Chapter- 1

Introduction

1.1 Background of the study

Microplastics, smaller than 5 mm, were originally described in 1972 as an aquatic contaminant, and now it has subsequently become a global issue due to possible harmful effects on the environment, human health and food security (Carpenter and Smith, 1972; Crew et al., 2020). Except for high-density polymers like polycarbonate (PC), polyvinylchloride (PVC), and polyethylene terephthalate (PET), the majority of microplastics float on the ocean's surface (Banik et al., 2022). Due to their stability, pervasiveness, and impact resistance, these floating microplastics remain in the marine environment for prolonged period of time and cannot be readily removed (Geyer et al., 2017). If sufficient action is not implemented to lessen the use of plastic goods, each year the quantity of plastic entering the ocean will increase to 16 million tons by 2030 and approximately 32 million tons by 2050. By 2050, it is also estimated that there will be more plastic in the ocean environments in terms of weight rather than fish (Neufeld et al., 2016).

Plastic goods are often referred to as primary microplastics when they are extensively employed as raw particles, medicines, cosmetics, or cleansing scrubs (microbeads and glitters) in the manufacturing of plastics and cleaning goods (Hahladakis et al., 2018; Camacho et al., 2019). The majority of plastic products are broken down into small, microscopic particles (< 5 mm) as a result of mechanical degradation caused by action of waves, photochemical oxidation by UV-B radiations, as well as biological degradations, which are referred as secondary microplastics (Corcoran et al., 2015). Many point and non-point sources, including inadequate disposal, losses during maritime activity, sewage systems, industrial byproducts, tourist activity, roadside dust (vehicle tires, grease, etc.), restaurants and beach adjacent hotels, motels, which are driven by atmospheric outfall, riverine output, and storm water activity, contribute to the introduction of plastics and their degraded products into the oceans (Corcoran et al., 2015; Li et al., 2020). The washing process of synthetic textiles is a major source of synthetic fibers in aquatic environments, accounting for approximately 35% of the global discharge of microplastics into the sea (Boucher and Friot, 2017). The widespread prevalence of microplastics has already been documented in the beaches

(Kunz et al., 2016; Lots et al., 2017), open ocean (Cozar et al., 2014), seashore (Turra et al., 2014), estuaries (Browne et al., 2010), deep-sea sediment (Van Cauwenberghe et al., 2013), remote islands (do Sul et al., 2009), and mudflats (Lo et al., 2018) from various parts of the world.

It has been reported that about 80-90% of the plastic that ends up in the ocean derives from land-based sources, with the residual coming from marine-based sectors including aquaculture, fishing, and shipping as well as private vessels (Gallo et al., 2020). Plastic fragments have been found all over the world, including in remote and pristine areas far from known point sources (e.g., Antarctica (Convey et al., 2002)), Arctic sea ice (Bergmann et al., 2019), and deep sea (Courtene-Jones et al., 2017). The literature reports that more than 660 marine species around the world are known to be impacted by the plastic wastes (Claessens et al., 2013). The accumulation of microplastics is hazardous to both human health and marine ecosystem and earlier research has shown that both marine vertebrates and invertebrates, such as zooplankton (Sun et al., 2017), molluscs (Naji et al., 2018), fish (Abbasi et al., 2018; Schmid et al., 2018), and seabirds (Provencher et al., 2018), intake and absorb microplastics through various mechanisms. Microplastics are engulfed by aquatic organisms while accidentally taking them during filter- or deposit-feeding, imagining them as prey, or devouring prey that already includes microplastics (Gallo et al., 2020). Furthermore, the toxicity of plastics, including additives made of plastics and adhered contaminants (such as trace elements, endocrine-disrupting compounds, and POPs) absorbed in plastic particles, may have an effect on higher trophic level species as well as human through the process of biological accumulation as well as biomagnification by means of the food webs (Andrady, 2011; Wang et al., 2018). Microplastics have been shown to cause oxidative damage and histological alterations in organisms, alter food choice and movements, delay the incubation of eggs and hatching, and reduce the rate of growth and survival (Carson et al., 2011; Lee et al., 2013; Cole et al., 2015; Lönnstedt and Eklöv, 2016; Lo and Chan, 2018; Wang et al., 2019; Luan et al., 2019). Therefore, the effect of microplastic should be evaluated in aquatic ecosystem to determine microplastic pollution.

Both macroplastics and microplastics from inland and maritime human activities are concentrated in considerable quantities at shorelines all across the world (Ryan et al., 2009). According to Browne et al. (2007), shoreline regions, particularly beaches, are habitats that provide the optimum circumstances for the breakdown of macroplastics into microplastics. These factors include high levels of radiation and warmth, extreme wind, and waves. Other elements that affect the fragmentation, accumulation, and spread of microplastics include climate and seasonality (Browne et al., 2007). One of the primary sources of microplastics in coastal regions is the increase in rainfall connected to areas near river mouths (Kang et al., 2015; Karthik et al., 2018). Many areas around the world have reported widespread distribution of microplastics in shoreline sediment, including the western Gulf of Lion, the Northwestern Mediterranean Sea (Constant et al., 2019), Brazil (Martinelli Filho and Monteiro, 2019), China (Qiu et al., 2015), Germany (Liebezeit and Dubaish, 2012), Portugal (Martins and Sobral, 2011), Canada (Mathalon and Hill, 2014), Italy (Fischer et al., 2016), and Orkney (Blumenröder et al., 2017).

Patenga Sea Beach of Chattogram is one of the most attractive and well-known sea beaches of Bangladesh. A great number of people assemble here every day for enjoying the sunsets and the relaxing wind. However, seaside stalls, restaurants, and tourist activities generate a huge amount of plastic debris, which is frequently discarded on the beach. Many unlicensed shops are currently damaging natural surroundings and polluting the beach with rubbish and other wastes. So far, no scientific investigation on microplastic pollution along the whole coastline beach sediment at Patenga beach has been conducted. Therefore, this study was the first step in revealing the identification and quantification of microplastics at Patenga beach sediment, which would assist in the establishment of guidelines for reducing plastic pollution.

1.2 Significance of the study

- This study represents a thorough overview of abundance and distribution of microplastics in the sediment of Patenga Sea Beach, Chattogram.
- Present study shows a variation in the abundance of microplastics between tourist and non-tourist areas along the Patenga Sea Beach.
- Moreover, the present study also analyses seasonal differences (Spring, Summer, Rainy, Winter) of microplastics abundance and identifies the physiochemical characteristics (types, shapes, colors, sizes) which will be helpful in the development of management guidelines to lessen plastic contamination.

1.3 Objectives of the study

- Estimation of the current status of microplastics abundance in the sediment of Patenga Sea Beach;
- Characterization of the types, shapes, colors and sizes of microplastic particles in the beach sediment of Patenga, Chattogram; and
- Evaluation of the seasonal differences of microplastics abundance in the beach sediment.

Chapter-2

Review of Literature

2.1 Microplastics concentration in sea water and beach sediment

Over the past ten years, research on marine microplastics has become one of the most significant fields in marine pollution. Although there are currently more than hundred studies on marine microplastics pollution covering beaches, central ocean gyres, continental shelf regions, and harbors all over the world, but the spatial coverage is constrained by the small number of research centers that focus on microplastics (do Sul and Costa, 2014). The regions with the greatest concentrations of microplastic fibers and other particles are those along the shore, in harbors, and close to industrial production facilities (Norén, 2008; Claessens et al., 2011; Desforges et al., 2014). Both primary sources (which originated from facial and hand cleansers, scrubbers used in air-blasting, cosmetic products, and the manufacture waste from plastic processing plants) and secondary sources (which is derived from disintegration of larger plastics because of physical and chemical effects) contribute to the occurrence and distribution of microplastics to the world's marine environments (Zitko and Hanlon, 1991; Gregory, 1996; Barnes et al., 2009).

In the surface seawater of Sanggou Bay, China, Xia et al. (2021) conducted a research on microplastic pollution. They found that the average microplastics abundance was 20.06 ± 4.73 items/L, with the majority of the particles being granular and transparent. According to Zhu et al. (2018), microplastics abundance in surface seawater of China's North Yellow Sea was 545 ± 282 items/m^3, with films and fibers being the most abundant microplastic categories. In the surface water of San Francisco Bay, microplastic concentrations were found to range from 15,000 to 2,000,000 particles per km^2 (Sutton et al., 2016).

In another study, Kor et al. (2020) discovered abundance of microplastics ranging from 138.3 ± 4.5 to 930.3 ± 49.1 particles/kg in Oman Sea beach sediment, with fibers and fragments being the most abundant kinds of microplastics. According to Patchaiyappan et al. (2020), the average abundance of microplastics from the eight stations studied along the South Andaman coastline was 414.35 ± 87.4 particles/kg of beach sediment. In a research by Patchaiyappan et al. (2021) on an Indian coastal beach in Odisha, the average abundance of microplastic particles was 258.7 ± 90.0 particles/kg of beach sediment. Another study investigated abundance of beach sediment at Suchada (SD), Laem Charoen (LM), and Saeng Chan (SC) beaches in the Rayong province of Eastern Thailand. The average abundance of microplastics in three beaches was 568.33 ± 153.05 items/ kg of on a dry weight basis (Prarat et al., 2020).

2.2 Microplastics in deep sea sediment

Deep sea sediments have gained attention as a possible sink for microplastics in the marine environment (La Daana et al., 2019). These small plastic particles have been accumulating in the ocean for many years and have been found in sediments on beaches, in the sublittoral zone, and throughout the water column. However, it has never been determined if the presence of microplastics in sediments is restricted to accumulation in hot places such as the continental shelf, or whether they are also prevalent in deep-sea sediments (Van Cauwenberghe et al., 2013).

In a research on the Atlantic Ocean and the Mediterranean Sea, Van Cauwenberghe et al. (2013) discovered plastic elements in the micrometer range in deep-sea sediments extracted from four sites covering various deep-sea ecosystems with depths ranging from 1100 to 5000 m. This research's findings showed that microplastic contamination has reached throughout the world's deep seas and oceans, which is isolated and mostly unexplored. Another study on the deep sea sediments of the Pacific Ocean revealed an average abundance of 240 microplastics per kg dry weight of sediment (Zhang et al., 2020). In a research by Bergmann et al. (2017), microplastics abundance was found of 42-6595 particles/kg in the Arctic deep sea sediments from the HAUSGARTEN Observatory, where nine sediment samples were collected at depths ranging from 2340 to 5570 m.

2.3 Microplastics in freshwater sediment

Microplastics pollute both upland and coastal waterways in nature. The risk posed by microplastics to inland water habitats is evaluated in relation to a number of different factors, including biological accumulation and biomagnification, sedimentation, spreading, etc. (Xu et al., 2020). Moreover, rivers are also thought to be the primary source of plastic waste for seas and oceans (Eerkes-Medrano et al., 2015; Schmidt et al., 2017). However, inland waterways have significantly gained far less attention than marine waters to far (Akdogan and Guven, 2019). Although there is an expanding body of research on plastics in freshwater (Blair et al., 2017), information on microplastic concentrations and their effects on freshwater environment and biota is very poor (Wagner et al., 2014; Akdogan and Guven, 2019).

In the Atoyac River basin of Mexico, a study by Shruti et al. (2019) discovered that the mean microplastics abundance in the Zahuapan river, confluence zone, Atoyac River, and Valsequillo dam was 1633.34 ± 202.56, 833.33 ± 80.79, 1133.33 ± 72.76, and 900 ± 346.12 items/kg, respectively. The quantities of microplastics in the sediments of the Sürgü Dam Reservoir in Turkey ranged from 760 to 1,440/ m^2, with fibers being the most common form (Turhan, 2021). Researchers Di and Wang (2018) looked at the amount of microplastics contamination in sediments from the Three Gorges Reservoir (TGR) in China. Microplastic abundance in the sediments was 25 to 300 n/kg on a wet weight (ww) basis along the Three Gorges Reservoir (TGR).

Research conducted in the Vembanad Lake of India showed an abundance of microplastics that ranged from 96-496 particles/ m^2, with a mean abundance of 252.80 ± 25.76 particles/ m^2 (Sruthy and Ramasamy, 2017). A study by Vaughan et al. (2017) in the sediments of an urban lake, a shallow eutrophic lake in the center of Birmingham, UK, where the researchers found that the highest concentrations of particles reached 25-30 per 100 g of dried sediment. The two most prevalent kinds of microplastic found were fibers and films. Another analysis of microplastic contamination in freshwater lake sediments was conducted in the Northwest Himalaya of India, and the results showed that there were 606 ± 360 particles/ kg of dry sediment (Neelavannan et al., 2022).

2.4 Microplastics in estuarine sediment

Microplastics are a growing pollutant of global concern because of their widespread dispersion via numerous channels. Estuaries are a significant channel for terrestrial microplastics to infiltrate the seas via rivers (Xu et al., 2020). The estuary is the meeting place of freshwater from rivers and saltwater from the seas, where suspended contaminants and particles from rivers deposit quickly into the sediment due to the combined impact of hydrological and sediment transport dynamics (Chapman and Wang, 2001; Yao et al., 2016).

The quantity of microplastics in the Changjiang Estuary of China was mapped in the research by Peng et al. (2017). The concentration ranged from 20 to 340 items/ kg, with the mean abundance being 121 ± 9 items per kg of dry weight. In a research on the west coast of Thailand, Jiwarungrueangkul et al. (2021) discovered that microplastic abundance varied between 300-900 and 33-400 items/kg dry weight in the dry and wet seasons, respectively. Another experiment was carried out in the sediment of the Jagir estuary and Wonorejo shoreline in Surabaya of Indonesia, where the abundance was 590 particles/kg dry weight (Firdaus et al., 2020). As a consequence, estuarine sediments are the most worried region for microplastic deposition. So, numerous research is required to collect data for the estimation of microplastic discharge from rivers into the oceans through estuaries as every estuary has its distinct physicochemical, topographical, and biological properties, including the past and continuing sediment pollution.

2.5 Microplastic pollution in the beach sediment of Bangladesh

Bangladesh is one of the fastest growing economy in Asia. It is one of the most densely populated nations in the world, with more than 166 million people living on 148,460 km^2 of land (Hossain et al., 2021). Around 3000 tons of plastic garbage are produced daily in Bangladesh, accounting for 8% of the entire amount of waste produced (Hossain et al., 2021). Microplastics are currently found across the Earth's geographical regions, in both marine and terrestrial ecosystems. The final phase of the plastic waste cycle is marine ecosystems, and marine sediments are increasingly thought to be a sink for plastic trash, with potentially negative consequences on seabed ecosystems (Phuong et al., 2021).

In the investigation on the presence and geographical distribution of microplastics in the Cox's Bazar beach sediments, Rahman et al. (2020) discovered a mean abundance of 8.1 ± 2.9 particles/kg, with fragment type microplastic predominating. Hossain et al. (2021) conducted another investigation on the prevalence and properties of microplastics in sediments from Cox's Bazar, the longest natural beach in the world. They found the average abundance was 368.68 ± 10.65 items/ kg and fiber was the most prevalent kind of microplastic. Microplastics were also identified from the Saint Martin’s Island by Tajwar et al. (2022), with mean abundance of 20.8 items per 100 g.

Tajwar et al. (2022) conducted another study on the prevalence of microplastics in sediment samples from coastal regions of Cox’s Bazar and found that fibrous microplastics accounted for 70% of all microplastics. In the Moheshkhali channel of Bay of Bengal, Al Nahian et al. (2023) conducted a study on the prevalence of microplastics, finding that the average concentrations ranged from 6.66 to 138.33 particles/ m^2. Microplastic assessment was also conducted on Kuakata Beach sediments by Banik et al. (2022). According to the findings, the average microplastics in the beach sediment were 232 ± 52 items/ kg of dry weight, with fiber type microplastic predominating at each sampling point.

However, very little investigation on microplastic pollution in Bangladesh has been conducted. Therefore, the aim of the study was to identify and quantify the abundance and types of microplastics in the beach sediment from Patenga Sea Beach, a crowded sea beach in Chattogram region, Bangladesh.

Chapter-3

Materials and Methods

3.1 Study area

One of Bangladesh's glorious and well-known beaches is Patenga Beach, stretches for miles close to where the Bay of Bengal and the river Karnaphuli meet. Currently, the coastal ecosystem of Patenga is becoming contaminated as a result of trash from illegal establishments and other wastes discarded by tourists. As a result, this study was carried out at the Patenga beach sediment to investigate microplastic pollution. For the purpose of the study, four different sampling stations were selected where two stations were denoted as tourist area (Abir point and Patenga beach) and other two stations as non-tourist area (Bay terminal and Char para). In the study area, the GPS coordinates was recorded and map of the study area is given in the figure 1.

1. Abir point (13^{o} 38′ 21‟N and 26^{o} 50′ 38‟E)
2. Patenga beach (56^{o} 19′ 43‟N and 41^{o} 28′ 29″E)
3. Bay terminal (22^{o} 14′ 38″N and 37^{o} 49′ 18″E)
4. Char para (30^{o} 42′ 16″N and 16^{o} 73′ 19″E)

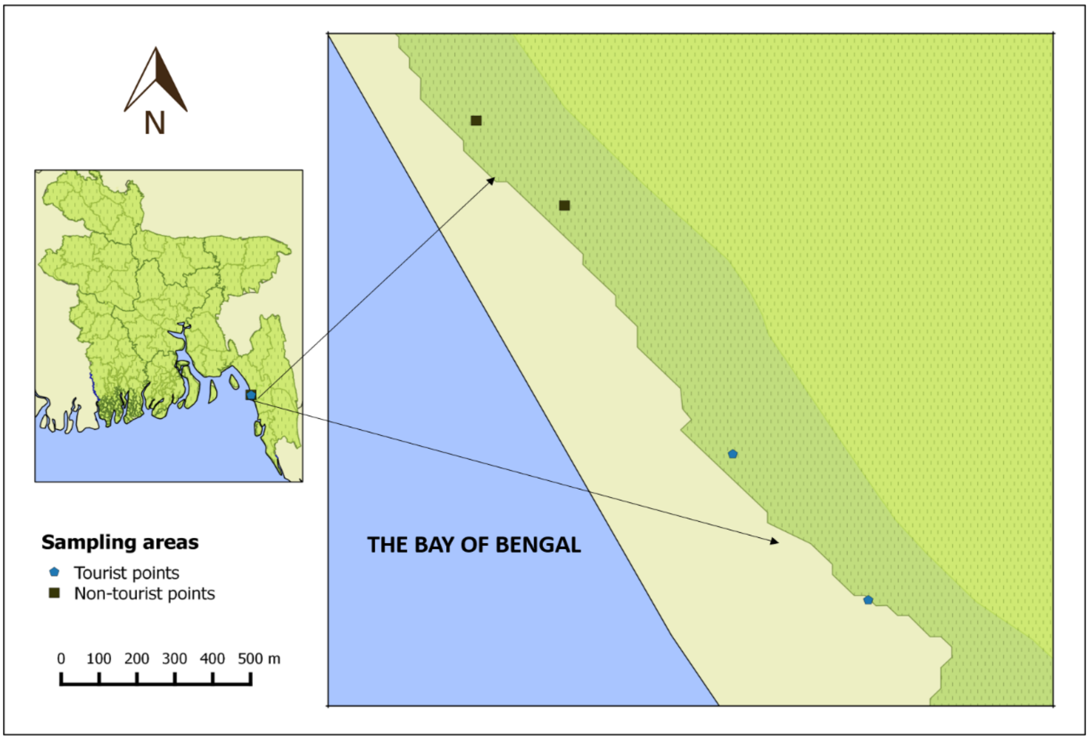

Figure 1. Map of study area

3.2 Sampling protocol

A total of 72 surface sediment samples were collected from four sampling locations, each with triplicates, in four seasons (Spring, Summer, Rainy, and Winter) from January 2022 to December 2022. All of the samples were obtained from the strandline during the lowest low tide of the sea. A transect of 100 m was measured in each sampling station. Surface sand samples were extracted by making a quadrate with the help of a ribbon and measured through a measuring scale (15cm× 15cm ×5cm) (de Carvalho and Neto, 2016; Li et al., 2018). Scale was pressed into the quadrates and all the sediments within the quadrate were carefully taken with using a shovel. Collected sand was subsequently placed into zipper bags. The sample bags were then securely packaged and returned to the Aquatic ecology laboratory of Chattogram Veterinary and Animal Sciences University for further analysis.

3.3 Laboratory analysis

This study followed the laboratory procedure of the National Oceanic and Atmosphere Administration (NOAA) with slight modifications. Laboratory analysis includes some steps such as weighing and drying, density separation-I, wet per oxidation (WPO), density separation-II, filtration and identification.

3.3.1 Weighing and drying

- Firstly, 200 g of collected sand samples were weighted using a precision balance (PS 1200. R2) and then taken into a 500 ml beaker.
- Every beaker was put into a hot air oven (Binder GmbH: ED 115) set to 90 °C for 24 hours, or longer if more sample dryness was needed.

3.3.2 Density separation-I

With slight modifications, density separation-I process of this study was followed by Coppock et al. (2017).

- For each 500 ml beaker of dried sand samples, 150 ml of $ZnCl_2$ (1.5 g cm^{-3}) salt solution was applied.
- In order to separate the floating debris by flotation, the samples were then left overnight after being continually agitated for few minutes with a spatula.
- Following that, a 0.3 mm stainless steel mesh sieve was used to filter all of the floating solids, and they were all transferred into a 500 ml beaker.

3.3.3 Wet per oxidation (WPO)

Wet per oxidation was carried out to break down the organic substances contained in the sample.

- The 500 ml beaker holding the 0.3 mm size of collected materials was filled with 20 ml of aqueous 0.05 M Fe(II).
- 20 ml of 30% hydrogen peroxide (H_2O_2) was then added, and the mixture was given a few minutes to settle at room temperature.
- After a while, a magnetic bar was added, and foil paper was placed on top of the beaker.
- The beaker was placed on a hotplate (HSD 180) and heated to a temperature of 75°C for 30 minutes. The beaker was taken out from the hotplate and put in the fume hood until the surface of the liquid started to bubble with gas.
- Then, a further 20 ml of 30% H_2O_2 was added if any kind of natural organic material remained and the procedure was repeated until none was discovered.
- To increase the density of the aqueous solution, 6 g of salt (NaCl) was added to each 20 ml of sample.
- In order to dissolve the salt, the liquid was heated to 75°C once more.

3.3.4 Density separation-II

The density separation-II procedure from Coppock et al. (2017) was also followed in this study with some modifications.

- The WPO solution was added to a density separator, composed of a 5-cm-diameter PVC pipe that is 1-foot long, and a ball bulb was placed in the middle of the pipe to make a distinction between the low-density solution and the high-density solution.
- 150 ml of filtered $ZnCl_2$ solution was added to each sample as floatation media before being placed into the density separator.
- The system was left to settle for overnight or until the debris from supernatant was completely gone.
- Undissolved residues sank at the bottom of the density separator, allowing less dense particles to be separated and a layer of microplastics floated upward.
- The headspace supernatant was collected in beakers after the valve had been properly sealed.

3.3.5 Filtration

A vacuum pump filter machine (Rocker 300) was used to filter the supernatant obtained from the density separator using cellulose nitrite filter paper with a pore size of 0.45 µm and a diameter of 47 mm. After filtering, the filter paper was put in a fresh petri dish and seen under an electron microscope (OPTIKA, B-192, Italy).

3.3.6 Identification of microplastics

- The filter paper was examined using a stereo microscope and microplastics were identified and counted at 40 × magnification according to Masura et al. (2015).
- The microplastic images were captured with a digital camera (OPTIKA-CB3) attached to the microscope.
- Morphological parameters such as color, shape, size, type and detailed criteria given in the study of Viršek et al. (2016) were used to identify the microplastics.
- Microplastics can be categorized into six different types, according to Viršek et al. (2016): fragments (rigid, dense, pointed edges and an unequal shape with variety of colors), filament (long or short, in various layers of thickness and colors), film (thin, flexible, primarily transparent), foam (soft, irregular shape), pellets (irregular, round forms, and generally bigger in size), and granules (in

comparison with pellets, it has a regular round form, smaller in size, and comes in natural colors).

3.3.7 Size measurement of microplastics

By calibrating the stage micrometer scale under a stereo microscope, identified microplastics were measured with the use of Proview digital camera software.

3.4 Microplastic abundance determination

The abundance of microplastics in a sample was determined using the protocol of Hossain et al. (2021). The abundance of microplastics in sediment samples was estimated for each station by dividing the number of isolated microplastics particles by the sediment sample's dry weight (kg). Then the means of the microplastic particles in the beach sediments were calculated (items/kg of dry weight samples).

3.5 Statistical analysis

Microsoft Excel was employed to examine percentage data on the size, shape, type and color of microplastics. An independent sample t-test was carried out to compare microplastic abundance between tourist and non-tourist areas over the four sampling seasons. Then the mean abundance was also calculated. A one-way ANOVA was used to examine the variance in total microplastic abundance among sampling sites. For statistical analysis, IBM SPSS statistics 26 software was employed.

Chapter-4

Results

4.1 Abundance of microplastics

4.1.1 Spatial variation of microplastics abundance

Microplastics were found in all of the 72 samples collected from Abir point, Patenga beach, Bay terminal, and Char para. In this study, Abir point and Patenga beach were designated as tourist areas, while Bay terminal and Char para were designated as non-tourist areas. This study discovered that the microplastics abundance in four stations decreased in the following order: Abir point > Patenga beach > Char para > Bay terminal. Microplastic abundance varied from 4.44 to 11.81 items/kg sediment, where Abir point had the highest abundance (11.81±0.87 items/kg) and Bay terminal had the lowest (4.44±0.98 items/kg) (Figure 2).

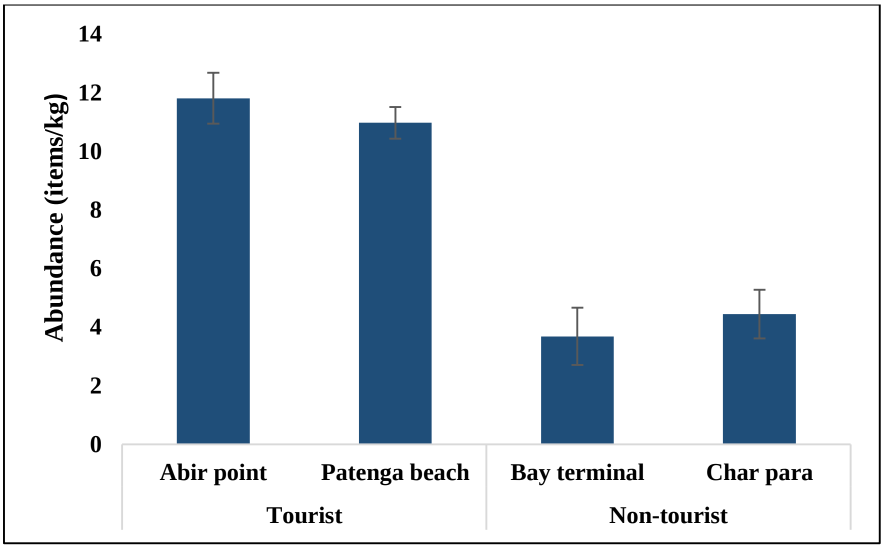

Figure 2. Spatial variation of microplastics abundance

An independent sample t test was run to determine abundance variation between tourist and non-tourist area where there was a significant variation exists ($P < 0.05$). Further, this study stated that tourist area had higher abundance (11.39 items/kg) over the non-tourist area (4.06 items/kg).

4.1.2 Seasonal differences of microplastics abundance

The occurrence and distribution of microplastics in sediment samples collected from tourist and non-tourist areas during the spring, summer, rainy, and winter seasons are presented in figure 3. In this research, tourist areas (11.92±0.54 items/kg) had higher microplastics abundance than non-tourist areas (7.08±0.73 items/kg) during the spring season. In contrast, the abundance of microplastics was lower both in tourist (1.53±0.42 items/kg) and non-tourist (20±0.37 items/kg) areas in winter season. Microplastic abundance in summer was nearly related with the rainy season (Figure 3).

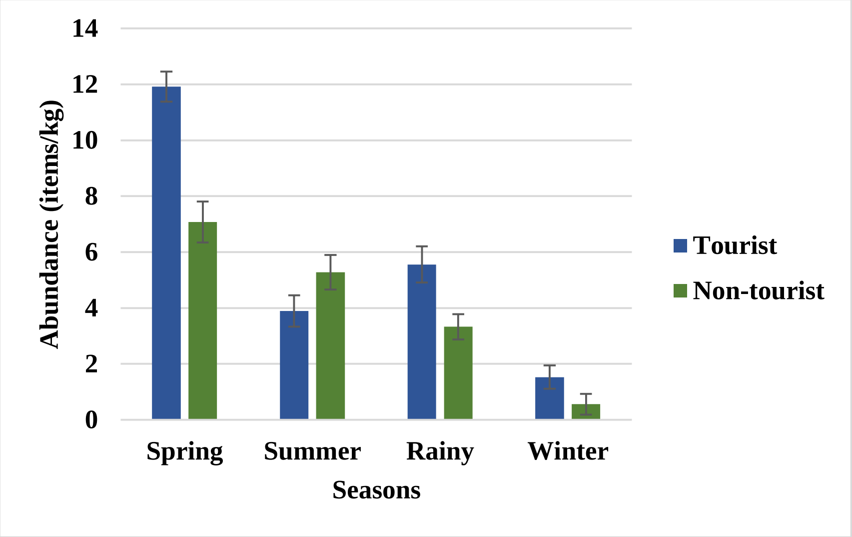

Figure 3. Seasonal differences of microplastics abundance among sampling sites

A one-way ANOVA test was employed to determine the mean variation of microplastics abundance among the seasons (Figure 4). There was a significant variation observed among the seasons in terms of microplastics abundance ($P < 0.05$). Microplastics abundance in spring was the highest and significantly varied from winter season.

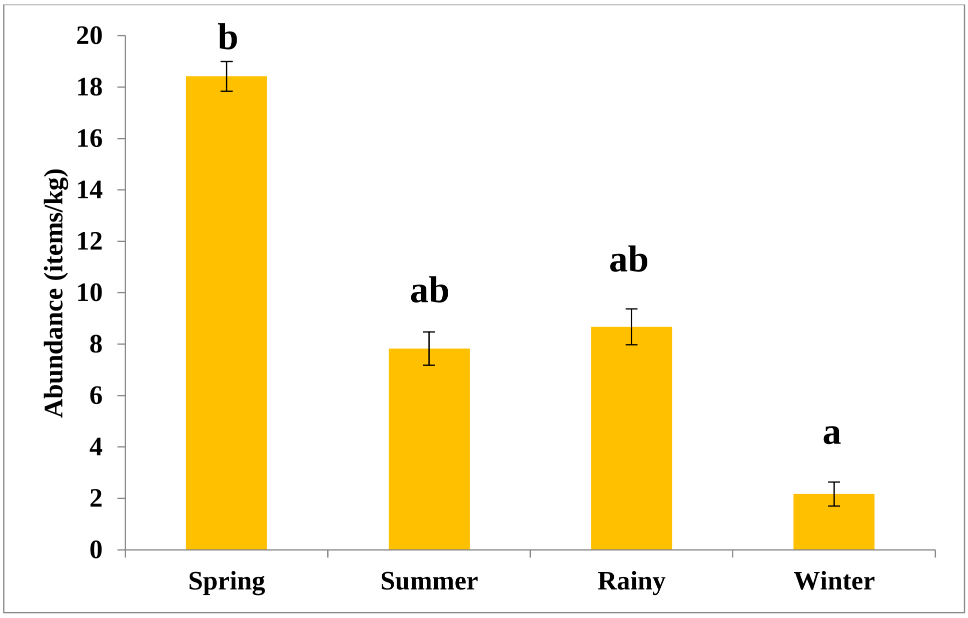

Figure 4. Seasonal differences of microplastics mean abundance

4.2 Physiochemical characteristics of collected microplastics

The collected microplastics were categorized into various types, shapes, colors, and sizes. In this study, variety of types, including fragments, filaments, granules, and pellets were identified. In case of size classes, five size ranges were recorded: 300 to < 500 µm, 500 to < 1000 µm, 1000 µm to < 2 mm, 2 mm to < 3 mm, and 3 mm to < 5 mm. Additionally, a variety of colors (red, blue, yellow, black, brown, green, transparent) and shapes (angular, irregular, rectangular, cylindrical, elongated, round) were identified.

4.2.1 Type features

Four distinct sampling stations yielded with five different types of microplastics (Figure 5). The most common type of microplastics, comprising 53.74% of the total amount discovered, were fragments, followed by filaments (40.92%), films (2.85%), granules (1.78%), and pellets (0.71%), respectively (Figure 6). The maximum (33.11%) number of fragments was found in the sample from Patenga beach and the minimum (18.54%) was found in the sample from Char para. On the contrary, the maximum number (36.52%) of second most dominant microplastic (filaments) was found in the sample from Abir point, whereas the minimum (13.04%) was found in the sample from the Bay terminal area.

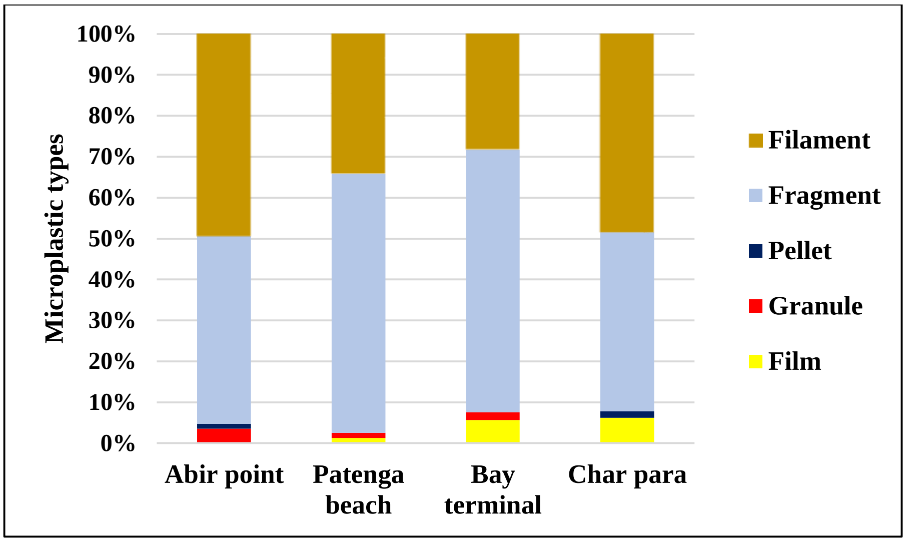

Figure 5. Percentage of microplastics types among sampling sites

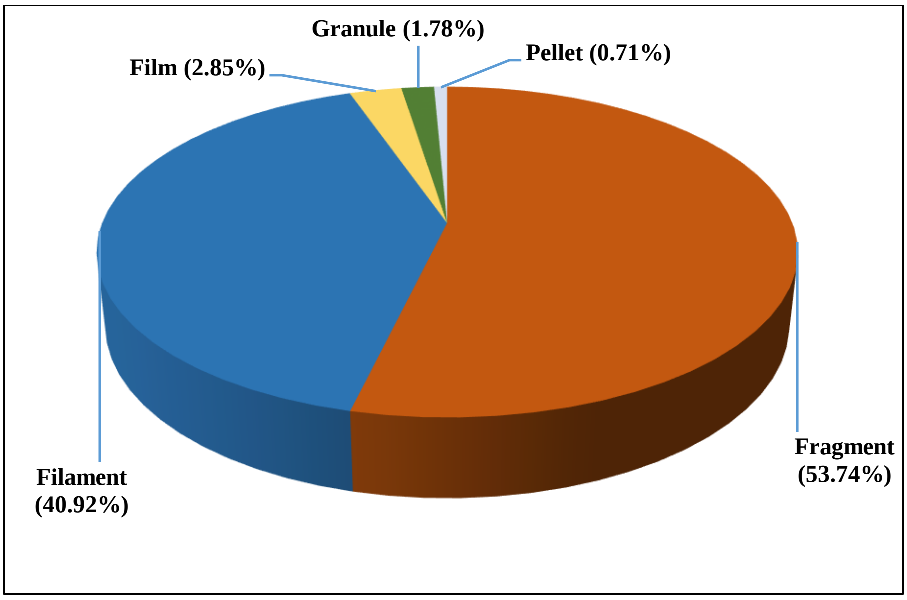

Figure 6: Percentage of different microplastics types

4.2.2 Color features

The majority of the microplastics in the sediment of Patenga beach were found to be transparent (59.14%) rather than colored (40.86%) (Figure 7). This research revealed that predominant colored microplastics were black, red, green, and blue, which was accounting for 18.28%, 9.68%, 6.45%, and 5.02% of the collected microplastics, respectively. Yellow (0.72%) and brown (0.72%) were the only colors that were found with a small ratio. This study showed that transparent colors were dominant in all the sampling stations over the other colored microplastics (Figure 8).

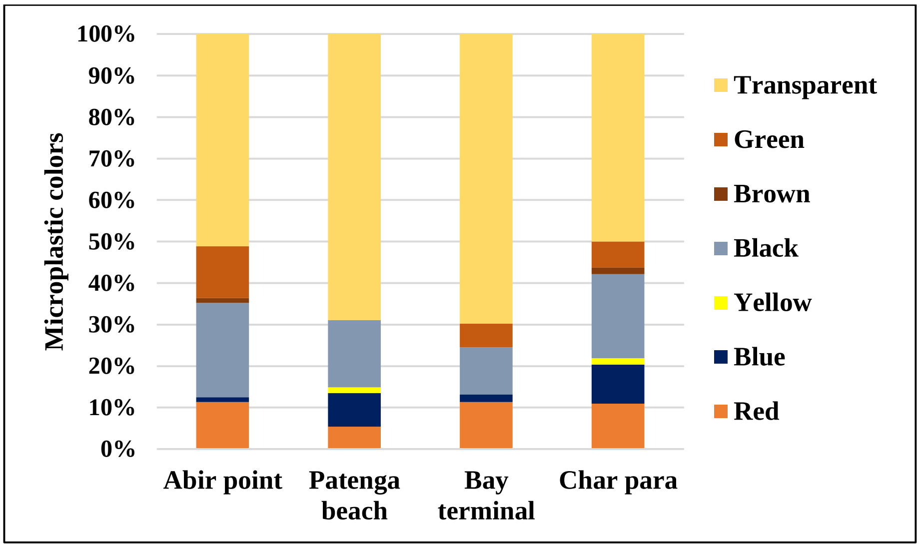

Figure 7. Percentage of microplastics colors among sampling sites

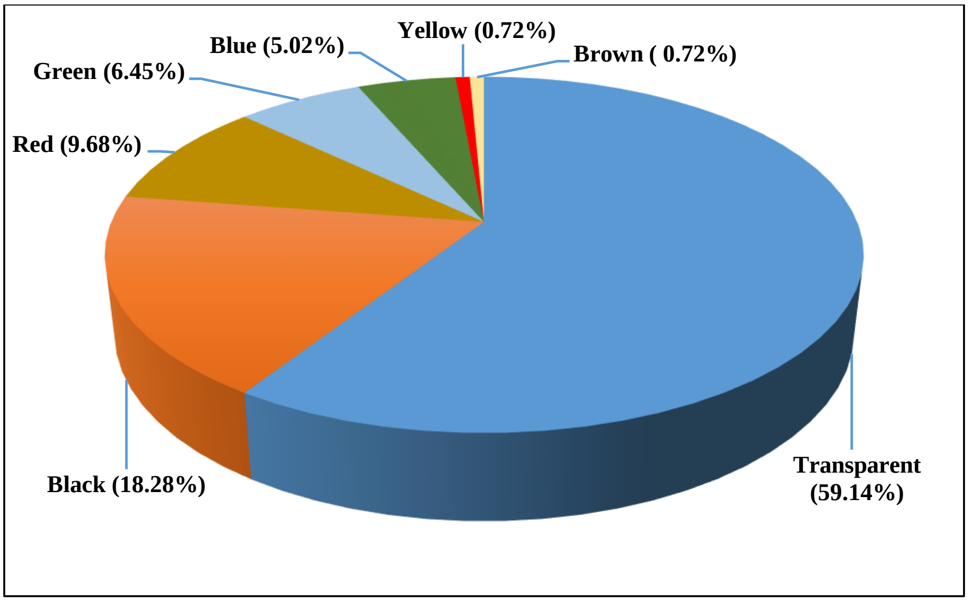

Figure 8. Percentage of different microplastics colors

4.2.3 Shape features

The identified microplastics shapes were divided into six different categories, which were arranged in decreasing order and were as follows: irregular (51.94%), elongated (40.28%), round (4.59%), angular (1.41%), rectangular (1.06%), and cylindrical (0.71%), respectively (Figure 9). The results of this research also showed that irregular and elongated microplastic shapes predominated over the other plastic shapes in all sampling sites of Patenga Sea Beach (Figure 10).

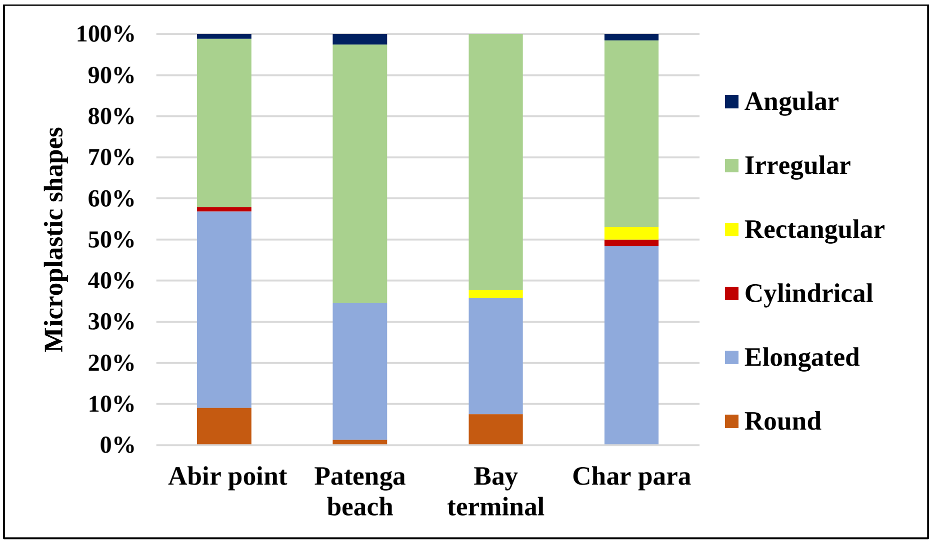

Figure 9. Percentage of microplastics shapes among sampling sites

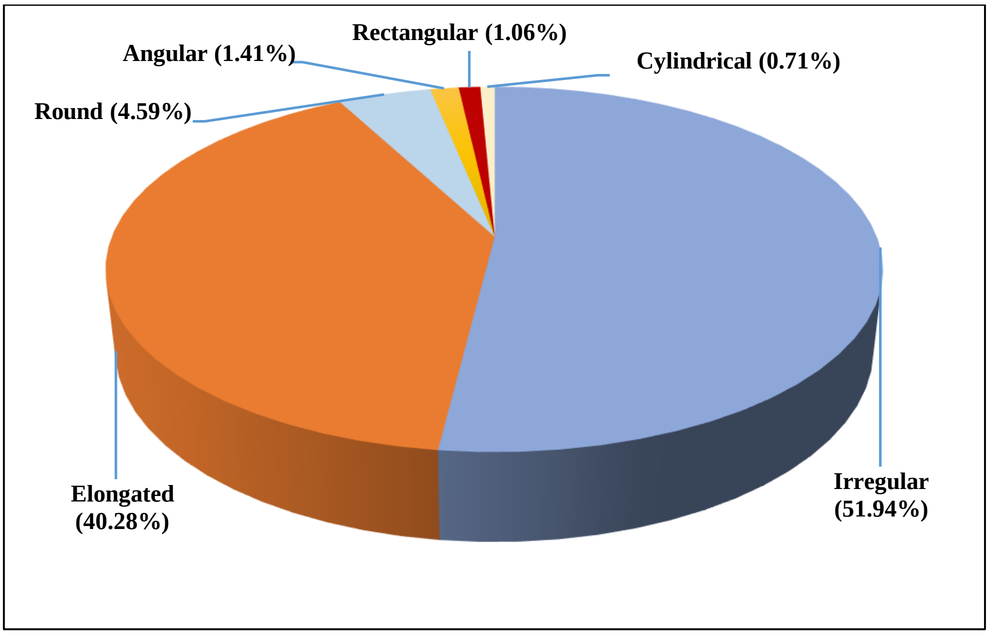

Figure 10. Percentage of different microplastics shapes

4.2.4 Size features

Microplastics between 300 to < 500 µm was the dominating microplastics size categories, accounting for 71.48% of the total. Additionally, this size group surpassed other size classes in all the sampling stations (Figure 11). The 500 µm to < 1000 µm was observed to be the second highest percentage size class of microplastics with 11.19%. The 1000 µm to < 2mm, 2 mm to < 3 mm and 3 mm to < 5 mm size classes also accounted for 6.86%, 5.05% and 5.41% of the collected microplastics, respectively. The percentages of each size category are depicted in Figure 12.

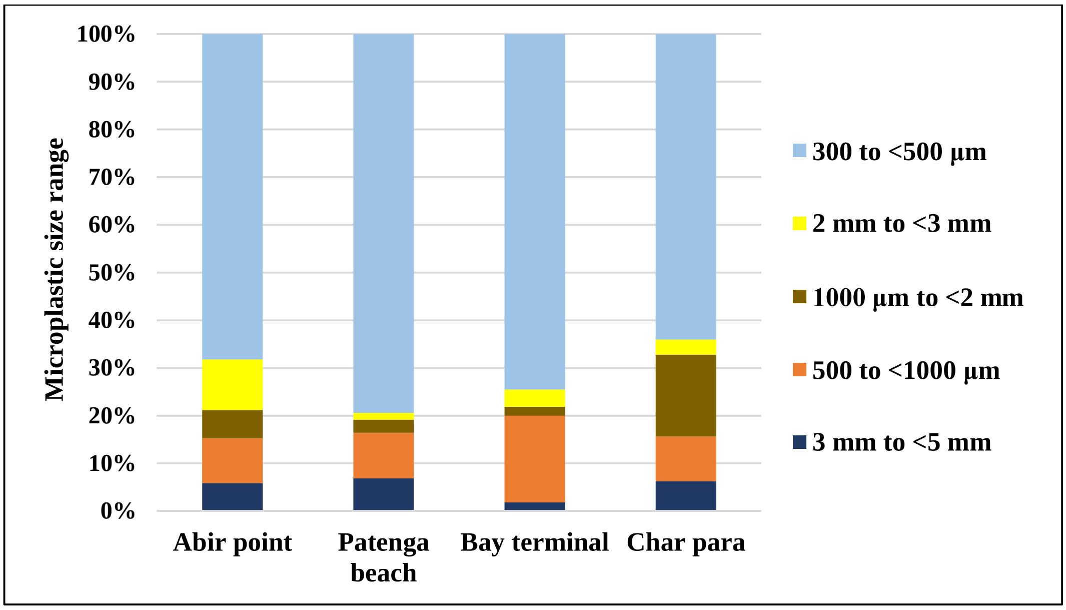

Figure 11. Percentage of microplastics size range among sampling sites

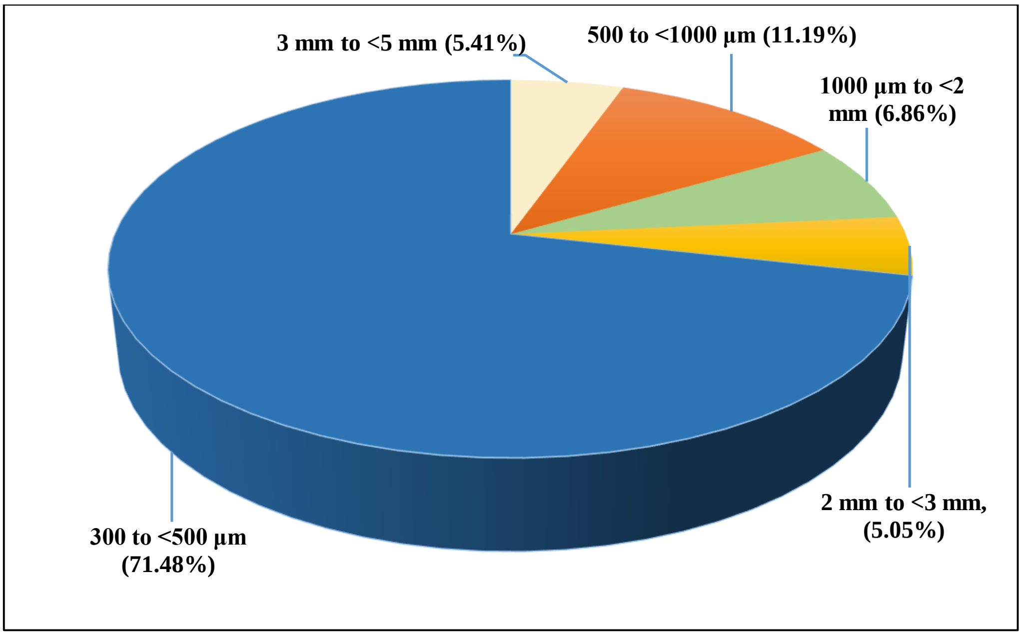

Figure 12. Percentage of different microplastics size range

Chapter-5

Discussion

5.1 Spatial variation of microplastics abundance

Microplastic concentrations might vary according to sampling techniques (e.g. depth of sediment, sediment pooling, position on the coastline), and laboratory procedures (separation technique, sieving). In this present study, microplastic abundance among four stations ranged from 4.44±0.98 to 11.81±0.87 items/kg, where Hossain et al. (2021) found greater abundance of microplastic in the beach sediments of Cox's Bazar than the present study. However, compared to the previous two studies, Prarat et al. (2020) discovered a greater abundance of microplastics along the coast of Rayong Province, Thailand. The key elements impacting the distribution and quantity of microplastics in the nearby marine ecosystems are thought to be human population, sewage drainage and wastewaters, tourism, wind direction, fishing, and industrial activities (Eerkes-Medrano et al., 2015). Abir Point, which was regarded as a tourist area, had the greatest density of microplastics among the four stations. Many visitors come to this location each year, and the greater microplastic concentration might be due to discarded plastic objects from the immense tourism activity. This is why, the primary cause of microplastic contamination is connected to tourism-related activities. On the other hand, Bay Terminal was a distant location for visitors, and therefore lowest microplastic abundance was recorded there.

The mean abundance of tourist areas in the beach sediment of Patenga Sea Beach was compared to the findings documented worldwide (Table 1). The mean abundance of tourist areas in this study were found to be higher than those in Cox's Bazar, Bangladesh (Rahman et al., 2020), Brest Bay, France (Frere et al., 2017), French Belgian Dutch coastline (Van Cauwenberghe et al., 2015) and Taihu Lake, China (Su et al., 2016). Studies in Three Gorges Reservoir, China (Di and Wang, 2018) and Small Island, Fiji (Ferreira et al., 2020) have shown that microplastic abundance at these locations were nearly close to the results of this study. The mean abundance in Kuakata beach, Bangladesh; Bohai Sea, China; Chennai, India; Lido di Dante, Italy; Southern Baltic Sea, Poland; Mangrove coast of Singapore; Coastal beach of Slovenia; Da Nang, Vietnam were found to be greater as reported by Banik et al. (2022); Zhu et al. (2021);

Sathish et al. (2019); Lots et al. (2017); Graca et al. (2017); Nor and Obbard (2014); Laglbauer et al. (2014) and Nguyen et al. (2020), respectively.

Table 1 | Comparison of mean abundance of beach sediment from Patenga Sea Beach, Bangladesh, with other relevant studies.

Country	Location	Sample	Mean abundance (items/kg)	Dominant type	References
Bangladesh	Patenga Sea Beach	Beach sediment	13.67	Fragments (53.74%)	Present study
Bangladesh	Cox's Bazar	Beach sediment	8.1	Fragments	Rahman et al., 2020
Bangladesh	Kuakata	Beach sediment	232	Fibers (55%)	Banik et al., 2022
France	Brest Bay	Surface sediment	0.97	-	Frère et al., 2017
French, Belgium, Netherlands	French Belgian Dutch coastline	Beach sediment	6	-	Van Cauwenberghe et al., 2015
China	Taihu Lake	Bottom sediment	11	Fibers (48-84%)	Su et al., 2016
China	Three Gorges Reservoir	Bed sediment	25	Fibers (33.9-100%)	Di and Wang, 2018
Fiji	Small Island	Surface sediment	19.8	Fibers (60.2%)	Ferreira et al., 2020
China	Bohai Sea	Subtidal sediment	458.6	Fibers (77.1%)	Zhu et al., 2021
India	Chennai	Beach sediment	309	Fibers (63%)	Sathish et al., 2019
Italy	Lido di Dante	Beach sediment	1512	Fibers (98.7%)	Lots et al., 2017

Poland	Southern Baltic Sea	Beach sediment	39	Fibers	Graca et al., 2017
Singapore	Coast	Mangrove sediment	36.8	Fibers (72.0%)	Nor and Obbard, 2014
Slovenia	Coastal beach	Beach sediment	133.3	Fibers (75%)	Laglbauer et al., 2014
Vietnam	Da Nang	Beach sediment	9238	Fibers (81.9%)	Nguyen et al., 2020

5.2 Seasonal differences of microplastics abundance

Among the four seasons, spring had the highest concentration of microplastics in both tourist and non-tourist areas while winter had the lowest concentration. The result of this study is somewhat identical to the findings of James et al. (2021), who discovered that microplastics were more prevalent in the sediments of Palk Bay, India during Spring Inter-monsoon and South West Monsoon whereas in the Gulf of Mannar, it was high during Late Winter Monsoon. However, seasonal variation of microplastic abundance in the study of Rasta et al. (2022) were inversed with the results of the current study, where microplastics abundance was higher in winter season and lower in spring. According to Gao et al. (2021), microplastics abundance was greater in summer and lower during the winter. One very possible cause was that July and August are high tourist months in Qingdao, China (Wu et al., 2021). The overall number of visitors during these two months is estimated to reach 14.05 million, accounting for 42.4% of the yearly tourist volume, according to the Qingdao Culture and Tourism Bureau (2019). Other studies found that seasonal fluctuations in microplastic abundance were often connected to rainfall, temperature and sea wind (Cheung et al., 2016; Eo et al., 2019).

5.3 Type features

In this study, a large number of microplastics found in beach sediments were fragments, followed by filaments, films, granules, and pellets. This finding is relevant with the findings of Patchaiyappan et al. (2020); Patchaiyappan et al. (2021); and Maes et al. (2017), who discovered that fragments were the most prevalent category of total microplastics observed along the South Andaman beaches, Odisha coast of India, and

Northeast Atlantic sea coast. While in other research, filaments were discovered to provide a considerable amount in most of the beach sediment over the other microplastics types (Graca et al., 2017; Sathish et al., 2019; Nguyen et al., 2020). Filaments were found in high amounts in sediments sampled from Belgium, Singapore, Slovenia, and South Africa (Claessens et al., 2011; Nor and Obbard, 2014; Laglbauer et al., 2014; Nel and Froneman, 2015). The presence of filaments in beaches and sediments has also been documented in the study of Hossain et al. (2021) and Banik et al. (2022) along the Cox's Bazar and Kuakata beaches of Bangladesh.

The quality and origin of plastic waste, the breakdown of plastic debris, wind drift, suspension, and sinking rate of marine debris in the beach environment are some of the key factors that may determine the types of microplastics (Critchell and Lambrechts, 2016). A greater concentration of microplastic particles can be associated with abrasion, breakdown of bigger plastic waste, and fibres originating from abandoned fishing line operations, maritime activities, and probable sewage sources (Andrady, 2011; Browne et al., 2011; Robin et al., 2020). The breakdown of items such as plastic bags, single-use plastics, and rubbish dumped due to tourist activities is the primary source of films (Robin et al., 2020). Granules are commonly found in many cleaning and cosmetic products, or they are formed when macro degradable plastics degrade (Cole et al., 2011). Pellets are often utilized as a feedstock in the production of plastics or in air blasting (Eerkes-Medrano et al., 2015).

5.4 Color features

The majority of the recorded microplastics were transparent, with the residuals being colored. The findings of this study are relevant with those of Hossain et al. (2019), who discovered that transparent microplastics were the dominant group in three marine species from Bay of Bengal of Bangladesh followed by black, red, green, and blue. In contrast to the current findings, Peng et al. (2017) found 58% colored and 42% clear particles in Changjiang Estuary, China. Patchaiyappan et al. (2020) discovered that the bulk of the particles along the South Andaman beaches are white and transparent, however Robin et al. (2020) discovered that colored plastic particles accounted for 58% of the total particles in beach sediments along the Southwest coast of peninsular India.

The color diversity of a microplastic particle can be defined to its origin from several sources (Sathish et al., 2019). Since bleaching processes occur in the marine ecosystem, commenting on microplastics color variability is difficult (Stolte et al., 2015). Nonetheless, because of their resemblance to actual marine food, colorful microplastics may mislead normal predator and prey behavioral patterns. For example, visual predators may confuse white, yellow, and tanned microplastics for food due to their physical appearance (Wright et al., 2013).

5.5 Shape features

Six distinct microplastics shapes were found in the current study, with irregular and elongated shapes predominating. According to Hossain et al. (2019) and Lusher et al. (2013), fish from the Bay of Bengal and the English Channel were shown to have a preponderance of elongated and irregularly shaped microplastics, which is comparable to the current findings.

A significant portion of the fragments had irregular forms and sharp edges, which might have been caused by bigger plastic products degrading. Additionally, all of the filaments were elongated and originated predominantly from cleaning and fishing net effluents. These variations of microplastics forms may be influenced by variety of other factors, including waste sources, debris quality, degradation of microplastics by UV-B radiation and wave action, plastic suspension mechanism on beaches, plastic sinking rate and wind drift (Critchell and Lambrechts, 2016; Karthik et al., 2018).

5.6 Size features

The observed microplastics in this present study were divided into five size categories. The majority of the microplastics tested fall under two size ranges such as 300-500 μm and 500-1000 μm. This observation is pertinent with the findings of Browne et al. (2010), Eriksen et al. (2013), Klein et al. (2015), and Kor et al. (2020), where microplastics shorter than 1 mm were mostly discovered. However, this pattern was different from several other previous studies (Laglbauer et al., 2014; Zhang et al., 2016; Sagawa et al., 2018; Hossain et al., 2021; Banik et al., 2022), where most of the microplastics were predominantly observed in a size range of 1-5 mm.

Microplastics in sediment have been confirmed to be derived from big plastic particles and home laundry wash effluent (Yu et al., 2018). Each 5 kg of polyester fabric washing effluent can release around 6,000,000 microfibers ranging from 20 to 2000 mm (De

Falco et al., 2018), which breakdown to microplastics (< 5 mm) because of water turbulence, strong UV action, and wave action (Auta et al., 2017).

Chapter-6

Conclusions

This study aimed to assess the current status of abundance and characteristics of microplastics, for the first time, in the beach sediments, from Patenga, Chattogram, Bangladesh. Microplastics were found for every sampling sites and this study shows a spatial distribution by falling the sampling sites into tourist and non-tourist areas in four seasons. Thus, present study includes a variation of microplastics abundance between tourist and non-tourist sites. Among the five forms of microplastics types, fragments (53.74%) were the most abundant and detected from the tourist areas in spring season as tourist gather higher in the beach during spring. The variation in microplastic concentrations along the sampling locations reveals that the designated tourist areas have much higher microplastic composition. As a result, the study indicates that land-based sources such as tourism might be a substantial source of microplastics in beach sediments.This discovery may contribute to better local and regional management of plastic waste. These findings provide the way for further investigation on the point and non-point causes of microplastic contamination. Moreover, this research might be used to establish a baseline for regulating beach contamination. Additionally, further long-term and systematic research on the effects of microplastics on marine life, ecosystems, and ultimately human health is needed to estimate microplastics pollution and to develop management recommendations and strategies to prevent plastic contamination.

Chapter-7

Recommendations

According to the findings of the current study, the following recommendations are suggested:

- As microplastic pollution is being an alarming issue around the world, many more investigations should be done on microplastic pollution including its possible sources to lessen its impact on aquatic environment.
- Management approaches should be taken immediately at the local and regional levels that will contribute to reduce plastic pollution along with plastic clean up programs.
- Regulatory frameworks and possible management guidelines should be developed by the policymakers to reduce deliberate plastic pollution.
- Locating possible sources and creating public awareness will be effective steps to reduce the negative impacts of plastics on human health. It can be done by arranging several workshop programs.
- It is also necessary to improve current research methodologies and laboratory facilities to determine microplastic pollution with minimal time and effort.

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APPENDICES

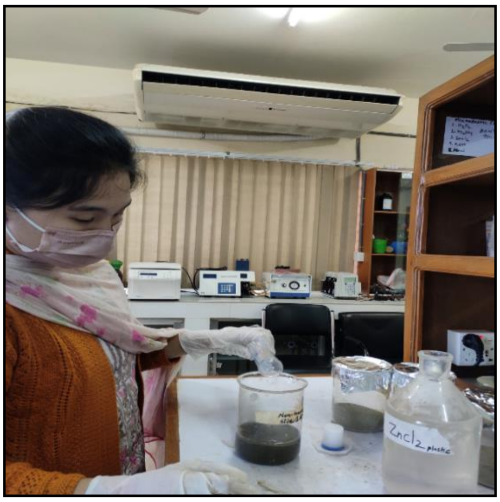
Transect measurement

Quadrate formation

Sample collection

Weighing

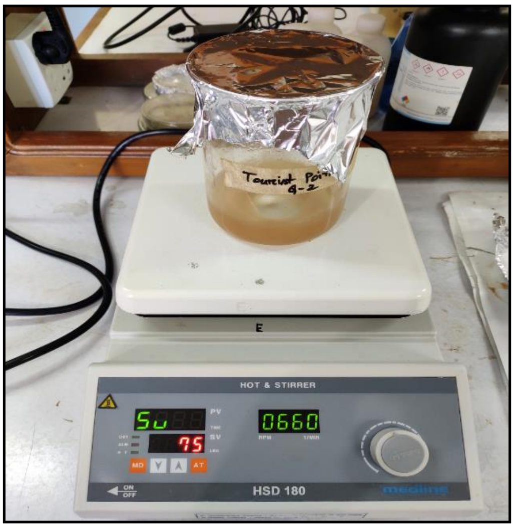
Drying



Adding $ZnCl_2$ solution

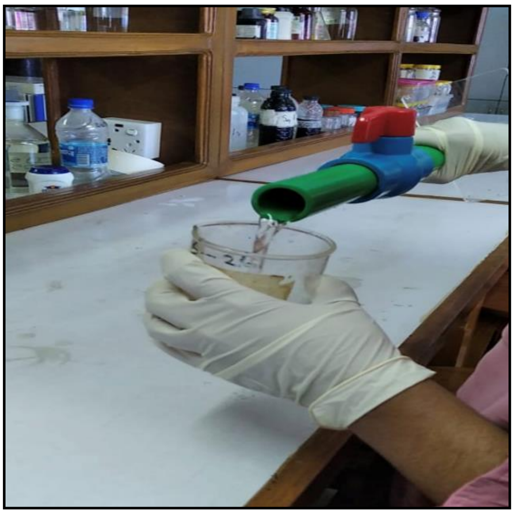
Sieving

Adding H_2O_2



Heating

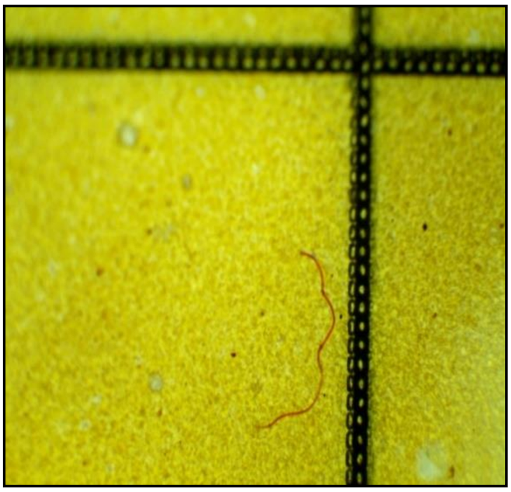
Pouring sample into density separator



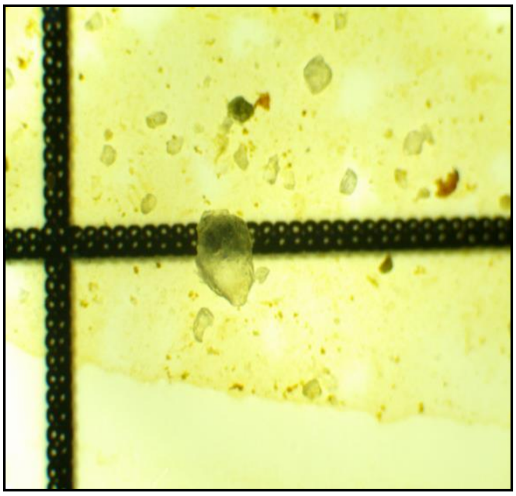
Collection of separated sample

Filtration

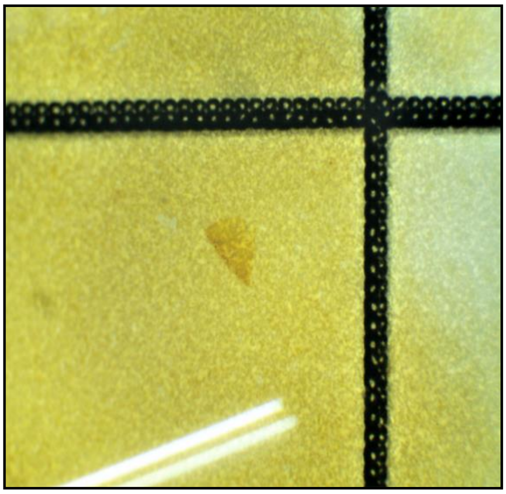
Microscopic identification



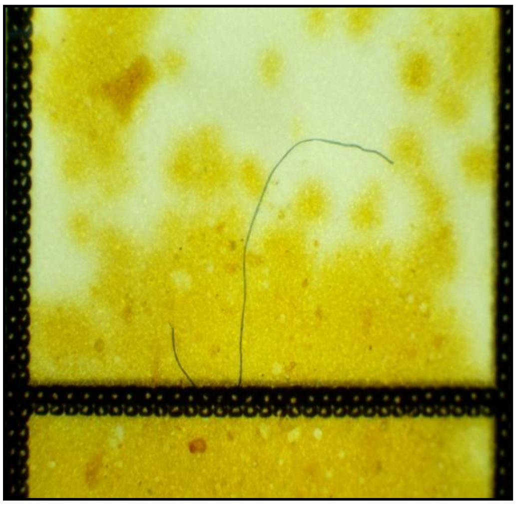
Red elongated filament



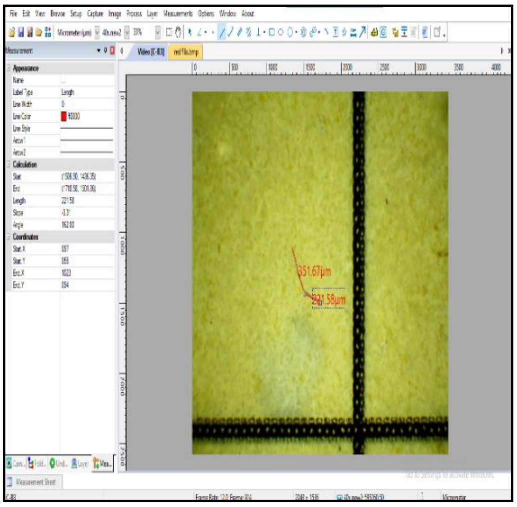
Transparent irregular fragment



Yellow angular film



Green elongated filament



Size measurement