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Baseline

COVID-19-related personal protective equipment (PPE) contamination in the highly urbanized southeast Brazilian coast

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ABSTRACT

This study aimed to report personal protective equipment (PPE) contamination in Santos beaches (Brazil) using standardized procedures for the first time while comparing two periods to understand the progression of PPE contamination. The occurrence of PPE items was ubiquitous in all sampled sites, although the densities were relatively low compared to those in other parts of the world. Unlike previous studies, reusable face masks were the most common type of PPE. PPE density in the studied areas was similar in both sampling seasons, probably because of the influence of tourism, urbanization, and local hydrodynamic aspects. PPE items can release microfibers into the aquatic environment and pose entanglement hazards to marine biota. A wider monitoring of PPE pollution, accompanied by surveys on PPE usage and behavior, as well as chemical characterization of the discarded PPE items, is needed to fully understand this unprecedented form of plastic pollution.

The mismanagement and poor environmental awareness make a significant part of plastic products to reach the oceans (Jambeck et al., 2015), causing negative impacts on several ecological and economical activities (De-la-Torre et al., 2021; Garcés-Ordóñez et al., 2020). The amount of waste generated worsened during the coronavirus disease (COVID-19) pandemic (Kho et al., 2021) because of the intensive measures adopted to prevent global-scale transmission, such as personal protective equipment (PPE) use enforcement (Saadat et al., 2020). In early 2020, PPE (such as face masks, gloves, and face shields) production, use, and disposal skyrocketed, became part of the so-called “new normal” (Cordova et al., 2021). With a weakened solid waste management system, discarded PPE nowadays contaminates urban, freshwater, and marine systems (Ammendolia et al., 2021; Cordova et al., 2021; Thiel et al., 2021).

Developing countries may be particularly susceptible to PPE contamination because of the increase waste generation, disposal, and the lack of proper solid waste managing systems (Ardusso et al., 2021). In South America, PPE has been monitored on beaches of Brazil (Neto et al., 2021), Chile (Thiel et al., 2021), Peru, and Argentina (De-la-Torre et al., 2021a, 2021c). Brazil is the largest country in South America, with a 10,929 km coast, and the first documented case of marine animal mortality by a face mask (PFF-2) ingestion (Neto et al., 2021). Although the majority of the Brazilian coast suffers from anthropogenic litter impacts (Andrades et al., 2020; Videla and Araujo, 2021), little is known about PPE contamination.

The Santos Estuarine System (SES), located in the center of São Paulo state, generates a significant contribution to Brazil’s economy (Venancio et al., 2020). This area shelters a pushful urban center that houses the biggest South American port complex. In addition, SES receives several contaminants released from attached industrial complexes and port terminals (Abreu et al., 2020; Pusceddu et al., 2019). Those activities may be the main source of anthropogenic litter to the region, mostly composed of plastic products, pellets, cigarette butts, and microplastics (Gimiliani et al., 2020; Ribeiro et al., 2021b, 2021a; Santana et al., 2016).

In Brazil’s fight against COVID-19, vaccination levels increased significantly mostly by late 2021, when virus transmission and hospitalizations decreased. As the sanitary scenario improved, São Paulo state authorities tried to ban PPE mandatory use, but because of the occurrence of new coronavirus variants of concern, the policies were not changed until now. The current PPE monitoring studies did not take into consideration the analysis of PPE contamination in different periods and comparing aspects such as increase in vaccination levels and hospitalization decrease. This study monitored PPE occurrence along the beaches located in the terminal portion of SES, during two periods of the pandemic. The aims of this study were to 1) report for the first time the

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current state of PPE contamination in Brazil after standardized sampling procedures and 2) compare two periods of the pandemic to understand the evolution of PPE contamination the pandemic progresses.

PPE items were sampled along Santos Bay (SB) beaches in 13 sampling sites (Fig. 1) in two distinct periods (June–July 2021 and November–December 2021), which represent different stages of measures against COVID-19 adopted in Brazil. In addition, the sampled sites were known to possess different levels of anthropogenic litter abundance based on previous studies (Ribeiro et al., 2021b, 2021a).

In each period, all sites were sampled in a 10-day interval (n = 3). PPE was sampled when the sun raised (around 6 a.m.) to avoid performing samplings after the beaches received public cleanups, which could underestimate the number of PPE found (Ribeiro and Santos, 2020). Our PPE sampling considered the entire beach area at each site and consisted of determining enough 8- to 10-m transects (parallel to each other) to cover from the high tide line up to the beach limit or vegetation (De-la-Torre et al., 2021c; Pizarro-Ortega et al., 2022). PPE items were visually identified by walking along the transects. The total area of each site was measured using Google Earth Pro (m²), and the PPE density (PPE/m²) was calculated by the PPE amount found divided by the sampled area (Okuku et al., 2020).

After visual identification, PPE items were manually picked up, and classified by their types: face mask, face shield, glove, and associated PPE packaging (Ammendolia et al., 2021). In addition, masks and gloves were visually classified into the following categories: surgical face masks, high-grade face masks, dust face masks, reusable face masks, associated PPE packaging, polyethylene glove, nitrile glove, vinyl glove, and disinfectant wipe (Ammendolia et al., 2021).

PPE density (mean ± SD) significant differences between all sites were analyzed by one-way analysis of variance (ANOVA) followed by Tukey’s multiple comparisons analysis. Alternatively, non-parametric statistics (Kruskal-Wallis test followed by Dunn’s analysis) were applied when ANOVA assumptions were not achieved. Additionally, we applied Mann–Whitney U to check significant differences in the PPE density among sites and the two periods. The level of significance was set to 0.05 for all the statistical analyses, which were performed in GraphPad Prism (version 8.4.3 for Windows).

Considering all samples sites, 131 PPE items were found distributed along SES beaches (7.46 × 10⁴ ± 1.37 × 10⁴ PPE/m²), which were more abundant in S11, S12, and S13. Unexpectedly, such areas are less urbanized beaches (5000, 300, and 0 inhabitants, respectively) than other sampled sites. Therefore, the PPE contribution in S11, S12, and S13 is probably due to the smaller beach area and influences of local hydrodynamics. Ribeiro et al. (2021a, 2021b) demonstrated, based on the occurrence of plastic pellets, that local oceanographic factors play an essential role in solid waste inputs to these sites. Moreover, this study indicated intense port activities held in the inner portion of SES as the main source of debris found in S11, S12, and S13. Thus, it is possible that PPE items have a similar origin. Some PPE items displayed a certain degree of damage or physical degradation (e.g., torn layers and broken earloops), similar to those reported by Akhbarizadeh et al. (2021). However, detailed assessments using X-ray diffraction, Fourier transformed infrared spectroscopy, and scanning electron microscopy are required to better understand degradation levels (De-la-Torre et al., 2021a). No significant differences (p > 0.05) were found between sampling sites when both periods were separately analyzed. Thus, PPE contamination in SES beaches occurred similarly considering the two sampling campaigns in different periods of the pandemic.

The mean and range of the PPE density found at SES beaches are one of the lowest thus far reported in the world, such as reported in Lima coastal zones (Table 1). Higher PPE densities were seen at Bushehr, Chile, Cox’s Bazar, Toronto, Kwale, and Kilifihod (10⁴ to 10⁵). Few studies provided the PPE density in urban and natural environments. In addition, Brazil has the more extensive coast in South America, and only a small part was briefly analyzed by Arduso et al. (2021) and Neto et al. (2021). Hence, more field data are needed to confirm that Brazil has a relatively low occurrence of PPE compared with coastal areas elsewhere. Recent anthropogenic litter samples at SES beaches showed dramatically higher abundance and densities of other types of litter. For instance, in S2, S5, S6, S8, and S9, the mean number of plastic pieces (other than PPE) ranged from 934.6 to 2280.5 items (0.32 to 0.80 items/m² equivalent density) and the number of cigarette butts from 348.8 to
Mean and range personal protective equipment (PPE) density (PPE/m²) in worldwide monitoring studies.

| Country  | City          | Area        | PPE density (PPE/m²) | Reference                           |
|----------|---------------|-------------|----------------------|-------------------------------------|
| Chile    | Nationwide    | Beach       | 6.00 ± 3.10 × 10⁻³  | (Thié et al., 2021)                 |
| Canada   | Toronto       | Urban       | 1.01 ± 7.44 × 10⁻⁴  | (Ammendolia et al., 2021)           |
| Peru     | Lima          | Beach       | 6.42 ± 0.50 × 10⁻⁵  | (De-la-Torre et al., 2021c)         |
| Peru     | Nationwide    | Beach       | 6.60 ± 5.60 × 10⁻³  | (De-la-Torre et al., 2021a)         |
| Argentina| Nationwide    | Beach       | 7.21 ± 5.60 × 10⁻³  | (Sanchez et al., 2021)              |
| Morocco  | Agadir        | Beach       | 1.13 ± 0.12 × 10⁻⁴  | (Haddad et al., 2021)               |
| Morocco  | Tetouan       | Beach       | 1.20 ± 3.67 × 10⁻³  | (Mghili et al., 2022)               |
| Kenya    | Kwale,        | Both        | 0.56 ± 7.16 × 10⁻³  | (Ogunesi et al., 2020)              |
| Iran     | Caspian       | Lake        | 1.02 ± 2.48 × 10⁻⁴  | (Itatami et al., 2022)              |
| Iran     | Bushehr       | Beach       | 7.71 × 10⁻³         | (Akhbarizadeh et al., 2021)         |
| Ethiopia | Bahr Dar      | Lake        | 1.54 ± 2.88 × 10⁻⁴  | (Aragaz et al., 2022)               |
| Bangladesh| Cox’s Bazar  | Beach       | 6.29 ± 2.18 × 10⁻³  | (Rakib et al., 2021)                |
| Brazil   | Santos Bay    | Beach       | 7.46 ± 3.89 × 10⁻⁴  | Present study                       |

727.1 items (0.08 to 0.25 items/m² equivalent density) (Ribeiro et al., 2021b). Similar results were found in sites S11-S13 (Ribeiro et al., 2021a). Compared with the number and densities of PPE found in this study, it became evident that the occurrence of PPE does not indicate a pollution issue in Brazilian beaches. However, the contamination levels reported establish baselines for this emerging type of waste that should be present in global daily life from now.

In November–December 2021, 90 PPE items were found (3.85 × 10⁻⁵ ± 1.02 × 10⁻⁵ PPE/m²) and 41 in June–July (1.75 × 10⁻⁵ ± 1.45 × 10⁻⁴ PPE/m²). SES receives a significant number of visitors during the summer (Pusceddu et al., 2019). However, the abundance of anthropogenic litter in this estuarine complex has been classified, according to the Clean-Coast Index, as “dirty” or “extremely dirty” regardless of the sampling season (Ribeiro et al., 2021b). This agrees with the PPE density observed between the two sampled seasons in this study (Fig. 2). Thus, SES beaches similarly received PPE items regardless of the selected sampling period, probably because of the influence of beachgoers and tourism, urbanization, and local hydrodynamic aspects.

The two selected periods represent different efficiency stages of Brazil’s measures against the COVID-19 pandemic. When comparing June–July and November–December 2021, vaccination levels increased (35.4–58.4% of the population with the first dose and 79.3% fully vaccinated, respectively), whereas virus transmission and hospitalizations levels decreased (Santos, 2021). State authorities announced in November 2021 that PPE use would not be mandatory in open spaces in December 2021, although this measure was not implemented because of the appearance of the Omicron variant. However, the progress made regarding vaccination and the significant reduction of respiratory syndromes attributed to COVID-19 may have had some impact on the population’s behavior. The pandemic progression and lack of PPE enforcement may have led to a sense of safety in the population. These changes were suspected to influence the willingness to use PPE in public places, such as beaches. However, our results disagree with this hypothesis because PPE abundance, density, and composition were very similar during the two sampling campaigns. Therefore, it is probable that PPE use and disposal were constant, even under a safer scenario. PPE use enforcement also did not change during those periods (despite it being initially announced), based on the guidelines of local authorities, which made us consider to it an important measure.

Face masks were the major type of PPE found in all sites (89–92.7%), followed by gloves (4.9–5.5%) and associated PPE (2.4–5.5%). Similar results were found in Bangladesh and Lima, but in urban Toronto and Bushehr beaches, gloves were the main PPE found (see Table 1).

The main mask composition found in Santos Beaches in both periods was reusable (53.6% in the first season and 38.9% in the second season), followed by single-use (36.5% in the first season and 31.1% in the second season), dust (2.4% in the first season and 13.3% in the second season), and high-grade masks (5.5%, found only in the second season) (Fig. 3). The prevalence of reusable masks was also reported by Neto...
et al. (2021) on the north coast of São Paulo in 2020. According to Cotrin et al. (2020), around half of Brazilians reuse masks (49.5%). Although it is foolhardy, from a public health point of view, it contributes to reduce the abundance of PPE contamination in coastal areas because reusable face masks are less likely to be immediately discarded upon usage. Like most types of plastic litter, PPE will likely become an entanglement and ingestion hazard to marine macrofauna as reported by Hiemstra et al. (2021). Furthermore, studies have shown that single-use surgical face masks are sources of microplastics and nanoplastics in to the aquatic environment (De-la-Torre et al., 2021b; Ma et al., 2021; Rathinamoorthy and Balasaraswathi, 2021), mostly in the form of microfibers. Similar to surgical masks, reusable masks are likely to also release microplastics into the aquatic environment. In this regard, microfibers have been shown as the main microplastic morphology found in sediments (Gimiliani et al., 2020) and soft tissues of bivalve molluscs (unpublished data) from the studied beaches. Microfibers are also present in the atmosphere and air (Akhbarizadeh et al., 2021) and have been found in human lung tissues (AmmatouLourenço et al., 2021). Although some studies suggest that microplastics may cause cytotoxic damage in human lung cells (Yang et al., 2021), their implications to human health are still under research. Importantly, microfibers can be directly inhaled while using a mask (Li et al., 2021).

In November–December 2021, dust face masks increased (13.3%), and high-grade masks (5.5%) were found for the first time, showing a slightly more diverse scenario on PPE use in SB. In fact, Neto et al. (2021) reported that high-grade masks were ingested by penguins, in the first documented case of mask ingestion by a marine animal, on the São Paulo's north coast. Gloves (latex and polyethylene) represented 2.4–5.5% of all PPE found in SB. The percentage of gloves among PPE can reach up to 44% in urban Toronto (see Table 1). In Brazil, glove use is not quite common in the population's on a daily basis because their use is indicated for health professionals but not for the general population (Bessa et al., 2020; World Health Organization, 2020). Associated PPE also represented 2.4–5.5% of PPE and was mainly identified as alcohol gel packaging. The differences in the types of PPE commonly found in coastal areas across the world provide some insights concerning the perception of safety on behalf of the population.

Various interviews/surveys have been performed concerning the face mask use preferences of the Brazilian population. The willingness to use face masks ranges from 29% to 99.1%, depending on various geographic and social variables (Cotrin et al., 2020; Fernandes et al., 2021; Pereira-Avila et al., 2020a, 2020b; Villela et al., 2021). In addition, a significant parcel of Brazilians said that only use face masks because it became mandatory (Cotrin et al., 2020; Fernandes et al., 2021). Based on the aforementioned studies, it is unclear what type of mask the Brazilian population prefers. Since characterizing discarded litter, such as PPE, provides some insights on consumer preferences, it is recommended to conduct standardized PPE monitoring programs across states accompanied by interviews/surveys to the population concerning their behavior towards PPE usage in coastal areas.

Previous studies that reported PPE contamination in Brazilian beaches only provided snapshot evidence (Arduoso et al., 2021) or focused on the mortality of a Magellanic penguin (Spheniscus magellanicus) driven by the ingestion of a face mask (Neto et al., 2021). Therefore, further studies must provide comprehensive characterization, abundance, and density of PPE items that are currently contaminating the Brazilian coast. One effective approach may be large-scale citizen science projects to compile data from widely distributed sites (Ammendolia and Walker, 2022). Furthermore, the chemical characterization of the recovered materials would be appropriate to not only categorize PPE by their type or morphology but also by their chemical composition and elucidate their degradation pathways in aquatic environments. Finally, in addition to the chemical contamination generated, masks are a very specific type of sanitary waste that can also spread microbiological contamination (Zhou et al., 2021). In this sense, risks to public health can also arise from this type of contamination and therefore deserve attention from the authorities.

CRediT authorship contribution statement

Victor Vasques Ribeiro: Project administration, Investigation, Data curation, Software, Formal analysis, Writing – original draft. Gabriel E. De-la-Torre: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. Italo Braga Castro: Investigation, Validation, Supervision, Resources.

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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