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Research article

Marine litter along the shores of the Persian Gulf, Iran

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ABSTRACT

Plastic wastes —including cigarette butts (CBs)— are dangerous for marine ecosystems not only because they contain hazardous chemicals but also because they can finally turn into micro- or even nano-particles that may be ingested by micro- and macro-fauna. Even large pieces of plastics can trap animals. In this research, the pollution status of macroplastics (abundance, size, type, and colour) and cigarette butts (CBs, number/m^2) on the northern coasts of the Persian Gulf has been investigated. A total of 19 stations were explored in Bushehr province (Iran), which covers a length equivalent to 160 km of the Persian Gulf coastline. Among the collected plastic waste (2992 items), disposable mugs were the most frequent (18 %). Plastics with sizes 5–15 cm were the most abundant, and the most common type of plastic was PET (*P*-value <0.05). The origin of most macroplastics was domestic (2269 items). According to the Index of Clean Coasts (ICC), most surveyed beaches were extremely dirty. The average number and density of CBs in this study were 220 and 2.45 items/m^2, respectively. Household litter was the most abundant type of waste in the studied beaches, and this problem can be better managed by training and improving the waste disposal culture. In general, it is suggested that an integrated and enhanced management for fishing, sewage and surface water disposal, and sandy recreational beaches be implemented in Bushehr to control plastic waste.

1. Introduction

Nowadays, plastic pollution is a concern for scientists, engineers, managers, and the public. The risks of plastics to human life and ecosystem function are significant [1,2]. Global generation of petroleum-based synthetic plastics has increased drastically from 2 to >400 million tons since the 1950s [3]. It is approximated that in 2050, an additional 33 billion tons of plastic will be added to our planet [4]. Plastic pollution and its adverse effects due to poor waste management are increasing annually and have become a global concern [5,6]. Recently, in a study conducted on ocean debris showed that the plastics in the ocean make up only 4.7 % of the plastic waste produced by mismanagement from the 1960s until now [7]. In the life cycle of plastics, their entry into the environment [8] and marine [9] is regular. They may enter the oceans in different ways [10], like from materials utilized in the fishing industry (fishing

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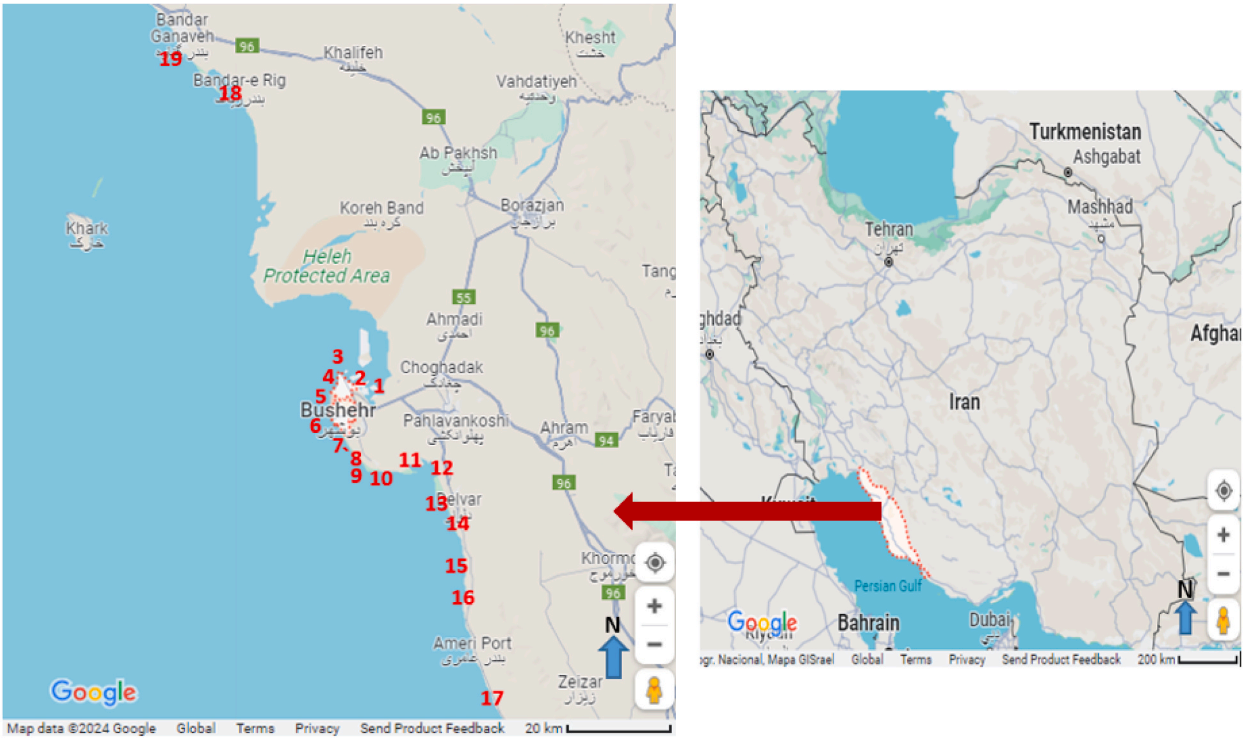

Fig. 1. Map of the study area (pictures were obtained from Google Maps) showing the sampling stations scattered along the shores of Bushehr Province, Iran.

gear, rope, or artificial packaging) [11] and discharge of wastewater to the water bodies [12].

Plastics are divided into different sizes (nano, micro, meso, and macro) with methodological limitations that determine the borderlines [13]. Plastics >5 mm are usually called macroplastics [14,15]. Macroplastics are continually transformed into microplastics by physical degradation, such as fragmentation and degradation by the sun's ultraviolet rays and other processes [16–18]. Plastic particles provide an absorption area for organic contaminants [19–21] and pathogens [22]. These wastes are usually contaminated with chemical compounds like phthalates and heavy metals [23,24]. Plastics in the environment may be categorized based on shapes, colours, potential source, and size. Macroplastics negatively affect animals, aquatic life, land, and vegetation and increase urban flooding due to the clogging of waterways and sewers [25–27]. In a study on the state of macroplastic degradation, it was concluded that fragmentation, stranding, and resuspension are important processes in the dynamics of floating plastic in Mediterranean surface waters [28].

Macroplastics and microplastics can accumulate on sandy beaches around the world for reasons such as tourism, fishing, swimming, maritime traffic, and waterborne aquatic sports [29–31]. Sea coasts, the most critical areas where land-based plastic waste reaches coastal waters, face increasing impacts of human activities and natural tidal changes [32–34]. Global monitoring of coastal plastic waste plays a vital role in establishing plastic wastes quantity, composition, and sources [35–37]. Recently, the distribution of macroplastics in the Santa Ana River, California, was investigated by measuring the river flux at different discharges, and the results showed that the number of macroplastics increased with increasing small discharges [38]. Plastic pollution has many negative effects on the environment, which have been listed in the studies [39–43]. Plastic particles may be mistaken for natural prey and ingested by organisms, which might lead to reduced food intake and overall fitness [44,45]. These chemicals may accumulate in the food web through ingestion [18,46]. However, at different trophic levels, its consequences for food webs are still not completely known [47]. The risks of ingested micro- and macro-plastics are also growing [48–50]. In addition, consumption of macroplastics by sea birds, fishes, and even marine animals has been reported [18,51,52]. It is estimated that 100,000 marine mammals die annually from entanglement in plastics [52]. Therefore, it is essential to study the presence of macroplastics to plan and manage them.

Along with plastics, cigarette butts (CBs) have also been found on beaches and extensively investigated around the world [35,53]. CBs consist of cellulose acetate. Toxicological investigations have revealed that refined natural microparticles, such as cellulose fibers used in textiles, personal care products, and cigarette filters, are harmful to animals and plants [54,55]. Greater than 4 trillion CBs are improperly disposed of in natural and urban environments [56,57]. These wastes contain 4000 chemical materials [58,59]. Studies have shown that fresh CBs can release a large amount of aromatic amines into the water, soil, and air [60]. CBs have lethal effects on aquatic organisms [61]. The presence of cigarette butts on sandy beaches releases chemical compounds into the water, which requires further study.

Many studies have been conducted regarding the pollution of plastics and CBs in the Persian Gulf sediments [62–65], which have

Fig. 2. An example of the transect used for collecting plastics and CBs in the sandy beaches around Bushehr city, Iran.

provided important data. Most of these studies have been done in seawater, sediments, and beaches without focusing on a specific type of beach. Sandy beaches are very important in the active ecosystems of the Persian Gulf, as these places host migratory birds and turtle spawning [66]. Bushehr province (southern Iran) was chosen to investigate the pollution load of CBs and plastics due to its activity in the commercial, fishing, industrial, and tourist sectors [40] and containing sensitive sandy beaches. Therefore, investigating the number of macroplastics and CBs in such environments is very important for researchers, policymakers, different governments, and coastal users. The abundance, colour, type, and source of macroplastics and the abundance of CBs were investigated. The level of cleanliness of different stations was compared using the index of clean coast (ICC). The type of macroplastics (polyethylene, polypropylene, polyethylene terephthalate, high-density polyethylene, low-density polyethylene, polystyrene, and cellulose fibre) has also been determined for all studied beaches.

2. Methods

2.1. Study area

The sampling stations were located on the northern shores of the Persian Gulf in Bushehr province, Iran. The population of the province increases seasonally, and the number of visitors to this area usually reaches 5 million people per year [67,68]. On the shores of the Persian Gulf in Bushehr province, there are activities such as marine import and export, fishing, agriculture, and oil and gas industries, which have created a great potential for pollution [69]. The investigated area has a hot summer and tropical climate with high evaporation. The average annual rainfall of Bushehr province is about 220 mm [67].

2.2. Sampling campaign and analysis

This study was carried out in the fall and winter over four months, from October 26th, 2022, to February 24th, 2023, on Bushehr province, Iran's sandy and rocky beaches. The stations and their specifications are shown in Fig. 1 and Table S1. The total number of stations was 19 and the distance from the first station to the last one was about 160 km. The minimum distance between the stations was 300 m. Due to the high density of parks, promenades, and fishing and boating places, the number of stations was chosen more in Bushehr city. In the studies, the area of the transects has been chosen differently [53,70]. In our study, all transects were considered 90 m^2 (30 m × 3 m) (see Fig. 2). To select the transect, one side was chosen parallel to the shore and at a distance of about 1 m from the high tide level, and then the boundaries of the other side were determined. Only one transect was investigated in each station. Visible surface plastics and CBs and those that were partially buried were collected, and no efforts were made to find fully buried ones. Examples of collected plastics and CBs are shown in Fig. 3. It is necessary to explain that cigarette butts were collected exactly at the same stations (and transects) where macroplastics were collected. In other words, the collection of CBs and macroplastics happened simultaneously. For cigarette butts, only their number was counted in each transect.

A checklist was prepared to list the characteristics of stations and macroplastics. In each station, plastic waste was first collected on a flat surface as a kind of examination table (Fig. 4). Then, the pieces of plastic were counted and categorized into two groups of soft (dishes, juice boxes, bottles, bags, mugs, cutlery, straws, cigarette boxes, pampers, masks, gloves, tissues, nets, ropes, others) and hard

Fig. 3. Examples of macroplastics collected on different beaches north of the Persian Gulf.

plastics (bottle caps, cassette tape boxes, etc.) [15], and also classified in terms of colour (red, white, blue, black, purple, orange, yellow, green), size (1–5 cm, 5–15 cm, 15–30 cm, and >30 cm), and type [38] (Table S1). The materials of macroplastics were determined based on the classification given in the literature [71,72]. Eight types of macroplastics (polyethylene, polypropylene, polyethylene terephthalate, high-density polyethylene, low-density polyethylene, polystyrene, cellulose fibre, and others) were assessed in this work. The waste was divided as follows: bottles (polyethylene terephthalate), cutlery, cups, plates (polystyrene), food boxes (polystyrene), bottle caps, containers, and hard items (high-density polyethylene), bags (low-density polyethylene), tissue (cellulose fibre), and other plastics.

The type of beach substrate (sandy, gravel, rocky, and stone) and the activity around the stations (the presence of hotels, parks, fishing or fish shops, etc.) were explored. On some beaches, the entry of household sewage into the sea and the accumulation of macroplastics were observed (Fig. S1).

In this study, the density of macroplastic waste (DMW) per square meter was computed using the following formula (Eq. 1):

$$DMW = \frac{n}{W \times L} \tag{1}$$

where n is the number of macroplastic items and W and L are the width and length of the station. It should be noted that 'number per square meter' was also used to analyze cigarette butts. The Index of Clean Coasts (ICC) was evaluated according to Eq. (2):

$$ICC = DMW \times K \tag{2}$$

The K factor is a constant and is considered 20 to make the results clearer for the public and for better interpretation of the data [73,

Fig. 4. Collecting macroplastics in a transect on a flat surface (as an examination table) to count their number, colour, size, and type.

74]. According to ICC, beaches can be classified from "very clean" to "extremely dirty" (Table S2), [70].

The gathered data were analyzed using the SPSS (version 23) software package. A statistical test of Shapiro-Wilk was utilized to confirm that the data were not normally distributed. The amount of statistical difference in abundance (in different stations), type, and colour of macroplastics were estimated using a Kolmogorov-Smirnov (K–S) test. A *P*-value less than 0.05 was considered a significance threshold.

3. Results and discussion

3.1. Top items

An area of 1710 m^2 was examined for all sampled beaches. The total number of macroplastics and cigarette butts in each station is shown in Fig. 5a. The total number of macroplastic was 2992 items (range: 15–579 items). The most significant number of macroplastics was 579 items and 313 items in the Sadaf Park and Jofreh stations, respectively. Because these two stations are closer than others to the densely populated centers of Bushehr city and they are more visited. The number of macroplastics found in these two stations was significantly higher than in other stations and the average (*P*-value <0.05, mean: 157). Among the collected macroplastics, Sadaf Park, Jalali, and TV Park were the most diverse stations. The least varied stations were Amery Port, Delvar A, and Marjan Park. The highest frequency and average macroplastics in most places related to mugs (545 pieces). After mugs, other dominant items included bags with a frequency of 65 (average: 25), bottles with a frequency of 380 (average: 20), and other macroplastics with a frequency of 394 (average: 20.74) (Fig. 5b). Sandy beaches are vulnerable to plastic pollution [75]. In recent decades, monitoring studies related to marine debris have expanded showing that plastic items are greater than 70 % of all waste [76]. On the other hand, the global monitoring of beach plastic waste plays a vital role in its quantity, composition, and sources [35,36]. As stated above, one of the most abundant plastic components in most of the investigated beaches in this study was "single-use" plastic cups, which needs to be considered to reduce them. Many countries worldwide have successfully implemented plans to ban single-use plastic bags. Other strategies to decrease single-use plastics include forbidding the use of plastic drinking straws, deposit schemes, and returning plastic bottles [77].

According to Fig. 6a, among all collected macroplastics, mugs (18 %), bags (16 %), and bottle caps (13 %) had the highest frequency ratio. Caps/lids, bottles, containers, drums, and crisp/sweet packets were most frequently found items on the coastline of Bandar Abbas (Iran) [62]. In a study in the Philippines, the collected plastic waste mainly consisted of food packaging, plastic bags, plastic parts, napkins and diapers, and toiletries, which accounted for more than 50 % of the gathered plastic waste [78]. Therefore, according to the type of these macroplastics, their origin was probably domestic and commercial.

3.2. Macroplastic colour

Based on Fig. 6b, the result reveals that the most significant colour observed was white with a frequency of 47 % (*P*-value <0.05), which is the predominance of white colour in agreement with other studies [79,80]. Macroplastics with purple colour had the lowest frequency percentage (2 %). Macroplastics eventually turn into coloured microplastics, which, due to their resemblance to natural

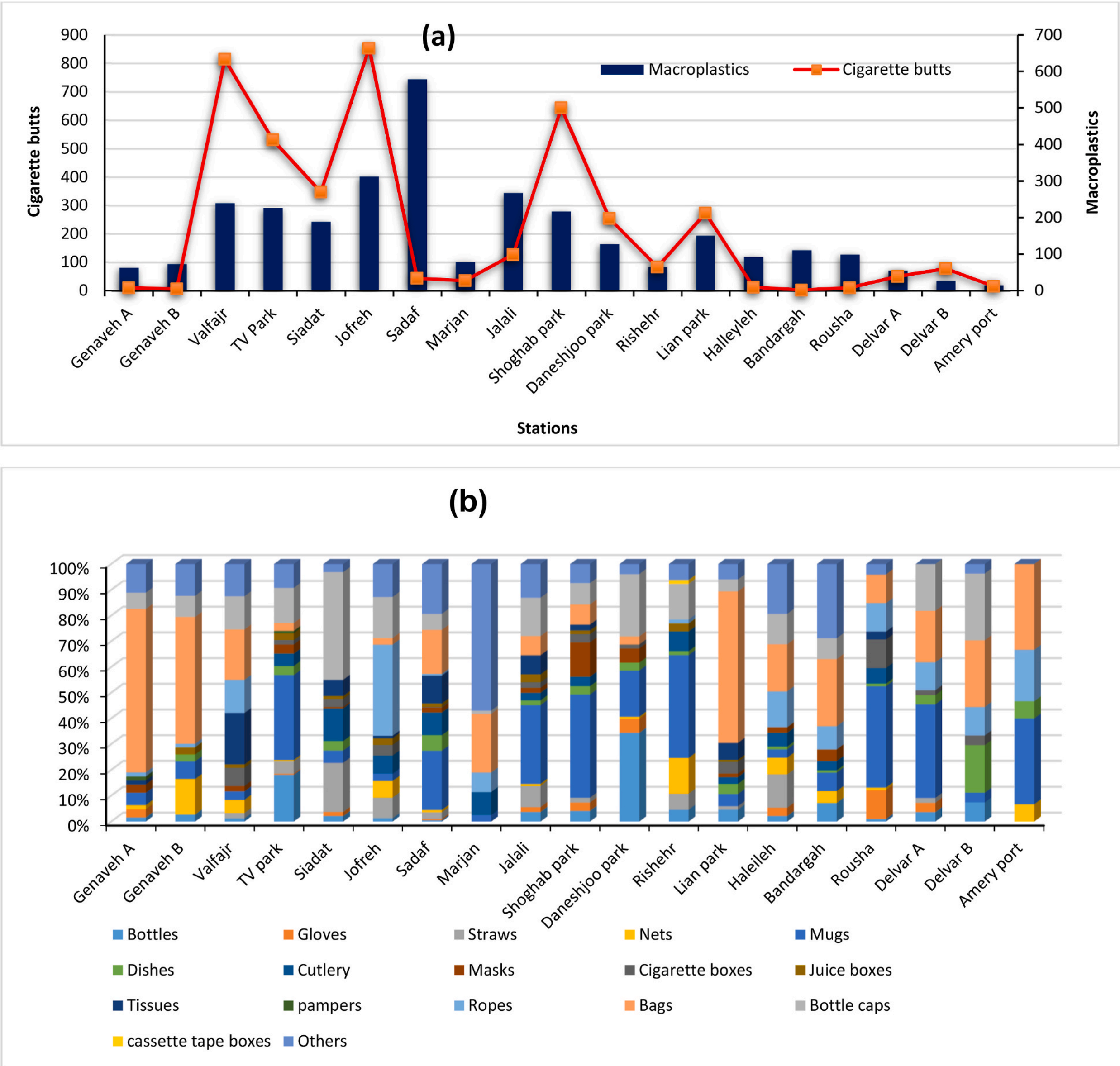

Fig. 5. (a) The total number of macroplastics and cigarette butts and (b) the abundance of macroplastics in each studied station on the beaches of the Persian Gulf (Bushehr, Iran).

prey, may be mistaken for food by living organisms [44]. Also, pollutants released from plastics can increase their health and environmental effects [81].

3.3. Macroplastic size

The outcomes of the assessment of the macroplastics size are listed in Table 1. Based on this table, the size of macroplastics in the range of 5–15 cm had the highest number per square meter (0.178 number/m^2) and was significantly higher than other studied sizes (*P*-value <0.05). In the Lebreton et al. (2023) study more than 75 % of plastic materials with a size > 5 cm [82]. Shredding of plastics into smaller plastic pieces can occur due to physical phenomena (sunlight, sea waves, etc.). The tiniest size of plastic in this work was >30 cm, with a 0.038 number/m^2. There was almost no relationship between the abundance of plastics and different sizes [83]. Small pieces of plastic may be buried on sandy beaches by people’s footsteps on the beach or may have moved to another place due to wind currents before the researcher’s visit. Therefore, the number of small-sized plastics (1–5 cm) on sandy beaches has been low.

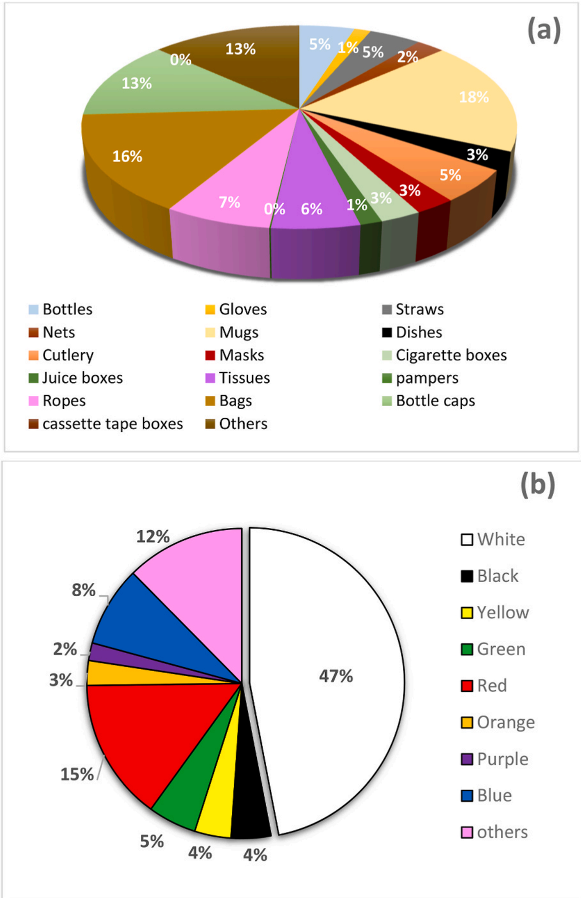

Fig. 6. The frequency percentage of (a) macroplastics and (b) the colours of macroplactics in all studied beaches in the north of the Persian Gulf (Bushehr, Iran).

Table 1
Size, range, abundance, and density of macroplastics collected in all transects in the northern part of the Persian Gulf (Bushehr, Iran).

Size	Range	Abundance	Mean	Number per m^2
1–5 cm	1–118	117.04	6.16	0.0684
5–15 cm	5–310	304.95	16.05	0.1783
15–30 cm	5–120	114.95	6.05	0.0672
>30 cm	3–68	64.98	3.42	0.0380

3.4. Macroplastics source and type

The specifications of plastics in terms of type of source, abundance, and number of each type are listed in Table 2. The types of plastics observed included PET (polyethylene), HDPE (high-density polyethylene), PS (polystyrene), LDPE (low-density polyethylene), PP (polypropylene), and cellulose fibre (tissues). The most abundant type of plastic was PET with a number of 737 items, which was significantly higher than other types (P-value <0.05). PET is used to make many types of bottles and mugs. This finding is consistent with those obtained in the sediments of the Caspian coast [84], Australia [85], and Qatar [86]. The second rank was related to LDPE, with 584 items. LDPE is usually used for making plastic such as bags and nylons. One of the reasons for the high frequency of PE, in this study, is that it is used for packaging and disposable plastic materials, such as bottles, mugs, and dishes. According to Table 2, the lowest amount is related to tissues with 165 items. The widest range of collected macroplastics (1–137 items) corresponded to mugs with a frequency of 77 items, and the lowest was linked to cassette tape boxes (0–1 item) with a frequency of 1 item. Most of the soft plastics are in the range of 11–504 items, except bottle caps and cassette tape boxes, which are hard macroplastics.

According to the studies carried out on the northern shores of the Persian Gulf, household macroplastics have the highest amount of 2269 items (mugs, cutlery, bags, juice boxes, straws, etc.), 454 items of them are sanitary (masks, pampers, tissues, etc.), and 269 items of them were related to fishing equipment (fishing nets and ropes). Pe and colleagues (2020) also showed that most plastic waste is

Table 2
Classification of collected macroplastics based on the source, type, range, and abundance of each component in the northern beaches of the Persian Gulf (Bushehr, Iran).

Source	Plastic articles	Range	Abundance	Type	Soft/hard
Household	Dishes	0–35	86	PET/Ps-E	Soft
	Juice box	0–8	42	LDPE	Soft
	Bottles	0–44	146	PET	Soft
	Bottle caps	0–79	380	HDPE	Hard
	Bags	0–99	465	LDPE	Soft
	Mug	1–137	545	PET	Soft
	Cutlery	0–51	155	PS	Soft
	Straws	0–36	137	PP	Soft
	Cigarette boxes	0–17	77	LDPE	Soft
	Cassette tape boxes	0–1	1	HDPE	Hard
Sanitary	Pampers	0–2	3	PET	Soft
	Masks	0–29	77	PP	Soft
	Gloves	0–11	44	HDPE	Soft
	Tissues	0–63	165	Cellulose fibre	Soft
Fishing	Nets	0–20	74	PS	Soft
	Ropes	0–111	201	PP	Soft
Others	Others	0–112	394	–	Soft/Hard

Table 3
The index of clean coasts (ICC) based on the macroplastics for studied beaches on the northern part of the Persian Gulf (Bushehr, Iran).

Station name	ICC	Results	Reference
Genaveh A	14	Dirty	This work
Genaveh B	16.22	Dirty	This work
Valfajr	53.33	Extremely dirty	This work
TV Park	50.44	Extremely dirty	This work
Siadat Park	42	Extremely dirty	This work
Jofreh	69.6	Extremely dirty	This work
Sadaf Park	128.66	Extremely dirty	This work
Marjan Park	17.55	Dirty	This work
Jalali Park	59.56	Extremely dirty	This work
Shohgab Park	48.22	Extremely dirty	This work
Daneshjoo Park	28.44	Extremely dirty	This work
Rishehr	14.44	Dirty	This work
Lian Park	33.56	Extremely dirty	This work
Halleyleh	20.6	Extremely dirty	This work
Bandargah	24.67	Extremely dirty	This work
Rousha	22	Extremely dirty	This work
Delvar A	12.22	Dirty	This work
Delvar B	6	Moderate	This work
Ameri Port	3.33	Clean	This work
Nha Trang, Viet Nam	39–791	Extremely dirty	[70]
Mediterranean Sea, Turkey	–	Dirty	[92]
Indian coast	0-35 (in 2019) 0.2–30 (in 2021)	Very clean- extremely dirty	[93]
Kanyakumari, Southern India	23.17–32.3	Extremely dirty	[94]
Caribbean and Pacific Coasts	–	Very clean- extremely dirty	[95]

related to household sources [87]. However, in another study, fishing and aquaculture were a source of the highest percentage of waste in Vietnam [70], which does not match the results of the present work. A possible explanation is that there is less fishing on the shores of Bushehr, and most fishermen go to the sea to fish [88]. Pedrotti et al. (2022) found a significant relationship between pollution sources and areas with high plastic concentrations [28]. Identifying the source of waste is required to design mitigation measures for plastic release into marine environments [89].

3.5. The index of clean coasts (ICC)

There is no standard method for reporting the abundance of plastic in the world [70]. However, according to ICC results in Table 3, in this research, there were 12 very dirty stations (Valfajr, TV Park, Siadat, Jofreh, Sadaf, Jalali, Shoghab and Daneshjoo Park, Lian Park, Halleyleh, Bandargah, Rousha stations), five dirty beaches (Genaveh A, Genaveh B, Marjan, Rishehr, Delvar A stations), one moderate polluted beach (Delvar B station), and one clean beach (Ameri Port station). There was no very clean station in our study. Dirty beaches were mainly used for recreation, and the surrounding areas held restaurants, hotels, canoeing, entertainment, *etc*. The primary sources of coastal litter are the public and the fishing industry [89]. Similar results in recent studies showed that most coastal

Table 4
Comparing the density of cigarette butts found in studied beaches in the world with the findings of this work.

Country	Cigarette butts (number/m^2)	Reference
Iran (2023)	2.45	This work
Thailand	2.26	[98]
Iran (2018)	2–38	[99]
Morocco	0.06	[57]
Spain	0.038	[29]
Latin America	0.6–0.10	[100]
Brazil	8.85	[56]
Germany/Lithuania	0.00–0.7	[101]

wastes are related to recreational and tourism activities [76,90]. Plastic pieces, cigarette butts, bottles, *etc.,* are discarded on the same beach after activities such as eating, drinking, and smoking [91]. Only one station was clean (Ameri Port station), which was used for fishing, and less household waste was observed there. The cleanliness of the beaches investigated in this research is compared with other studies in the world based on the ICC index (Table 3). As seen in this table, similar to the current work, most studies have reported from clean to very dirty for this indicator.

3.6. Cigarette butts

The results related to the number of cigarette butts in each station are presented in Fig. 5a. The amount of 4190 pieces of CBs was observed in all studied beaches combined. The highest number was related to Jofareh Beach, with 853 pieces, and Valfajr Beach, with 814 pieces, and the lowest number of cigarette butts was related to Bandargah Beach (2 pieces). The number of cigarette butts in Jofareh Beach and Valfajr Beach stations was significantly different from the average of all stations (mean: 220) and the CBs number in other stations (P-value <0.05). These two beaches are close to relatively busy areas and have different uses. Therefore, frequent visits to these beaches can be one of the main causes of being more contaminated by cigarette butts. Also, the beaches that have less population and are far from the city (like Bandargah, Genaveh A, Genaveh B, and Rusha) have fewer cigarette butts. These cases are consistent with another study in Iran, which showed that the number of CBs in each station differs depending on the activity type [91]. The average is 220 CBs per station and 2.45 CBs/m^2 were found in 19 investigated beaches. The data presented in this study have shown that cigarette butts are found as significant waste. A similar report has been presented for cigarette butts in Moroccan beaches in 2017 [96]. The density of cigarette butts on different coasts of the world is compared in Table 4. Various amounts of CBs have been reported per square meter of beach. Depending on the education of the environmental culture, the presence of trash bins, the use of the surrounding area, and the laws related to this issue, the amount of cigarette density varies [97].

4. Conclusions

In this research, the contamination of the northern shores of the Persian Gulf (Bushehr, Iran) with macroplastics and cigarette butts (CBs) was concurrently examined. Widespread pollution of cigarette butts and macroplastics was proven in all stations (a total of 1710 m^2 of beaches). Among collected plastics, the most dominant colour was white (47 %), and the lowest one was purple (2 %). The variety of colours of plastics indicates that their source is different. The highest frequency of macroplastic was related to disposable cups. The most abundant type of macroplastics was PET (737 items), related to disposable cups and plastic bottles. In terms of plastic and cigarette butts, the cleanest stations were related to fishing, and the dirtiest had recreational use. Considering that the sources of plastics were the fishing, domestic, and tourism industry, it is necessary to increase the inter-sectoral cooperation of government, private, and non-governmental organizations to reduce pollution. Educating citizens, encouraging voluntary action, facilitating CBs and plastic collection, and enforcing laws can be helpful. Monitoring and planned cleaning of beaches can also be effective in reducing pollution.

CRediT authorship contribution statement

Zahra Jokar: Writing – original draft, Formal analysis. **Nafiseh Banavi:** Writing – original draft, Formal analysis. **Sara Taghizadehfard:** Writing – original draft, Formal analysis. **Fatemeh Hassani:** Writing – original draft, Formal analysis. **Rezvan Solimani:** Writing – original draft, Formal analysis. **Nahid Azarpira:** Writing – original draft, Formal analysis. **Hanieh Dehghani:** Writing – original draft, Formal analysis. **Atefeh Dezhgahi:** Writing – original draft, Formal analysis. **Ali Mohammad Sanati:** Methodology, Investigation. **Sima Farjadfard:** Methodology, Investigation. **Bahman Ramavandi:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30853.

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