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RESEARCH ARTICLE

Spatial-seasonal variations and ecological risk of heavy metals in Persian gulf coastal region: case study of Iran

Mohsen Mirzaei[1] · Masoud Hatamimanesh[2] · Arash Haghshenas[3] · Saghi Movahhed Moghaddam[4] · Alexandru Ozunu[5] · Hossein Azadi[6,7,8]

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Abstract

Purpose This study aimed to perform a systematic review to analyse the seasonal concentration and ecological risk assessment of heavy metals (HMs) in seawater and sediment samples collected from the coastline of Jam city in Bushehr, Iran.

Methods A total of 96 sediment and seawater samples were collected from 16 sampling stations during the spring, summer, autumn, and winter of 2017. Then, the concentrations of Pb, Ni, Cd, Cr, Cu, Zn, and Fe were determined. Finally, the pollution load index (PLI), ecological risk (Er), and environmental risk (RI) were calculated to assess the HM ecological risk.

Results The results showed that the mean concentrations of HMs were lower than the maximum acceptable concentration by SQG and NOAA. In addition, the PLI assessed a low pollution load level in the region. The ER and RI results also showed that the region was at low risk, and the metal risk was classified as Cd > Cu > Pb > Ni > Zn > Cr. In some samples, the mean concentrations of HM were found to be higher with a statistically significant difference ($P<0.05$). The results also showed that sediments were engaging in a moderate Er by Cd.

Conclusions Generally, the rapid growth of urbanization, as well as industrial and human activities, along this coastline and area has increased the pollutants dumped into the seawater and sediments. Thus, it is necessary to take regular monitoring programs and develop better management strategies to minimize the amount of HMs entering into this coastal area.

Keywords Pollution load index · Heavy metals · Ecological risk assessment · Sediment, seawater · Persian gulf

Introduction

The coastal areas are located between aquatic and terrestrial ecosystems that are able to display the outcome of both ecosystems [1]. Aquatic ecosystems are one of the most important ones among renewable sources on earth, and all living organisms need this huge resource [2]. Development in cities and various industries such as mining, agriculture, oil, petrochemical, etc., cause large volumes of sewage and agricultural and industrial wastewater to increase toxic pollutants such as heavy metal (HM) in aquatic ecosystems [3, 4].

Among the aquatic ecosystems, the Persian Gulf is one of the most critical Gulfs in terms of contamination risks [5, 6]. This Gulf is surrounded by eight countries and extensively influenced by different anthropogenic pressures due to experiencing rapid developments [7]. Environmental disasters, like enormous oil spill throughout the world in 1991, as well as oil platforms, petrochemical plants, refineries, movement of oil tankers and various marine transportation, and also solid waste and wastewater of coastal metropolis make this

✉ Hossein Azadi
hossein.azadi@ugent.be

[1] Grape Environmental Science Department, Research Institute for Grapes and Raisin (RIGR), Malayer University, Malayer, Iran

[2] Department of Environment, Malayer University, Malayer, Iran

[3] Iran Shrimp Research Center, Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization, Bushehr, Iran

[4] Department of Agroecology, Environmental Sciences Research Institute, Shahid Beheshti University, Tehran, Iran

[5] Faculty of Environmental Science and Engineering, Babeş-Bolyai University, Cluj-Napoca, Romania

[6] Department of Geography, Ghent University, Ghent, Belgium

[7] Research Group Climate Change and Security, Institute of Geography, University of Hamburg, Hamburg, Germany

[8] Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

region prone to severe contamination crises. Persian Gulf coastal sediments have a high absorption power of pollutants due to the nature of clay, a high electrical load, and a high capacity of cationic exchange, which can be considered as the stability of the pollutants [8].

HM has become a global concern because of toxicity and adverse effects on the environment and human health [9]. The presence of HMs in the environment can be due to many natural and human resources [10]. Discharging urban, industrial, agricultural wastewater and solid waste into seawater sources can be noted as important human resources [11]. Metals such as Cd, Cu, Pb, Fe, and Zn are resistant to biological and chemical degradation and because of properties such as stability, high toxicity in organisms, and adverse effects on humans are highly interesting for research [12, 13]. Moreover, these metals are the most dangerous contaminants in the food chain due to bioaccumulation and bio magnification properties [14]. However, some elements such as Cu and Zn are essential in small quantities, but their very high concentrations can lead to serious danger for living organisms [15].

It is necessary to determine the concentration and assess the risk posed by them in aquatic ecosystems (i.e., sediments and seawaters) [7]. In many previous studies, high concentrations of HM were reported in the sediments of coastal regions around the world [10, 11, 16]. Sediments are recognized as the sink and reservoir for HMs accumulation [8, 14, 17, 18].

Therefore, detecting the concentrations of HM in seawater and sediment samples is one of the effective ways for monitoring human interference and the entrance of toxic pollutants with human origin into marine environments [7]. In addition, to provide a more holistic view of environmental pollution, using ecological risk indices such as the potential ecological risk index of single metal (Er) and the ecological risk of the environment (RI) can be practical [19–21]. These indices are based on metal concentration and toxicity in order to determine the potential risk of seawater pollution in sediments [22]. There are a considerable number of studies regarding the contamination of HM in seawater and coastal sediments. Rajeshkumar et al. (2018) [23] investigated the seasonal variation of HM in the Meiliang Bay of Taihu Lake in China in seawater, sediment, fish, and oysters. Based on these results, contamination caused by Pb and Cr in sediment samples was moderate to high. Sharifinia et al. (2018) [7] also evaluated the ecological risk of HMs (Zn, Pb, Cu, and Cd) in surface sediments of the Persian Gulf and Oman sea. In their area of study, they reported a moderate or significant ecological risk. Performing such studies leads to the awareness of HM pollution state and the reduction of environmental risks. Considering the importance of the northern coasts of the Persian Gulf, some studies have been conducted to investigate the concentration and risk assessment of HM [5, 7, 9], but time/seasonal variations of metals were not considered. Therefore, this study was performed with the following aims: i) determining HMs (Pb, Ni, Cd, Cr, Cu, Zn, and Fe) concentration in seawater and sediment samples of a coastal region of Bushehr province (Persian Gulf), ii) investigating the seasonal and spatial variation of metals in the study area, and iii) assessing the ecological risks caused by the metal in the study area.

Materials and methods

Study area

Persian Gulf is a shallow seawater basin with an average depth of 35 m and an area of 240,000 km^2 [5]. This Gulf is located in the south of Iran, which is connected to Oman Sea and international waters by Hormuz strait. The intensity of human activities in Persian Gulf is more than usual because there are huge reserves of gas and oil. It is estimated that annually 20 to 30 thousand oil tankers are transferred through Persian Gulf which include 30% of the total world's transportation [5, 8].

The study area is located in a coastal strip with about18.89 km length in the northern part of Persian Gulf in Jam city, Bushehr province. The region is extended between latitude 27, 46, 38″- 27, 23, 23″ N and longitude 52, 7, 1.9″-52, 34, 45″ E (Fig. 1). In this study, 16 sampling stations were selected at the downstream of the important pollutant release industries.

Sediment sampling

The sampling took place in the four seasons in 2017. In this regard, a total of 48 sediment samples (each sample triplicates) were collected using van Vienna grab sampler (20 × 20) from 16 studied stations. The sediment samples were put in an oven at 100 C for 24 h to dry completely. Then one gram of each sample was poured into digestion tubes filled with PTFE seal, and 10 ml of nitric acid (65%) and perchloric acid (67%) in a ratio of 1:4 were added. The PTFE tubes were put on the heater at 40 C for one hour, and then, the temperature slowly increased to 140 C for 3 h. The content of each tube was passed through Whatman filter paper grade 1 and reached the total volume of 25 ml with deionized seawater. To control the quality of analyses, three blank samples were prepared along with other samples such as the examined samples [24].

Seawater sampling

In each sampling station, seawater samples were collected at the same time. Therefore, a total of 48 seawater samples from a depth of 0.5 m in white polyethylene bottles of one litter volume were collected. Then, 50 ml of each seawater sample was taken, and 20 ml of concentrated nitric acid was added. All samples were heated under the hood until they reached the

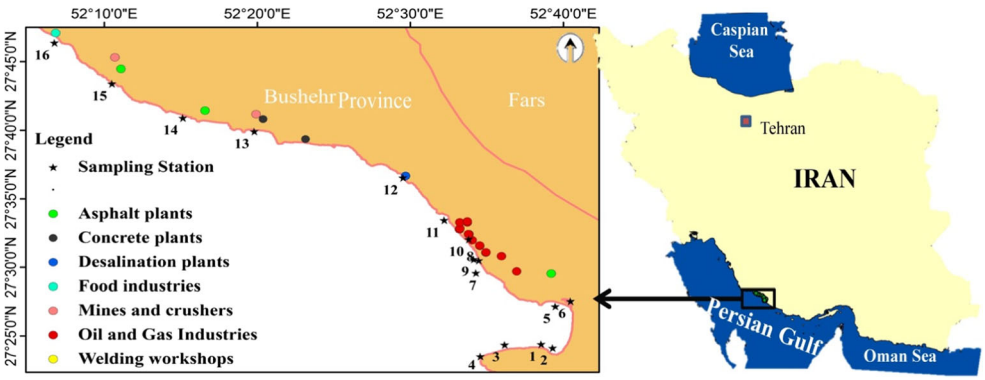

Fig. 1 Location of the study area and sampling stations in the Persian Gulf, Bushehr Province

total volume of 50 ml. Digested samples were passed through Whatman filter paper grade No. 42 and then reached the total volume of 25 ml with deionized seawater [24]. Finally, the concentrations of Pb, As, Cd, Cr, Cu, Zn, and Fe in sediments and seawater were determined by Shimadzu Atomic Absorption Spectrophotometer equipped with a graphite model (AA-670G). All measurements were repeated three times for each sample. Furthermore, for the blank samples of sediments and seawater, this method was used to determine the concentration of HM.

Risk assessment methods

Pollution load index

To assess the risks of HM in sediments at different seasons and studied stations, Pollution Load Index (PLI) was applied. PLI was originally suggested by Tomlinson et al. (1980) [25] to assess the overall risk of all HMs. This index is expressed as follow (Eq. 1 and 2):

$$\mathrm{CF} = \frac{C_i}{C_b} \tag{1}$$

$$\mathrm{PLI} = \sqrt[7]{\mathrm{CF_{Fe}} \times \mathrm{CF_{Hg}} \times \mathrm{CF_{cd}} \times \mathrm{CF_{Pb}} \times CF_{Cr} \times \mathrm{CF_{Zn}} \times \mathrm{CF_{Cu}} \times \mathrm{CF_{Ni}}} \tag{2}$$

where, for seven metals (Pb, Ni, Cd, Cr, Cu, Zn, and Fe), CF is the contamination factor and C_i and C_b are the concentration of individual HM in the sediment sample and background, respectively. The classifications of the results obtained from PLI are presented in Table 1.

Ecological risk index

Hakanson (1980) [26] introduced the potential ecological risk index (Er) in order to assess the risk of metals in sediments. In order to use the Hakanson ecological risk index (RI), Er of each HM would be calculated. Based on Hakanson (1980) [26] approach, the toxic response factors are Cu = Ni = Pb = 5, Cr = 2, Cd = 30, and Zn = 1 [22]. RI is expressed as follows:

$$E_r^i = \frac{C^i}{C_0^i} \times T_r^i \tag{3}$$

$$RI = \sum_{i=1}^{7} E_r^i \tag{4}$$

where E_r^i is the potential ecological risk index and Ci and C_o^i are the measured and background value of the specific metal concentrations in the sediment. T_r^i is the metal's toxic response factor. The following Er and RI values and their effect categorization are shown in Table 1.

Statistical analysis

The normality distribution of data was tested by Shapiro-Wilk test. ANOVA (analysis of variance) test with a 95% confidence level ($p = 0.05$) was used to compare the average data of each section and detect any significant difference of means in different seasons. For statistical analysis and graph drawing, Microsoft Excel 2010 and the Social Sciences Statistical Package (SPSS) version 21 were used.

Results

HM concentrations

The average concentrations of HMs in sediment and seawater samples are shown in Table 2. The average concentrations of heavy metals in the analyzed sediment and seawater samples were ranked as: Cu > Fe > Zn > Cr > Ni > Pb > Cd and Fe > Pb > Zn > Ni > Cu > Cr > Cd, respectively (Table 2). The concentrations of Fe, Zn, Cu, Ni, Cr, Pb, and Cd in the sediment samples were 59.84 ± 1.86, 47.99 ± 1.35, 29.62 ± 2.03, 20.13 ± 0.89, 18.89 ± 1.11, 9.51 ± 0.73, and 0.53 ± 0.04 mg/kg, respectively, whereas the concentrations in seawater samples were 9.05 ± 1.04, 8.01 ± 1.27, 7.09 ± 1.13, 6.26 ± 0.7, 4.32 ± 0.73, 3.44 ± 0.45, and 0.065 ± 0.03 mg/l, respectively.

Table 1 Standard degree of ecological risk assessment indices (PLI, E_r^i, and RI)

Ecological risk of environment	***RI***	Ecological risk for heavy metal	$\boldsymbol{E_r^i}$	(PLI)	Risk outcomes degrees of PLI
Low Risk	$150 \geq RI$	Low Risk	$40 \geq E_r^i$	PLI = 0	Non-Pollution
Moderate Risk	$150 \geq RI \geq 300$	Moderate Risk	$40 \leq E_r^i \geq 80$	$0 < \text{PLI} \leq 1$	Non to Moderate Pollution
Considerable Risk	$300 \geq RI \geq 600$	Considerable Risk	$80 \leq E_r^i \geq 160$	$1 < \text{PLI} \leq 2$	Moderate Pollution
Significantly High Risk	$RI \leq 600$	High Risk	$160 \leq E_r^i \geq 320$	$2 < \text{PLI} \leq 3$	Moderate to High Pollution
–	–	Very High Risk	$E_r^i \leq 320$	$3 < \text{PLI} \leq 4$	High Pollution

Spatial variation of HM concentrations

Figures 2 and 3 show the general trend of seawater and sediment HM concentrations in the study area. The results showed that there is an almost regular change in the seawater samples. The increasing trend of heavy metal contamination loads was reported from stations 1 to 9 (except for station 4 which disrupted the trend). On the other hand, a decrease in the trend of HM contamination load was reported from stations 9 to 16 (Fig. 2). Among the studied seawater samples, stations 4 and 9 had the lowest and highest HM contamination loads, respectively (Fig. 2).

The results showed that there is an almost regular change in seawater samples in such a way that pollution increases from station 3 to station 4 and from station 9 to station 10, and then, decreases (Fig. 2). According to Fig. 3, there was an irregular trend in HM concentrations between the studied stations. Stations 9, 6, 12, and 5 had the highest HM contamination among the studied stations, and the lowest contamination was measured at stations 10, 16, and 4 (Fig. 3). As observed in the water samples, station 9 had the highest load of HM contamination in the sediment samples. This station had the maximum levels of Cr, Pb, and Cd with concentrations of 20.0, 10.1, and 0.57 mg/kg, respectively (Fig. 3).

Seasonal variations of HM concentrations

Table 3 shows the seawater HM concentration range (minimum and maximum) during various seasons. All maximum and minimum seawater HM concentrations were detected in winter and spring, respectively. According to the table, the concentration ranges (minimum and maximum) of Zn, Cu, Ni, Pb, Cd, Cr, and Fe were 5.37 ± 0.75 and 11.05 ± 1.15, 2.62 ± 0.90 and 8.795 ± 0.662, 1.27 ± 0.005 and 7.99 ± 0.23, 4.53 ± 0.94 and 8.792 ± 1.127, 0.065 ± 0.027 and 0.395 ± 0.051, 1.88 ± 0.17 and 5.562 ± 0.684, and 3.65 ± 1.18 and 10.997 ± 1.64 mg/l, respectively. In Fig. 4, seasonal variations of each HM concentration were compared by using one-way ANOVA. Significant seasonal differences were found among each metal concentration in different seasons ($P < 0.05$) (Fig. 4).

Table 4 demonstrated the HM concentration range (minimum and maximum) in surface sediment samples during the four seasons. The results revealed that for all HMs, the maximum and minimum mean concentrations were detected in winter and spring, respectively. By using one-way ANOVA, the seasonal variations among concentrations of each HM were compared (Fig. 5). Significant seasonal differences were found among each metal concentration in different seasons ($P < 0.05$).

According to the results, there is a significant difference ($P < 0.05$) among the average concentration of Ni in sediment samples of different seasons (Fig. 5). The highest average concentration of Ni in winter, autumn, summer, and spring was 22.98 ± 0.85, 21.67 ± 0.79, 19.63 ± 0.28, and 16.24 ± 1.65 mg/kg on a dry weight (DW) basis, respectively (Table 4). Among the studied metals, Cd had the lowest average concentration.

Furthermore, there was a significant difference (at 95% confidence level) among the average concentrations of Cd in sediment samples during different seasons (Fig. 5). The highest average of Cd concentration in winter, autumn, summer, and spring was 0.72 ± 0.068, 0.58 ± 0.026, 0.55 ± 0.014, and 0.28 ± 0.068 mg/kg-DW, respectively. Cr concentrations in sediment samples collected in different seasons have shown that the variation ranges of their concentrations were measured between 13.066 ± 0.13 and 23.12 ± 0.41 in spring and winter, respectively (at 95% confidence level). Its highest concentration in sediment samples can be ranked as winter, autumn, summer, and spring (Table 3).

The findings showed that there is not a significant difference for Zn between summer and autumn, but this difference

Table 2 Average concentrations of HMs in the seawater and sediment samples

Zn	Samples	Fe	Cr	Ni	Cd	Pb	Cu	Zn
1.35 ± 47.99	**Sediment (mg/kg)**	1.86 ± 59.84	1.11 ± 18.89	0.89 ± 20.13	0.04 ± 0.53	0.73 ± 9.51	2.03 ± 29.62	1.35 ± 47.99
1.04 ± 9.05	**Seawater (mg/l)**	1.27 ± 8.01	0.45 ± 3.44	0.73 ± 4.32	0.03 ± 0.065	1.13 ± 7.09	0.7 ± 6.26	1.04 ± 9.05

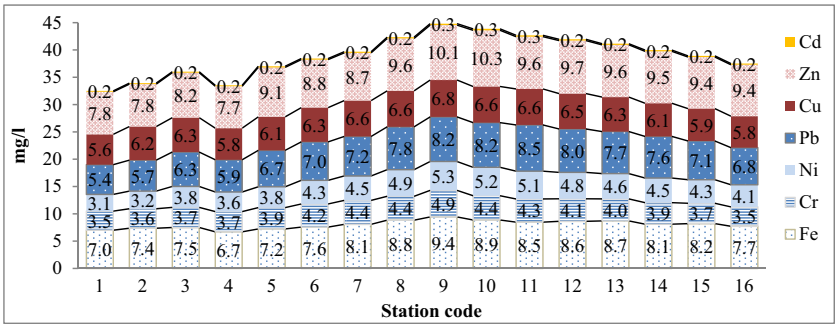

Fig. 2 Overall mean of heavy metal concentrations in seawater samples of the studied stations

is significant among other seasons (Fig. 5). The highest average of the concentration of Zn was measured as 39.82 ± 2.93, 48.49 ± 0.69, 50.19 ± 0.77, and 53.563 ± 1.035 mg/kg -DW for winter, autumn, summer, and spring, respectively.

Seasonal correlation of HM concentration

Correlation coefficients among HM concentrations in seawater and sediment samples at various seasons are shown in Table 5. There was a significant positive correlation for Fe and Cr ($P < 0.05$) in coastal sediments and seawater in spring, autumn, and winter. The findings showed that no significant correlation was observed for Zn and Cd, between their concentration in seawater and sediment samples in various seasons (Table 5).

Ecological risk assessment of heavy metals

In order to obtain a better understanding of coastal sediment pollution status, the ecological risks and pollution load index were evaluated for HMs (Cr, Pb, Cd, Cu, Zn, Ni, and Fe) based on an approach by Hakanson (1980) [26] and Tomlinson et al. (1980) [25]. Table 5 shows the pollution load and ecological risk of these metals in sediment samples. The results indicated that Er and RI values for all metals (Cr, Pb, Cd, Cu, Zn, Ni) in all seasons were lower than 40 and 150, receptivity. RI of metals from 16 stations was ranged as 26.086–41.371, 47.969–53.338, 51.373–58.606, and 58.632–74.835 in spring, summer, autumn, and winter, respectively. For all sampling stations, this index was lower than 150 (Table 6). The value of the pollution load index in all 16 sampling stations is lower than 1, indicating that these stations bear low pollution load in the study area (Table 6).

Discussion

HM concentrations

The results indicate that HMs pollution in the study area was slightly high, which is due to extensive human activities such as widespread industrial activities, transportation, discharge of wastewater and urban run-off, petrochemical effluent, and oil spills from boats and ships [27]. In Table 7, HMs contents of sediments in the Persian Gulf (this study) were compared with other studies. The Pb, Zn, Cd, and Cu contents in the Persian Gulf sediments (Jam coastal area) were lower than the Northern part of the Persian Gulf [31]. On the other hand, the concentrations of Pb and Cu were higher than those in Imam Khomeini Port sediments (Persian Gulf) [5]. The Cr concentrations in this study were lower than the Oman Sea and the Caspian Sea [28, 30]. The Ni and Fe concentrations were lower than those in the Black Sea and Imam Khomeini Port of Persian Gulf [5, 35]. The average concentration of studied metals in seawater was within the range of measured contents in a similar study in other coastal seawater of the world. For example, the concentrations of Pb and Cd of the Persian Gulf (Jam coastal area) were lower than Taihu Lake in China, and the concentrations of Cu and Cr in the Persian Gulf (Jam coastal area) were higher than those in Taihu Lake in China [23]. According to previous researches, the concentration of metal pollution varies in coastal areas around the world [22].

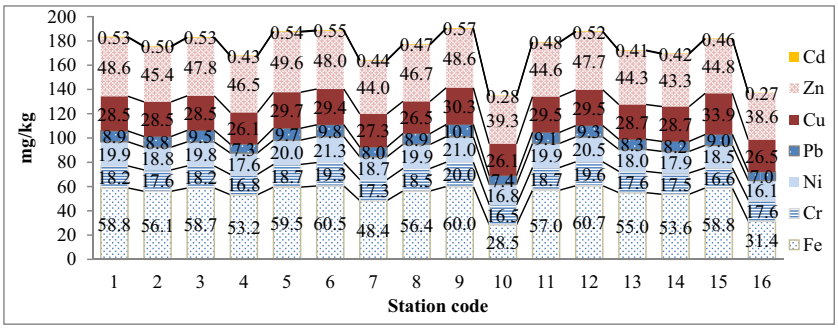

Fig. 3 Overall mean of heavy metal concentrations in sediment samples of the studied stations

Table 3 Statistical description of seawater HM concentrations (mg/l) in different seasons with the relevant station code

		Spring	Summer	Autumn	Winter
Zn	Min	3.99 ± 0.10	7.45 ± 0.72	8.34 ± 0.35	9.12 ± 0.27
	Station code	4	1	1	1
	Max	6.65 ± 0.19	10.34 ± 0.82	12.38 ± 0.44	12.68 ± 0.26
	Station code	3	13	9	9
	Mean ± Standard Error	5.37 ± 0.76	9.27 ± 0.99	10.57 ± 1.26	11.005 ± 1.15
Cu	Min	1.77 ± 0.03	4.95 ± 0.51	6.19 ± 1.02	7.82 ± 0.55
	Station code	4	1	1	1
	Max	4.94 ± 0.22	5.86 ± 0.21	9.56 ± 0.47	9.87 ± 0.36
	Station code	3	16	9	9
	Mean ± Standard Error	2.63 ± 0.91	5.51 ± 0.27	8.11 ± 0.98	8.79 ± 0.66
Pb	Min	1.97 ± 0.19	4.26 ± 0.67	6.38 ± 0.31	6.57 ± 0.25
	Station code	4	1	1	1
	Max	6.11 ± 0.21	8.66 ± 0.06	9.83 ± 0.22	10.18 ± 0.56
	Station code	11	10	9	10
	Mean ± Standard Error	4.53 ± 0.94	6.84 ± 1.41	8.22 ± 1.05	8.79 ± 1.13
Cd	Min	0.02 ± 0.002	0.10 ± 0.002	0.24 ± 0.003	0.27 ± 0.002
	Station code	4	1	1	1
	Max	0.09 ± 0.002	0.15 ± 0.001	0.42 ± 0.004	0.44 ± 0.001
	Station code	15	16	9	9
	Mean ± Standard Error	0.065 ± 0.027	0.13 ± 0.02	0.32 ± 0.06	0.36 ± 0.05
Ni	Min	1.27 ± 0.05	2.06 ± 0.10	3.57 ± 0.22	4.75 ± 0.32
	Station code	4	1	2	1
	Max	2.65 ± 0.04	3.51 ± 0.01	7.38 ± 0.25	7.99 ± 0.23
	Station code	9	15	9	10
	Mean ± Standard Error	2.11 ± 0.33	3.03 ± 0.43	5.75 ± 1.22	6.39 ± 0.95
Cr	Min	1.43 ± 0.05	2.34 ± 0.23	3.44 ± 0.15	5.64 ± 0.23
	Station code	4	1	16	16
	Max	2.13 ± 0.01	3.09 ± 0.31	5.95 ± 0.18	8.78 ± 0.22
	Station code	15	14	9	9
	Mean ± Standard Error	1.88 ± 0.18	2.75 ± 0.26	4.56 ± 0.68	6.56 ± 0.68
Fe	Min	1.988 ± 0.054	6.117 ± 0.431	7.48 ± 0.21	8.35 ± 0.33
	Station code	4	16	1	1
	Max	5.979 ± 0.414	7.593 ± 0.233	13.04 ± 0.25	13.99 ± 0.27
	Station code	2	15	9	9
	Mean ± Standard Error	3.563 ± 1.185	7.023 ± 0.451	10.51 ± 1.83	10.98 ± 1.64

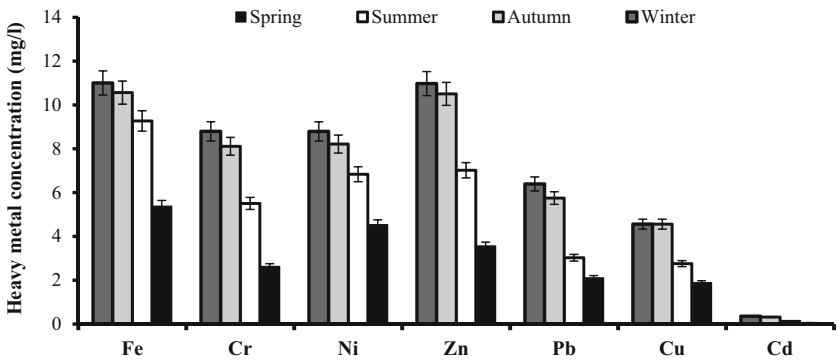

Fig. 4 Comparison of the seasonal average concentration of HMs in seawater samples using ANOVA test, at 95% confidence level

Table 4 Statistical descriptive of sediment HM concentrations (mg/kg) in different seasons with the relevant station code

		Spring	Summer	Autumn	Winter
Zn	Min	34.75 ± 0.18	46.35 ± 0.25	49.34 ± 0.32	52.43 ± 0.54
	Station code	11	1	1	1
	Max	46.09 ± 0.23	49.99 ± 0.01	51.83 ± 0.53	55.28 ± 0.43
	Station code	5	13	9	9
	Mean ± Standard Error	39.82 ± 2.93	48.49 ± 0.69	50.19 ± 0.77	53.56 ± 1.03
Cu	Min	18.74 ± 0.16	22.40 ± 0.14	29.76 ± 0.23	30.67 ± 0.34
	Station code	4	8	1	1
	Max	34.91 ± 0.12	36.34 ± 0.11	32.98 ± 0.24	33.92 ± 0.37
	Station code	15	15	9	2
	Mean ± Standard Error	26.16 ± 3.16	29.02 ± 2.78	31.23 ± 1.04	32.08 ± 1.14
Pb	Min	3.49 ± 0.13	7.63 ± 0.07	9.23 ± 0.32	10.97 ± 0.38
	Station code	4	1	1	12
	Max	8.15 ± 0.09	9.72 ± 0.9	10.96 ± 0.35	13.45 ± 0.28
	Station code	2	15	9	9
	Mean ± Standard Error	6.77 ± 0.99	9.09 ± 0.57	10.02 ± 0.49	12.18 ± 0.89
Cd	Min	0.14 ± 0.003	0.51 ± 0.002	0.54 ± 0.003	0.62 ± 0.004
	Station code	4	1	1	1
	Max	0.43 ± 0.005	0.56 ± 0.002	0.62 ± 0.004	0.81 ± 0.006
	Station cod	1	13	9	9
	Mean ± Standard Error	0.28 ± 0.07	0.55 ± 0.02	0.58 ± 0.03	0.72 ± 0.07
Ni	Min	11.71 ± 0.12	19.12 ± 0.08	20.19 ± 0.62	21.97 ± 0.38
	Station code	4	2	15	1
	Max	19.95 ± 0.35	20.01 ± 0.07	22.89 ± 0.47	24.21 ± 0.65
	Station code	6	13	9	9
	Mean ± Standard Error	16.24 ± 1.65	19.63 ± 0.28	21.67 ± 0.79	22.98 ± 0.85
Cr	Min	13.06 ± 0.13	13.31 ± 0.47	18.98 ± 0.14	20.43 ± 0.61
	Station code	4	15	2	1
	Max	17.55 ± 0.14	19.34 ± 0.09	21.94 ± 0.45	23.12 ± 0.41
	Station code	16	13	9	9
	Mean ± Standard Error	15.78 ± 0.93	17.74 ± 1.49	20.32 ± 0.98	21.74 ± 1.03
Fe	Min	24.42 ± 0.18	66.04 ± 0.31	67.43 ± 0.24	67.79 ± 0.33
	Station code	4	1	1	3
	Max	38.71 ± 0.07	72.07 ± 0.63	69.76 ± 0.24	71.74 ± 0.32
	Station code	13	15	9	9
	Mean ± Standard Error	32.17 ± 3.43	68.74 ± 2.16	68.63 ± 0.70	69.81 ± 1.15

The average concentrations of Pb, Ni, Cd, Cr, Cu, Zn, and Fe in the sediments of Jam beaches were 9.51 ± 1.92, 20.13 ± 2.67, 0.53 ± 0.165, 18.89 ± 2.45, 35.3 ± 29.61, 48.83 ± 5.45, 59.84 ± 17.7 (mg/kg –DW), respectively. Compared to the results obtained from other areas, the type of metal and the locations are different. However, the comparison should be made carefully since there are differences in physico-chemical properties or parameters between their concentrations at different locations and time [36, 37]. The concentrations of HMs in this study were in the same range as other studies in the Persian Gulf (Table 7).

Abdollah et al. (2013) [5] have found the average concentration of Pb in the sediments of west north of Persian Gulf in Emam Khomeini port to be about 6.52 mg/kg which is less than the concentration in our study (9.51 mg/kg). This is because of the rivers flowing into the sea and the rate of human activities across different places. The environment of Jam beaches is affected by risks caused by human activities due to the pollution increase and the expansion of industrial activities related to oil, petrochemical, fishing, and tourism industry. This issue needs continuous monitoring of pollutants and proper scientific research.

Spatial variation of HM concentrations

The evaluation of metal concentration in seawater and sediments at different stations showed the highest concentration of

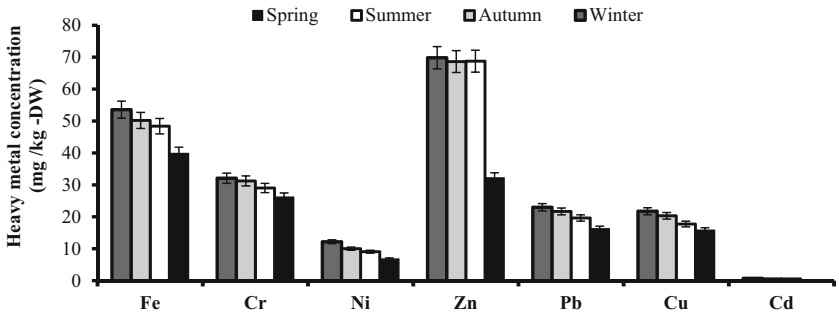

Fig. 5 Comparison of the seasonal average concentration of HMs in sediment samples using the ANOVA test, at 95% confidence level

Fe, Cu, Cr, and Ni at station 9, for lead in station 11, and for Cd and Zn in station 10. This means that the highest concentration of HMs is related to stations 9, 10, and 11.

As Fig. 1 shows, these sampling stations are located near residential areas and gas and oil industries, and the untreated sewage of these areas is discharged into the coastal waters. This subject can increase the concentration of a manifold of pollutants in the stations. Furthermore, according to Fig. 1, the most important oil and gas industries such as Kangan gas refinery phases 1, 9, and 10; south Pars refinery phases 2, 3, 4, and 5; and Jam petroleum companies (Mobin, Borzouyeh, Zagros, Pardis, and Aria Sammon) are located within a radius of 3 km of coastline, at the upstream of stations 9, 10, and 11. Thus, the high concentrations of metals in the stations in comparison to other sites could be due to their location in the vicinity and downstream of various industrial and petrochemical estates and the entrance of their untreated wastewater into the coastal area.

Seasonal variations of HM concentrations

Seawater variations

There was a significant difference ($P < 0.05$) among the concentrations of each metal in different seasons (Fig. 4). The highest metal concentrations in seawater samples were obtained during the rainy season (winter). One of the most important reasons for this subject is the entrance of a large amount of urban run-off and sewage, especially in winter, into the rivers and coasts around the sampling sites. The rivers leading to Jam beach mainly include Jam river and Mond that transport sediments and pollutants from industrial, agricultural, and urban areas. The increase in the rainfall in winter transports a greater volume of sediments and a large amount of pollutants from overland to rivers and then the deposits in the sea [3]. The concentration of metals in seawater varied seasonally. In the present study, the observed metal concentration increases in seawater during the rainy season showed a very close similarity with other reported studies such as Radakovitch et al. (2008) [38] and Sharma et al. (2018) [39]. The lower concentration of HMs during the summer may be due to the dilution effect of the seawater [40, 41] where the winter season was longer than the summer season. In addition, the higher concentration of metals during the rainy season might be due to the perturbation of sea bed by the longshore current, upwelling phenomenon, and waves that could increase metals concentration in seawater and sediment [38].

In winter and at station 10, the highest concentration of Pb was found. The issue could be due to its location around and in the downstream of the Jam petroleum company's industrial estates and South Pars refinery phases 2, 3, 4, and 5. The other reasons might be the urban run-off and effluent discharge from paint industries. Domestic wastewater discharge without prior treatment is also responsible for the station's high Pb level. Virha et al. (2011) [4] have measured the highest level of Pb concentration in winter in Bhopal Lake which is in agreement with the findings of this research.

In the seawater samples, the highest concentration of Cr was found in winter at station 9. This is probably due to the occurrence of intense idol immersion phenomenon. Generally, in analysed seawater samples, Cr concentration was found to be higher than the acceptable limit (i.e., 0.05 mg/l). The same results were obtained in the study. One of the most important reasons for this is the introduction of a large amount of industrial wastewater and metal waste from the factories' doors and windows and car repair shops to the coastal waters [41].

Table 5 Correlation among the concentration of heavy metals in seawater and sediment samples of each season using the Pearson test

Heavy metals	Spring	Summer	Autumn	Winter
Fe	0.289**	0.201	0.894**	0.798*
Cr	0.658**	0.167	0.783**	0.864**
Ni	0.712**	0.26	0.343	0.828**
Cd	0.234	0.69	0.405	0.573
Pb	0.672**	0.100	0.728**	0.189
Cu	0.004	0.283	0.610**	0.684**
Zn	0.313	0.46	0.163	−0.018

**A significant correlation between seawater and sediment samples at a 99% confidence level

*A significant correlation between seawater and sediment samples at a 95% confidence level

Table 6 The Er, RI, and PLI of sediments from different seasons in the study area

Station Cod																	
Season		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Spring	Cr	0.334	0.357	0.332	0.29	.345	0.362	0.367	0.355	0.362	0.366	0.351	0.353	0.351	0.35	0.358	0.390
	Ni	1.750	1.617	1.658	1.171	1.561	1.995	1.772	1.772	1.699	1.677	1.735	1.666	1.606	1.615	1.560	1.611
	Cd	34.105	32.763	24.868	10.974	20.763	21.316	25.500	25.500	21.632	22.263	21.711	19.184	21.000	21.553	20.684	21.158
	Pb	1.811	2.038	1.935	0.873	1.810	1.711	1.698	1.698	1.637	1.838	1.794	1.661	1.760	1.691	1.798	1.74
	Cu	2.886	3.012	2.676	2.082	2.935	2.671	2.854	2.854	2.783	2.904	2.969	2.813	3.085	3.091	3.879	2.94
	Zn	0.475	0.416	0.435	0.445	0.485	0.404	0.416	0.416	0.406	0.414	0.366	0.409	0.418	0.396	0.378	0.406
	RI	41.37	40.202	31.905	15.835	27.900	28.459	32.606	32.606	28.518	29.461	28.925	26.086	28.219	28.696	28.657	28.245
	PLI	0.262	0.26	0.244	0.17	0.242	0.242	0.244	0.232	0.234	0.241	0.236	0.227	0.237	0.234	0.226	0.219
Summer	Cr	0.386	0.393	0.392	0.392	0.394	0.398	0.403	0.404	0.417	–	0.423	0.425	0.430	0.427	0.296	–
	Ni	1.931	1.912	1.926	1.939	1.948	1.960	1.974	1.986	1.969	–	1.992	1.993	2.001	1.958	1.983	–
	Cd	40.18	42.553	43.263	43.579	43.421	43.579	43.658	43.737	44.974	–	44.053	44.132	44.211	44.368	43.105	–
	Pb	1.908	2.140	2.151	2.225	2.274	2.284	2.295	2.322	2.334	–	2.365	2.412	2.410	2.420	2.432	–
	Cu	3.085	3.170	3.167	3.186	3.194	3.206	3.220	2.490	3.239	–	3.251	3.254	3.285	3.291	4.038	–
	Zn	0.475	0.416	0.435	0.445	0.485	0.404	0.416	0.426	0.406	–	0.366	0.409	0.418	0.396	0.378	–
	RI	47.97	50.582	51.335	51.766	51.716	51.83	51.966	51.364	53.338	–	52.449	52.624	52.754	52.860	53.233	–
	PLI	0.286	0.289	0.293	0.296	0.301	0.294	0.297	0.289	0.300	–	0.298	0.304	0.306	0.304	0.296	–
Autumn	Cr	0.430	0.422	0.433	0.435	0.438	0.447	0.452	0.475	0.488	–	0.472	0.469	0.464	0.452	0.454	–
	Ni	2.098	2.099	2.125	2.175	2.195	2.212	2.168	2.275	2.298	–	2.232	2.205	2.168	2.180	2.020	–
	Cd	42.72	43.737	44.921	46.658	47.211	47.605	45.789	48.553	48.868	–	47.526	46.500	46.105	46.579	43.737	–
	Pb	2.308	2.387	2.473	2.367	2.496	2.536	2.505	2.567	2.742	–	2.637	2.504	2.505	2.495	2.490	–
	Cu	3.308	3.331	3.360	3.419	3.471	3.541	3.470	3.570	3.665	–	3.606	3.477	3.471	3.463	3.381	–
	Zn	0.519	0.520	0.523	0.524	0.528	0.534	0.531	0.537	0.546	–	0.526	0.526	0.528	0.528	0.520	–
	RI	51.37	52.496	53.834	55.578	56.338	56.875	54.915	57.976	58.606	–	56.999	55.681	55.241	55.697	52.601	–
	PLI	0.313	0.315	0.320	0.322	0.327	0.332	0.327	0.338	0.346	–	0.337	0.331	0.329	0.328	0.320	–
Winter	Cr	0.454	0.474	0.460	0.505	0.484	0.504	0.497	0.484	0.514	–	0.511	0.499	0.496	0.486	0.507	–
	Ni	2.197	2.219	2.209	2.219	2.299	2.368	2.297	2.422	2.422	–	2.319	2.359	2.279	2.318	2.197	–
	Cd	49.18	52.34	53.053	55.500	58.658	63.079	54.711	63.316	64.263	–	56.132	54.632	54.237	56.132	58.263	–
	Pb	2.836	2.945	2.942	3.094	3.157	3.249	2.994	3.188	3.363	–	2.997	2.744	2.994	3.113	3.030	–
	Cu	3.408	3.457	3.441	3.548	3.604	3.665	3.545	3.769	3.691	–	3.691	3.558	3.492	3.478	3.565	–
	Zn	0.552	0.557	0.557	0.553	0.565	0.570	0.560	0.578	0.582	–	0.580	0.558	0.562	0.561	0.564	–
	RI	58.63	61.99	62.662	65.418	68.766	73.434	64.603	73.755	74.835	–	66.230	64.349	64.061	66.087	68.126	–
	PLI	0.338	0.348	0.345	0.358	0.363	0.374	0.356	0.372	0.381	–	0.364	0.354	0.355	0.359	0.361	–

Table 7 Comparison of the obtained results of average sediment heavy metal concentrations (mg/kg-DW) in the study area with other coastal areas

Location	Pb	Cu	Zn	Ni	Cr	Cd	Fe	Reference
North west Persian Gulf (Emam Khomeini Port)	6.52 ± 1.12	15.32 ± 1.99	48.16 ± 8.57	54–58.33	–	–	21.833–315.400	[5]
Shuangtaizi Estuary, China	6.88	6.5	53.65	–		0.49	–	[18]
Black Sea, Turkey	0.03–31.1	4–95.5	33.9–267.4	2.65–13.55	–	0.02–0.93		[28]
Qusier Harbour	10.5	4.10	21.4	26.5	–	1.00	1.39%	[29]
Oman Sea	21.42	9.99	36.72	40.85	24.08	1.42	–	[30]
Caspian Sea	17.08	29.65	76.92	37.04	30.84	–	–	[31]
Persian Gulf	30.83 ± 11.03	32.87 ± 4.06	62.08 ± 12.18	–	4.19 ± 1.17	–	–	[27]
Persian Gulf	19.20–45.59	4.82–15.97	13.85–31.72			0.63–2.82		[7]
Persian Gulf (Emirates)	5.88–6.9	–	–	139	–	0.02–0.11	–	[32]
Persian Gulf (Nayband Bay)	3.56–5.25	–	–	–	–	1.16–1.44	–	[33]
Persian Gulf (Nayband Bay)	–	3.38 ± 1.5	10.37 ± 2.05	15.490 ± 2.3	104.16 ± 86.4	–	1.108 ± 0.26	[34]
Present Study	9.51	29.62	48.83	20.13	18.89	0.434	59.84	

Cd is a toxic metal with no documented biological significance and creates chronic toxicity even at low concentrations in living creatures [38]. Among the metals, the concentration of Cd is in the least, and its variation range is limited. The results showed that there is a significant difference between the concentrations of Cd in seawater samples in various seasons. The maximum and minimum concentration was observed in spring and winter as 0.44 ± 0.001 and 0.02 ± 0.002 (mg/l), respectively, that is because of entering run-off and transporting sediments containing this metal to the sea (Table 3). Fluctuation in flows to the sea, rainfall, water drainage, and run-off are the most important reasons for changes in the concentration of Cd in seawater [40].

Cu concentration of coastal water varied during different seasons (0.357 ± 9.87 and 1.76 ± 0.031 mg/l). The results showed that there is a significant difference between the measured values in spring and winter ($P < 0.05$), while the difference between summer and autumn is not significant. Cu exists in ships and buoys structure as well as domestic and municipal wastewater [42–44]. The highest concentrations of Cu were measured as 76.1 ± 0.031 and 9.87 ± 0.357 mg/l in winter and spring, respectively (Table 3). Virha et al. (2011) measured the highest concentration of Cu in summer, and their results are in contrast with the results of this study. They also concluded that Cu pollution was caused by the disposal of medical solid waste and municipal and industrial wastewater [4].

The variation range of Ni concentration in seawater samples of different seasons was measured in spring and winter as 1.27 ± 0.05 and 7.99 ± 0.23 mg/l, respectively (Table 3). Comparing the results showed that there is a significant difference ($P < 0.05$) among the concentrations of Ni in different seasons (Fig. 4). Basically, the majority of Ni is in colloidal form and mainly deposit in estuaries and beaches. It is possible that sludge from dredging docks and shipping channels was contaminated with this metal [43, 44]. In addition, the sludge from sewage contains a significant amount of Ni.

According to Table 3, the variation range of obtained Zn concentration is between 3.99 ± 0.10 and 12.68 ± 0.26 mg/l for spring and winter, respectively. The results showed that there is a significant difference among the concentration of Zn in seawater samples of different seasons ($P < 0.05$), and the maximum average of their concentration was obtained in winter, autumn, summer, and spring, respectively.

Fe concentration of coastal water varied a lot during different seasons. Its variation range in all seasons was measured from 1.98 ± 0.054 to 13.98 ± 0.267 mg/l. Generally, the results showed that there is a significant difference among all seasons ($P < 0.05$), and the ranking order of average concentration was winter, autumn, summer, and spring (Table 3).

Furthermore, the results showed that the sequence of HMs in seawater samples of different stations in Jam city beaches was obtained as Fe > Pb > Zn > Ni > Cu > Cr > Cd. According to the position of Jam city and due to the development of the region and numerous projects underway in this area, it is necessary to use strategies to help reduce pollutants.

Sediment variations

There were seasonal variations in the concentration of metals in sediments. Different changes in the concentration of HMs in sediments at different stations and seasons (Table 4) suggest variability and point sources of these metals [36]. Other important factors in the changes in the concentration of toxic metals in various stations and seasons can be the changes in the volume of incoming seawater to the region. The other reason may be upwelling, and the physicochemical parameters may also affect the spatial and seasonal distribution of HMs or the amount of dilution and concentration caused by the evaporation and circulation of Persian Gulf beaches [45].

For all studied metals, station 9 was the most polluted area both in winter and autumn. On the other hand, in spring and summer, more polluted stations varied depending on the type of metal. This issue suggests different sources of those metals in these two seasons. Generally, the results in Table 3 show that for all studied metals, the highest and lowest concentration were measured in winter and spring. Furthermore, comparing metal concentration in sediments showed that there is a significant difference ($P < 0.05$) in different seasons (Fig. 5).

Marine environment was influenced by various processes such as physicochemical, biological, and hydrological ones (tides, waves, and other marine flows) and rivers [1]. Therefore, the existence of a significant difference among the amounts of measured HMs in various seasons is the reason that pollution sources of these coasts are a function of seasonal factors. The differences may be due to the changes in precipitation, the entrance of seawater into the sea in different seasons, the amount of evaporation, sea flows in various seasons, the trend of human activities related to the petrochemical industry, and transportation in different seasons [45].

The results showed that there is a significant difference ($P < 0.05$) among the average concentration of Pb in the sediments of different seasons (Fig. 4). Therefore, the highest average concentration of Pb was 12.18 ± 0.89, 10.021 ± 0.49, 9.078 ± 0.57, and 6.77 ± 0.99 (mg/kg-DW) in winter, autumn, summer, and spring, respectively (Table 4).

In all seasons, the highest concentration of Pb has been measured in the sediments of stations 9 and 10. Activities associated with fishing and the extraction and transportation of oil can contaminate the area with Pb. In addition, the highest concentration of Pb was observed in winter. In this season, abundant rainfall can enter large amounts of Pb from overland into the sea area. Furthermore, the increase in the occurrence of upwelling and evaporation in this season is the possible reason for the increase in Pb contamination in sediments. The results showed that there is a significant difference ($P < 0.05$) among the average concentration of Ni in the sediments of different seasons (Fig. 5).

Among the studied metals, the lowest average concentration was for Cd. Furthermore, comparing the average concentration of Cd in the sediment samples from different seasons showed a significant difference at a 95% confidence level among them (Fig. 5). The changes of Cr concentration in the sediment samples collected in different seasons have shown that the variation range was between 13.066 ± 0.13 and 23.12 ± 0.41(mg/kg -DW) in spring and winter, respectively (a significant difference at 95% confidence level). The highest concentration of Cr was measured in winter, autumn, summer, and spring, respectively (Table 4).

The findings showed that there is not a significant difference for Zn between summer and autumn, but this difference is significant among other seasons (Fig. 5). The highest average of Zn concentration was measured for winter, autumn, summer, and spring as 39.82 ± 2.93, 48.49 ± 0.69, 50.19 ± 0.77, and 53.563 ± 1.035 (mg/kg -DW), respectively. These results are in agreement with the findings of Rajeshkumar et al. (2018) [23].

Hamed et al. (2007) [46] have reported that Zn can be deposited as $ZnCO_3$, so this can be one of the reasons to increase Zn in marine sediments. Furthermore, they added that being at a high rate is an indicator of a very high sedimentation rate. The average of Zn concentration in sediments was obtained as 83.48 mg/kg-DW. For Cu like Zn, there was no significant difference between the summer and autumn. On the other hand, during other seasons, this difference was significant at a 95% confidence level (Fig. 5).

Variations in Fe concentration of coastal sediments were extremely high during different seasons. The results showed that there is a significant difference among the average Fe concentration of sediments in different seasons at a 95% confidence level.

The results showed that the highest concentration in sediments was during the rainy seasons (winter). In addition, the amount of HMs that enter the sea by Jam and Mond seasonal rivers from industrial, agricultural, and urban areas can be a reason to increase the concentration of HMs in winter [40, 47]. Increasing organic compounds, nutrients, and phosphate and reducing salt during the rainy season as well as forming complex metal compounds and reducing their movement can increase the concentration of HMs in sediments [39, 48]. Evidence shows that in winter, because of the occurrence of the upwelling phenomenon in the region, the majority of the area would be chaotic and can result in increasing the metal concentration in sediments and seawater. The results showed that the high concentration of HMs in sediments is due to pollutants such as municipal and industrial wastewater, surface run-off, agricultural effluent, and atmospheric deposition resources [16, 23]. Kammala-Kannan et al. (2008) [47] investigated the metal concentration in the seawater of Pulicat Lake in various seasons. Their results showed that there is a significant difference among metals concentration in various seasons. They said that the differences in the distribution of metals in different stations and seasons are due to the fluctuations in the flow of rivers feeding the lake, solid waste, and channels of polluted water.

Seasonal correlation of HM concentration

Analysing the seasonal correlation among HMs of seawater and sediment samples showed that there is a significant positive correlation ($P < 0.05$) between coastal sediments and seawater in spring, autumn, and winter for Fe and Cr, respectively (Table 5). A significant positive correlation was also found for Pb among seawater and sediment samples in spring and autumn. On the other hand, no significant correlation was observed for both summer and winter. Irwin et al. (1997) [49]

reported that Pb was effectively removed from the seawater column by the adsorption into organic and clay matter. Furthermore, for Ni, a correlation among the concentration of seawater and sediment elements was observed in spring and winter. In addition, the findings showed that for Zn and Cd, no significant correlation was observed between seawater and sediment samples in various seasons (Table 5). The remarkable point is that in all studied metals, no significant correlation was observed between seawater and sediment samples in summer. By comparing the correlation among HMs in seawater and sediment of various seasons, this significant and positive correlation can indicate that the source of their changes is somewhat the same. One of the influencing factors on the concentration of HMs in sediments is the presence of suspended and organic matters in seawater [41, 50].

Because of wind and sea currents in winter, turbulence and stirring of the seawater will arise, and the adsorption on suspended particles heats up. However, in the summer and early autumn, when the region is faced with a reduction in inflow and run-off, suspended solids are deposited. Basically, the findings show that in rainy seasons, along with river flooding and ripple of the coast, metals isolate from sediments and re-suspend in the seawater [51]. Therefore, high correlation of some metals concentration in winter can be due to re-suspending them from sediments to seawater.

Ecological risk assessment of HM

According to the results, Er values for Cr, Pb, Cu, Zn, and Ni in all samples are lower than 40. This indicates that these metals possess a low Er in the study area. However, in three seasons (summer, autumn, and winter) Cd Er values were higher than 40, indicating a moderate Er during these seasons in the study area. The ranking order of HM Er values were Cd > Cu > Pb > Ni > Zn > Cr. Among these, Cd displayed the highest Er value in all sampling sites. The highest Er values for Cd (Er = 64.263 and 63.316) were found in stations 9 and 8. These results are in line with the results of Arfaeinia et al. (2017) [36] as they revealed that these stations are located near the Asaluyeh's oil and petrochemical industrial sites, which have the highest industrial activities and are the main zones discharging petrochemical industrial effluent into the coastal areas. In addition, these sites coincided with the area where human activities were historically concentrated, such as urban run-off, wastewater, and effluent discharge from ballast water due to boating and shipping activities [44]. In particular, this station showed the greatest range of metal concentration in all seasons. Although the Zn concentration, as a required trace element for living organisms, was high, and its biological toxicity coefficient was low, it leads to a low Er value [52]. Based on the results, Er value for all sampling stations in all seasons was lower than 150, indicating that Er was at a low level.

The values of pollution load index in all 16 sampling stations are lower than 1, indicating that these stations bear a low pollution load in the study area (Table 6). Gained PLI values are 0.17–0.262, 0.286–0.306, 0.313–0.346, and 0.338–381 in spring, summer, autumn, and winter, respectively. Among these 16 stations, higher PLI values were observed in spring at station 1, in summer at station 13, and in autumn and winter at station 9, with the values of 0.346 and 0.381, respectively, which are clearly lower than 1 (Table 6).

Comparison with international standards and previous studies

International sediment quality guidelines were used in order to assess the studied sediments and estimate their potential ecological effects on biota in this area. The threshold effects level (TEL), probable effect level (PEL), effects range low (ERL), and severe effect level (SEL) are useful tools to evaluate the ecological risk effects of organic and inorganic contaminants in aquatic sedimentary substrates [36]. These regulations were developed by comparing different marine organisms' sediment toxicity responses with the observed metal sediment concentrations (Table 8). Moreover, it can be used as a suitable tool to estimate risk levels and the protection of aquatic ecosystems [41]. The comparison of analysed HM concentrations with the standards of NOAA and SQGs determines the extent of sediments' pollution. Generally, the average annual concentration of Cu, Pb, Ni, Cd, Zn, and Cr in the sediments was lower compared to these measurements, which may indicate the lack of metal pollution. Therefore, there is no concern for these metals in the study area. It should be noted that due to the unavailability of cited standards for Fe, no comparison has been done for this metal. Furthermore, among the studied metals, only for Ni and Cu the measured amounts were more than LEL, and they were so close to their amounts in TEC and ERL. Therefore, we can say that the concentration of these two metals can be a threat to the creatures of the studied area. In addition, the annual average concentrations of Pb, Cu, Ni, and Cd were mainly higher in comparison with their background concentrations (Table 8).

TEL: threshold effect level, PEL: probable effect level, LEL: lowest effect level, SEL: severe effect level (values in mg/kg-DW).

As discussed earlier, the shores of the Persian Gulf are exposed to severe oil, industrial, and urban pollution. These shores are strategically important internationally due to their rich oil and gas resources. The Persian Gulf is also one of the largest habitats for marine creatures such as corals, small ornamental fish, edible and non-edible fish, mussels, snails, molluscs, sea anemones, sea sponges, brides, turtles, dolphins, sharks, and many other creatures. [33, 34, 37]. Continuous monitoring of pollution on these coasts is therefore essential for the protection of biodiversity and human health. [5, 6, 8].

Table 8 Comparison of average concentrations of Ni, Cd, Cr, Zn, Cu, and Fe with NOAA and SQGs

Guidance	Pb	Cu	Zn	Ni	Cr	Cd	Fe	Reference
Metal background guidelines	5.00	15.00	100	10	–	0.3	–	[29]
ERL	47	34	150	20.9	81	1.2		[32]
ERM	218	270	410	51.6	370	9.6	–	[32]
TEC	38.8	31.6	121	35	43.4	0.99	–	[53]
PEC	128	149	458	81.3	111	4.98	–	[53]
LEL	31	16	120	16	26	0.6	2%	[54]
SEL	250	110	820	75	110	10	4%	[54]
The annual average in this study	9.51	29.62	48.83	20.13	18.89	0.434	59.84	

Due to the importance of contamination studies in the Persian Gulf, this study focused on one of the most critical shores (Jam Coastal Province of Bushehr, Iran) of the Persian Gulf. Since seasonal variation is an important factor in the amount of contaminants released into the Persian Gulf [34], this study paid particular attention to this factor. Moreover, this study is one of the few studies that conducted a one-year monitoring system and considered seasonal variations in heavy metals as well. It is worth mentioning that this factor has not been considered in other previous studies such as those by Bastami et al. (2015) [31], Dobaradaran et al. (2018) [27], Dehghani et al. (2019) [45], Janadeleh et al. (2018) [33], and Davoodi et al. (2017) [34].

It should be noted that Sharifinia et al. (2018) [7] also implemented a one-year monitoring system of the metals in sediments, but they did not examine the seawater (their study areas were located in Khamir, Tiyab, and Jagin, while the current study focused on Jam beaches). This can, therefore, be noted that the difference between the present study and other studies includes: 1) calculating the concentration of large numbers of metals (seven metals), 2) evaluating and determining the concentrations of metals and their environmental hazards in both seawater and sediment samples, and 3) examining the seasonal variations of metals over a year.

Conclusions

This study was designed to acquire information on the concentration of HMs in seawater and bottom sediments of Persian Gulf in the coastal region of Jam city (an area with residential, industrial, and agricultural activities). Boats and ferries traffic, discharge of municipal and industrial wastewater, medical solid wastes, and rivers polluted with HMs are the main factors for the emission of these metals into the sea of this region. In some cases, HMs pollution is more than SQGs and NOAA, but this study showed that at this time, the concentration of the metals is often lower than the cited standards. Among the studied metals, only for Ni and Cu, the measured values were more than LEL. Therefore, it can be said that the concentration of these two metals is mainly a threat to the creatures of this area. As a result, it is necessary to take steps to minimize the amount of these HMs in the seawater. This is because the rapid growth of industrial and human activities along the coastline and the surrounding areas has increased the pollutants dumped into the seawater and sediments. The evaluation of the potential ecological risk index (Er) and the ecological risk of the environment (RI) of HMs showed that among different metals, Cd bears a moderate Er during spring, autumn, and winter. Moreover, the ecological risk of the environment index (RI) for all sampling stations in all season was lower than 150, indicating that the Er was low.

The concentration of Cd compared with the background concentration is much more. The results from this study showed that there was a positive significant correlation between the HMs concentration increase in seawater and bottom sediments with the rate of surface entrance run-off after the rainfall in residential and industrial areas and agricultural lands (concentration in winter). Based on the results obtained in this study, because of the region's sensitivity and fragility due to pollution sources and the potential for the increased concentration of HMs, a continuous monitoring program to protect human health, food chain, and biodiversity in marine and coastal sediments and Persian Gulf ecosystem waters is extremely important. This study recommends that point and nonpoint sources of HMs in the coastal zone should be strongly monitored. In addition, there should be an improvement in conditions and a reduction of industrial and domestic wastewater discharge. Hence, various sources of HM such as industrial effluent and domestic sewage that discharge into waters should be treated before mixing with coastal waters.

Compliance with ethical standards

Conflict of interest none.

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