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Personal protective equipment (PPE) pollution associated with the COVID-19 pandemic along the coastline of Agadir, Morocco

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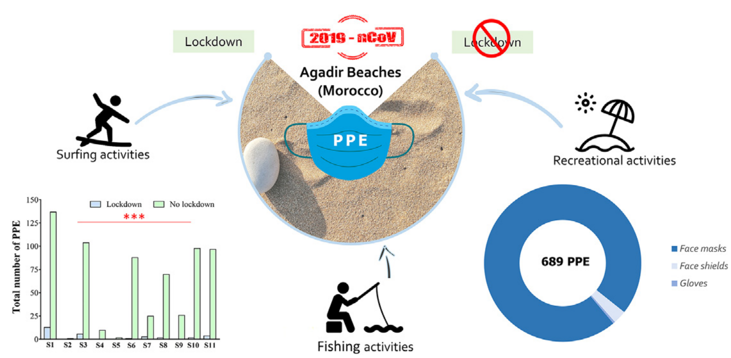
HIGHLIGHTS

- Beaches in Agadir, Morocco, were polluted with personal protective equipment (PPE).
- PPE items were dominated by face masks (96.8%), followed by face shields (2.76%).
- The vast majority of PPEs were found after opening of public beaches (95.5%).
- Recreational and surfing beaches presented the highest PPE densities.

GRAPHICAL ABSTRACT



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ABSTRACT

The increasing use of personal protective equipment (PPE) as a sanitary measure against the new coronavirus (SARS-CoV-2) has become a significant source of many environmental risks. The majority of the governments enforce the use of PPE in public areas, such as beaches. Thus, the use and disposal of PPE have compromised most solid waste management strategies, ultimately leading to the occurrence of PPE polluting the marine environment. The present study aimed to monitor the PPE pollution associated with COVID-19 along the coastline of Agadir, Morocco. In parallel, the influence of the activities carried out in each sampled beach before and after the lockdown break was reported. Overall, a total number of 689 PPE items were identified, with a mean density of 1.13×10^{-5} PPE m^{-2} ($0–1.21 \times 10^{-4}$ PPE m^{-2}). The majority of the PPE items found were face masks (96.81%), out of which 98.4% were surgical masks and 1.6% were reusable cloth masks. The most polluted sites were the beaches with recreational activities, followed by surfing, and fishing as the main activity. Importantly, PPE density increased significantly after lockdown measures. Additionally, the discarded PPE sampled in the supralittoral zone was higher than PPE recorded in the intertidal zone. This confirms that PPE items are driven by the beachgoers during their visit. PPE items are a source of microplastic and chemical pollutants, a substrate to invasive species colonization, and a potential threat of entanglement, ingestion, and/or infection among apex predators. In the specific case of Agadir beaches, significant efforts are required to work on the lack of environmental awareness and education. It is recommended to improve beach cleaning strategies and to penalize incorrect PPE disposal. Additional alternatives may be adopted, as the involvement of biodegradable materials in PPE manufacturing, recycling through pyrolysis, and encouraging reusable and washable masks.

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1. Introduction

The World Health Organization (WHO) declared the novel coronavirus disease "COVID-19" as a global health emergency at the beginning of 2020 (Saadat et al., 2020; Xu et al., 2020). The Kingdom of Morocco lives, like many countries in the world, a particular situation following the spread of the COVID-19 in March of 2020. The Moroccan government has put in place a series of the most effective and affordable measures to prevent the transmission of the virus, including sanitary, social, economic measures (Governement, 2020). In this sense, the government has also announced other measures, including the temporary closure of beaches, to strengthen prevention against the spread of the virus. In addition, Morocco has a set of legal and institutional tools largely adequate and appropriate to ensure proper management of the coastal zone, as indicated by Nachite et al. (2019). Nevertheless, Morocco reaches a value between 0.05 and 0.12 million tons of mismanaged plastic waste per year (18th among the top waste producers) (Jambeck et al., 2015). Many studies investigating marine litter in the Moroccan Mediterranean beaches revealed a high abundance of plastics (Alshawafi et al., 2017; Maziane et al., 2018; Loulad et al., 2019; Nachite et al., 2019; Mghili et al., 2020). Nevertheless, investigations about plastic pollution are still scarce and have focused on fish (Alshawafi et al., 2018; Maaghloud et al., 2020), sediment, and surface water (Haddout et al., 2021).

After the opening of public beaches following intensive lockdowns, some authors reported an increase in litter densities (Ryan et al., 2020; Thiel et al., 2021). On the other hand, beach visitors use single-use personal protective equipment (PPE) such as masks, gloves, disinfectant wipes, and protective suits on a daily basis to protect themselves from the virus (Ardusso et al., 2021). However, the exponential growth of PPE use and disposal has created many problems related to solid waste management (Patrício Silva et al., 2020; Prata et al., 2020; De-la-Torre and Aragaw, 2021). PPE items could potentially pose an ecological risk to the marine environment through entanglement, dispersal of alien invasive species (AIS), the release of chemical additives, among other mechanisms (De-la-Torre and Aragaw, 2021; Thiel et al., 2021). In addition, exposure of discarded face masks to UV light and degradation conditions may lead to its fragmentation and release of fiber-like microplastics (MPs) (Cózar et al., 2014; Galgani et al., 2014; De-la-Torre and Aragaw, 2021). MPs are known for their ubiquity in the environment and ability to sorb chemical contaminants, such as heavy metals, pesticides, hydrocarbons, among others (Torres et al., 2021). Given their small size and bioavailability, MPs are likely to be ingested and impact aquatic biota (Aragaw and Mekonnen, 2021a), which has been discussed as a relevant issue in African countries (Aragaw, 2021).

The amount of face masks that have entered the ocean in 2020 has been estimated as 1.56 billion (OceansAsia, 2020), which could cause detrimental impacts on marine wildlife. Particularly, recent studies have lightened the occurrence of different types of PPE in the marine and urban environment worldwide: South America (Ardusso et al., 2021), North America (Ammendolia et al., 2021), Africa (Okuku et al., 2021), Europe (Prata et al., 2020), Asia (Akhbarizadeh et al., 2021b). To the best of our knowledge, no previous study has reported the abundance and distribution of PPE items in northern Africa. In order to provide effective solid waste management guidelines under the ongoing pandemic context, it is crucial to first elucidate the current state and identify the main sources and drivers of PPE pollution. Previous studies reported the occurrence, density, and characteristics of PPE pollution, as well as determined the activity carried out in each beach as the main possible source of contamination (De-la-Torre et al., 2021; Rakib et al., 2021). However, the influence of lockdown periods and distribution of PPE items within the beach area are yet to be investigated. These variables are of particular interest to understand the variability of PPE pollution based on COVID-19 measures (i.e., lockdown periods) and the source of pollution based on their distribution. Therefore, the aim of the present study was to determine the abundance, characteristics, and density of PPE items on the beaches of Agadir, Morocco. Also, the influence of lockdown measures (closure and opening of public beaches), beach zone (intertidal and supralittoral zone), and activity (recreational, surfing, and fishing) were evaluated. To achieve this, 11 beaches in Agadir were monitored following standardized protocols for four consecutive months.

2. Materials and methods

2.1. Area of study

Agadir metropolis (Agadir Ida-Outanane district, Souss Massa region) is located in the southwestern part of Morocco (Fig. 1), with a growing population of about 535,653 habitants in 2015, and 624,960 habitants in 2016, with a perspective of reaching more than one million individuals in Agadir Ida-Outanane district by the end of 2021 (HCP, 2016). Home of a beautiful bay (~50 km, from Oued souss estuary to Cape Ghir), it is considered one of the most important touristic cities in the country. However, Agadir bay is under the pressure of human activities (tourism, industry, fishing, etc.) that impact coastal life (Ben Haddad et al., 2021; Chahouri et al., 2021; Lamine et al., 2020). Indeed, these activities represent a major source of marine plastic pollution (Schwarz et al., 2019), which is likely to be aggravated by the current pandemic.

2.2. PPE monitoring

The study was conducted in two consecutive periods of 2021, including the period of lockdown, when the beaches were still closed to the public (1–8 weeks from 01 February to 30 March), and after the lockdown, when the beaches reopened (9–16 weeks from 01 April to 30 May). Eleven sites were evaluated, as displayed in Fig. 1. To standardize PPE monitoring, the methodology carried out on the coasts of Peru and Bangladesh was followed (De-la-Torre et al., 2021; Rakib et al., 2021). In each site, several parallel transects (separated by 8–10 m between transect) covering the whole extent of the beach were determined. The number and length of the transects varied according to the beach size and morphology in order to fit their full extent. The sampling strategy consists of walking along each transect, visually scanning the surroundings, and identify PPE items, which were categorized as face masks, face shields, bouffant caps, hazard suits, and gloves. All of the PPE items were photographed. Dumpsites within the beach area were also checked. To understand the distribution of PPE items, their location was recorded if they fell within one of the two major beach zones, regarded as the intertidal zone (from the low tide line to the high line tide) and supralittoral zone (up to ~2 m into natural or artificial limits). The 16 consecutives sampling campaigns were carried out before the start of the local municipality cleanup season (between June and July) in order to avoid bias. In each site, the area covered, and coordinates were estimated using Google Earth (https://www.google.com/earth/) (Table 1). The surveyed area (a) and the number of PPE (n) are used to calculate the PPE density per m^2 (C), using the equation (Okuku et al., 2021):

$$C = \frac{n}{a}$$

2.3. Statistical analysis

Results were expressed in mean PPE density (PPE m^{-2}) ± SD. Upon invalidation of the assumption of normality (Shapiro-Wilk test, $p < 0.05$) of each of the following datasets, nonparametric tests were conducted. In order to compare PPE density during and after lockdown, a Mann-Whitney U test was conducted per sampling site by considering each sampling week (n = 8) as a repetition. Based on the results from

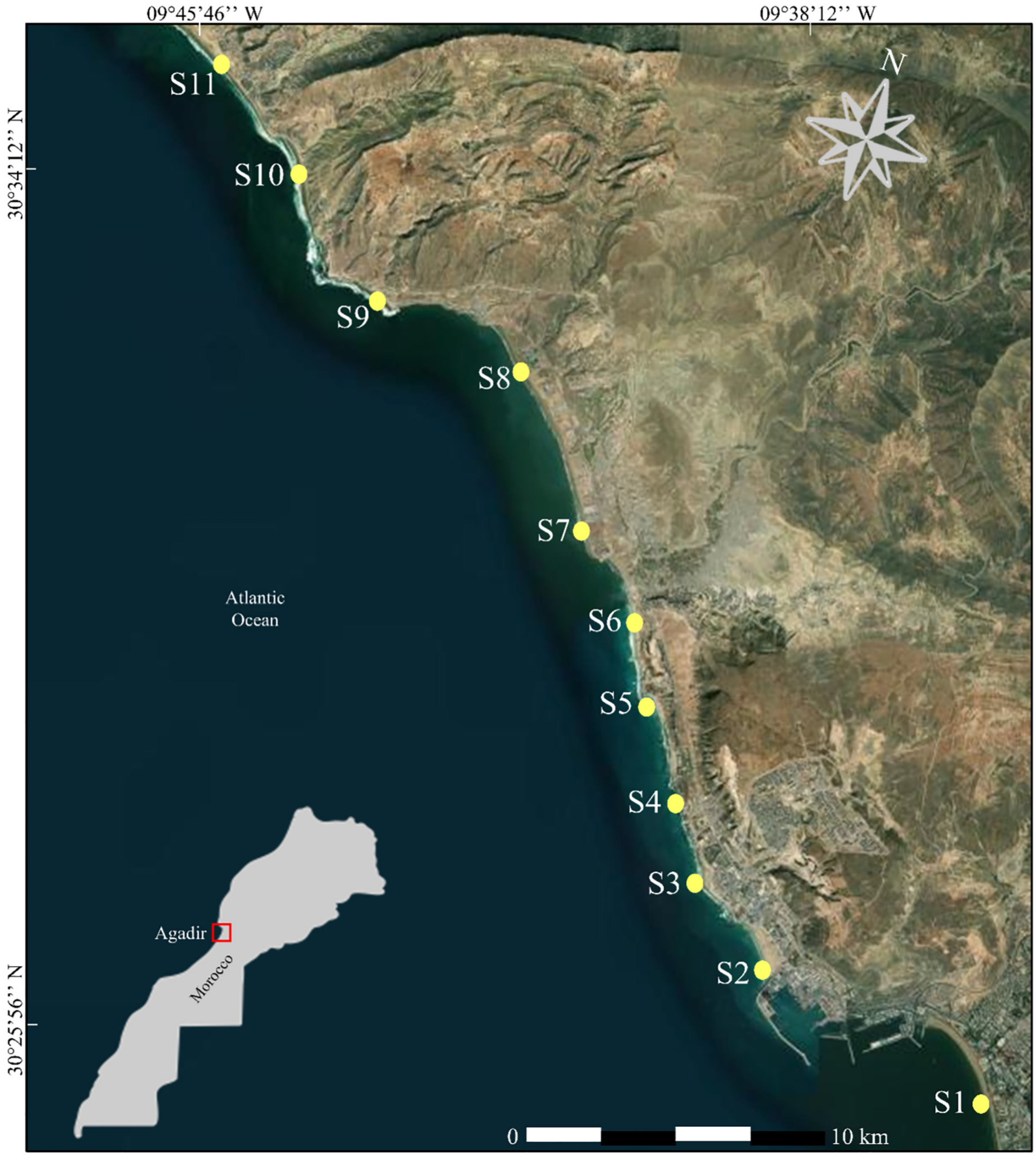

Fig. 1. Map of sampling sites in Agadir coastline, Morocco.

Table 1
The main activity, substrate, coordinates, and estimated area of each sampling site along the Agadir coastline.

Code	Activity	Substrate	Area covered	Coordinates
S1	Recreational	Sand	45,320 m^2	30°34′54″ N; 09°36′04″ O
S2	None	Sand	21,520 m^2	30°26′13″ N; 09°39′01″ O
S3	Recreational + surfing	Sand	23,200 m^2	30°28′01″ N; 09°40′08″ O
S4	Fishing	Rock	12,020 m^2	30°27′44″ N; 09°40′07″ O
S5	None	Sand	22,874 m^2	30°28′41″ N; 09°40′26″ O
S6	Recreational	Sand	23,685 m^2	30°29′28″ N; 09°40′36″ O
S7	Surfing	Rock	26,503 m^2	30°30′31″ N; 09°41′20″ O
S8	Recreational	Sand	43,250 m^2	30°31′51″ N; 09°41′49″ O
S9	Fishing	Rock	16,256 m^2	30°32′40″ N; 09°43′31″ O
S10	Recreational	Sand	23,065 m^2	30°33′44″ N; 09°44′37″ O
S11	Recreational	Sand	24,681 m^2	30°34′59″ N; 09°45′27″ O

the Mann-Whitney U tests, datasets from sampling weeks 9 to 16 (April to May, without lockdown) were grouped based on the activity carried out in each site (recreational, surfing, fishing, or no activity) and compared with a Kruskal-Wallis test followed by Dunn's multiple comparison test. In order to compare the accumulation of PPE items between beach zones (intertidal and supralittoral), an additional Mann-Whiney U test was conducted to compare datasets from both zones across sampling sites after the lockdown. The significance level was set to 0.05. All statistical analyses and graphs were performed using GraphPad Prism (version 8.4.3. for Windows).

3. Results

PPE monitoring was effectively carried out for 16 weeks, encompassing two main sampling periods (during and after lockdown) and two beach zones (intertidal and supralittoral) across 11 sampling sites in Agadir (Morocco). A total of 689 PPE items were found. Fig. 2 shows some examples of stranded and abandoned PPE items across sites. PPE types were dominated by face masks (96.8%), followed by face shields and gloves (Fig. 3). Face masks were mainly composed of single-use surgical masks (98.4%) and the rest were reusable cloth masks. No bouffant caps or hazard suits were found. A notorious increase in PPE items was observed from sampling weeks 9 to 16 (after the lockdown) in most sampling sites (Fig. 4). Indeed, 95.5% of all identified PPEs were found after the lockdown. These results evidence the influence of lockdown measures over PPE scarcity in public beaches.

The mean PPE density during the lockdown period was 1.13×10^{-5} (range of $0.00–1.21 \times 10^{-4}$), significantly lower than after the lockdown (mean: 2.79×10^{-4}, range of $0.00–7.37 \times 10^{-4}$). The results from the Mann-Whitney U tests are displayed in Table 2. Only two sites (S2 and

Fig. 2. Photographs of different PPE types found across sampling sites.

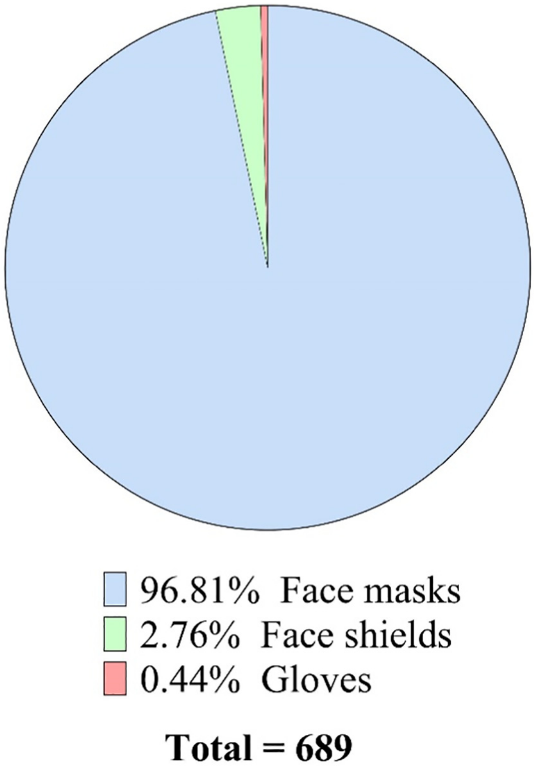

Fig. 3. Pie chart displaying the contribution of each PPE type.

S5) presented no significant differences ($p > 0.05$) in the PPE density between the two sampling periods. Interestingly, in S2 (industrial area) and S5 (private area), no particular activity is carried out, and, thus, a very low presence of beachgoers is expected. Conversely, all of the other sites where at least one activity is carried out presented significantly higher PPE densities after the lockdown (beaches open to the public). These results suggest that the presence of beachgoers, fishermen and the general population are the main drivers of PPE pollution in coastal sites.

An additional Mann-Whitney U test was conducted to compare PPE accumulation between beach zones across sampling sites after the lockdown. Results indicated the number of PPE items in the supralittoral zone was significantly ($p = 0.01$) higher than in the intertidal zone (Fig. 5).

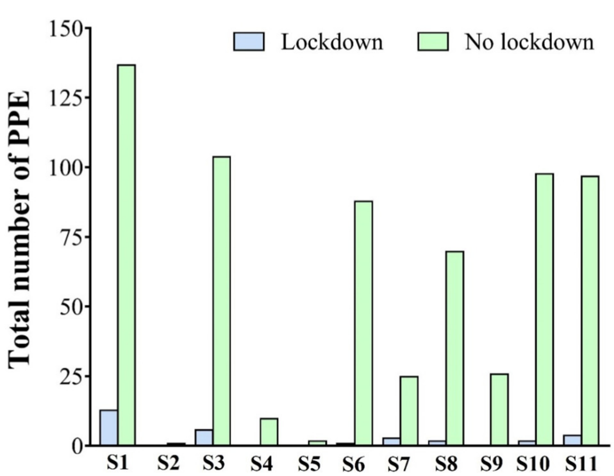

Fig. 4. Column graph displaying the accumulated number of PPE items during (sampling weeks 1–8) and after lockdown (sampling weeks 8–16) among sampling sites.

The Kruskal-Wallis test indicated significant differences (Chi-square = 54.42, $p < 0.0001$) in the PPE density across activities (Fig. 6). According to Dunn's multiple comparison test, recreational activities differed significantly from fishing and sites with no apparent ("none") activities, while surfing only differed from "none" sites. The remaining comparisons are displayed in Fig. 6.

4. Discussions

First evidence and concerns regarding PPE pollution in the natural and urban environments were displayed by media outlets (Boehnert, 2020), and announced by NGOs, like OceansAsia (OceansAsia, 2020). After that, many studies surveyed different environments to provide an overview of PPE pollution caused by the COVID-19 pandemic, including cities and urban environments (Fadare and Okoffo, 2020; Prata et al., 2020; Ammendolia et al., 2021; Okuku et al., 2021), freshwater bodies (Aragaw, 2020; Cordova et al., 2021), and coastal environments (Akhbarizadeh et al., 2021b; Ardusso et al., 2021; De-la-Torre et al., 2021; Okuku et al., 2021; Rakib et al., 2021; Thiel et al., 2021). The total number of PPE items in the present study (689 items) were ~5 times higher than the number reported in beaches from Lima, Peru (De-la-Torre et al., 2021), and 42 times lower than the total items found in Cox's Bazar beach, Bangladesh (Rakib et al., 2021). Thus, the comparison between studies should be based on PPE density values to minimize the influence of various methodological factors related to the number of PPE, such as beach size and sampling efforts. In this study, we have conducted surveys in two different periods. The lockdown period comes after the second wave of the COVID-19 pandemic, when the Moroccan government decided, from November 2020 until the end of March 2021, to close public beaches to avoid agglomerations. The low occurrence of PPE items during the lockdown period was in accordance with the results from "La Herradura" beach (Coquimbo, Chile) before and after the quarantine (Thiel et al., 2021). However, the mean density (1.13×10^{-5} PPE m^{-2}) registered in Agadir sites is 5.7 times lower than the density reported in Lima (6.42×10^{-5} PPE m^{-2}). This difference between the density and the number of PPE is explained by the difference in the sampled area between the two studies (Lima: 110,757 m^2, Agadir: 282,374 m^2). In Cox's Bazar beaches, the high number of PPE is not influenced by the covered area parameter (Covered area: 516,683, density: 6.29×10^{-3} PPE m^{-2}). Thus, the density recorded in Cox's Bazar is 560 times higher than the PPE density of Agadir. In the Persian Gulf, the mean density of PPE along the coastline of Bushehr port ranged between 7.71×10^{-3} to 2.70×10^{-2} (Akhbarizadeh et al., 2021b). By conducting sampling stock surveys, Okuku et al. (2021) recorded different densities reaching up to 5.6×10^{-2} PPE m^{-2}, which may be influenced by the methodological differences (Table 3).

The dominance of face masks (96.81%) in the composition of PPE is similar to the studies conducted on the beaches of Lima: (87.7%), and Cox's Bazar (97.9%). Even in two rivers of Indonesia, and in urban areas in the city of Toronto, the face masks category is the most abundant one (Ammendolia et al., 2021; Cordova et al., 2021). The other categories vary across studies and present low percentages. The analyses by statistical tools revealed that the beaches, knowing mainly the recreational activities, are the most polluted by the discarded PPE, followed by surfing, then fishing activities. This is related to the high number of beachgoers visiting these beaches every day, especially when authorities opened the beaches after about 5 lockdown months. The absence of PPE in the control sites when the beaches are closed was evident, but, after the opening, a few face masks were found. We suggest that these items may have been driven by local surface currents. Similar findings are reported by De-la-Torre et al. (2021) in Lima beaches. Indeed, the separation between the coastal zones during the sampling has detected that the number of PPE in the supralittoral zone is significantly higher from the number sampled in the intertidal zone. This suggests that the majority of the items were brought and left by beachgoers

Table 2
Mean, range, significant PPE density differences in each site during and after lockdown.

Site	Mean PPE density (range)[a]		p-Value[b]
	Lockdown (weeks 1–8)	No lockdown (weeks 9–16)	
S1	3.59×10^{-5} ($0.00–8.83 \times 10^{-5}$)	3.78×10^{-4} ($1.99 \times 10^{-4}–5.52 \times 10^{-4}$)	<0.001
S2	0.00	5.81×10^{-6} ($0.00–4.65 \times 10^{-5}$)	>0.999
S3	3.23×10^{-5} ($0.00–8.62 \times 10^{-5}$)	5.60×10^{-4} ($3.45 \times 10^{-4}–6.90 \times 10^{-4}$)	<0.001
S4	0.00	1.04×10^{-4} ($0.00–2.50 \times 10^{-4}$)	0.026
S5	0.00	1.09×10^{-5} ($0.00–4.37 \times 10^{-5}$)	0.467
S6	5.28×10^{-5} ($0.00–4.22 \times 10^{-5}$)	4.65×10^{-4} ($3.38 \times 10^{-4}–5.49 \times 10^{-4}$)	<0.001
S7	1.42×10^{-5} ($0.00–7.55 \times 10^{-5}$)	1.18×10^{-4} ($3.77 \times 10^{-5}–1.89 \times 10^{-4}$)	0.001
S8	5.78×10^{-6} ($0.00–2.31 \times 10^{-5}$)	2.02×10^{-4} ($1.39 \times 10^{-4}–2.77 \times 10^{-4}$)	<0.001
S9	0.00	2.00×10^{-4} ($6.15 \times 10^{-5}–3.69 \times 10^{-4}$)	<0.001
S10	1.09×10^{-5} ($0.00–4.34 \times 10^{-5}$)	5.31×10^{-4} ($2.60 \times 10^{-4}–7.37 \times 10^{-4}$)	<0.001
S11	2.03×10^{-5} ($0.00–1.22 \times 10^{-4}$)	4.91×10^{-4} ($3.24 \times 10^{-4}–6.48 \times 10^{-4}$)	<0.001

[a] Mean and range densities expressed in PPE m^{-2}.
[b] Results from the Mann-Whitney *U* test.

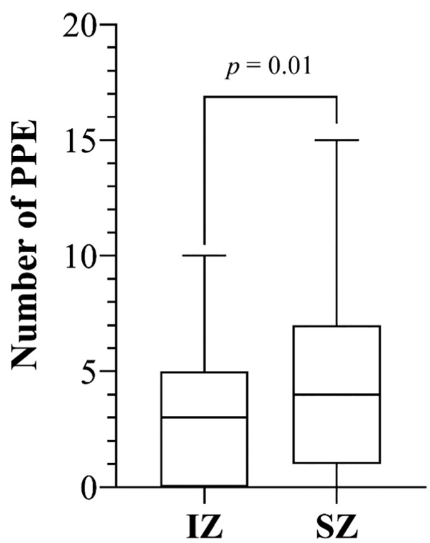

Fig. 5. Boxplot of total PPE number in beach zones per sampling site after the lockdown (weeks 9–16). *p*-Value results from the Mann-Whitney U test. IZ: Intertidal zone. SZ: Supralittoral zone.

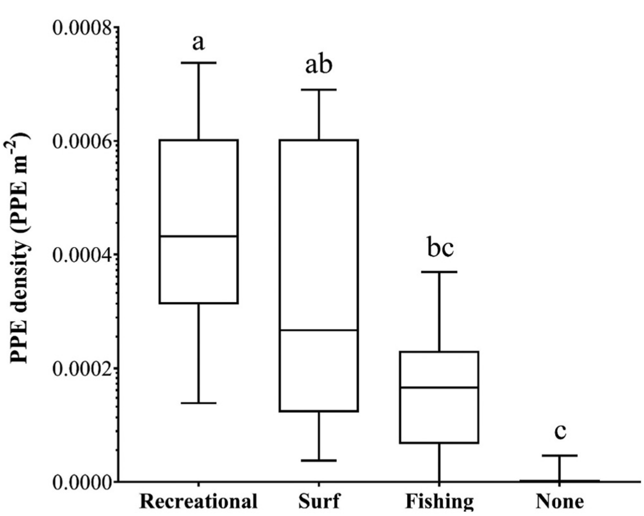

Fig. 6. Boxplot of the PPE density grouped per activity in datasets after the lockdown (weeks 9–16). Letters indicate significant differences according to Dunn's multiple comparison test.

who sit most of the time in the supralittoral area to remain distanced from the high tide line. This behavior is likely due to poor environmental education and a lack of awareness (De-la-Torre et al., 2020b).

During the several sampling campaigns, we have recorded the sight of multiple seabirds species, including the yellow-legged gull (*Larus michaellis*), the great Moroccan cormorant (*Phalacrocorax carbo maroccanus*) (Fig. 7), and the rare endangered bald Ibis (*Geronticus eremita*). PPE litter (mainly elastic cords from face masks) may pose a danger of entanglement to coastal avifauna (Hiemstra et al., 2021; Patrício Silva et al., 2021). Moreover, disposed face masks could contain the SARS-CoV-2. These fomites (objects carrying infection) could be a conduit for zoonotic transmissions as registered in some marine mammals from wastewater treatment plants (Mathavarajah et al., 2020). Besides, there are some assumptions about the ability of wild birds to be zoonotic spreading vectors of coronaviruses (Rahman et al., 2021). Meanwhile, in Lima beaches, De-la-Torre et al. (2021) have noticed the proliferation of red algae on two masks. This observation gives the presumption that PPE items might be an artificial substrate for sessile species colonialization, and a new vector of non-indigenous species transport between ecosystems. However, no signs of visible colonization were registered in the present study.

Commercially available 3-ply surgical masks are mostly composed of polypropylene (PP), while other types of masks contain other synthetic polymers, such as polystyrene (PS), polycarbonate (PC), polyethylene (PE), and polyester (Chua et al., 2020). Preliminary analyses of surgical face masks found in the urban environment determined PP and PE as their main plastic components depending on the layer (inner or outer) (Aragaw, 2020; Fadare and Okoffo, 2020). Also, these studies were the first to propose PPE items as significant sources of MPs in the form of microfibers. Recently, laboratory tests confirmed the release of MPs, nanoplastics, and chemical pollutants from different types of face masks (Saliu et al., 2021; Shen et al., 2021; Sullivan et al., 2021). Moreover, exposure to weathering conditions, such as UV irradiation and physical abrasion, exacerbates the release of MPs (Wang et al., 2021). MPs are ubiquitous in the environment (Dioses-Salinas et al., 2020; Dobaradaran et al., 2018; Takdastan et al., 2021), and many studies recorded their presence in plankton (Lin, 2016), seaworms (Missawi et al., 2020), earthworms (Rillig et al., 2017), mollusks (De-la-Torre et al., 2020a), crustaceans (Goldstein and Goodwin, 2013), fish (Wang et al., 2020), sea turtles and marine mammals (Meaza et al., 2021; Santillán et al., 2020). The presence of MPs along the terrestrial and marine food chains suggests that humans are exposed through the consumption of contaminated seafood and food products (Akhbarizadeh et al., 2020). Moreover, inhalation of suspended MPs may be a relevant human uptake pathway (Akhbarizadeh et al., 2021a).

The fact that plastic pollution has been exacerbated with the introduction of PPE items puts into perspective the mismanagement of waste, the lack and limitation of innovative ideas, and the low degree of consciousness among the beachgoers. Thus, it is necessary to provide

Table 3
Studies reporting mean and range of PPE densities in beaches.

Country	City	PPE density (PPE m^{-2})		Reference
		Mean	Range	
Morocco	Agadir	1.13×10^{-5}	$0.00–1.21 \times 10^{-4}$	This study
Peru	Lima	6.42×10^{-5}	$0.00–7.44 \times 10^{-4}$	(De-la-Torre 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)
Kenya	Kwale and Kilifi	–	$0.00–5.6 \times 10^{-2}$	(Okuku et al., 2021)
Chile	Nationwide	6.00×10^{-3}[a]	–	(Thiel et al., 2021)
Persian Gulf	Bushehr	–	$7.71 \times 10^{-3}–2.70 \times 10^{-2}$	(Akhbarizadeh et al., 2021b)

[a] Only face masks were counted.

recommendations based on scientific research studies. Patrício Silva et al. (2020) suggest decoupling plastics from fuel-based resources, minimizing the single-use plastics and PPE, and encouraging waste management engineering. Other authors gave some thermo-chemical operations (pyrolysis) to achieve PPE recycling (Jung et al., 2021; Aragaw and Mekonnen, 2021). Further viable solutions may require a shift towards different types of materials, such as biodegradable plastic items (Ccorahua et al., 2017; Sari et al., 2021; Torres et al., 2020), and giving more interest on 3D eco-friendly printing (Torres and De-la-Torre, 2021; Vanková et al., 2020). However, the production of novel biodegradable materials and products should be supported by life-cycle assessment studies (García-Rengifo et al., 2021; Rojas-Bringas et al., 2021). In the specific case of Agadir city, these ideas should be supported by the local institutions (the innovation city of Souss Massa, the regional center of investments of Souss Massa, the national school of applied sciences, etc.), and invest in eco-friendly biotechnology to create startups for young researchers. In addition, the global mismanagement of coastal environments, with a focus on the recreational sites, in compliance with the absence of environmental consciousness among beachgoers are the major causes of PPE pollution and marine litter on the coasts of Agadir.

5. Conclusion

The outbreak of the new coronavirus disease "COVID-19" has forced beachgoers in Agadir to use the PPE as a preventive way against the transmission. In light of the poor solid waste management conditions and lack of environmental awareness, the incorrect disposal of these single-use items in the environment has become uncontrollable. Thus, the many forms of plastic pollution, including micro- and nano-plastics, have been exacerbated. Besides, the discarded PPE threatens marine top predators through ingestion and entanglement and possibility to harbor potentially invasive species. In the current study, public beaches in Agadir, Morocco, were monitored for PPE pollution for 4 consecutive months, considering both during and after lockdown periods. Overall, the recreational sites were the most affected by PPE (96.8% face masks). This is related to the high visiting of beachgoers in comparison to sites where surfing and fishing are the dominant activities. As well, the reopening of public beaches after the lockdown period has led to a remarkable increase of PPE on the beaches of Agadir, especially in the supralittoral zone. The situation, then, requires the instant supervision of marine littering, and penalization against incorrect disposal of PPE. The current state also requires an extension of the cleaning operations in time and space for better waste management in Agadir beaches. In addition, the coastline in this region plays an essential role in the local economy as well as for the country through touristic activities. Hence, the aesthetic landscape of the beaches should be in the priorities of the policymaker's strategies. It is necessary to improve the waste management collection and disposal systems, which have been heavily impacted by the pandemic and encourage better waste practices among the population. Given the lack of environmental awareness regarding plastic pollution among the population, long-term measures must address this issue through educational campaigns. Additional alternatives to mitigate the span of life and reduce the risk, it is suggested to include biodegradable and eco-friendly materials in PPE manufacturing. Additionally, liquid and gas fuels can be recovered from discarded PPE as an alternative way to recycle this material. The encouragement of reusable masks may attenuate this waste and contribute to better management. Scientists may include citizens in the investigation process through "citizen science programs" in order to provide a wider range of study and create long-term environmental awareness and education.

Fig. 7. Photograph of seabirds *Larus michaellis* (Yellow-legged gull) and *Phalacrocorax carbo macroccanus* (Great Moroccan cormorant) taken during sampling procedures.

CRediT authorship contribution statement

Mohamed Ben Haddad: Conceptualization, Methodology, Investigation, Writing – original draft, Resources, Data curation, Project administration. **Gabriel E. De-la-Torre:** Investigation, Writing – original draft, Writing – review & editing, Methodology, Formal analysis. **Mohamed Rida Abelouah:** Conceptualization, Validation, Investigation, Resources, Writing – review & editing. **Sara Hajji:** Conceptualization, Validation, Investigation, Resources, Writing – review & editing. **Aicha Ait Alla:** Conceptualization, Validation, Investigation, Resources, Writing – review & editing.

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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