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RESEARCH ARTICLE

Assessing the relationship between the abundance of microplastics in sediments, surface waters, and fish in the Iran southern shores

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Abstract
The purpose of this study was to investigate the microplastic (MP) pollution in sediments, surface waters, and four fish species in the northern coast of the Persian Gulf. Sampling was conducted in seven important regions during December 2019. The abundance of MPs was respectively 190 ± 35.5 items/kg dry weight for sediments, 9.28 ± 2.1 items/km^2 for surface waters, and 0.33 ± 0.05 items/individual for fish. There was no correlation between MP abundance in surface water, sediment, and fish samples. Except for *Cynoglossus arel*, abundance of isolated MPs did not show significant relationships with body weight, body length, and gastrointestinal tract weight ($P > 0.05$). MPs were ranged from 0.3 to 5 mm in size and were prevailed by fiber in shape; black, red, and blue in color; and polypropylene and polyethylene in polymer. This study may help in increasing our knowledge regarding MP pollution in marine water systems and biota.

Keywords Microplastics · Sediments · Surface waters · Fish · Polymer · Persian Gulf

Introduction

Microplastic (MP) pollution exists in all aquatic ecosystems of the world. MPs are considered a permanent threat since they are found in different marine animal species including zooplankton (Cole et al. 2011), birds (Van Franeker et al. 2011), sea turtles (Tourinho et al. 2010), marine mammals (Besseling et al. 2015), and fish (e.g., Romeo et al. 2015; Güven et al. 2017; Arias et al. 2019; Rasta et al. 2021). These small particles can enter the environment directly (primary MPs) or following the decomposition of larger plastics (secondary MPs) (Carr et al. 2016; Auta et al. 2017). Due to the high stability, it is difficult to remove MPs from the environment, especially in marine ecosystems, and it increases the worldwide concerns about these particles.

In the last few decades, a large number of MPs have been detected in the sediments, water columns, and water surface of marine environments (Cole et al. 2011; Eriksen et al. 2013; do Sul and Costa 2014; Auta et al. 2017; Rasta et al. 2020). Moreover, MP particles were reported in the gastrointestinal (GI) tract of many species of marine fish (e.g., Rochman et al. 2015; Neves et al. 2015; Ferreira et al. 2016), which are among the largest and most diverse groups of animals of high biological and economic importance. In fact, particles can be taken up from the sediments and water column by marine organisms. Besides, when the particles are consumed by various organisms, they can penetrate the food web and may result in bioaccumulation followed by possible negative effects on marine creatures (Kashiwada 2006; Akdogan and Guven 2019).

The risks associated with plastic particles are included: physical effects of materials (von Moos et al. 2012; Rochman et al. 2013), chemical compounds of plastics and chemicals adsorbed from the environment (Hirai et al. 2011) (e.g., stable bioaccumulation and toxic substances PBTs) (Holmes et al. 2012), and metals (Hosseini et al. 2020). Intestinal

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obstruction, inhibition of gastric secretion, reduction of nutritional stimuli, reduction of steroid hormone levels, delayed ovulation, and lack of successful reproduction are the physiological effects of MPs on marine creatures (Auta et al. 2017; Hermabessiere et al. 2017). On the other hand, Wang et al. (2019) examined the effects of MP exposure on parental fish of marine medaka and reported MP accumulation in their liver, intestine, and gill, along with causing oxidative stress and histological changes. They also reported parental exposure to MP postponed incubation time and decreased the hatching rate. Moreover, consumption of polystyrene also changes the behavior of fish and disrupts the fat metabolism of freshwater fish (Pedà et al. 2016). Other studies also reported that ingestion of MP particles such as PE, PP, and PS by fish larva leads to death, decreasing head/body ratios, DNA breaking, and changing to swimming behavior (Pannetier et al. 2020), and exposure to PVC MPs caused inhibition of weight increase and growth, changing antioxidant-related gene expression in the livers (Xia et al. 2020).

The Persian Gulf is a waterway along the Oman Sea and the third largest gulf in the world. It has access to open sea from the east through the Strait of Hormuz and the Oman Sea and ends in the Arvand Rud delta (Arvand River) from the west (Taghizade et al. 2012; Bibak et al. 2021). This waterway is considered as an important and strategic region at the international level because of its abundant oil and gas resources. whereas oil-related activities, untreated urban discharges, and industrial sewages impose high pollution pressure on the fauna and flora of the Gulf (Hosseini et al. 2015). Recently, different studies have been reported the MP pollution in the sediments, surface waters, and biota of the Persian Gulf (Naji et al. 2017; Akhbarizadeh et al. 2018; Naji et al. 2019, Nabizadeh et al. 2019), although there is no study on the relationship between MP pollution in the Gulf aquatic environments and fauna in a single study to date, reflecting the importance of a comprehensive study on MP pollution in the Persian Gulf. Consequently, the aim of this comprehensive study was to investigate the MP pollution in surface waters, sediments, and fish in different areas of the northern coast of the Persian Gulf (coast of Iran) as well their relationship with each other in the sampling areas for the first time.

Materials and methods

Sampling region

Sediments, surface waters, and fish species were sampled in seven sampling stations in December 2019 from the northern shores of the Persian Gulf. The stations are located in three provinces of Khuzestan, Bushehr, and Hormozgan (Fig. 1)

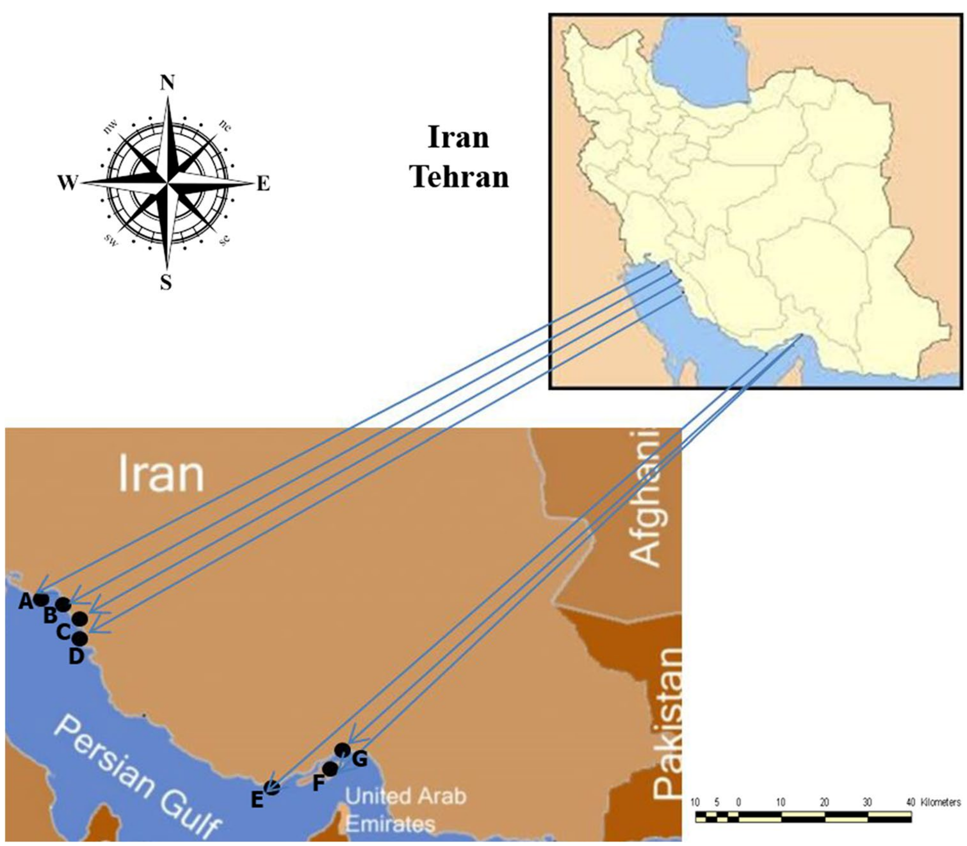


Fig. 1 Sampling region. (A) Hendijan-Khozestan province, (B) Emam Hassan-Bushehr province, (C) Genaveh-Bushehr province, (D) Bushehr-Bushehr province, (E) Lengeh-Hormozgan province, (F) Qeshm-Hormozgan province, and (G) Bandar Abbas-Hormozgan province

and are selected on the basis of environmental characteristics and sources of pollutants. For instance, Hendijan (in Khuzestan province) is affected by fishing ports and residential houses. In Bushehr province, Emam Hassan, Genaveh and Bushehr stations are important commercial areas which are located near fishing and tourist areas and residential buildings. In Hormozgan province, Lengeh port is one of the important fishing and commercial area. Bandar Abbas and Qeshm are not only considered as important fishing and commercial ports, but also essential tourist areas in the southern region of Iran.

Sample collection

Triplicate surface water samples were collected from each site (A to G) at the depth of 3–4 m and about 150–200 m distance of shoreline by a neuston net with an opening diameter of 50 cm, a length of 180 cm, and a mesh size of 50 µm (Thompson et al. 2004). The net was towed for 10 min at a speed of 3 knots on the water surface (depth of ≈ 30 cm) and in the direction of the wind (Free et al. 2014). A flow meter was used to obtain the volume of filtered water through the net. The collected samples in the cod end were washed in glass containers. Next, they were stabilized with 70% isopropyl alcohol to prevent water from putrefaction (Martins and Sobral 2011; Toumi et al. 2019) and transferred to the laboratory at 4 °C.

Sediment samples were collected from a depth of 5 cm at the intertidal zone and also at the same time as water sampling. This sampling was performed using a stainless-steel core with a diameter of 15 cm (Claessens et al. 2011; Löder and Gerdts 2015). Approximately 1-kg sediment of each site was collected and placed in glass containers and packaged with aluminum foil to avoid air contamination. Following the transfer of sediments to the lab, the sediment was kept at 60 °C to dry completely (Nor and Obbard 2014). The temperature is less than the melting point and deformation of polymers, so it is not expected that the shape of the polymers will change.

A total of 280 fish specimens were bought from local fishermen in the Persian Gulf from 4 commercial species (*Otolithes ruber*, *Liza abu*, *Sphyraena forsteri*, and *Cynoglossus arel*) (40 fish per region or in other words, 10 individuals for each species at each sampling station). The target fish are commonly caught by cast net (for *Liza abu*), gill net (for *Otolithes ruber* and *Sphyraena forsteri*), and fish pot (for *Cynoglossus arel*) by local fishermen in the limited location of each sampling station. The fishes were wrapped in aluminum foil and transferred to the laboratory via a cool box (Lusher et al. 2013; Su et al. 2019). In the laboratory, the total length (TL) (cm), total weight (TW) (g), and weight of gastrointestinal tract (*W* of GI tract) were measured (Table 1).

Microplastic extraction

The surface waters and sediment from each station were initially filtered through a metal sieve with a mesh size of 5 mm in order to separate large plastic pieces. Afterward, the filtrates were subjected to 30% hydrogen peroxide oxidation (20 mL) in the presence of aqueous 0.05 M Fe (II) solution (20 mL) as a catalyst to digest unstable organic matter at 60 °C (Free et al. 2014). Hydrogen peroxide was added until no more natural organic material can be seen. For extraction of sediments, 100 g of dry sediment was added to a glass flask. Then, 800 mL of saline solution (NaCl; 1.2 g cm^{-3}) was added to a glass flask and shaken for 5 min by hand (Graca et al. 2017; Toumi et al. 2019). After about 1-h settlement, the supernatant was filtered on a 5-µm Whatman cellulose nitrate filter to preserve MPs. The filter papers were washed with ionized water for removing the salt and finally were dried at 60 °C. The procedure was repeated thrice for every sediment sample. For surface water MPs were also separated by NaCl 1.2 g cm^{-3} and analyzed. It is considered that NaCl solution cannot separate MPs with high density (Van Cauwenberghe et al. 2015; Quinn et al. 2017), although recent studies have been indicated that density separation with NaCl solution probably allows separation of fibers regardless of their density (Graca et al. 2017; Rasta et al. 2020).

For fish species, the GI tract of each individual was transferred to a 250-mL glass jar and then 10% potassium hydroxide solution (KOH) was added into the glass jar (Rochman et al. 2015). Recent studies have recognized 10% KOH as the most suitable solution for the digestion of intestinal contents of fish (Karami et al. 2017). The added solution was at least three times the volume of biological material. The samples were incubated within 5 days to ensure the entire

Table 1 The biometric of all of the species fish (mean ± *SD*), total length (TL), total weight (TW), and *W* of GI tract (the weight of gastrointestinal tract)

Species	Number	TL (cm), mean ± *SD*	TW (g), mean ± *SD*	W of GI tract (g), mean ± *SD*
O. ruber	70	29.5 ± 1.3	255.8 ± 24.5	24.7 ± 0.7
L. abu	70	21.6 ± 1.3	123.6 ± 19.5	14.5 ± 4.1
S. forsteri	70	52.8 ± 5.8	589.5 ± 151.7	38.7 ± 13.9
C. arel	70	29.4 ± 2.8	139.2 ± 64.5	3.2 ± 2.0

digestion via the digestive tract at 60 °C (Savoca et al. 2019). Afterward, the residual substance was filtered through 5-μm Whatman paper. The filters were dried in a Petri dish at 60 °C for 24 h (Li et al. 2020).

Identification of microplastics

At the end, the filters were observed under a stereomicroscope ZTX-E with × 40 magnification, and MPs were removed from other components. Several criteria including similar thickness in the length of fibers, identical of colors all over the MPs, and lack of cellular structures on particles were applied for visual observation of MP particles (Hidalgo-Ruz et al. 2012). Moreover, we discarded organic matter like wood through testing for hardness via pressure applied by forceps. Particles were counted and classified in different shapes (film, fiber, and fragment) and colors (red, blue, black, yellow, white, green, and purple). In terms of size, MP particles were measured by a calibrated scaled lens (Abidli et al. 2017) and categorized into six classes: 300–500, 500–1000, 1000–2000, 2000–3000, 3000–4000, and 4000–5000 μm. The maximum length of particles was considered for measuring the MPs.

The chemical composition and morphological properties of each MPs were analyzed by scanning electron microscope (SEM; Hitachi SU 3500) and an energy-dispersive X-ray microanalyzer (EDS; Amptek, USA). Besides, in terms of polymer identification, 120 particles (33.61% of all isolated particles) were selected in different shapes, colors, and sizes and validated using ATR-FTIR by a Nicolette Nexus 470 (Thermo Nicolet, USA) connected to the OMNIC Software. The spectral range of each spectrum was in 650–4000 cm^{-1} region, 4 cm^{-1} resolution, and average over 50 scans. Before each test, a background air spectrum was recorded (Qiu et al. 2016). Hummel polymer sample library was used to identify MP polymer in the sample. Spectra matching with ≥ 70% were accepted among the reference substance and sample.

Quality control and quality assurance

To prevent air-borne contamination, nitrile gloves and cotton lab coats were worn in the whole steps of experiments. All apparatuses and work surfaces were rinsed with alcohol 70% before and after using. All solutions were filtered before using to decrease the possibility of contamination. Aluminum foils were used to cover the samples during the experiments. Nine control blanks (three for surface waters, three for sediments, and three for fish) containing pure water were run during the analysis. A total of 8 fibers were detected in the control blanks which final data were corrected by subtracting the blank contamination from particles counted in samples.

Data analysis

One-way ANOVA was used to compare the mean abundance of micro plastics (total of films, fragments, and fibers) of water, sediment, and fish between the stations. The same test was also applied for each fish species. Before ANOVA, normality of the data was examined with the Kolmogorov–Smirnov test. The significance of Pearson's correlation coefficient was tested for the relationships between microplastic abundance for water–sediment, water-fish, and fish-sediment combinations and between microplastic abundance in GI tract and fish size (body length, body weight, and GI tract weight). Excel 2019 and MiniTab 17 were performed to draw graphs, and SPSS 22 was used for the statistical analysis of the data.

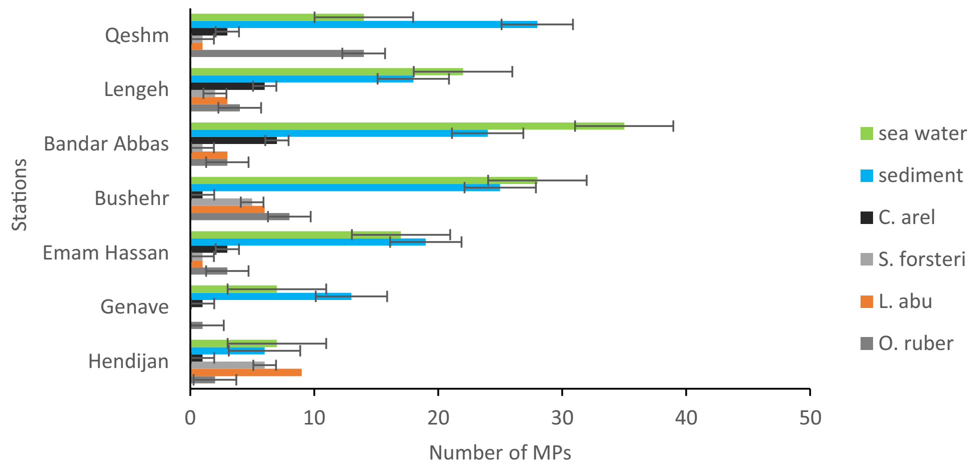
Results

Microplastic abundance in surface waters, sediments, and fish

Generally, MPs were found in all surface water and sediment stations as well as fish species. A total number of 133, 130, and 94 particles were detected in the sediments (mean ± SD = 190 ± 35.5 items/kg dry weight), surface waters (9.28 ± 2.1 items/km^2), and fish (0.33 ± 0.05 items/individual), respectively. The highest abundance of MPs in the surface waters were detected in Bandar Abbas, Bushehr, and Lengeh stations, respectively. There were no significant differences between the different sampling stations, while they were highest in Qeshm, Bushehr, and Bandar Abbas stations in sediment samples. The results of the present study illustrated that 28.5% of fish had MPs in their GI tract, and *Otolithes ruber* (mean ± SD = 0.43 ± 0.12 items/individual), *Liza abu* (0.34 ± 0.09 items/individual), *Cynoglossus arel* (0.33 ± 0.14 items/individual), and *Sphyraena forsteri* (0.24 ± 0.08 items/individual) were the most polluted fish species, respectively. Bushehr, Qeshm, and Hendijan were the most polluted region based on the numbers of MPs in investigated species, respectively (Fig. 2).

Based on Pearson correlation, there was not any correlation between shape, size, color, and number of MPs in surface water-fish, fish-sediment, and sediment-surface water. According to one-way ANOVA analysis, there was no significant relationship between the number of extracted MPs from fish GI tract with MP particles taken from surface water and sediment (P > 0.05). The results of the correlation analysis did not show significant relationships in the abundance of MPs isolated from fish GI tract with body length, body weight, and GI tract weight in *S. forsteri*, *L. abu*, and *O. ruber*, while their abundance in *C. arel* displayed

Fig. 2 The number of MPs per sampling items in different regions (items/kg for sediments, items/km^2 for surface waters, and items/individual for fish GI tract)



significant relationships with body weight, body length, and GI tract weight ($P < 0.05$).

Characterization of microplastics

Fiber was the most prevalent shape in all sampling stations, and those samples were taken from the surface waters (84.71% frequency), sediments (88%), and fish (86.67%). Fragments and films were the next dominant shape in the samples, respectively (Fig. 3A). In terms of color, black, red, and blue were the most common particles in both sediments and surface waters respectively, while blue, black, and red were the most frequent MPs in the fish GI tract, respectively. Other colors such as white, purple, yellow, and green were detected in extracted particles as well (Fig. 3B). MP particles were ranged from 300 to 5000 µm in size. The category 1000–2000 µm was the most common size in the fish (30.85% frequently) and sediment (44.36%) samples, while the class 500–1000 µm with 27.69% was the predominant size in the surface waters.

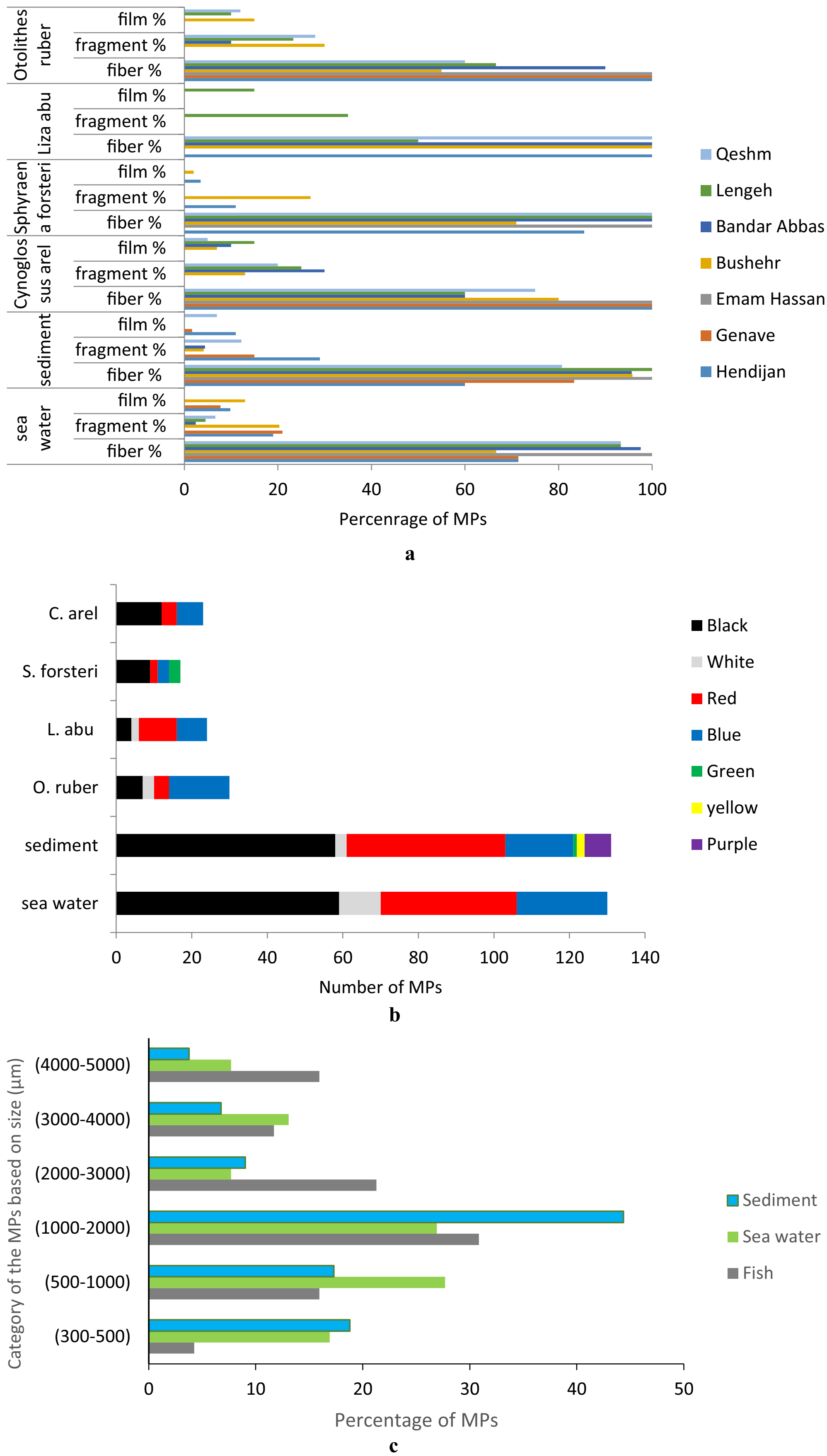
Surficial textural characteristics and chemical composition of the MPs

Figure 4 shows the results obtained from the analysis of the SEM images. Generally, MP particles appeared with different surfaces of non-smooth, smooth, and edged shapes. The fiber MPs were observed as narrow and smooth shapes (Fig. 4B, H). Fragment MPs appeared with non-smooth structures (Fig. 4A, E, F) and irregularly edged shapes (Fig. 4D, G). Film MPs showed an irregularly edged shape with a soft texture (Fig. 4C). The analysis results of X-ray diffraction (EDS) spectroscopy revealed some elements such as carbon (C), oxygen (O), iron (Fe), aluminum (Al), silicon (Si), calcium (Ca), magnesium (Mg), and potassium (K) in the structures of MPs. Carbon and oxygen were the main elements of MPs (Fig. 4). Of the 120 selected particles for validation, 76 particles (63.3%) were confirmed as MPs. As a whole, five different polymers including polypropylene (PP), polystyrene (PS), polyethylene (PE), polyvinyl acetate (PVAC), and polyvinyl propionate (PVPR) were identified using ATR-FTIR spectrometry (Fig. 5). PE was the dominant polymer (43.42%) in the collected MPs. Other identified polymers were included: PP (25%), PS (18.42%), PVAC (6.58%), and PVPR (6.58%) in the identified MPs.

Discussion

This study investigated the occurrence and distribution of microplastics in the sediments, surface waters, and fish of the Persian Gulf, coastal environment of Iran. MPs were detected in all sample stations and fish species. The average number of MPs in the present study was 190 ± 35.5 items/kg dry weight for sediments and 9.28 ± 2.1 items/km^2 for surface waters. There are several studies addressing MP pollution in the sediments and surface waters of the Persian Gulf. Naji et al. (2017) found 307 MP particles with a range of 0 to 125 and mean ± *SD* 61 ± 49 items/kg dry weight of littoral sediments of the Persian Gulf which was lower than the present study, and they considered that fishing activity is a possible source of pollutant. Kor and Mehdinia (2020) reported that all 15 examined stations in the surface waters of the Persian Gulf were contaminated by MPs with a range of 1.5×10^3–4.6×10^4 and a mean of 1.8×10^4 items/km^2 which was much higher than the present study. Merchant ships, fishery, and tourist activities likely are the different sources of MP pollution in the examined stations.

In this study, MPs were detected in all four fish species with a total number of 94 particles. Other studies in the Persian Gulf also reported the MP pollution in the fish tissues and other biotas. For instance, Akhbarizadeh et al. (2018) examined the MPs and toxic element pollution in fish muscles of the Persian Gulf and reported that the



Otolithes ruber
Liza abu
Sphyraena forsteri
Cynoglossus arel
sediment
sea water
film %
fragment %
fiber %
0
20
40
60
80
100
Percenrage of MPs
Qeshm
Lengeh
Bandar Abbas
Bushehr
Emam Hassan
Genave
Hendijan
a
C. arel
S. forsteri
L. abu
O. ruber
sediment
sea water
0
20
40
60
80
100
120
140
Number of MPs
Black
White
Red
Blue
Green
yellow
Purple
b
Category of the MPs based on size (µm)
(4000-5000)
(3000-4000)
(2000-3000)
(1000-2000)
(500-1000)
(300-500)
0
10
20
30
40
50
Percentage of MPs
Sediment
Sea water
Fish
c

◂**Fig. 3** Comparison of microplastics in terms of shape (**A**), color (**B**), and size (**C**) in surface water, sediment, and fish species from Persian Gulf

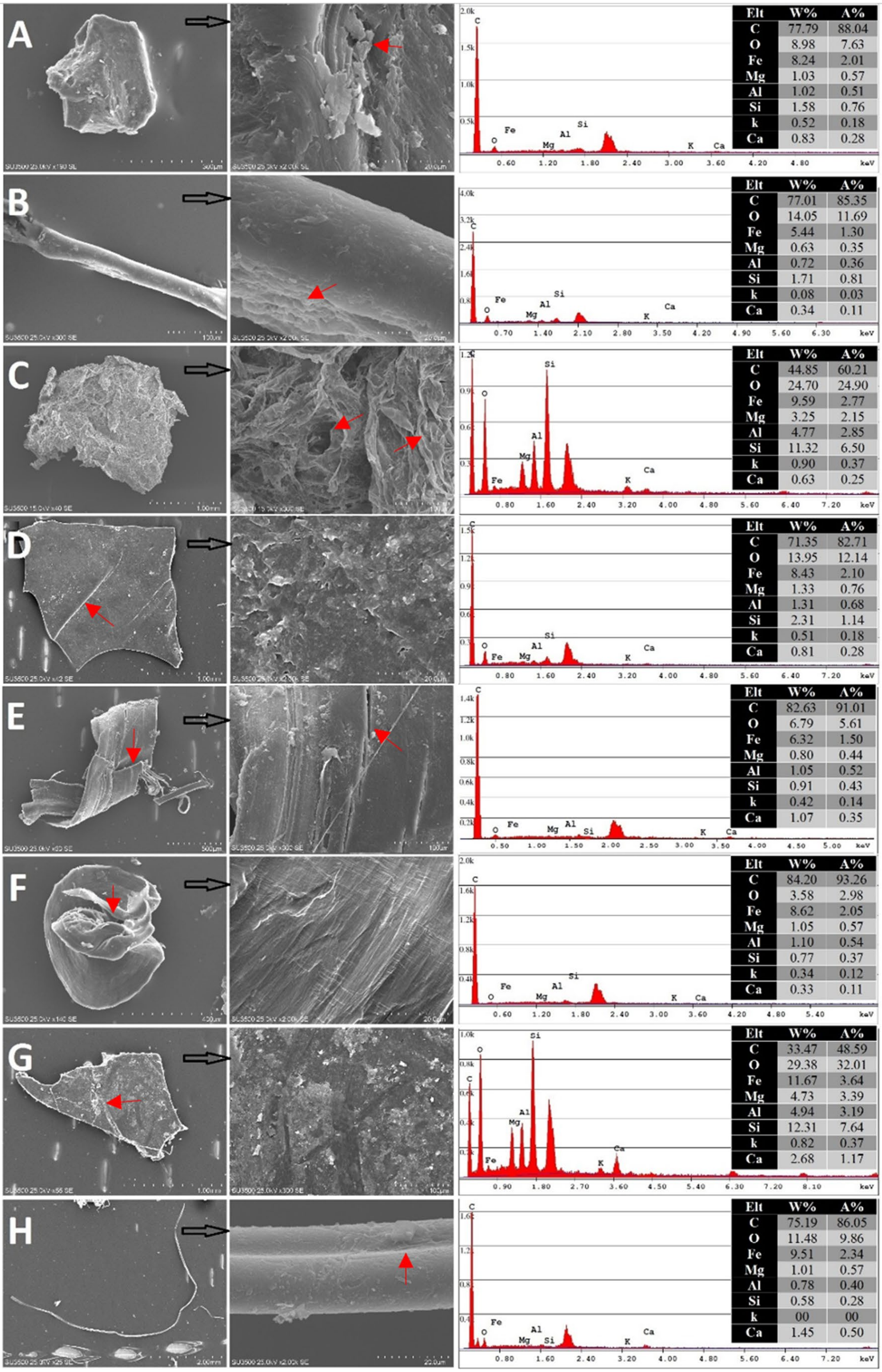
average abundance of MPs in the *Platycephalus indicus*, *Alepes djedaba*, *Epinephelus coioides*, and *Sphyraena jello* was 18.50 ± 4.55, 8.00 ± 1.22, 7.75 ± 2.16, and 5.66 ± 1.69 items/10 g fish muscle, respectively. Abbasi et al. (2018) investigated the GI tract, gills, skin, and muscle of four fish species and also the muscle and exoskeleton of a tiger prawn of the Musa Estuary in the Persian Gulf and extracted 828 MP particles from all caught species. The mean abundance of MPs ranged from 7.8 items/individual for tiger prawn (*Penaeus semisulcatus*) to 21.8 items/individual for a fish species (*Platycephalus indicus*). The results of the present study showed 28.5% of fish with an average of 0.33 ± 0.05 items/individual contaminated with MPs. These values are lower than those previously reported for fish in the northern Persian Gulf. Generally, the abovementioned studies reported MP pollution in different internal organs of fish, and it can be the reason for the low abundance of MPs in the GI tract of fish in this study. Moreover, recently, some studies have demonstrated that MPs found in some fish tissues such as the muscle and liver may be affected by background or external contamination during experimental analysis (Su et al. 2019; Akoueson et al. 2020). In fact, Akoueson et al. (2020) suggested that it is not feasible to decrease lab environment contamination to zero, even with high-quality assurance approaches. Consequently, it can be likely that MP content in the fish muscle may be due to laboratory environment contamination in the previous studies in the Persian Gulf which led to reporting a higher value of MPs than the present study. Moreover, differences in the protocol such as the kind of chemicals used to digest tissues, MP size classes, and identification methods have a great influence on resulting MP abundances. On the other hand, the intake of MPs by fish can be various depending on species, location, sampling time, habitat, and feeding habit, although Baalkhuyur et al. (2020) reported a low level of MPs in the commercial fish from the western part of the Persian Gulf, with an average of 0.057 ± 0.019 items/individual. There are numerous studies in other parts of the world which reported low levels of MP ingestion in the fish GI tract similar to the present study as well. For example, Neves et al. (2015) investigated 26 species of commercial fish from the Portuguese coast in different habitats and detected a mean of 0.27 ± 0.63 items/individual of MPs in their GI tract. The MP abundance range in the wild fish of Pearl River Estuary from South China was 0.17 to 1.33 items/individual (Lin et al. 2020). Consequently, the low prevalence of MPs in the studied fish suggests that these species is not as extremely affected by MPs as other fish in other regions of the world (e.g., Vendel et al. 2017; Ory et al. 2018). Another aspect to consider is that regardless of some studies that reported KOH as a suitable solution for the digestion of fish tissues (e.g., Dehaut et al. 2016; Karami et al. 2017), other studies reported that KOH can degrade some polymers such as PET and PVC (Pfeiffer and Fischer 2020). Therefore, it can affect the abundance of MPs found in fish in this study.

There was no correlation in MP abundance between surface water with sediment and also sampling sites in sediments and surface waters with fish species. It can be due to several complicated factors such as water quality, water circulation, and the MP characteristics. Similarly, Yuana et al. (2019) did not found a significant correlation between MP abundance in surface waters and sediments in Poyang Lake, China. On the contrary, Zhang et al. (2020) detected a positive correlation between the MP abundance in fish and sediment based on the different shapes and colors, while no correlation was found between fish and water samples according to any classification in Shengsi, China.

Significant correlations were found between fish body weight, body length, and GI tract weight with MP abundance isolated from the fish GI tract in *C. arel* ($P < 0.05$), in line with the results of Huang et al. (2020) who reported the same relationships in the fish caught from Zhanjiang mangrove wetland, China. As a result, it seems that by increasing fish size (length and weight) and GI tract weight, the number of MPs in the *C. arel* will be raised, while it is not true for *S. forsteri*, *L. abu*, and *O. ruber* since the abundance of MPs did not show significant relationships with body weight, body length, and GI tract weight ($P > 0.05$).

The result of this study showed that fiber was the most typical shape of MPs found in the surface waters, sediments, and fish. Domestic sewage, degradation of fishing net, and textile are considered as the most common origin of fibers in the marine environments (Browne et al. 2011; Cole et al. 2011). A high amount of fibers in the present study can be concluded from fishing gears such as rope and net, since our sampling sites were located in the areas with high fishing activity and also most polymer type of fiber found in this study was PP and PE which are used for fishery industry. This is consistent with several previous studies in the Persian Gulf which reported fibers as the main shape (Naji et al. 2017, 2019 and Kor and Mehdinia 2020). Fragment and films were also found in this study that can be originated from the fragmentation of larger plastics such as plastic bottles and bags (Rocha-Santos and Duarte 2017). Consequently, it can be stated that secondary MPs (taken from segregation of larger plastics) were the main types of shape in the Gulf.

Regarding the color, black, blue, and red were the most dominant in all sampling sites and fish GI tract. A reason for the higher number of colored particles may be that these particles are more easily identified by visual detection compared with white or transparent particles. Although, the


A
Elt W% A%
C 77.79 88.04
O 8.98 7.63
Fe 8.24 2.01
Mg 1.03 0.57
Al 1.02 0.51
Si 1.58 0.76
k 0.52 0.18
Ca 0.83 0.28
B
Elt W% A%
C 77.01 85.35
O 14.05 11.69
Fe 5.44 1.30
Mg 0.63 0.35
Al 0.72 0.36
Si 1.71 0.81
k 0.08 0.03
Ca 0.34 0.11
C
Elt W% A%
C 44.85 60.21
O 24.70 24.90
Fe 9.59 2.77
Mg 3.25 2.15
Al 4.77 2.85
Si 11.32 6.50
k 0.90 0.37
Ca 0.63 0.25
D
Elt W% A%
C 71.35 82.71
O 13.95 12.14
Fe 8.43 2.10
Mg 1.33 0.76
Al 1.31 0.68
Si 2.31 1.14
k 0.51 0.18
Ca 0.81 0.28
E
Elt W% A%
C 82.63 91.01
O 6.79 5.61
Fe 6.32 1.50
Mg 0.80 0.44
Al 1.05 0.52
Si 0.91 0.43
k 0.42 0.14
Ca 1.07 0.35
F
Elt W% A%
C 84.20 93.26
O 3.58 2.98
Fe 8.62 2.05
Mg 1.05 0.57
Al 1.10 0.54
Si 0.77 0.37
k 0.34 0.12
Ca 0.33 0.11
G
Elt W% A%
C 33.47 48.59
O 29.38 32.01
Fe 11.67 3.64
Mg 4.73 3.39
Al 4.94 3.19
Si 12.31 7.64
k 0.82 0.37
Ca 2.68 1.17
H
Elt W% A%
C 75.19 86.05
O 11.48 9.86
Fe 9.51 2.34
Mg 1.01 0.57
Al 0.78 0.40
Si 0.58 0.28
k 00 00
Ca 1.45 0.50

◂**Fig. 4** SEM/EDS analysis of found MPs in the sediment MPs (**A** fragment, **B** fiber), surface water (**D**, **E** fragment, **C** film), and fish GI tract (**F**, **G** fragment, **H** fiber). Left: SEM picture with low magnification; center: SEM picture with high magnification; right: EDS results showing the different elements found with respective percentages. Red arrows illustrate the cracks and different structures of MPs

most likely reason can be due to their high frequency in the environment. These colored MPs likely originated from anthropogenic sources such as synthetic textiles (clothing and carpets from beach dwellers), breaking down of consumer products, and releasing colored fibers through the fishing industry into the Persian Gulf. Other studies found that white and blue (Kor and Mehdinia 2020), black (Naji et al. 2019), blue and white (Castillo et al. 2016), and black or gray (Abbasi et al. 2018) are the most prevalent colors in the sediments, surface waters, and biota of the Persian Gulf. In fact, MP colors can be applied to initially assess the origins and types of chemical compounds and also the source of MPs (Rocha-Santos and Duarte 2017). However, colors can change by weathering and the formation of biofilms (Eriksen et al. 2013; Stolte et al. 2015). Therefore, this results in a nearly controversial discussion about colors. Furthermore, colored MPs may attract predators since they can resemble the prey color (Kühn et al. 2015; Abayomi et al. 2017) reflecting the increasing concerns about colored MP particles, although, in this study, a significant correlation was not found between MP color in GI tract contents compared to the water and sediment.

In terms of size, the most predominant MPs were smaller than 2000 μm in the present study. Similarly, other studies in the English Channel (Lusher et al. 2013), Lake Hovsgol, Mongolia (Free et al. 2014), and Haikou Bay, China (Qi et al. 2020) reported particles > 2000 μm as the predominant size in the sediments, surface waters, and fish. Previous studies in the Persian Gulf showed that particles 1000–3000 μm (Kor and Mehdinia 2020), > 2000– ≤ 5000 μm (Dobaradaran et al. 2018), and 100–500 μm (Abbasi et al. 2018) were the most common MP size in the surface waters, sediments, and biota, respectively, although sampling methods can influence the MP size composition of this study with other studies. Kor and Mehdinia (2020) reported that MP size distribution in the Persian Gulf likely is in conformity with MP size in global ocean surface water. In fact, particle size is an important factor affecting MP bioavailability and bioaccumulation since their size can be similar to the food size of organisms (Dantas et al. 2012; Ory et al. 2018). Therefore, the abundance of MPs, especially smaller sizes (< 2000 μm), detected in the present study raises the ingestion potential through a range of biota.

Based on EDS analyses, carbon and oxygen were the main elements of particles in this study which are considered as the main components of plastics (do Sul and Costa 2014). Also, silicon is applied in polymeric materials (Mehdinia et al. 2020). Consequently, it can be concluded that the analyzed particles in this study were microplastic, although other elements such as iron, aluminum, calcium, potassium, and magnesium detected on particles can be absorbed by MPs from the surrounding area (Liu et al. 2019; Mataji et al. 2020) or they can be used as chemical additives in the production process of plastic materials (do Sul and Costa 2014). The cracks and abrasions observed on the surface of MPs can indicate the period of MP exposure to the environment, weathering by physical or chemical agents, or mechanical degradation that occurred in larger pieces of plastics (Abbasi et al. 2018; Liu et al. 2019). These developed structures on the surfaces of MPs have already intensified their capacity to absorb various environmental pollutants, including heavy metals and organic pollutants (such as stable organic pollutants and polycyclic aromatic hydrocarbons) (Wardrop et al. 2016; Wen et al. 2018).

The result of ATR-FTIR spectrometry indicated that 63.3% of particles were MPs, while PP (density 0.90 g/cm^3), PE (0.91–0.96 g/cm^3), PS (1.05 g/cm^3), PVAC (1.19 g/cm^3), and PVPR (0.91 g/cm^3) were the dominant polymers. The low ratio of validation particles as plastics in this study can be due to inadequate spectrum intensity of fibers by ATR-FTIR spectrometry; nevertheless, none of the lest particles (36.7%) were identified as natural organic materials. Besides, the density of all found polymers in the current study was lower than 1.2 g/cm^3 which can indicate the limits of suspending high-density MPs by NaCl. Fishing nets, supermarket bags, packaging, and plastic bottles are the most important sources of PP, PE, and PS in aquatic ecosystems (Claessens et al. 2011; Elvers 2016; Fu et al. 2020). In the present study, sampling sites (e.g., Bushehr, Bandar Abbas, and Qeshm) were situated in the regions with high fishing activity, leading to the generation of fragmented ropes and nets (which are usually made of PP and PE) into the Gulf. Moreover, the tourist industry, recreational and commercial boating, and releasing of untreated sewage by dwelling buildings near beaches (De Sales-Ribeiro et al. 2020; Rasta et al., 2020) can transport a variety of types of polymers into the Persian Gulf.

Conclusion

In this study, microplastic pollution was investigated in the surface waters, sediments, and four fish species in 7 sampling stations located on the northern shores of the Persian Gulf. MPs were found in all sampling stations and fish species. There was no correlation between MP abundance in surface water, sediment, and fish samples. Except for *C. arel*, the abundance of MPs did not show significant relationships with body weight, body length,

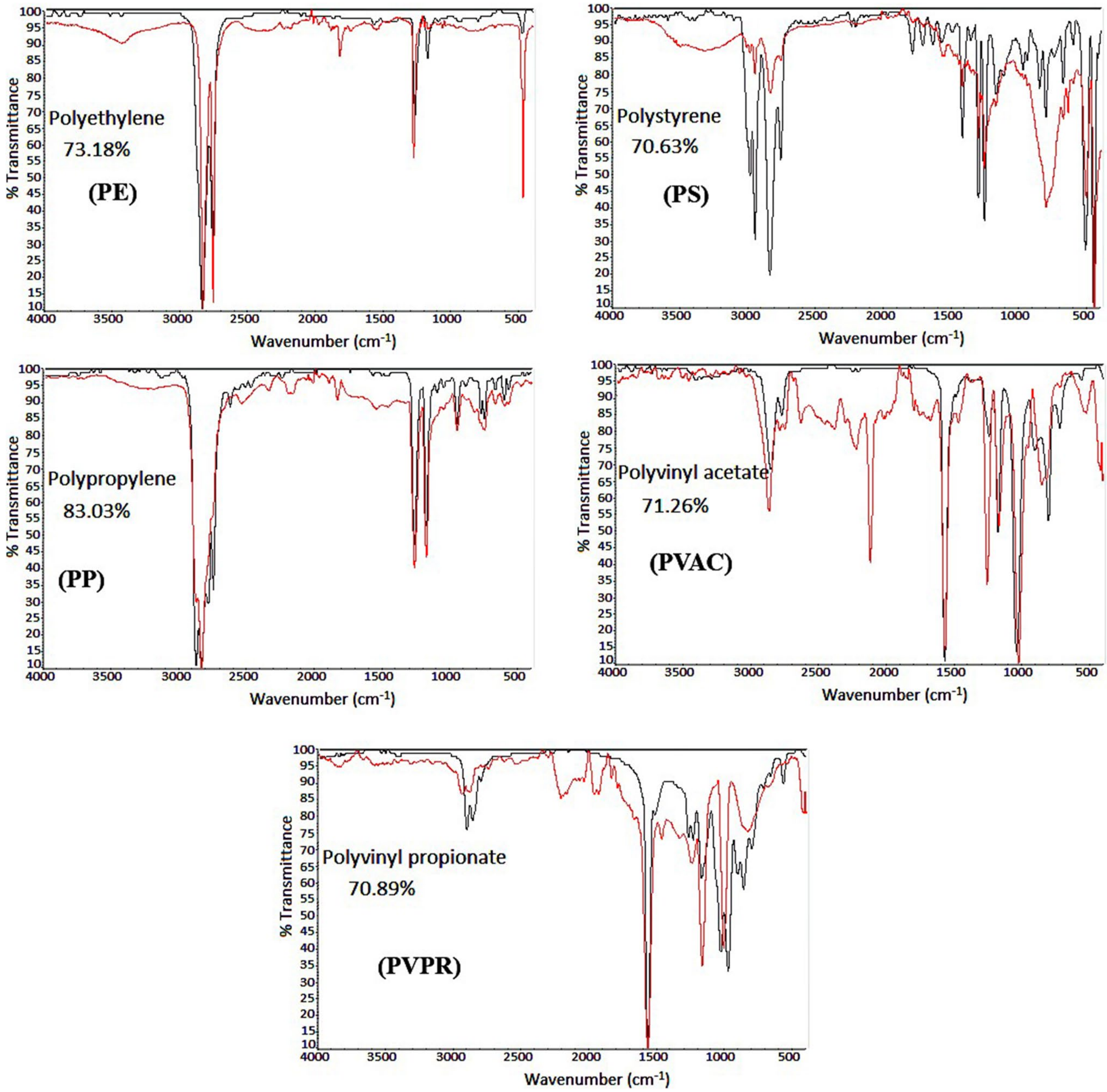


Fig. 5 ATR-FTIR of representative samples identified in the north of Persian Gulf (black line is polymer reference; red line is sample polymer)

and GI tract weight ($P > 0.05$). Although the abundance of MPs in fish and sampling stations in the present study was lower than in other regions of the world, we suggest to continue monitoring MP prevalence in sediments, seawaters, and coastal fishes from the Persian Gulf to recognize the changes in time. We also recommend that MP pollution must be investigated in the fish food chain of these areas.

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Authors' contributions AA: formal analysis. MST: methodology and data curation. MB: methodology and writing—original draft. MR: data curation and writing—original draft. HTJ: formal analysis. BRA: conceptualization and methodology.

Data availability All data in this article will be available upon request.

Declarations

Ethics approval The authors pledged that no data from this study have been published elsewhere.

Consent to participate To avoid damage to the fish stock, the lowest number of fish sample was collected.

Consent for publication All the authors agreed to publish the data in this journal.

Conflict of interest The authors declare no competing interests.

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