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REVIEW ARTICLE

A critical review of the emerging research on the detection and assessment of microplastics pollution in the coastal, marine, and urban Bangladesh

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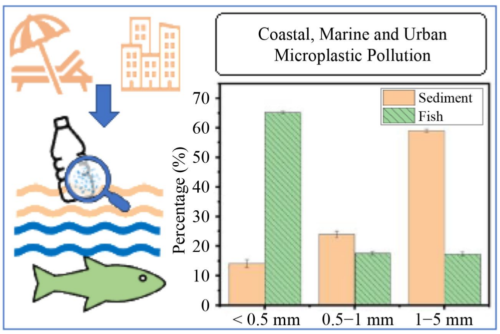
HIGHLIGHTS

- Coastal and marine regions are the most studied for microplastic pollution.
- Tourism is a major cause of microplastic pollution in coastal regions.
- Sediments contain larger microplastics while fish ingest smaller microplastics.
- Inland lakes, rivers, and freshwater fish are impacted by microplastic pollution.
- Microplastics are found in edible salts, however, presence is less in refined salt.

GRAPHIC ABSTRACT



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ABSTRACT

The research on the extent and effects of microplastics pollution in the Global South is only getting started. Bangladesh is a South Asian country with one of the fastest growing economies in the world, however, such exponential economic growth has also increased the pollution threats to its natural and urban environment. In this paper, we reviewed the recent primary research on the assessment of the extent of microplastics pollution in Bangladesh. From the online databases, we developed a compilation of emerging research articles that detected and quantified microplastics in different coastal, marine, and urban environments in Bangladesh. Most of the studies focused on the coastal environment (e.g., beach sediment) and marine fish, while limited data were available for the urban environment. We also discussed the relationship of the type of anthropogenic activities with the observed microplastic pollution. The Cox's Bazar sea beach in south-east Bangladesh experienced microplastics pollution due to tourism activities, while fishing and other anthropogenic activities led to microplastics pollution in the Bay of Bengal. While microplastics larger than 1 mm were prevalent in the beach sediments, smaller microplastics with size below 0.5 mm were prevalent in marine fish samples. Moreover, the differences in microplastic abundance, size, shape, color, and polymer type found were depended on the sampling sites and relevant anthropogenic activities. It is imperative to identify major sources of microplastics pollution in both natural and urban environment, determine potential environmental and human health effects, and develop mitigating and prevention strategies for reducing microplastics pollution.

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1 Introduction

Microplastics i.e., plastic particles with a size below 5 mm have become a major global pollutant and are now ubiquitous in the environment (Arthur et al., 2009). Microplastics are divided into two categories: primary and secondary (Cole et al., 2011). Micro-sized plastic particles utilized for commercial purposes are known as primary microplastics (Cole et al., 2011) and microplastics that are degraded from bigger plastic particles after entering the environments are known as secondary microplastics (Rillig et al., 2017; Rillig, 2018). Because of their persistence and extensive mobility in the environment, microplastics are found everywhere including urban areas, rural areas, freshwater bodies, and marine environment (Cable et al., 2017; Naidoo and Glassom, 2019). Due to their smaller size, wildlife and aquatic species often ingest microplastics which later cause severe damage to their health and even end up in the human body through the food chain (Hollman et al., 2013; Haegerbaeumer et al., 2019).

The exposure, fate, transport, and toxicity of microplastics have become a research priority for environmental and human health researchers, state and federal agencies, and plastic industries to determine the extent, causes, and effects of microplastics pollution worldwide. Recent studies in several South Asian countries have indicated that the substantial and rapid economic growth in this region along with much slower, unorganized, and ineffective waste management activities have led to the significant surge of microplastics pollution that require immediate attention (Muthu, 2021). Bangladesh is a South Asian country with one of the largest population densities in the world and is now experiencing an exponential economic growth along with increased manufacturing, usage, and subsequent disposal of plastics. Per capita plastic use in Bangladesh was determined to be 2.07 kg in 2005 and quickly rose to 3.5 kg in 2014 (Hossain et al., 2020b). Bangladesh gained roughly USD 340 million in 2013–2014 from the export of plastic products (Ahmed, 2014), and the plastic sector employs around 2 million people (Islam, 2012). The latest survey shows that Bangladesh produces >16000 tons of urban waste per day with an increasing rate of 7.5% per year (Bahauddin and Uddin, 2012; Markus et al., 2014) and about 5% of these wastes are plastic wastes (Newaj and Masud, 2014). Although Bangladesh was one of the first countries to ban plastic bags (i.e., polyethylene) in early 2000s, consumer products and packaging along with other sources of plastics have seen surge in their usage and disposal as wastes. This has raised the concerns for understanding the overall plastics pollution, especially microplastics pollution in the context of Bangladesh – which have been largely ignored in the past.

Very recently i.e., in the past 2–3 years, few research articles have been published that are investigating microplastics pollution in different regions of Bangladesh. While these research efforts are commendable and highly important, they are quite sporadic in nature with respect to the sampling locations and scope of the assessment. Few review papers and perspectives (Karim et al., 2020; Sarker et al., 2020; Chowdhury et al., 2021) have also been published in recent years to discuss majorly the plastic waste generation, waste management issues, and the needs for microplastics pollution research in Bangladesh. However, these reviews don't include information about the developing primary literature on microplastics pollution research in Bangladesh. In this frontiers article, for the first time, we reviewed the ongoing and emerging primary research on the extent and characteristics of microplastics pollution in Bangladesh. We identified a comprehensive set of primary literature on microplastics pollution research in Bangladesh, categorized these studies according to specific environmental compartments or organisms (e.g., marine fish or beach sediment or urban rivers), compared the microplastics concentration, size, shape, polymer types found in those studies, and discussed the potential environmental and human health implications of these findings along with suggestions for future research directions.

2 Methods

2.1 Data collection

To perform a comprehensive review of the ongoing research on microplastics pollution in Bangladesh, we searched through databases such as Web of Science, Science Direct, and Google Scholar. The keywords used in this search process were "microplastic Bangladesh", "microplastics in Bangladesh", "microplastic pollution in Bangladesh", "micro debris", or "micro plastic fragments". A total of 8 peer-reviewed journal articles (research), 3 review/perspective papers (journal articles), 3 conference papers, and 2 reports were found**.** The previous 3 review/perspective papers majorly discussed about potential of microplastics pollution in the context of plastic generation and waste management in Bangladesh, however, didn't report any ongoing research on microplastics pollution in Bangladesh. This also highlights the importance of documenting the recent research progress and provides the premise for our review. We included in our review only the journal articles, conference papers, and reports that presented primary research results. The microplastics pollution research is an emerging field and therefore, we wanted to maximize the literature sources ranging from journal articles to conference papers and reports to develop the state-of-the-art review of microplastics pollution research in Bangladesh.

2.2 Data analyses

We divided the existing studies on microplastics pollution in Bangladesh into three broad groups based on regions of analysis: 1) coastal, 2) marine, and 3) urban. The coastal region includes Cox's Bazar area that is in the southeast Bangladesh, consists of the longest sandy beach of the world, and is a major tourism spot. The marine region consists of the Bay of Bengal – the sea on the south of Bangladesh and part of Indian ocean. Cox's Bazar is located on the shores of Bay of Bengal. The urban region consists of the freshwater bodies as well as soil and landfill areas around Dhaka, the capital city of

Bangladesh.

The studies selected in this review reported microplastics abundance found in sediment samples or within biological specimens (e.g., fish or shrimp) to describe the extent of microplastic pollution in different regions. However, these studies reported these microplastic abundance values using different units. To generalize the analyses and for ensuring the ease of comparison between studies within a certain region or sample type, we converted the reported units to a common unit. For example, we expressed the amount of microplastics detected in sediments using particles per kg sediment sample (Lots et al., 2017; Yuan et al., 2019). Similarly, microplastics found in gastrointestinal tracts (GT) of different fresh water and marine fish and shrimp species were expressed using particles per gram gastrointestinal tract (GT) (Hossain et al., 2019; Hossain et al., 2020a). To carry out detailed comparison for the microplastic abundance between marine sediments and fish samples, number of particles per kg body weight of fish species were used.

The reported studies here are the first sets of microplastics pollution studies in Bangladesh, and many of them report only a small set of samples for assessing or detecting the microplastics. Within this limitation, we attempted to show the relationships between results from different studies using total number of microplastic detected, variation in the sizes of microplastics found, and finally the color, shape, and polymer types for the observed microplastics. The various analysis parameters have been summarized in Table 1.

3 Results and discussion

3.1 Effect of tourism on coastal microplastics pollution

Cox's Bazar is known as the tourism capital of Bangladesh with the longest uninterrupted sandy seabeach in the world (120 kilometers or 74.5 miles) (Dey et al., 2013). Nearly 2 million tourists visit Cox's Bazar from November to March every year (Dey et al., 2013), which makes it one of the most appropriate places for studying the correlation between marine tourism and microplastics abundance. We reviewed the three recent studies that determined the extent of microplastics pollution in the sediments of Cox's Bazar and were published between August, 2020 and April, 2021. These studies include Rahman et al. (2020), Hossain et al. (2021), and Tajwar et al. (2022). These three studies divided the entire Cox's Bazar beach region into subregions at different distances along the shoreline from north to south. Also, these studies considered 21, 24, and 20 sediment samples from

Table 1 Different regions, sample types, and analysis parameters used in the published research on microplastics pollution in Bangladesh. (Hossain et al., 2019; Hossain et al., 2020a; Rahman et al., 2020; Ghosh et al., 2021; Hossain et al., 2021; Parvin et al., 2021; Tajwar et al., 2022)

Categories	Description of parameters in each category
Region	Cox's Bazar/Bay of Bengal, Urban region/Dhaka
Samples	Marine beach sediments (at Cox's Bazar), biota (fish and shrimp from Bay of Bengal or urban water bodies)
Sizes of microplastics	< 0.5 mm, 0.5 mm–1 mm, 1 mm–5 mm
Types of microplastics	Rayon, nylon, polyethylene (PE), polystyrene (PS), polyester, polypropylene (PP), polyurethane (PU), alkyd, epoxy, polyvinyl chloride (PVC), polyethylene terephthalate (PET), alkyd resin (AR), the polyethylene–polypropylene copolymer (PE + PP), polyamide, styrene butadiene rubber
Shapes of microplastics	Fragments, fibers, beads, film, foam
Colors of microplastics	White, transparent, yellow, orange, green, blue, black/grey, brown, pink, violet/purple

Table 2 Major observations from the microplastics pollution studies in Cox's Bazar beaches

Studies	Rahman et al., 2020	Hossain et al., 2021	Tajwar et al., 2022
Total samples taken	21	8 × 3 = 24	20
Highest concentration in an area	11.8 particles/kg sediment (Kolatoli beach)	368.68 ± 10.65 particles/kg sediments (Jhautola seabeach)	1110 particles/kg sediments (Laboni point)
Lowest concentration in an area	3.3 particles/kg sediment (Samiti para)	209.1 ± 9.09 particles/kg sediments (Inani)	50 particles/kg sediments (Bardeil point)
Dominant size	1500–3000 μm	1000–1500 μm	< 1000 μm
Dominant type of Polymer	PP (50%)	FTIR not Performed	Rayon (27%)
Dominant shape	Fragments (64%)	Fibers (53%)	Fibers (55%)
Dominant color	Yellow/Orange (38%)	Purple (18%)	White (59%)

7, 8, and 10 different regions, respectively (Table 2).

The three studies reported significantly varying ranges for the abundance of microplastics in the sediment samples, however, all three studies found that the amount of microplastics were dependent on the tourism activity around a specific region. For example, as shown in Table 2, the first study by Rahman et al. (2020) reported the lowest microplastics abundance of 3.3 particles/kg sediment at Samiti para (a much restricted zone due to the existence of airport) to the highest microplastics abundance as 11.8 particles/kg of sediment at the Kolatoli beach; however, the microplastics abundance found by Hossain et al. (2021) ranged from a minimum of 209 particles/kg sediment to a maximum of 368 particles/kg sediment at Jhautola beach and the microplastics abundance found by Tajwar et al. (2022) ranged from a minimum 50 particles/kg sediment at Bardeil to a maximum of 1110 particles/kg sediments (Rahman et al., 2020; Hossain et al., 2021; Tajwar et al., 2022). Kolatoli, Jhautola, and Laboni point beaches are among the most popular beaches in Cox's Bazar and therefore, the highest microplastics concentration were found in those beaches. For example, Laboni point experiences more than 30000 daily visitors on average (Dey et al., 2013). This confirms that the existence of plastic particles in natural systems can be correlated with anthropogenic activities, hence, in this case tourism. Moreover, the microplastics abundance in the beach sediment found by Rahman et al. is significantly lower than that found in other two studies (Rahman et al., 2020). This could be a result of differences among these studies with respect to sampling methodology, time, and locations. Furthermore, such differences in the amount of microplastics between studies might also be due to the intensity of the interruptions and impact of sea waves that each sampling site has endured (Tiwari et al., 2019).

Rahman et al. further used an unpaired *t*-test (two-tailed) for the comparison between two categories, i.e., tourist activity zones, and non-tourist activity zones (Rahman et al., 2020). The results showed significant difference ($p < 0.005$) in microplastics abundance between the two zones. These results further confirm the correlation between the abundance of microplastics and tourism. It is found that microplastics concentration is considerably higher along the beach areas where urbanization and tourism business is extensive and microplastics concentration is lower in the vegetation areas and bare lands. Previous studies show that plastic wastes discarded on the beach produce plastic debris and remain in the sediments due to nearshore circulations and shore tides (Rahman et al., 2020). Several studies from the neighboring country, India, also showed severe abundance of microplastics on the coastal area due to high amount of plastic presence in different tourism, industrial and fishing activities (Veerasingam et al., 2016; Jeyasanta et al., 2020; Martin et al., 2020).

Rahman et al. further analyzed the spatial distribution of microplastics across the shore. Beach sediment samples were analyzed for micropastics in the swash zone, beach face, and wrack lines at different sampling sites (Rahman et al., 2020). The average microplastics abundance was the highest in the wrack line (22.50 particles/kg sediment) followed by that in swash zone (7.5 particles/kg sediment) and in the beach face (12.5 particles/kg sediment). However, the distribution of microplastics in each sampling site varied significantly from each other and such variations could be attributed to the differences in the anthropogenic activities in these sites. For example, the samples from Kolatoli beach did not contain any microplastics in the wrack line, while the wrack line samples from other beaches contained microplastics. Majorly the intensity and pattern of tourism related activities including beach maintenance work, beach cleaning activities by the locals, and nourishment of beach have been implied as the reasons behind the differences in microplastics abundance in different beach and shorelines.

Differences were observed among the studies with respect to the microplastics shape, size, polymer, and color variations (Fig. 1). For example, Hossain et al. (2021) and Tajwar et al. (2022) found fibers as the dominant microplastics shape, whereas Rahman et al. (2020) reported fragments to be the dominant shape. Other shapes and morphologies of microplastics found in these studies included but were not limited to foams, beads, and films. Microplastics within the size range of 1.5–3 mm were the most abundant according to Rahman et al. (2020), followed by those in the 3–4.5 mm size range. Similarly, microplastics between sizes ranging from 1–1.5 mm were the highest (59% of the total sample) found in the study by Hossain et al. followed by microplastics within 0.5–1 mm size range (at 27% of the total sample) (Hossain et al., 2021). Tajwar et al. on the other hand reported the dominant microplastics size to be < 1 mm (Tajwar et al., 2022). Only a low amount (i.e., 5%–20%) of microplastics had the size of less than 0.5 mm (Hossain et al., 2021).

All three above studies reported different polymer types for the retrieved microplastics from sediment samples. However, only Rahman et al. (2020) and Tajwar et al. (2022) identified the polymer types using attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy. These identified types of polymers included rayon, nylon, polyethylene (PE), polystyrene (PS), polypropylene (PP), polyurethane (PU), alkyd, epoxy, polyvinyl chloride (PVC), polyethylene terephthalate (PET), alkyd resin (AR), and the polyethylene–polypropylene copolymer (PE + PP). In both studies, PP and PE were found to be the most abundant polymers type. The potential reason behind this result could be the floating ability or density, wide usage for packaging, single usage of PP and PE, contributing to the ease of distribution in water bodies. The authors inferred that the sources of PE to be rigid plastics, bundled fishing nets and ropes (Lebreton et al., 2017), the sources of PS to be industrial/ municipal effluent discharges (Wu et al., 2019), and the sources of AR to be paints and boat varnishes (Haave et al., 2019). Furthermore, the dominant color of microplastics varied between the studies. Rahman et al. found yellow/ orange (38% of samples), Hossain et al. found purple (18% of the samples), and Tajwar et al. found white (59% of the samples) as the most dominant color of the microplastics, in their respective studies (Rahman et al., 2020; Hossain et al., 2021; Tajwar et al., 2022).

To get a clearer perspective, we studied the existing literature on microplastics abundance in the coastal regions as observed in other parts of the world. The abundance of microplastics in Cox's Bazar beaches found by Hossain et al. (2021) were similar to those observed in Hiroshima Bay, Japan (Sagawa et al., 2018), remote lakes in Tibet plateau, China (Zhang et al., 2016), and beaches in Slovenia (Laglbauer et al., 2014). However, the data from Cox's Bazar were dissimilar with the findings from other estuarine shorelines (Browne et al., 2011) including those from Laurentian Great Lakes (Eriksen et al., 2013) and Rhine-Main area of Germany (Klein et al., 2015). For example, the mean number of microplastics in 1 kg beach sediments in the Cox's Bazar beach was higher than those reported along the German North Sea coast, with (2.3 particles/kg) (Dekiff et al., 2014). However, the number of microplastics (in particles/kg) found in sandy beaches of Mumbai (220 ± 50) and Tuticorin (181 ± 60), India (Tiwari et al., 2019); Tamil Nadu, India (439 ± 172–119 ± 72) (Sathish et al., 2019); Baltic Coast, Germany (41.7–532.2) (Stolte et al., 2015); Halifax Harbor, Canada (4500) (Mathalon and Hill, 2014); and Beibu Gulf, China (6870) (Qiu et al., 2015) were much higher than those found in Cox's Bazar. While comparing these studies are important, the different beaches have differences in tourist population, anthropogenic activities, seasonal variation, and weather pattern making the comparison across studies more difficult.

3.2 Microplastics contamination among marine biota of the Bay of Bengal and urban freshwater fish species

Marine and freshwater systems are often polluted by microplastics as they are discharged from various anthropogenic sources. These microplastics are often ingested by aquatic organisms including fish and shrimp. Recently, few studies focused on the presence and exposure of microplastics in the marine and freshwater organisms in Bangladesh. For determining the presence of microplastics in the marine ecosystems of Bangladesh i.e., within the Bay of Bengal, recent studies focused on detecting microplastics existence and abundance in marine fish (Hossain et al., 2019; Ghosh et al., 2021) and shrimp (Hossain et al., 2020a). All three papers followed the exact same procedures for microplastics extraction and observation. Microplastics extraction using alkali digestion of the fish/shrimp was followed by microplastics observation using optical and electron microscopes as well as via chemical characterization by a micro-Fourier Transformed Infrared Spectroscope (mFTIR). Table 3 shows the major findings from each of these

Table 3 Major observations from the microplastics pollution studies in marine and freshwater organisms of Bangladesh

Study parameters	Hossain et al., 2019	Hossain et al., 2020a	Ghosh et al., 2021	Parvin et al., 2021
Collection time	September 2017–March 2018	September 2017–March 2018	September, 2019	–
Total fish or shrimp sample	75	150	100	48
Fish or shrimp species	*Harpadon nehereus, H. translucens, Sardinella gibbosa*	*Metapenaeus monocerous, Penaeus monodon*	*Priacanthus hamrur, Sciades sona, Carangoides Chrysophry, Harpadon nehereus, Otolithoides pama, Setipinna tenuifilis, Coilia neglecta, Anodontostoma chacunda, Sardinella brachysoma, Megalaspis cordyla*	*Labeo calbasu, Cirrhinus reba, Awaous grammepomus, Mystus vittatus, Heteropneustes fossilis, Notopterus notopterus, Silonia silondia, Mystus cavasius, Anabas testudineus, Mastacembelus armatus, Nandus meni, Labeo bata, Puntius sophore, Cypinus carpio, Labeo rohita, Ompok bimaculatus, Eutropiichthys vacha, Oreochromis mossambiscus*
Total microplastics detected	43	72	215	107
Avg. abundance	From 0.37 to 1.55 (particles/per gram GT)	From 3.40 to 3.87 (particles/per gram GT)	From 2.11 to 2.29 (particles/per gram GT)	From 0.04 to 6.3 particles/kg body weight
Dominant size	0.5–1 mm (37%)	1–5 mm (32%)	< 500 μm (85%)	< 500 μm (36%)
Dominant type of polymer	Polyamide (75%)	Polyamide (59%)	Polyethylene (55%)	High density polyethylene (40%)
Dominant shape	Fibers (50%–55%)	Fibers (57%–32%)	Fibers (53.4%)	Fibers (75%)
Dominant color	White/transparent (26%–68%)	Black (51%–48%)	Green (39%)	Transparent(43%)

studies with respect to microplastics abundance, size, shape, polymer type, and color.

The first study in 2019 by Hossain et al. investigated the presence of microplastics in the gastrointestinal tracts (GT) of three species of fish: pink Bombay-duck (*Harpadon nehereus*), white Bombay-duck (*H. translucens*), and gold-stripe sardine (*Sardinella gibbosa*) (Hossain et al., 2019). For each species, 25 fish samples were collected and studied for microplastics abundance in them. A one-way analysis of variance (ANOVA) analysis was performed which concluded that the total microplastics abundance was significantly different among the three fish species (p = 0.0008). *S. gibbosa* (or the sardine) showed the highest percentage of the smallest size microplastics (< 0.5 mm; 43%; 35 items), followed by microplastics within the size classes of 0.5–1 mm (37%; 29 items) and 1–5 mm (20%; 16 items), respectively. Whereas, in *H. translucens* (white Bombay-duck) fish, the highest amount of microplastics were in the largest size range i.e., within 1–5 mm (43%; 69 items), followed by moderate size range of 0.5–1 mm (35%; 48 items) and smallest size range of < 0.5 mm (22%; 28 items). Finally, in *H. nehereus* (pink Bombay-duck), the highest amount of microplastics were in the moderate size range of 0.5–1 mm (41%; 92 items) followed by the largest size range of 1–5 mm (34%; 72 items) and the smallest size range of < 0.5 mm (25%; 54 items). The difference in microplastics abundance of different sizes found within different species of fish may have resulted from the variations in microplastics presence at different sea levels of the Bay of Bengal. Microplastics accumulate at different sea levels according to their densities, size, and shape (Andrady, 2011; Cózar et al., 2015). Pink Bombay-duck (*H. nehereus*), white Bombay-duck (*H. translucens*), and gold-stripe sardine (*S. gibbosa*) were collected, respectively, from 2–3 m, 10–20 m, and 40–60 m depth of the sea. Smaller microplastics dominated in the gold-stripe sardine GT, while larger microplastics dominated in white and pink Bombay-duck GT. Furthermore, microplastics within each fish species also correlated positively to the weights of the fish according to one-way ANOVA, in the results showing that the more was the weight of the fish, the more likely it was contaminated with microplastics.

Hossain et al. investigated the presence of microplastics in the GT of 150 samples of two species of Penaeid shrimp, namely, brown shrimp (*Metapenaeus monocerous*) and tiger shrimp (*Penaeus monodon*) (Hossain et al., 2020a). Tiger shrimp and brown shrimp were collected from 40–60 m and 2–3 m respectively. The 70% (23 particles) microplastics found in the tiger shrimp were of larger size (1–5 mm), while 27% (9 items) and 3% (1 item) were of smaller sizes (0.5–1 mm and 0.2–0.5 mm, respectively). The type of shrimp species and sample collection sites have a substantial impact on dominant microplastics size. Shrimps occupying nearshore habitats close to Chittagong city's metropolitan areas contain more plastic debris than shrimps inhabiting offshore habitat.

The most recent study on microplastics in marine fish by Ghosh et al. investigated 100 fishes from 10 different species and found microplastics in all 10 species of the study (as mentioned in Table 3), with *P. hamrur* having the most (3.8 microplastics per fish sample) and *M. cordyla* having the least (1 microplastic per fish sample) amount of microplastics (Ghosh et al., 2021). Like the above-mentioned studies, in this study, the presence of microplastics in fish species was positively linked with per unit body weight (r^2 = 0.73) and per unit GT weight (r^2 = 0.45). This implies that fish species with more weight and a larger GT are more likely to have microplastics. The biggest fractions of microplastics were within the size < 0.5 mm, which accounted for 85% of the microplastics and was observed in all studied species. Smaller microplastics can be easily ingested by marine species and have the highest chances to be found within their GT.

Both Hossain et al. (2019) and Hossain et al. (2020a) reported polyamide as the dominant polymer type with 75% and 59% of the identified microplastics polymers, respectively, while Ghosh et al. (2020) reported polyethylene (55%) as the dominant polymer type. Hossain et al. (2019) showed 13 particles of polyethylene terephthalate and 66 particles of polyamide and Hossain et al. (2020a) showed 13 particles of polyamide-6 and 6 particles of rayon polymers. These results indicate that ropes, fishing nets, floats, fish baskets/bags, coatings made of paints, used clothing, furnishing, female hygiene products and nappies may be the sources of microplastics in the Bay of Bengal (Thushari et al., 2017).

Microplastics have become ubiquitous in all sorts of environment, especially in marine environment. About 700 marine species are being affected by microplastics (Gall and Thompson, 2015; Prokić et al., 2019) and microplastics can be found in the digestive tract of fishes all around the world (Ory et al., 2018; Strungaru et al., 2019). For example, microplastics have been found in 77% fishes of the Tokyo Bay (Tanaka and Takada, 2016), 68% fishes around the Balearic Islands (Nadal et al., 2016), 58% fishes from the Mediterranean Sea (Güven et al., 2017), 37% fishes from the English Channel (Lusher et al., 2013), 35% fishes from the North Pacific Central Gyre (Boerger et al., 2010), 18% fishes from the Spanish coast (Bellas et al., 2016), and 11% mesopelagic fishes of the North Atlantic Ocean (Lusher et al., 2016). Microplastics amounts in marine fish in Bangladesh reported by Ghost et al. (2021) (as shown above) are similar to the microplastics levels found in marine fish in other countries. Tanaka and Takada studied *Engraulis japonicus* from Tokyo Bay and found 2.3 pieces of microplastics/fish sample (Tanaka and Takada, 2016), where another study from Turkish territorial waters of the Mediterranean Sea found 2.36 pieces of microplastics per fish (Güven et al., 2017). Also, a study conducted on the fish samples from Spanish Atlantic and Mediterranean coasts reported 1.56 items of microplastics per fish (Bellas et al., 2016). Therefore, more studies should be carried out to understand the extent and impact of microplastics pollution on marine biota in developing countries like Bangladesh, where plastic production and use is exponentially increasing, and the plastic wastes are unregulated and unmanaged.

The presence of microplastics in Bangladeshi freshwater is presently unknown, and in comparison to other countries across the world, lesser is known about the presence of this pollutant in freshwater fish. Very recently, the quantity, features, and fluctuation of microplastics in 48 freshwater fish samples, from 18 different species were examined by Parvin et al. (2021). These fish samples were collected from Buriganga river that is surrounding Dhaka which is the capital city of Bangladesh and also one of the largest megacities in the world (due to excess population). It was found that the fish species *Mystus vittatus* had the highest concentration of microplastics that included high density polyethylene, polypropylene-polyethylene copolymer, and ethylene vinyl acetate. Dominant color and type of microplastics were transparent and fiber, respectively. However, *Heteropneustes fossilis, Notopterus notopterus,* and *Mystus cavasius* did not have any microplastics in them. Fish that dwell and feed on or near the bottom, just above the bottom, and around the open surface zone of the water column are classified as demersal, benthopelagic, or pelagic, respectively (Pauly et al., 1998). The findings of Parvin et al. revealed that demersal fishes ingested more microplastics than benthopelagic and pelagic fish, implying that fish ingestion of plastics is related to their eating environment (Parvin et al., 2021). However, unlike marine fishes mentioned above, the microplastics intake in freshwater fishes was not affected by variations in body weight or length of the fish.

Marine plastic debris has a concerning high level of persistence. Therefore, they impact the ecosystem heavily including fisheries, tourism, and navigation (Dias, 2016; Guzzetti et al., 2018). Plastic debris deforms into smaller pieces eventually by photo-degradation, oxidation, and mechanical abrasion in the marine environment and can lead to the generation of microplastics (Thompson et al., 2009; Andrady, 2011). The results of all the above studies indicate an alarming presence of microplastics in the Bay of Bengal especially with the marine fish and shrimp that can cause harmful effects. Such exposure of microplastics in marine organisms (e.g., fish and shrimps) can cause physiological injuries and inflammation, blockage of the digestive tract, alteration of feeding and reproductive activity, reduction in survival rate of progeny, cellular toxicity and decreased immune response to the biodiversity of this region (Cole et al., 2015; Prokić et al., 2019; Savoca et al., 2019; Strungaru et al., 2019). The studies reviewed in the manuscript only investigated the microplastics concentration in the fish GT which is the primary location for most of the fish-ingested microplastics, however, microplastics have shown to translocate from GT to other organs (Smith et al., 2018). Therefore, there is a potential risk of microplastics exposure to humans through the food chain from fish and other organisms and animals that are exposed to microplastics contamination. In such a scenario, microplastics pollution for a country like Bangladesh, which produces about 4.27 $\times 10^6$ tons of fish and the fishing and aquaculture being one of the main sources of livelihoods for nearly 11% of the total population, can be devastating (DoF, 2018; Hossain et al., 2021).

3.3 Comparison of microplastics abundance and characteristics in coastal sediment and marine fish samples

The Cox's Bazar is located at the shore of Bay of Bengal, and the anthropogenic microplastics pollution of Cox's Bazar may be linked to the microplastics pollution in the marine organisms. Yet, the abundances and characteristics of microplastics found in the beaches along the shoreline can be quite different from the microplastics ingested by marine fish or shrimp. This comparison is depicted in Fig. 1 that presents cumulative analyses of results obtained from the above-mentioned studies in section 3.1 and section 3.2 which determined the extent of microplastics pollution and exposure in the beach sediment and marine fish, respectively. The average numbers of microplastics found in these two types of samples have been depicted in Fig. 1(a). The average number of microplastics in the beach sediment (231.3 particles/kg) is almost 3.4 times higher than that in the fish samples (68.9 particles/kg). This is expected because the tourism affects much more the beach than the sea through anthropogenic activities related to plastic waste disposal and accumulation. Figure 1(b) shows the size distribution of microplastics found in the beach sediment and marine fish. Microplastics found in the beach sediment are dominated by particles within size range of 1–5 mm while the microplastics found in the fish GT are dominated by particles with size below 0.5 mm. This difference in the size distribution of microplastics between sediment and fish samples may be related to their sedimentation rate. Larger microplastics often sediment out near shore while the smaller microplastics are transported within the water column and thereby can be ingestible by marine fish. Moreover, the prey of these fish species often is less than 0.5 mm in size which resembles the smallest sized microplastics (Ory et al., 2017; Gago et al., 2018; Naidoo and Glassom, 2019).

Figure 1(c) shows the shapes of microplastics found in the sediment and marine fish samples. Among the detected microplastics in sediment samples, fragments were the highest (36.4%) with closely followed by fibers (32.4%) and then films (14.5%) and others. On the other

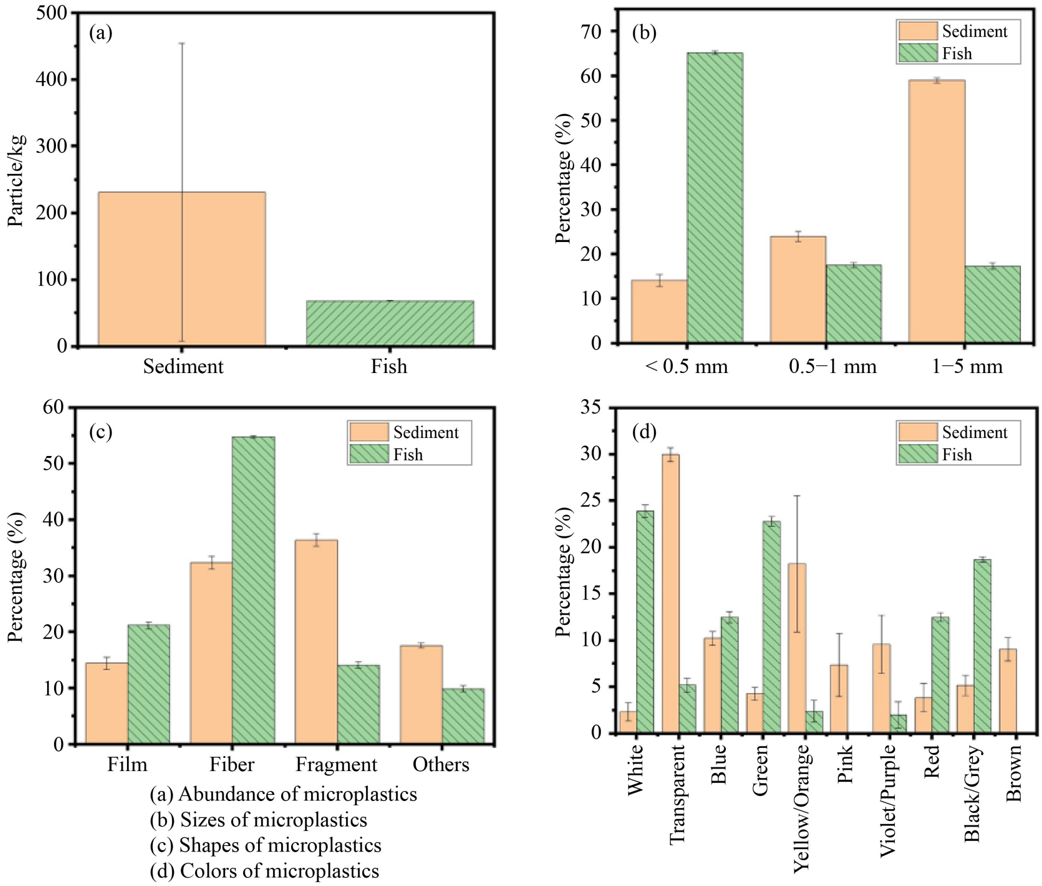

Fig. 1 The comparison of the extent and characteristics of the microplastics pollution between sediments from the beaches of Cox's Bazar and fish species from Bay of Bengal with respect to microplastics abundance (a), size (b), shape (c), and color (d).

hand, among the detected microplastics in fish samples, fibers were the most dominant shape (54.8%) followed by films (21.2%) and fragments (14.1%). Microplastic fragments are typically found from the mechanical or chemical degradation products of larger plastics (Hossain et al., 2021). The anthropogenic activities in the beach area can lead to the disposal of larger plastics which can lead to abundant formation of fragment-like microplastics. Fibrous microplastics are quite abundant in sediment and are the most abundant in fish samples. Other studies also reported that fiber is one of the most abundant shapes of plastics found in various environmental samples (Browne et al., 2011; Gago et al., 2018). Near the beach where anthropogenic activities are high, the clothing of the tourists along with the municipal wastewater containing fibers released from domestic laundry can contribute to the high abundance of fiber shaped microplastics. Fishing instruments used in the marine environment can also contribute to the total number of fibers (Browne et al., 2011). Fibers are often more buoyant than other forms of plastics and can be transported a long way from the shore and can be ingested by marine fish. Films and fragments mainly come from the improper management and unplanned dumping of used plastics (Ghosh et al., 2021).

Figure 1(d) presents the color distribution of the identified microplastics found in the beach sediment and marine fish samples. In fish samples, white, green, and black are the most prevalent colors. Fishes feel attracted to the microplastics of these colors as they resemble the colors of fish preys (Boerger et al., 2010). On the other hand, in sediment samples, transparent microplastics dominate, as the largest portion of microplastics used by human in daily life is transparent. Transparent microplastics can be composed of various types of polycarbons including polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), or polyvinyl chloride (PVC) as these are common type of polymers used in plastic products (Tajwar et al., 2022).

3.4 Microplastics in edible salt and ship breaking industry near Bay of Bengal

Some researchers have looked at the relationship of economic and industrial activities other than tourism with the microplastics pollution near shore or in the marine ecosystems. These activities include the production of edible salts and the ship breaking industry.

A recent study by Zafar et al. has focused on edible salt contamination by microplastics (Zafar et al., 2020). The edible salt manufacturing industry in Bangladesh is majorly located near Bay of Bengal where salt is typically made by solar drying of sea water followed by refinement and purification steps. The usage of microplastics contaminated sea-water in salt production can contribute to the microplastics contamination of the edible salts as identified in this study by Zafar et al., where both raw and refined salt were collected from Cox's Bazar area industries and then analyzed for microplastics identification (Zafar et al., 2020). Number of microplastics in the raw unrefined, refined, and super refined salts was found to be 2105, 283, and 0.8 particles/kg of salt, respectively. The result indicates that under various refining intensities, the degree of microplastics contamination may progressively diminish, however, that doesn't diminish totally and there is a concern of chronic exposure of microplastics in low concentration to humans through edible salts. The most prevalent microplastics size found in the salts was as small as 0.058 mm. Fragmented microplastics were the most dominant in both unrefined (17%) and refined salts (19%). Most of the microplastics were black in both unrefined (24%) and refined salt (27%). Similar studies have been carried out around the world and the results vary significantly from each other. Microplastics were found in all of the tested 15 brands of commercial salts in China with an average of 550–681 microplastics per kg of sea salts (Yang et al., 2015). Similar studies from India, Spain, Italy and Croatia showed microplastics in local salts in the amounts of 56–103 microplastics per kg (Seth and Shriwastav, 2018), 50–280 microplastics per kg (Iñiguez et al., 2017), 22–594 microplastics per kg, and 13500–19800 microplastics per kg (Renzi et al., 2018), respectively.

Bangladesh hosts one of the largest ship-breaking and repairing industries of the world and the ship breaking and recycling activities can generate a lot of solid wastes including plastic wastes. Haque et al. investigated microplastics on soils of five different ship breaking and repairing zones on the Sitakunda-Bhatiary shore of the Bay of Bengal and found an average of 217 particles/kg soil (Haque et al., 2020). Plastic fragments (45%) and fibers (40%) were the most common microplastics detected at the shipbreaking yard, with transparent (22%), red (10%), and black (10%) being the most common colors. In terms of morphology, 45% of the total microplastics found in these areas were irregularly shaped. Total 71% of the microplastics were between the sizes of 0.3 and 1 mm. Polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyvinylchloride (PVC), polyurethane (PU), and polystyrene (PS) constituted the different types of plastics as detected using FTIR. Ship breaking and repairing industry has been proposed to have been responsible for increased microplastic pollution of the coastal environment, with PVC and PU being the major contributors.

3.5 Microplastics contamination in urban regions

Apart from the earlier mentioned freshwater fish study in Buriganga river (that surrounds Dhaka city) by Parvin et al., there have been limited reports of water and soil contamination in the urban region of Bangladesh (Parvin et al., 2021). Shadia et al. examined the presence of microplastics and determined their amount in 5 clean waterbodies within and adjacent to Dhaka city (Shadia et al., 2020). These waterbodies are three major urban lakes including Dhanmondi Lake, Ramna Lake, and Hatirjheel within Dhaka city and two adjacent rivers i.e., Turag river and Buriganga river. Among the inland waterbodies, Hatirjheel contained the highest amount of microplastics (4% of total solids) followed by Ramna Lake (1.5% of total solids) and Dhanmondi Lake (0.5% of total solids). Hatirjheel has a high percentage of microplastics because it receives stormwater combined with household waste especially during the wet season. Because the lakes are in residential neighborhoods, the deterioration and abrasion of unregulated dumping of plastic items into the lake, such as food packaging, polythene bags, and microbeads incorporated into the personal care products are likely sources of microplastic contamination. The plastic fibers in Hatirjheel might have come from the sand containing geotextile bags that are used to protect banks from soil erosion (Wahed et al., 2011). Geotextile bag is a three-dimensional geosynthetic container (i.e., bag) constructed of textile fabric such as polyethylene (PE) or polypropylene (PP) with adequate tensile strength and used as a temporary or permanent earth construction filled with soil, crushed rock, recycled concrete, etc (Hataf et al., 2019). On the other hand, Dhanmondi and Ramna Lakes don't receive residential sewage directly from sewer outfall, making the direct dumping of plastic items by visitors as the major source of microplastics in these lakes.

Between the two peripheral rivers, microplastics found from Buriganga river (3.3% of total solids) were much lower than those found in Turag river (9.5%). The higher amount of microplastics found in Buriganga and Turag rivers compared to the microplastics found in inland lakes might be the result of various anthropogenic activities that include dumping of household plastic products e.g., plastic buckets, plastic bottles, and polythene bags; discharge of plastic-containing municipal and industrial wastewater by the many sewer outlets coming from the city; washing of plastic wastes from informal plastic recycling industries that are near the shore of these rivers. The samples from Turag river also contained glitters which may have resulted from drainage of plastic embroidery works from discarded pieces of clothing or the garment industry located within Dhaka city. Numerous other industries, such as manufacturing, pharmaceuticals, dyeing, and textile industries are also located near the river, giving rise to multiple potential sources of microplastics in the river. Low density plastics made up the majority of the microplastics found in Dhanmondi Lake and Hatirjheel, as well as in Buriganga river. On the other hand, high density made up the majority in Ramna Lake.

An urban landfill site in Dhaka city, known as Aminbazar Sanitary Landfill sites, was investigated by Afrin et al. and 10 unmixed soil samples were collected from this site to determine the extent of microplastics pollutions in the landfills (Afrin et al., 2020). Microplastics with a size range of 0.001–2 mm and a variety of shapes including fims, fibers, and fragments were identified both in the top and core soil samples. The polymer types for these microplastics identified using FTIR were low-density polyethylene (LDPE), high density polyethylene (HDPE), and cellulose acetate (CA), respectively.

4 Environmental implications, knowledge gaps, and future perspectives

The above review of the existing research revealed that there is emerging evidence of ubiquitous microplastics pollution in Bangladesh. However, majority of these studies are focused on the marine and coastal environment in the south and southeast region of the country, and less information is available about the microplastics pollution in the urban region, while the information about rural areas is non-existent. The existing literature indicates that marine tourism is one of the major sources of anthropogenic occurrence of microplastics pollution in coastal Bangladesh, especially in Cox’s Bazar. It is also probable that the marine fish and shrimp population are being impacted by the near-shore anthropogenic activities or by fishing and marine transportation activities. The presence of microplastics in the edible salts produced in Cox’s Bazar along with their presence in fish species indicate the possibility of direct exposure scenarios to humans through the food consumption. Previous studies in other countries have shown that microplastics can be found in various stages of the food chain (Ivar do Sul and Costa, 2014). Zooplankton (Botterell et al., 2019), bivalves (Wang et al., 2018; Cho et al., 2019), crustaceans (Devriese et al., 2015), corals (Hall et al., 2015), fishes (Ory et al., 2018) and seabirds (Amélineau et al., 2016; Zhao et al., 2016) have all shown to contain microplastics. This indicates the need for future research on microplastics abundance and exposure on other biological organisms (i.e., other than fish and shrimp) of the Bay of Bengal to understand and estimate the overall ecological impact of the microplastics pollution in that region.

The limited literature reports on urban regions especially for the inland lakes, rivers, and freshwater fish as well as the landfill soil samples provide evidence for the environmental pollution with microplastics and exposure to biological species. Even within the limitations of these studies, that are typically caused by lack of resources for extensive scientific research in case of developing countries like Bangladesh, the ongoing research indicates towards a potentially extensive case of microplastics pollution throughout the country. The possible environmental and human health implications of these microplastics pollution such as environmental fate, transport, and ecotoxicity as well as human health exposure, body burdens, and subsequent health hazards in the context of Bangladesh have not yet been investigated and are urgently needed.

Furthermore, previous studies in other countries have shown that microplastics can adsorb other pollutants or chemicals, i.e., heavy metals, pesticides, organic micropollutants including pharmaceuticals and per- and polyfluoroalkyl substances (PFASs) and further enhance the co-exposure through the food chain (Kühn et al., 2015). Microplastics can also act as vectors for chemical micropollutants that are already persistent, highly toxic, and have the propensity for long-distance migration. Many of these pollutants can adsorb on the surface of the microplastics, can be ingested by aquatic organisms with the microplastics, and then desorb from the microplastics surface inside the organism (Yu et al., 2021). However, the reviewed studies majorly focused on only the microplastics pollution in or near the waterbodies in Bangladesh without any analyses of the co-occurring contaminants. Interestingly, a recent study in the informal plastic recycling industry in Bangladesh found existence of hazardous heavy metals such as lead, copper, and nickel in the air samples in these areas as well as in the blood samples of the plastics recycling workers (Ahmed et al., 2020). This further indicates the need for research on co-contaminant occurrence, exposure, and effects on microplastics polluted sites in Bangladesh.

The emerging and exponential nature of the microplastics pollution research in Bangladesh by the scientific community is encouraging, however, further improvement and efforts will need particular attention from government organization, plastics manufacturing industries, consumers, and other stakeholders. The authors of this review are aware of recent engagements during May to June of 2021 from the Department of Environment (DoE) of Bangladesh government with the microplastics and plastics pollution researchers to understand the current scenario and discuss potential future activities. This is certainly a promising development in the right direction; however, such initiatives will require the enthusiastic engagement and cooperation from plastics manufacturing, selling, and recycling industries to be more effective.

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