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Environmental assessment of coastal surface sediments at Tarut Island, Arabian Gulf (Saudi Arabia)

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ABSTRACT

Thirty eight surface sediments samples have been collected in the area around Tarut Island, Saudi Arabian Gulf to determine the spatial distribution of metals, and to assess the magnitude of pollution. Total concentrations of Fe, Mn, As, B, Cd, Co, Cr, Cu, Hg, Mo, Pb, Se, and Zn in the sediments were measured using ICP-MS (Inductively Coupled Plasma-Mass Spectrometer). Nature of sediments and heavy metals distribution reflect marked changes in lithology, biological activities in Tarut bay. Very high arsenic concentrations were reported in all studied locations from Tarut Island. The concentrations of Mercury are generally high comparing to the reported values from the Gulf of Oman, Red Sea. The concentrations of As and Hg exceeded the wet threshold safety values (MEC, PEC) indicating possible As and Hg contamination. Dredging and land filling, sewage, and oil pollution are the most important sources of pollution in the study area.

The marginal environments appear to be an active environment with both circumstantial and temporary tendency. The main sources of land pollutions are ports harbors, shipment, power plants, pulp factories, oil and gas sills, placer deposits, sailing, and water sports centers (Pati and Patra, 2012). Heavy metals are one of the most serious pollutants in the natural environment due to their toxicity, persistence and bioaccumulation problems (Tam and Wong, 2000). The Arabian (Persian) Gulf is a shallow marginal semi-enclosed sea of the Indian Ocean (Price and Robinson, 1993). The Arabian Gulf characterized by very high evaporation rates and poor flushing characteristics (Sheppard, 1993). The average depth of the Arabian Gulf is only 36 m depth. It is characterized by the abnormal salinity. The Saudi Arabian coastline of the Arabian Gulf extends for about 450 km.

Arabian Gulf countries have witnessed major economic, social and industrial developments. The coastlines of the Arabian Gulf have been extensively developed and modified. Dredging and reclamation, industrial and sewage effluents, hypersaline water discharges from desalination plants, and oil pollution are examples of anthropogenic stresses that contribute to environmental degradation in the Arabian Gulf (Sheppard et al., 2010; Naser, 2013). The Arabian Gulf sediments consist principally of carbonates and terrigenous materials (Al-Ghadban et al., 1994; Basaham and El-Sayed, 1998; Maeda et al., 1998; Basaham, 2010). Major and trace metals enter the Gulf from both natural weathering

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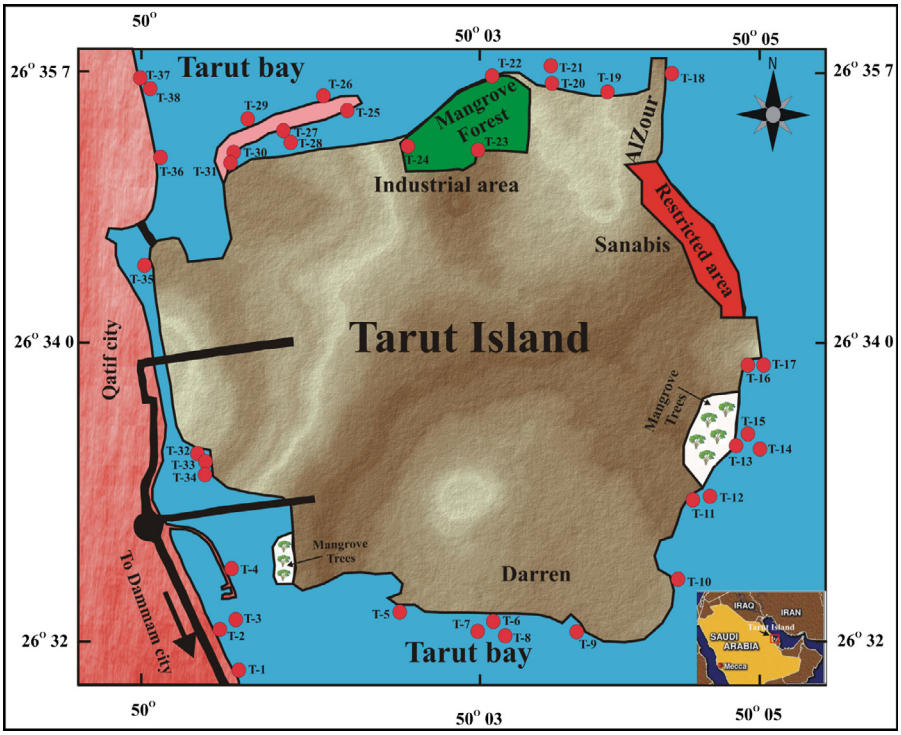

Fig. 1. Location map of Tarut Island.

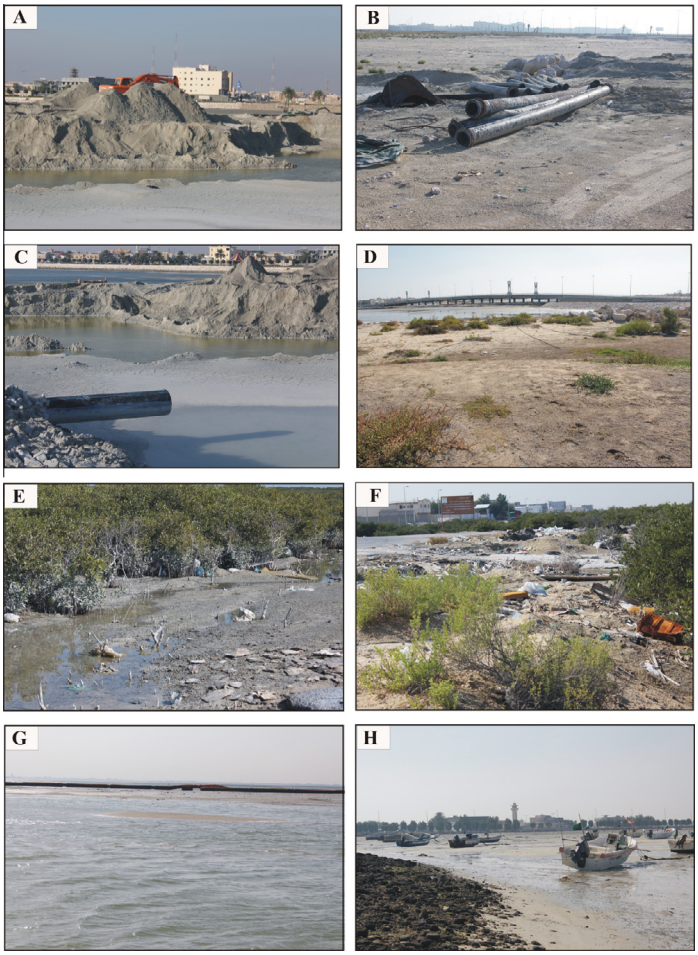

Fig. 2. Different environmental hazards of study area (A–C) constructions directly on the beach, (D) the construction of the third new bridge connect the island to Qatif, (E and F) of general view of Waste dumps near the mangrove forest although the presence of sign referred to that is a protected area, (G) the oil pipeline go around the Island, and (H) fishing boats around the Island.

Fig. 3. Different anthropogenic sources of pollution in study area (A–D) drainage of reject sewages directly to the Tarut bay surrounding the Island, (E–G) close-up views of Waste dumps of different waste materials directly on the coast of the Island in different locations, and (H) automobiles tires distributed in the beaches around the Island.

processes and anthropogenic activities. The determination of the total metal content in the bulk sediments of coastal areas of the Arabian Gulf have been carried out in many studies (e.g. El Sayed et al., 2002; Samir et al., 2006; Basaham, 2010; Biati et al., 2012; Elhabab and Adsani, 2013; Al Kahtany et al., accepted for publication).

Tarut Island is belonging to the Eastern Province of Saudi Arabia, now connected by three causeways to Qatif. It is six kilometers from the coast; the island has an area of 70 square kilometers extending from Ra's Tannurah in the north to Qatif in the west (Fig. 1). The human and tourism activities in Tarut Island contribute to the pollution of the coastal environment. No attentions have been paid to the geochemical studies of Tarut coastal area. The present study aims to (1) analyze the heavy metals content in the surface sediment of the coastal area around Tarut Island and (2) evaluate and identify potential sources of contamination and the pollution level in the environment.

Fifty years ago, Tarut Island was considered the largest Saudi island in the Gulf region, this is no longer true. Continuous land reclamation that occurred over several decades connected the island to the city of Qatif (Fig. 2A–C). Two bridges connect the island to Qatif city and the third one is now constructed (Fig. 2D). Three decades ago, mangrove forests could be found all over the eastern Saudi coast near the cities of Dammam, Sihat, Qatif, Safwa, and all the way to Ra's Tanura. But the mangrove forests have almost disappeared from these cities because of the expansion of coastal construction and industrial activities (Fig. 2E and F) oil pipelines (Fig. 2G), and Fishing activities (Fig. 2H). Draining the sewage on the shores attract our attentions in the Island coast (Fig. 3A–D), the waste, trash materials (Fig. 3E–G), and tiers (Fig. 3H) also, mostly cover the Island coast.

Thirty eight surface sediment samples were collected in December 2014 from the subtidal zone of 38 stations covering the whole coast of the Island (Table 1), we cannot sample the area of Sanabis because it is a restricted area (Fig. 1). The samples were

Table 1
Locations of studied sediments samples, and physical properties of surface water from the studied localities.

Sample no.	Latitude	Longitude	D.O mg/L	D. O sat %	R.P	PH	TDS	Conductivity
1	N 26 28 50	E 50 3 52	7.7	91.2	298	8.05	55,800	36,700
2	N 26 29 15	E 50 3 14	7.8	92	296	7.83	56,400	37,000
3	N 26 29 14	E 50 3 15	7.8	90	297	7.8	56,300	36,000
4	N 26 30 10	E 50 2 46	7.6	88.9	295	7.97	56,600	37,200
5	N 26 32 39	E 50 2 2	8.2	97.3	292	7.88	56,100	36,900
6	N 26 32 41	E 50 3 15	8.8	102.5	298	7.21	55,600	36,600
7	N 26 32 41.5	E 50 3 15.5	8.7	100	295	7.31	55,700	35,600
8	N 26 32 42	E 50 3 16	8	95	296	8.1	55,900	36,400
9	N 26 32 39	E 50 3 25	7.9	93.5	299	8.13	56,600	37,300
10	N 26 32 40	E 50 3 44	7.3	86	306	3.37	28,430	18,700
11	N 26 32 45	E 50 3 49	7.85	93.25	302	5.81	37,115	24,100
12	N 26 32 45.5	E 50 3 49.5	7.9	96	300	6.2	37,100	25,100
13	N 26 32 46	E 50 4 49	8.4	100.5	299	8.25	45,800	29,400
14	N 26 32 46.5	E 50 4 49.5	8.5	101	298	8.1	44,500	28,200
15	N 26 32 47	E 50 4 50	8.3	93.4	297	8.3	55,200	39,100
16	N 26 33 58	E 50 5 11	7.9	92.3	300	8.23	60,200	40,000
17	N 26 33 58.5	E 50 5 11.5	7.8	75	290	8.2	62,300	42,500
18	N 26 35 49	E 50 4 13	5.4	63.2	286	7.1	67,400	45,400
19	N 26 35 46	E 50 4 29	8.1	94.8	301	7.73	66,000	44,400
20	N 26 35 49	E 50 4 13	7.9	92.3	291	8.06	59,700	39,500
21	N 26 35 49.5	E 50 4 13.5	7.8	92	293	8.2	60,300	40,000
22	N 26 36 7	E 50 3 51	5.3	62.8	304	7.6	73,800	50,300
23	N 26 35 25	E 50 02 33	10	117.2	302	7.1	90,700	64,000
24	N 26 35 25.5	E 50 02 33.5	8.2	96.7	304	7.27	55,100	36,100
25	N 26 35 21	E 50 02 08	8.1	94.8	295	7.89	60,900	40,500
26	N 26 35 21.5	E 50 02 08.5	7.9	92.3	296	7.79	60,700	40,300
27	N 26 34 57.5	E 50 01 28.5	7.9	92.3	295	7.75	61,200	40,200
28	N 26 34 58	E 50 01 29	8.6	101	293	7.88	60,400	40,100
29	N 26 34 57	E 50 01 28	8.8	102.5	292	7.76	56,000	36,800
30	N 26 34 52	E 50 01 17	8.4	100.5	308	8.02	59,000	39,000
31	N 26 34 52.5	E 50 01 17.5	8.2	100	302	8.3	56,700	38,000
32	N 26 33 39	E 50 01 36	8.9	103.6	297	8.47	54,900	36,000
33	N 26 33 39.5	E 50 01 36.5	8.7	102	296	8.35	53,200	37,000
34	N 26 33 40	E 50 01 37	8.8	101	297	7.91	54,600	38,000
35	N 26 32 44	E 50 01 24	8.8	102.5	298	7.89	55,600	36,500
36	N 26 34 52	E 50 01 17	7.9	92.3	302	7.82	61,800	41,100
37	N 26 35 34	E 50 01 14	7.8	92	301	7.71	62,100	41,400
38	N 26 35 34.5	E 50 01 14.5	7.7	94	300	7.81	65,100	40,200

D.O = dissolved oxygen, R.P. = redox potential, T.D.S = total dissolved salts, temperature of water samples = 25 °C during measurements.

stored in a clean polyethylene bags until metals analysis was performed. The grain-size distribution of desalted sediments was determined by wet sieving of sand and gravel and by the pipette technique for silt and clay fractions (Folk, 1974). The sediment samples were prepared by accurately weighing around 100 mg of samples into a dry and clean Teflon microwave digestion vessels, 2 ml of HNO_3, 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 trace metals was carried out by ICP-MS (Inductively Coupled Plasma-Mass Spectrometer): NexION 300D (Perkin Elmer, USA).

Sediments in Tarut Island area composed of a mixture of terrigenous and biogenic materials. However, terrigenous activity is regarded as the major source of sediments to the area. The sediments of the investigated area consist of a wide variety of texture classes, from coarse sand to sandy mud. The marine sediments in the area are mainly composed of sand (88.12%), Mud constitutes 2.14 and gravel is (9.14) (Table 2). Terrigenous matter including angular, subrounded to well-rounded quartz grains. Biogenic materials including: gastropods 0.5–1.5 cm length turreted and turbinoid forms, sea grass, foraminifera, and ostracoda.

The maximum values of iron content (12,924, 6499, and 6192 $\mu g\, g^{-1}$) were recorded in the station 10, 35, and 16 respectively (Fig. 4a). The high concentration in these localities is due to human activities. The anthropogenic sources of iron to the marine environment in these areas are: paints of marine ships, corrosion of the marine constructions, landfilling and construction residuals. The Fe content in the present study is very high comparing to the content reported from the surface sediments of other areas (Table 3). The rate of atmospheric deposition of Fe to the ocean surface varies from minimum values in the remote Pacific and Southern Ocean to maximum values near desert source regions (Duce and Tindale, 1991; Fung et al., 2000).

The highest contents of Mn (243.9, 235.3, and 229 $\mu g\, g^{-1}$) were recorded at stations 35, 32, and 33 respectively (Fig. 4b). Manganese transfer to the marine environments by many sources, some of this sources are natural input from wadies. The concentrations of Mn in other sites are varying (Table 3).

The concentration of As in the studied sediments ranges from 53–338 $\mu g\, g^{-1}$ (Fig. 4c). These concentrations are very high comparing to other sites (Table 3). The arsenic values exceed the Canadian Interim sediment quality guidelines (7.24 $\mu g\, g^{-1}$). Uncontaminated coastal sediments normally have concentrations in the range 5–15 $\mu g\, g^{-1}$ (Neff, 1997). The concentration of arsenic in the studied area exceeded the MEC, PEC indicating possible As contamination (Table 4). According to the Swedish Environmental Protection Agency, the studied area is very large contaminated with arsenic (Table 5). The sources of pollution from arsenic in the Island are agricultural chemicals such as herbicides, fungicides, rodenticides and insecticide. Leaching of exposed wastes of draining from large industrial areas carry increased arsenic from a variety of industrial and domestic sources.

Table 2
Heavy metals concentrations (in $\mu g\,g^{-1}$) for the surfaces sediments from studied locations in Tarut Island.

S. no.	As	B	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Pb	Se	Zn	S. no.	As	B	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Pb	Se	Zn
1	135	2.5	1	5.1	18.1	3.2	3124	0.5	20.7	1.2	86.9	0.4	16.8	20	335	5.9	0.4	8.9	22.4	3.4	5307	0.5	11.9	1.3	25.1	0.1	25.4
2	91	3.1	0.2	6.9	27	15.7	3393	0.4	183.5	2.3	8.9	0.2	15.9	21	342	6.6	0.4	9.3	24	3.6	4992	0.4	13.2	1.1	30	0.2	27.5
3	88	4	0.3	7.5	28.9	21	3520	0.4	179	2.5	9.3	0.3	17	22	119	24.1	2.4	5.7	43.2	15.9	2617	0.6	52.9	9.2	471	0.8	40.3
4	75	3	0.2	5.7	14.2	3	3163	0.3	18.1	2.4	5.2	0.2	6.3	23	135	4.6	0.3	9.7	21.2	4.3	5673	0.4	29.8	1.6	37.3	0.3	28.3
5	137	2.7	1.2	4.1	36.5	5.9	1841	0.6	46.5	2.6	45.8	0.2	16.3	24	140	5.2	0.4	10	23.5	4.7	5524	0.4	32.6	1.4	40.1	0.5	31.2
6	246	9	0.3	5.7	41.7	9	2665	1.7	113.8	5.3	15.8	0.1	10	25	53	3	0.4	5.7	20.6	6.5	2832	0.5	83.8	1.9	30.6	0.8	35.7
7	166	4.4	1.6	3.3	35.6	5	1517	0.6	48	1.3	78.8	0.1	16.2	26	59	2.3	0.4	6	19.2	7	3015	0.6	90	1.7	35.7	0.4	37.1
8	297	6.5	0.3	5.1	48.4	4.8	2327	0.8	84.5	1.3	13.3	0.1	13.2	27	125	5	1.3	4.4	43.9	5.5	1968	0.5	60.1	3	29.5	0.6	35.8
9	75	3.7	0.2	5.4	23.4	3.7	2815	0.4	46.5	2.1	12.9	0.1	5.3	28	138	2.7	0.2	2.4	26.4	1.8	619	0.5	49.5	1.3	15	0.7	7.4
10	338	6.8	0.8	7.2	47.5	3.5	12,924	0.9	213	1.7	318.8	0.2	12.1	29	126	2.5	0.1	2.4	19.3	1.4	599	0.4	36.2	0.7	15	0.5	6.5
11	223	4.1	0.3	5.6	40.5	4.1	2218	0.7	78.7	1.1	13.3	0.1	12.9	30	89	2.2	0.3	1.8	15.8	1.8	606	0.4	14.1	1.6	30.4	0.5	6.5
12	145	2.8	0.2	4.1	25.8	3.3	907	0.6	65.8	1.2	8.7	0.1	5.9	31	92	2.5	0.4	2.1	17	1.6	710	0.5	18.1	1.8	32.7	0.4	7.2
13	139	3.3	0.7	4.3	16.1	2.7	2131	0.4	22.3	0.7	40.9	0.3	7.8	32	137	4.2	0.4	8	33.7	6.6	3830	0.7	235.2	1.9	19.6	0.7	17.4
14	154	4.1	0.9	6.2	22.4	3.1	3216	0.5	38.9	0.8	53.3	0.1	7.7	33	122	5.1	0.3	9.1	30	7.2	4012	0.8	229	2.3	22	0.6	15.9
15	120	4	0.7	6.5	21.2	2.5	3332	0.4	44.5	0.8	74.6	0.2	7.6	34	131	4	0.4	7.8	35.1	6	3904	0.6	218.9	1.8	23.1	0.8	21
16	167	5.4	0.4	9.7	13.8	2.7	6192	0.5	12.6	1.5	51.1	0.3	7	35	96	5.8	0.5	12	41	15.1	6499	0.5	243.9	6.4	36.3	0.9	51.9
17	152	6.1	0.4	11.2	14	3	5811	0.4	15.2	1.3	58	0.2	8.5	36	114	3.8	3.5	4	32.7	4.1	2139	0.7	38.7	2.3	239	0.4	14
18	240	7	0.5	8.1	21.4	5.2	4685	0.5	29.4	1.8	24.5	0.3	27.8	37	102	2.7	0.9	7.2	19	3.5	4062	0.4	44.9	1.6	71.9	0.3	10
19	68	6.9	0.6	5	22.7	15.1	2316	0.4	44.7	7.3	25.5	0.3	25.1	38	111	3	1.1	8	21.7	3.2	3985	0.5	48.1	1.5	80	0.4	9.2
Mean	148	5	0.7	6.3	27.1	5.8	3447	0.6	75.2	2.2	58.7	0.4	17.6	S.D	76.2	3.6	0.7	2.5	10.0	4.6	2247	0.2	71.7	1.8	91.3	0.23	11.6

The average distribution of Pb contents in the studied localities varies from 5.2 $\mu g\,g^{-1}$ in sample 4 and 319 $\mu g\,g^{-1}$ in sample 10 (Fig. 4d) with hot spot at sample 22 (471 $\mu g\,g^{-1}$). The average level of Pb was previously reported in surface sediments of adjacent areas are shown in Table 3. Lead occurs naturally from the decomposition of parent rocks and may accumulate from anthropogenic sources, including traffic exhaust, lead–zinc smelters, dumps, industrial and household lead, e.g., paints and batteries (Cameron, 1992). Other sources of Pb include; oil spills, motor boats and untreated wastes (Mansour et al., 2011). The Tarut Gulf crowded by fishing boat (Fig. 2H), receiving large amount of waste materials (Fig. 3A–D) and receive industrial and household lead. Only three samples exceed the effect range median (ERM) and three samples considered very large contaminated by Pb according to Swedish Environmental Protection Agency (Tables 4 and 5).

The highest concentration of B in the sediments of the study area is 24.1 $\mu g\,g^{-1}$ recorded in sample 22 (Fig. 5a). This recorded value is higher than the highest value (15 $\mu g\,g^{-1}$) recorded in Gulf of Aqaba by Al-Taani et al. (2014). The highest B concentration may be due to seawater interaction with sediments.

The concentration of Cu in the study area varies from 1.4 to 21 $\mu g\,g^{-1}$ (Fig. 5b). The concentrations of Cu in different coastal areas are shown in Table 3. The distribution of copper contents in the study area is attributed to the influence of terrigenous sediments. In addition, antifouling paint from ships can contain copper, which may be relevant considering the extensive boat traffic of fishing. The use of fertilizers, especially following excessive irrigation or during flash floods, is also a potential source.

Cr concentrations in surface sediments showed little spatial variations (Fig. 5c), with average value of 27.1 $\mu g\,g^{-1}$, a peak (48.4 $\mu g\,g^{-1}$) recorded in sample 8. These values are low in comparison to the recorded values in Gulf of Oman (Mora et al., 2004). However, it is high comparing to the concentration reported from the Gulf of Aqaba. The concentrations of Cr in surface sediments show a spatial distribution in different coastal sites (Table 3). The recorded concentrations are 57–347 $\mu g\,g^{-1}$ in Florida bay (Caccia et al., 2003). The distribution pattern of Cr suggests that the relative higher Cr levels are probably attributed to discharge of water from desalination plant (Lattemann and Höpner, 2008). The surface sediment samples of Tarut Island show little or non-contamination of Chromium according to Swedish Environmental Protection Agency (Table 5).

The average zinc concentrations in the studied localities range from 5.3 to 51.9 $\mu g\,g^{-1}$ (Fig. 5d). The average level of Zn was previously reported in surface sediments of adjacent areas are shown in Table 3. Zinc presents as a common contaminant in agricultural, food wastes, manufacturing of pesticides as well as antifouling paints (Badr et al., 2009). The main anthropogenic source of zinc includes zinc sulfate used in house construction, air-conditioning ducts, garbage cans, galvanized pipes, batteries and wear of automobiles tires (Fig. 3).

The Se content was found in sediment sampled from the Tarut Island range 0.1–0.9 $\mu g\,g^{-1}$ (Fig. 6a). These values are higher than the only reported values from the Gulf of Aqaba which was 0.45–0.69 $\mu g\,g^{-1}$ (AL-Taani et al., 2014). Anthropogenic sources causes of selenium in surface waters include coal ash from coal-fired power plants, irrigation of wastewaters from some industrial processes (Ccrem, 1987). The other possible source of Se in Tarut Island is the power station. Sediments near a power station in Mannering Bay, Australia contained very Se concentration (Peters et al., 1999).

The concentrations of Hg in sediments of the study area (Fig. 6b) were quite high (0.3–1.7 $\mu g\,g^{-1}$). For comparison within the adjacent areas Hg levels were vary between 0.19 and 2.34 $\mu g\,g^{-1}$ in coastal sediments from Qatar (Al-Madfa et al.,

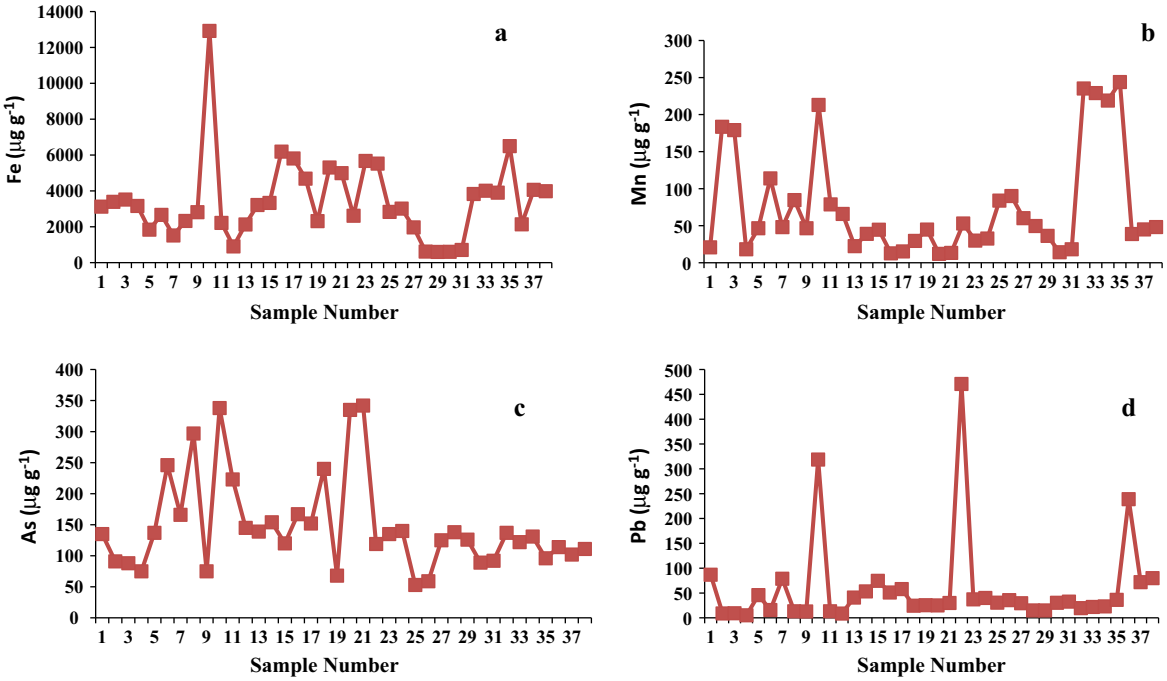

Fig. 4. The concentrations of heavy metals in surface sediments samples collected from Tarut Island coast, (a) Fe, (b) Mn, (c) As, and (d) Pb.

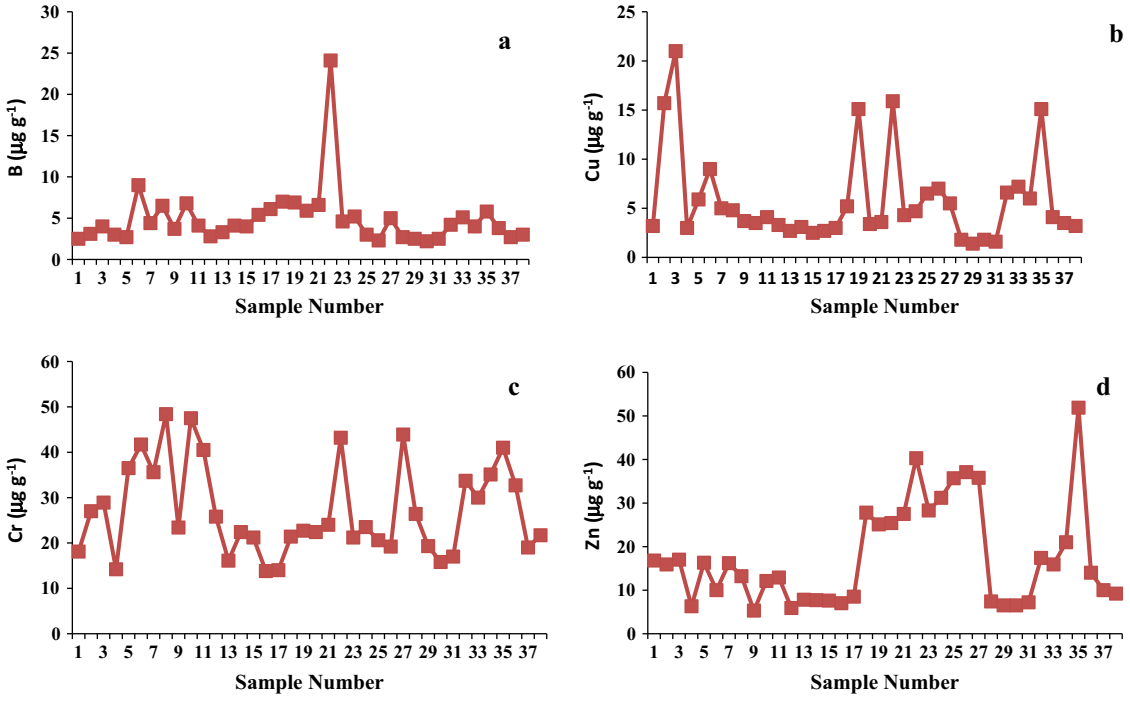

Fig. 5. The concentrations of heavy metals in surface sediments samples collected from Tarut Island coast, (a) B, (b) Cu, (c) Cr, and (d) Zn.

1994), from 0.032 to 0.27 µg g^{-1} in surface sediments of Arabian Gulf (Kureishy and Ahmed, 1994), and from 0.042 to 0.375 µg g^{-1} (Al-Majed and Rajab, 1998). Gulf of Aqaba surface sediments have very high Hg concentration (2.36–2.37 µg g^{-1}) and these values interpret by Al-Taani et al. (2014) as a geologic source of Hg to seawater. For other Hg concentrations see Table 3. The level of Hg load depends mostly on anthropogenic emissions but its variability is greatly associated with meteorological conditions and with climate change (Bełdowska et al., 2014). The concentration of Mercury in the studied area exceeded the MEC, indicating possible Hg contamination (Table 4). The concentrations of Mercury in the sediments of studied area are generally high comparing to the reported values from the Gulf of Oman, Red Sea, and Gulf of Finland. According to the Swedish Environmental Protection Agency (SEPA), 33 samples occur in class 4 and 5 samples occur in class 5, which mean that the sediments of Tarut Island are large to very large contaminated with Hg (Table 5).

Table 3
Concentrations of metals (μg g^{-1}) in the surface sediments regionally and worldwide compared to the studied area.

Location	Fe	Mn	As	B	Cd	Co	Cr	Cu	Hg	Mo	Pb	Se	Zn	Reference
Tarut Island	599–12,924	11.9–243.9	53–342	2.2–24.1	0.1–3.5	1.8–12	13.8–48.4	1.4–21	0.3–1.7	0.7–9.2	5.2–471	0.1–0.9	5.3–51.9	Present study
Qatar	305–5680	13.2–127	1.0–6.3	–	0.03–0.09	0.10–2.2	11.5–40.8	1.22–8.17	0.0007–0.17	–	0.43–3.88	–	–	
UAE	874–29,600	32.9–360	0.7–9.6	–	0.02–11	0.34–45.2	17.6–303	0.64–3.58	0.0006–0.002	–	0.69–5.88	–	–	Mora et al. (2004)
Bahrain	471–6475	22.6–84.3	3.16–6.88	–	0.04–0.18	0.17–2.43	3.4–41.8	2.38–48.3	0.011–0.22	–	0.67–99	–	6.12–52.2	
Oman	334–11,600	27.8–265	0.74–5.01	–	0.10–0.21	0.13–6.92	6.5–133	0.60–6.66	0.0001–0.011	–	0.25–1.82	–	1.57–11.4	
Bushehr, Persian Gulf	–	319–455	–	–	–	–	–	–	–	–	29–32	–	35–56	Biati et al. (2012)
Arabian Gulf	1.0–2.5 [a]	18–415	–	–	–	–	–	2–21	–	–	–	–	4–58	Basaham and El-Sayed (1998)
Red Sea (Saudi Arabia)	1366–3912	33.71–412.9	–	–	2.26–3.95	–	12.98–35.36	17.4–25.8	–	–	74.59–98.77	–	41.36–93.86	Badr et al. (2009)
Red Sea (Suadi Arabia)	–	–	1.4–21.0	–	0.024–0.238	–	–	0.45–83	0.0003–0.133	–	0.46–69.38	–	5.3–179.0	Pan et al. (2011)
Red Sea (Egypt)	0.07–2.81[a]	32.76–1557	–	–	0.04–4.1	0.5–27.7	–	0.5–366	–	–	0.03–187	–	0.6–114.7	Mansour et al. (2011)
Red Sea (Egypt)	2266–3306	163–968	–	–	0.02–0.16	0–4	–	5–454	–	–	13–96	–	18–283	Madkour et al. (2013)
Red Sea (Egypt)	1.22–2.84[a]	53–775	–	–	0.10–3.14	5.30–20	–	–	–	–	18.0–77.0	–	18.0–77.0	Mohamed (2005)
Red Sea (Yemen)	3078–4236	20.7–65.0	–	–	–	–	15.9–24.5	24.8–39.3	–	–	5.12–8.7	–	88.6–138	Hassan and Nadia (2000)
Hodeidah, Yemen	–	–	–	–	0.6–14.20	–	6.25–20.2	1.9–11.13	–	–	1.2–3.48	–	13–30	Al-Adrise (2002)
Gulf of Aden	2139–2769	138–695	–	–			17–234	8.1–111	–	–	14.8–138	–	21.9–263.5	Saleh (2006)
Gulf of Aqaba	1172–1437	3.93–3.61	12.2–15.1	7.49–8.29	0.06–0.07	0.51–0.77	3.67–7.97	7.57–10.77	2.36–2.37	0.60–0.70	3.72–6.75	0.45–0.69	7.02–7.73	Al-Taani et al. (2014)
Gulf of Aqaba	–	–	–	–	5.25	–	1.12	0.03	–	–	4.07	–	0.42	Al-Najjar et al. (2011)
Mediterranean, Egypt	1748–2030	191.4–254.3	–	–	1.4–2.3	–	–	4.0–9.4	–	–	18.4–24.4	–	28.0–42.2	El-Serehy et al. (2012)
Gulf of Mannar, India	1200–11,800	290.301	–	–	–	–	148–195	–	–	–	15.97–16	–	71–74.06	Jonathan and mohan (2003)
Gulf of Mexico	–	12.5–448.9	–	–	–	–	3–100	3.82–18.7	–	–	0.22–20.2	–	0.04–79.6	Macias-Zanora et al. (1999)
East China Sea	0.62–3.97 [a]	152–1152	–	–	–	–	–	4.29–41.5	–	–	10–49	–	18.2–114.2	Fang et al. (2009)
Gulf of Finland	–	–	7.25–19.1	–	0.84–2.69	10.1–16.1	45.8–82.7	42.1–76.3	0.11–0.32	–	37.3–58.9	–	152–260	Vallius et al. (2007)

Concentration in μg g^{-1}.
[a] Concentration in %.

Table 4
Number of samples that had metal concentrations above the sediment effect data of ERL and ERM in the collected samples.

Metal ($\mu g\ g^{-1}$)	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	148	0	0	38
Cd	1.2	9.6	0.66	34	4	0
Cr	81	370	27.1	38	0	0
Cu	34	270	5.78	38	0	0
Pb	46.7	218	58.68	27	8	3
Hg	0.15	0.71	0.55	0	25	13
Zn	150	410	17.6	38	0	0

Data after Long et al. (1995).
ERL = effect range low, ERM = effect range median.

The concentration of Cd in the study area ranges 0.1–1.6 $\mu g\ g^{-1}$, the highest value was recorded in sample 7 (Fig. 6c). Comparing to the concentration of Cd in other marine sediments, our values was considered high (Table 3). Cadmium is closely associated with zinc, where rock phosphates contain large amounts of Cd and Zn as impurities (McMurtry et al., 1995). Our results may suggest an anthropogenic input of Cd directly into these sediments. The most likely sources are industrial wastewaters, and sewage (Fig. 3). The cadmium concentrations in the sediments also reflect increased automotive traffic entering the harbor, where sample 10 is located near to the harbor in Tarut. The studied area has slight to significant contamination of Cd according to Swedish Environmental Protection Agency (Table 5).

The average concentrations of Co level in marine sediments of the studied localities vary from 1.8 $\mu g\ g^{-1}$ at sample 30 to 11.2 $\mu g\ g^{-1}$ at sample 17 (Fig. 6c and Table 2). The concentrations of Co from surroundings areas are shown in Table 3. Higher concentration of Co was reported by Mora et al. (2004) in Gulf of Oman is due to local mineralogy rather than pollution. The highest value of Co in the surface sediments of Quseir, Red Sea (Mansour et al., 2011) principally derived from ultramafic rocks surrounding the wadis. Several factors such as grain size, organic matter, pH and redox control the cobalt accumulation (Smith and Paterson, 1990). The area of study is little or non-contaminated with Cobalt.

Mo concentrations were highly variable (Fig. 7). It ranges in concentration between 0.7 and 9.2 $\mu g\ g^{-1}$. Mo in sediment samples shows relatively lower average value (0.6–0.7 $\mu g\ g^{-1}$) in the Gulf of Aqaba (Al-Taani et al., 2014). No other observations related to Mo in the Gulf or Red Sea region. Mo is possible corrosion product discharge from desalination plants in the Gulf among other metals like Ni, Cr, and Fe, where seawater desalination capacity in the Gulf

Table 5
Classification of sediment heavy metal contamination according to the Swedish environmental Protection Agency ($\mu g\ g^{-1}$ dry weight) of selected heavy metals. After Vallius et al. (2007).

Metal ($\mu g\ g^{-1}$)	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	0	10–16	0	16–26	0	26–40	0	>40	38
Cd	<0.2	1	0.2–0.5	24	0.5–1.2	9	1.2–3	3	>3	1
Co	<14	38	14–20	0	20–28	0	28–40	0	>40	0
Cr	<80	38	80–110	0	110–160	0	160–220	0	>220	0
Cu	<15	33	15–30	5	30–60	0	60–120	0	>120	0
Hg	<0.04	0	0.04–0.10	0	0.10–0.27	0	0.27–0.7	33	>0.7	5
Pb	<31	20	31–46	7	46–68	3	68–100	5	>100	3
Zn	<85	38	85–125	0	125–195	0	195–300	0	>300	0

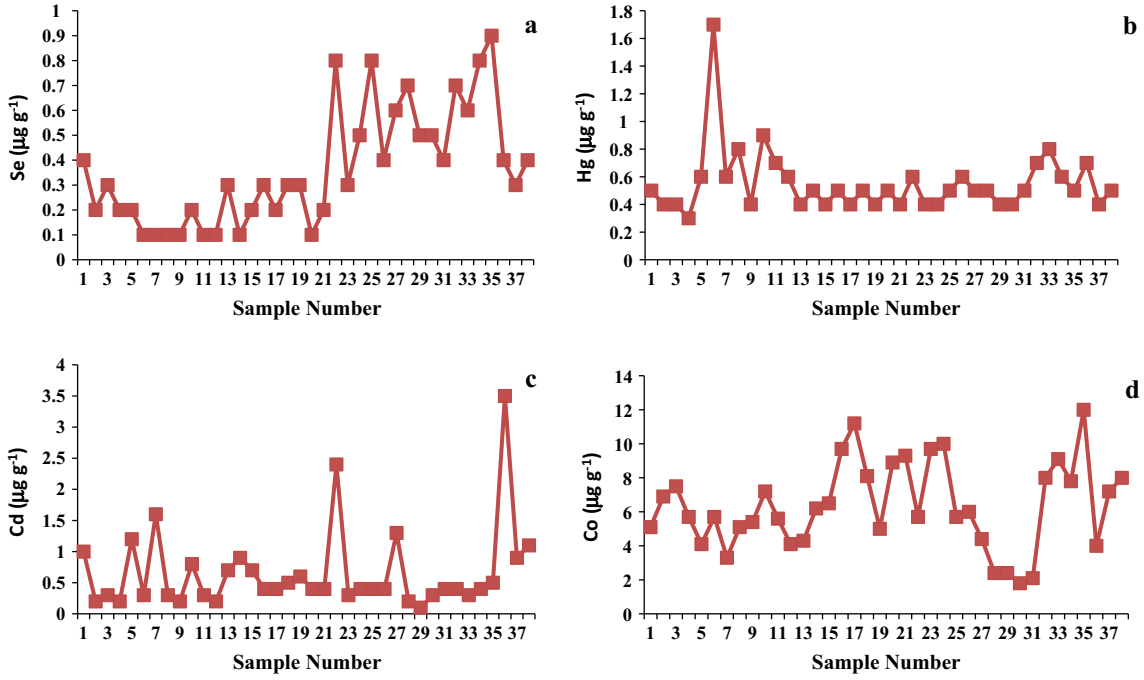

Fig. 6. The concentrations of heavy metals in surface sediments samples collected from Tarut Island coast, (a) Se, (b) Hg, (c) Cd, and (d) Co.

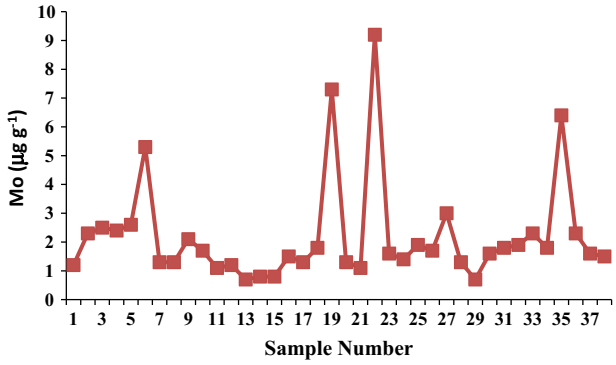

Fig. 7. Mo concentrations in surface sediments samples collected from Tarut Island coast.

countries exceeds 11 million cubic meters per day (Lattemann and Höpner, 2008).

Thirteen heavy metals (major and trace) were determined in coastal sediments from Tarut Island, Saudi Arabian Gulf. Most interesting, is the observation of very high arsenic concentrations in all studied samples from Tarut Island, when compared to those from other regions in the world. The concentrations of As exceeded the wet threshold safety value set by many countries (MEC, PEC) indicating possible As contamination. According to the Swedish Environmental Protection Agency (SEPA), all studied samples occur in class 5, which mean that the sediments of Tarut Island are very large contaminated with As. It is not clear whether this contamination is related to anthropogenic sources or to natural biogeochemical processes in the region. The concentrations of Mercury in the sediments of studied area are generally high comparing to the reported values from the Gulf of Oman, Red Sea, and Gulf of Finland. The concentrations of Hg exceeded the wet threshold safety values (MEC, PEC) indicating possible Hg contamination. According to the Swedish Environmental Protection Agency (SEPA), 33 samples occur in class 4 and 5 samples occur in class 5, which mean that the sediments of Tarut Island are large to very large contaminated with Hg. Zinc is essential element in all living systems; therefore, their uptake by marine biota may be increased with high temperature. This may be the reason for decreasing the concentration of zinc in sediment of the study area which characterized by high temperature. Dredging and land filling, sewage, and oil pollution are the most important sources of pollution in the study area. Incomplete or no sewage treatment, increasing wastes from different human activities, oil spills, constructions, waste and trash materials, tires are the chronic problems associated with heavy metal pollution. Increasing of populations in the island 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 surface sediments are classified as largely polluted, due to high concentrations of some metals especially Arsenic and Mercury, the situation in the island cannot be considered satisfactory and it is critical, which need from government and the decision makers to establish an effective pollution control programs, which include serious efforts to protect the island and the marine habitat.

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References

Al-Adrise, M., 2002. Concentration of some heavy metals in Khor-Kutheb Area (Al-Hodiedah) as a result of the sewage effluent impacts. MSc Thesis, Hodeida University.
Al-Ghadban, A., Jacob, P., Abdali, F., 1994. Total organic carbon in the sediments of the Arabian Gulf and need for biological productivity investigations. Mar. Pollut. Bull. 28, 356–362.
Al-Kahtany, Kh., Youssef, M., El-Sorogy, A., accepted for publication. Geochemical and faunal analysis of the surface sediments of Dammam coast, Arabian Gulf (Saudi Arabia). Arabian J. Geosci.
Al-Madfa, H., Dahab, O., Holail, H., 1994. Mercury pollution in Doha (Qatar) coastal environment. Environ. Toxicol. Chem. 13, 725–735.
Al-Majed, N., Rajab, W., 1998. Levels of mercury in the marine environment of the ROPME sea area. In: Otsaki, A., Abdulraheem, M.Y., Reynolds, R.M. (Eds.), Offshore Environment of the ROPME Sea Area after the War-Related Oil Spills. Terra Scientific, Tokyo, pp. 124–147.
Al-Najjar, Al., Rasheed, M., Ababneh, Z., Ababneh, A., Al-Omarey, H., 2011. Heavy metals pollution in sediment cores from the Gulf of Aqaba, Red Sea. Nat. Sci. 3 (9), 775–782.
Al-Taani, A., Batayneh, A., Nazzal, Y., Ghrefat, H., Elawadi, E., Zaman, H., 2014. Status of trace metals in surface seawater of the Gulf of Aqaba, Saudi Arabia. Mar. Pollut. Bull. 86, 582–590.
Badr, N., El-Fiky, A., Mostafa, A., Al-Mur, B., 2009. Metal pollution records in core sediments of some Red Sea coastal areas, Kingdom of Saudi Arabia. Environ. Monit. Assessment 155, 509–526.
Basaham, A., 2010. Distribution and partitioning of heavy metals in subtidal sediments of the Arabian Gulf coast of Saudi Arabia. JKAU: Earth Sci. 21 (1), 201–222.
Basaham, A., El-Sayed, A., 1998. Distribution and phase association of some major and trace metals in the Arabian Gulf sediment. Estuar. Coast. Shelf Sci. 46, 185–194.
Bełdowska, M., Saniewska, D., Falkowska, L., 2014. Factors influencing variability of mercury input to the southern Baltic Sea. Mar. Pollut. Bull. 86, 283–290.
Biati, A., Nikoomaram, H., Karbassi, A., 2012. Study of metals concentrations in surface sediments of the Persian Gulf coastal area (Bushehr Province). Int. J. Mar. Sci. Eng. 2 (1), 75–80.
Caccia, V., Millero, F., Palanques, A., 2003. The distribution of trace metals in Florida Bay sediments. Mar. Pollut. Bull. 46 (11), 1420–1433.
Cameron, R., 1992. Guide to site and soil description for hazardous waste site characterization. Metals, vol. 1. Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Las Vegas, NV.
Ccrem, 1987. Canadian Water Quality Guidelines. Canadian Council of Ministers of Resources and Environment, Ottawa, Ontario.
Duce, R., Tindale, N., 1991. Atmospheric transport of iron and its deposition in the ocean. Limnol. Oceanogr. 36, 1715–1726.
El Sayed, M., Basaham, A., Gheith, A., 2002. Distribution and geochemistry of trace elements in central Red Sea coastal sediments. Int. J. Environ. Stud. 59, 1–31.
El Serehy, H., Aboulela, H., Al-Misned, F., Kaiser, M., Al-Rasheid, Kh., Ezz El-Din, H., 2012. Heavy metals contamination of a Mediterranean Coastal Ecosystem, Eastern Nile Delta, Egypt. Turk. J. Fish. Aquat. Sci. 12, 751–760.
Elhabab, A., Adsani, I., 2013. Geochemical and Mineralogical Characters of the Coastal Plain Sediments of the Arabian Gulf, Kuwait. J. Geol. Geosci. 3, 137.
Fang, T., Li, J., Feng, H., Chen, H., 2009. Distribution and contamination of trace metals in surface sediments of the East China Sea. Mar. Environ. Res. 68, 178–187.
Folk, R., 1974. Petrology of Sedimentary Rocks. Hemphill Publ. Co., p. 192.
Fung, I., Meyn, S., Tegen, I., Doney, S., John, J., Bishop, J., 2000. Iron supply and demand in the upper ocean. Global Biogeochem. Cycles 14, 281–295.
Hassan, M., Nadia, A., 2000. Trace Metals in Fish, Mussels, Shrimp and Sediment from Red Sea Coast of Yemen. Bulletin of Institute of Oceanography and Fisheries, A. R. E (Norwalk, Connecticut), vol. 26, pp. 339–353.
Jonathan, M., Mohan, V., 2003. Heavy metals in sediments of the inner shelf off the Gulf of Mannar, South East Coast of India. Mar. Pollut. Bull. 46, 258–268.
Kureishy, T., Ahmed, M., 1994. Total mercury distribution in surface sediments from the Arabian Gulf. Qatar Univ. Sci. J. 14, 390–394.
Lattemann, S., Hoepner, T., 2008. Environmental impact and impact assessment of seawater desalination. Desalination 220 (1–3), 1–15.
Long, E., MacDonald, D., Smith, S., Calder, F., 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ. Manage. 19 (1), 81–97.
Macias-Zanora, J., Villaescusa-Celaya, J., Munoz- Barbosa, A., Gold-Bouchot, G., 1999. Trace metals in sediment cores from the Campeche Shelf, Gulf of Mexico. Environ. Pollut. 104 (1), 69–77.
Madkour, H., Abdelhalim, M., El-Taher, A., 2013. Assessment of heavy metals concentrations resulting natural inputs in Wadi El-Gemal surface sediments, Red Sea coast. Life Sci. J. 10 (4), 685–694.

Maeda, M., Akitake, H., Kamiya, I., Shibata, F., Kamatani, A., 1998. Otsuki, A., et al. (Eds.). Trace Metals in the Finest Fraction of Surface Sediments from the Inner Part of ROPME Sea Area. Offshore Environment of the ROPME Sea Area after the War-Related Oil Spill, pp 160–180.

Mansour, A., Nawar, A., Madkour, H., 2011. Metal pollution in marine sediments of selected harbours and industrial areas along the Red Sea coast of Egypt. Ann. Naturhist Mus. Wien, Ser. A 113, 225–244.

McMurtry, G., Wiltshire, J., Kauahikaua, J., 1995. Heavy metal anomalies in coastal sediments of Oahu, Hawaii. Pac. Sci. 49 (4), 452–470.

Mohamed, A., 2005. Geochemistry and sedimentology of core sediments and the influence of human activities; Quseir, Safaga and Hurghada harbors, Red Sea, Egypt. Egypt. J. Aquat. Res. 31 (1), 92–103.

Mora, S., Fowler, S., Wyse, E., Azemard, S., 2004. Distribution of heavy metals in marine bivalves, fish and coastal sediments in the Gulf and Gulf of Oman. Mar. Pollut. Bull. 49, 410–424.

Naser, H., 2013. Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: a review. Mar. Pollut. Bull. 72, 6–13.

Neff, J., 1997. Ecotoxicology of arsenic in the marine environment. Environ. Toxicol. Chem. 16, 917–927.

Pan, K., Lee, O., Qian, P., Wang, X., 2011. Sponges and sediments as monitoring tools of metal contamination in the eastern coast of the Red Sea, Saudi Arabia. Mar. Pollut. Bull. 62, 1140–1146.

Pati, P., Patra, K., 2012. Benthic foraminiferal responses to coastal pollution: a review. Int. J. Geol. Earth Environ. Sci. 2 (1), 42–56 (ISSN: 2277-2081).

Peters, G., Maherb, W., Krikowab, F., Roachc, A., Jeswani, H., Barford, J., Gomesa, V., Reible, D., 1999. Selenium in sediments, pore waters and benthic infauna of Lake Macquarie, New South Wales, Australia. Mar. Environ. Res. 47, 491–508.

Price, A., Robinson, J., 1993. The 1991 Gulf War: Coastal and marine environmental consequences. Mar. Pollut. Bull. 37 (Special Issue).

Saleh, S., 2006. Environmental assessment of heavy metals pollution in bottom sediments from the Gulf of Aden, Yemen. Ph.D. Thesis, Alexandria University, Egypt, 235p.

Samir, M., Mohamed, A., Shaif, M., 2006. Environmental assessment of heavy metal pollution in bottom sediments of Aden Port, Yemen. Int. J. Oceans Oceanography 1, 99–109.

Sheppard, C., 1993. Physical environment of the Gulf relevant to marine pollution: an overview. Mar. Pollut. Bull. 27, 3–8.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., 2010. The Gulf: a young sea in decline. Mar. Pollut. Bull. 60, 13–38.

Smith, K.A., Paterson, J.E., 1990. Manganese and cobalt. In: Alloway, B.J. (Ed.), Manganese and cobalt. John Wiley & Sons, New York, pp. 224–244.

Tam, N., Wong, Y., 2000. Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. Environ. Pollut. 110, 195–205.

Vallius, H., Ryabchuk, D., Kotilainen, A., 2007. Distribution of heavy metals and arsenic in soft surface sediments of the coastal area off Kotka, North-Eastern Gulf of Finland, Baltic Sea. Geol. Surv. Finland Spec. Pap. 45, 33–48.