Variance (One Way ANOVA) along with a Post Hoc (LSD) test was also performed to compare the variability among the stations or places. In all cases, a 5 % level of significance was used. All results are shown in tabular form and charts. To analyze and create the charts, Statistical Package for the Social Sciences (SPSS) version-25 and Microsoft Excel version-19 were used.

3. Results and discussion

3.1. Spatiotemporal distribution of microplastic abundance

Results demonstrated the presence of significant quantities of microplastics in all 7 sampled beaches in both the monsoon and winter seasons. In this study, a total of 340 particles of microplastics were extracted from 1.4 kg (100 gm for each beach in two seasons) of sand samples collected from the beaches, and the particle abundance of microplastic was 242.86 particles/kg dw. The abundance of microplastic particles for the monsoon and winter seasons was 208.57 particles/kg dw and 277.14 particles/kg dw respectively. However, microplastics with a density lower than 1.2 gm/cm^3 could not be separated due to the cost of the other reagents (salts like $ZnCl_2$) used in density separation. Microplastics falling in the nanometer size class could not be detected due to technological constraints. The degree of microplastic contamination and concentration were variable throughout the sampled beaches (Fig. 3).

The particle number is plotted using both station-wise and season-wise approaches in pie charts (Figs. S01 and S02). Fig. S01 showed that Kumira accounts for the highest 23.2 % of the total sampled microplastic, which is 79 particles. This site is particularly renowned for ship breaking, tourism, fisheries and other commercial activities that run throughout the year, and this is the likely reason for it to perform as a hub for microplastic contamination. Shamlapur accounts for the lowest 4.4 % of the total sampled microplastic, 15 particles. Shamlapur is a non-touristic and isolated beach lying just before Teknaf along the marine drive of Cox's Bazar, used by local inhabitants and some small-scale fishing activities to meet the local need without the influence of outsiders or any other heavy impact economic activities. Fig. S02 showed that both the monsoon and winter seasons exhibited distinct amounts of microplastic contamination in the surface sediment of sandy beaches. 146 particles representing 43 % of the total load were found from the samples collected during the monsoon season and a higher amount of 194 particles representing 57 % of the total load was collected from the sediments sampled in the winter season. There is a distinct spatial variation (p value = 0.004) in the amount microplastic particles among all the seven sampling stations along the southeastern coast of Bangladesh, and the amount of

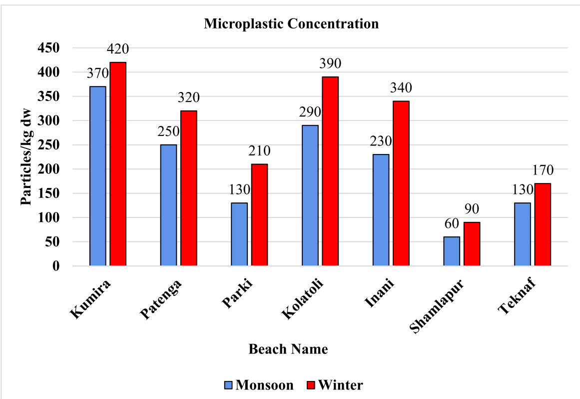

Fig. 3. Microplastic concentration in beach sediments expressed in units of particles/kg dw.

microplastic particles differed significantly (p value = 0.001) from monsoon to winter.

Relatively high abundances of microplastics were found in urbanized, industrialized, anddensely populated areas with more tourism, due to sewage effluents from stationed cruise vessels, hotels, restaurants, and laundry facilities etc. [9,28–31]. Heavy to very heavy rainfall and wind action in the monsoon promotes surface runoff that easily washes away sediment grains and microplastics from the beach sediment to the open sea, and increases microplastic contamination in the seawater. During winter, light, occasional rainfall, lack of removal by storm events and the mild wind speed provide favorable conditions for microplastics to persist on the surface sediment of the beaches, making the seawater less polluted by microplastic contaminants. A study conducted in the south-western coast of Taiwan also suggested that microplastics in sediments accumulate during the dry season and are transported during the wet season [32]. Similarly, the concentration of microplastics on the surface beach sediment in the winter season was found to be higher than in the rainy season.

The abundance of microplastics from different coastal beaches and estuaries worldwide is listed below, for comparison with the results of the present study (Table 1).

3.2. *Spatiotemporal analysis of microplastic polymer types*

In the present study, a total of 7 types of polymers were identified and characterized from 79 selected microplastic particle samples using FT-IR spectrophotometry. These are namely: Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyurethane (PU), Polyethylene + Polyethylene terephthalate (PE + PET), Polyethylene terephthalate (PET) and Polyvinyl chloride (PVC). Each type produced different spectrums that had distinct peaks which were nearly identical to their respective reference spectrum. The resultant spectrums of polymer types are given below (Fig. 4).

Seasonal and stationwise abundance of microplastic polymer type, coloration, shape and size class distribution among the 7 studied beaches are presented in Fig. 5.

The synthetic origin of polymers identified from FT-IR spectroscopy was typical post-consumer plastic fragments. Polymer composition (Fig. 5(a)) showed spatial and temporal variation in varying degrees of magnitude in all the 7 stations situated in the southeastern coast of Bangladesh. The most abundant polymer type among all the locations is PP (28.8 %), followed by PE (27.6 %), PS (20.9 %), PU (20 %), PE + PET co-polymer (1.5 %), PET (0.6 %) and PVC (0.6 %). PE, PS and PU are ubiquitous in all sampling locations. However, PP was found everywhere except Shamlapur, PET and PE + PET copolymer was only found in Kumira, and PVC was found only in Shamlapur. Only PU showed statistically significant variation (p value = 0.009) among the stations.

Seasonal analysis of polymer type composition (Fig. 5(a)) showed that, in winter all the 7 polymer types were present. The most abundant polymer type among all the locations in winter is PP (33 %), followed by PE (24.7 %), PU (20.6 %), PS (19.1 %), PET (1.0 %), PVC (1.0 %) and PE + PET co-polymer (0.5 %). In the monsoon season, a total of five polymer types were found in all the sampling stations, and PET and PVC were totally absent. The most abundant polymer type among all the locations was PE (31.5 %), followed by PP (23.3 %), PS (23.3 %), PU (19.2 %) and PE + PET co-polymer (2.7 %).

The spatiotemporal analysis of polymer composition has revealed that both polymer diversity and polymer abundance were higher in the dry winter season due to weaker surface winds and less rainfall. This finding is somewhat similar to a study conducted on the southwestern coast of Taiwan, where higher microplastic abundance and inventory and lower microplastic diversity were found in the dry season than in the wet season [32]. Furthermore, winter is the main tourism season, adding the increased pressure of tourists. These factors justify the fluctuation in microplastic abundance and diversity in winter. PP and PE constitute a higher proportion of

Table 1
Global studies on microplastics abundance.

Location	Abundance	Reference
Cox's Bazar, Bangladesh	200–378.8 items kg^{-1}	[18]
Khark Island Coast, Iran	59–217 items per kg dw	[33]
Yangtze Estuary, China	121 ± 9 items per kg dw	[34]
Haihe Estuary, Bohai Bay, China	216.1 ± 92.1 items per kg dw	[35]
Bohai Coast (Xingcheng, Dongdaihe and Bijiashan), China	102–163.2 items per kg dw	[36]
Caribbean beaches	261 pieces/kg dw	[37]
Southern Portugal	0-263 per kg dw	[38]
Venice, Italy	672–2175 items per kg dw	[39]
Scapa Flow, UK	730–2300 items per kg dw	[40]
European beaches	72 to 1512 pieces/kg dw	[20]
Baltic Beaches in Russia	1.3–36.3 items per kg dw	[41]
Singapore Coast	36.8 ± 23.6 items per kg dw	[42]
Persian Gulf, Iran	61 ± 49 items per kg dw	[43]
Po River Delta, Italy	3-23 per kg dw	[44]
Southern Baltic Sea	39 ± 10 per kg dw	[45]
Virginia and North Carolina, USA	1410 ± 810 per kg of dw	[46]
Nigeria (Gulf of Guinea), Atlantic Ocean	3.4 ± 3.5–173 ± 21.3 per kg dw	[47]
Eastern Coast, Australia	83–350 particles/kg dw	[48]
Southeastern Coast (Cox's Bazar, Chattogram) Bangladesh	242.86 particles/kg dw	Present Study

Comparing the results from previous studies (Table 1) with other countries, it can be concluded that the pollution level at the southeastern coast of Bangladesh is presently at a moderate level.

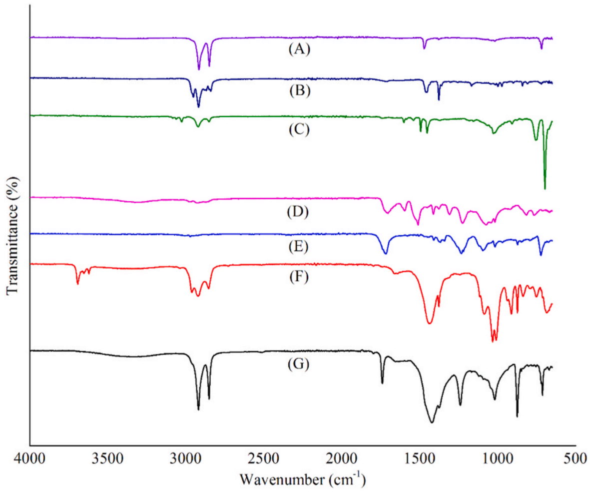

Fig. 4. Infrared spectra from FT-IR analysis for A) PE, B) PP, C) PS, D) PU, E) PET, F) PVC and G) PE + PET from samples collected from 7 locations in Monsoon and Winter.

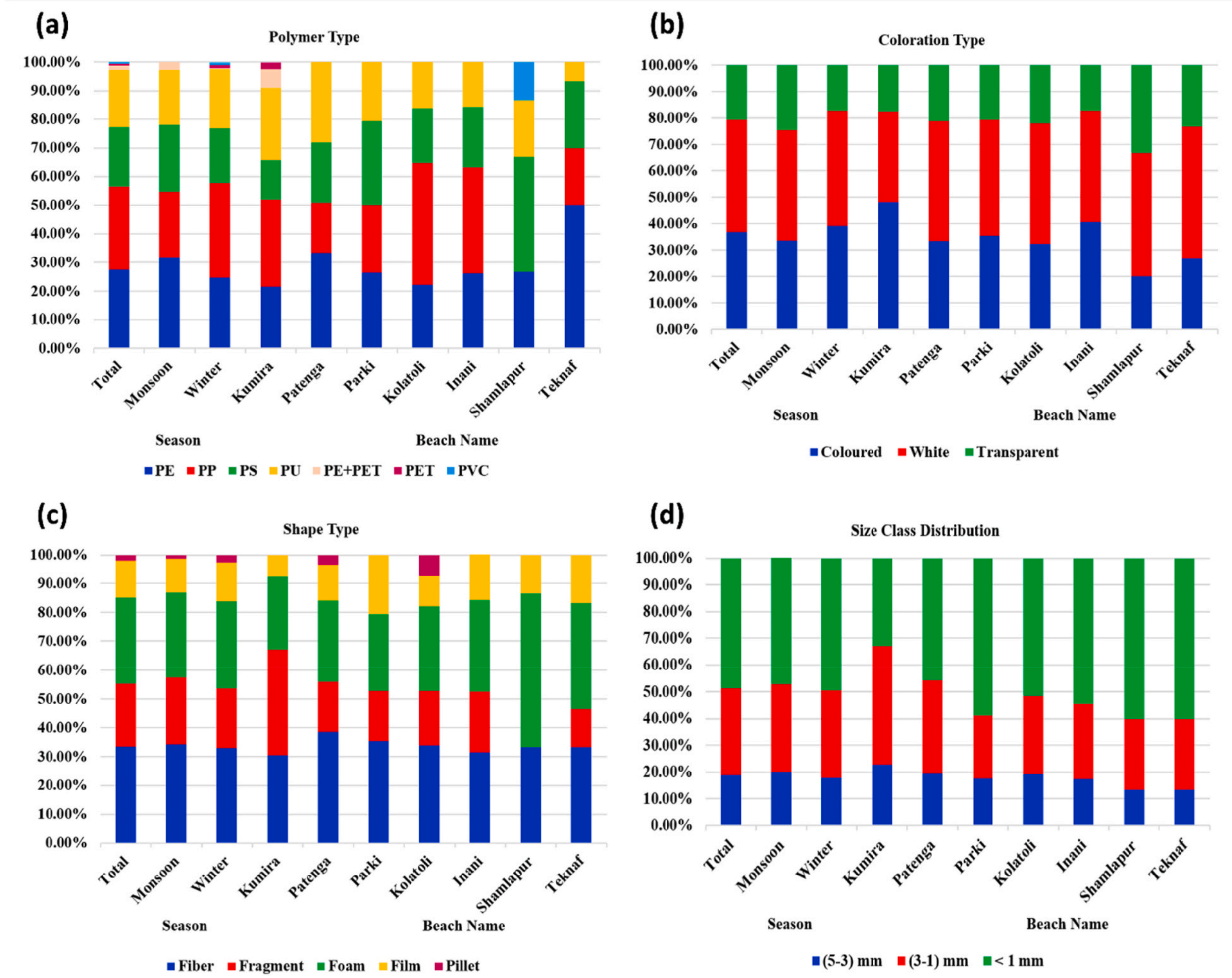

Fig. 5. Seasonal and stationwise abundance of microplastics - (a) Polymer type, (b) Coloration, (c) Shape, and (d) Size.

abundance in both the wet monsoon season and the dry winter season in this study. Presence of plastic bags, geo bags, packaging, beverage, buckets, pipes, daily household goods, ropes used in ship docking, fishing line and nets, bottle caps, container lids, textiles from beach umbrella and tourist clothing etc. are sources of PP and PE microplastic particles [49,50]. Studies conducted on sediments from the Bay of Brest from France, the Lagoon of Venice, Italy, the Sri Lankan coast, and Northern Taiwan also showed high occurrence of PP and PE in the marine environment [39,51–56].

3.3. Spatiotemporal analysis of microplastic coloration type

The sampled microplastic particles from 7 beaches in the monsoon and winter seasons were divided into 3 colour classes: coloured, white and transparent, and all three types of coloration were found both in monsoon and winter in microplastic particles (Fig. S03). Microplastic coloration type among the 7 studied beaches for both monsoon and winter is presented in bar diagrams (Fig. 5(b)).

All three types of colours were found in all of the 7 locations of sampled beaches (Fig. 5(b)). White particles were the most abundant (42.6 %), followed by coloured particles (36.8 %), and lastly transparent particles (20.6 %). Coloured and white microplastic particles showed statistically significant mean differences (p value = 0.018 and p value = 0.044 respectively) among all of the 7 stations. The seasonal analysis (Fig. 5(b)) reflected that all 3 coloration types of microplastics were available in both the monsoon and winter season. In the monsoon season, white particles were the most abundant (41.8 %), followed by coloured particles (33.6 %) and lastly transparent particles (24.7 %). In winter, white particles were the most abundant (43.3 %), followed by coloured particles (39.2 %) and

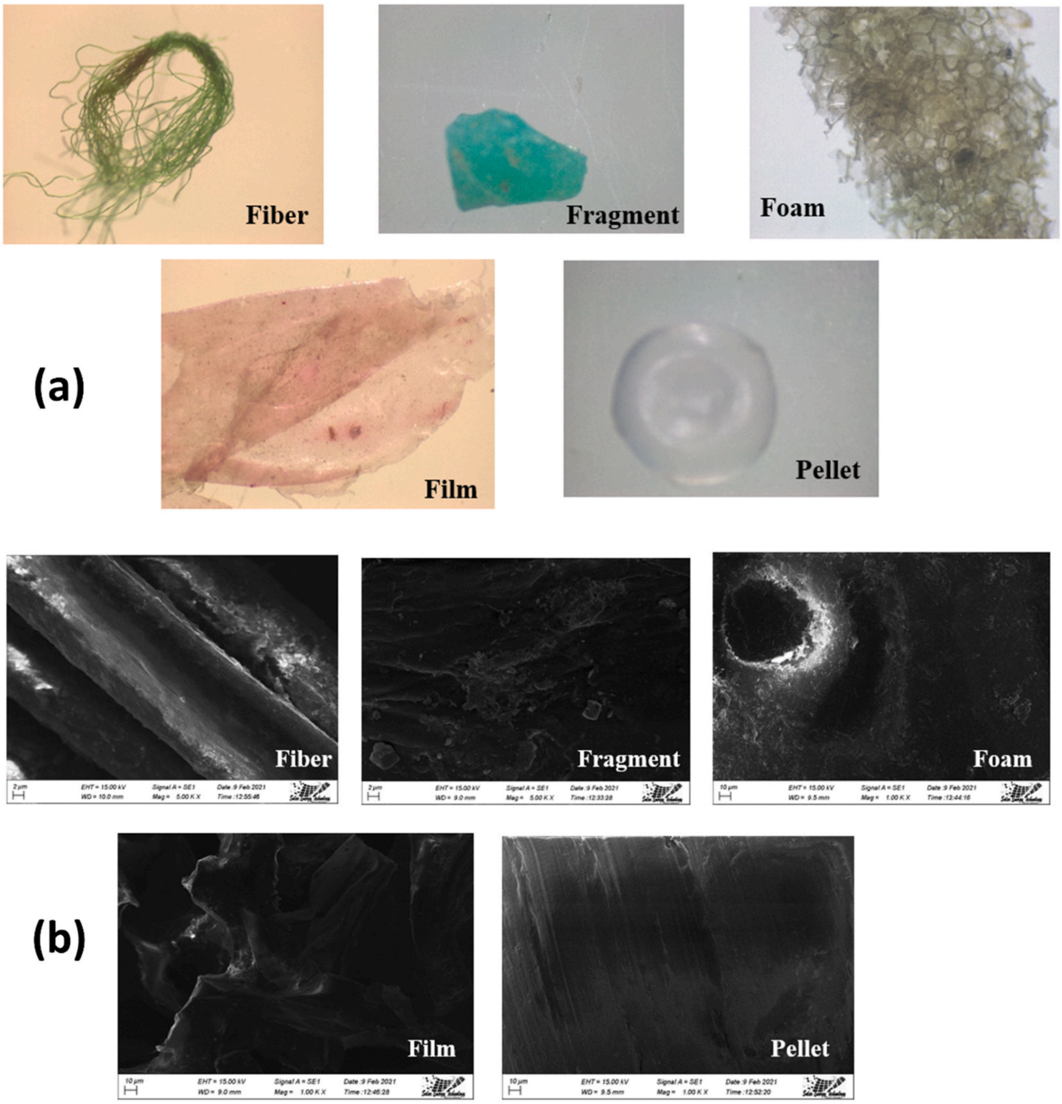

Fig. 6. Images of different shape types of microplastic particles collected from 7 beaches of the southeastern coast of Bangladesh in monsoon and winter - (a) Stereomicroscope and (b) SEM.

transparent particles (17.5 %). The abundance of coloured and white particles increased from monsoon to winter, while transparent particles showed a slight decrease from monsoon to winter. Both coloured and white particles exhibited a significant mean difference (p value = 0.017 and p value = 0.023 respectively) in abundance between the monsoon and winter seasons.

It is evident from the present study that white particles constituted the highest proportion in both the monsoon and winter seasons. Several studies conducted on sandy beaches in northern Taiwan, Hengchun Peninsula in Taiwan and Aveiro, Portugal also reported white microplastic as the most prominent and abundant type in the marine environment [57,52,53,55,58]. Colours can indicate the synthetic origin of microplastic waste and its role as a contaminant [28]. A study conducted in La Graciosa Island, Spain found that white and translucent particles were dominated by PP and PE respectively, which are the most abundant polymer type in the present study [59]. Literature suggests that marine fauna like different commercially sold fish and oysters misinterpret white, tan and yellow microplastic as zooplankton, and feed on the microplastic particles [60,61]. This can pose a serious threat to the biodiversity and environment by blocking the gastrointestinal tracts of these animals. Therefore, results found in the present study showing a high proportion of white coloured particles in both the monsoon and winter is alarming and may cause health hazards for the marine fauna of Bangladesh.

3.4. Spatiotemporal analysis of microplastic shape type

The extracted microplastic particles from 7 beaches in monsoon and winter exhibited 5 different morphological shapes: fiber, fragment, foam, film and pellet. All 5 types of shape were found both in the monsoon and winter seasons in microplastic particles and were analyzed through stereomicroscope (Fig. 6(a)) and SEM (Fig. 6(b)).

Shape can indicate their source of origin and degradation environment. The morphological shape of microplastics among the 7 studied beaches for both the monsoon and winter seasons is presented in bar diagrams (Fig. 5(c)). Fibers were the most abundant (33.5 %), followed by foam (30 %), fragments (21.8 %), film (12.6 %) and lastly pellet (2.1 %). Fiber, foam and film were ubiquitously present in all the 7 sampling locations, and fragments were also present everywhere except Shamlapur. Film was present in all the locations in more or less similar amounts. Pellet was exclusively found only in Patenga and Kolatoli. Only fiber and fragments showed statistically significant mean differences (p value = 0.004 and p value= <0.001 respectively) among all the 7 stations. Seasonal analysis (Fig. 5(c)) showed that all 5 shape types of microplastic were available in both the monsoon and winter seasons. In the monsoon season, fibers were the most abundant (34.2 %), followed by foam (29.5 %), fragments (23.3 %), film (11.6 %) and lastly pellet (1.4 %). In winter, fibers were the most abundant (33.0 %), followed by foam (30.4 %), fragments (20.6 %), film (13.4 %) and lastly pellet (2.6 %). Fibers, foam and film exhibited significant mean differences (p value = 0.006, p value = 0.023 and p value = 0.035 respectively) in abundance between monsoon and winter.

The spatiotemporal analysis of the morphological shape of microplastics showed that fibers were the most prevalent type of microplastic found in the beach sand in both the monsoon and winter seasons. Several other studies conducted in different locations worldwide such as Belgium, Dubai, Hengchun Peninsula in Taiwan, Baja California Peninsula in Mexico, Bohai Bay in China, Southern Baltic Sea, California coast in USA and also European beaches, have also reported fibers as the predominant particle type in sandy beach sediment [57,20,21,34,45,62–64].

High amounts of fibers were extracted from Kumira, Patenga and Kolatoli beaches which are known as famous tourist hotspots. Sources of high fiber concentrations in these stations can be geo bags, ropes, fishing net, beach umbrellas, tourists' clothes, sewage and laundry effluents from hotels, cruise and water sport activities etc. [21,28]. Locations sighted with the second highest particle foam are Kumira, Patenga, Kolatoli and Inani which are renowned tourist attractions for both local and seasonal tourists. The main source of foam is single use cutlery used by tourists, packaging of goods, food container, floats, footwear, toys etc. High proportion of fragments found in Kumira can be originated from heavy ship breaking activities. Pellets found in Patenga and Kolatoli are suspected to originate from the nearby construction facilities [49]. There is an inevitable danger related to the huge abundance of fiber in the marine environment in the southeastern coast of Bangladesh. Mistaken ingestion of fibers is evident by organisms in different trophic levels like zooplankton, fish larvae, turtles and even whales, which can lead to non-digestion of microplastic in the gastrointestinal tract with lethal physiological effects [65–69].

3.5. Spatiotemporal analysis of microplastic size class distribution

Size can indicate the pre-consumer form and weathering environment of a primary or secondary microplastic. In the present research, the sampled microplastic particles from 7 beaches in the monsoon and winter seasons were divided into 3 different size classes, 5-3 mm, 3-1 mm and <1 mm. Size distribution of microplastics among the 7 studied beaches for both monsoon and winter is presented in bar charts (Fig. 5(d)).

Particles falling in all 3 size classes were found throughout all 7 sampled beaches (Fig. 5(d)). Particles <1 mm constituted nearly half of the total microplastics load and were the most abundant (48.5 %), followed by particles of 3–1 mm (32.6 %) and lastly particles of 5–3 mm (18.8 %). Two size classes measuring 5-3 mm and 3-1 mm showed statistically significant mean differences (p value = 0.002 for both) among all the 7 stations. All the 3 size classes of microplastic were available in both monsoon and winter seasons (Fig. 5(d)). In the monsoon season, particles <1 mm constituted nearly half of the total microplastics found, and were the most abundant (47.3 %), followed by particles of 3–1 mm (32.9 %) and lastly particles of 5–3 mm (19.9 %). During winter, particles <1 mm predominantly constituted half of the total microplastics found in the winter season and were the most abundant (49.5 %), followed by particles of 3–1 mm (32.5 %) and lastly particles of 5–3 mm (18.0 %). Smaller particles in the size class of 3–1 mm and <1 mm exhibited a significant mean difference (p value = 0.041 and p value = 0.009 respectively) in abundance between monsoon and winter.

It is notable from the present study that in both the monsoon and winter season in all the stations regardless of the touristic, non-touristic or commercial nature of the beaches, particle abundance was seen to be increasing with decreasing particle size. In other words, there was a negative correlation between particle size and particle abundance in the present research. This finding is compliant with other studies reporting on microplastic sizes conducted in the Southern Baltic Sea, Bohai Bay in China and Nakdong River in South Korea [34,45,70]. Each of the studies exhibited a higher presence of smaller sized particles or a peak around the smaller size class in the sediment. Increasing distance from a potential source of plastic makes the microplastic particles more vulnerable to an increased degradation rate and therefore they appear in smaller size ranges at distant locations [45]. In the present study, coastal beaches were chosen as the sampling locations, and they are the marginal land point situated furthest from the pollution sources of the inland area. Therefore, the dominance of smaller size microplastics (<1 mm) in the southeastern coast of Bangladesh is not an exception and is in line with other studies.

High availability of smaller sized particles (<1 mm) in the southeastern coastal beaches of Bangladesh is a matter of serious environmental and biological concern. The smaller sizes of microplastics make them more bioavailable to lower trophic level organisms making them a potential threat for filter feeders [69]. Smaller plastic debris has a large surface area making it an efficient absorber and vector of pollutants like chemical toxicants, heavy metals and POPs. It can lead to severe toxicological effects on organisms upon ingestion and bioaccumulation [71,72].

4. Conclusion

This study is the first of its kind to assess the spatiotemporal variation of microplastic debris along the southeastern coastal beaches of Bangladesh. The studied beaches report the ubiquitous presence of microplastic debris in all the sampled locations with distinct temporal variations and spatial distribution. The total particle abundance of microplastics is 242.86 particles/kg dw and the seasonal variation is 208.57 particles/kg dw for the monsoon and 277.14 particles/kg dw for the winter season. A higher degree of microplastic contamination and polymer diversity was observed in the dry season of winter due to lower levels of precipitation, resulting in less removal of sediment particles by surface runoff. The size, shape, colour and polymer type of microplastics in the monsoon and winter seasons were more or less similar in chronological order but were varying in degree. Obtained results indicated that the dominating factors affecting microplastics concentration in beach sediments of the southeastern coast of Bangladesh might have originated from anthropogenic sources such as urbanization, industrialization and tourism. Sampling in higher temporal and spatial resolution is necessary for a more accurate estimate of the trends of microplastic pollution. Future research is needed to understand the transportation, fate and behavior of microplastics and their ecological and physiological effects on coastal and marine ecosystems. Providing government subsidies for plastic recycling, promoting biodegradable products rather than plastic manufacturing, and reward based beach-cleaning programs run by local authorities should be adopted encourage people to prevent littering. Beach cleaning should be done more rigorously during the dry winter season since more microplastics are likely to be encountered during this time. Practicing the 4Rs strategy of waste management- Refuse, Reduce, Reuse, Recycle can mitigate microplastic pollution to a great extent. The present study is expected to generate baseline data for improved management of microplastic litter on coastal beaches and their watersheds in Bangladesh and to help achieve the goal of SDG-14 by reducing marine pollution and safeguarding marine ecosystems.

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Animal experimental ethics

The authors would like to confirm that they did not harm any animal or human during the entire course of the present research.

Data availability statement

Data associated with the study has not been deposited into a publicly available repository and data will be made available on request.

CRediT authorship contribution statement

Jarin Tasnim: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Md Kawser Ahmed:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Kazi Belayet Hossain:** Visualization, Supervision, Software, Methodology, Formal analysis, Conceptualization. **Muhammad Saiful Islam:** Visualization, Validation, Software, Resources, Investigation, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Jarin Tasnim reports financial support was provided by National Science and Technology (NST) fellowship, Ministry of Science and Technology, Government of the People's Republic of Bangladesh and International Centre for Ocean Governance (ICOG) merit scholarship. If there are other authors, they 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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e21864.

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