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Research article

Status and contamination assessment of heavy metals pollution in coastal sediments, southern Kuwait

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Abstract: To assess the heavy metals concentration in the coastal sediments of the southern Kuwait coast, Fe, Mn, Cu, Pb, Ni, Co, Cd and Cr were measured by inductively coupled plasma mass spectroscopy. Whereas, the south of Kuwait coast is characterized by the presence of tourist resorts, and commercial and oil exports harbors. Moreover, environmental indicators were used to help in evaluating the degree and the intensity of pollutants in these sediments. Geoaccumulation index (Igeo) revealed that the sediments of hard all Hamara and Al-Khiran coasts are moderately polluted by Cu, while Ras Al-Zour and Ras Al-Jula'ia coasts are moderately polluted by Cd. Moreover, the enrichment factor (EF) indicated that the sediments of Hadd Al-Hamara coast are severely enriched with Ni, Cr and Pb, while the Al-Khiran coast is moderate severely enriched with the same metals. Ras Al-Zour and Ras Al-Jula'ia coasts are severely enriched with Ni and very severely enriched with Pb. Simultaneously, all studied sites are extremely severely enriched with Cu and Cd. These results were confirmed by the results of the contamination factor (CF) and the soil pollution index (SPI) indicated that Hadd Al-Hamara and Al-Khiran coasts are highly contaminated with Cu and Cd, while Ras Al-Zour and Ras Al-Jula'ia coasts are highly contaminated with Cd. Generally, the pollution load index showed that the sediments of all studied sites are no heavy metal pollution (PLI < 1). Pollutants might be originated from commercial wastes and construction activities.

Keywords: contamination; assessment; heavy metals; sediments; Kuwait

1. Introduction

Kuwait is in the northeastern part of the Arabian Peninsula, with a coastline that stretches for about 500 km, including the shores of the islands. The southern coast of Kuwait is dominated by parks, private housing, and investment projects, in addition to industrial activities such as the Al-Zour power plant and ports for transporting goods and oil. Kuwait City is influenced by the environment of the dry Gulf area, where summer temperatures may reach dangerously high levels. It varies from 42 and 48 degrees Celsius, and the city is afflicted by dusty winds with high humidity throughout this season, although temperatures during the winter season are generally low with little rain; It has an average temperature of 18 °C and annual precipitation of 7 mm.

Heavy metal pollutants find their way into coastal environments through industrial, agricultural, and wastewater effluents generated by coastal cities and resorts [1–4]. As a result, pollution monitoring activities for the maritime environment are a critical concern [5–7]. Where the marine environment plays a major role in achieving environmental balance. The degree of micro pollution in aquatic ecosystems can potentially be determined by analyzing water, sediments, or local biota. However, marine sediments are far superior to seawater or marine shells as a technique for monitoring heavy metal contamination [8–11]. Multiple sampling must be done often and over a large enough geographic area to remove pollutant concentration changes caused by time, season, and other physicochemical phenomena. Terrestrial metals make up most anthropogenic metals in a marine coastal environment [12,13]. Heavy metals, unlike many other pollutants in our environment, are natural elements of the aquatic environment and can be obtained from a variety of human sources. These contaminants reach the maritime environment through industrial and domestic waste, fishing boats, shipping, oil tanker activities, and oil/gas exploration [14,15], as well as naturally through rock weathering [14,16]. Several metals have already been mobilized by a man at rates equivalent to, and occasionally exceeding, those of nature, thanks to the usage of mineral oils and industrial wastes.

Recently, the world began to pay attention to the quality of the environment because of its great impact on human health and living organisms. Therefore, environmental impact assessment studies vary in many regions around the world, but this type of studies is rather few in Kuwait. Due to the presence of a high percentage of tourist resorts and the presence of many vacationers most times of the year, in addition to the presence of commercial and oil ports. Wherefore, the major goal of the present work is to figure out the distribution and the status of the heavy metals in Kuwait's south coastal sediments. Furthermore, to examine and evaluate their possible environmental risk in the study area. In addition, this study provides a reference database for the Ministry of Environment and researchers assessing the concentration of some heavy metals in the coastal sediments of the southern Kuwait region.

2. Materials and methods

2.1. Overview of the study area

A total of 48 surface coastal sediments was collected along the southern coastline of Kuwait beach, (Figure 1). In each site 12 samples were taken equally at high tide, sea level and offshore (60 cm depth). The collected sediment sample process was done in four different locations for the southern coast of Kuwait. This area extends to 34 km, starting from the southernmost point, which is called Had Hamara (south of Al-Khiran); followed by Al-Khiran; Ras Al-Zour; and Ras Al-Jula'ia toward the north (Figures 1 and 2).

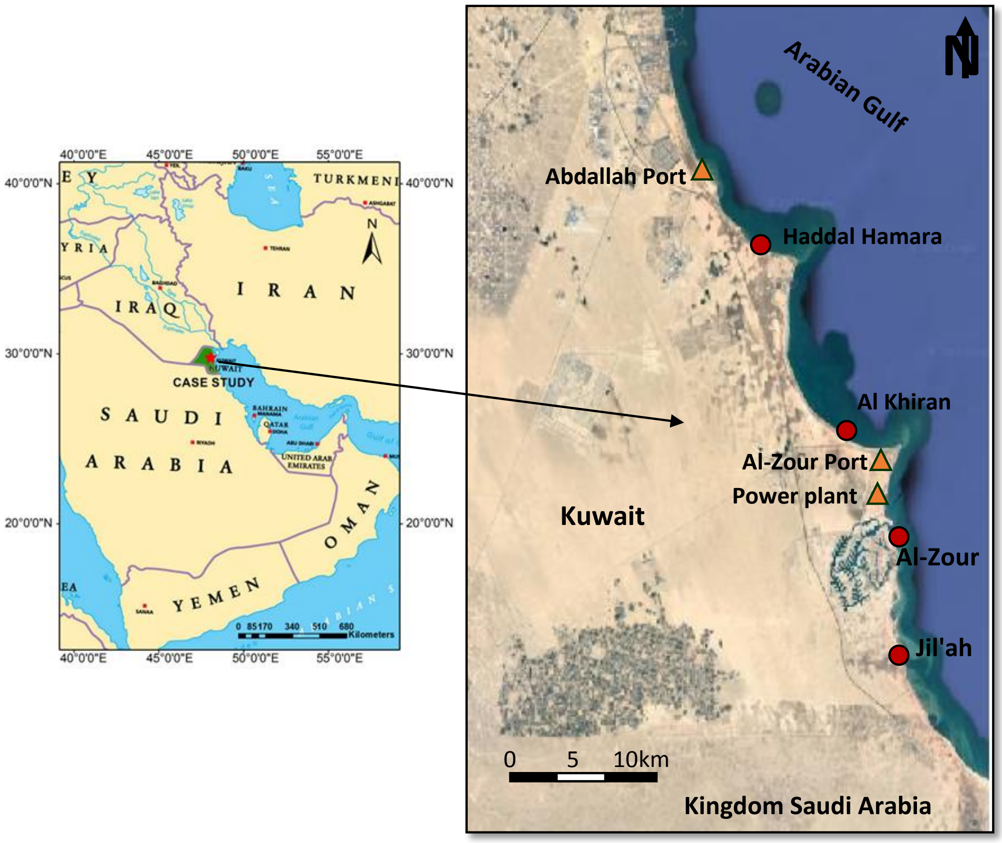

Figure 1. Location map of sampling sites.

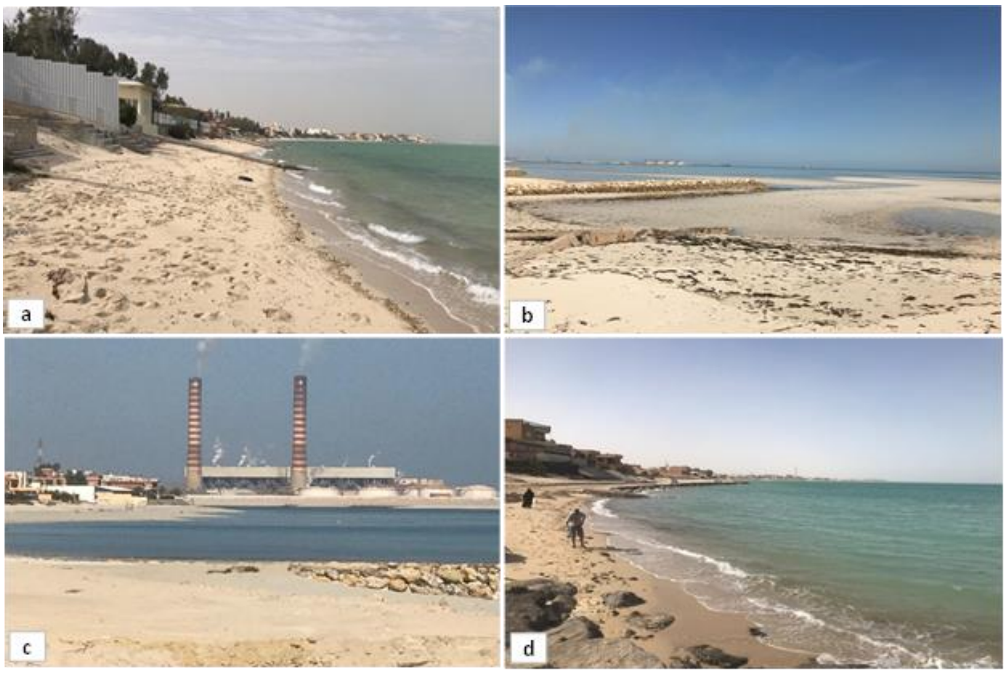

Figure 2. A close of the study area. a: Hadd Al-Hamara; b: Al-Khiran; c: Ras Al-Zour; d: Ras Al-Jula'ia beaches.

Al-Khiran area is in the extreme southeast of Kuwait, and it is part of the coastal strip that overlooks the Arabian Gulf. It is 17 km long from north to south, and it continues inland for 8 to 10 km. The Khor Al-Muftah and Khor Al-Ami, located in the center of the region, are two tidal canals that run for many km across the land. It brings Gulf waves behind a rather high surface range of coastal limestone cliffs. Based on their method of occurrence, recent Aeolian deposits cover the majority of the Al-Khiran region. Mobile and immobile sand deposits have been identified in these Aeolian deposits.

The Ras Al-Zour coastal area, in Kuwait's southern region, is a hotspot for industrial water consumption and existing power plant sea intake outfall. Some building projects are now underway, including the Al-Zour Refinery, the Al-Zour LNG import facility, and the extension of an existing power plant. The Al-Zour region has developed into one of Kuwait's most important industrial complexes. It is one of the oil-producing locations, with an oil well discovered in 1958. It has certain facilities, such as the Al-Zour power station. Al-Zour is the world's largest single-stage oil refining and refinery. The southern coastline of Kuwait's gibbons' winds makes up several sub-bays separated by the heads, such as Ras Asheerj and Ras Kazma, and to the south of the area. The coastline straightens apart from some prominent few heads such as Ras Al-Zour and Ras Al-Jula'ia.

2.2. Analytical work

Sediment samples were collected randomly using a stainless-steel box sampler during winter 2020. Sediment samples were crushed in an agate mortar to 63 µm and then about 0.2 g were digested in a mixture of HNO_3, HCl and HF by method EPA-3050 B, using a machine called Microwave Digestion from Anton Paar Company at the research sector project unit, faculty of science, Kuwait university. To determine the concentration of Fe, Mn, Cu, Pb, Ni, Co, Cd and Cr in the studied samples, inductively coupled plasma mass spectrometry (ICP-MS) was used. Before entering the sample into this device, the device was calibrated and programmed to extract the concentration of the elements whose concentration in the sample is to be determined.

2.3. Environmental statistical analysis

Some environmental indicators and statistical analysis were used to evaluate the assessment of the extent of the environmental pollution of the study area and identify the expected sources responsible for the presence of pollutants in the environment such as the Geo-accumulation index (Igeo), the enrichment factor (EF), the contamination factor (CF), sediments pollution index (SPI), the contamination degree (C_{deg}) and the pollution load index (PLI) according to [17–22]. In addition to Pearson correlation coefficients, hierarchal cluster analysis (HCA) and principal component analysis (PCA) were calculated by using SPSS program ver.20.

3. Results and discussion

South Kuwait coastal sediments ranged from coarse quartz and carbonate sands to very fine mud. Complete and fragmented of invertebrate skeletons as bivalves, gastropods, foraminifers, and others can be found in the biogenic component of the sediments. The following is a full explanation of the examined metals' spatial distribution, including their maximum and lowest values, averages and comparisons to other coastal areas across the world (Table 1).

Table 1. Comparing the distribution of heavy metal concentrations (ppm) in the sediments of Kuwait bay and other regions around the world.

Studied area /background	Fe	Mn	Cu	Pb	Ni	Cd	Co	Cr	References
South Kuwait coast	598.60	21.98	130.35	4.06	9.31	0.70	0.42	9.69	Present work
Sulaibikhat Bay, Kuwait			10–100	2.0–32.0	25–130	2.00–4.0		65–190	[23]
Iran coast			19–45	7.6–15	98–200			93–184	[24]
Arabian Gulf, Bahrain	471–6475	22.6–84.3	2.4–48.3	0.7–99	2.46–23.2	0.04–0.2	0.17–2.43		[25]
Sharm El-Sheikh, Egypt	2629	428	30	32.4	45	2.53	1.95		[26]
Mediterranean coast, Libya	2048	34.07	17.1	11.1	21.9	0.81	5.8		[27]
Caspian Sea, Russia	5520	200	8.3	4.19	14	0.06	3.8		[28]
Lowest effect level (LEL)	20000	460	16	31	16			26	[29]
Severe effect level (SEL)	40000	1100	110	250	75			110	

3.1. Heavy metals distribution

Heavy metals concentrations in the studied sediments were obtained in supplementary Table 1. These results showed that the Al-Khiran area recorded the highest levels of Fe (1599 ppm), Cu (423 ppm) and Co (0.971 ppm) with an average (598.6, 130.3 and 0.420 ppm) respectively. However, Ras Al-Jula'ia area recorded the highest levels of Mn (52.9 ppm), Cd (1.96 ppm) and the total organic matter (TOM) (680) with an average (21.9, 0.69 and 296 ppm) respectively. Moreover, Pb recorded the highest value of 8.47 ppm at Ras Al-Zour area with an average (4.06 ppm). Furthermore, the Hadd Al-Hamara area recorded the highest value of Ni (21.37 ppm) and Cr (46.04 ppm) with an average (9.31 and 9.69 ppm) respectively.

Figure 3 explains clearly that the sources of the heavy metals in the study area are different according to the nature of each site. Hadd Al-Hamara area has an increase in the concentrations of Fe, Mn in the landward samples, while the concentrations of Cr, Cd, Co, Ni and TOM in the sediments towards the seaward direction were increased. This may refer to natural weathering and vacationers' activity. However, the Al-Khiran area recorded high levels of Cu, Pb, Ni and Cd in onshore samples. As this area is one of the most famous tourist areas in southern Kuwait. On the other side, the Ras Al-Zour area recorded the highest levels of Pb, Cd and Co in offshore samples. This may be due to the fact that it is close to the commercial and oil port of Al-Zour. Moreover, the Ras Al-Jula'ia area recorded the highest levels of Pb and Cd onshore samples. This may be due to the fact that it is also close to the commercial and oil port of Abdullah.

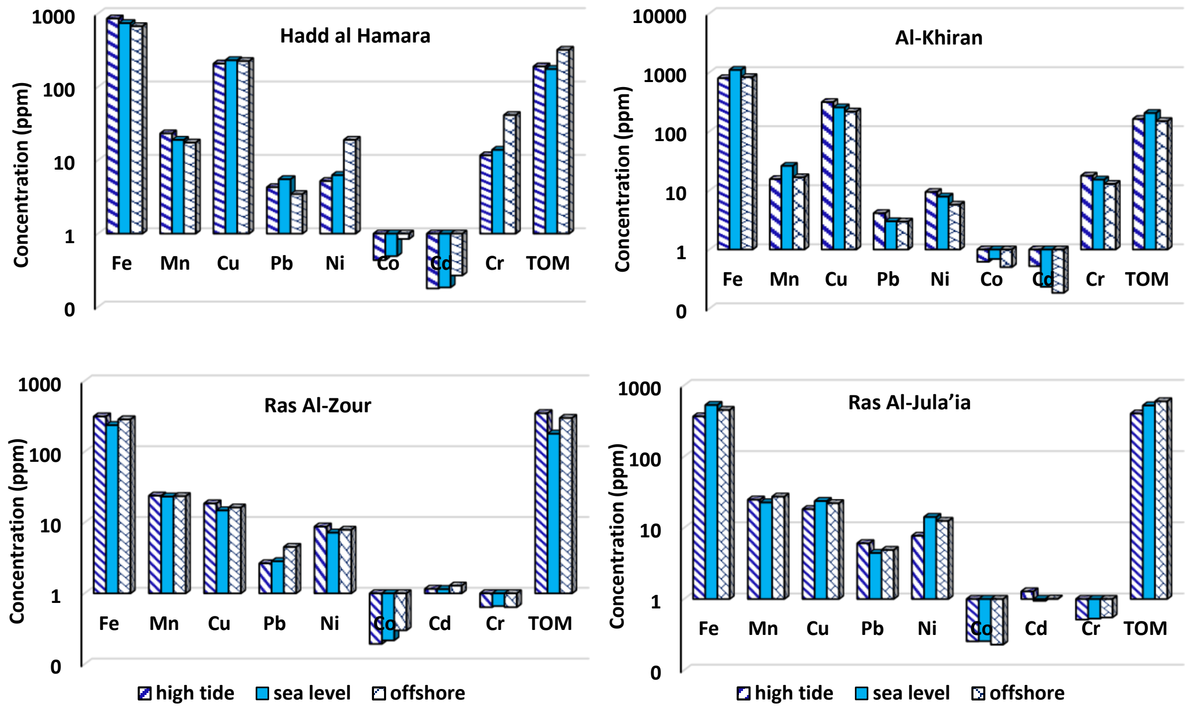

Figure 3. The distribution of heavy metals in offshore and onshore sediments samples in the studied area.

The main concentration of Fe, Mn, Ni, Pb and Co in the present work were lower than all sites in Table 1 as Arabian Gulf (Bahrain), Sharm El-Sheikh (Egypt), Mediterranean coast (Libya), the Caspian Sea (Russia), Sulaibikhat Bay (Kuwait) and Iran coast. In contrast, Cu and Cr were higher than in all these comparison sites. Cd was higher than in Arabian Gulf and Caspian Sea, while it lower than ones in Sulaibikhat Bay, Arabian Gulf, Sharm El-Sheikh and Mediterranean coast. On the other hand, the concentrations of all studied heavy metals were lower than references value as lowest effect level (LEL) and severe effect level (SEL).

3.2. Evaluation of pollutants in the coast of southern Kuwait

To assess the effect of heavy metals on the coastal sediments in the studied area, some environmental pollution indicators were calculated in Table 2 and Figure 4. The geoaccumulation index (Igeo) assesses the degree of metal pollution in terms of seven enrichment classes based on the increasing numerical values of the index [30]; Igeo < 0 means uncontaminated; Igeo (0–1) means uncontaminated to moderately contaminated; Igeo (1–2) means moderately contaminated; Igeo (2–3) means moderately to heavily contaminated; Igeo (3–4) means heavily contaminated; Igeo (4–5) means heavily to extremely contaminated; and Igeo ≥ 5 means extremely contaminated. This index is calculated as follows: Igeo = log2 (C_n/1.5 × B_n), where C_n is the concentration of the element in the enriched samples, and the B_n is the background or pristine value of the element. These results revealed that the sediments of Hadd Al-Hamara and Al-Khiran coasts are moderately polluted by Cu, while Ras Al-Zour and Ras Al-Jula'ia coasts are moderately polluted by Cd.

Table 2. The evaluation status of the heavy metals in the sediments of southern Kuwait coast.

Site		Igeo			EF			CF			SPI		
		Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.
Hadd al Hamara	Fe	−6.83	−5.89	−6.55				0.013	0.025	0.016			
	Mn	−6.55	−5.27	−6.03	1.21	1.69	1.45	0.016	0.039	0.024	0.02	0.06	0.03
	Cu	1.14	2.38	1.68	172.1	553.5	330.3	3.302	7.782	5.002	4.95	11.67	7.50
	Pb	−3.44	−2.09	−2.81	9.61	19.90	14.04	0.138	0.353	0.225	0.28	0.71	0.45
	Ni	−4.83	−2.25	−3.60	3.28	22.88	10.54	0.053	0.314	0.154	0.09	0.53	0.26
	Co	−6.42	−4.95	−5.67	1.19	3.54	2.08	0.017	0.049	0.031	0.04	0.12	0.07
	Cd	−2.03	0.01	−1.18	22.2	103.1	48.0	0.368	1.507	0.736	1.84	7.53	3.68
	Cr	−3.97	−1.55	−2.85	5.16	37.24	17.37	0.096	0.512	0.255	0.09	0.46	0.23
Al-Khiran	Fe	−6.94	−5.47	−6.35				0.012	0.034	0.020			
	Mn	−7.07	−4.91	−6.18	0.90	1.47	1.14	0.011	0.050	0.024	0.02	0.07	0.03
	Cu	1.42	2.65	1.93	172.9	532.2	335.0	4.017	9.404	5.957	6.03	14.11	8.94
	Pb	−3.99	−2.51	−3.21	4.57	16.42	9.69	0.095	0.264	0.170	0.19	0.53	0.34
	Ni	−4.71	−2.96	−3.82	4.00	10.28	6.28	0.057	0.192	0.115	0.10	0.33	0.19
	Co	−6.31	−4.88	−5.64	1.38	2.24	1.70	0.019	0.051	0.032	0.04	0.12	0.08
	Cd	−1.87	1.23	−0.76	18.87	257.28	72.30	0.412	3.525	1.178	2.06	17.62	5.89
	Cr	−3.64	−2.46	−3.16	5.75	13.49	9.56	0.120	0.273	0.174	0.11	0.25	0.16
Ras Al-Zour	Fe	−8.51	−7.33	−8.01				0.004	0.009	0.006			
	Mn	−6.08	−5.29	−5.76	3.06	7.26	4.96	0.022	0.038	0.028	0.03	0.05	0.04
	Cu	−2.47	−1.53	−2.04	55.64	71.29	62.96	0.271	0.519	0.372	0.41	0.78	0.56
	Pb	−3.55	−1.82	−3.18	17.53	86.05	33.15	0.128	0.424	0.182	0.26	0.85	0.36
	Ni	−4.75	−2.90	−3.75	11.32	23.77	19.44	0.056	0.201	0.119	0.09	0.34	0.20
	Co	−7.85	−5.62	−6.99	0.89	3.94	2.16	0.006	0.030	0.013	0.02	0.07	0.03
	Cd	0.78	1.83	1.37	448.8	1043.4	705.7	2.570	5.316	3.981	12.85	26.58	19.90
	Cr	−8.13	−7.31	−7.72	0.88	1.94	1.28	0.005	0.009	0.007	0.00	0.01	0.01
Ras Al-Jula'ia	Fe	−7.74	−6.85	−7.32				0.007	0.013	0.010			
	Mn	−6.36	−4.59	−5.72	1.91	6.67	3.36	0.018	0.062	0.031	0.03	0.09	0.04
	Cu	−2.11	−1.30	−1.68	41.36	58.90	50.28	0.348	0.608	0.476	0.52	0.91	0.71
	Pb	−3.34	−2.16	−2.60	13.15	47.80	28.63	0.149	0.336	0.254	0.30	0.67	0.51
	Ni	−4.13	−2.63	−3.24	12.04	20.53	17.28	0.086	0.243	0.168	0.15	0.41	0.29
	Co	−7.70	−6.45	−6.93	0.75	2.10	1.41	0.007	0.017	0.013	0.02	0.04	0.03
	Cd	0.64	2.12	1.24	206.8	930.9	421.6	2.337	6.543	3.710	11.68	32.72	18.55
	Cr	−8.36	−7.53	−8.00	0.46	1.05	0.66	0.005	0.008	0.006	0.00	0.01	0.01

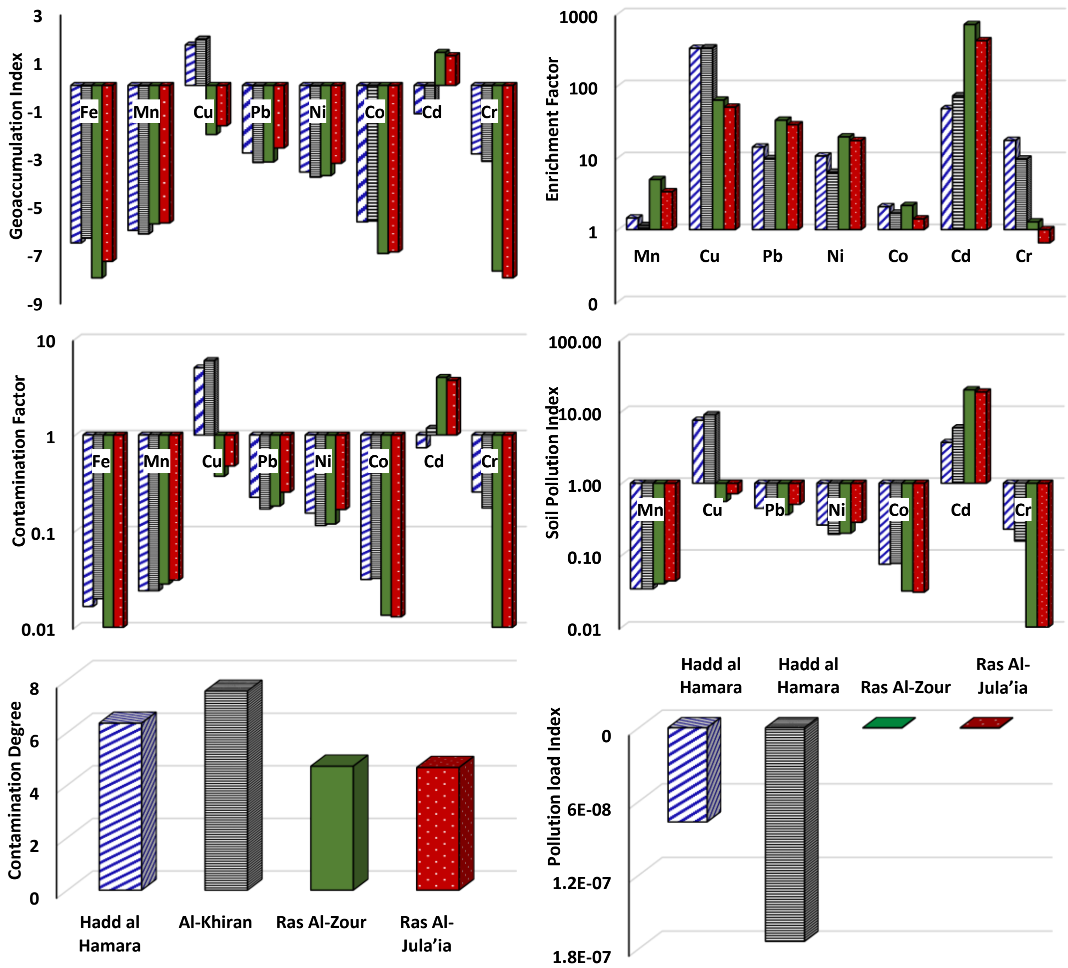

Figure 4. The environmental indicators result in sediments of southern Kuwait coast.

The enrichment factor (EF) was used to determine the potential source of pollutants [31]. This factor is mathematically expressed as EF = (M/Fe) sample/(M/Fe) background, where: M is the concentration of heavy metal in the sample. EF can be divided into several categories as EF < 1 is no enrichment; EF (1–3) is minor enrichment; EF (3–5) is moderate enrichment; EF (5–10) is moderately severe enrichment; EF (10–25) is severe enrichment; EF (25–50) is very severe enrichment; and EF > 50 is extremely severe enrichment. These results indicated that the sediments of Hadd Al-Hamara and Al-Khiran coasts are minor enriched with Mn and Co, while Ras Al-Zour and Ras Al-Jula'ia coasts are minor enriched with Co and Cr. However, the sediments of Hadd Al-Hamara coast are severely enriched with Ni, Cr and Pb, while the Al-Khiran coast is moderate severely enriched with the same metals. Ras Al-Zour and Ras Al-Jula'ia coasts are severely enriched with Ni and very severely enriched with Pb. Simultaneously, all studied sites are extremely severe enriched with Cu and Cd.

The contamination factor has been used to assess the level of contamination and the possible anthropogenic impact of contaminants in sediments [32]. This factor can be calculated from the following relation: CF= C metal/C background, where: C is the concentration of metal in sample and C background refers to the measured concentrations of metals in average shale rocks. CF can be classified into CF < 1 is low contamination; CF (1–3) is moderate contamination; CF (3–6) is considerable contamination; and CF > 6 is very high contamination. These results have confirmed the results of Igeo where all studied sites are low contaminated with Fe, Mn, Pb, Ni, Co, Cd, Cr and Cd. Whereas Hadd Al-Hamara and Al-Khiran coasts are considerably contaminated with Cu, while Ras Al-Zour and Ras Al-Jula'ia coasts are considerably contaminated with Cd.

Soil pollution index (SPI) is used to identify a single element contamination index in sediment samples [33,34]. This index can be calculated as SPI = Cs/Cm, where: Cs is the concentration of metal in the sample, and Cm is the world permissible level of metal. SPI can be divided into three categories as SPI ≤ 1 is low contamination; (1 < SPI ≤ 3) is moderate contamination; and SPI > 3 is high contamination. These results are in an agreement with the other environmental indicators. In details, Hadd Al-Hamara and Al-Khiran coasts are highly contaminated with Cu and Cd, while Ras Al-Zour and Ras Al-Jula'ia coasts are mainly contaminated with Cd.

The degree of contamination C_{deg} is used to describe the extent of contamination of a metal contaminant in the studied area [33]. This index is calculated as follows: $C_{deg} = \sum CF$. These results revealed that the sediments of hard all Hamara and Al-Khiran coasts are moderate degree contaminated by heavy metals, while Ras Al-Zour and Ras Al-Jula'ia coasts are low degrees of heavy metal contamination.

The pollution load index (PLI) is used to estimate the degree of pollution in the studied area [35–37]. This index is calculated as follows: $PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n}$. These results showed that the sediments of all studied sites are no heavy metal pollution (PLI < 1).

Table 3. The Pearson correlation of heavy metals and TOM in sediments of southern Kuwait coastal.

	Fe	Mn	Cu	Pb	Ni	Co	Cd	Cr	TOM
Fe	1.00								
Mn	0.207	1.00							
Cu	0.734**	−0.24	1.00						
Pb	0.054	0.217	−0.10	1.00					
Ni	0.045	0.105	0.025	−0.04	1.00				
Co	0.778**	0.056	0.770**	−0.02	0.366*	1.00			
Cd	−0.656**	0.310*	−0.751**	0.118	0.123	−0.558**	1.00		
Cr	0.518**	−0.24	0.754**	−0.14	0.455**	0.844**	−0.646**	1.00	
TOM	−0.314*	0.195	−0.510**	0.265	0.410**	−0.310*	0.372**	−0.28	1.00

Note: **: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed).

Multivariate analysis as the correlation coefficient (Table 3) indicated that there is a significant positive relation between Fe with Cu, Co and Cr, while Fe has a negative relation with Cd. Cu has a positive relation with Co and Cr, whereas it has a negative relation with Cd and TOM. However, Co has a strong positive relation with Cr and negative relation with Cd. The results of cluster analysis data (Figure 5) revealed that there are three metal clusters, the first one included Co, Cr, Cu and Fe. While the second cluster included Mn, Cd and Pb, whereas the third one has only Ni. Confirmed that the principal component analysis (PCA) showed that the studied heavy metals were classified into three component matrix (Table 4) for the total cumulative value of 78.59%. The first one showed high positive loading between four metals (Cu, Co, Cr and Fe) with a cumulative value of 45.36%. While the second component proved positive loading between Mn, Ni and TOM with a cumulative value of 64.34%. The third component matrix illustrated a positive relation between Mn and Pb, whereas it pointed to negative relation with Ni. Each heavy metal component might have come from the same origin [37,38]. These results indicated that the pollutants in the studied area come from various sources as industrial effluent, ship transportation of oil and goods, Al-Zour power plant, and illegal domestic sewage discharge. in addition, throwing wood waste, backfilling works in the sea, docks to drop boats have contributed to this problem (Figure 2).

Table 4. The principal component matrix of heavy metals in the studied area.

Component matrix[a]			
	Component		
	1	2	3
Fe	0.806	0.181	0.424
Mn	−0.190	0.543	0.601
Cu	0.932	−0.103	0.052
Pb	−0.149	0.373	0.559
Ni	0.148	0.790	−0.534
Co	0.889	0.342	0.039
Cd	−0.822	0.231	−0.046
Cr	0.869	0.224	−0.322
TOM	−0.509	0.623	−0.184
% of Variance	45.36	18.99	14.25
Cumulative%	45.36	64.34	78.59

Note: Extraction method: principal component analysis. [a]: 3 components extracted.

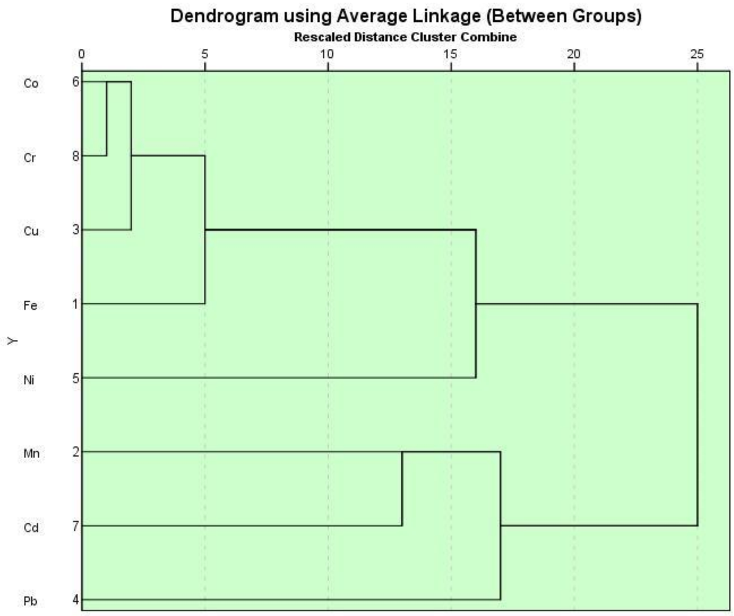

Figure 5. The dendrogram of the heavy metals cluster analysis in the studied area.

4. Conclusions

The distribution of heavy metals concentrations in the coastal sediments of the southern Kuwait coast showed that Hadd Al-Hamara area has the highest concentrations of Fe and Mn in onshore samples, while it has the highest concentrations of Cr, Cd, Co, Ni and TOM in the offshore sediments. Meanwhile, the Al-Khiran area has the highest levels of Cu, Pb, Ni and Cd in onshore samples. On the other side, the Ras Al-Zour area recorded the highest levels of Pb, Cd and Co in offshore samples. Moreover, the Ras Al-Jula'ia area recorded the highest levels of Pb and Cd in onshore samples.

The geo-accumulation index revealed that the sediments of Hadd Al-Hamara and Al-Khiran coasts are moderately polluted by Cu, while Ras Al-Zour and Ras Al-Jula'ia coasts are moderately polluted by Cd. While the enrichment factor indicated that the sediments of Hadd Al-Hamara and Al-Khiran coasts are minor enriched with Mn and Co, while Ras Al-Zour and Ras Al-Jula'ia coasts are minor enriched with Co and Cr. However, the sediments of Hadd Al-Hamara coast are severely enriched with Ni, Cr and Pb, while the Al-Khiran coast is moderate severely enriched with the same metals. Ras Al-Zour and Ras Al-Jula'ia coasts are severely enriched with Ni and very severely enriched with Pb. Simultaneously, all studied sites are extremely severe enriched with Cu and Cd. Soil pollution index conformable with other environmental indicators. It indicated that Hadd Al-Hamara and Al-Khiran coasts are highly contaminated with Cu and Cd, while Ras Al-Zour and Ras Al-Jula'ia coasts are highly contaminated with Cd. The degree of contamination revealed that the sediments of Hadd Al-Hamara and Al-Khiran coasts are a moderate degree of contamination by heavy metals, while Ras Al-Zour and Ras Al-Jula'ia coasts are low degrees of heavy metal contamination. The pollution load index showed that the sediments of all studied sites are no heavy metal pollution. Nevertheless, we can decide that the sources of the pollutants in the studied area were industrial effluent, industrial pollutants, ship transportation of oil and goods, Al-Zour power plant, domestic sewage discharge and backfilling works.

Conflict of interest

The authors unanimously declare that this paper is free from any conflict of interest.

Supplementary

Table 1. Heavy metals concentrations (ppm) in the studied sediments of south Kuwait coast.

Site	SN	depth	Fe	Mn	Cu	Pb	Ni	Co	Cd	Cr	TOM
Hadd al Hamara (south of Al-Khiran)	1	High tide (> SL = 3 m)	679.4	18.1	200	2.77	4.74	0.33	0.11	9.88	170
	2		876.5	25.0	149	4.06	4.58	0.43	0.12	8.62	330
	3		1191.7	33.0	216	6.32	5.63	0.57	0.26	13.57	160
	4		671.2	16.7	267	4.00	5.89	0.40	0.23	14.54	100
	5	Sea level	663.6	18.7	350	4.99	9.30	0.53	0.21	17.73	250
	6		1033.4	26.5	170	7.05	5.71	0.66	0.20	13.07	160
	7		621.6	13.6	254	4.63	6.48	0.40	0.14	13.49	130
	8		641.5	16.9	149	5.41	3.60	0.40	0.19	11.12	160

Continued on next page

Site	SN	depth	Fe	Mn	Cu	Pb	Ni	Co	Cd	Cr	TOM
	9	Offshore (60 cm)	689.4	21.0	189	4.12	15.65	0.85	0.31	33.78	190
	10		652.9	15.6	198	3.39	19.84	0.79	0.16	43.01	210
	11		648.4	15.7	251	3.12	21.37	0.92	0.16	46.04	600
	12		689.5	17.3	260	3.18	18.96	0.82	0.45	42.08	280
Al-Khiran	13	High tide (> SL = 3 m)	625.8	12.8	197	3.18	5.71	0.39	0.21	11.87	190
	14		1090.8	20.2	423	5.27	13.08	0.97	0.60	24.60	190
	15		824.6	16.8	310	3.57	9.33	0.54	0.23	18.08	110
	16		646.6	12.6	328	4.50	9.58	0.58	1.06	16.64	160
	17	Sea level	580.8	9.5	268	1.89	5.35	0.39	0.12	14.18	160
	18		1267.7	29.8	209	3.43	8.29	0.85	0.40	13.91	290
	19		1599.3	42.3	345	3.10	11.01	0.89	0.19	19.22	140
	20		960.9	22.8	200	3.61	6.80	0.64	0.22	13.87	230
	21	Offshore (60 cm)	581.7	10.2	202	2.51	5.12	0.38	0.19	11.16	160
	22		745.9	14.6	250	3.48	5.81	0.46	0.23	13.44	150
	23		1418.1	32.6	235	3.36	8.17	0.81	0.18	16.24	170
	24		577.7	9.5	181	2.54	3.89	0.36	0.15	10.83	120
Ras Al-Zour (North of Al-Khiran)	25	High tide (> SL = 3 m)	344.1	19.0	20	2.56	8.30	0.12	0.98	0.58	430
	26		312.5	32.6	19	2.73	9.86	0.19	1.03	0.72	570
	27		299.7	24.6	19	2.63	9.05	0.25	1.45	0.70	70
	28		305.2	19.7	16	2.70	7.88	0.21	1.16	0.56	330
	29	Sea level	193.6	25.3	12	3.35	5.88	0.31	0.96	0.72	280
	30		222.3	20.9	15	2.66	7.61	0.19	1.16	0.59	140
	31		237.1	26.4	15	2.59	7.02	0.18	1.40	0.67	230
	32		297.7	20.4	17	2.77	8.26	0.19	1.07	0.67	70
	33	Offshore (60 cm)	206.1	23.9	14	2.77	7.00	0.16	1.37	0.63	390
	34		232.4	18.9	13	8.47	3.79	0.16	0.77	0.48	410
	35		267.4	27.3	15	2.80	7.06	0.30	1.40	0.60	130
	36		440.2	24.2	23	4.02	13.69	0.58	1.59	0.85	270
Ras Al-Jula’ ia	37	High tide (> SL = 3 m)	331.8	36.2	18	6.72	8.99	0.28	1.96	0.66	390
	38		462.3	24.9	22	6.43	9.49	0.29	1.23	0.56	370
	39		337.4	17.7	16	5.20	6.54	0.25	0.96	0.43	580
	40		335.7	20.6	17	5.93	5.82	0.21	0.96	0.41	270
	41	Sea level	533.4	19.1	23	2.97	15.30	0.16	0.70	0.47	360
	42		498.5	24.8	26	5.40	14.75	0.32	0.88	0.65	480
	43		612.7	26.5	27	5.27	16.50	0.22	1.28	0.58	570
	44		476.7	20.5	19	4.08	10.20	0.32	0.91	0.43	680
	45	Offshore (60 cm)	441.1	52.9	22	5.32	12.77	0.31	0.96	0.73	560
	46		477.8	16.8	22	4.97	12.43	0.24	1.10	0.43	610
	47		450.8	15.5	20	5.21	12.07	0.23	1.02	0.46	620
	48		437.2	24.2	25	4.02	12.69	0.14	0.95	0.59	600

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