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Research paper

Abandoned Covid-19 personal protective equipment along the Bushehr shores, the Persian Gulf: An emerging source of secondary microplastics in coastlines

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ABSTRACT

During the Covid-19 pandemic, personal protection equipment (PPE) was widely used to control the virus further spared. In this study, the presence of PPE wastes along the coastline of Bushehr port, the Persian Gulf from nine stations was investigated (4 times during 40 days), and their potential for microplastics (MPs) creation was preliminarily assessed. In total, more than 2380 PPE were collected in the study area. No significant differences were found between various beaches regarding their types and common activities. In addition, the estimated disposal rate of PPE per day and year is 350 and 127,750 items, respectively. More than 10% of the collected PPE from Bushehr's coastal areas on each sampling day were damaged. Based on the microscopic analysis, the left surgical masks and torn plastic gloves in the coastal regions are emerging sources of secondary microfibers and MP particles (mostly fragments and films) in the marine environments, respectively.

1. Introduction

During the last year, human beings have faced deadly infectious disease, and since March 2020, Covid-19 was declared as a pandemic by the World Health Organization (WHO) (Ducharme, 2020). Then, different measures have been used in different parts of the world, such as staying at home (lockdown), travel restriction, social distancing, washing of hands, surface disinfection, and isolation (Aragaw, 2020; Fadare and Okoffo, 2020; Rhee, 2020). Moreover, various personal protective equipment (PPE-i.e., face masks, gloves, face shields, alcohol spray) was used in different countries in order to control the virus further spared (De-la-Torre and Aragaw, 2021; Nowakowski et al., 2020). It is estimated that more than 129 billion face masks and 65 billion gloves have been used monthly all around the world (Prata et al., 2020). Discarded only 1% of these PPE exceeds ten million items (Celis et al., 2021) and can cause an environmental crisis.

Single-use face masks, N95 masks, gloves, and face shields are mainly produced from plastic polymers such as polypropylene, polystyrene, polyacrylonitrile, polyester, and polyurethane (Aragaw, 2020; Ardusso et al., 2021; Potluri and Needham, 2005; Sangkham, 2020). Most of the surgical masks have three layers: 1) an inner layer with soft fibers, 2) a middle layer with melt-gusted filter, and 3) an outer layer with nonwoven fibers which are usually colored and water-resistant (Aragaw, 2020; Fadare and Okoffo, 2020). Approximately the weight of polypropylene (PP) in a single N95 mask and surgical mask is 11 and 4.5 g, respectively (Abbasi et al., 2020; Liebsch, 2020). In addition, the most commonly single-use gloves are made of polyethylene (PE), latex, and nitrile (Nowakowski et al., 2020). Although these types of plastics can easily be recycled, they are usually mixed with other wastes or left in the environment (i.e., parks, beaches, forests) (Nowakowski et al., 2020).

Disposal of PPE is an important environmental issue, as most of these goods are single-use and mostly made of plastics. Single-use plastic materials (i.e., take-out food containers and drinking bottles) are known

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as the main sources of plastic pollution in the environment (Akhbarizadeh et al., 2020b; Du et al., 2020; Fadare et al., 2020; Schnurr et al., 2018). Similarly, face masks and gloves are single-use plastic materials. Unfortunately, many people leave their PPE in streets, waterways, rivers, and shores (Ammendolia et al., 2021; Ardusso et al., 2021; Cordova et al., 2021). These emerging types of plastic debris will potentially promote a spike in plastic pollution in the near future (De-la-Torre and Aragaw, 2021). Regardless of the aesthetic perspective, the presence of plastics may generate impacts on the ecosystem at different levels (Ryan, 2016; Thiel et al., 2018). Similar to most plastic debris, PPE items can be positively, neutrally, or negatively buoyant in the water bodies. Hence, some PPE items are expected to transport by oceanic currents, while others may become buried in the sediments (De-la-Torre and Aragaw, 2021; De-la-Torre et al., 2020). In addition, the bio-photochemical weathering of large plastics may result in their fragmentation and degradation to produce secondary microplastics (MPs) (Wright et al., 2013). Hence, it's not far-fetched that PPE is the emerging source of secondary MPs in the environment and might endanger wildlife as well as human health (De-la-Torre and Aragaw, 2021). Moreover, since plastic litters are known to propagate micro-organisms (i.e., pathogens), the left face masks and gloved could also act as a medium for disease outbreak (Fadare and Okoffo, 2020; Kampf et al., 2020; Reid et al., 2019).

In Iran, Covid-19 began to spread from February 2020, and the infection protection protocols have been similar to other countries (the mandatory use of face masks in public places). Moreover, some people use gloves and face shields to protect their selves. Although these plastic litters become waste after single-use and should be disposed in waste bins, many of them are left in the environment. Hence, the main source of PPE items on Bushehr coasts during the pandemic is their incorrect disposal along the coastline. To the best of our knowledge, left items in coastal areas have never been picked up by municipal workers due to their possible pathogenicity. The main objectives of this study are to investigate 1) the presence of PPE along the shore of Bushehr port, the Persian Gulf, 2) their characteristics and disposal rate in the study area, and 3) their probable role in the creation of secondary MPs in the near future.

2. Materials and methods

2.1. Study area

Bushehr province with 27,653 km^2 area is located in the southwest of Iran and northwest of the Persian Gulf (E: 52°–58°, N: 27°–14°). Bushehr port is the capital of Bushehr province (Fig. 1) and has a population of 223, 504 in 2017 (Statistical Center of Iran, 2017). Both sandy beaches and rocky beaches are presented in Busher port coastline. In detail, stations S_1, S_4, S_7, S_8, and S_9 are sandy beaches, and other stations were rocky beaches. The common activities on beaches of Busher port are swimming, walking, playing with sand, seaside camping, and fishing. As shown in Fig. 1, stations S_1, S_2, S_3, and S_4 are near downtown. In sites S_1, S_2, and S_4, general recreational activities are carried out. Stations 4 (S_4), 5 (S_5), and 7 (S_7) are the most crowded beach along the Bushehr port's coastline. The most activities in these stations are seaside camping and walking. Sites S_3 and S_6 are fishing harbors. Stations S_8 and S_9 have the highest distance from downtown and are mainly meant for beachgoer's general recreational activities (i.e., swimming). The mentioned activities were assigned according to their popularity and field observation. However, activities in most sites are not exclusive. For instance, swimming can be carried out in S_5 but is less likely.

2.2. Sampling and samples preparation

In November and December 2020, 9 stations were chosen to sample the PPE along the Bushehr port's coastline (Fig. 1). For sampling in each site, several transects were established, covering the entirety of the beach. (Statistical Center of Iran, 2017)Each station was sampled four times in 40 days with interval times of 1, 10, and 40 days after the first sampling (Table S1). The coast type (rock and sand) and estimated sampled area of each site are presented in Table S1. The visible PPE samples from the eye-level of researchers (mean 160 cm) were collected along the coastlines of Busher port. The collected samples were separately put in aluminum foil and plastic bags. The density of PPE items in each station was calculated using the following equation (De-la-Torre et al., 2021; Okuku et al., 2021):

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

where C is the density of PPE items per m^2, n is the number of PPE, and A is the surveyed area (m^2).

After sampling, the collected samples (mostly medical face masks and plastic gloves) were air-dried at room temperature in the laboratory. Then each sample was checked carefully with the naked eye and then by binocular microscopes to find a probable sign of weathering and/or degradation in the environment. Each sample with the sign of degradation was considered as damaged PPE. Daily PPE release in this study was estimated using the following equation:

$$D = \frac{n}{t}$$

where D is the daily release of PPE (items/day), n is the number of collected undamaged PPE items on the second day of sampling, and t is observation time (day).

2.3. Data analysis

The XLSTAT software (2016) and Microsoft Excel 2016 were applied for the statistical analysis. To clarified if parametric or non-parametric tests were appropriate, the descriptive statistics, and the Shapiro-Wilk test was conducted on the data. Due to not normal distribution, non-parametric tests (Kruskal Wallis test or the Mann-Whitney *U* test) were used to check the significance of differences in number of face masks and gloves at different stations and sampling times. A linear regression analysis was used to determine the relationship between the face masks and the gloves numbers at different stations. Statistical significance was accepted at $p < 0.05$.

3. Results and discussions

3.1. Presence and distribution of PPE

The abundance of PPE along the shores of Bushehr port during 40 days is presented in Table 1. According to the obtained results, high amounts of different kinds of PPE were left in coastal areas of Bushehr port during the pandemic (Fig. 2). In total, 1578 face masks (surgical masks, N95, and cloth masks) and 804 gloves (plastic gloves, nitrile gloves, vinyl gloves, and latex gloves) were found over a cumulative area of 43,577 m^2. However, no face shields and alcohol sanitizer spray were found in the study area. According to the results of previous studies, the number of found PPE debris was 1306 in 6 sampled locations (245,190 m^2) in Toronto, Canada (Ammendolia et al., 2021), while only 138 PPE were counted in coastal zones of Lima, Peru (De-la-Torre et al., 2021). The probable reasons for these differences are the different lockdown policies in various countries and also different behavior and lack of environmental awareness. Based on the results, the most collected items in Bushehr coastlines were face masks. Some of the previous studies were reported similar results (Cordova et al., 2021; De-la-Torre et al., 2021), while in Toronto, the most reported items were disposable gloves (Ammendolia et al., 2021). However, regardless of the number and types of released PPE items, the single-use plastic wastes generated by the people during the pandemic are a new environmental issue. It is expected that left PPE (i.e., face masks) in the environment

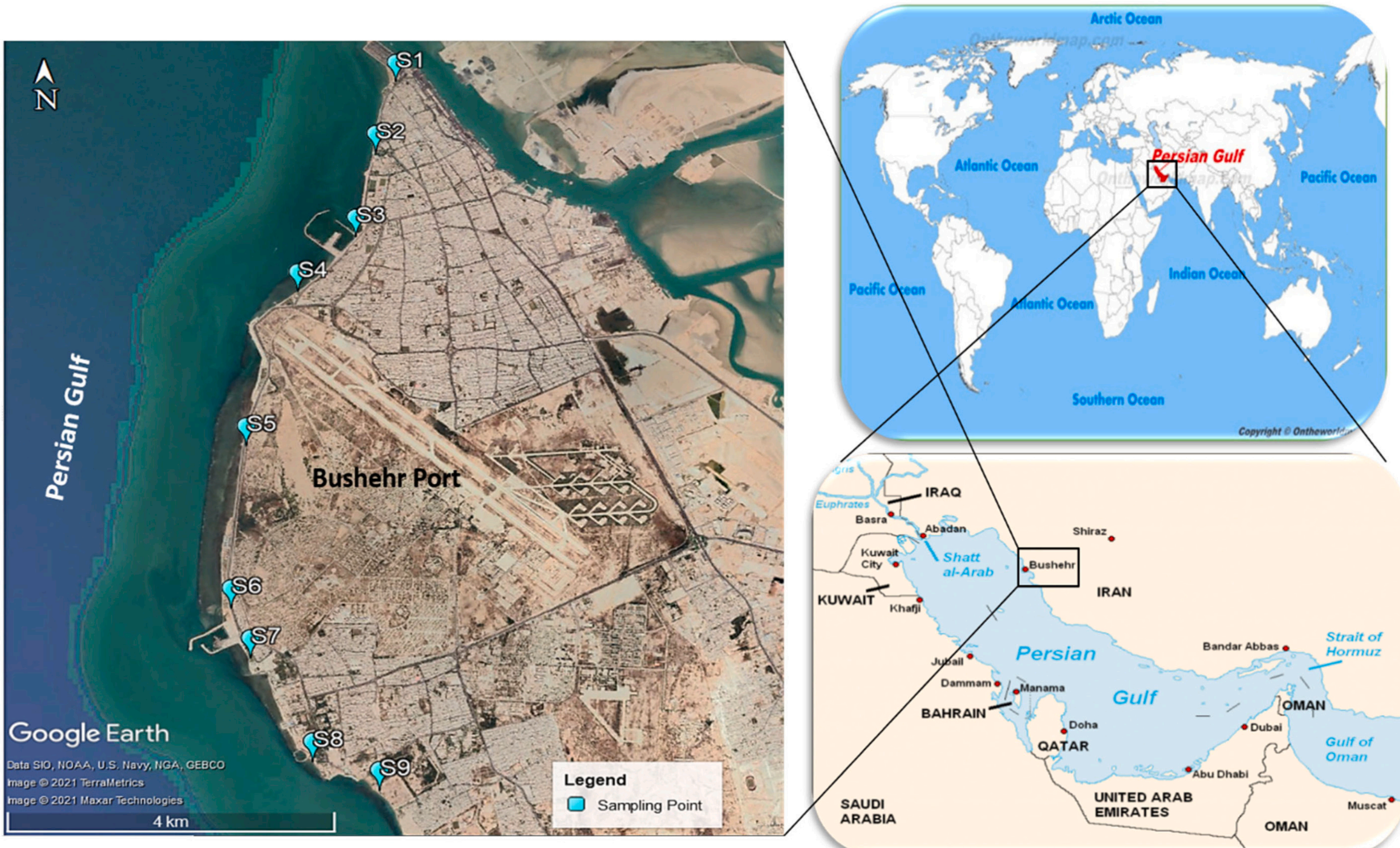

Fig. 1. Geographical location of Bushehr port and sampling locations.

Table 1
Abundance of PPE along the shores of Bushehr port along the Persian Gulf.

	Face masks				Gloves			
	1st day of sampling	2nd day of sampling (24 h after the 1st day)	3rd day of sampling (10 days after the 1st day)	4th day of sampling (40 days after the 1st day)	1st day of sampling	2nd day of sampling (24 h after the 1st day)	3rd day of sampling (10 days after the 1st day)	4th day of sampling (40 days after the 1st day)
S1	28	6	16	33	17	0	37	21
S2	47	18	30	19	9	2	4	1
S3	138	79	83	79	15	7	25	23
S4	117	64	83	91	56	14	66	28
S5	91	31	62	26	93	38	41	43
S6	59	25	39	40	18	19	11	20
S7	69	22	58	76	105	23	48	14
S8	20	2	0	9	2	0	2	0
S9	5	5	4	4	0	1	1	0
Sum	574	252	375	377	315	104	235	150
Mean	63.78	28	41.67	41.89	35	11.56	26.11	16.67
SD[1]	42.25	25.25	29.91	30.42	37.58	12.39	21.96	13.74
CV	66.24	90.18	71.78	72.62	107.37	107.18	84.11	82.42

SD: Standard deviation.

Fig. 2. Face masks and gloves along the coastlines of Bushehr port, the Persian Gulf.

interact with wildlife, mainly marine organisms (De-la-Torre et al., 2021). Besides physical injuries such as PPE entanglement to marine species, contaminated PPE items with Coronavirus could potentially threaten marine mammals (De-la-Torre et al., 2021).

Based on the coefficient of variation (CV) (Table 1), the number of PPE in coastal areas of Bushehr port showed large spatial variations (CV > 66% for face masks and CV > 82% for gloves). The spatial distribution of collected PPE along the Bushehr port's coastline during the sampling days is presented in Fig. 3. According to the obtained results, stations S_4, S_5, and S_7 were the most polluted beaches of Bushehr port. As previously mentioned, stations 4 (S_4), 5 (S_5), and 7 (S_7) are the most crowded recreational beach along the Bushehr port's coastline with recreational activities. The higher presence of left PPE in most recreational stations was also reported in previous studies (Ammendolia et al., 2021; De-la-Torre et al., 2021). In total, the highest and lowest number of PPE items were found at S_4 ($n = 519$) and S_9 ($n = 20$), respectively. S_4 is one of the most crowded beaches along the Bushehr port's coastline, while S_9 has the highest distance from downtown (Fig. 1). There were no significant differences between the number of PPE items in sandy beaches and rocky beaches ($p > 0.05$ for both masks and gloves). Also, no significant differences were found between various beaches regarding their common activities (swimming, walking, sand playing, and fishing). The probable reason for this result is that activities in most sites are not exclusive. In contrast, the number of PPE in crowded areas and beaches closer to downtown was significantly higher than other stations ($p < 0.05$ for both masks and gloves). Similar results were reported in previous studies in different parts of the world (Ammendolia et al., 2021; De-la-Torre et al., 2021). Hence, the most critical factors in PPE pollution along the coast of Bushehr port are high population density and lower distance to downtown.

The mean density of PPE along the coastline of Bushehr port was 2.70E-02 ± 0.02, 7.71E-03 ± 0.01, 1.72E-02 ± 0.02, and 1.70E-02 ± 0.01 in the first day to the fourth day of sampling, respectively (Table S2). As expected, the PPE density in crowded areas and beaches closer to downtown was higher than other stations. The PPE density along the Bushehr coast was much higher than reported values from

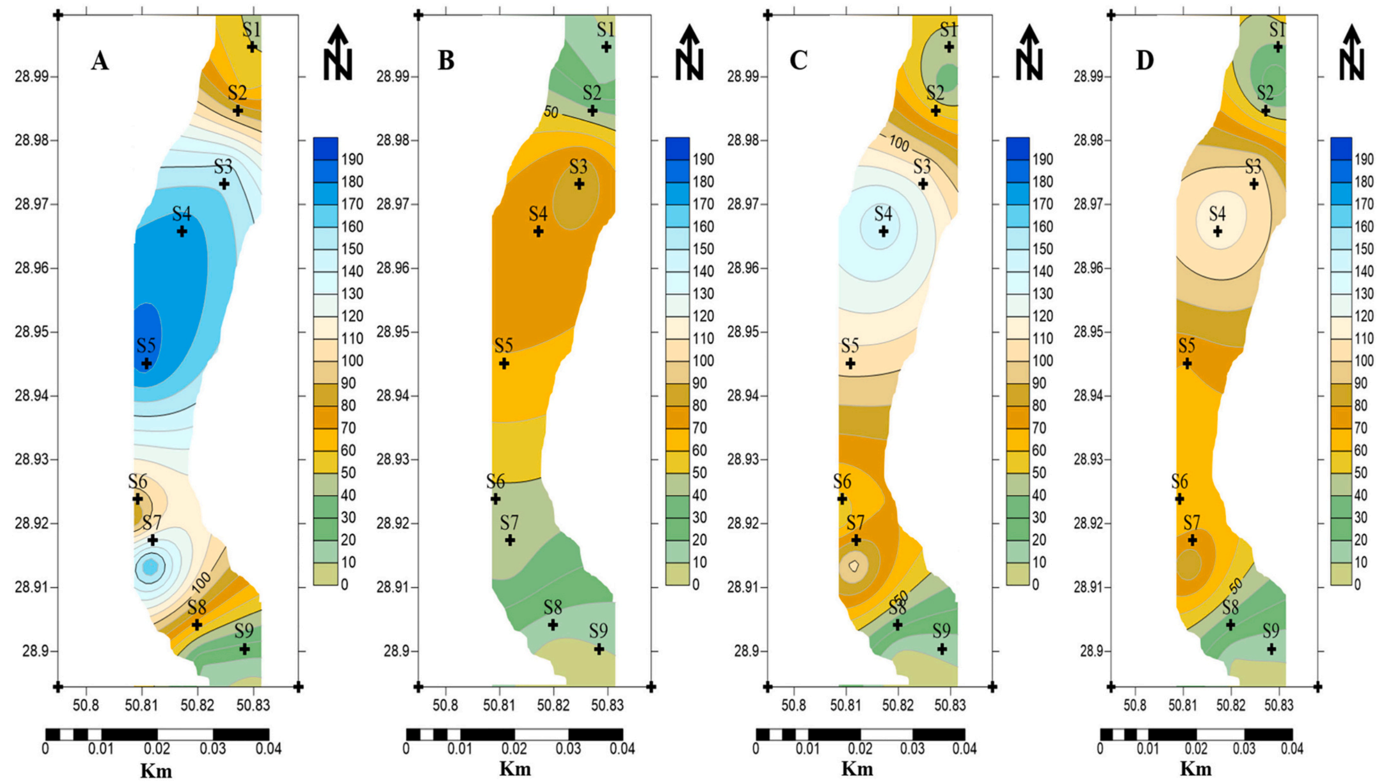

Fig. 3. Spatial distribution of personal protection equipment (PPE) along the coastline of Busher port, Persian Gulf. A: the first time of sampling, B: the second time of sampling (after 1 day), C: the third time of sampling (after 10 days), and D: the fourth time of sampling (after 40 days).

Lima, Peru (6.42E-05 ± 1.11 E-05 items/m^2) (De-la-Torre et al., 2021) and Toronto, Canada (1.01E-03 ± 1.55 E-03 items/m^2) (Ammendolia et al., 2021). In contrast, the density of PPE litter in Kenya's urban beaches (0–3.8E-02 items/m^2) was comparable with the results of this study (Okuku et al., 2021).

Avoid pollution is an important part of coastal management (Sharma et al., 2020) and could be considered a socio-ecological problem (Ardusso et al., 2021). Since plastic waste threatens the wildlife and ecosystem in all marine and coastal environments, citizens and tourists should take more care of plastic litters' incorrect disposal in beach areas. Governments should also improve waste management systems, and scientists should design new reusable and adequate PPE to reduce the environmental impacts of plastics waste, especially in coastal areas.

3.2. Characteristics of discarded PPE and their disposal rate

The presence of surgical masks and polyethylene gloves was higher than the other found PPE in the study area (Fig. 4). On the other hand, the abundance of cloth masks and latex gloves was the least in Bushehr Port's shoers. Indicating the common use and/or more discarding the cheaper PPE rather than other ones. Moreover, the transparent gloves (92–96% in different sampling days) and blue face masks (57–63% in different sampling days) were the most predominant type and color (Fig. 5). Since these types of gloves are made by high-density polyethylene (HDPE) and the mentioned masks are mainly composed of micro-and nano polypropylene fibers (Abbasi et al., 2020; Fadare and Okoffo, 2020), increased MPs with low density (0.95 and 0.92 g/cm^3, respectively) in the environment in the near future is an important concern.

The number of PPE on the first day of sampling was significantly higher than the other days ($p < 0.05$), indicating that municipal workers have not picked up these left items in the beach areas. No significant differences were found between other sampling days. However, the left plastic litters (even a small one) on the beach can easily transport to the sea and impacted the wide variety of aquatic organisms. It is difficult to estimate the daily discarded PPE in the beach areas; however, in the present study, the number of the collected undamaged samples on the 2nd day of sampling is a reasonable estimation for the abandoned PPE

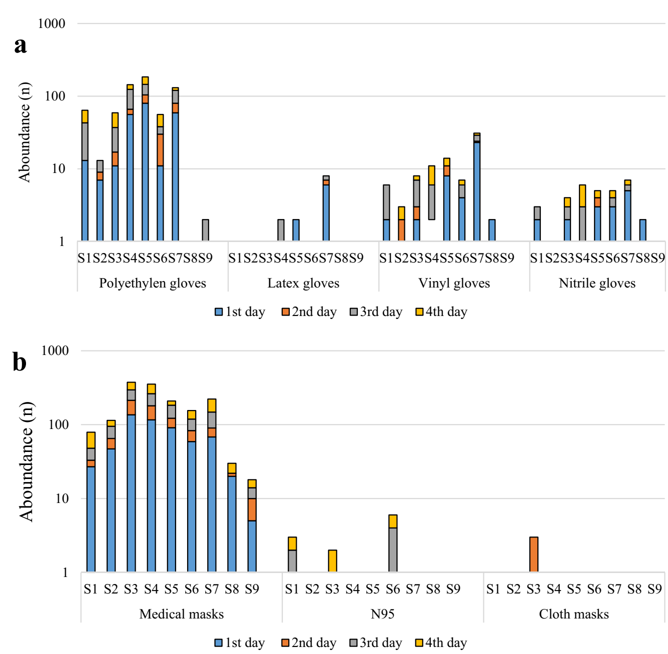

Fig. 4. PPE along the coastal line of Bushehr port a: the abundance of different types of gloves and b: the abundance of various types of face masks. Note: the 2nd, 3rd, and 4th days of sampling are 1 day, 10 days, and 40 days after the 1st day of sampling, respectively.

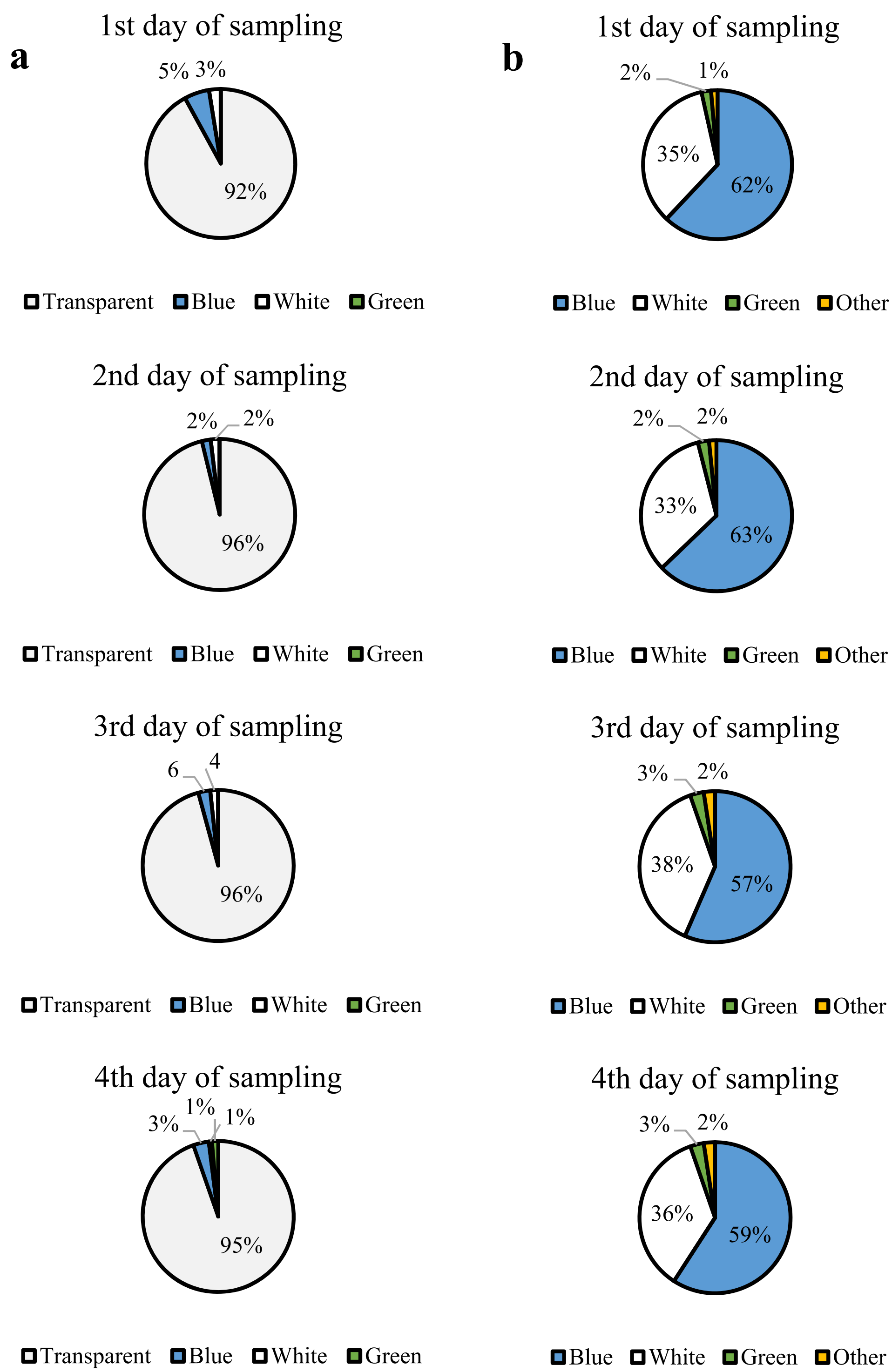

Fig. 5. The color diversity of collected PPE along the shores of Busher port: a: gloves, and b: face masks. Note: the 2nd, 3rd, and 4th days of sampling are 1 day, 10 days, and 40 days after the 1st day of sampling, respectively.

rate in the beach areas per day. It's worth saying that damaged face masks and torn gloves may reach the beach by waves; hence, they were excluded from the abandoned items' daily estimation. According to the results, on the 2nd day of sampling, 350 undamaged PPE items (250 face masks and 100 gloves) were found in the coastal areas of Busher port (mean 28.0 ± 25.2 masks and 11.6 ± 12.4 gloves per station-day). Hence, the daily and annual disposal rates of PPE items in Bushehr port's coastlines are 350 and 127,750 items, respectively (assuming stable conditions). Moreover, the disposal rate of masks and gloves in each station is approximately 28 and 12 items per day and 10,000 and 4500 items per year, respectively. Hence, incorrect disposal of PPE during the pandemic can cause an environmental crisis.

3.3. *Secondary MPs' creation*

Large discarded plastic items might generate secondary MPs by photo and mechanical degradation processes and impact wildlife and the ecosystem. Under ambient conditions, the degradation could happen slowly, while in the aquatic environment, the rate of degradation increases and threatening aquatic organisms (Anastopoulos and Pashalidis, 2021). More than 10% of the collected PPE from Bushehr port's coastal areas in each sampling day were damaged (Fig. 6). The gloves were torn, the layers of masks were separate, and in most cases, layers of masks were severely damaged. Water can easily damage the melt-blown fabrics; hence, the surgical masks' structure can damage, and the risk of secondary microfibers generation is increased significantly (Li et al., 2021). Separated masks' layer and the microfibers' deterioration are illustrated in Fig. 6a, b, and c. According to the microscopic analysis results, the left surgical masks in the coastal areas are obviously emerging sources of microfibers in the marine environments. In addition, torn plastic gloves (Fig. 6d) should also be considered as new sources of secondary MP particles (mostly fragments and films) in the coastal areas. The generated MP items can easily suspend from beach surfaces by wind currents and blown into the atmosphere (Akhbarizadeh et al., 2020c; Allen et al., 2019; Enyoh et al., 2019) or make their ways to the sea (Guven et al., 2017; Liu et al., 2020).

Upon entrance to the aquatic environments, the uptake of MPs by organisms could have happened both directly from the surrounding environment and indirectly from their food (Lusher et al., 2013). The ingestion of MPs by aquatic organisms their bioaccumulation, and biomagnification through the food web are well documented (Akhbarizadeh et al., 2019; Avio et al., 2020; Carbery et al., 2018; Diepens et al., 2018; Wang et al., 2019; Welden et al., 2018; Zhang et al., 2019). Although MPs' possible effects on human health are still unknown, their presence in seafood can be consider as an emerging risk (Akhbarizadeh et al., 2020a; Smith et al., 2018). Hence, where the environment is more polluted with plastic particles (such as PPE) and the consumption rate of seafood is high, MPs' human uptake should be more contemplated.

4. Conclusion

During the last year, high usage of single-use plastic PPE to reduce the risk of human-to-human transmission of the COVID-19 viruses and drop them in the environment are among the most critical environmental issues in the world. The presence of PPE along the Bushehr Port's coastal line, the Persian Gulf, was investigated for 40 days (in November and December 2020) during the pandemic. The results showed high levels of left PPE items in the study area. In addition, our results demonstrate the differences in the spatial distribution of PPE debris among different sampling stations, and the highest number of disposal PPE were found in crowded stations with recreational activities. Considering the fact that the Persian Gulf is a semi-enclosed basin, these plastic particles may endanger the wildlife and ecosystem for a long time. A detailed investigation with naked eyes and microscope confirmed the high potential of left PPE in the beaches to break down and create secondary microplastics at least in 1 year. Hence, not only the discarded large facemasks and gloves but also their derived MPs are increased during the pandemic and may threaten the aquatic organisms and human (as a top predator of seafood) for many years. Reducing and addressing the problem of left plastic PPE items requires collaboration between natural and social scientists, policymakers, and waste managers on both national and international levels. The most important keys to reducing single-use PPE waste are replacing them with reusable non-plastic ones, mandatory regulation, and environmental awareness to control their leakages into the environment, especially water bodies during and after the pandemic. In addition, long-term programs are needed to shift people's behavior and encourage sustainable actions that could prevent incorrect disposal of debris (i.e., plastic items, cigarette butts, PPE items, etc.) in the future.

Author contribution

Razegheh Akhbarizadeh: Conceptualization, Methodology, Writing-original draft and revision, Software.

Sina Dobaradaran: Supervision, Conceptualization, Methodology, Writing-Review and Editing, Project administration.

Iraj Nabipour: Writing-Review and editing.

Mahbubeh Tangestani: Sampling, Sample's preparation.

Delaram Abedi: Sampling, Sample's preparation.

Fatemeh Javanfekr: Sampling, Sample's preparation.

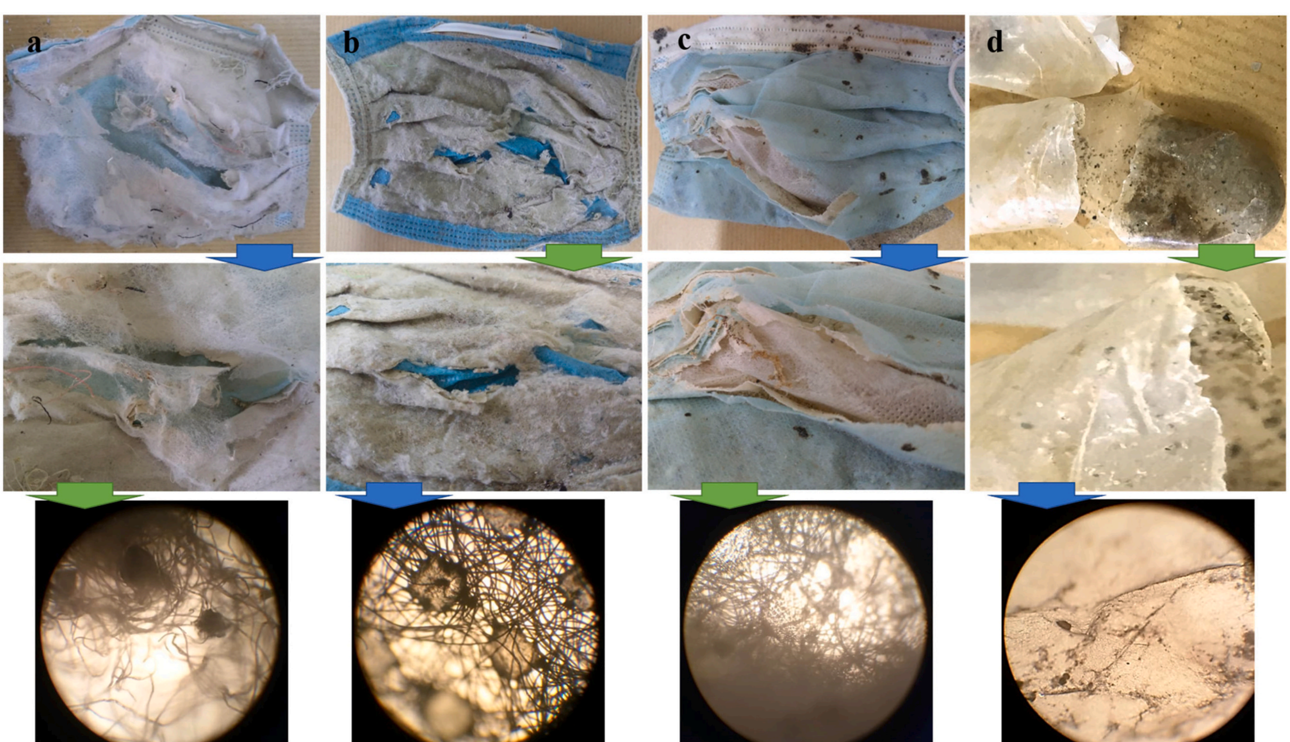

Fig. 6. Dameged masks and gloves from coastal areas of Bushehr port by naked eyes, and binocular microscope.

Faezeh Jeddi: Sampling, Sample's preparation.
Atefeh Zendehboodi: Sampling, Sample's preparation.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2021.112386.

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