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Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in Cox's Bazar, the longest natural beach in the world

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ABSTRACT

The extensive use of personal protective equipment (PPE) driven by the COVID-19 pandemic has become an important contributor to marine plastic pollution. However, there are very few studies quantifying and characterizing this type of pollution in coastal areas. In the present study, we monitored the occurrence of PPE (face masks, bouffant caps, and gloves) discarded in 13 sites along Cox's Bazar beach, the longest naturally occurring beach in the world. The vast majority of the items were face masks (97.9%), and the mean PPE density across sites was 6.29×10^{-3} PPE m⁻². The presence of illegal dumping sites was the main source of PPE, which was mainly located on touristic/recreational beaches. Fishing activity contributed to PPE pollution at a lower level. Poor solid waste management practices in Cox's Bazar demonstrated to be a major driver of PPE pollution. The potential solutions and sustainable alternatives were discussed.

1. Introduction

The outbreak of the novel coronavirus disease (COVID-19) by the end of 2019 (Xu et al., 2020) was declared a global health emergency by the World Health Organization (WHO) on January 30 of 2020 (Saadat et al., 2020). The worldwide spread of the virus led to intensive measures to prevent the transmission of the virus, such as lockdowns, border closures, enforced use of personal protective equipment (PPE), among others (Alfonso et al., 2021; Siam et al., 2020). Initially, it was reported that the reduction of greenhouse gas emissions, limited pressure on touristic destinations, and the absence of humans in natural habitats may have caused a positive impact on the environment (Rume and Islam, 2020). However, these were short-term effects. The immense increase in the demand for face masks, face shields, gloves, and other forms of PPE poses a great challenge to solid waste management (Rhee, 2020), which could lead to long-term environmental impacts.

Marine litter, one of the most severe forms of environmental pollution, threatens the wellbeing of marine biodiversity (Miranda-Urbina et al., 2015). The vast majority of litter entering the ocean (estimated ~80%) comes from land-based sources and anthropogenic activities (Cordova and Nurhati, 2019; Jambeck et al., 2015). Marine litter

encompasses many types of materials but is mostly composed of synthetic plastics (Hidalgo-Ruz and Thiel, 2015). Conventional plastics are strong, cheap, and persistent materials synthesized from fossil fuels (Andrady, 2011). Their massive production, use, and incorrect disposal or mismanagement have turned plastics into one of the most challenging environmental issues of current times (De-la-Torre et al., 2021b). The ongoing COVID-19 pandemic exacerbated plastic pollution due to the increase in demand for plastic-based PPE and constraints to efficient waste management (Adey, 2020; Patricio Silva et al., 2021). Fadare and Okoffo (2020) and Aragaw (2020) determined that surgical face masks found in an urban drainage and natural lake, respectively, consisted of polypropylene (PP) and high-density polyethylene (HDPE), two of the most commercially available plastic polymers. Other types of PPE may be composed of polyacrylonitrile, polystyrene (PS), polycarbonate (PC), or polyesters (Potluri and Needham, 2005). Recent studies have reported the occurrence of PPE polluting cities, beaches, and rivers (Ammendolia et al., 2021; Arduoso et al., 2021; Cordova et al., 2021), which demonstrates the arrival of this new form of plastic pollution in the environment. Moreover, the breakdown of PPE items may produce secondary microplastics (MPs, <5 mm), which are a serious concern to aquatic organisms by inducing ecotoxicological effects upon ingestion

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(Aragaw and Mekonnen, 2021a). MPs interact with contaminants in the environment, such as volatile organic compounds, heavy metals, pharmaceuticals, and emerging contaminants (Torres et al., 2021), serving as a carrier of xenobiotics and potentially exacerbating detrimental effects on marine biota (Bhagat et al., 2021).

Like most forms of plastic pollution, PPE could severely impact the environment and marine biota. De-la-Torre and Aragaw (2021) discussed and identified the knowledge gaps regarding PPE pollution in the marine environment, such as their suitability as a source of MPs, the potential transport of alien invasive species (AIS), sorption of chemical contaminants, and magnitude of PPE pollution worldwide. The objectives of the present article were to determine the abundance, characteristics, and distribution of PPE, namely face masks, gloves, and bouffant caps, polluting the longest natural beach in the world, Cox's Bazar, Bangladesh. To achieve this, a 12-week monitoring program was carried out on 13 beaches along the coast of Cox's Bazar. Each sampling site was characterized by its main activities (tourism, fishing, or fishing + tourism).

2. Materials and methods

2.1. Study area

Cox's Bazar District, Chittagong Division, is located in east

Bangladesh, home to the longest natural beach in the world (Mahamud and Takewaka, 2018). Cox's Bazar coast is a sandy beach expanding about 125 km along the coast of the Bay of Bengal. This place is known for its natural landscapes and subject to notorious national and international tourism and fishing activities (Rahman et al., 2020). The presence of hotels, gastronomic premises, and cultural and religious events poses a significant burden on solid waste management along the coast of Cox's Bazar beach. Previous studies have demonstrated that MPs are already polluting Cox's Bazar (Rahman et al., 2020), which elucidates the anthropogenic influence on these areas. To have a better overview of PPE pollution in Cox's Bazar, we have monitored 13 sampling sites (Fig. 1) for 12 consecutive weeks. These sites are well distributed and representative of almost the entire coast of Cox's Bazar beach. Based on field observations, we have determined the main activities carried out in each site, categorized as tourism (including recreational activities), fishing, or both tourism and fishing activities. This categorization will allow us to determine the influence of the activities carried in Cox's Bazar over the pollution with PPE associated with the COVID-19 pandemic.

2.2. Sampling strategy

For the sake of standardization, PPE monitoring followed our previous study carried out on the coast of Peru (De-la-Torre et al., 2021). In

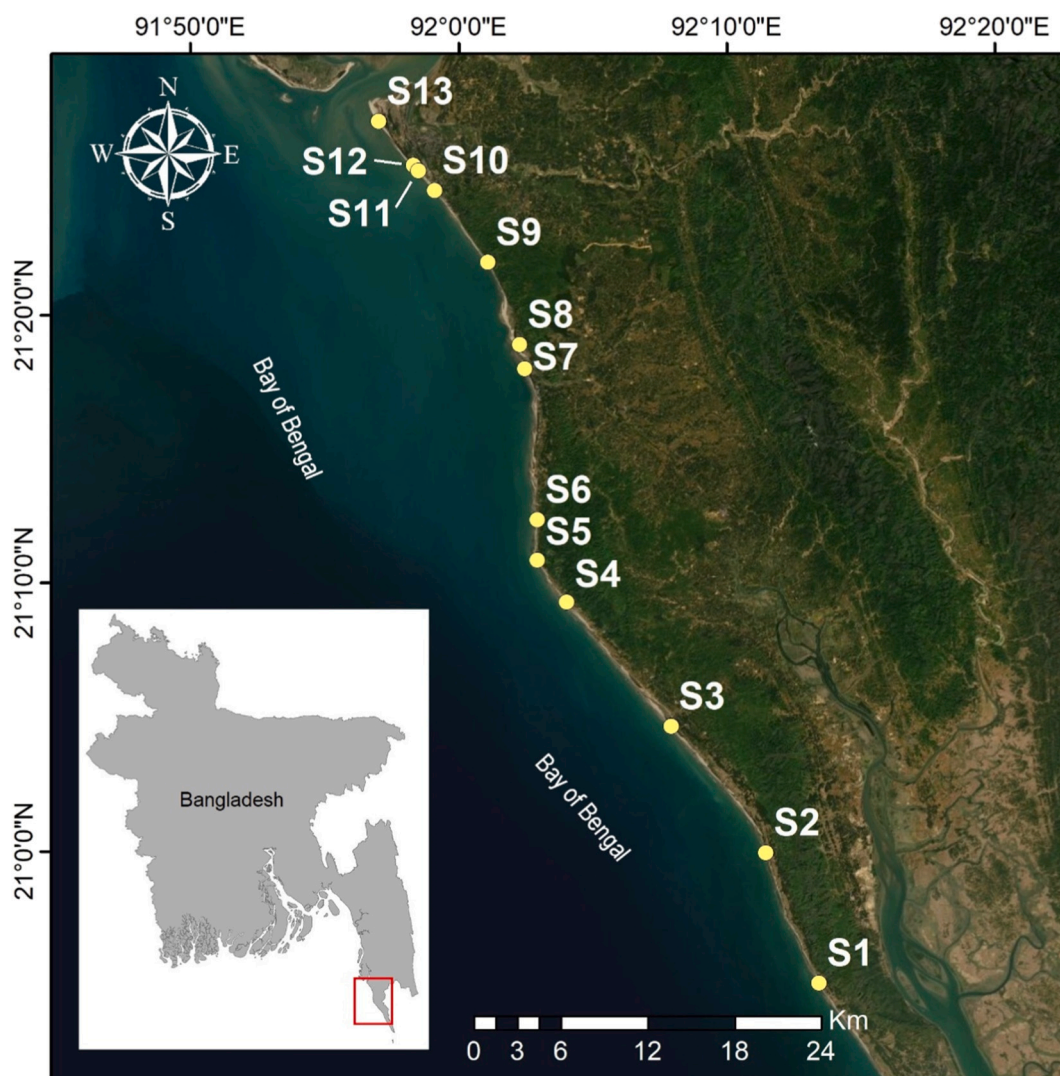


Fig. 1. Map of the sampling sites in Cox's Bazar, Bangladesh.

brief, several transects were established for each sampling site that allowed the beach to be completely surveyed (up to ~2 m into vegetation). Observers walked along each transect and visually identified PPE, which were categorized as face masks, face shields, bouffant caps, and gloves. Some recreation/touristic beaches are subject to solid waste dumping. The litter dumpsites were also checked carefully to identify PPE reaching the ocean from this source. Sampling campaigns covering the 13 sites were carried out weekly during 12 consecutive weeks from November 2020 to January 2021. The area covered in each sampling site was estimated using Google Earth (<https://www.google.com/earth/>) (Table 1). These values were used to calculate the PPE density in each sampling site as described by Okuku et al. (2020):

$$C = n/a$$

where C is PPE density (PPE m^{-2}), n is the number of PPE, and a is the covered area (m^2).

2.3. Statistical analysis

PPE density was expressed in $\text{PPE m}^{-2} \pm$ standard deviation. Sampling sites were grouped by activity (tourism, fishing, or tourism + fishing) to determine its influence on the PPE density. The Gaussian distribution of the datasets was invalidated by Shapiro-Wilk normality tests. To compare the PPE density among activities, a Kruskal-Wallis test followed by Dunn's multiple comparison test was conducted. The significance level was set to 0.05 for all the analyses. Statistical tests and graphs were performed using GraphPad Prism (version 8.4.3 for Windows).

3. Results

All of the sampling sites in Cox's Bazar beach were contaminated with PPE. An absolute total of 29,254 PPE items was counted across sites during the 12 weekly sampling campaigns (Fig. 2a), most of the time accumulating near fishing or litter dumping sites (Fig. 2b,c). The vast majority of the items were face masks, accounting for 97.2% of the total, followed by gloves (1.3%), and bouffant caps (0.79%) (Fig. 3a). No face shields were found on any site. The total amount of PPE per week increased over time up to the 10th week (Fig. 3b).

The mean PPE density across sites was 6.29×10^{-3} PPE m^{-2} and ranged from 3.16×10^{-4} PPE m^{-2} in S5 to 2.18×10^{-2} PPE m^{-2} in S12. Fig. 4 displays a boxplot with the PPE density of the 12 sampling weeks per site. As observed, the highest densities are found in touristic beaches, with the exception of S5. According to the Kruskal-Wallis test, PPE density varied significantly (Chi-square = 53.57, $p < 0.0001$) among different activities. Specifically, the sites where only touristic or recreational (T) activities are carried out, demonstrated a significantly higher PPE density ($p < 0.001$) than those where only fishing (F) or fishing and touristic (F + T) activities are carried out together, as revealed by the Dunn's multiple comparison test (Fig. 5).

Table 1
Coordinates, activities, and areas covered of the 13 sampling sites.

Code	Coordinates	Activity	Area covered
S1	20.918018, 92.223913	Fishing and tourist	18,690 m^2
S2	20.998981, 92.191373	Fishing and tourist	12,258 m^2
S3	21.077660, 92.132420	Fishing	45,066 m^2
S4	21.154814, 92.066642	Fishing and tourist	33,456 m^2
S5	21.181083, 92.049206	Tourist	74,581 m^2
S6	21.206303, 92.048947	Tourist	28,761 m^2
S7	21.300112, 92.041482	Fishing	74,281 m^2
S8	21.315069, 92.037589	Fishing and tourist	36,048 m^2
S9	21.366336, 92.018106	Tourist	13,826 m^2
S10	21.410881, 91.985406	Tourist	52,577 m^2
S11	21.423341, 91.974897	Tourist	42,816 m^2
S12	21.426620, 91.971975	Tourist	22,240 m^2

4. Discussions

Overall, the results found in the present study show higher PPE pollution than in other reports. In our previous research, we found a total of 138 PPE items in 12 beaches from the metropolitan city of Lima, Peru, after 12 sampling campaigns (De-la-Torre et al., 2021). In this study, however, the number of PPE items was ~212 times higher, despite having similar sampling methods and number of sampling campaigns. It should be noted that the 13 sites in the present study encompass 516,683 m^2 of sampled area, while in Lima only 110,757 m^2 and including three control sites (non-touristic sites of difficult access) with almost no PPE pollution. Given the influence of various methodological factors in the number of PPE, we suggest PPE density (PPE m^{-2}) as a more precise unit of measurement. The dominance of face masks (97.9%) among different PPE types is in accordance with the PPE composition in Lima (87.7%) (De-la-Torre et al., 2021). In the Cilincing and Marinda rivers, Indonesia, face masks of different types (cotton, sponge, and medical masks) were the most frequent PPE found (Cordova et al., 2021). However, in streets and recreational trails from the city of Toronto, Canada, the mean proportion of face masks was 32% (Ammendolia et al., 2021). The PPE density found in Cox's Bazar beach (3.16×10^{-4} – 2.18×10^{-2}) was similar to that of Toronto (urban areas) but larger than in Lima (Table 2). There are insufficient studies currently available to have a complete reference frame on the magnitude of the PPE pollution and density.

The results of the statistical analyses suggest that touristic beaches are the most polluted with PPE. On the touristic beaches, multiple recreational and cultural events and gatherings are carried out constantly, where about 2 million tourists are expected to visit during peak season (between November and March) (Dey et al., 2013). It is plausible that these activities, along with the lack of environmental awareness, could induce higher rates of incorrect disposal of PPE. However, the most notorious source of PPE within beach areas is illegal dumping and waste burning, as depicted in Fig. 2c. The vast majority of PPE in highly polluted sites are attributed to the presence of illegal dumping sites, and most of these are located in touristic sites (except for S5). Waste generation in Chittagong has been increasing continuously, despite municipal solid waste management systems being not sufficient to treat and adequately dispose all of it. Due to weak institutional capacity and a limited budget for waste management (Chowdhury et al., 2013), plastic pollution driven by the COVID-19 pandemic in Cox's Bazar is likely to exacerbate. Other sites that included fishing activities showed generally lower PPE densities. As shown in Fig. 2b, the areas in the vicinity of artisanal fishing harbors were highly polluted with various objects, such as broken fishing lines, fabrics, wood pieces, and paint particles, but a reduced number of PPE items. Additionally, illegal dumping sites were less frequent in fishing areas, resulting in lower PPE densities.

Recent studies determined that the outer and inner layers of common surgical face masks are made of PP and polyethylene (PE), respectively (Aragaw, 2020; Fadare and Okoffo, 2020). The vast majority of commercially available face masks are made of PP due to its low cost and low melt viscosity for facile processing (Chua et al., 2020), although several other materials, such as PS, PC, PE, and polyester, may also be used in face masks. Gloves, on the other hand, are made of latex, nitrile, or PVC (De-la-Torre and Aragaw, 2021), while surgical bouffant caps generally consist of woven textiles, like cotton and cotton-polyester layers (Behera and Arora, 2009). Each disposable N95 and surgical face mask contain approximately 9 and 4.5 g of PP, respectively (Akber Abbasi et al., 2020), and an additional 2 g in the N95 filter (Liebsch, 2020). Likewise, earloops are mostly made of PA (Battagazzore et al., 2020). Based on the chemical identity of most PPE materials, its contribution to plastic pollution becomes evident.

The potential effects of PPE pollution in coastal environments are diverse. It has been suggested that face masks may be notable sources of MPs in the form of fibers (Aragaw, 2020; Fadare and Okoffo, 2020). The occurrence of microplastics in Cox's Bazar has already been



Fig. 2. a) Examples of surgical face masks, a glove and plastic bouffant cap found in different sampling sites along Cox’s Bazar beach, b) evidence of plastic pollution near fishing sites, and c) evidence of large solid waste dumping sites within the beach.

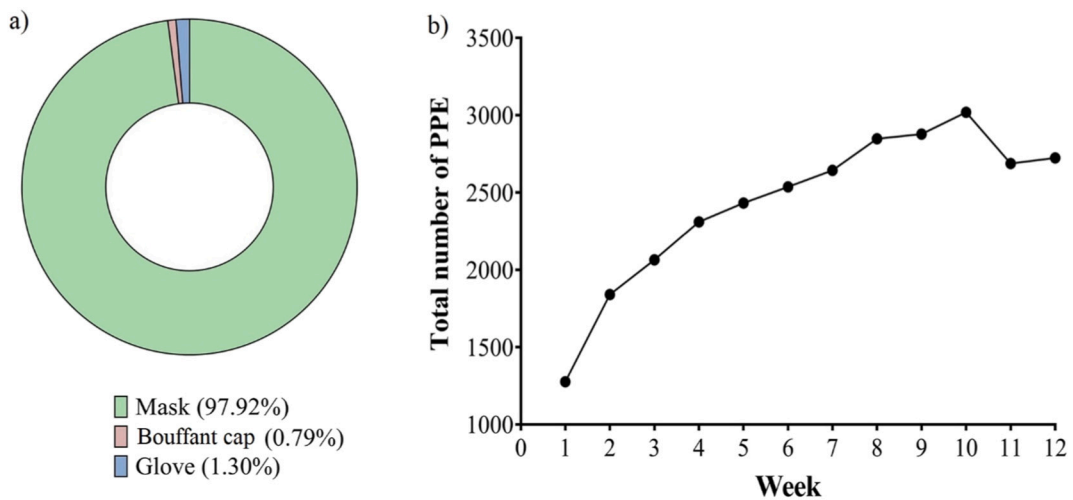


Fig. 3. a) Proportion of face masks, face shields, gloves, and other PPE. b) Weekly evolution of the total number of PPE across sampling sites.

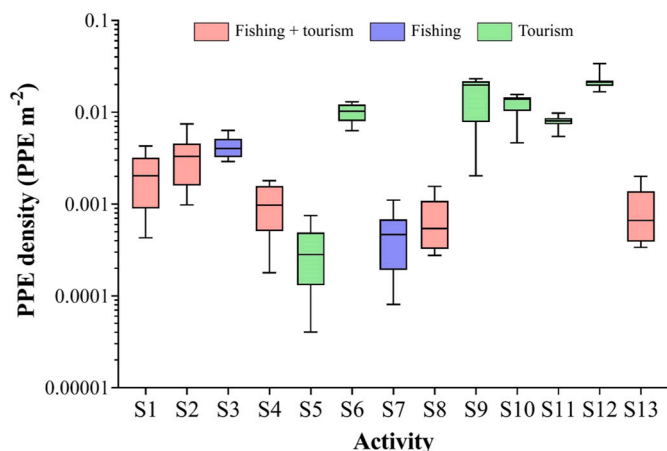


Fig. 4. Box plot diagram of the PPE density among sampling sites.

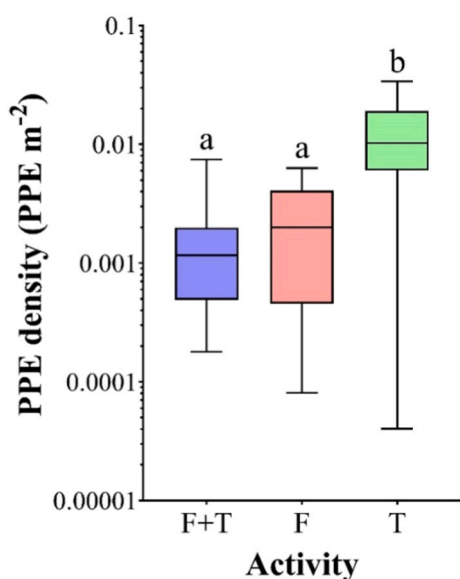


Fig. 5. Box plot of the PPE density for the three different activities. F + T: Fishing and tourism. F: Exclusively fishing. T: Exclusively tourism or recreational. Letters indicate significant differences according to Dunn's multiple comparisons test.

Table 2
Mean and range of PPE densities across studies.

Country	City	Area	PPE density (PPE m ⁻²)		Reference
			Mean	Range	
Bangladesh	Cox's Bazar	Beach	6.29 × 10 ⁻³	3.16 × 10 ⁻⁴ -2.18 × 10 ⁻²	This study
Peru	Lima	Beach	6.42 × 10 ⁻⁵	0-7.44 × 10 ⁻⁴	(De-la-Torre et al., 2021)
Chile	Nationwide	Beach	6.00 × 10 ⁻³ ^a	-	(Thiel et al., 2021)
Kenya	Kwale and Kilifi	Beach	-	0-5.6 × 10 ⁻²	(Okuku et al., 2020)
Persian Gulf	Bushehr	Beach	-	7.71 × 10 ⁻³ -2.70 × 10 ⁻²	(Akhbarzadeh et al., 2021)
Canada	Toronto	Urban	1.01 × 10 ⁻³	0-8.22 × 10 ⁻³	(Ammendolia et al., 2021)

^a Only face masks were counted.

demonstrated (Rahman et al., 2020), with fragments and fibers among the most abundant MP types. With the large amount of PPE wastes introduced to the beach, we hypothesize that MP pollution may become more pronounced, especially in areas with high PPE densities. However, the extent of the contribution of PPE to MPs in the environment remains unknown. Regardless, MPs are considered as contaminants of concern due to their ubiquitous presence in the environment (De-la-Torre et al., 2020b; Dioses-Salinas et al., 2020; Garcés-Ordóñez et al., 2020; Hidalgo-Ruz et al., 2012) and the likelihood of being ingested by organisms of various taxa (De-la-Torre et al., 2020a; Ory et al., 2017; Santillán et al., 2020). Additionally, open plastic burning as shown in the illegal dumping sites could lead to the formation of new types of plastic pollutants, such as pyroplastics and plastiglomerates (Corcoran et al., 2017; Turner et al., 2019). Also, plastic litter is known to harbor sessile organisms, which could be transported to foreign locations and turn into AIS (Rech et al., 2018a, 2018b). In our previous study conducted in Peru, we found a KN95 face mask colonized by macroalgae of the Rhodophyta division in an area of high presence of fouled marine litter (De-la-Torre et al., 2021, 2021a), which suggests the suitability of PPE as an artificial substrate for benthic organisms. However, none of the PPE found in the present study showed evidence of colonization. PPE may also interact with local biota through entanglement or ingestion. Hiemstra et al. (2021) reviewed these reports, showing photographic evidence of fish entrapped in surgical gloves, bird entangled in a face mask, and different PPE incorporated in bird nests from different locations.

The face mask use guidelines provided by the Department of Operational Support of the United Nations indicate that medical face masks (mostly single-use) are recommended for medical personnel, while the general public must opt for reusable cloth masks (UN, 2020). However, from our observations, it was evident that the vast majority of PPE items in Cox's Bazar were single-use surgical face masks (Fig. 2). We were unable to determine a precise number of face mask types (surgical, cloth, N95, etc.) during the sampling campaigns since most of these were indistinguishable in the presence of larger partially burned litter in dumping sites. Regardless, we recommend prioritizing reusable over single-use face masks as an economic and simple way to reduce face mask waste generation. Incorrectly disposed face masks could carry pathogenic microbiota, including the SARS-CoV-2 virus, thus becoming fomites (materials or objects that carry infection) (van Doremalen et al., 2020), and may be treated as hazardous waste (Dharmaraj et al., 2021a).

As a potential solution to the increasing face mask waste generation, Aragaw and Mekonnen (2021a, 2021b) and Jung et al. (2021) proposed and reported preliminary results of using thermo-chemical processes for recycling. In brief, PP wastes are converted into gas and liquid fuels through pyrolysis. Additionally, Dharmaraj et al. (2021a, 2021b) reviewed the conversion of various medical wastes through pyrolysis. Another alternative to prevent synthetic plastic waste generation is the use of degradable plastics. Biobased and biodegradable plastics have been extensively studied for their environmentally friendly properties, biocompatibility, and formation of composite materials (Ccorahua et al., 2017; Torres et al., 2019). Several studies developed N95 nano-porous filters based on degradable plastics, such as polybutylene succinate (PBS) and polylactic acid (PLA), through electrospinning (Choi et al., 2021; He et al., 2020). Also, Vaňková et al. (2020) fabricated PLA-based respirators by 3D printing. Although some fully biobased disposable masks are commercially available (Selvaranjan et al., 2021), the available market for this type of product is still very limited. Other preliminary studies incorporated surgical face masks as additives to pavements base/subbase (Saberian et al., 2021) and as a source of porous carbon for electrochemical applications (Hu and Lin, 2021).

5. Conclusions

The COVID-19 pandemic has turned the tide in favor of marine plastic pollution. However, the studies reporting pollution with PPE in

coastal areas are very few. Here, we reported the results from a large-scale PPE monitoring study along the coast of Cox's Bazar, the longest naturally occurring beach in the world. Large numbers of PPE (a total of 29,254 PPE items) were found, out of which 97.9% were face masks. However, after calculating the area-based PPE density (PPE m⁻²), our results are comparable to those in the literature. The most notorious source of face masks was illegal dumping sites in most touristic/recreational beaches. This evidences the poor solid waste management practices and lack of environmental awareness in beachgoers. The potential impacts of PPE in marine environments are the formation of MPs, harboring transportation of potentially invasive species, and entanglement or ingestion by larger organisms. This is one of the very few articles to report PPE pollution in coastal environments. It is necessary to display important research efforts in order to have a better understanding of the magnitude and impact of PPE pollution across different environmental compartments and organisms.

CRedit authorship contribution statement

Md. Refat Jahan Rakib: Project administration, Visualization, Funding acquisition, Formal Analysis, Resources, Investigation, Writing Original – Draft and review. **Carlos Ivan Pizarro-Ortega:** Formal Analysis, Writing – Original Draft, Data Curation. **Diana Carolina Dioses-Salinas:** Investigation, Data Curation, Formal Analysis, Writing Original – Draft. **Sultan Al-Nahian:** Data curation, Resources. **Gabriel Enrique De-la-Torre:** Conceptualization, Methodology, Software, Writing – Original Review & Editing, Supervision.

Declaration of competing interest

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

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