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Baseline

Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in coastal environment, Southeast Coast of India

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ABSTRACT

The rise in the use of single-use plastics and personal protective equipment (PPE) has increased plastic waste in the marine environment. In this study, we surveyed the presence of PPE (face masks and gloves) discharged in 6 beaches along the coast of India. A total of 496 PPE were counted with an average density of 1.08×10^{-3} PPE m^{-2}. The PPE density found was comparable to previous studies. Face masks were the most recorded type of PPE (98.39%), with gloves accounting for only 1.61% of the total. However, a significant reduction in the appearance of PPE was recorded on all six beaches, likely due to the increase in vaccination rates. The most contaminated places were the beaches with recreational activities + fishing. It has been noticed that the lack of awareness of environmental pollution and the negligence of the population and the mismanagement of municipal waste are the main causes of beach pollution by PPE. This study confirms the potential threat of PPE to terrestrial and aquatic organisms of multiple taxa in India, but further studies are needed to quantify the impact of this type of waste on marine animals.

1. Introduction

Plastic pollution has become one of the most pressing environmental problems (Beaumont et al., 2019; De-la-Torre et al., 2021a). Due to population growth, plastic generation has increased spectacularly during the last decades, from a total of 1.7 million tons produced worldwide in 1950 to a total of nearly 360 million tons in 2018 (PlasticsEurope, 2019). It is estimated that this number will double over the next 20 years. Most plastic waste ends up in the environment due to improper disposal and/or management of plastic products (Mghili et al., 2020; MacLeod et al., 2021; Larsen Haarr et al., 2022). Plastic litter poses a threat to marine wildlife. The most noticeable impacts of plastic litter are the ingestion, entanglement and suffocation of many hundreds of marine species (Gall and Thompson, 2015; Kühn and van Franeker, 2020). Also, plastic litter poses aesthetic issues and constitutes a danger to marine activities, including tourism and fishing (Krelling et al., 2017; Beaumont et al., 2019).

The novel SARS-CoV-2 coronavirus, which affected nearly 7.3 million people globally in mid-June 2020 (WHO, 2020). Due to the COVID-19 outbreak, the global community has used personal protective equipment (PPE) to prevent its transmission and spread. As a result, the manufacture and use of PPE has undoubtedly increased in all nations around the world (Patrício Silva et al., 2020). PPE includes masks, gloves, hand sanitizer and other essential safety equipment which is utilized to protect the transmission of the SARS-CoV-2 virus (Patrício Silva et al., 2020; Selvaranjan et al., 2021). The most largely utilized type of PPE is the disposable surgical face masks. Millions of these masks are being disposed of every day in the environment (Kutralam-Muniasamy et al., 2022). As a result, significant amounts of PPE waste have been generated worldwide, adding further pressure to solid waste management practices (Patrício Silva et al., 2020; Selvaranjan et al., 2021). These PPE are transported from area to area by wind, rivers, streams and water or human activities (Patrício Silva et al., 2021). Recent studies shows that, the occurrence of PPE pollution driven by the COVID-19 pandemic in the cities, lakes, and beach environment gets more attention in worldwide (Ammendolia et al., 2021; Aragaw, 2020; Ardusso et al., 2021; Akhbarizadeh et al., 2021a, 2021b; Cordova et al., 2021; Ben Haddad et al., 2021; De-la-Torre et al., 2021b; De-la-Torre et al., 2022; Hassan et al., 2021; Patrício Silva et al., 2020; Rakib et al., 2021; Aragaw et al., 2022; Hatami et al., 2022; Mghili et al., 2022).

The recent report also shows that, the nearly 1.56 billion face masks were estimated to enter in the Ocean in 2020 (OceansAsia, 2020), as

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results the massive amount PPE could cause harmful impacts to marine wildlife. The most PPE contains plastics with higher percentages of polyethylene (PE) and polypropylene (PP), as well as other polymeric materials such as polyurethane, polyester, nylon, and polystyrene (Aragaw, 2020; Fadare and Okoffo, 2020). Consequently, PPE debris in marine environments is considered as an emerging form of plastic debris and an addition to the existing microplastics crisis (Ma et al., 2021; Saliu et al., 2021; Shen et al., 2021; Wang et al., 2021a). PPE items have already become a new threat to marine wildlife. Studies have documented the impacts of COVID-19 litter on wildlife through entanglement, entrapment, and ingestion (Hiemstra et al., 2021; Neto et al., 2021; Patrício Silva et al., 2021).

India has a shoreline of 7517 km, with sand beaches accounting for 43% of this. A large part of the population of India lives in coastal areas, which contribute to the production of large amounts of marine litter. Some of the research on debris monitoring evaluations carried out along different parts of the Indian shoreline indicates that ineffective waste management, principally in coastal region, as well as population behavior is one of the fundamental causes of marine litter pollution (Sulochanan et al., 2019; Jeyasanta et al., 2020; Krishnakumar et al., 2020; Sathish et al., 2020; Vidyasakar et al., 2020; Mugilarasan et al., 2021). In India, the first confirmed case of COVID-19 was recorded in Kerala on January 30, 2020. In the following days, the cases are increasing exponentially. The Government of India has made it obligatory to wear face masks in public places. As a result of the government's declaration, the production and consumption of PPE has increased in India (Ranjan et al., 2020). According to the Central Pollution Control Board (CPCB, 2022), India generated 47,200 tons of COVID-19-related biomedical waste between August 2020 and June 2021; these include face masks, gloves and other medical items. Unfortunately, these PPE

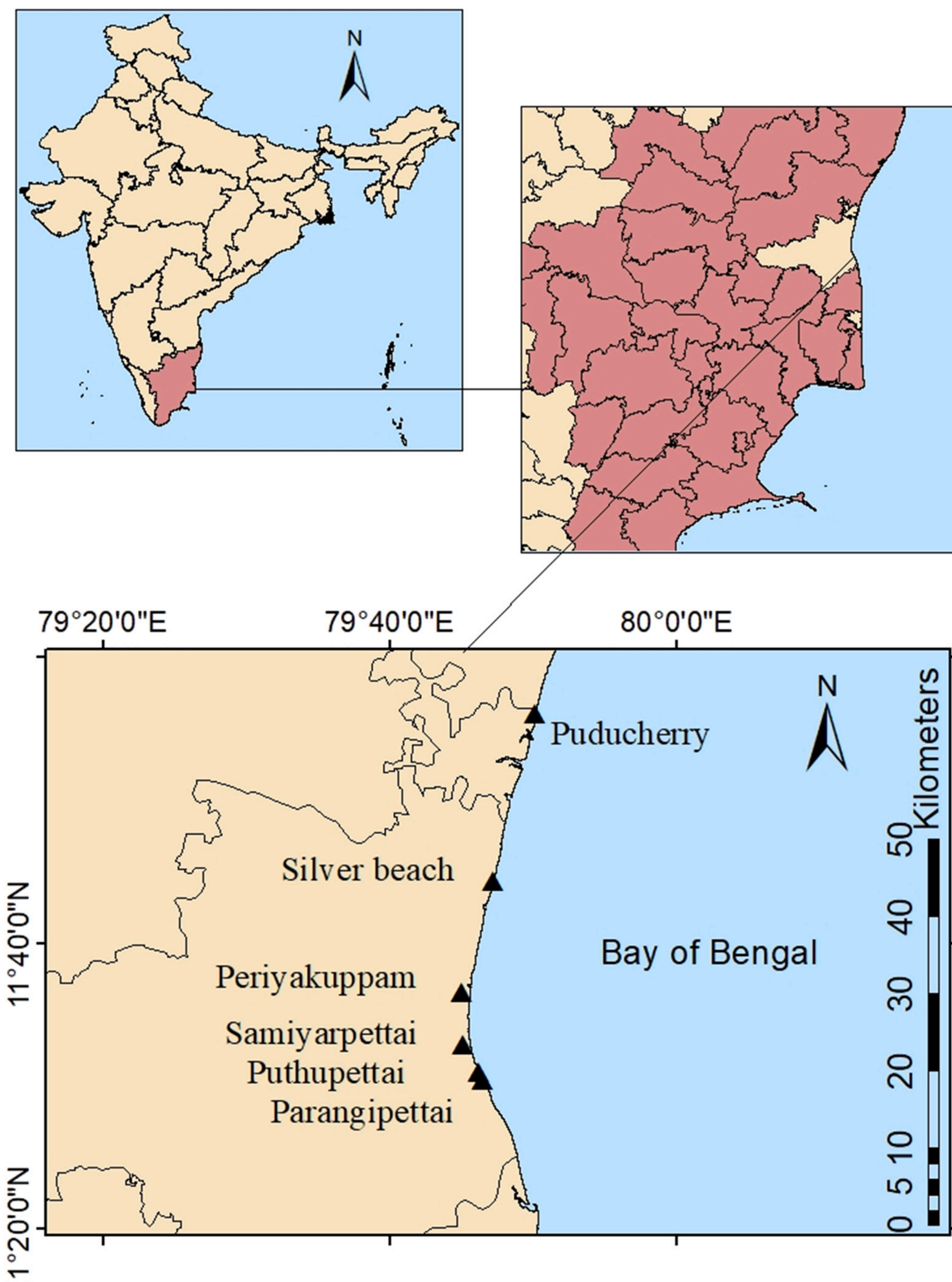

Fig. 1. Study area map.

are poorly managed by users. These PPE are found along coasts, beaches and rivers, as well as in cities, but little is known about the magnitude of PPE pollution on Indian beaches.

The present study provides baseline information on the occurrence, source, and distribution of COVID-19-associated PPE along the beaches of Tamil Nadu, southeast coast of India, in order to better understanding the impacts of plastic pollution on the marine environment in India during the COVID-19 pandemic.

Pondicherry Union territory and Tamil Nadu is located southern part of India, connected to the Bay of Bengal on the east (Fig. 1). The Tamil Nadu is third largest coastal state of India and it has 1076 km of long coastal length, with an Exclusive Economic Zone (EEZ) of 1.9 lakh Km^2, contributing 5.209 million tons of fish production. This coastal region widely used for fishing, culture tourism and recreational activities. Thus these activities are represent a major source of plastic and microplastic pollution entering the marine environment (Sathish et al., 2019; Jeyasanta et al., 2020; Vidyasakar et al., 2020). The occurrence of PPE was carried out in Pondicherry and Tamil Nadu beaches. According to the field observations, the present study have evaluated the major activities carried out in each sampling stations, categorized as recreational activities, fishing, and both recreational activities and fishing activities.

In order to assess the PPE pollution in Pondicherry and Tamil Nadu coast, the present study has examined 6 sampling stations for 3 months. These sampling site are well scattered and representative of part of the Southeast coast of India. To standardize the PPE observing, the methodology carried out on the coast of Peru and Bangladesh was followed (De-la-Torre et al., 2021b; Rakib et al., 2021). In each and every sampling site, numerous parallel transects (separated by 6–8 m between transect) covering the whole extent of the beach were established. The number and length of transects were differed based on the beach size and morphology of their total length. The sampling method consists of walking along each transect, visually scanning the environments, and recognized the PPE items, which were classified as face masks, face shields, bouffant caps, and gloves. All of the PPE items were photographed. In each location, the area sampled, and coordinates were estimated using Google Earth (https://www.google.com/earth/) (Table 1). Thus, in order to calculate the PPE density in each and every sampling station was followed by Okuku et al. (2020).

$$C = n/a$$

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

The mean density of PPE in each station was presented as a boxplot. Sample locations were combined by activity (recreational activities, fishing, or recreational activities + fishing) to investigate its influence on PPE density. In the first, the Shapiro-Wilk normality tests are used to check the Gaussian distribution of the datasets. The Kruskal-Wallis test followed by Dunn's multiple comparison test was performed to compare

Table 1
The major activity, substrate, surveyed area of each sampling site, geographical coordinates along the Southeast coast of India, Tamil Nadu.

Site code	Activity	Substrate	Area covered (m^2)	Coordinates
S1	Recreational	Rock	31,691	11°56′3.46″N; 79°50′11.17″E
S2	Recreational + fishing	Sand	29,279	11°44′21.16″N; 79°47′13.15″E
S3	Fishing	Sand	14,212	11°36′32.29″N; 79°45′32.29″E
S4	Recreational + fishing	Sand	27,015	11°32′54.88″N; 79°45′37.42″E
S5	Recreational	Sand	21,402	11°30′59.37″N; 79°46′14.57″E
S6	Recreational + fishing	Sand	19,481	11°30′27.35″N; 79°46′29.03″E

the density of PPE among the activities. The significance level was fixed at 0.05 for all analyses. Statistical tests were performed using SPSS (version 20).

The occurrence of PPE items was monitored along the 6 beaches of Southeast coast of India, Tamil Nadu. A total of 496 COVID-19 associated PPE items were found in the 6 beaches. This number of PPE is higher than that recorded in most studies. Fig. 2 shows few examples of beach PPE items along the Southeast coast of India. Commonly, two type of PPE items found in all the sites, of which face masks were the most abundant type of PPE (98.39%) and gloves (1.61%) (Fig. 3). Face masks were mainly composed of single-use surgical masks (97.96%), followed by cloth masks (1.43%) and N-95 mask (0.61%). Face shields and hazard suits were not found in the beaches. The predominance of face masks has been reported in coastal zones of different countries, including Morocco (Ben Haddad et al., 2021; Mghili et al., 2022), Peru (De-la-Torre et al., 2021b; De-la-Torre et al., 2022), Bangladesh (Rakib et al., 2021), Brazil (Ribeiro et al., 2022), Ethiopia (Aragaw et al., 2022) and Iran (Hatami et al., 2022). In Argentina, however, the number of gloves equaled to the number of face masks (48% each) found in 15 sites along the coast (De-la-Torre et al., 2022).

The overall mean density of PPE items were 1.08×10^{-3} m^{-2} and ranged from 2.81×10^{-4} to 2.80×10^{-3} PPE m^{-2}. The mean densities found in this paper are comparable to previous studies, as presented in Table 2. The density registered in this paper was much lower than values reported from Lima, Peru (De-la-Torre et al., 2021b), Argentina (De-la-Torre et al., 2022), Brazil (Ribeiro et al., 2022), Ethiopia (Aragaw et al., 2022), Iran (Hatami et al., 2022) and Agadir, Morocco (Ben Haddad et al., 2021). Simultaneously, the mean density was lower than that reported from the beaches of the Cox's Bazar coast (Rakib et al., 2021) and the Chilean coast (Thiel et al., 2021). As Table 2 shows, PPE pollution is not uniform in all countries. This is due to the different factors involved in this question, such as solid waste management systems and infrastructure, seasonality (beaches are mainly preferred during the summer season) and legislation and enforcement (Hatami et al., 2022). It can be influenced by the area sampled, sampling methods, weather conditions (rainfall and wind), and type of region and population density (Ben Haddad et al., 2021; De-la-Torre et al., 2021b; Patrício Silva et al., 2021; Kutralam-Muniasamy et al., 2022).

The higher number of PPE items were recorded in all the station on January 2022, (expect site-6) followed by December 2021 and lower number of PPE items were found on February 2022. The high number of PPE recorded in January is probably due to the celebration of the New Year 2022 and the regional activities (Pongal celebration from January 14 to 18). A positive correlation between PPE abundance and the number of visitors to the beach was observed in some areas. This is consistent with studies in marine environments, which have linked the growing number of beach visitors to greater PPE disposal (De-la-Torre et al., 2021b; Hassan et al., 2021; Thiel et al., 2021). The lowest total number of PPE was registered during the last sampling campaign. Aragaw et al. (2022) and Hatami et al. (2022) also documented the decline in the number of PPE during the last sampling in Ethiopia and Iran respectively. This may be due to various causes regarding the progression of the pandemic and the rate of use and disposal of face masks. With the increase in vaccination rates, the use of face masks is not mandatory, which explains the decrease in the number of PPE during the last sampling. The increase in vaccination coverage will probably be a return to normal for the population in the near future.

As summarized in Fig. 4, the largest total number of PPE was observed in S1 (35.89%; $n = 178$), followed by S4 (21.98%; $n = 109$), S2 (17.75%; $n = 88$), S3 (9.07%; $n = 45$), S5 (8.26%; $n = 41$) and S6 (7.05%; $n = 35$). The boxplot shows the mean density in each beach (Fig. 4). PPE densities were combined according to the main activities conducted in each sample area. The most of the PPE items were recorded in recreational + fishing activity ($n = 232$), followed recreational activity ($n = 219$). The present study observed that the lower number of PPE items found in fishing sites (45 PPE items, representing 9.07%). No

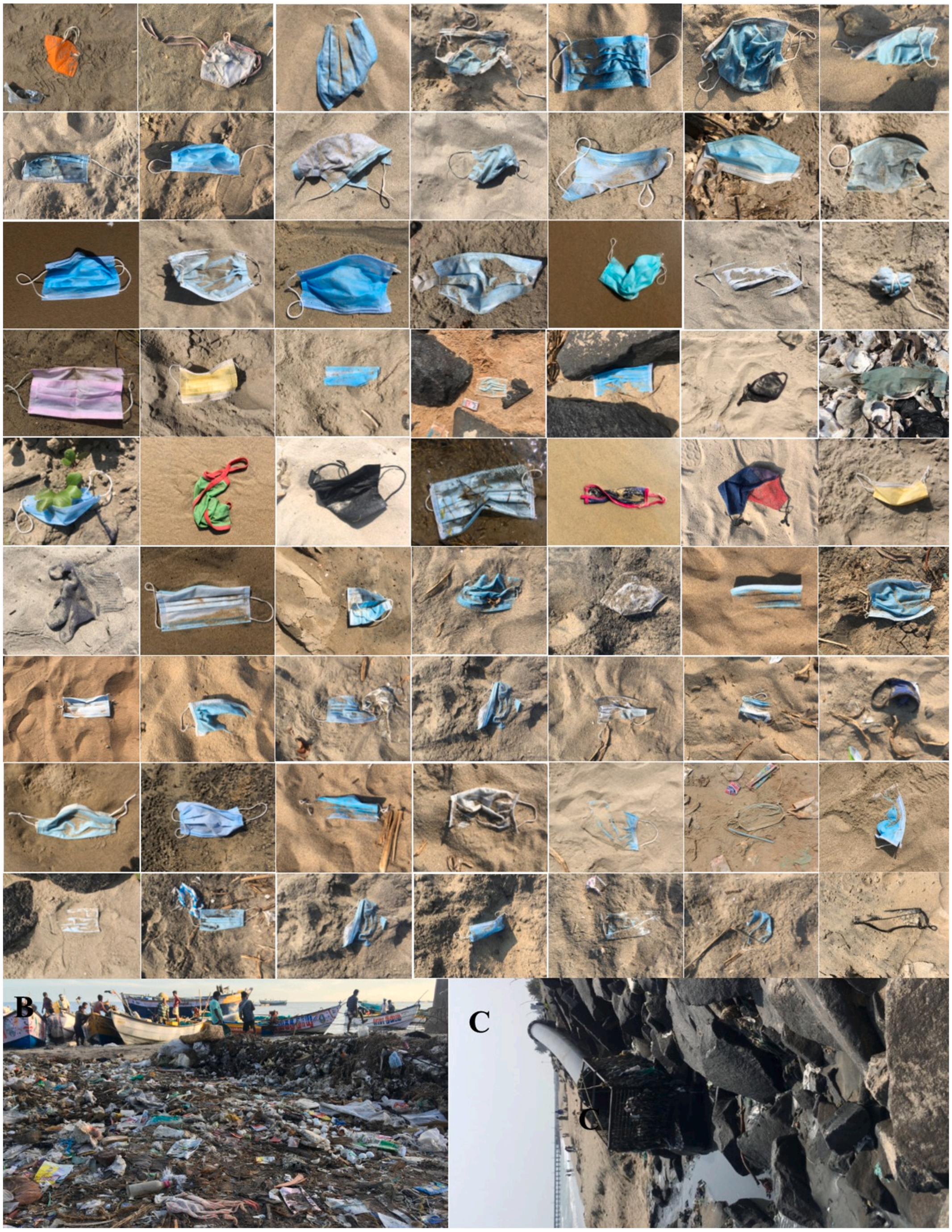

Fig. 2. A) Different types of surgical face masks, a glove found in sampling sites along the Southeast coast of India, B) evidence of large solid waste dumping sites within the beach and fishing region, C) evidence of sewage channels carrying PPE waste in sites beach (S1- Puducherry beach).

significant differences were observed between sample sites (Kruskal-Wallis test, $p \geq 0.05$). Previous studies showed a significant influence of the type of activity on the average PPE density. On the popular tourist beaches, numerous recreational and cultural events and celebrations are conducted continuously. These activities are likely the source of PPE on the beaches. Recreational beaches in Cox's Bazar, Bangladesh (Rakib et al., 2021), and Lima, Peru (De-la-Torre et al., 2021b), the Bushehr coast, in the Persian Gulf (Akhbarizadeh et al., 2021a, 2021b) and Tetouan, Morocco (Mghili et al., 2022) were considerably more contaminated than in fishing beaches. Illegal deposits are important sources of PPE as shown in Fig. 2B. The Covid-19 driven PPE litter are disposed into landfills without adequate management due of the lack of resources to manage this type of litter. Due to the lack of proper waste management, these PPE wastes can be transported into the aquatic environment by rivers, wind and drainage systems. We have already observed the presence of face masks on drainage systems, as shown in Fig. 2C.

Like other countries, India also has poor waste management and infrastructure. Insufficient waste treatment and disposal infrastructure is one of the main problems in developing nations, including India. Approximately 60 to 85% of plastic waste in India has been mismanaged with a tendency to enter the environmental matrix, including surface-water systems (Geyer et al., 2017; Ministry of Housing &amp and Urban Affairs Government of India, 2019). According to the annual

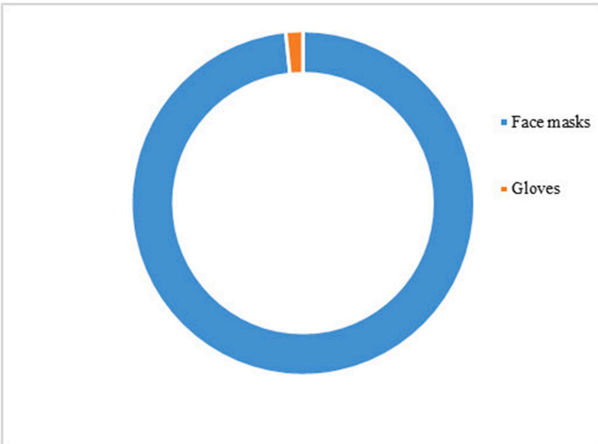

Fig. 3. Pie chart demonstrating the contribution of each PPE type.

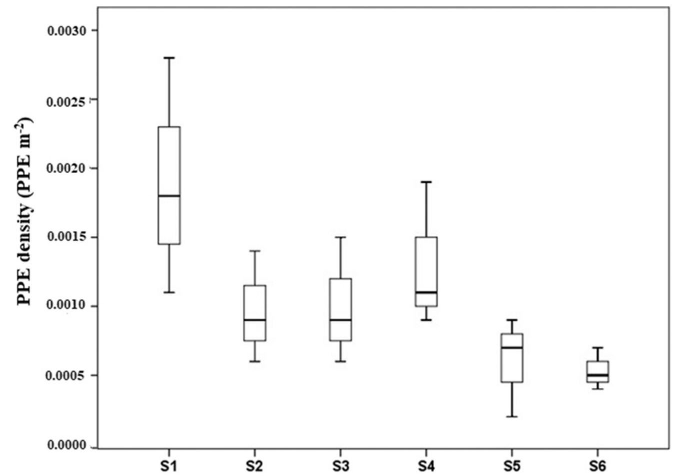

Fig. 4. Box plot diagram of the PPE density among sampling sites.

Table 2
Comparison of the mean and range of PPE densities on the beaches of different countries.

Country	City	PPE density (PPE m^{-2}) Mean	PPE density (PPE m^{-2}) Range	Reference
Morocco	Tetouan	1.2×10^{-3} [a]	$0.00–3.67 \times 10^{-3}$	Mghili et al, (2022)
Morocco	Agadir	1.13×10^{-5}	$0.001.21 \times 10^{-4}$	Ben Haddad et al. (2021)
Kenya	Kwale and Kilifi	–	$0.00–5.6 \times 10^{-2}$	Okuku et al. (2020)
Ethiopia	Bahir Dar	1.54×10^{-4}	$1.22 \times 10^{-5}–2.88 \times 10^{-4}$	Aragaw et al. (2022)
Peru	Lima	6.42×10^{-5}	$0.00–7.44 \times 10^{-4}$	De-la-Torre et al. (2021b)
Peru	Multiple	6.60×10^{-4}	$0.00–5.01 \times 10^{-3}$	De-la-Torre et al. (2022)
Argentina	Multiple	7.21×10^{-4}	$0.00–5.60 \times 10^{-3}$	De-la-Torre et al. (2022)
Brazil	Santos	7.46×10^{-5}	$0.00–3.89 \times 10^{-4}$	Ribeiro et al. (2022)
Chile	Nationwide	6.00×10^{-3} [a]	–	Thiel et al. (2021)
Bangladesh	Cox's Bazar	6.29×10^{-3}	$3.16 \times 10^{-4}–2.18 \times 10^{-2}$	Rakib et al. (2021)
Iran	Bushehr	–	$7.71 \times 10^{-3}–2.70 \times 10^{-2}$	Akhbarizadeh et al. (2021a, 2021b)
Iran	Mazandaran	1.02×10^{-4}	$0.00–7.16 \times 10^{-4}$	Hatami et al. (2022)
India	Tamil Nadu	1.08×10^{-3}	$2.80 \times 10^{-4}–2.80 \times 10^{-3}$	Present study

[a] Only face masks were counted.

reports of the Central Pollution Control Board (CPCB, 2016), India generates nearly 9.4 million tons plastic waste per year, of which 5.6 million tons of plastic waste are recycled and 3.8 million tons of plastic waste are left uncollected/littered (9400 tons of waste/day) in land (MoEFCC, 2018). The developing countries like India are already facing existing challenges of waste management (Srivastava et al., 2015), and the waste produced by the COVID-19 pandemic period has added to the already existing issues. India generating nearly 517 tons of biomedical waste/day from the hospital, quarantine wards, health care or medical institution and other departments (Anwer and Faizan, 2020), during the COVID-19 pandemic, hospitals are expected to produce nearly six fold more biomedical waste (Ranjan et al., 2020). At present, an average amount of COVID-19 related biomedical waste generation during January 2022 is nearly 38.41 tons per day, of which 4.81 tons per day of biomedical waste produce by Tamil Nadu state (CPCB, 2022). Inappropriately disposed PPE can penetrate the environment due to poor waste management, littering, intentional dumping, or rainwater runoff. In India, discarded PPE has become ubiquitous in the marine environment of India, likely contributing greatly to plastic pollution.

Like other plastic litter, once face masks are discarded in the marine ecosystem, they undergo degradation processes including, temperature fluctuations, ultraviolet radiation, physical abrasion, chemical oxidation, increased humidity and biodegradation (Jemec Kokalj et al., 2022). Studies have reported that the presence of PPE waste on beaches could be a significant source of microplastics (Aragaw, 2020; Fadare and Okoffo, 2020). Later studies have confirmed the release of microplastics in vitro and estimating the release rate using various analytical techniques. For example, Saliu et al. (2021) identified 61 and 117,400 microplastics varying from 1 to 5 mm and 25 to 500 μm, respectively, liberated from a single surgical mask under UV light irradiation. On the other hand, Wang et al. (2021a) estimated a release of >16 million microplastic (1–500 μm) per surgical mask under natural alteration conditions (UV light irradiation in the presence of sand for 24 h). Also, Ma et al. (2021) estimated the release of nanoplastic (<1 μm) per mask. Other experiments (Chen et al., 2021; Wang et al., 2021a) have confirmed that face masks are significant sources of nanoplastics and microplastics in the aquatic system. Recently, Wang et al. (2022) documented the release of microplastics from gloves. Reusable masks are also important sources of microplastics (Ribeiro et al., 2022). In our study, some face masks showed some degree of physical degradation (e.g., torn layers, Fig. 5), similar to those reported by Akhbarizadeh et al. (2021a, 2021b) and Mghili et al. (2022). The appearance of microplastics in the study area has already been documented by Sathish et al. (2019) and Sanjai Gandhi et al. (2021). For example, studies have documented pollution of corals (Patterson Edward et al., 2020), mangrove patches (Sulochanan et al., 2014) and sediments by microplastics in India (Karthik et al., 2018; Sathish et al., 2019; Sulochanan et al., 2019; Jeyasanta et al., 2020; Vidyasakar et al., 2020). With the high quantity of PPE litter introduced to the shore, we hypothesize that microplastic pollution may become more marked, particularly in areas with high PPE numbers.

Like other types of plastic waste, PPE will likely become an ingestion and entanglement threat to marine wildlife. Ingestion of face masks by animals has also been reported in Brazil (Neto et al., 2021). These authors reported the mortality of a Magellanic penguin (*Spheniscus magellanicus*) due to the ingestion of a whole face mask. In many cases, ingestion of masks by wildlife causes death or urgent surgery, which demonstrates the gravity of discarded masks for marine wildlife (Neto et al., 2021). Hiemstra et al. (2021) showed photographic evidence of many types of PPE-wildlife interactions, including entanglement,

Fig. 5. Damaged masks found in the study area.

entrapment and ingestion of gloves or masks. Mghili et al. (2022) also documented a bird wearing a face mask.

Indian Waters is home to hundreds of vulnerable species of various taxa such as mammals and reptiles and fish. It offers important sites for nesting birds and migratory. Apart from the marine ecosystem of the Indian coast, other terrestrial habitats in the proximity may also be threatened. For example, in the study area, we find the Pichavaram mangrove forest, located along the Bay of Bengal, in southeast India. These mangroves also attract migratory and local birds. About 177 species of birds have been counted. This mangrove forest acts as nursery ground for various fish and shell fish larvae, plankton diversity, macrobenthic communities and meiofauna assemblage etc., (Chandrasekaran, 2000; Mahesh and Saravanakumar, 2015; Punniyamoorthy et al., 2021; Saravanakumar et al., 2021). However, this richness of biodiversity could be threatened by pollution from PPE.

The IUCN endangered species such as olive ridley (*Lepidochelys olivacea*) and green turtle (*Chelonia mydas*) are frequently occurred in the study area region (Chandrasekar and Srinivasan, 2013). The study area is an important nesting area for the olive ridley turtle (Chandrasekar and Srinivasan, 2013). Sea turtles were among the first marine wildlife documented to ingest plastic litter, a phenomenon that occurs in most regions of the world (Kühn and van Franeker, 2020). Unfortunately, the accumulation of PPE on the main nesting beaches means that juvenile turtles are among the most threatened by plastic entanglement. Recently, Fukuoka et al. (2022) found a face mask in the feces of a juvenile green turtle captured alive in a set net off the northeast coast of Japan. PPE represent a serious threat to marine turtle species in Indian waters.

In recent years, several studies have been published on the ingestion of microplastic by marine wildlife in India. Bioaccumulation of microplastics in mesopelagic and epipelagic fish, Indian edible oyster, Indian white shrimp, bivalves, and in some commercially important fish and other marine wildlife has been documented very recently (Patterson et al., 2019; Daniel et al., 2020; Dowarah et al., 2020; James et al., 2020; Karuppasamy et al., 2020; Sathish et al., 2020). When PPE is subjected to mechanical forces, they becomes smaller and therefore can be easily consumed by marine organisms (De-la-Torre et al., 2021b). Recently, Ma et al. (2021) recorded the ingestion and bioaccumulation of microplastic released from disposable masks in diverse model organisms, including the shrimp *Penaeus vannamei*, the copepod *Parvocalanus crassirostris*, the rotifer *Brachionus rotundiformis*, the scallop *Chylamys nobilis* and the juvenile grouper *Epinephelus lanceolatus*. Also, Sun et al. (2021) demonstrated that microplastics liberated from disposed face masks were ingested by the marine copepod *Tigriopus japonicus* under experimental conditions (10 PM/mL for 24 h). The ingestion of this type of debris induces a significant decrease in the fecundity of this species. PPE items can potentially pose an ecological risk to the marine environment. PPE can be colonized by microbes transferring these microorganisms to new locations, which increases the risk of biological invasion (De-la-Torre and Aragaw, 2021). De-la-Torre et al. (2021a, 2021b) have already suggested the suitability of PPE as an artificial substrate for benthic organisms. These authors found a KN95 face mask colonized by macroalgae of the division Rhodophyta.

Like plastic, PPE can absorb and concentrate contaminants from the surrounding environment, posing risks of contaminant transfer to animals through different trophic levels (Dobaradaran et al., 2018; Akhbarizadeh et al., 2021a, 2021b; Takdastan et al., 2021; Hajiouni et al., 2022). Existing studies have documented that masks and wipes contain a wide range of inorganic and norganic contaminants utilized as UV stabilizers, plasticizers, and flame retardants in plastic production, including antioxidants, organophosphate esters, phthalates (di- and mono) and non-phthalates, bisphenols, and plastic additives (Liu and Mabury, 2021; Sullivan et al., 2021; Wang et al., 2021b; Kutralam-Muniasamy et al., 2022). Ardusso et al. (2021) and De-la-Torre et al. (2022) reported the appearance of metallic nanoparticles, such as Ag and Cu nanoparticles on used face masks. Based on the previous work, we confirm the potential threat of PPE to terrestrial and aquatic organisms of multiple taxa, but further studies are needed to quantify the impact of this type of waste, particularly on marine animals in the Indian marine environment.

Public behaviors concerning PPE disposal tend to continue in Indian beaches. This could be due to a lack of social responsibility and public awareness concerning PPE disposal. This lack of environmental awareness among visitors to Indian beaches has been reported previously by many studies (Sulochanan et al., 2019; Jeyasanta et al., 2020; Vidyasakar et al., 2020; Mugilarasan et al., 2021). There is a need to improve the waste management collection and disposal systems, which has been severely affected by COVID-19 pandemic and to encourage better waste management among the population. As a result, awareness campaigns in the media should be launched to raise public awareness of the impact of haphazard dumping and poor management of hazardous waste. In addition, the environmental impacts of plastic pollution should be introduced into school curriculum to raise awareness among future generations. Recommendations include the use of environmentally friendly and reusable PPE, recyclable or biodegradable materials. During our PPE evaluation, we observed that there were no containers for dumping solid waste. Also, there were no signs directing that PPE not be discarded in the environment, but rather in the garbage cans. We suggest installing sufficient and strategically located trash cans for disposed PPE.

We also need an urgent and coordinated engagement to circular economy approaches, especially PPE recycling policies and practices. Various methods such as glycolysis, aminolysis, hydrogenation, hydrolysis, gasification and pyrolysis are now focusing on seeking advanced technologies to convert litter PPE into value-added products (Siwal et al., 2021). Recent studies show that pyrolysis of PPE litter related to COVID-19 is the most effective method and environmentally friendly solution with large application potential (Aragaw and Mekonnen, 2021; Mekonnen and Aragaw, 2021). The recycling of PPE can yield value-added products and mitigate disposal problems and at the same time provide energy sources (Mekonnen and Aragaw, 2021). PPE are already released into the environment, so policymakers must focus on recycling these litter to minimize their impact on the environment. In India, there are some initiatives to recycle PPE, but they are insufficient. For example, Eco Eclectic Technologies creates “Brick 2.0” made from recycled PPE face masks. This may solve the problems of waste disposal and provide a value-added product. The composition of brick consists of

52% of shredded PPE materials, 45% of paper waste, and 3% of binding. (https://www.thebetterindia.com/235645/face-mask-recycle-ppe-masks-waste-bricks-gujarat-low-cost-innovation-covid-19-eco-friendly-ros174/). The Indian authority may adopt the most appropriate treatment method for PPE waste, namely pyrolysis. Thus, the challenge of PPE management can be converted into opportunities by producing oil and gas in India. The recycling of PPE will preserve the environment and provide pyrolysis oil, gas for different automotive applications and coal for the cement industries.

The principal limitation of the study is that it was not possible to perform a long-term survey as in previous studies. Meteorological factors can transport PPE in marine environments but their role is not investigated in this document. Cleanup efforts were conducted between sampling dates, decreasing the accumulation rates of PPE on beaches. To avoid this, the sampling frequency should be increased to adequately track the spatial and temporal distribution of these wastes. Regarding the degradation of PPE on the beach, this study provided only preliminary data on the presence of signs of mask degradation. There is a need to study the chemical composition of PPE to assess the environmental impact of this type of waste entering the beach. On the other hand, the principal strength of this research is to gives a clear picture of PPE pollution on the Indian coast, the density and source of PPE pollution, the degradation of face masks on the micoplastic, provides information on the best management practices of these wastes by the local authorities, and finally shows the threats presented by these wastes on the marine fauna.

2. Conclusions

Here we presented the findings of a PPE monitoring study on the southeast coast of India. PPE became a common type of litter on Indian beaches. A high number of PPE (496) were detected, of which 98% were face masks. However, the PPE densities recorded in this study are comparable to those in the literature. Due to the carelessness of Indian citizens, a significant number of used PPE are entering in the marine ecosystem, which is a grave and alarming problem. This new type of pollution will increase the plastic pollution on the Indian coast. The presence of these wastes in the marine environment poses ingestion and entanglement hazards to marine biota, as well as the release of microplastics and chemical additives. However, additional investigations should be carried out by filling the knowledge gaps on the environmental risks of waste related to COVID 19 in India. Authorities should develop alternative mitigation options based mainly on waste recycling strategies. The challenge of environmental remediation and PPE management can be converted into opportunities by producing oil and gas.

CRediT authorship contribution statement

Kannan Gunasekaran: Conceptualization, Investigation, Methodology, Writing- Original draft preparation.

Bilal Mghili: Methodology, Writing- Original draft preparation, Writing- Reviewing and Editing Data.

Ayyappan Saravanakumar: Reviewing and Editing Data, Validation.

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Declaration of competing interest

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