Chapter

Microplastic Contaminants in the Sediment of the East Coast of Saudi Arabia

Hamza Jawad Al-Shaikh Ali, Assad Ahmed Al-Thukair, Abdurahiman Kambrath Pulikkoden and Basheer Chanbasha

Abstract

Microplastic contamination in the sediment of the east coast of Saudi Arabia was not addressed by any study. The objective of this study is to obtain the first measurement of microplastic abundance at four different beaches on the east coast of Saudi Arabia (Khafji, Jubial, Dammam, and Salwa). Sediment samples were collected from both high tide and low tide zone. A total of 586 microplastic particles were collected from all the sites with an average particle size of 1.55 ± 0.94 mm. The majority of microplastic particles (77%) were less than 2 mm in size. Microplastic abundance ranged from 5.5 ± 1.55 to 21.2 ± 0.68 particle/kg (51.1 ± 14.71 to 152.8 ± 21.32 particle/m^2) in low tide region, and from 6.3 ± 4.05 to 16.5 ± 4.98 particle/kg (50.6 ± 31.21 to 204.5 ± 64.15 particle/m^2) in high tide region. The most dominant colors were transparent (34%) and blue (30%), while the fiber was the most common shape (96%). Polyethylene terephthalates were the common polymer type of fibers, while polyethylene and high-density polyethylene were common in fragments and filaments.

Keywords: microplastic, marine contamination, sediments, Arabian Gulf

1. Introduction

The plastic production rate is increasing exponentially since the 1950s reaching more than 400 million tons per year in 2020 [1]. People favor plastic over other materials mainly because of its properties, such as durability, lightweight, and flexibility. A study done by Ritchie and Roser in 2018 estimated that the total plastic floating on the global ocean surface is about 269,000 [2]. Plastic polymers are often combined with an additive, which includes chemical compounds, metals, or persistent organic pollutants (POP) [3–5]. Some of these additives are significantly toxic to humans if ingested, inhaled, or even during dermal contact [6]. Plastic litter can degrade or break into smaller micro-size plastic via various routes, such as mechanical forces, UV light from the sun, biological degradation, oxidation, or hydrolysis [7–9].

Microplastics are defined as synthetic polymer particles, that is, less than 5 mm in diameter. The first identification of microplastic was done in 1972 by carpenter et al. in the Sargasso Sea in plankton net trawls [10]. Microplastic is introduced to the marine environment either as primary or secondary microplastic. Primary microplastics are plastic particles that are manufactured to be less than 5 mm in size. Secondary microplastics are created by the fragmentation of large plastic products into smaller particles [11]. Microplastic is usually introduced to the marine environment through wastewater, surface runoff, or fragmentation of plastic products in landfill and coastal areas [11].

Microplastic pollution is measured in water, sediments, and organisms. In marine environments, beaches are considered to be the reservoir of macroplastic and microplastic debris [12]. They receive plastic pollution from land and transport it to coastal water, and then open ocean. However, the fate of microplastic spatial distribution is uncertain and it depends on several factors: (1) chemical structure of microplastic, (2) seawater density, (3) weather, (4) microplastic additives, (5) polymer type, (6) ecological impact, and (7) fragmentation ability [13, 14]. Rivers are also considered a major source of microplastic contamination in the marine environment, and this is because they usually pass through several urban areas before discharging into the ocean [15].

Microplastics can interact with marine organisms mainly through ingestion due to their small size similar to organisms' natural food. Several studies were done to measure microplastic contamination and risk in microorganisms [10, 16, 17], fish and mammals [18–21], and birds [22]. It was found by scientists that biota exposed to microplastic will have negative health effects, such as decreasing food consumption [23], decrease in weight [24], growth rate [25], and fertility [26]. In the aquatic environment, bivalves are the most commonly used organism in the labs for exposure studies [27]. Also, because of their filter-feeding behavior, bivalves are used in several studies as a bioindicator for microplastic contamination [28].

2. Study area

Arabian Gulf is an important sea to the surrounding countries due to the existence of huge oil and gas reservoirs, supplying the countries with domestic water through desalination plants, and because of its richness in a variety of biological resources that supply the countries. Saudi Arabia has a coastline of around 800 km long on the Arabian Gulf starting from Khafji and ending in Salwa Bay [29]. The kingdom's territorial water covers an area of 27,050 km^2, which is more than 10% of the total Arabian Gulf area (240,000 km^2) [30]. Arabian Gulf is considered one of the most stressful environments for marine organisms due to its high salinity caused by the high temperate and low precipitation rate [29]. The gulf is a semi-enclosed sea surrounded by arid lands in the west and the Zagros mountains in the east and connected to the Indian Ocean through the Straits of Hormuz. The average depth of the gulf is 35 m and reaches a maximum depth of 100 m near the Straits of Hormuz [29]. The circulation in the Arabian Gulf is counterclockwise mainly driven by wind, and thermohaline [29]. A model of the gulf was created by Yousef Alosairi et al. [31] using a three-dimensional numerical model estuary, lake and coastal ocean model (ELCOM) which shows that the flushing time along the Arabian coast is more than 3 years, a slow process compared to other seas. The Arabian Gulf is surrounded by eight developing countries, including Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Oman, Kuwait, Iraq, and Iran. Each of these countries has several cities and projects along the Arabian Gulf coastline, such as desalination plants, treated sewage disposal, nuclear plants, and many oil and gas production industries.

Only 17 published studies related to microplastic were done in the Arabian Gulf in which most of which are on Iranian coasts and the Strait of Hormuz. Therefore, the objective of this study is to characterize and compare microplastic contamination

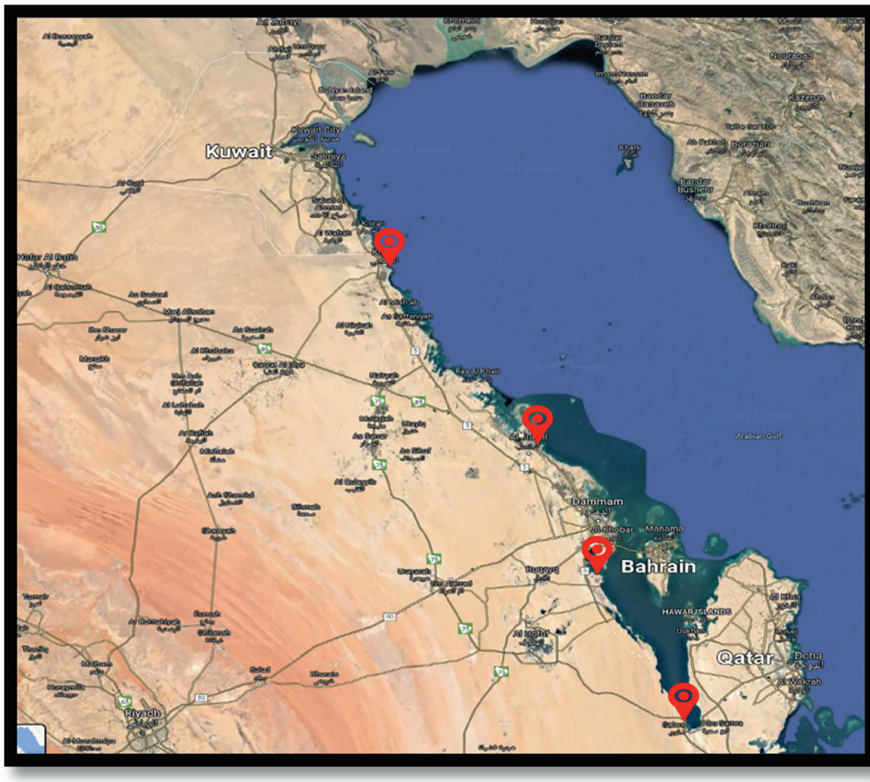

Figure 1.
Location of the four different beaches on Saudi Arabia's east coast.

in the sediment at Saudi Arabia's east coast at four different beaches (Khafji, Jubail, Dammam, and Salwa Bay) (**Figure 1**). By measuring the following parameters:

- The microplastic abundance will be reported as particle/kg of sand, and particle/m^2.
- The microplastic size will include sizes from 5 mm down to 1 mm.
- The microplastic shape which usually classifies as fragment, foam, fiber, or pellet.
- Microplastic polymer types will be identified using ATR-FTIR.

3. Methodology

3.1 Sampling

To have a representative sample, samples were collected from beaches that were not developed and prepared for recreational purposes. The sand of recreational beaches usually is replaced or cleaned on regular basis. Therefore, it is recommended to sample from the original uncleaned sand. Moreover, low tide (LTZ) and high tide (HTZ) zones must exist and be identifiable in the sampling site to achieve our sampling objective. Northing and easting coordinates were recorded for each sample using global positioning system (GPS). Six samples were collected from each beach of which three samples were from the high tide zone (HTZ), and three from the low tide zone (LTZ). A wooden quadrat with 50× 50 cm was used for sampling with a small metal shovel. After removing the debris and other liters, the top 5 cm sediment within the quadrat was collected in a metal bucket, weighted, and covered with foil aluminum. Then, 2 kg of each sample was filtered through 5, and 0.5 mm mesh-size stainless steel sieves. The remaining sand in between the sieves was collected in labeled glass bottles and sent to the lab for the next steps.

3.2 Sample preparation

The density separation method was used to separate microplastic from the sand. Sodium Chloride salt (NaCl) was added gradually to a beaker filled with distilled water. The beaker was placed under a magnetic stirrer for continuous stirring. NaCl was added to the distilled water up to saturation point when the salt is not dissolving in the water anymore. To confirm the density of the brine, the weight of 1 L of brine was measured which was around 1.18 g/cm^3. Sand samples were extracted from the glass bottles into a stainless-steel container using a stainless-steel spoon and distilled water to make sure all the samples is collected. Brine was filtered through 100 μm mesh and then added to the containers using a volume equal to two to three times the sand volume to submerge the sample. Sand then was stirred for 5 minutes to allow light components like microplastics to float. The container then was covered with aluminum foil and kept for 24 hours to settle. After 24 hours, the brine in the samples along with the supernatant material was filtered through 100 μm stainless-steel mesh. The materials caught in the mesh were then washed using distilled water into a glass beaker. Then, the collected materials in the beaker were filtered using a 47 mm Whatman glass microfiber filter, ceramic funnel, and electric vacuum pump. Glass microfiber filter was then kept in a glass petri dish to dry and covered with aluminum foil.

3.3 Sample analysis

Glass filters are then analyzed under the stereo microscope "Olympus" with 450× magnification for any suspected microplastics. Suspected particles are collected using metal forceps and placed in a glass slide to be analyzed using Leica CME 1000× compound microscope. Particles are then identified as microplastic based on the following criteria [32–33]: 1. the absence of organic and cellular structures, 2. the color is homogenous, and 3. not segmented and evenly thick. After that, the color and shape of microplastics were recorded and a picture was taken of each sample with the scaled optical glass inserted in the microscope lens. Later with the help of a calibration slide, the length of each particle was measured using IC Measure software. Part of the identified microplastics was isolated in a small glass bottle and was analyzed for polymer types using Bruker ATR-FTIR. To cover all possible polymer types, samples with different characteristics (shape and color) were used. The resulting spectrums were matched with referenced polymer spectra using the library in OPUS-spectroscopy software. Statistical analysis was performed on the data using Microsoft excel. First, using the Kolmogorov–Smirnov test for normal distribution. Then, one-way analysis of variance (ANOVA) was applied for microplastic abundance, size, and color considering $p < 0.05$ as statistically significant.

4. Results

Microplastics were found in all 24 samples taken from the four different beaches Dammam, Jubail, Khafji, and Salwa (**Table 1**). A total of 586 particles were extracted

Area	Sample		Abundance		Size		Shape		Color				
DMMM		Total MP	Particle/kg	Particle/m^2	Ave Size	Fiber	Fragment	Filament	Transparent	Blue	Black	Red	Green
	DMMM-1 LT	42	22.1	141	1.7	39	2	1	18	9	2	12	1
	DMMM-2 LT	43	20.5	134	1.47	37	5	1	15	14	9	4	1
	DMMM-3 LT	44	21.0	183	1.62	44	0	0	24	12	3	4	1
	DMMM-1 HT	17	8.5	62	1.75	11	6	0	5	7	3	2	0
	DMMM-2 HT	35	16.7	124	1.51	34	0	1	11	11	7	6	0
	DMMM-3 HT	24	12.0	87	1.3	24	0	0	6	6	8	3	1
JUBL	JUBL-1 LT	14	7.0	66	1.36	14	0	0	7	4	1	2	0
	JUBL-2 LT	7	3.3	31	1.21	7	0	0	0	2	3	2	0
	JUBL-3 LT	14	6.1	57	1.63	14	0	0	3	7	3	0	1
	JUBL-1 HT	3	1.5	13	2.55	2	1	0	2	0	0	0	1
	JUBL-2 HT	24	11.4	90	1.68	24	0	0	8	6	4	4	2
	JUBL-3 HT	12	6.0	49	1.62	10	2	0	4	3	1	2	2
KHFJ	KHFJ-1 LT	39	17.7	194	1.52	38	1	0	14	8	7	7	3
	KHFJ-2 LT	20	9.1	96	1.16	20	0	0	6	8	6	0	0
	KHFJ-3 LT	28	12.2	139	1.52	28	0	0	4	9	6	6	3
	KHFJ-1 HT	15	7.1	77	1.32	15	0	0	3	7	2	1	2
	KHFJ-2 HT	20	9.1	76	1.27	20	0	0	4	2	3	9	2
	KHFJ-3 HT	21	10.0	84	1.13	21	0	0	7	6	5	2	1

Area	Sample		Abundance		Size		Shape			Color			
SALW	SALW-1 LT	21	10.5	123	1.7	18	2	1	8	8	2	2	1
	SALW-2 LT	12	5.5	66	1.8	11	1	0	6	1	1	4	0
	SALW-3 LT	21	9.1	120	1.64	21	0	0	8	7	5	1	0
	SALW-1 HT	48	20.9	265	1.85	48	0	0	21	14	6	7	0
	SALW-2 HT	42	19.1	232	1.53	42	0	0	8	20	7	7	0
	SALW-3 HT	20	9.5	116	1.44	19	1	0	7	7	3	3	0

Table 1.
Detailed results of all of the samples analyzed for the microplastic study.

with an average size of 1.55 ± 0.94 SD mm and an overall average abundance of 11.5 ± 5.02 SD particle/kg (109.4 ± 50.26 SD particle/m^2). The highest abundance among the low tide is found in the Dammam sample with an average of 21.2 ± 0.68 SD particle/kg (152.8 ± 21.3 SD particle/m^2), while the lowest is in the Jubail sample with an average of 5.5 ± 1.56 SD particle/kg (51.1 ± 14.71 SD particle/m^2). On the other hand, Salwa has the highest abundance among the high tide with 16.5 ± 4.98 SD particle/kg (204.5 ± 64.15 SD particle/m^2) and Jubil is the least with 6.3 ± 4.06 SD particle/kg (50.6 ± 31.21 SD particle/m^2) (**Figures 2** and **3**). No significant differences were reported between the overall low tide average abundance (12 ± 5.94 particle/kg, 112.5 ± 40.08 SD particle/m^2) and overall high tide average abundance (11 ± 3.85 particle/kg, 106.3 ± 58.54 SD particle/m^2). However, when low tide and high tide average microplastic abundance were compared for each site separately, discrepancies were observed in all of the beaches except the Jubail sample. The low tide abundance average was higher than the high tide in Dammam and Khafji, but the opposite was reported in Salwa.

Average particle size was showing no significant variation between both low tide (1.53 mm) and high tide (1.58 mm). Microplastics with a size range from 1 to 2 mm were the most common size with 44%, followed by particles that were less than 1 mm in size (33%), then the range from 2 to 3 mm (14%). Therefore, only 9% of the collected particles were bigger than 3 mm (**Figure 4**).

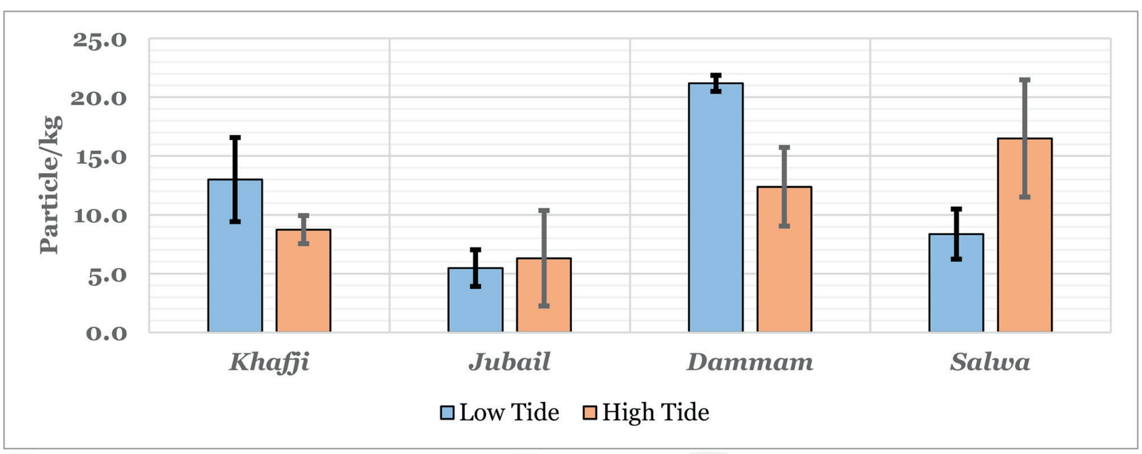

Figure 2.
Average microplastic abundance (particle/kg).

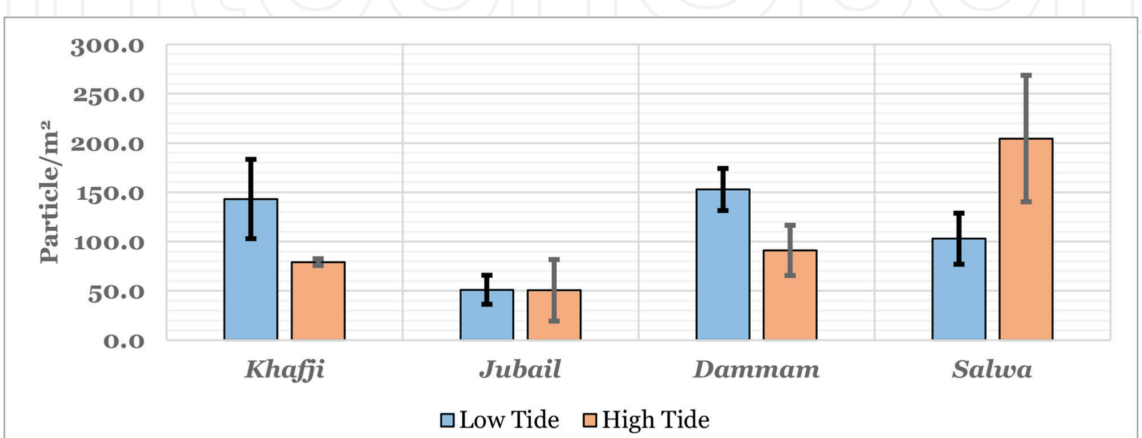

Figure 3.
Average microplastic abundance (particle/m^2).

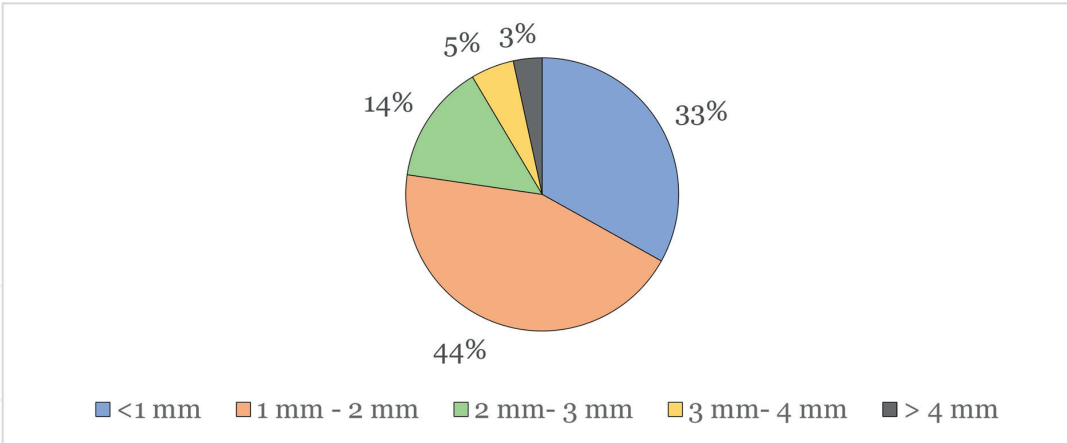

Figure 4.
Microplastic size distribution.

Regarding microplastic types, 96% of the collected particles were fibers leaving only 4% as fragments and filaments. Fragments and filaments were found in both low-tide and high-tide samples.

Different colors of microplastic particles were observed in all the samples. The majority is for transparent (34%) followed by blue (30%), black (17%), red (15%), and green (4%).

Using ATR-FTIR analysis, four different polymers as polyethylene terephthalate (PET), polyethene (PE), high-density polyethylene (HDPE), and polypropylene (PP) were identified. Fibers with different colors (transparent, blue, and red) were found to be PET. PE and HDPE were found in fragments and filaments with blue, green, and transparent colors while only one white fragment was found in PP (**Figure 5**).

Statistical analysis using the Kolmogorov–Smirnov test shows that microplastic abundance and size are normally distributed. One-way analysis of variance (ANOVA) shows no significant differences between microplastic abundance, size, and color considering $p < 0.05$ as statistically significant.

5. Discussion

Numerous studies were conducted around the world to characterize microplastic abundance in water, sediment, and biota. However, still the methodology and reporting unit is not yet standardized. Different sampling procedures for sediment can be found in the articles. For example, sample quadrat varies in the studies from 1 × 1 m to 0.3 × 0.3 m [34, 35], and the most common quadrat is 0.5 × 0.5 m. This is the case with sampling thickness in which some studies collect the sample from 5 cm [36] while others take only the top 1 cm [33, 36, 37]. Also, density separation fluid density varies from 1.2 g/ml for NaCl to 1.8 g/ml for NaI. In this study, NaCl was used since it is the most popular choice, easy to use, and low cost. Moreover, reporting units in the published papers are different such as particle/kg, particle/m^2, mg/g sediment, mg/m^2, and particle/0.0125m^3. Weight in some studies is presented as dry sediment weight, while in others is a wet sediment weight. Therefore, comparison between the results is not a straightforward process. Multiple published articles and review papers summarized the methodologies and results of many microplastic studies done around the world [38–40].

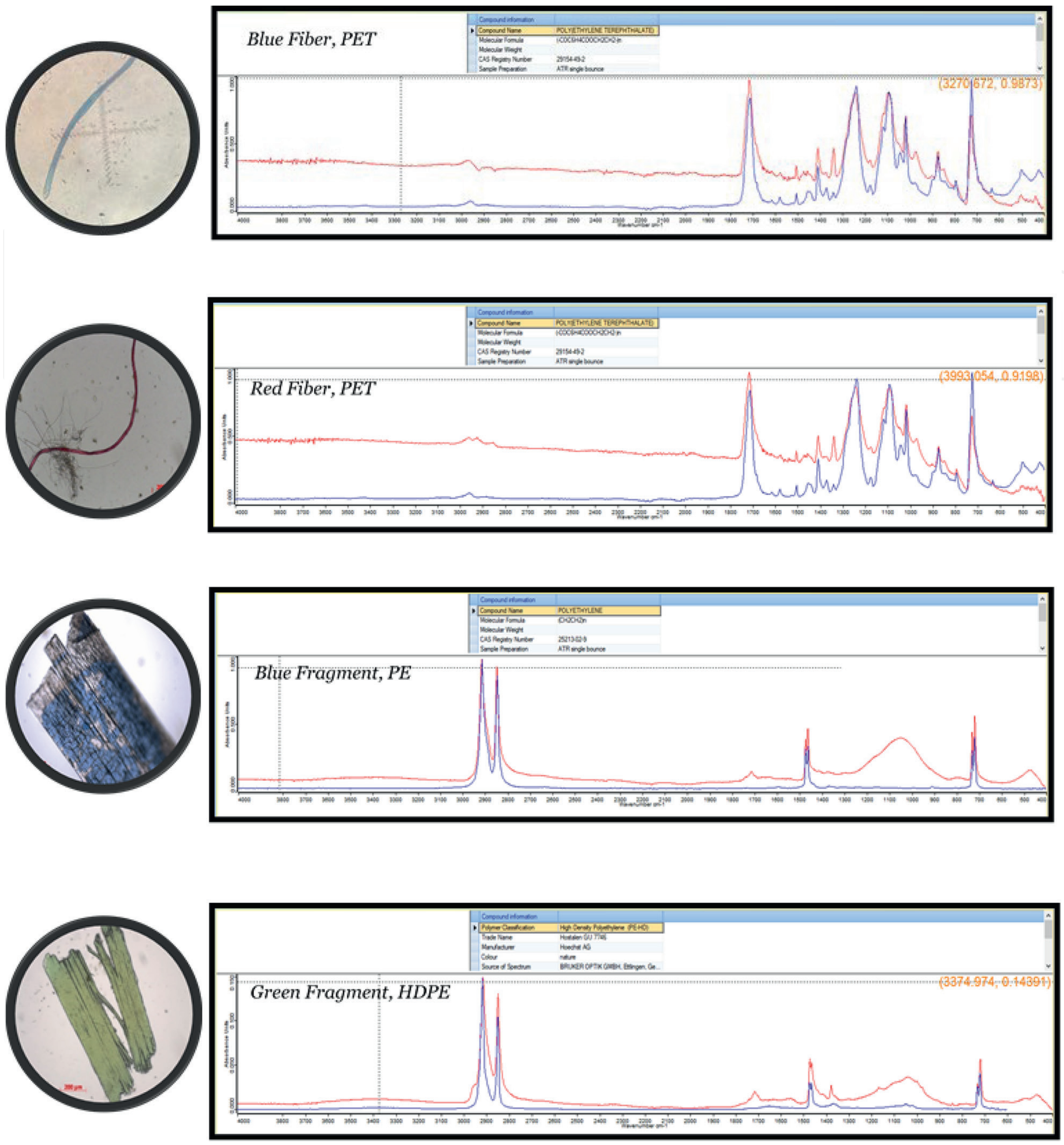

Figure 5.
Spectrum for different shapes and colors of microplastic.

Microplastic abundance per area was estimated in this study since part of the studies done in the Arabian Gulf described microplastic abundance as particle/m^2 [33, 41]. To calculate the abundance in particle/m^2, equal vertical distribution along the 5 cm depth must be assumed. Also, it is important to clarify that the reporting unit is a particle of microplastic in an area of 1 m^2 and at 1 cm depth. The results showed an average abundance of 112.5 particles/m^2 for the low tide zone and 106.3 particles/m^2 for the high tide zone.

Comparing microplastic abundance on the east coast of Saudi Arabia against worldwide countries shows that the Saudi east coast of the Arabian Gulf is among the least polluted coasts (5.5 to 21.2 particles/kg, 50.6 to 204.5 particles/m^2). Multiple studies with similar microplastic extraction procedure done on the southwestern side of the USA coast and at several European beaches [43, 44] shows a higher abundance of microplastic [42–44]. Same with Asian countries where microplastic abundance tends to be higher than our results [12, 45, 46]. **Table 2** summarizes some results of various studies around the world taking into consideration similar methodologies and reporting units. Higher abundance in smaller particle sizes is also observed in most of the studies. Black and blue were the most common colors in these articles, and fiber is the common shape.

With regards to the gulf countries, a review paper by Saif Uddin et al. [38] summarizes all the studies carried out in the Arabian Gulf in terms of the type of samples, sampling methodology, and results. From the Iranian coast to the Oman sea through the Strait of Hormuz to Bander Abbas city beaches, studies show greater microplastic abundance compared to the Saudi east coast [36, 41, 47, 48]. This might be due to the geology of the area and the counterclockwise movement of the seawater [29]. In these studies, density separation was done using brine density higher than NaCl which led to extracting more microplastic particles. As stated by Naji et al. [49] in their study that around 74% of microplastic was extracted using NaCl, while the remaining 26% was recovered by NaI. However, the studies done in Qatar by Abayomi [50] and UAE by Aslam [33] used the KI solution for density separation and it shows much lower microplastic abundance than that of the Iranian coast. The results of both studies are comparable with this study's numbers and that gives more confidence in our methodology. This was also supported by the similarity in having fiber, blue, and PE as the most common properties of the collected microplastic.

Despite that the average of low tide and high tide abundance is very close to each other; it may vary a lot when compared site by site. The difference is observed in all the sites except Jubial which has the lowest abundance among all the sites. Low tide shows higher abundance in Dammam and Khafji samples while it was less in Salwa. Therefore, there is no trend between the high tide and low tide abundance which was also observed [47]. It was expected to have higher microplastic abundance in Dammam, Jubail, and Khafji since they are both crowded and industrial cities. However, Jubail shows a very low number which was unexpected for the biggest industrial city in the eastern region. Several reasons might cause these low numbers which are as follow:

1. The geology and location of Jubail city where the counterclockwise current is blocked by Abu Ali Island in the north.

2. The effective recycling of the wastewater, which is treated and reused for irrigation instead of discharging it in the sea.

3. The frequent cleaning of the developed beach will reduce the amount of plastic runoff to the seawater.

On the other hand, Salwa which is considered a rural city showed high microplastic abundance and this also can be explained by the following reasons:

1. Although Salwa has a very low population, the sea there is surrounded by land from three directions which makes it a trap for floating contamination.

2. Multiple resorts in Qatar side in front of Salwa beach.

3. Salwa beach is considered a destination for tourism to practice fishing and camping.

Since Salwa is located near the border of Qatar, it will be useful to compare its results with Abayomi's results [50]. Umm Bab sampling site is the closest one to Salwa beach, and it shows a microplastic abundance of 8.3 particles/kg which is similar to our results for Salwa average low tide (8.4 particles/kg) (**Figure 4**).

Microplastic with a size ≤2 mm was the most common size among the samples (77%). It is expected to have even smaller (<0.5 mm) microplastics that already passed the 0.5 mm stainless steel sieve. The smaller the microplastic particles are, the more vulnerable they became to a smaller organism. Based on a study done by Naji et al. [49], microplastics with sizes ranging from 0.02 to 1.68 mm were the most common size found in cyclopoids, shrimps, and zoea. Having microplastic induced in the organisms at the base of the food web could cause biomagnification in the bigger organisms that feed on them.

As mentioned before, around 96% of the collected particles were fiber. This result is similar to all the studies done in the Arabian Gulf and most worldwide studies (**Tables 2** and **3**). This could be due to disposing sewage rich in synthetic fiber released from textiles, or clothes into the sea [6, 51]. Degraded fishing ropes and nets are considered a source of microplastic fiber in seawater. Treatment of wastewater before disposing to the sea may remove more than 80% of the microplastic [52]. Unfortunately, some countries dispose of the wastewater without primary treatment [53] which may increase the microplastic fiber in the oceans. Microplastic fibers were found to be one of the most shapes to be ingested by zooplankton [33, 54, 55]. More studies also showed that microplastic fiber is the most ingested by turtles, fish larvae, and Mesoplodon mirus [56–58].

Transparent and blue colors like most of the studies in the area were the most common colors followed by black color (**Figure 6**). No significant change in color distribution was found among the sampling sites. The importance of quantifying microplastic color was described by Shaw et al. [59] research which shows that colored microplastic is more likely to be ingested by organisms as prey, and the white, transparent, blue, and black colors were the most commonly found [59]. During microscope analysis, some particles were found with a partially faded color. This indicates that some of the originally colored microplastic particles turned into colorless particles and that could be because of the physical or chemical reactions between the particles and the surroundings. The changing of color was also mentioned by Chen et al. [60] and by Wibowo et al. [61] which show that time is playing a role in changing the microplastic color and size.

Attenuated total reflectance fourier transform infrared spectroscopy (ATR-FTIR) analysis shows that different colors of microplastic fibers had similar polymer types which are polyethylene terephthalate (PET). Since fiber was the most common shape (96%), then this suggests that PET is the most common polymer type in the collected samples. This result is consistent with the studies done in the Arabian Gulf, and most of the studies around the world. PET is commonly used in making ropes and drinking bottles which are heavily used in KSA specifically for water bottles. Fragments and filaments particle were identified as polyethylene (PE) and high-density polyethylene (HDPE). These polymer products are also commonly used in our daily life, such as bags and shampoo bottles. Only one particle was identified as polypropylene (PP) which was also reported in Qatar by Abayomi et al. [50]. This suggests that most of the microplastic contamination in Saudi east beach is coming from the daily used plastic product which reaches the sea through wastewater effluent, direct dumping of plastic into the sea, or run-off.

Country	Location	Abundance		Average Particle Size	Most Common			Reference
		Particle/kg	**Particle/m2**		**Shape**	**Color**	**Polymer**	
USA	Southeastern Beach	43–306 (D. W.)	—	—	Fiber	—	PET	[42]
	Mobile bay, Alabama	50.6 ± 9.96	—	2.5 mm	Fragment		PE & PP	[62]
	Kamilo/Kahuku Beach, Hawai'i	—	1143/1774	2–4 mm	Fragment	White	PE	[63]
Italy	Sicily	160 ± 31 (D. W.)	—	1.32 mm	Fiber	Blue/Black	—	[43]
	Tyrrhenian Sea	—	151–678.7	—	Filament	—	—	[64]
Spain	Denia	156 ± 29 (D. W.)	—	1.96 mm	Fiber	Blue/Black	—	[43]
	Lambra/Famara/Las Caneras	—	430.9–1656	—	Fragment	—	—	[65]
France	Normandy	143 ± 13 (D. W.)	—	1.28 mm	Fiber	Blue/Black	—	[43]
UK	Scapa Flow Orkney	730–2300 (D. W.)	—	—	Fiber	Blue	PTFE	[44]
Netherlands	Rottumeroog	124 ± 27 (D. W.)	—	1.28 mm	Fiber	Blue/Black	—	[43]
Denmark	Fyns Hoved	164 ± 21 (D. W.)	—	1.26 mm	Fiber	Blue/Black	—	[43]
Russian	Baltic Coast	0.2–36.2 (D. W.)	5560	—	Foam	—	—	[66]
China	Guangdong Province	—	6675	0.315–1 mm	Foam		PS	[12]
South Korea	Nakdong River Estuary	—	27,606	—	Foam	—	—	[45]
Maldives	Coral Island	—	647 ± 720	—	Foam	—	PE	[46]
South Africa	Indian Ocean	—	688.9 ± 348.2 & 3308 ± 1449		Fiber	Blue/Black	PS	[67]

Table 2.
Examples of microplastic studies around the world.

Country	Location	Abundance		Density Separation Brine	Most Common			Reference
		Particle/kg	Particle/m^2		Shape	Color	Polymer	
Iran	Strait of Hormuz	2 ± 1 to 1258 ± 291 (D. W.)	—	NaCl	Fiber		PET & Nylon	[36]
	Oman Sea	138.3 ± 4.5 to 930.3 ± 49 (D. W.)	—	NaCl & ZnCl2	Fiber & Fragment	White	PE	[48]
	Bandar Abbas	—	3252 ± 2766	—	Foam	—	PS & PET	[41]
	Bandar Abbas	36 ± 7.2 to 125 ± 25 (D. W.)	—	NaCl & NaI	Fiber	—	PE & PET	[47]
	Khor-e-Khoran Mangrove	19.5 to 34.5 (D. W.)	—	NaCl & NaI	Fiber	Black	—	[49]
Qatar	Qatar Coasts	—	36 to 228	KI	Fiber	Blue	PE & PP	[50]
UAE	Dubai Coast	59.71 (D. W.)	165	KI	Fiber	Blue	PE	[33]
Kuwait	Kuwait Coasts	—	—	—	Filament & Fragment	Blue	PP & PE	[35]

Table 3.
Microplastic studies in the Arabian Gulf (sediment).

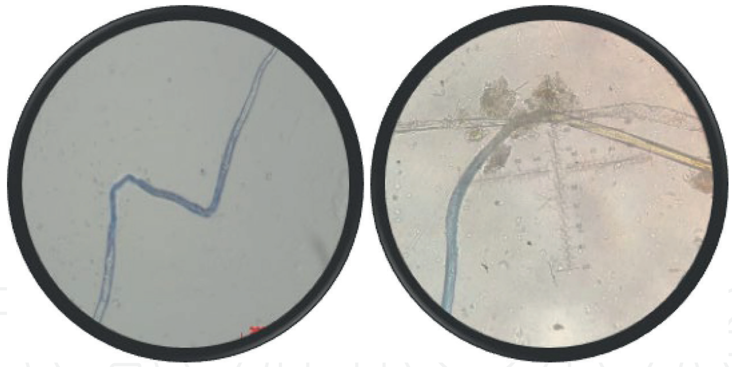

Figure 6.
Microplastic color fading and changing.

6. Conclusion and recommendation

This study is the first study to measure microplastic pollution in the sediment of the eastern coast of the kingdom of Saudi Arabia. The common size of microplastic particles measured (77%) was less than 2 mm in size. Microplastic abundance within the study sites ranged from 5.5 to 21.2 particles/kg (51.1 to 152.8) in the low tide region, and from 6.3 to 16.5 particles/kg (50.6 to 204.5 particles/m^2) in the high tide region. The main goal of this study is to provide a baseline and glimpse of the quantity and identity of microplastic in our selected sites, however, those values consider to be a baseline for a coast length of 800 km. The future researcher will have some expectations of microplastic distribution along this coastline. Several recommendations can be suggested to whom is interested in curry microplastic research on Saudi Arabia's eastern coast:

- Identify the effect of sampling time in microplastic quantity by collecting the sample from a single location at a different time interval.
- Measure microplastic contamination in both water and sediment in the same area to find the relationship.
- Identify an organism to be used as a bioindicator in our area, such as Clam in China [28].
- Use multiple brine solutions with different densities to find the difference between the quantity and type of microplastic extracted from each one.
- Measure microplastic abundance in sediment with respect to depth
- Provide the results with a different unit to allow comparison with different studies.
- Measure microplastic in a protected area (mangroves and islands) which is important to preserve the area and the organisms living there.
- Digestion of organic material by acids can make microplastic identification easier, however, it can affect color and shape identification.
- Filtering the supernatant using a fine mesh size stainless steel (300 µm) can ease the filtration of supernatant later in the glass filter paper.

Acknowledgements

The authors would like to thank King Fahd University of Petroleum and Minerals (KFUPM) for their support by providing all the materials and equipment to conduct the study.

Author details

Hamza Jawad Al-Shaikh Ali[1], Assad Ahmed Al-Thukair[2]*, Abdurahiman Kambrath Pulikkoden[3] and Basheer Chanbasha[4]

1 Environmental Science Program, Department of Geoscience, Collage of Petroleum Engineering and Geoscience, King Fahad University for Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

2 Department of Bioengineering, Collage of Chemical and Materials, King Fahad University for Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

3 Center for Environment and Marine Studies, Research Institute, King Fahad University for Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

4 Department of Chemistry, College of Chemical and Materials, King Fahad University for Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

*Address all correspondence to: thukair@kfupm.edu.sa

References

[1] Isangedighi IA, David GS, Obot OI. Plastic waste in the aquatic environment: Impact and management. Environment Science and Policy for Sustainable Development. 2018;**2**:2

[2] Ritchie H, Roser M. Plastic pollution. September 2018. [Online]. Available from: https://ourworldindata.org/plastic-pollution

[3] Teuten EL, Saquing JM, Knappe DR, Barlaz MS, Rowlan J, et al. Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical Transactions of The Royal Society B. 2009;**364**:2027-2045

[4] Antunes JC, Frias J, Micaelo A, Paula S. Resin pellets from beaches of the Portuguese coast and adsorbed persistent organic pollutants. Estuarine Coastal and Shelf Science. 2013;**130**:62-69

[5] Massos A, Turner A. Cadmium, lead and bromine in beached microplastics. Environmental Pollution. 2017;**227**:139-145

[6] UNEP. Marine Plastic Debris and Microplastics. Nairobi: United Nations Environment Programme; 2016

[7] Andrady AL. Microplastic in The Marine Environment. Marine Pollution Bulletin. 2011;**62**:1596-1605

[8] Browne MA, Galloway T, Thompson R. Microplastic—An emerging contaminant of potential concern? Integrated Environmental Assessment and Management. 2007;**3**:559-561

[9] Barenes DK, Galgani F, Thompson RC, Barlaz M. Accumulation and fragmentation of plastic debris in global environment. Philosophical Transactions of The Royal Society B Biological Sciences. 2009;**364**

[10] Carpenter EJ, Smith KL Jr. Plastics on the sargasso sea surface. ScienceMag. 1972;**175**:1240-1241

[11] GESAMP. Sources, fate and effects of microplastics in the marine environment: A global assessment. In: Kershaw PJ, editor. IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP. Joint Group of Experts on the Scientific Aspects of Marine Environmetal Protection. 2015. p. 96

[12] Fok L, Cheung PK, Tang G, Li WC. Size distribution of stranded small plastic debris on the coast of Guangdong, South China. Environmental Pollution. 2017;**220**:407-412

[13] Andrady AL. The plastic in microplastics: A review. Marine Pollution Bulletin. 2017;**119**:12-22

[14] Arias-Andres M, Klumper U, Rojas-Jimenez K, Grossart H-P. Microplastic pollution increases gene exchange in aquatic ecosystems. Environmental Pollution. 2018;**237**:253-261

[15] Sighicelli M, Pietrelli L, Lecca F, Lannili V, Falconieri M, Coscia L, et al. Microplastic pollution in the surface waters of Italian Subalpine Lakes. Environmental Pollution. 2018;**236**:645-651

[16] Cole M, Lindeque P, Fileman E, Halsband C, Goodhead R, Moger J, et al. Microplastic ingestion by Zooplankton. Environmental Science & Technology. 2013;**47**:6646-6655

[17] Bhattacharya P, Lin S, Turner JP, Chun Ke P. Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. The Journal of Physical Chemistry C. 2010;**114**:16556-16561

[18] Lusher AL, McHugh M, Thompson RC. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English channel. Marine Pollution Bulletin. 2013;**67**:94-99

[19] Baalkhuyur FM, Bin Dohaish E-JA, Elhalwagy ME, Alikunhi NM, AlSuwailem AM, Rostad A, et al. Microplastic in the gastrointestinal tract of fishes along the Saudi Arabian Red Sea Coast. Marine Pollution Bulletin. 2018;**67**:94-99

[20] Abbasi S, Soltani N, Keshavarzi B, Moore F, Turner A, Hassanaghaei M. Microplastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. Chemosphere. 2018;**205**:80-87

[21] Boerger CM, Lattin GL, Moore SL, Moore CJ. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin. 2010;**60**:2275-2278

[22] Bond AL, Provencher JF, Elliot RD, Ryan PC, Rowe S, Jones IL, et al. Ingestion of plastic marine debris by common and thick-billed Murresin the northwestern Atlantic from 1985 to 2012. Marine Pollution Bulletin. 2013;**77**:192-195

[23] Besseling E, Wegner A, Foekema EM, Heuvel-Greve MVD, Koelmans A. Effects of microplastic on fitness and PCB bioaccumulation by the lugworm Arenicola marina (L.). Environmental Science & Technology. 2013;**47**:593-600

[24] Wright S, Rowe D, Thompson RC, Galloway TS. Microplastic ingestion decreases energy reserves in marine worms. Current Biology. 2013;**23**:R1031-R1033

[25] Huerta E, Gertsen H, Gooren H, Peters P, Salanki T, Van Der Ploeg MJ, et al. Microplastics in the terrestrial ecosystem: Implications for lumbricus terrestris (oligochaeta, lumbricidae). Environmental Science & Technology. 2016;**50**:2685-2691

[26] Sussarellu R, Suquet M, Thomas Y, Lambert C, Fabioux C, Pernet EJ, et al. Oyster reproduction is affected by exposure to polystyrene microplastics. Proceedings of The National Academy of Sciences. 2016;**113**:2430-2435

[27] Lusher A, Hollman P, Mendoza-Hill J. Microplastics in fisheries and aquaculture, food and agriculture organization of the United Nation. 2017

[28] Su L, Cai H, Kolandhasmy P, Wu C, Chelsea RM. Using the Asian clam as an indicator of microplastic pollution in freshwater ecosystems. Environmental Pollution. 2018;**234**:347-355

[29] Krishnakumar PK, Ashraf M, Sheppard C, M. J. D. Chapter 2: The physical environment of the Western Arabian Gulf. In: Ecosystems and biodiversity of the Arabian Gulf-Saudi Arabian Waters, Dhahran, Saudi Aramco and KFUPM. 2019

[30] Abuzinada AH, Barth H-J, Krupp F, Boer B, Al Abdessalaam TZ. Protecting the Gulf's Marine Ecosystem from Pollution. Switzerland: Birkhauser; 2008

[31] Alosairi Y, Imberger J, Falconer RA. Mixing and flushing in the Persian Gulf (Arabian Gulf). Journal of Geophysical Research. 2011;**116**:1-14

[32] Norén F. Small Plastic Particles in Coastal Swedish Waters. N-Reserarch. Sweedn-Lysekil; 2007

[33] Aslam H, Ali T, Mortula MM, Attaelmanan AG. Evaluation of microplastics in beach sediments along the coast of Dubia, UAE. Marine Pollution Bulletin. 2020;**150**:110739

[34] Karthik R, Robin R, Purvaja R, Ganguly D, Anadavelu I, Raghuraman R, et al. Microplastics along the beaches of Southeast coast of India. Science of the Total Environment. 2018;**645**:1388-1399

[35] Saeed T, Al-Jandal N, Al-Mutairi A, Taqi H. Microplastic in Kuwait marine environment: results of first survey. Marine Pollution Bulletin. 2020;**152**:110880

[36] Naji A, Esmaili Z, Khan FR. Plastic debris and microplastics along the beaches of the strait of Hormuz, Persian Gulf. Marine Pollution Bulletin. 2017;**114**:1057-1062

[37] Enrique De-la-Torre G, Dioses-Salinas DC, Marlith Castro J, Antay R, Fernandez NY, Espinoza-Morriboron D. Abundance and distribution of microplastic on sandy beaches of Lime, Peru. Marine Pollution Bulletin. 2020;**151**:110877

[38] Uddin S, Fowler SW, Saeed T. Microplastic particles in the Persian/Arabian Gulf – A review on sampling. Marine Pollution Bulletin. 2020;**154**:111100

[39] Rezania S, Park J, Md Din MF, Taib SM, Talaiekhozani A, Yadav KK, et al. Microplastics pollution in different aquatic environments and biota: A review of recent studies. Marine Pollution Bulletin. 2018;**133**:191-208

[40] Shahul Hamid F, Agamuthu P. Worldwide distribution and abundance of microplastic: How dire is the situation? Waste Managment & Research. 2018;**36**:873-897

[41] Nabizadeh R, Sajadi M, Rastkari N, Yaghmaeian K. Microplastic pollution on the Persian Gulf shoreline A Case Study of Bandar Abbas City, Hormozgan Province, Iran. Marine Pollution Bulletin. 2019;**145**:536-546

[42] Yu X, Ladewig S, Bao S, Toline CA, Whitmire S, Chow AT. Occurrence and distribution of microplastics at selected coastal sitesalong the Southeastern United States. Science of the Total Environment. 2018;**613-614**:298-305

[43] Lots FA, Behrns P, Vijver MG, Horton AA, Bosker T. A large-scale investigation of microplastic contamination: Abundance and characteristics of microplastics in European beach sedimen. Marine Pollution Bulletin. 2017;**123**:219-226

[44] Blumenroder J, Sechet P, Kakkonen JE, Hatl MG. Microplastic contamination of intertidal sediments of Scapa Flow, Orkney: A first assessment. Marine Pollution Bulletin. 2017;**124**:112-120

[45] Lee J, Hong S, Song YK, Hong SH, Jang YC, Jang M, et al. Relationships among the abundances of plastic debris in different sizeclasses on beaches in South Korea. Marine Pollution Bulletin. 2013;**77**:349-354

[46] Imhof HK, Sigl R, Brauer E, Feyl S, Giesmann P, Klink S, et al. Spatial and temporal variation of macro-, meso- and microplastic abundance on a remote coral island of the Maldives, Indian Ocean. Marine Pollution Bulletin. 2017;**116**:340-347

[47] Naji A, Esmaili Z, Mason SA, Vethaak D. The occurrence of microplastic contamination in littoral sediments of The Persian Gulf, Iran. Environmental Science and Pollution Research. 2017;**24**:20459-20468

[48] Kor K, Ghazilou A, Ershadifar H. Microplastic pollution in the littoral sediments of the Northern Part of the Oman Sea. Marine Pollution Bulletin. 2020;**155**:111166

[49] Naji A, Nuri M, Amiri P, Niyogi S. Small microplastic particles (S-MPPs) in sediments of mangrove ecosystem. Marine Pollution Bulletin. 2019;**146**:305-311

[50] Abayomi OA, Range P, Al-Gouti MA, Obbard JP, Almeer SH, Ben-Hamadou R. Microplastics in coastal environments of The Arabian Gulf. Marine Pollution Bulletin. 2017;**124**:181-188

[51] Rebelein A, Int-Veen I, Kammann U, Scharsach JP. Microplastic fibers - Underestimated threat to aquatic organisms? Science of the Total Environment. 2021;**777**:146045

[52] Shen M, Zhang Y, Almatarfi E, Hu T, Zhou C, Song B, et al. Efficient removal of microplastics from wastewater by an electrocoagulation process. Chemical Engineering Journal. 2022;**428**:131161

[53] Corcoran E, Nellemann C, Baker E, Bos R, Osborn D, Savelli H. Sick water. In: The Central Role of Wastewater Managment in Sustainable Development. United Nation Environment Programm; 2010

[54] Amin RM, Sohaimi ES, Anuar ST, Bachok Z. Microplastic ingestion by zooplankton in Terengganu coastal waters, southern South China Sea. Marine Pollution Bulletin. 2020;**150**:110616

[55] Desforges J-PW, Galbraith M, Dangerfield N, Ross PS. Widespread distribution of microplastics in subsurface seawaterin the NE Pacific Ocean. Marine Pollution Bulletin. 2014;**79**:94-99

[56] Duncan EM, Broderick AC, Fuller WJ, Galloway TS, Godfrey MH, Hamann M, et al. Microplastic ingestion ubiquitous in marine turtles. Global Change Biology. 2018;**25**:744-752

[57] Steer M, Cole M, Thompson RC, Lindeque PK. Microplastic ingestion infish larvae in the western English channel. Environmental Pollution. 2017;**226**:250-259

[58] Lusher AL, Hernandez-Milian G, O'Brien J, Berrow S, O'Connor I, Officer R. Microplastic and macroplastic ingestion by a deep diving, oceaniccetacean: The true's beaked whalemesoplodon mirus. Environmental Pollution. 2015;**199**:185-191

[59] Shaw DG, Day RH. Colour- and form-dependent loss of plastic micro-debris from the North Pacific Ocean. Marine Pollution. 1994;**28**:39-43

[60] Chen Q, Zhang H, Allgeier A, Zhou Q, Ouelle JD, Crawford SE, et al. Marine microplastics bound dioxin-like chemicals: Model explanation and risk assessment. Journal of Hazardous Materials. 2019;**364**:82-90

[61] Wibowo YG, Rosanti D. Microplastic in marine environment and its impact. Sainmatika. 2019;**16**:81-87

[62] Wessel CC, Lockridge GR, Battiste D, Cebrian J. Abundance and characteristics of microplastics in beach sediments insights into microplastic accumulation in northern Gulf of Mexico estuaries. Marine Pollution Bulletin. 2016;**109**:178-183

[63] Young AM, Elliott JA. Characterization of microplastic and mesoplastic debris in sediments from Kamilo Beach and Kahuku Beach, Hawai'i. Marine Pollution Bulletin. 2016;**113**:477-482

[64] Faselli P, Blaskovic A, Bernardi G, Romeo T, Cizmek H, Andaloro F, et al. Plastic litter in sediments from a marine area likely to become protected (Aeolian Archipelago's islands, Tyrrhenian Sea). Marine Pollution Bulletin. 2016;**113**:526-529

[65] Herrera A, Asensio M, Martinez I, Santana A, Packard T, Gomez M.

Microplastic and tar pollution on three Canary Islands beaches: An annualstudy. Marine Pollution Bulletin. 2016;**129**:494-502

[66] Esiukova E. Plastic pollution on the Baltic beaches of Kaliningrad region, Russia. Marine Pollution Bulletin. 2017;**114**:1072-1080

[67] Nel H, Froneman P. A quantitative analysis of microplastic pollution along the south-easterncoastline of South Africa. Marine Pollution Bulletin. 2015;**101**:274-279