Distribution, source finding, and ecological hazard of polycyclic aromatic hydrocarbons and polychlorinated biphenyls in coastal surface sediments of South Pars industrial region (Iran)

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Research Article

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Distribution, source finding, and ecological hazard of polycyclic aromatic hydrocarbons and polychlorinated biphenyls in coastal surface sediments of South Pars industrial region (Iran)

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Research Highlights

- The first ecologic risk assessment of PCBs in south Pars coastal sediment.
- The first source finding of PCBs in south Pars coastal sediment.
- PAHs ecologic risk assessment and source finding.
- Increases in pollutants were found in the vicinity of industrial units.
- Increases in carcinogenic compounds in the vicinity of industrial units.
- Spatial distribution of PCB and PAH compounds in the South Pars region.

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Abstract

The South Pars Industrial Zone is one of the most important regions in Iran due to the presence of gas, petrochemical, and related industries which is known as Iran's energy capital. In this study, the effects of pollution made by polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) on coastal sediments were investigated. Ten stations in different places such as vicinities of industries exit flow, ports, shipping terminals, export tanks, beaches and their surface sediments were selected and sampled for analysis in summer and winter in 2019. The samples were tested using the gas chromatography-mass spectrometry (GC-MS) analyzer.Concentrations of $\sum PAH$ and $\sum PCB$ were measured in the range of 26.50–306.45 ng. g^{-1}dw (dry weight) and BDL (below the detection limit) –59.70 ng. g^{-1}dw, respectively. There was a significant increase near the outputs of refineries, petrochemicals, and the shipping industry. The ecological risks were reported "low" in all stations for PAH components, except for one station that recorded moderate levels of Acenaphtlen (Ace) and Fluorene (Flu) in the summer. The ecological risks related to PCB components were found to be in low-moderate levels. Three sources were suggested for PAHs: petrogenic (31%), fossil fuel combustion (51%), and biomass/coal combustion (18%). Power plants and wastewater treatment units (34%) and electrical waste disposal sites (66%) were predicted as the main sources of PCBs.It is necessary to prepare and implement a long-term monitoring plan for all outlets to the sea such as electrical waste.

Keywords: Polycyclic Aromatic Hydrocarbons, Polychlorinated Biphenyls, Ecologic Risk Assessment, South Pars Coastal Sediment, Source Finding and Spatial Distribution

Introduction

About 600 million people worldwide are living within 10 m from the sea so their health and life depend on marine sources and is endangered by pollution(Loiseau et al. 2021). Eighty percent of marine pollution comes from land-based activities, (Landrigan et al. 2020) such as oil, gas, petrochemical industries, energy production, transfer units, industrial waste storage sites, storage tanks, facilities, and export terminals (Kunili et al. 2021Nozar et al. 2014). The most important pollutants in the above activities are the persistent organic pollutants (POPs) (Benson et al. 2020).

Coastal sediment pollution caused by PAHs and PCBs is the most harmful marine pollution due to their physical and chemical properties such as hydrophobicity, carcinogenicity, lipophilicity, and stability in the marine environment. These compounds also have harmful effects on human health such as embryonic abnormalities and fetal stillbirth; therefore, they can be the main cause of many cancerous diseases due to their concentrations. (Löf et al. 2016) (Aghadadashi et al. 2019Park et al. 2020) (Girones et al. 2021Guo et al. 2019). The US Environmental Protection Agency (US-EPA) released a list containing 16 combinations of PAHs as environmental pollutants including seven combinations known to cause cancer in humans called carcinogenic polycyclic aromatic hydrocarbons (CPAHs) (Farrington. 2020).

The United Nations Environment Program (UNEP) estimated that 83% of previously produced PCBs still exist in the environment, which is why they need to be treated and removed properly (EPA. Mahmoudi et al. 2020). Contamination with PCBs has been reported in the samples taken from water and sediments worldwide. (Sakizadeh. 2020) In this regard, some studies conducted in recent years are reviewed here.

The levels of PAHs and PCBs in the northern vicinity of Persian gulf reported 55.3-1231.6,2-5-462ng. g^{-1}dw, respectively(Nozar et al. 2014). The total PAHs in Qatar marine environment was observed to be 3.15-14.35ng. g^{-1}dw. (Hassan et al. 2018). The levels of PAHs and PCBs in the Sea of Marmara were analyzed and reported to be lower than the allowable limits (Kunili et al. 2021).

According to sediment quality guidelines (SQGs), the potential ecological risks of PAHs in sediments along the Yangtze river Estuary Deepwater Channel are at low to medium levels (X. Liu et al. 2020). Also, PCB contamination was studied globally within the last three decades, which the most polluted area with numerous heavy factories and residential was reported to be the Italian Ionian Sea.

Pars gas field is located 105 km away from the nearest coast in Iran in the north of Persian Gulf. This area has led to the development of oil refineries and other industrial complexes in the region(Samadi Kuchaksaraei et al. 2021).The development of industries have led to population growth and resulted in an increase in the number of transportation services on these beaches.

Assaluyeh city, the most important industrial city in Iran, is constrained by the Persian Gulf from the south and the mountains from the north. Large and polluting industries such as petrochemical complexes, gas refineries, power plants, storage tanks, and export wharves near the urban fabric (Danesh et al. 2021), have the potential to produce and emit PAHs and PCBs (Benson et al. 2020Dumanoglu et al. 2017Sari et al. 2020). In the years 2016.17 Arfaeinia et al. and Hossein Khezri et al. reported the levels of PAHs and PCBs in the south pars industrial especial zone coastal area as 54.44-292.72ng. g^{-1}dw,312-10965pg. g^{-1}dw respectively (Arfaeinia et al. 2017Hoseyn Khezri et al. 2018).

Recently, most industrial units such as refineries, power plants, petrochemical complexes, and new export facilities have reached full potential in operation, making it essential to upgrade the pollution situation and increase the effectiveness of remedial measures.

To the best knowledge of the authors, there has not been a similar study conducted on the ecological hazards and source finding of PCBs in the coasts of the South Pars Industrial Zone, the results of this study can be a sufficient guide for further studies to reduce the risk of possible damage to the environment.

The main goals of the present study are first to provide spatial distribution maps of PAHs and PCBs in coastal sediments, secondly to determine the origin while assessing the ecological risk of PAHs and PCBs.

Material and Method

- Study area

The south Pars Industrial Zone is located on the shores of Persian Gulf, 300 km on the east of Bushehr and 570 km on the west of Bandar Abbas (which are two important ports in Iran). There are a combination of light and heavy industries such as 10 gas refining complexes, 7 petrochemical complexes, power generation units, and storage tanks, export facilities in the vicinity of residential and commercial areas of Assaluyeh city. The geographical coordinates of the mentioned region are 27.53438 to 27.41403 N and 52.25648 to 52.67028 N with an approximate area of 521.5 square kilometers. The climate of the region is excruciating hot and humid (Figure 1) (Mahmoudi et al. 2020).

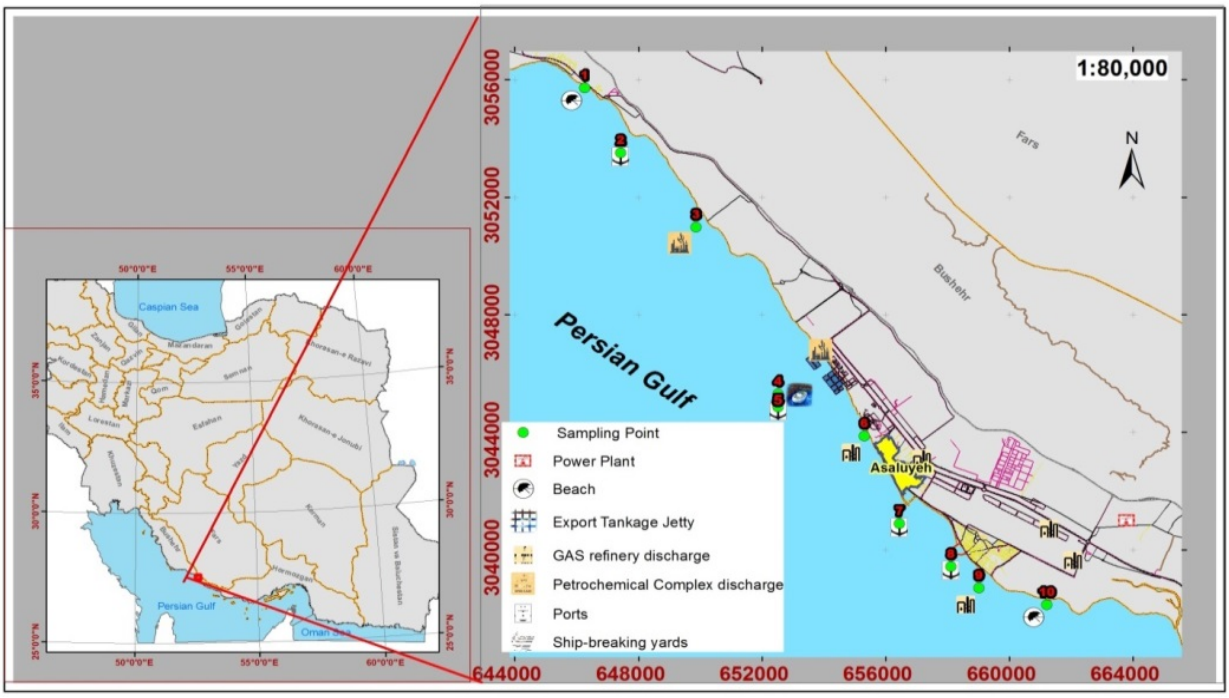


Figure 1. The study area in the South Pars industrial region (Iran) and the sampling locations (green dots)

- **Sampling method and collection of samples**

According to the purpose of the study, to investigate the role of industrial outputs in marine pollution, sampling stations was selected by a suitable systematic method. (Batley et al. 2016) Ten stations were considered along the sea line of the south pars industrial regions adjacent to the industrial zone, ports, discharge points, residential areas, and one beach site far from the potential contamination sources as a control station (Fig. 1). Each station was sampled twice in summer and winter 2019 (winter and summer) (Hoseyn Khezri et al. 2018). Surface sediments were sampled (Odabasi et al. 2017). Sampling points were positioned by the Global Positioning System (GPS).

Samples were collected by Van Veen Grub sampler with an area of 250 cm2 (made of stainless steel, with approximate dimensions of 55 × 30 × 22 cm and mass 5 kg). The water depths of the sampling sites were in the range of 10 to 32 meters. Approximately 350 grams of uniform sediment was stored in aluminum containers and sent to the laboratory in an icebox. The physical and chemical parameters of seawater such as PH, temperature, and salinity were also measured at each station(Odabasi et al. 2017).

- **Samples preparation**

Samples after freeze-drying kept laboratory until the test at -20 °C (Nozar et al. 2014)

- **PCBs** Extraction

The frozen samples were crushed and passed through a sieve with a mesh size of 250 µm. Then, 20 g of the sample was weighed and transferred without hands using aluminum foil fingers and pliers. Moreover, 1 ml of a PCB 198 and PCB 29

128 solution with a concentration of20 ng/ml was added as an internal standard. Extraction was performed with 250 ml of
129 hexane/dichloromethane solution (50:50 ratios) and many boiling stones for 8 hours. To prepare the standard peak, 1 ml of
130 internal standard solution was added, then Soxhlet operation was performed without any samples. The copper powder was
131 used to remove free sulfur and mercaptans. (Benson et al. 2020).

132 - **PAHs Extraction**

133 The frozen sediment samples were crushed and passed through a sieve with a mesh size of 250 μm Then 15 g of the samples
134 were weighed and poured into the thimble, then extracted with a 50: 50 hexane-dichloromethane solution in Soxhlet
135 apparatus, the internal standard was added to the sample to determine the yield. The internal standard is 50 microliters of a
136 mixture containing 20 ng / μl of N-C19 D40 and N-C32 D66 solution for the first fraction and about 20 ng / μl of
137 hexamethyl benzene, cadalene, and naphthalene D8 for the second fraction. Extraction in Soxhlet was done with 250 ml of
138 hexane/dichloromethane mixture. The copper powder was used to remove free sulfur and mercaptans (Nozar et al. 2014).

139 - **Instrumental Analysis**

140 The samples were injected with an auto sampler to a GC/MS Agilent-7890 B, mass detector 5977, a MSD with a DB-5MS
141 column type and chromatogram to obtain the mass spectrum. The results were compared with a calibration reference
142 standard. The temperature program for PAHs was chosen as follows: initially, in 2 minutes it reached 160 °C and then
143 reached the temperatures of 200, 290 and, 300 °C in 3 steps with slopes of 12, 3, and 10 °C. For PCB, the temperature
144 reached 150 °C. Then in 3 steps, with a slope that reached 12.3 and 20 degrees Celsius to 210, 270, and 280 degrees Celsius
145 in a minute.

146 PAHs and PCBs congeners: all samples were analyzed for 41 PCBs and 195 16PAHs (Nisbet et al. 1992) which are
147 abbreviated in Table 1. The amount of organic matter (OM) was determined by weight method via heating to 600 °C for 4 h
148 (W. Wang et al. 2011).

149 **Table 1.** PAH components/abbreviations

Compound	Abbreviation	Compound	Abbreviation
Benzo[a]pyrene	BaP	Acenaphthene	Ace
Benzo[a]anthracene	B(a)A	Acenaphthylene	Acy
Benzo[b]fluoranthene	B(b)F	Fluranthene	Flt
Benzo[k]fluoranthene	B(k)F	Fluorene	Flu
Indeno[l23-c,d]pyrene	IND	Naphthalene	Nap
Anthracene	Ant	Phenanthrene	Phe
Benzo[g,h,i]peryIene	B(ghi)P	Dibenzo(a,h)anthracene	DBA
Chrysene	Cry	pyrene	Pyr

150

151 - **QA/QC**

152 To control the quality and ensure the reliability of results, the tests were conducted by the standards of the Iran's
153 Department of Environment (Moghadam et al. 2018) valid articles and using devices with a valid calibration certificate. All
154 sampling and testing equipment were washed with water and purified water, respectively. A solution with specific
155 concentrations was prepared for PAHs and PCBs and was added to each sample and control sample to calculate the

recovery efficiency before extraction. Recovery efficiencies for PCBs and PAHs were 85.4% - 107.5% and 75.4% - 115.2%, respectively. Hence, the data were acceptable and did not need to be modified

We analyzed the data in case of the accuracy of prepared materials, a blank sample was prepared and the results below the detection limit were read (LOD).

Standard PCB and PAH solutions were used to construct GC/MS calibration curves with five calibration points at concentrations of 10, 50, 100, 250, and 500 ng/ml. A linear response ($r2 > 0.999$) was observed by the GC-MS. The method detection limits (MDL in terms of ng/g) for PAHs and PCBs were calculated 0.3 and0.15 ng/g respectively.

- **Sources finding**

One of the most important classifications for PAH to obtain the source of contamination is based on the number of aromatic rings and their molecular weight (Ghosh et al. 2021). Regarding PCB congeners, it is based on the number of chlorine. (Lu et al. 2021)

General sources for the release of PCBs congeners, such as emissions of combustion, incineration of plastic waste, leaks from sites containing PCBs compounds, coal and related waste, which are transported by air and water (Dumanoglu et al. 2017). The composition of PCBs is divided into homologs based on the number of chlorine (di-Teri-tetra-Penta –Hexa-Hepta-Octa). The source of emission is also different depending on the homolog.

Low chlorine originates from the used equipment, electrical waste and productions of unintentional products (U-PCB). The sources are paint additives and building materials which are mostly released inadvertently. U-PCBs are usually the primary sources of decomposition and adsorption of lightweight PCBs, which include combustion sources, process industries, power plants, and incinerators.

- **EPA's Unmix**

The US EPA-UNMIX software was used to model the conditions, predict the sources of PAHs and PCBs pollution production (share detection). (Y. Wang et al. 2016). This software is based on the using share modeling and provides appropriate profiles using mathematical matrices. In principle, the model follows and applies the following equation, where xij is the concentration of specie i in sample j, f_{ik} is the concentration of specie at sources k, and G_{kj}= the share of source k in sample j (Cao et al. 2020).

$$X_{ij} \equiv \sum_{i} f_{ik} G_{kj} \qquad (1)$$

The advanced release modeling analysis using EPA UNMIX6 software was implemented to accurately identify the sources of production and release of PAHs and the share of each source, along with forecasting. After performing all components, the software was run by feeding the laboratory results and introducing three sources with a suitable signal-to-noise index (more than 1.5). The report of the model's certainty was appropriate. For more information, refer to the EPA UNMIX 6 fundamentals and user guide (EPA. 2007).

- **Diagnostic indexes**

The sources of PAH were detected using diagnostic indexes and EPA's Unmix software. These indicators are related to the surrounding producer resources. Compounds with lighter molecular weights are the result of burning at low temperatures, such as wood-burning, and those with heavier molecular weights result from burning at higher temperatures (Manoli et al. 2004). The diagnosis indicators of the PAH, which were used in this study, are shown in table 2(Benson et al. 2020Sari et al. 2020).

Table 2. Relative indexes used to find the origin of PAHs

Origin of production	Value	Indicators Index (II)	Ref.
Petrogenic Pyrogenic	II< 0.1 II> 0.1	Ant. / (Ant+Phe.)	(Lorenzi et al. 2011)
Petrogenic Fossil fuel combustion Grass, wood, coal Biomass/coal combustion	II< 0.4 < 0.5 II 0.4 < II> 0.5	Flt/(Flt +Pyr)	(Franco et al. 2017)
Petrogenic Combustion	< 0.2.II II> 0.35	Bap/(BaP +Chr)	(J. Liu et al. 2019)
Pyrogenic Petrogenic	II< 1 II> 1	LMWPAH /HMWPAH	(Tucca et al. 2020)

In general, sediments are usually the destination of cyclic aromatic hydrocarbon compounds poured into the sea (Duran et al. 2016). Two PAH diagnostics indices used in similar studies were used in the present study. An ant./(Ant. + Phe.) The ratio lower than 0.1 indicates the production of PAH by petroleum (crude oil and its derivatives). When this index is higher than 0.1, the petrogenic source is the main role in the production of compounds of the PAH is. Based on the ratios mentioned in 20% of the stations in the region, Crude oil compounds were the predominant source. The reason for this is the proximity of the above stations to the export tanks of oil derivatives and fishing boats, leaks, and deliberate leaks into the sea. Flt/ (Flt +Pyr) were used as the second index, and a result less than 0.4 indicates the main role of petrogenic fossil fuel combustion, a result in the range of 0.4-0.5 indicates the grass, wood, and coal as the main factor of production, and a value greater than 0.5 represents the predominant source of biomass/coal combustion (Cao et al. 2020).

- **Ecotoxicological Assessment**

Considering the effects of PCBs and PAHs compounds on ecological sediments and their destructive role in the health of living organisms and its resulting hazards, sediment hazards in the marine environment were assessed using the information, risks, and complications of the Sediment Quality Guide (SQG) (Y. Li et al. 2017). The low impact range (ERL) and the moderate range (ERM) indicate probabilities of biological complications less than 10% and more than 50%, respectively

(Long et al. 1995). PAH densities below ERL, between ERL and ERM, and above ERM indicate that destructive biological effects occur in the order of infrequently (low), occasional (moderate), and often (high) (Cao et al. 2020Y. Li et al. 2017).

- **Statistical Analysis**

Statistical analysis was performed by using the SPSS software, Version 22 of IBM product, copyright of 2018. In this study, Shapiro-Wilk, Kolmogorov-Smirnov normality tests, ANOVA analysis of variance, and t-test were used. The significance level for all results considered 0.05 (Umasangaji et al. 2020).

Results and discussion

- **The density of PAHs and PCBs**

The results of the density of PCBs and PAHs by the components/congeners are shown in Tables 2 and 3. PAHs were present (summer and winter) in all stations and their ranges were 26.5-306.5 and 97-210 $ng.g^{-1}dw$, respectively. PCBs were present in all stations in winter; stations no.1, 4, 5, and 6,8,10 in summer with the concentration range of BDL-59.7, BDL-54.4$ng.g^{-1}dw$, respectively. As shown in the spatial distribution of pollutants maps (Figs.4a, b), the highest concentrations of PAHs and PCBs were related to stations number 6 and 3, respectively; these two stations are close to the effluent of industrial complexes.

The average concentration of PAHs has decreased compared to the previous study in the region conducted in 2016. The maximum values increased significantly, which indicates the creation of pollution distribution points (Hoseyn Khezri et al. 2018). Concentrations of PCB congeners showed higher concentrations than studies done in the study zone and northern Persian Gulf(Arfaeinia et al. 2017) (Nozar et al. 2014). The highest concentrations of carcinogenic PAHs were reported from stations 10 (local boat pier), 9, and 6 (effluent of refineries and the port), 4 (tank repair pier), and 5 (shipping port) with percentages of 21, 15, 13, 13, and 11%, respectively.

The results showed that low molecular weight PAH compounds were predominant in 75% and medium molecular weight compounds in 25% of the study area. It was reported that Phenanthrene, Pyrene, Naphthalene, and Acenaphthene compounds have the highest concentrations at the stations, PCB18, PCB44, PCB105 were the most dominant congeners in the all stations, respectively.

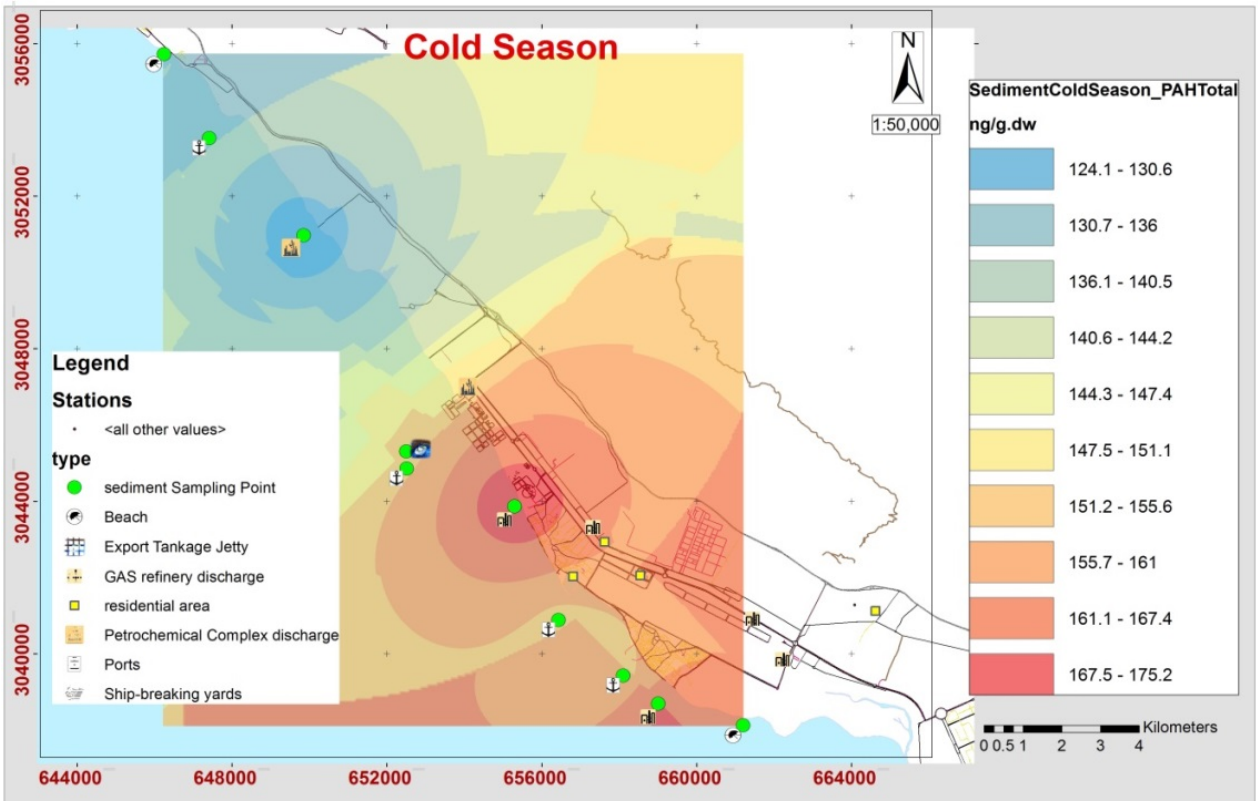
As shown in Figure 5 the highest amounts of LMW-PAH, HMW-PAH compounds were observed in station number 6 (Refineries effluent and port) and station 10 (Local boat pier) 155 $ng.g^{-1}dw$ 26.83$ng.g^{-1}dw$ respectively. The highest amount (43.57 $ng.g^{-1}dw$) of low chlorine PCB congeners DI-PCB was observed in station 3 (effluent of industrial complexes) and more chlorinated PCB congeners (Penta-PCB, Hexa-PCB, and hepa-PCB) were measured at 3.45, 10.67, and 5.1 $ng.g^{-1}dw$ at station 9, 4, and 1, respectively.

Table 3. Concentrations of PCBs according to the season ($\mathbf{ng.g^{-1}dw}$)

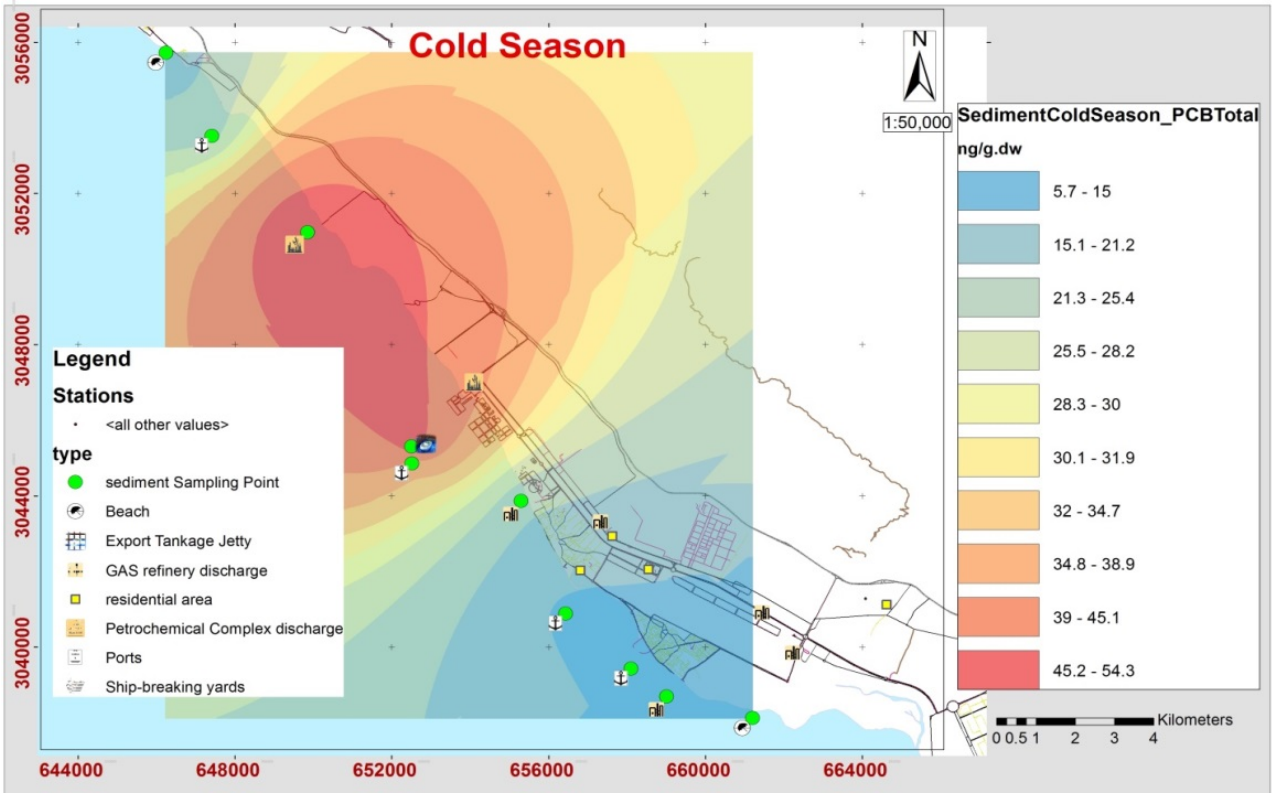
PCBs								
	Winter				Summer			
Component	Range	Mean	Median	SD	Range	Mean	Median	SD
PCB 18	ND- 43.57	13.48	6.91	15.06	ND- 2.00	0.30	0.00	0.64
PCB 31	ND	-	-	-	ND	-	-	-
PCB 28	ND- 1.97	0.38	0.00	0.76	ND	-	-	-
PCB 44	ND- 10.85	4.47	4.52	4.17	ND- 566.00	56.60	0.00	169.80
PCB 52	ND	-	-	-	ND- 3.00	0.80	0.00	1.25
PCB 105	ND- 3.45	2.00	1.90	0.91	ND- 14.00	1.60	0.00	4.18
PCB 141	ND	-	-	-	ND	-	-	-
PCB 149	ND	-	-	-	ND	-	-	-
PCB 138	ND- 5.09	1.47	1.86	1.51	ND	-	-	-
PCB 151	ND- 5.26	1.76	1.80	1.76	ND	-	-	-
PCB 180	ND- 5.09	1.41	0.91	1.68	ND- 11.00	1.10	0.00	3.30
PCB 194	ND	-	-	-	ND	-	-	-
PCBs	5.68- 54.42	24.98	20.63	15.41	ND- 579.00	60.40	1.50	172.94

Table 4. Concentrations of PAHs according to the seasons($\mathbf{ng.g^{-1}dw}$)

PAHs								
	Winter				Summer			
Component	Range	Mean	Median	SD	Range	Mean	Median	SD
Naphthalene	0.34-48.14	16.07	16.07	14.13	ND	-	-	-
Biphenyl	13.50-33.78	19.51	19.51	6.05	ND	-	-	--
Acenaphtylen	0.25-5.06	2.06	2.06	1.34	ND- 185.5	23.08	0.00	55.08
Acenaphtlen	2.70-30.41	9.08	9.08	10.68	ND- 7.3	1.62	0.00	2.66
Florene	5.47-7.61	6.52	6.52	0.66	ND- 35.2	4.69	0.50	10.31
Phenanthrene	19.97-41.74	29.73	29.73	6.06	ND- 8.5	4.19	4.17	2.10
Anthracene	13.32-20.58	16.58	16.58	2.02	ND- 14.0	6.88	6.45	3.60
Fluoranthene	0.23-14.20	8.96	8.96	4.57	ND- 4.4	1.87	1.55	1.22
Pyrene	1.13-61.69	26.96	26.96	16.58	ND- 17.5	5.57	2.90	5.68
Benzo(a)ant	0.82-2.30	1.60	1.60	0.44	ND- 3.9	0.60	0.00	1.27
Chrysene	ND-3.70	0.82	0.82	1.32	ND- 5.8	0.89	0.00	1.88
B(b)F	0.38-11.62	2.47	2.47	3.23	ND- 86.0	36.99	23.50	33.13
B(k)F	ND-8.54	4.39	4.39	2.61	ND- 65.8	36.44	45.75	25.21
B(a)P	0.20-26.73	7.59	7.59	7.41	ND- 12.5	5.79	5.40	4.25
Dibenzo(a,h)Anthracene	ND	-	-	-	ND- 9.6	0.96	0.00	2.88
Benzo(g,h,i) PeryIene	.ND	-	-	-	ND- 0.9	0.09	0.00	0.28
Indeno(1,2,3cd)Pyrene	.ND	-	-	-	ND- 8.4	1.78	0.00	2.70
$\sum PAHs$	97.94-210.49	152.35	152.35	30.17	ND- 306.7	131.45	125.55	79.25



261
262 **Figure 2.** The spatial distribution of PAHs (GIS software output)



263
264 **Figure 3.** The spatial distribution of PCBs (GIS software output)
265
266

b

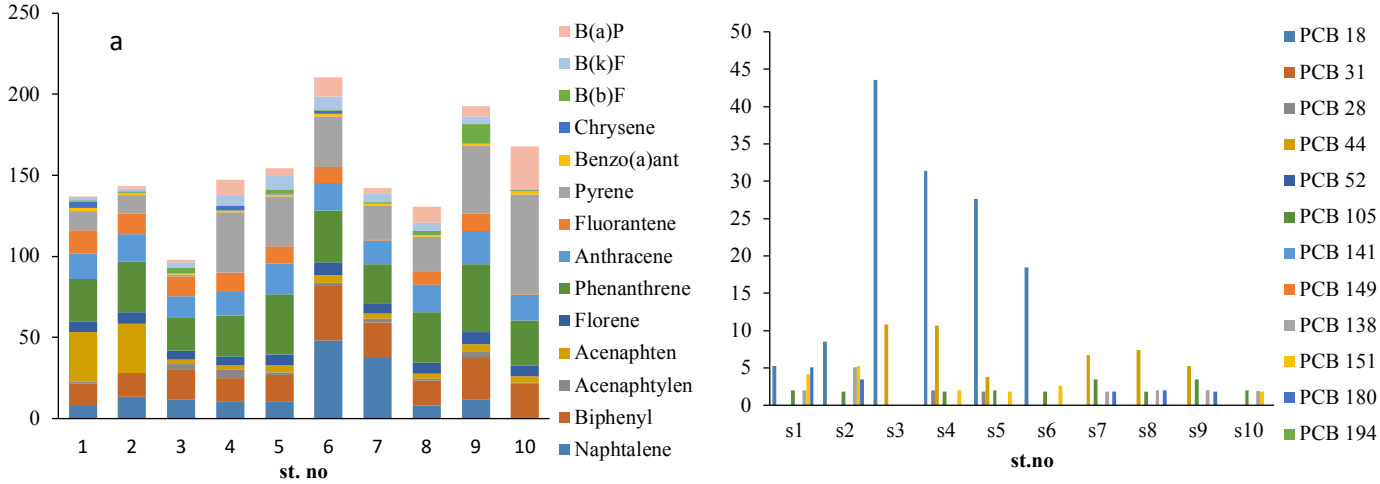


Figure 4. Concentrations of PAHs (a) and PCBs (b) measured in $\mathbf{ng.g^{-1}dw}$

- **Impacts of changes**

The statistical analysis of the results by statistical software and the t-index indicated no significant changes in the results of PCBs which were obtained in the summer and winter ($p = 0.05$). On the other hand, the concentrations of PAHs were significantly correlated with seasonal changes ($p = 0.05$). In summer, the concentration increased significantly; therefore, this can refer to the Persian Gulf marine meteorological conditions.

The main cause of sediment deposition in waters, seas, and estuaries is done by currents and the dynamics of water movement (W. Li et al. 2021). In summer, the organic matter settles in the seabed, and the organic matter of the sediment reaches its maximum, which shows a significant increase compared to that of winter (Pruski et al. 2021). Due to the role of the South Pars Industrial Zone in supplying Iran's gas in winter and the need to have the units repaired in summer, the probability of pollutants entering the storage tanks and the sea in summer increases. (Kaveh Pishghadam et al. 2021Sarkheil. 2021).

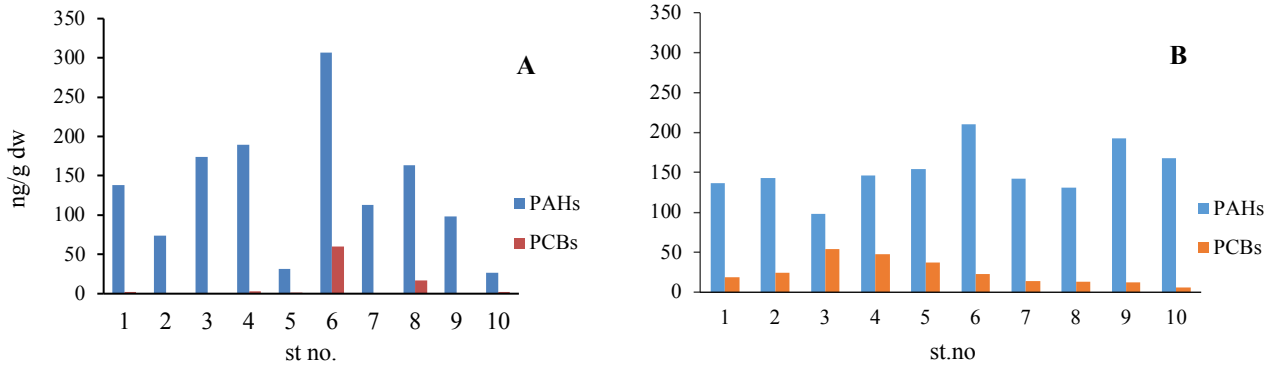


Figure 5. Concentrations of PAHs and PCBs (A: summer and B: Winter) measured in $\mathbf{ng.g^{-1}dw}$

- **Source finding**

PAHs

According to the results as shown in Fig6, 70% of the stations were the predominant source of fossil fuel combustion and vehicle combustion (the activity of commercial and fishing boats is seen in the above stations), and 30% of the stations are the predominant source of biomass/coal combustion, which can be caused by proximity to the output of industrial complexes and wastewater treatment plants. In the present study, the first release factor of PAH compounds was vehicles and subsequent biomass production.

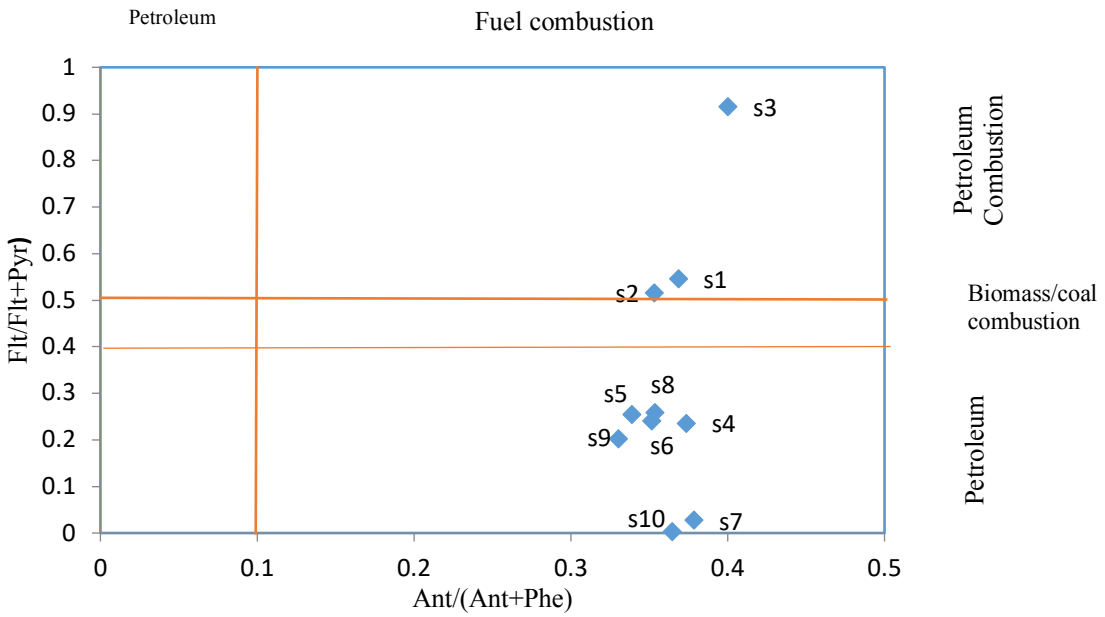


Figure 6. The diagnostic ratio ant/(ant+phe) vs. Flt/(Flt+Pyr). Flt, Pyr, Ant, and Phe symbolize Fluranthene, pyrene, Anthracene, and Phenanthrene, respectively.

Three sources according to the UNMIX report were identified. Examinations of the conditions of the study area were as follows.

1- Petrogenic / natural (crude oil and its derivatives ((discharge to the sea)) and discharge of port effluent and storage tanks).

2- Fossil fuel combustion (vehicles and traffic)

3- Biomass combustion sources / incomplete combustion and discharge of wastewater treatment units of gas and petrochemical industries. The charts show the results of modeling (Figs.7, 8).

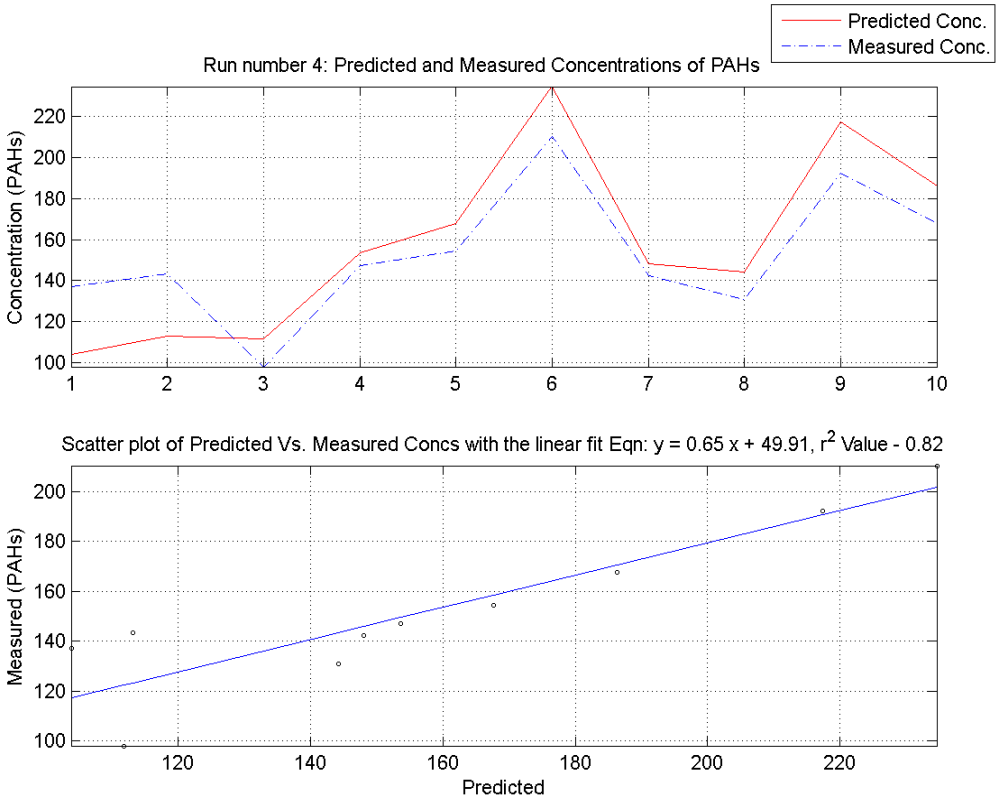
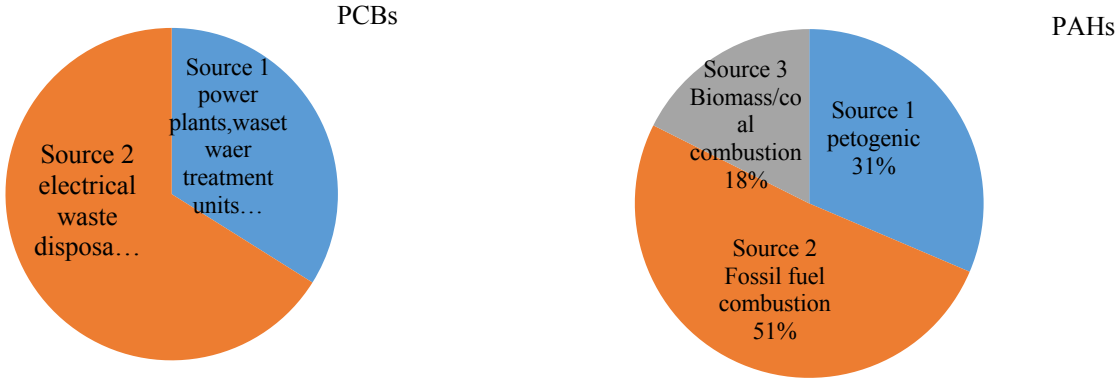


Figure 7. Prediction and measurement indicate the appropriateness of matching the actual and predicted values by the model

PCBs

Two main sources were predicted for PCBs. In the first source High-chlorine compounds (PCB105, PCB131, PCB151, and PCB180) were found to be dominant with 68.1%. These congeners were used in a high percentage of commercial compounds PCB1254 and PCB1260, which had various applications such as electric converters, gas distribution turbines, hydraulic fluids, adhesives, rubbers, heat transfer systems, wax diluents, and carbon-free papers (Information. 2021). This source can be considered as industrial units such as power plants and industrial wastewater treatment units of industrial complexes and refineries.

In source 2, low-chlorine compounds (PCB 18, PCB28, and PCB44) were in the majority with 93.4%. These compounds make up a high percentage of arcolor1016 and mostly were used as capacitors and electrical insulators. This source can be considered as electrical waste disposal sites.



318 **Figure 8.** The percentage of production sources of PAHs and PCBs in the study area

319 - **Ecological risk evaluation**

320 The results of ecological risk of all stations except Station 7 were assessed as "low" (Table 3). As the station was located
321 near the outlets of storage tanks, ports, refineries and other industries, this result shows the role of industries in coastal
322 pollution.

323 **Table 5.** PAH densities (mg/kg) of PA, Hs, ERL, and ERM (Burton. 2002)

PAHs	ERL	ERM	Current study	
			Min.	Max.
Naphthalene	0.16	2.10	0	0.0073
Acenaphthylene	0.04	0.64	0	0.1855
Acenaphthene	0.02	0.50	0	0.0352
Fluorene	0.02	0.54	0	0.0085
Phenanthrene	0.24	1.50	0	0.014
Anthracene	0.085	1.10	0	0.0044
Fluoranthene	0.60	5.10	0	0.0175
Pyrene	0.66	2.50	0	0.0039
Benzo(a)anthracene	0.26	1.60	0	0.0058
Chrysene	0.38	2.80	0	0.086
Benzo(b)fluoranthene	0.32	1.88	0	0.0658
Benzo(k)fluoranthene	0.28	1.62	0	0.0125
Benzo(a)pyrene	0.43	1.60	0	0.0096
Dibenzo(a,h)anthracene	0.43	1.60	0.0000	0.00094
Indeno(123-c,d)pyrene	0	0	0.0000	0.00814
Benzo(g,h,i)perylene	0.063	0.26	0.0000	0.00094
Σ16PAHs	4.02	44.79	0.0265	0.30645
LMW	0.55	3.16	0	0.237
HMW	1.70	9.60	0	0.229
Total PCBs	0.023	0.18	0	0.0597

ERL — Effect Range Low; ERM — Effect Range Median Long (1992), (Burton. 2002).

- **Comparison with other studies**

Comparison of the results of the present study with the reported studies (Table 6) has shown that the concentration of PCBs and PAHs, and ecological hazards are lower than in the northern part of the Persian Gulf. However, compared to the previous study conducted on the coasts of Assaluyeh, the coastal areas adjacent to the Aliaga Industrial Zone in Turkey and the coastal areas of Qatar and Bahrain are more concentrated due to the commonality of the coastal areas under study with the coasts of Qatar and Bahrain (Persian Gulf), pollution monitoring and removal is essential.

Table 6. Some ecological risks from world waters

Study area	Ecological risk	Component (ng·g−1dw)	Reference
Urbanized semi-enclosed Jiaozhou Bay, China	Rarely	PAH: 37.7-290.9	(Cao et al. 2020)
Northern Persian Gulf	The sites with amounts > ELR 10.3% and > ERM were estimated at 2.9%	PAHs: 55.3-1231.6 PCBs: 2.5-462	(Nozar et al. 2014)
KimNguu river, Northern area of Vietnam	Low to medium risk	PAHs: 3.57 to 84.39 PCBs: 4.73 to 36.34	(Toan et al. 2020)
Danshui River basin, Taipei, Taiwan	Relatively low	PCBs: 0.02 to 54.9 PAHs:96 to 3803	(Cheng et al. 2020)
South pars industrial region coast	Low to moderate	PAHs:26.5-306.45 PCBs: 0-59.7	Current study
Aliaga industrial region, Turkey	-	PAHs:35.5–49,682 PCBs:2.7–2450	(Odabasi et al. 2017)
Pearl River Estuary China	Medium	PCBs: 4.6 to 187.4	(Tang et al. 2020)
Volturno River, Southern Italy	The integrity is possibly at risk.	PCBs: 4.3 to 64.3	(Montuori et al. 2020)
Lagos lagoon, Nigeria	considerable	PAHs:1.43–5.90 PCBs: BDL – 6.41	(Benson et al. 2020)
Liaohe Estuary, China	Low	PCBs: 106.7 to 270.0 pg·g−1dw	(Zhong et al. 2020)
Multi-industrial city of Ulsan, South Korea	-	The mean concentration of Σ16 PAHs was 722.	(Seo et al. 2020)
Marine sediments collected from the Kingdom of Bahrain	Low	-	(Bersuder et al. 2020)
Qatar marine environment	Low	PAHs were in the range of 3.15–14.35	(Hassan et al. 2018)
Persian Gulf surface sediments, Bushehr, Iran	Low	The range of total 15 PAHs in sediment was from 6.5 to 35.5 ng g-1	(Bateni. 2019)
The Persian Gulf, five commercially important fish species from Larak coral Island, Iran	Low	PCBs in surface sediments 2.95–7.95 ng g^{-1}dw)	(Ranjbar Jafarabadi et al. 2019)
Pars Special Economic Energy Zone, Iran	Lower than the standard limits	PAHs in sediment was 292.72±54.44 ng/g dw	(Hoseyn Khezri et al. 2018)
heavily industrialized area of Assaluyeh, Iran	---------	PCBs in surface sediments : 313-14107pg g−1dw	(Arfaeinia et al. 2017)

- Conclusion

Nowadays, pollution can be one of the main concerns due to the presence of stable organic compounds, such as PAHs and PCBs in aquatic areas, especially in coastal areas. The present study demonstrated that the concentrations of PAHs and PCBs increased in locations close to the outlets of refineries, other industrial complexes, and shipping industries compared to other areas. However, the environmental risk was evaluated from low to medium according to the defined indicators. In the report of resource analysis in places with activities such as exporting petroleum products and fishing boat routes, the predominant sources of PAHs were shown to be petrogenic. The predominant sources of PCBs were power plants, wastewater treatment plants, and landfills. Thus, it is necessary to prepare and implement a long-term monitoring plan for all outlets to the sea such as electrical waste. Possible leaks must be repaired and deliberate dumping of materials into the sea must be prevented. Likewise, further studies focusing on other persistent organic pollutant classes, origins of compounds, and sampling of fish and other marine organisms are required.

Author contribution Fazel Amiri and Tayebeh Tabatabaie: conceptualization, methodology, writing-reviewing, and editing. Alireza Ghadrshenas: sample preparation and chemical analysis. Abdul Rahim Pazira: writing, reviewing, and editing. All authors read and approved the final manuscript.

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Conflicts of 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.

Availability of data and materials The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Declarations

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Consent for publication Not applicable

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