

# Environmental assessment of heavy metal contamination in bottom sediments of Al-Kharrar lagoon, Rabigh, Red Sea, Saudi Arabia

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**Abstract** In order to assess the pollution levels of selected heavy metals, 45 bottom sediment samples were collected from Al-Kharrar lagoon in central western Saudi Arabia. The concentrations of the heavy metals were recorded using inductively coupled plasma-mass spectrometer (ICP-MS). The results showed that the concentrations of Pb and Cd exceeded the environmental background values. However, the heavy metal contents were less than the threshold effect level (TEL) limit. The concentrations of heavy metals in lagoon bottom sediments varied spatially, but their variations showed similar trends. Elevated levels of metals were observed in the northern and southern parts of the lagoon. Evaluation of contamination levels by the sediment quality guidelines (SQG) of the US-EPA revealed that sediments were non-polluted-moderately to heavily polluted with Pb; non-polluted to moderately polluted with Cu; and non-polluted with Mn, Zn, Cd, and Cr. The geoaccumulation index showed that lagoon sediments were unpolluted with Cd, Mn, Fe, Hg, Mo, and Se; unpolluted to moderately polluted with Zn and Co; and moderately polluted with Pb, Cr, Cu, and As. The

high enrichment factor values for Pb, As, Cu, Cr, Co, and Zn (>2) indicate their anthropogenic sources, whereas the remaining elements were of natural origins consistent with their low enrichment levels. The values of CF indicate that the bottom sediments of Al-Kharrar lagoon are moderately contaminated with Mn and Pb.

**Keywords** Environmental assessment · Heavy metals · Al-Kharrar · Rabigh · Red Sea · Saudi Arabia

## Introduction

The heavy metal contamination in sediments of aquatic system, from natural or anthropogenic origin, represents one of the most important coastal environment problems (Ridgway and Shimmield 2002). Heavy metal concentrations in coastal environment have been rapidly increasing due to human activities. Coastal environments are subjected to metal contamination throughout various inputs such as natural, industrial, and urban sources. Metals released into coastal environments rapidly sink to the bottom and accumulate in sediments (Cukrov et al. 2011; Ra et al. 2011). The main sources of the anthropogenic metal load in the sea sediments may be terrestrial or from mining and industrial developments (Sundaray et al. 2011).

The Saudi Arabia coastline extends for about 1840 km (79 %) of the Red Sea eastern coast. Many industrial activities were conducted in Saudi Arabia in the last few years (Badr et al. 2009; Pan et al. 2011). The Saudi coastal environments have been affected by

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extensive exploitation and metal load. The original sources of coastal pollution are oil pipeline leaks and domestic sewage from coastal cities (Al-Thukair et al. 2007). Jeddah is the most polluted area along the eastern coast (Badr et al. 2009).

Rabigh city is one of the provinces of Makkah region. It is located on the Red Sea coast in the Tihama provenance at longitude 39° E and latitude 22.48° N. Many industrial activities exist along the coast of Rabigh (e.g., Arabian Cement Factory, Electric Power Plant, Water Supply Plant, Aramco Company Refinery, and Aramco Residential Area). Additionally, King Abdullah Economic City and King Abdullah Port, which are among the top ten largest ports in the world, are close to Rabigh city. Several studies have been carried out to investigate the heavy metal contaminations in the sediments of the Red Sea coast in Jeddah provenance (e.g., Basham 2008; Badr et al. 2009; Pan et al. 2011; Usman et al. 2013). Most of the previous studies deal with the surface sediments from the tidal area and showed that the surface sediments are highly contaminated.

The present study aimed to (1) assess the current status and spatial distribution of heavy metals in the bottom sediments of Al-Kharrar lagoon and (2) identify potential sources of contamination. This evaluation will

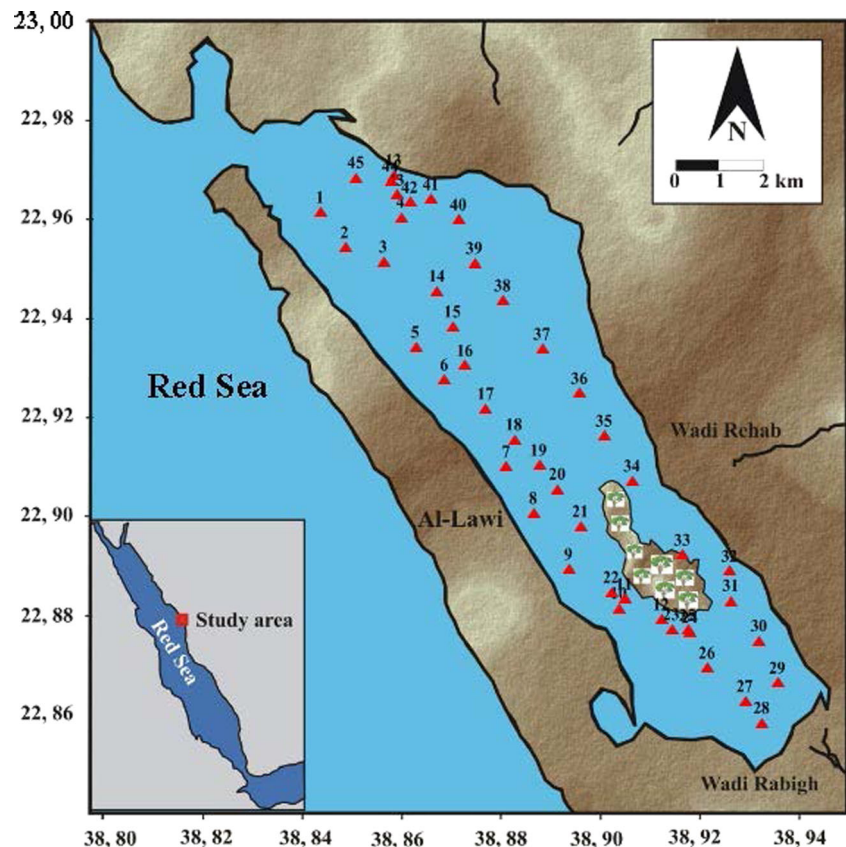
help in developing effective coastal management guidelines and strategies for better management of coastal activities. These guidelines are of particular significance, as the Saudi Coastal zones are important in terms of marine waterways, tourism, and various commercial and industrial activities.

## Materials and methods

### Study area

Al-Kharrar lagoon lies northwest of Rabigh city between latitude 22° 45 and 23° 00 N and longitude 39° 00 and 38° 45 E (Fig. 1). The lagoon is 17 km long with an average width of 3 km. The lagoon water depth ranges from 1 to 11 m. It is connected to the Red Sea through a narrow channel located at the northwestern side. The southern and eastern parts of the lagoon are bounded by extensive intertidal and supratidal flats (sabkha). Mangroves are common in the lagoon islands (Fig. 2a, b). Tidal range at the lagoon is very low (20–30 cm). Sediment textures consist of mud, gravelly sand, and sandy mud. Mud is dominant in the southern half and along the southeast fringes of the lagoon. Sediment is mainly of biogenic origin. Sea grass covers the floor of the lagoon (Fig. 2d), and coral

**Fig. 1** Location map of Al-Kharrar lagoon. The locations of studied samples plotted using Surfer 9



**Fig. 2** Field photos. **a, b** The mangrove trees around the lagoon, occupying the small island in the lagoon; **c** the fishing boat and grab sampler used in the sample collection; **d** sea grass in the lagoon floor; **e, f** the fishing boats which cross the lagoon the whole day



reefs are present in many places in the lagoon. Sponges also occur in the lagoon. The lagoon is crowded with the fishing boats (Fig 2e, f). The area of the lagoon was marked as a protected area due to the presence of mangrove and sea grass beds as well as large stands of dense halophyte (IUCN 1987).

### Methodology

Forty-five bottom sediment samples were collected in February 2014 from the bottom of the lagoon using grab sampler (Figs. 1 and 2c; Table 1). The physical properties were measured in situ for surface water. The samples were stored in clean polyethylene bags until metal analysis was performed. The sediment samples were prepared by accurately weighing 100 mg of samples into dry and clean Teflon microwave digestion vessels; 2 mL of HNO<sub>3</sub>, 6 mL HCl, and 2 mL HF were added to the vessels. Samples were digested using scientific microwave (Model Milestone Ethos 1600). The resulting digest was transferred to a 15-mL plastic volumetric tube and made up to mark

using deionized water. A blank digest was carried out in the same way. The analytical determination of heavy metals was carried out by inductively coupled plasma-mass spectrometer (ICP-MS): NexION 300D (Perkin Elmer, USA).

### Results

#### Physical properties

The seawater is highly oxygenated due to near saturation and relatively uniform DO levels, which ranges from 5.8 to 6.91 mg/L (Fig. 3 and Table 1). Eh values range from 278 to 304 mV (Table 1, Fig. 3). The total dissolved salts (TDS) show spatial distribution (Fig. 4) range from 38.1 to 40.7 g/L (Table 1). The global average TDS is 34.5 g/L (Gaid and Treal 2007). Higher TDS levels observed in the studied lagoon is probably due to the dissolution and leaching of the surrounding limestone of Tertiary rocks. As the lagoon is situated in a desert belt, the atmospheric

**Table 1** Locations of studied samples and physical properties of surface water from the studied lagoon

NO	Lat	Long	W. depth	Surface water parameters			
				Ph	Do	Eh	TDS
1	22.96	38.86	8.5	7.92	6.7	294	38.1
2	22.95	38.87	4.5	7.96	5.8	301	38.8
3	22.95	38.87	2	7.91	6.47	294	38.4
4	22.96	38.88	3	7.96	5.8	290	40.1
5	22.93	38.88	3.5	7.79	6.3	288	40.1
6	22.93	38.89	4.7	7.95	6.8	292	38.4
7	22.91	38.90	5	7.92	6.42	290	40.5
8	22.90	38.91	5	7.8	6.22	282	40.1
9	22.89	38.92	4.7	7.84	6.8	292	40.3
10	22.88	38.93	5.7	7.97	6.2	292	38.4
11	22.88	38.93	1.5	7.88	6.42	300	40.7
12	22.88	38.94	3.7	7.82	6.8	288	40.1
13	22.97	38.88	1	7.95	6.2	290	39.4
14	22.94	38.89	8.7	7.88	6.7	295	40.5
15	22.94	38.89	8.5	7.89	6.4	284	40.3
16	22.93	38.89	9.5	7.78	6.2	298	40.3
17	22.92	38.90	8	7.98	6.22	302	40.5
18	22.91	38.90	8.5	7.77	6.8	291	40.5
19	22.91	38.91	8.5	7.89	6.8	294	40
20	22.90	38.91	8.5	7.85	6.8	288	40.7
21	22.90	38.92	5.7	7.78	6.8	295	40.1
22	22.88	38.93	3.5	7.99	6.42	288	40.7
23	22.88	38.94	5	7.82	6.8	302	38.8
24	22.87	38.94	3.5	7.9	6.42	285	40.5
25	22.88	38.94	0	7.88	6.8	304	39.4
26	22.87	38.95	5.5	7.98	6.22	290	40.3
27	22.86	38.96	2.6	7.77	6.91	298	40.1
28	22.86	38.96	2.2	7.92	6.4	289	40.3
29	22.86	38.96	2	7.84	6.71	294	40
30	22.87	38.96	4	7.92	6.22	283	40.5
31	22.88	38.95	4.5	7.88	5.8	279	40
32	22.89	38.95	1	7.82	6.42	292	40.5
33	22.89	38.94	6.5	7.72	6.4	280	40
34	22.91	38.93	9	7.95	6.8	288	40.1
35	22.92	38.92	11	7.92	6.8	286	39.4
36	22.92	38.92	8	7.9	6.47	279	40.3
37	22.93	38.91	7.6	7.93	6.47	296	40.3
38	22.94	38.90	7.6	7.8	6.42	278	40
39	22.95	38.89	8	7.84	6.37	288	40.1
40	22.96	38.89	6.3	7.86	6.8	292	39.9
41	22.96	38.88	5	7.95	6.7	280	40
42	22.96	38.88	5.5	7.93	6.8	285	40.3
43	22.96	38.88	5.5	7.92	6.8	294	40.1
44	22.97	38.88	3.5	7.88	6.47	292	40
45	22.97	38.87	1.5	7.92	6.22	293	39.8

*DO* dissolved oxygen, *Eh* redox potential, *TDS* total dissolved salts

Temperature of water samples = 25 °C during measurements

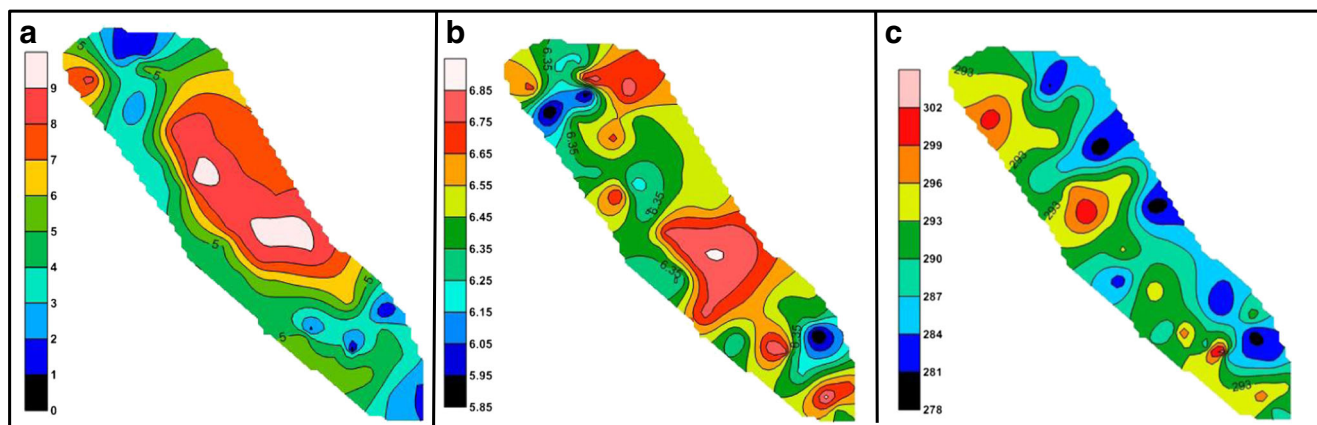
dust input from the surrounding arid region is also a source of salts (and heavy metals) to seawater.

### Heavy metal concentrations

Concentrations of Fe range from 1708 to 3686  $\mu\text{g g}^{-1}$  with an average 2249.42  $\mu\text{g g}^{-1}$ . The concentrations of Mn are 53–225 and the average is 102.7  $\mu\text{g g}^{-1}$ . The concentrations of Pb range from 40 to 63  $\mu\text{g g}^{-1}$ . Pb

displays its highest concentration in sample 30 (63  $\mu\text{g g}^{-1}$ ). Concentrations of Cu range from 11 to 28  $\mu\text{g g}^{-1}$ . The highest Zn concentration (51  $\mu\text{g g}^{-1}$ ) is measured in sample 39. Concentrations of Cd are very low with values less than 1  $\mu\text{g g}^{-1}$ . Co concentrations range from 2.2 to 8.1  $\mu\text{g g}^{-1}$ . The concentrations of Cr range from 14 to 25  $\mu\text{g g}^{-1}$  with the highest value in sample 39. The concentrations of Ni have the same trend of Co ranges from 7.9 to 9.8  $\mu\text{g g}^{-1}$ . Mo concentrations





**Fig. 3** Some measured physical parameters in the water of the lagoon, depth (a), dissolved oxygen (b), Eh (c)

are very low and range from 0.21 to 1.1  $\mu\text{g g}^{-1}$ . The concentrations of Ni range from 7.9 to 9.8  $\mu\text{g g}^{-1}$ . The concentrations of Hg are also relatively low, ranging from 0.007 to 0.17  $\mu\text{g g}^{-1}$ . Concentrations of As range from 1.20 to 2.30  $\mu\text{g g}^{-1}$  with an average 1.67  $\mu\text{g g}^{-1}$  (Table 2).

**Spatial distribution of heavy metals**

Spatial distribution patterns of the heavy metals Fe, Mn, Pb, Cu, Zn, Cd, Co, Cr, Mo, Ni, Hg, and As in the sediments of Al-Kharar lagoon are shown in Figs. 5 and 6. Higher levels of Pb are located in the northern part of the lagoon (Fig. 5c), whereas lower values are found in the southern corner of the lagoon. These spatial distribution trends are closely linked to grain size distribution. The clay-silt facies are dominant in the northern part, while coarse facies are accumulated in the southern part of the lagoon. The concentrations of Cd (Fig. 5f) are higher in the center, northern, and southern parts of the lagoon. Higher concentrations of Fe are recorded in the southeastern corner (Fig. 5a).

This area is a designated parking area for motor boats in the lagoon. Likewise, the concentrations of Mn, Cu, Zn, (Fig. 5b–e), Co and Cr, Mo, Ni, Hg, and As (Fig. 6 a–f) vary spatially with increasing values in the northern and southern directions, where the predominant fine fraction occurred and decreased eastwards closer to the bank, the portion with high percent of coarser grained sediments

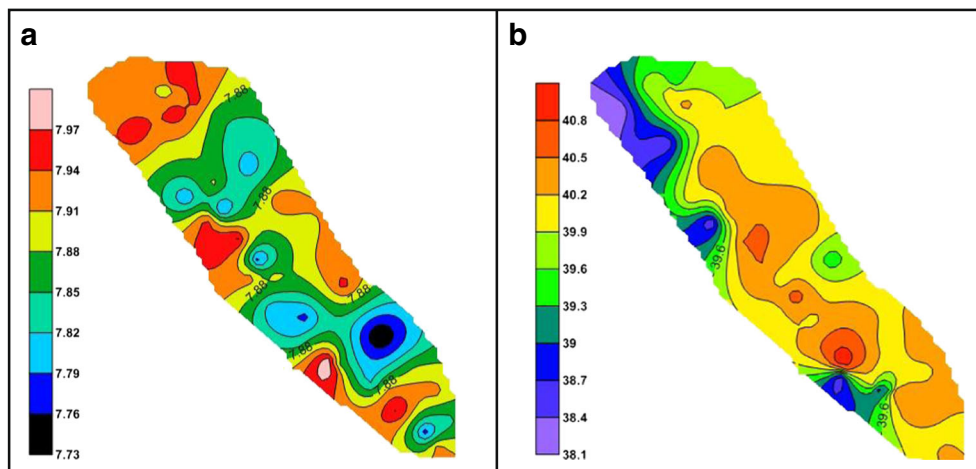
**Discussion**

**Assessment of sediment contamination**

*Assessment of heavy metals pollution using sediment quality guidelines*

The extent of heavy metal pollution in bottom sediments of Al-Kharar lagoon is assessed by the sediment quality guidelines (SQG) (Giesy and Hoke 1990). Based on the SQG, all bottom sediments fall in the non-polluted and moderately polluted classes, except for Pb (Table 3). Pb is the only metal with

**Fig. 4** Some measured physical parameters in the water of the lagoon Ph (a), TDS (b)



**Table 2** Summary statistics of trace element content in surficial sediments of Al-Kharrar lagoon, compared to other reference concentrations

Samples (45)	Fe	Mn	Pb	Cu	Zn	Cd	Co	Cr	Ni	Mo	As	Hg
Minimum	1708.00	53.00	40.00	11.00	30.00	0.18	2.20	14.00	7.90	0.21	1.20	0.01
Maximum	3686.00	225.00	63.00	28.00	51.00	0.33	8.10	25.00	9.80	1.10	2.30	0.02
Average	2249.42	102.73	50.87	16.00	39.71	0.26	4.77	20.62	8.69	0.51	1.67	0.01
SD	574.19	33.00	7.39	4.03	5.39	0.04	1.61	2.70	0.48	0.22	0.29	0.00
Background	3800	950	12.5	55	70	0.2	25	100	75	–	–	–
TEL <sup>b</sup>	–	–	35	35.7	123	0.6	–	37.3	22.7	–	–	–
PEL <sup>b</sup>	–	–	91.3	197	315	3.53	–	90	48.6	–	–	–
Non-polluted	–	<300	<40	<25	<90	–	–	<25	<20	–	–	–
Moderately	–	–	–	–	–	–	–	20–	–	–	–	–
Polluted	–	300–500	40–60	25–50	90–200	–	–	25–75	50	–	–	–
Heavily polluted	–	>500	>60	>50	>200	>6	–	>75	>50	–	–	–

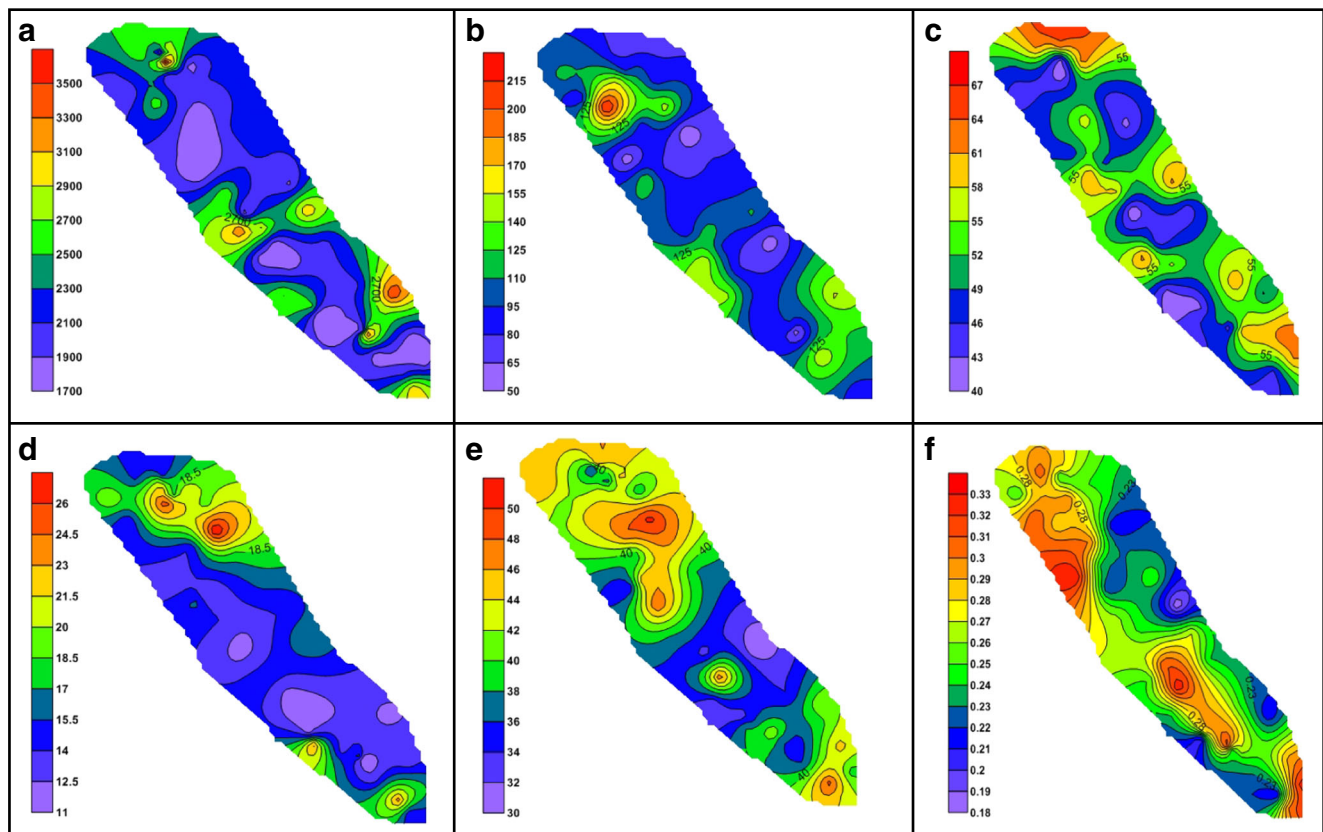
SD standard deviation, CV coefficient of variation, TEL threshold effect level, PEL probable effect level

<sup>a</sup> From Taylor (1964)

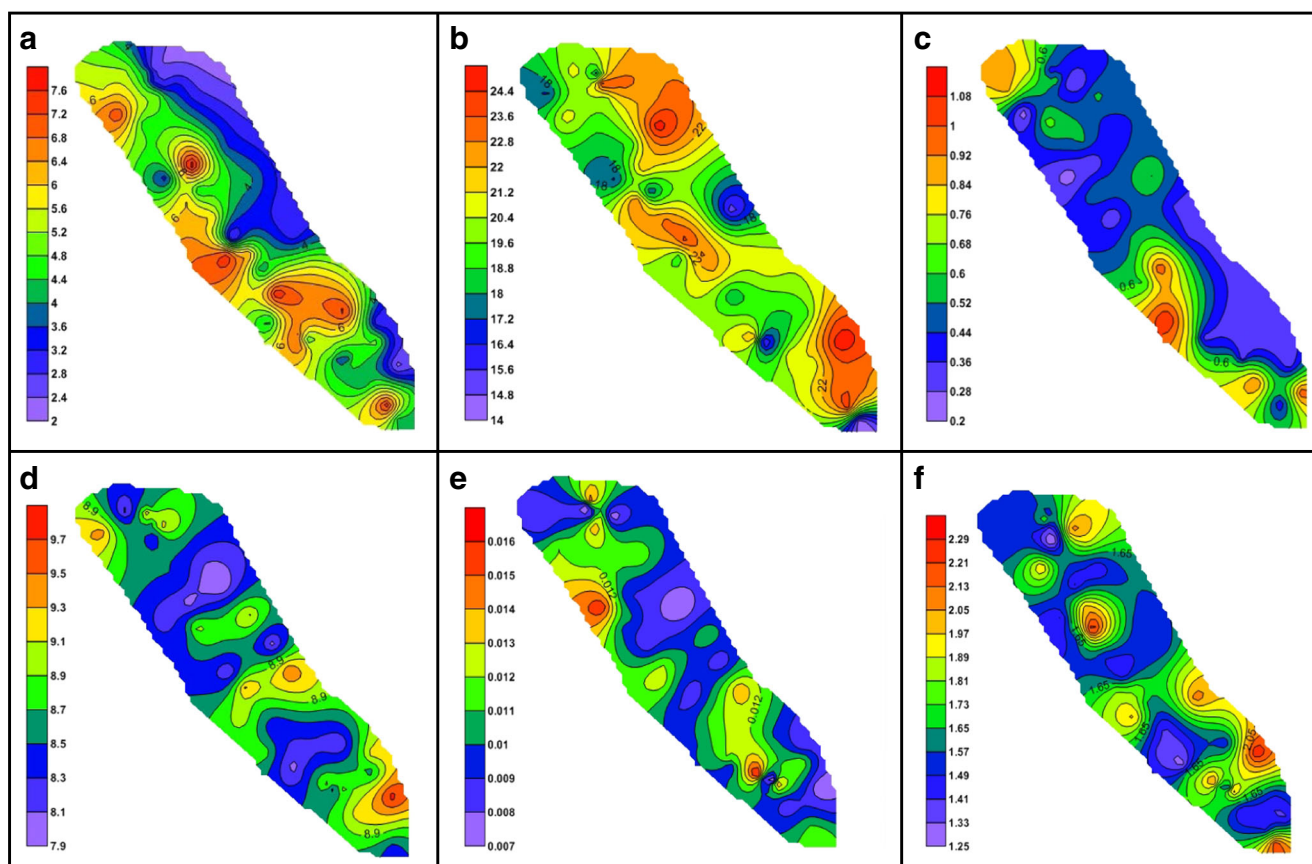
<sup>b</sup> From Smith et al. (1996); MacDonald et al. (2000)

higher values indicating heavily polluted sediments (22 % of the samples). About 4.5 % of sediment samples are moderately contaminated with Cu, whereas the rest of the sediments are non-polluted with Cu. The sediments are non-polluted with Zn, Cd, Mn, and Cr.

Using the effect range low (ERL), the effect range median (ERM), and the guidelines of the Swedish Environmental Protection Agency (Tables 3 and 4), all samples are below the ERL for all the metals; however 31 samples lie between the ERL and ERM for Pb. According to the Swedish Environmental



**Fig. 5** Spatial distribution patterns. Fe contents (a), Mn contents (b), Pb contents (c), Cu contents (d), Zn contents (e), and Cd contents (f), in bottom sediments from Al-Kharrar lagoon



**Fig. 6** Spatial distribution patterns. Co contents (a), Cr contents (b), Mo contents (c), Ni contents (d), Hg contents (e), and As contents (f), in bottom sediments from Al-Kharrar lagoon

Protection Agency (SEPA), all samples are little or none to slightly contaminated with heavy metals. Twenty-nine samples are considered significantly contaminated with Pb.

*Assessment of heavy metals pollution using geoaccumulation index*

The geoaccumulation index (Igeo) is a common criterion used for evaluating the heavy metal pollution in

sediments (Leopold et al. 2008). It was originally defined by Muller (1979), where heavy metal contaminations in sediments are determined by comparing their current concentration levels with those from preindustrial times. The Igeo can be defined as

$$I_{geo} = \log_2 \left( \left( \frac{C_n}{1.5 \times B_n} \right) \right)$$

where Cn is the measured concentration of metal (n) in the sediments, Bn is the geochemical background concentration of

**Table 3** Number of samples that had metal concentrations above the sediment effect data of ERL and ERM in the collected samples

Metal ( $\mu\text{g g}^{-1}$ )	Guidelines		Study area average	No. of samples below the ERL	No. of samples between ERL and ERM	No. of samples above the ERM
	ERL	ERM				
As	8.2	70	1.67	45	0	0
Cd	1.2	9.6	0.26	45	0	0
Cr	81	370	20.62	45	0	0
Cu	34	270	16.00	45	0	0
Pb	46.7	218	50.87	14	31	0
Hg	0.15	0.71	0.01	45	0	0
Zn	150	410	39.71	45	0	0

Data after Long et al. 1996

ERL effect range low, ERM effect range median

**Table 4** Classification of sediment heavy metal contamination according to the Swedish environmental Protection Agency ( $\mu\text{g g}^{-1}$  dry weight) of selected heavy metals from Vallius et al. 2007

Metal ( $\mu\text{g g}^{-1}$ )	Class 1 little or none	Samples in class 1	Class 2 slight	Samples in class 2	Class 3 significant	Samples in class 3	Class 4 large	Samples in class 4	Class 5 very large	Samples in class 5
As	<10	45	10–16	0	16–26	0	26–40	0	>40	0
Cd	<0.2	0	0.2–0.5	45	0.5–1.2	0	1.2–3	0	>3	0
Co	<14	45	14–20	0	20–28	0	28–40	0	>40	0
Cr	<80	45	80–110	0	110–160	0	160–220	0	>220	0
Cu	<15	20	15–30	25	30–60	0	60–120	0	>120	0
Hg	<0.04	19	0.04–0.10	26	0.10–0.27	0	0.27–0.7	0	>0.7	0
Pb	<31	0	31–46	16	46–68	29	68–100	0	>100	0
Zn	<85	45	85–125	0	125–195	0	195–300	0	>300	0

the metal (n) in shale (Turekian and Wedepohl 1961), and 1.5 is a background matrix correction factor for lithogenic effects.

The basic statistics of Igeo calculations for heavy metals in the sediments of Al-Kharrar lagoon are listed in Table 5. Based on Muller scales (Muller 1981), the sediments of Al-Kharrar lagoon are classified as moderately polluted with Pb, Cr, Cu, and As ( $1 < I_{\text{geo}} < 2$ ). The sediments are classified as unpolluted to moderately polluted with Zn and Co ( $0 < I_{\text{geo}} < 1$ ). All other metals (Cd, Mn, Fe, Hg, Mo, and Ni) in the studied samples show lower values ( $I_{\text{geo}} < 0$ ) indicating that the sediments are unpolluted.

On the basis of mean Igeo values, heavy metals are ranked in the following order: Pb (1.8) > As (1.7) > Cr (1.3) > Cu (1.2) > Co (0.8) > Zn (0.1) > Mo (−0.3) > Cd (−0.8) > Mn

(−1.5) > Fe (−5.0) > Hg (−6.6). The majority of heavy metals show similar distribution patterns, i.e., more positive Igeo values in the northern and southern part. This may be due to the high loading of the concentration of these metals from the adjacent rock facies.

#### Assessment of trace element pollution using enrichment factor

Enrichment factor (EF) analysis is a method proposed by Simex and Helz (1981) to assess heavy metal concentrations. It is mathematically expressed as

$$EF = \frac{(M/Fe)_{\text{sample}}}{(M/Fe)_{\text{crust}}}$$

**Table 5** Geoaccumulation index (Igeo), enrichment factor (EF), and contamination factor (CF) of heavy metals in the bottom sediments of the studied lagoon

	Fe	Mn	Pb	Cu	Zn	Cd	Co	Cr	Ni	Mo	Hg	As
<b>Igeo</b>												
Minimum	0.40	−2.49	0.98	−1.12	−0.86	−0.22	−1.87	−1.57	−1.86	−2.23	−3.76	−2.09
Maximum	1.81	−1.04	1.44	−0.19	−0.33	0.38	−0.56	−0.99	−1.65	−0.57	−2.87	−1.44
Average	0.96	−1.87	1.21	−0.77	−0.59	0.14	−1.15	−1.19	−1.77	−1.42	−3.39	−1.78
SD	0.32	0.30	0.14	0.23	0.13	0.14	0.34	0.14	0.05	0.42	0.24	0.17
<b>EF</b>												
Minimum		5.13	0.32	0.78	1.68	0.18	0.26	0.18	0.35	0.15	1.19	0.14
Maximum		15.99	1.45	2.23	5.14	1.06	0.77	0.41	2.13	0.63	3.97	0.52
Average		10.80	0.77	1.50	3.46	0.51	0.54	0.31	0.90	0.34	2.44	0.28
SD		0.10	2.99	0.27	0.39	0.91	0.21	0.13	0.07	0.45	0.10	0.62
<b>CF</b>												
Minimum	0.04	0.59	2.00	0.24	0.32	0.60	0.12	0.16	0.12	0.08	0.02	0.09
Maximum	0.08	2.50	3.15	0.62	0.54	1.10	0.43	0.28	0.14	0.42	0.04	0.18
Average	0.05	1.14	2.54	0.36	0.42	0.87	0.25	0.23	0.13	0.20	0.03	0.13
SD	0.01	0.37	0.37	0.09	0.06	0.12	0.08	0.03	0.01	0.09	0.01	0.02



where  $(M/Fe)_{\text{sample}}$  is the ratio of metal and Fe concentrations in the sample, and  $(M/Fe)_{\text{crust}}$  is the ratio of metal and Fe concentrations in the Earth's crust.

The EF values for the heavy metals are tabulated in Table 5. According to Zhang and Liu (2002), elements with  $EF < 2$  are considered to entirely originate from the crustal materials or natural processes, while those elements with  $EF > 2$  are most likely the product of anthropogenic activities. The high EF values for Pb, As, Cu, Cr, Co, and Zn (with an average of 7.4, 6.4, 5.1, 5.1, 3.8, and 2.3, respectively) (Table 5) indicate anthropogenic impact of those metal concentrations in bottom sediments. The remaining metals showed EF values of less than 2 [i.e., Mo (2) > Cd (1.3) > Mn (0.8) > Hg (0.0)]. These values suggest that they originated from natural sources.

The EF for all metals in bottom sediments of Al-Kharrar lagoon showed similar variations, with more positive EF values found in the western and northern parts, compared to the eastern portion of the lagoon.

#### *Assessment of heavy metals pollution using contamination factor*

The CF is the ratio obtained by dividing the concentration of each heavy metal in the sediment ( $C_{\text{heavy metal}}$ ) by the concentration in background ( $C_{\text{background}}$ ):

$$CF = \frac{C_{\text{heavy metal}}}{C_{\text{background}}}$$

CF values were interpreted as follows: low contamination,  $CF < 1$ ; moderate contamination,  $1 < CF < 3$ ; considerable contamination,  $3 < CF < 6$ ; and very high contamination,  $CF > 6$  (Hakanson 1980).

The CF values for the heavy metals are tabulated in Table 5. According to Hakanson (1980), elements with  $CF < 1$  are low contamination, while those elements with  $1 < CF < 3$  are most likely moderate contamination. The average of CF values for Fe, Cu, Zn, Cd, Co, Cr, Ni, Mo, Hg, and As are  $< 1$  (Table 5). Mn and Pb showed average value of CF (1.14 and 2.54, respectively). These values indicate that the bottom sediments of Al-Kharrar lagoon are moderately contaminated with Mn and Pb, low contaminated with the other metals.

#### **Pollution sources and environmental assessment**

One of the expected sources of the metal concentration in the lagoon includes the flash floods from Wadi Rabigh (Masoud 2015) which contains the eroded sediments from the surrounding rocks. The other source of the heavy metals is the diffusion from the anthropogenic activities. Many industries are located in the Rabigh area such as Petroleum refinery, Aramco Oil Company, Petro Rabigh Company, Rabigh

Industrial Port, Rabigh Cable Factory, and a desalination plant. The waste effluents of these industrial activities are dumped into the seawater either treated or partially treated.

The coastal areas of Saudi Arabia have a lot of construction activities that are often associated with intensive dredging and reclamation. The coastal and marine environment of the Red Sea is the target for most of the major housing, tourism, and economic developments. The King Abdullah Economic City (KAEC) which was founded in 2006 is also close to the study area. The city has a total development area of 173 km<sup>2</sup>. The city is divided into six main components and includes a big industrial zone; the largest sea port in the region is also close to the study area.

Dredging and land filling, sewage, and oil pollution are the most important sources of pollution in the study area. Dredging and reclamation processes are typically associated with elevated levels of heavy metals (Guerra et al. 2009; Hedge et al. 2009). These contaminants may enter important food web components including fish and shellfish. Incomplete or no sewage treatment, increasing wastes from different human activities, oil spills, constructions, and trash materials are the chronic problems associated with heavy metal pollution in the study area. Sewage discharges are the major source of coastal pollution in the coastal area of the Red Sea (El Sayed 2002; Al-Farawati 2010). Petroleum refinery wastewater is composed of, among different chemicals, heavy metals like chromium, iron, nickel, copper, selenium, and zinc (Wake 2005).

An increase in population of the area after the completion of KAEC, which includes a big residential area, will increase the sources of pollution considerably in the coming years if measures for control and management are not created.

The pollution stress in the study area is generally not very high; however, the sediments are classified as highly polluted with Pb. The sediments of Al-Kharrar lagoon were classified as moderately polluted with Pb, Cr, Cu, and As levels according to the Igeo index. The high EF values for Pb, As, Cu, Cr, Co, and Zn indicate anthropogenic impact of metal concentration in bottom sediments. The values of CF indicate that the bottom sediments of Al-Kharrar lagoon are moderately contaminated with Mn and Pb.

#### **Conclusions**

The present study focused on the spatial distribution and contamination levels of heavy metals in bottom sediments of Al-Kharrar coastal lagoon along Red Sea, Saudi Arabia. Heavy metal concentrations varied spatially with relatively similar distribution patterns. The main sources of contaminations are atmospheric input and

diffusion from anthropogenic activities like dredging and reclamation processes. The pollution stress in the study area is generally not very high; however, the sediments are classified as highly polluted with Pb. The sediments of Al-Kharrar lagoon were classified as moderately polluted with Pb, Cr, Cu, and As levels according to the Igeo index. The high EF values for Pb, As, Cu, Cr, Co, and Zn indicate anthropogenic impact of metal concentration in bottom sediments. The values of CF indicate that the bottom sediments of Al-Kharrar lagoon are moderately contaminated with Mn and Pb. The expected sources of metal concentrations in the lagoon include flash floods coming from Wadi Rabigh and the diffusion from anthropogenic activities.

The situation in the lagoon cannot be considered satisfactory, and it is critical, which requires government and the decision makers to establish an effective pollution control strategy. This may include serious efforts to protect the area and the marine habitat. The environmental evaluation helps to develop an effective coastal management plan and better management strategies of coastal activities. This is of particular significance, as the Red Sea coastal area is important in terms of marine waterways, fishing, tourism, and various commercial and economic activities.

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