Marine Pollution Bulletin 191 (2023) 114908

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

# COVID-19 personal protective equipment (PPE) contamination in coastal areas of Granada, Spain

F. Ortega [a], M. Calero [a,*], N. Rico [b], M.A. Martín-Lara [a,*]

[a] Chemical Engineering Department, Faculty of Sciences, University of Granada, Granada, Spain
[b] Department of Statistics and Operations Research, Faculty of Sciences, University of Granada, Granada, Spain

ARTICLE INFO

*Keywords:*
Plastic pollution
Beaches
COVID-19
Personal protective equipment (PPE)
Granada

ABSTRACT

The use of disposable personal protective equipment (PPE) as a control measure to avoid transmission against COVID-19 has generated a challenge to the waste management and enhances plastic pollution in the environment. The research aims to monitor the presence of PPE waste and other plastic debris, in a time interval where the use of face mask at specific places was still mandatory, on the coastal areas of Granada (Spain) which belongs to the Mediterranean Sea. Four beaches called La Rijana, La Charca, La Rábita and Calahonda were examined during different periods. The total amount of sampled waste was 17,558 plastic units. The abundance, characteristics and distribution of PPE and other plastic debris were determined. Results showed that the observed amount of total plastic debris were between $2.531 \cdot 10^{-2}$ and $24.487 \cdot 10^{-2}$ units per square meter, and up to $0.136 \cdot 10^{-2}$ for PPE debris, where face masks represented the 92.22 % of the total PPE debris, being these results comparable to previous studies in other coastal areas in the world. On the other hand, total plastic debris densities were in the range from $2.457 \cdot 10^{-2}$ to $92.219 \cdot 10^{-2}$ g/m$^2$ and densities were up to $0.732 \cdot 10^{-2}$ for PPE debris. PPE debris supposed 0.79 % of the weight of total waste and the 0.51 % of total items. Concerning non-PPE plastic waste: cigarettes filters, food containers and styrofoam were the most abundant items (42.95, 10.19 and 16.37 % of total items, respectively). During vacation periods, total plastic debris amount increased 92.19 % compared to non-vacation periods. Regarding type of beaches, the presence of plastic debris was significantly higher on touristic/recreational than in fishing beaches. Data showed no significant differences between accessible and no-accessible beaches, but between periods with restrictive policy about mask face use and periods with non-restrictive policy data suggest significant differences between densities (g/m$^2$) for PPE litter. The amount of PPEs debris is also correlated with the number of cigarettes filters (Person's $r = 0.650$), food containers ($r = 0.782$) and other debris ($r = 0.63$). Finally, although interesting results were provided in this study, further research is required to better understand the consequences of this type of pollution and to provide viable solutions to this problem.

## 1. Introduction

Plastic pollution is one of the biggest environmental issues nowadays. Despite the efforts made by all stakeholders involved in its production, consumption and management, plastic pollution continues to aggravate over time. The current production system is a net generator of waste and there are many aspects that influence the generation of waste. Global plastic waste generation reached 353 million tonnes in 2019 and 22 % of this plastic waste bypasses waste management systems and ends up in uncontrolled landfills, burned in open pits or ends up in terrestrial or aquatic environments. There is now an estimated 30 Mt of plastic waste in seas and oceans, and a further 109 Mt has accumulated in rivers (OECD, 2022).

The most used plastics today are considered non-biodegradable. Pollution by these plastics causes adverse effects on aquatic environments. Large plastic debris has been observed to cause entanglement with marine biota, such as turtles, fish, and seabirds. In addition, plastics can be colonised by marine macroinvertebrates, drift into alien ecosystems and cause biological invasions (De-la-Torre et al., 2021). Plastics also break down into smaller particles reaching sizes of less than 5 mm, which are considered as microplastics (MP) (Eriksen et al., 2014). MP are present in all aquatic environments, contaminating coastal areas,

* Corresponding authors.
*E-mail addresses:* f.ortega@ugr.es (F. Ortega), mcaleroh@ugr.es (M. Calero), nrico@ugr.es (N. Rico), marianml@ugr.es (M.A. Martín-Lara).

https://doi.org/10.1016/j.marpolbul.2023.114908
Received 1 March 2023; Received in revised form 31 March 2023; Accepted 2 April 2023
Available online 7 April 2023

surface waters, sediments and are ingested by a wide range of organisms (Jambeck et al., 2015).

On the other hand, COVID-19 has generated a serious public health emergency for citizens, societies, and economies worldwide, elevated to pandemic by the World Health Organization (WHO) on March 11, 2020, since then posing important challenges for public administrations at all levels (Leach et al., 2021). Its evolution was vertiginous, requiring urgent responses and maximum efficiency and coordination from the perspective of public action at all institutional levels. Consequently, in Spain, the mandatory use of the mask for people 6 years of age and older was initially established. Finally, the positive evolution of the COVID-19 epidemic, favoured by the vaccination coverage that has been achieved in Spain and by the application of non-pharmacological measures to control the transmission of SARS-CoV-2 by the population until March 2022, made it possible to propose modifications in the strategies to control the epidemic, modifying the mandatory use of masks during the health crisis caused by the COVID-19. This use of disposable personal protective equipment (PPE), mainly masks, as a control measure to avoid transmission against COVID-19 has generated a challenge to the waste management and enhances plastic pollution in the environment (Benson et al., 2021).

The WHO carried out a study on the impact that this pandemic is having on the generation of PPE waste. According to their calculations, between March 2020 and November 2021, 87,000 tons of PPE were purchased worldwide through a joint United Nations initiative. Most of this equipment was expected to have ended up as waste (WHO Water Sanitation Hygiene and Health Unit, 2022).

Plastic materials used in PPE and in PCRs tests that have been extensively utilized during the COVID-19 pandemic can cause serious problems if they are improperly managed and disposal. For example, in coastal marine environments they can break down under the effects of heat, wind, ultraviolet radiation, and ocean currents, eventually forming MP (Aragaw, 2020; Aragaw and Mekonnen, 2022; Sun et al., 2021; Wang et al., 2021). Multiple studies have also investigated the release of chemical additives from PPE under different environmental conditions (De-la-Torre et al., 2022a; Fernández-Arribas et al., 2021; Kutralam-Muniasamy et al., 2022; Pizarro-Ortega et al., 2022; Sullivan et al., 2021). This has been poorly examined in contrast with MP release. For example, recently, De-la-Torre et al. (2022a) analysed the release of MP and phthalate esters by gloves and face masks in aquatic media. Higher release of MP was found for face masks compared to gloves; however, the release of phthalate esters was higher for gloves. Also, Pizarro-Ortega et al. (2022) examined the release of MP and other contaminants such as heavy metals. The authors also provided interesting recommendations for monitoring programs and strategies to mitigate PPE pollution. Even, ecotoxicological techniques have been widely applied to evaluate the impact of PPE-derived contaminants on flora and fauna (Cabrejos-Cardeña et al., 2023).

In recent times, the first information from in situ monitoring activities in beaches and are being published (Akhbarizadeh et al., 2021; Ardusso et al., 2021; De-la-Torre et al., 2021; Kouvara et al., 2022; Okuku et al., 2021; Rakib et al., 2021; Thiel et al., 2021). Also, other studies have investigated PPE pollution caused by the COVID-19 pandemic in lakes (Aragaw et al., 2022), rivers (Cordova et al., 2021) or urban environments (Ammendolia et al., 2021).

There is growing interest in determining the extent and rate of PPE pollution in the coastal environments and growing appreciation that safe and rational use of PPE will reduce environmental harm from waste. In this sense, this research aims to contribute to the analysis of PPE waste by monitoring the presence of PPE waste and other plastic waste on the coastal areas of Granada (Spain) which belongs to the Mediterranean Sea. Particularly, the abundance, characteristics and distribution of PPE and other waste were examined following protocols from previous studies (De-la-Torre et al., 2022b; Haddad et al., 2021; Rakib et al., 2021) in four different beaches called La Rijana, La Charca, La Rábita and Calahonda during four different periods (a total of 16 samplings were performed). Information concerning PPE pollution in the coastal environments of Spain is largely lacking. To the best of our knowledge, this is the first work that reports and discusses data of PPE waste in beaches of Spain and authors expect it supports to change behaviours.

## 2. Materials and methods

### 2.1. Study area

The province of Granada is in the southeast of the Iberian Peninsula, with a population of 921,338 inhabitants in 2021 (INE, 2022). Its coasts are washed by the Mediterranean Sea (from 36°44′56.35″N; 3°8′16.54″W to 36°44′27.08″N; 3°46′ 42.29″W). Due to the topography of the province of Granada, the coasts of Granada are quite rugged in many areas. At present, these coasts are undergoing intense landscape transformation due to tourism development, the expansion of greenhouse and crop agriculture, and road and transport infrastructure (Godoy et al., 2020). These activities represent a major source of marine plastic pollution which coupled with COVID-19 prevention measures involving the use of single-use plastic PPE intensify this problem.

The beaches carefully chosen for sampling were La Rijana, La Charca, La Rábita and Calahonda. The criteria to choose the beaches were: their activity (tourist/recreational and fishing), their location (remote and accessible) and that they occupied the eastern, central, and western areas of the coast of Granada. Fig. 1 shows the geographical location of the selected beaches.

The beach of La Rijana (S1) belongs to the municipality of Gualchos. This beach is in the central region of the coast of Granada, approximately 35 km from the province of Málaga and 25 km from the province of Almería. This cove of barely 250 m in length is isolated (separated, inaccessible), with no buildings around it, and its main use is for tourism.

The beach of La Charca (S2) is in the town of Salobreña, in the western region of the coast of Granada, less than 20 km from the province of Málaga. In this town of around 12,500 inhabitants (12,472 in 2021) tourism is the main activity followed by agriculture where the extension of subtropical fruit crops exceeds 900 ha (Instituto de Estadística y Cartografía de Andalucía, n.d.). This 1.80-kilometre-long beach is urbanised, accessible (nearby) and its main use is for tourism.

The beach of La Rábita (S3) belongs to the town of Albuñol. This beach is in the eastern region of the coast of Granada, approximately 5 km from the province of Almería. In this population centre of just over 2000 inhabitants, agriculture is the main activity, followed by tourism. This 1-kilometre-long beach is urbanised; it is accessible (nearby), and the main use of the sampled area is fishing.

The beach of Calahonda (S4) belongs to the local autonomous entity of Carchuna-Calahonda, in the city of Motril. This beach is in the central region of the coast of Granada, approximately 30 km from the province of Málaga and at a similar distance from the province of Almería. In this population centre of approximately 4000 inhabitants, agriculture is the main activity, followed by tourism. This 1.30-kilometre-long beach is urbanised, accessible and its main use is for tourism despite the proximity of agricultural exploitations.

### 2.2. PPE and other plastic waste survey strategy

The PPE and other waste sampling strategy followed the procedures of previous studies carried out in other parts of the world such as the coast of Perú (De-la-Torre et al., 2021), Argentina (De-la-Torre et al., 2022b), Bangladesh (Rakib et al., 2021) and Morocco (Haddad et al., 2021). This strategy consists in the establishment at each site of a sampling area covering the entire length of the beach (from the low tide line to the upper limit of the beach) and several parallel transects established 5 m apart to visually cover all areas of the beach. During the transects, all the plastic waste found was collected, counted, and recorded and classified into categories according to their typology,


**Fig. 1.** Geographical location of the sampled beaches (Google Maps).

while PPE waste was collected separately, counted, and classified as FFP2 mask, surgical mask, other mask, face shield, protective suit, and glove. In addition, the different groups of materials were weighed for mass quantification.

Four sampling campaigns were conducted from March to September 2022 (first sampling campaign in March, second in April, third in June and fourth in September). This allows us to observe some characteristics related to the sample collection dates. The first date, March, is a non-vacation period, where the mask use policy is restrictive. April sample is for a vacation period, with still restrictive policy for mask use. June and Septembers are both non-vacation period with permissive policy of mask use.

The area covered at each sampling site was estimated using the Google Maps tool. Table 1 shows the main characteristics of each sampled beach. These values were used to calculate the PPE amount per square meter at each sampling site according to Eq. (1) (Okuku et al., 2021):

$$C = n/a \tag{1}$$

where **C** is the amount of PPE per square metre (PPE/m$^2$), **n** is the number of PPE observed and **a** is the area covered (m$^2$).

### 2.3. Statistical analysis

With the collected data, we calculate weight/item, weight/m$^2$ and item/m$^2$ measurements, for PPE and other plastic debris.

Firstly, absolute, and relative frequency tables for each debris type and for different times and different locations were obtained. This allows to observe the distribution of the waste. Secondly, we try to find if there are significant differences between locations, times, or other characteristics of the beaches. Given the lack of normality in the data, popular non-parametric techniques (i.e., the Mann Whitney U and Kruskal-Wallis tests) were used to compare outcomes between sampling areas and waste collection time, using significant level $\alpha = 0.05$.

It is also of our interest to know the relationship that may exist between PPE waste and the rest of the waste found, for which Pearson linear correlation coefficients were calculated.

**Table 1**
Main characteristics of the examined beaches.

| Location | Beach | Sampling area, m$^2$ | Accessibility | Activity |
|---|---|---|---|---|
| Gualchos | La Rijana (S1) | 6217 | Remote | Recreational |
| Salobreña | La Charca (S2) | 48,308 | Accessible | Recreational |
| Albuñol | La Rábita (S3) | 9548 | Accessible | Fishing |
| Carchuna-Calahonda (Motril) | Calahonda (S4) | 27,580 | Accessible | Recreational |

The statistical software IBM SPSS 28 was used to carry out the analysis.

## 3. Results and discussion

### 3.1. PPE waste

Table 2 includes the results obtained for the found PPE waste by typology. According to the obtained results, during the sampling period and even though the pandemic situation was not at its most critical moment, different types of PPE were found in the coastal areas. A total of 90 PPE items were found. Face masks were the most abundant type of PPE on the analysed beaches distributed as follows: 61 surgical masks, 10 FFP2 masks and 12 other types of masks such as reusable cloth masks. In addition, 7 gloves were collected in a cumulative area of 366,612 m$^2$ and in a total of four different dates. However, no other type of personal protective equipment derived from COVID-19 such as face shields was found in the study area. Based on the indicated results, the most accumulated PPE waste on the coasts of Granada was single-use surgical masks (67.78 %) and the rest were reusable cloth masks (13.33 %) or FFP2 masks (11.11 %). Gloves only represented 7.78 % of the total waste. Regarding the impact of period of the sampling campaigns, a noticeable increase in PPE items was observed from sampling campaign performed on April which represented the 40.0 % of all identified PPE. Location S2 is where the largest amount of PPE waste is collected, 37 items, which represents 41.11 % of the total amount.

In relation to the number of items found, if a comparison is made with other studies on other beaches around the world, the number of PPE litter found in Granada beaches is relatively low. For example, Hassan et al. (2022) counted a total of 1689 items of PPE waste in

**Table 2**
Number of items found on the collection of PPE waste on selected beaches of Granada in the four different sampling campaigns.

| PPE | Beach | Sampling campaigns | | | | Total PPE |
|---|---|---|---|---|---|---|
| | | March | April | June | September | |
| FFP2 masks | S1 | 0 | 0 | 0 | 1 | 1 |
| | S2 | 2 | 4 | 0 | 2 | 8 |
| | S3 | 0 | 0 | 0 | 0 | 0 |
| | S4 | 0 | 0 | 0 | 1 | 1 |
| Surgical masks | S1 | 3 | 2 | 2 | 1 | 8 |
| | S2 | 3 | 10 | 9 | 5 | 27 |
| | S3 | 8 | 4 | 0 | 0 | 12 |
| | S4 | 2 | 8 | 2 | 2 | 14 |
| Other masks | S1 | 0 | 0 | 0 | 0 | 0 |
| | S2 | 0 | 0 | 2 | 0 | 2 |
| | S3 | 2 | 0 | 0 | 0 | 2 |
| | S4 | 0 | 5 | 2 | 1 | 8 |
| Gloves | S1 | 0 | 0 | 0 | 0 | 0 |
| | S2 | 0 | 0 | 0 | 0 | 0 |
| | S3 | 3 | 3 | 0 | 0 | 6 |
| | S4 | 1 | 0 | 0 | 0 | 1 |
| Total PPE | | 24 | 36 | 17 | 13 | 90 |

Alexandria (Egypt) in an area of just 500 m$^2$ in a single day. In contrast, De-la-Torre et al. (2021) found 138 PPE residues during the entire sampling period (12 consecutive weeks from September 2020) conducted in the coastal areas of Lima, Peru. However, Akhbarizadeh et al. (2021), reported similar numbers of mask and glove residues found on the beaches of Bushehr (Iran) in the 40-day period from November to December 2020. The probable reasons for such high variations are the different prevention measures in each country, the behaviour of ocean currents and the different environmental awareness of the population in each region.

Regardless of the problem associated to PPE waste abandoned in coastal areas, the single-use plastic waste generated as a result of the pandemic is a new environmental problem that can interact with the wildlife, mainly marine organisms, causing physical injuries, such as entanglements and obstructions, or act as transport vectors for invasive species or generators of MP that end up being ingested by marine species (Fadare and Okoffo, 2020). Therefore, there is a need for regulatory standards that ensure the correct management of this type of waste in coastal areas, as well as innovation in the design of reusable or biodegradable PPE to reduce the environmental impact of this waste (De-la-Torre et al., 2021).

On the other hand, if the PPE amount per square meter is analysed, the mean of PPE residues found on the coast of Granada was 2.5·10$^{-4}$ items/m$^2$ (ranging between 0 and 1.36·10$^{-3}$ items/m$^2$). These results have been compared with data published in previous works carried out in other parts of the world and a summary of the main values obtained is presented in Table 3. The density of PPE waste on the coast of Granada was slightly higher than the values reported from Lima, Peru (6.4·10$^{-5}$ items/m$^2$) (De-la-Torre et al., 2021), Agadir, Morocco (1.1·10$^{-5}$ items/m$^2$) (Haddad et al., 2021) and São Paulo, Brazil (7.5·10$^{-5}$ items/m$^2$) (Ribeiro et al., 2022a). On the other hand, the density of PPE litter on beaches in Argentina and Peru was comparable to the results of this study (De-la-Torre et al., 2022b). Likewise, the waste density in places such as Bushehr, Iran (Akhbarizadeh et al., 2021) or Alexandria, Egypt (Hassan et al., 2022) is much higher than that reflected in this study. In addition, as expected, the density of PPE in the peak tourist seasons was higher than in other seasons.

Concerning the place and temporal variations of PPE litter, two of the four monitored beaches showed an increase of PPE items in second period of sampling (April) compared to first, third and four periods. Also, La Rábita showed important densities of PPE waste in the first and second periods but no items in third and four samplings (Fig. 2). In Subsection 3.3 a detailed statistical analysis was performed to examine the effect of different factors on PPE litter.

**Table 3**
Summary of the mean and range of PPE densities in previous studies.

| Region | PPE density, items/m$^2$ | PPE range, items/m$^2$ | Reference |
|---|---|---|---|
| *Granada, Spain* | *2.5·10$^{-4}$* | *0.00–1.36·10$^{-3}$* | *This study* |
| Lima, Peru | 6.4·10$^{-5}$ | 0.00–7.44·10$^{-4}$ | (De-la-Torre et al., 2021) |
| Lima, Peru (recreational beaches) | 1.6·10$^{-4}$ | – | (De-la-Torre et al., 2021) |
| Peru (nation) | 6.6·10$^{-4}$ | 0.00–5.01·10$^{-3}$ | (De-la-Torre et al., 2022b) |
| Argentina (nation) | 7.2·10$^{-4}$ | 0.00–5.60·10$^{-3}$ | (De-la-Torre et al., 2022b) |
| Greece (nation) | 3.1·10$^{-3}$ | 0.0–7.50·10$^{-2}$ | (Kouvara et al., 2022) |
| Cox's Bazar, Bangladesh | 6.3·10$^{-3}$ | 3.16·10$^{-4}$ - 2.18·10$^{-2}$ | (Rakib et al., 2021) |
| Agadir, Morocco | 1.1·10$^{-5}$ | 0.00–1.21·10$^{-4}$ | (Haddad et al., 2021) |
| Kenya (urban beaches) | – | 0.00–0.38·10$^{-1}$ | (Okuku et al., 2021) |
| Kenya (remote beaches) | – | 0.00–0.56·10$^{-1}$ | (Okuku et al., 2021) |
| Alexandria, Egypt | 2.8 | – | (Hassan et al., 2022) |
| Hurghada, Egypt | 2.9·10$^{-1}$ | – | (Hassan et al., 2022) |
| Jeddah, Saudi Arabia | 8.6·10$^{-1}$ | – | (Hassan et al., 2022) |
| Tetouan, Morocco | 1.2·10$^{-3}$ | 0.00–3.67·10$^{-3}$ | (Mghili et al., 2020) |
| São Paulo, Brazil | 7.5·10$^{-5}$ | 0.00–3.89·10$^{-4}$ | (Ribeiro et al., 2022a) |
| Mazandaran, Iran | 1.0·10$^{-4}$ | 0.00–7.16·10$^{-4}$ | (Hatami et al., 2022) |
| Bushehr, Iran | 1.7·10$^{-2}$ | 7.71·10$^{-3}$ - 2.70·10$^{-2}$ | (Akhbarizadeh et al., 2021) |
| Chile | 6·10$^{-3}$ | – | (Thiel et al., 2021) |
| Tamil Nadu, India | 1.1·10$^{-3}$ | 2.8·10$^{-4}$ - 2.8·10$^{-3}$ | (Gunasekaran et al., 2022) |
| Palawan, Philippines | 8·10$^{-3}$ | 0.0–6.1·10$^{-2}$ | (Sajorne et al., 2022) |

### 3.2. Other plastic waste

Table 4 shows the results obtained during the collection of waste (mainly plastic waste) on the coast of Granada. A total of 17,558 items were collected on Granada beaches. PPE waste represents an emerging fraction of plastic waste that should be considered, reaching a value of 0.51 % of the total waste collected (in number of items). However, it is noteworthy that, despite their relatively low degradation time, the most

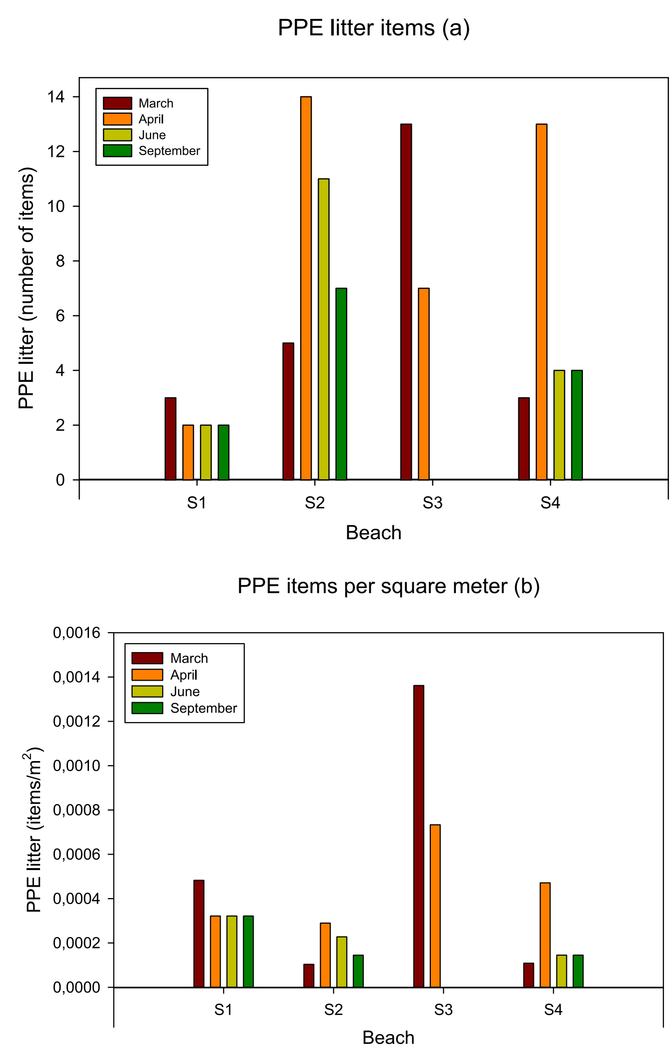


**Fig. 2.** Temporal variation of PPE items (a) and PPE items per square meter (b) in the four monitoring beaches.

**Table 4**
Data on waste sample collection at selected beaches in Granada.

| Material | Sampling campaigns | | | | Total |
|---|---|---|---|---|---|
| | March | April | June | September | |
| Total PPE | 24 | 36 | 17 | 13 | 90 |
| Plastic bag | 11 | 83 | 56 | 32 | 182 |
| Bottle | 25 | 52 | 44 | 47 | 168 |
| Food packaging and utensils | 324 | 616 | 457 | 392 | 1789 |
| Film | 85 | 282 | 224 | 185 | 776 |
| Plastic cup | 15 | 19 | 16 | 33 | 83 |
| Cigarette butt | 2024 | 2598 | 1561 | 1359 | 7542 |
| Fishing net/line | 64 | 173 | 130 | 103 | 470 |
| Plastic cap | 132 | 204 | 94 | 82 | 512 |
| Foam | 145 | 1597 | 613 | 520 | 2875 |
| Tube | 44 | 67 | 33 | 27 | 171 |
| Other | 597 | 1130 | 738 | 435 | 2900 |
| Total | 3490 | 6857 | 3983 | 3228 | 17,558 |

common plastic waste found are cigarette butts (42.95 %). Other plastic wastes that are relevant on the coast of Granada are food packaging (10.19 %) and foams (16.37 %). It is remarkable that most of the waste on the beaches is directly related to tourism and recreational use of the coasts. For this reason, social awareness campaigns are considered necessary, as well as disciplinary measures to control the dumping of this waste.

The large number of cigarette butts that releases into the beaches is a potential threat for the aquatic and terrestrial organisms (including human health) since cigarette butts may contain high levels of different chemicals (more than 7000) that include hazardous substances as polycyclic aromatic hydrocarbons (PAHs), toxic metals, aromatic amines, insecticides, and other toxic compounds (Dobaradaran et al., 2022; Ribeiro et al., 2022b; Soleimani et al., 2023b). Once cigarette butts are in seawater the dissolution of the mix of chemicals found in cigarette butts or even direct ingestion of cigarette butts by aquatic and terrestrial organisms can produce toxic effects on them (Dobaradaran et al., 2023; Montalvão et al., 2019; Soleimani et al., 2023a).

Policies to decrease the occurrence of cigarette butts in the environment including smoking prohibition in public areas, beaches cleaning (especially during tourist seasons), education campaigns, between others have been proposed by some researchers (Stigler-Granados et al., 2019).

A significant aspect is the increase in plastic waste collected during sampling after a holiday period (sampling in April) compared to the ones carried out on dates when there is less tourism on the coasts (Sampling in March, June, and September). These facts indicates that environmentally unconscious tourism generates a relatively relevant impact on marine ecosystems.

On the other hand, plastic pollution on the coasts of Granada is significantly lower than in evaluations conducted in other regions such as Alexandria, Hurghada and Jeddah (Hassan et al., 2022). Table 5 shows a comparison of the results obtained of the coast of Granada compared to these regions.

**Table 5**
Comparison of density of plastic waste collected on beaches.

| Site | Plastic density, items/m$^2$ | Reference |
|---|---|---|
| *Granada, Spain* | *$4.78 \cdot 10^{-2}$* | *This study* |
| Alexandria, Egypt | 7.20 | (Hassan et al., 2022) |
| Hurghada, Egypt | 0.51 | (Hassan et al., 2022) |
| Jeddah, Saudi Arabia | 1.77 | (Hassan et al., 2022) |
| Odisha, India | $9.89 \cdot 10^{-1}$ | (Khadanga et al., 2022) |
| Sarayköy, Turkey | 1.87 | (Aytan et al., 2019) |
| Trabzon, Turkey | 1.46 | (Terzi et al., 2020) |
| Senegal | 1.92 | (Tavares et al., 2020) |
| Santos bay, Brazil | $3.70 \cdot 10^{-1}$ - $6.81 \cdot 10^{-1}$ | (Ribeiro et al., 2021) |
| Caribbean islands | 6.34 | (Schmuck et al., 2017) |

### 3.3. Hypothesis tests and statistical measures

The Kruskal-Wallis test, a nonparametric (distribution free) test, was used to assess significant differences on dependent variable (mean density in g/m$^2$ and items/m$^2$) by the categorical independent variable (periods and beaches). Main results are provided in Table 6. Significant results in the Kruskal–Wallis test have been marked with stars and were found for beach factor for No-PPE waste and total plastic waste indicating that there are differences between groups. However, not significant differences were obtained for period factor.

Table 7 shows the results of the test of Mann Whitney U Test (as known as Mann Whitney-Wilcoxon Rank Sum Test) for periods (vacations/non-vacations and restrictive/non-restrictive) and beaches (tourism/fishing and accessible-nearby/separated-inaccessible). The main important remarks are that there are no significant differences in the two types of periods (vacations/non-vacations) for all type of waste, that there is a significant difference in the weight per square meter and in the units per square meter of the non-PPE waste and total plastic waste found on the beaches with recreational use and the beaches with fishing use. Also, there is a significant difference in the weight per square meter of the PPE waste found in moments of restrictive policy for the use of masks and in moments with a permissive policy.

Finally, the Pearson correlation coefficient (r) was calculated to measure the relationship between number of items of PPE waste and other type of plastic waste. The amount of PPE (items) showed a significant correlation with the food packaging and utensils (r of Pearson 0.782, p-value = 0.000), with cigarette butts (r = 0.65, p = 0.006) and other waste (r = 0.63, p = 0.009). A significant correlation coefficient was observed between the number of collected surgical masks and the number of food containers (r = 0.737, p = 0.001) and the number of collected surgical masks and filters (r = 0.619, p = 0.011). The rest of PPE objects (FFP2 masks, other masks, and gloves) did not show significant relationships with the number of other types of collected waste.

## 4. Risks and recommendations to reduce plastic litter pollution in coastal areas of Granada (Spain)

Marine litter poses a serious threat to marine life, both due to its high quantity in the marine environment and its composition (mostly plastics with long residence times in the medium, sometimes over 200 years, which fragment into small particles or MP), and can negatively affect individuals, populations, and marine ecosystems. The most important impacts produced by pollution by marine litter are the entanglement of marine fauna in litter, the ingestion of marine litter by living organisms of all sizes, the effects derived from its potential as a vector for the introduction of alien species, the alteration of the structure of benthic communities and degradation of the seabed. On the other hand, floating marine debris can harbour entire communities of fouling and attached organisms and transport them long distances, beyond their natural boundaries, thus contributing to their introduction into environments

**Table 6**
Statistics of Kruskal Wallis Test.

| Factor | Type of waste (group) | | Chi-square | df | Asymp. sig. |
|---|---|---|---|---|---|
| Period | PPE | g/m$^2$ | 5.341 | 3 | 0.148 |
| | | items/m$^2$ | 3.939 | 3 | 0.268 |
| | No-PPE | g/m$^2$ | 0.574 | 3 | 0.902 |
| | | items/m$^2$ | 3.706 | 3 | 0.295 |
| | Total waste | g/m$^2$ | 0.574 | 3 | 0.902 |
| | | items/m$^2$ | 3.706 | 3 | 0.295 |
| Beach | PPE | g/m$^2$ | 2.253 | 3 | 0.522 |
| | | items/m$^2$ | 2.960 | 3 | 0.398 |
| | No-PPE | g/m$^2$ | 11.846 | 3 | 0.008* |
| | | items/m$^2$ | 10.478 | 3 | 0.015* |
| | Total waste | g/m$^2$ | 11.846 | 3 | 0.008* |
| | | items/m$^2$ | 10.743 | 3 | 0.013* |

Significant results in the Kruskal–Wallis test have been marked with stars.

**Table 7**
Statistics of Mann Whitney *U* Test (Wilcoxon Rank Sum Test).

| Comparative | Type of waste (group) | | Mann-Whitney U | Wilcoxon W | Z | Asymp. Sig. (2-tailed) | Exact Sig. [2*(1-tailed Sig.)] |
|---|---|---|---|---|---|---|---|
| Periods (vacations/non vacations) | PPE | g/m$^2$ | 9.000 | 87.000 | −1.820 | 0.069 | 0.078 |
| | | items/m$^2$ | 10.000 | 88.000 | −1.705 | 0.088 | 0.103 |
| | No- PPE | g/m$^2$ | 19.000 | 97.000 | −0.606 | 0.544 | 0.599 |
| | | items/m$^2$ | 10.000 | 88.000 | −1.698 | 0.090 | 0.103 |
| | Total waste | g/m$^2$ | 19.000 | 97.000 | −0.606 | 0.544 | 0.599 |
| | | items/m$^2$ | 10.000 | 88.000 | −1.698 | 0.090 | 0.103 |
| Periods (restrictive/nonrestrictive) | PPE | g/m$^2$ | 11.000 | 47.000 | −2.207 | 0.027 | 0.028* |
| | | items/m$^2$ | 15.000 | 51.000 | −1.793 | 0.073 | 0.083 |
| | No- PPE | g/m$^2$ | 28.000 | 64.000 | −0.420 | 0.674 | 0.721 |
| | | items/m$^2$ | 24.000 | 60.000 | −0.840 | 0.401 | 0.442 |
| | Total waste | g/m$^2$ | 28.000 | 64.000 | −0.420 | 0.674 | 0.721 |
| | | items/m$^2$ | 24.000 | 60.000 | −0.840 | 0.401 | 0.442 |
| Beach (use) | PPE | g/m$^2$ | 23.000 | 33.000 | −0.121 | 0.903 | 0.953 |
| | | items/m$^2$ | 24.000 | 34.000 | 0.000 | 1.000 | 1.000 |
| | No- PPE | g/m$^2$ | 5.000 | 83.000 | −2.304 | 0.021 | 0.020* |
| | | items/m$^2$ | 0.000 | 78.000 | −2.910 | 0.004 | 0.001* |
| | Total waste | g/m$^2$ | 5.000 | 83.000 | −2.304 | 0.021 | 0.020* |
| | | items/m$^2$ | 0.000 | 78.000 | −2.910 | 0.004 | 0.001* |
| Beach (accessibility) | PPE | g/m$^2$ | 13.000 | 91.000 | −1.335 | 0.182 | 0.212 |
| | | items/m$^2$ | 11.000 | 89.000 | −1.583 | 0.113 | 0.133 |
| | No- PPE | g/m$^2$ | 11.000 | 89.000 | −1.576 | 0.115 | 0.133 |
| | | items/m$^2$ | 22.000 | 100.000 | −0.243 | 0.808 | 0.862 |
| | Total waste | g/m$^2$ | 11.000 | 89.000 | −1.576 | 0.115 | 0.133 |
| | | items/m$^2$ | 21.000 | 99.000 | −0.364 | 0.716 | 0.770 |

where they did not previously exist. If they find favourable conditions in the new habitat, alien species can settle, colonize the area, and establish themselves with detrimental effects for native species. Likewise, effects on feeding, respiration, growth, and reproduction capacities have been verified in a wide variety of organisms due to MP. It is also important to indicate that the harmful effects on organisms are not only produced by the incorporation of MP but also by the effect of the additives they contain.

In addition to these physical impacts, there is growing concern about the impact on human health because of the toxic substances released by plastic waste or the influence that MP have in enhancing the transport and bioavailability of toxic, bioaccumulative, and persistent substances that could enter the food chain.

Marine debris has also a negative socioeconomic impact and can cause economic losses to industries such as commercial fishing and maritime traffic (propeller clogging), as well as recreational activities and tourism.

For the reduction of general plastic litter pollution and particular PPE litter pollution, we recommend five general actuations. The first, focused on generating updated information on plastic and PPE waste, establishing a baseline to develop a good response to the increase in marine litter. In this way, it is possible to identify the most problematic plastics, as well as the current causes, magnitude, and impact of its mismanagement. The second, focused on reducing the leakage of these materials in the environment, prevent plastic waste and increase recycling. For example, using reusable bottles, increasing number of local potable drinking fountains to fill the bottles with water, promoting the use of textile reusable bags, considering introducing deposit refund schemes, including information panels indicating the correct way to discard used PPE, etc. The third, aimed at improving the infrastructure of plastic waste disposal. For example, locating bins or storage spaces near the entrance of the beach with supervisor to check and inform to the visitors (Dioses-Salinas et al., 2022). The fourth, focused on the expansion of recovery systems, the expansion of the producer responsibility and the promotion of the sustainable recycling systems, aiming to avoid plastic waste to reach landfills or natural environments. For example, as possible sustainable recycling system, the recycling of PPE waste via pyrolysis that has shown promising results (Aragaw and Mekonnen, 2021; Ortega et al., 2023). Finally, the fifth, focused on education about the importance of reducing the use and consumption of single-use plastics and providing relevant information about the environmental and socio-economic impacts of plastic litter pollution.

## 5. Conclusions

The COVID-19 has driven the use of PPE as a form of prevention against transmission between the Spanish population. Given the poor solid waste management conditions for these materials and lack of adequate citizen's campaigns, improper disposal of PPE waste in the environment has become intense. Thus, multiple forms of plastic pollution, including MP and nanoplastics, have been intensified. In the present study, four different beaches in Granada (Spain) were monitored for PPE contamination for months after periods of confinement. To the best of our knowledge, this is the first analysis of the abundance of PPE debris on the beaches of Spain. The results of this study present temporary data in a context of COVID-19 pandemic, in our opinion, this is the main limitation of the study, nevertheless results can be useful for policymakers as well as the public to avoid future environmental contamination via PPE and plastic waste. Particularly, results showed that PPE represented 0.51 % of all litter items and dominated by face masks (92.22 %). In general, recreational sites were the most affected by plastic and PPE waste. This is related to the large influx of bathers to beaches compared to sites where fishing is the dominant activity. In addition, the reopening of public beaches after the period of confinement has led to a marked increase in PPE on the beaches of Granada. The obtained results are comparable to those from the coastal environments around the world. The situation therefore requires actuations against improper disposal of PPE. This work also includes five interesting recommendations for better waste management on the beaches of Granada and prevention of plastic marine litter. For example, the generation of updated information on plastic and PPE waste, establishing a baseline to develop a good response to the increase in marine litter or improving the infrastructure of plastic waste disposal.

## CRediT authorship contribution statement

**F. Ortega:** Methodology, Formal analysis, Investigation, Writing – original draft. **M. Calero:** Conceptualization, Resources, Supervision, Project administration, Funding acquisition. **N. Rico:** Software, Formal analysis, Validation, Data curation, Writing – review & editing. **M.A. Martín-Lara:** Conceptualization, Resources, Supervision, Project administration, Funding acquisition, 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.

## Data availability

No data was used for the research described in the article.

## Acknowledgements

This research was funded by project “RECOMAR” (PYC20 RE 041 UGR), co-financed 80 % by the ERDF, ERDF Operational Program 2014-2020 and the Ministry of Economic Transformation, Industry, Knowledge and Universities, Junta de Andalucía. European Union – European Regional Development Fund (ERDF) - “Andalusia moves with Europe”.

Authors thank “*Commonwealth of Municipalities of the Tropical Coast of Granada*” that greatly assisted the sampling campaigns. Funding for open access charge: Universidad de Granada / CBUA.

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