CrossMark

ORIGINAL ARTICLE

Assessment of toxic metals in coastal sediments of the Rosetta area, Mediterranean Sea, Egypt

Abdelbaset S. El-Sorogy[1,2] · Mohamed Tawfik[2] · Sattam A. Almadani[1] ·
Abdullah Attiah[2]

Abstract The purpose of the present study is to assess the level and distribution of Mg, Co, Cu, Cd, U, Sr, Zn, As, V, Pb, Ti, Mn, Ba, Ce, Ni, P, Cr, Zr, Hf and Fe in coastal sediments of Abu Khashaba beach, Rosetta area, Egyptian Mediterranean coast. The level of pollution was evaluated using enrichment factor, geoaccumulation index and contamination factor. The results indicated that Abu Khashaba coastal sediments were extremely enriched and very strongly polluted with Cd; severely enriched and strongly polluted with As and Pb, and moderately severely enriched and polluted with Ni, Co, Sr and Ce. The highest Fe, Ba, Ce, Ni, Pb, V, Zn, Sr, Co, Cd, U, Cu, Hf, Cr and Zr were recorded along the shoreline. Fe, Mn, Pb, Co, Cd, Cu and Cr values in the Abu Khashaba coastal sediments were much higher than those recorded in the coastal sediments of the Gulf of Aqaba, the Red Sea, the Arabian Gulf and the Daliao River System of China. The enrichment of Cd, As, Pb, Ce, Ni in the sediments could be partially attributed to anthropogenic inputs and also to other already existing naturally occurring metals.

Keywords Assessment · Toxic metals · Rosetta area · Mediterranean Sea coast · Egypt

✉ Abdelbaset S. El-Sorogy
  elsorogyabd@yahoo.com; asmohamed@ksu.edu.sa

1 Geology and Geophysics Department, College of Science, King Saud University, P.O Box: 2455, Riyadh 11451, Saudi Arabia

2 Geology Department, Faculty of Science, Zagazig University, Zagazig, Egypt

Introduction

Metals are introduced into the aquatic system as a result of weathering of soil and rocks, volcanic eruptions and from a variety of human activities involving mining, processing and use of metals and/or substances containing metal contaminants (Karageorgis et al. 2003; El-Sorogy et al. 2012). The distribution of metals within the aquatic environments is governed by complex processes of material exchange affected by various anthropogenic activities, water drainage, discharge of urban and industrial wastewaters (Leivouri 1998; Carman et al. 2007; Christophoridis et al. 2009).

Heavy metals are of critical ecological significance due to their toxicity, resistance to degradation and their consequent tendency to bioaccumulation (Diagomanolin et al. 2004). Trace metal contamination in a marine coastal environment is related to sources of pollution in the adjacent estuaries and rivers. Metals are mainly transported to the marine environment by rivers through estuaries. In most circumstances, the major contribution of anthropogenic metals in a marine coastal area is of terrestrial origin, i.e., from mining, industrial, and urban developments, and other human practices near rivers and estuaries (Morton and Blackmore 2001; Carman et al. 2007).

Egypt has about 1050 km of coastline on the Mediterranean Sea, which is of great environmental, economic and recreational value. Some of the Egyptian coastal areas of the Mediterranean Sea (especially in front of the large cities) receive different types of pollution sources. The Rosetta black sands are the end products of the disintegrated materials from igneous and metamorphic rocks (Dabbour 1980, 1995; Dawod and Abdelnaby 2007). These black sands have been the subject of many

articles concerning the mineralogy and economics (El-Miligy and El-Azab 1994; Kaiser et al. 2012; Mahmoud et al. 2013).

The objectives of this study were: (1) to examine the spatial variations of the toxic metal concentrations in the coastal sediments of Abu Khashaba beach, Rosetta area (Egypt), (2) to use the enrichment factor (EF), the geoaccumulation index (Igeo), and the contamination factor (CF), to evaluate the level of anthropogenic participation in the pollution caused by toxic metals in the area.

Material and methods

Study area

Abu Khashaba beach area is located in the north-west of the Nile delta along the Mediterranean coast as a part of Rosetta city, between longitudes 30°21′–30°28′E and latitudes 31°26′–31°29′N (Fig. 1). It is located northeast of Abu Khashaba village, east of Rosetta and bounded by the Mediterranean Sea shoreline from the north. Abu-Khashaba beach area is an open area, nearly flat, very gently
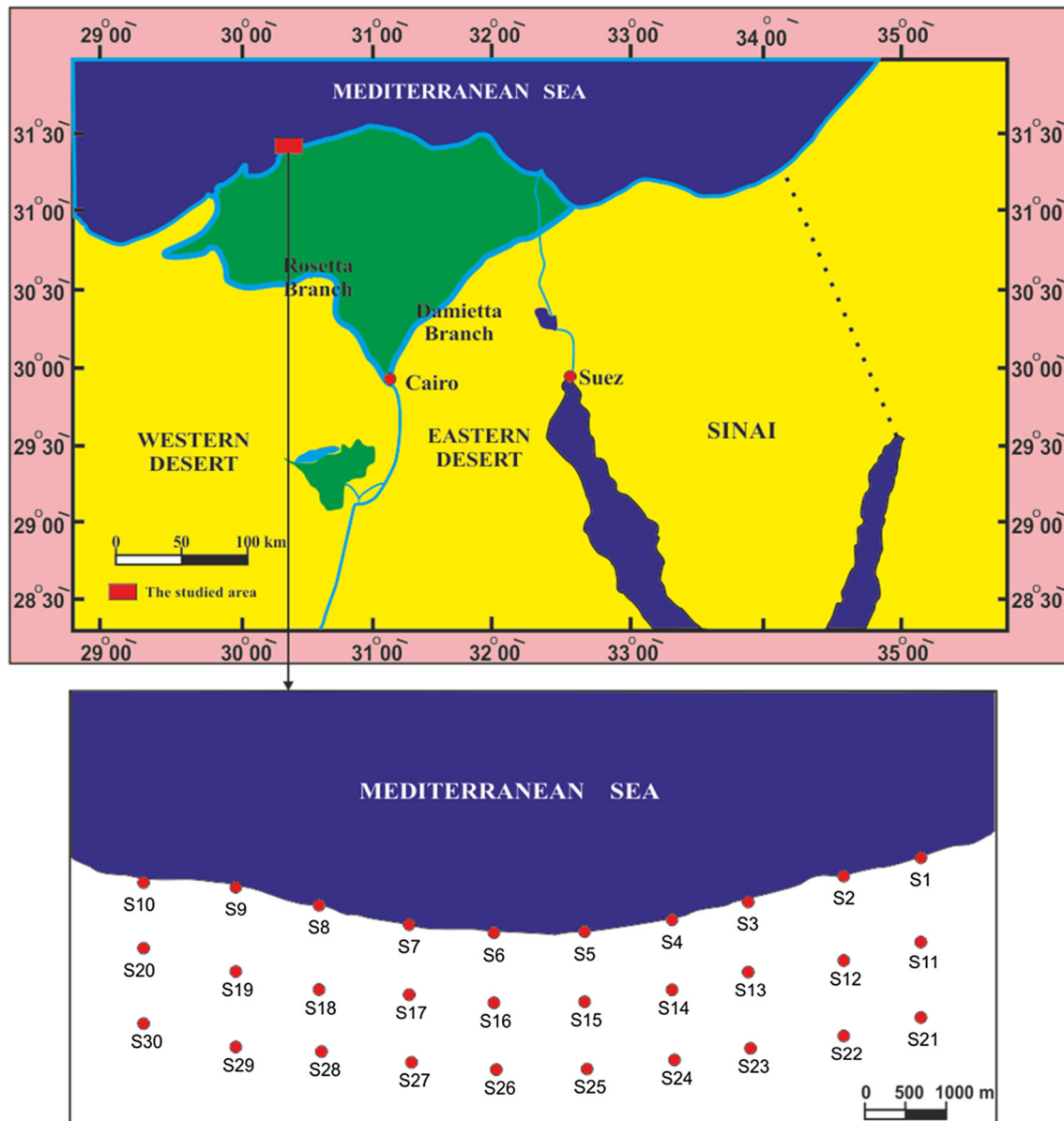
Fig. 1 Location map of the Abu Khashaba coastline and the locations of sediment samples along the coast

Fig. 2 Field photo shows a flat coastal plain at Abu Khashaba area

dipping to north and occupied mainly by sabkha. The study area is characterized by a low relief mainly below 2 m above sea level, and slope gently from south to north (Fig. 2). Geomorphologically, it is represented by a flat coastal plain dissected by some hummocky sand dunes in the south. The beach face slope increases from zero near the Rosetta mouth and becomes relatively steeper eastwards where it reaches about 15° at a distance of about 20 km from the mouth (Frihy et al. 2008).

The beach deposits are composed of loose fine sands with a considerable amount of heavy minerals. The sand particles are composed of quartz, feldspars and mafic minerals with specific gravities between 2.65 and more than 5 gm/cm³. The heavy minerals of the black sands are ilmenite, magnetite, zircon, garnet, rutile, and monazite. The black sands also contain traces of gold, cassiterite, beryl, chromite, corundum, apatite, collophane, uranothorite and gangue minerals. The latter include hornblende, actinolite, augite, hedenbergite, hypersthene, enstatite and minor amounts of biotite, epidote, staurolite, sphene, tourmaline, sillimanite and olivine (Frihy and Lotfy 1994; Mange and Wright 2007).

Sampling and analytical methods

30 sediment samples were collected from the coastal area through three profiles parallel to the beach (Fig. 1). Samples were analyzed for Mg, Co, Cu, Cd, U, Sr, Zn, As, V, Pb, Ti, Mn, Ba, Ce, Ni, P, Cr, Zr, Hf and Fe using ICP-MS (Inductively Coupled Plasma-Mass Spectrometer): Nex-ION 300D (Perkin Elmer, USA) in Central Laboratory for Elemental and Isotopic Analysis, Nuclear Research Center, Atomic Energy Authority, Egypt (Fig. 1; Table 1). The samples were 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 (Cheremisinoff 2002). The sediment samples

were prepared by drying in an oven at 115 °C, mechanically cursed, sieved through a 200 mesh sieve and 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 by using a 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 Statistical Program for Social Sciences (SPSS program) was used for Pearson's correlation coefficients matrix.

Estimation of pollutant indicators

The anthropogenic contribution of the selected trace elements in marine sediments can be estimated from the metal enrichment relative to unpolluted reference materials or widely accepted background (pre-industrial) levels. For calculation of pollutant indicators of toxic metal pollution in the surface sediments of the Abu Khashaba beach, the following factors were taken into consideration.

Enrichment factor

This method is proposed by Sinex and Helz (1981) to estimates the anthropogenic impact on sediments calculating the EF, which uses a normalization element (Al or Fe) to alleviate the variations produced by heterogeneous sediments. Since the sediments of Abu Khashaba beach are rich in iron content, this element was selected to normalize the data as normalization factor. It is mathematically expressed as:

$$EF = (M/Fe) \text{ sample}/(M/Fe) \text{ background}$$

where (M/Fe) sample is the ratio of metal and Fe concentrations in the sample, and (M/Fe) crust is the ratio of metal and Fe concentrations in the Earth's crust. The EF is a good tool to differentiate between the anthropogenic and natural sources of metals in environmental samples (Selvaraj et al. 2004; Adamo et al. 2005; Hung et al. 2009; Fang and Chen 2010).

Geoaccumulation index

The geoaccumulation index (Igeo) is a common criterion used for evaluating the trace metal pollution in sediments (Leopold et al. 2008). It was originally introduced for bottom sediments by Muller (1979) (Abrahim and Parker 2002; Hahladakis et al. 2013), where trace metal contamination in sediments was determined by comparing their current concentration levels with those from preindustrial times using the following equation:

Table 1 Concentrations of 25 heavy metals in 30 surface coastal sediments in Abu Khashaba beach, Egyptian Mediterranean coast

S. n.	Fe	Mg	Ti	P	Mn	Ba	Ce	V	Cr	Ni	Sr	Zr	Zn	Cu	Co	Cd	As	Pb	Hf	U
1	193,900	570	320	1570	610	1880	1690	638.93	0.264	894.17	162.34	0.214	298.5	42.66	80.95	36.97	352.65	476.45	1.759	41.05
2	193,100	560	430	1350	600	1580	1740	636.29	0.29	819.24	128.88	0.224	314.42	35.26	84.46	32.17	315.86	457.99	1.853	41.54
3	194,900	560	420	1590	610	1880	1740	633.65	0.262	744.32	175.01	0.317	320.91	37.41	87.2	30.28	279.06	465.94	1.7833	42.03
4	189,800	590	340	2150	610	2140	1670	512.4	0.263	722.54	143.61	0.279	324.5	35.48	88.35	36.16	325.35	471.47	1.847	47.49
5	192,600	570	380	2370	610	2030	1720	638.92	0.261	877.94	121.1	0.304	347.25	33.43	88.95	29.43	299.06	388.22	1.889	40.82
6	193000	580	330	1490	610	1990	1750	638.87	0.262	706.91	132.3	0.283	336.46	25.41	89.4	29.99	234.32	338.5	1.916	43.28
7	195,400	580	400	1310	610	2020	1690	652.32	0.251	839.54	148.43	0.349	334.35	37.26	87.22	35.06	309.99	460.57	1.859	45.77
8	198,100	570	410	1750	620	2030	1680	555.46	0.233	844.37	123.42	0.276	348.5	33.26	82.8	34.36	376.14	378.45	2.026	46.33
9	191,500	530	390	1920	640	2140	1720	535.82	0.254	722.74	126.73	0.236	387.91	31.98	87.81	36.9	399.16	364.86	1.98	46.48
10	196,200	540	340	2160	630	1960	1690	538.54	0.265	817.74	118.81	0.342	353.25	33.38	86.99	36.97	344.53	368.23	1.891	47.12
11	84,800	560	430	1530	590	380	540	271.71	0.181	295.44	107.19	0.138	117.37	36.48	70.81	31.97	363.55	440.87	0.408	15.85
12	81,300	500	490	1310	590	390	500	280.69	0.22	362.22	102.55	0.144	151.49	33.69	69.56	28.217	306.54	437.24	0.397	14.29
13	75,800	530	430	1530	560	410	560	289.67	0.159	459.01	119.91	0.236	161.48	30.09	68.31	24.45	249.53	435.13	0.408	17.72
14	77,400	560	430	1740	560	480	520	437.76	0.162	470.37	115.61	0.218	194.41	24.88	69.28	30.15	308.23	455.5	0.412	20.25
15	85,100	510	430	1710	540	470	530	313.13	0.158	377.1	98.44	0.233	165.87	19.32	63.33	23.42	215.37	376.5	0.432	23.41
16	90,100	530	420	1290	560	490	510	360.63	0.167	424.95	113.44	0.206	183.92	24.79	67.66	26.23	221.17	330.17	0.46	20.96
17	74,200	520	410	1220	590	430	560	435.31	0.148	342.26	122.44	0.213	122.5	24.84	69.2	31.16	340.82	409.85	0.414	25.54
18	83,400	550	430	1670	550	410	570	244.98	0.159	359.81	116.62	0.183	128.5	23.37	64.85	29.24	390.22	373.35	0.39	16.92
19	82,600	510	440	1440	580	470	560	369.75	0.173	420.75	117.76	0.192	116.77	23.57	63.24	32.7	357.17	318.98	0.414	18.68
20	79,900	490	460	1730	580	400	520	439.09	0.147	437.18	105.43	0.236	166.3	19.41	61.93	28.49	322.45	298.18	0.424	20.11
21	54,300	390	620	1410	490	190	360	115.15	0.131	197.44	82.75	0.112	56.64	21.43	56.359	24.35	268.32	433.2	0.22	8.96
22	57,000	480	530	1030	470	160	390	191.94	0.175	210.71	94.18	0.112	61.85	18.25	56.95	22.81	271.65	434.13	0.278	9.07
23	59,700	450	640	1130	460	190	320	168.74	0.118	363.99	86.02	0.124	64.38	15.07	57.54	21.27	274.98	435.06	0.236	11.19
24	59,800	440	640	1400	510	190	480	212.17	0.119	318.47	93.03	0.114	63.35	10.04	61.15	29.1	283.65	348.5	0.237	12.82
25	48,400	470	510	1460	490	170	410	156.33	0.113	113.94	90.46	0.128	66.75	9.83	52.8	21.09	246.16	362.5	0.262	9.76
26	47,900	460	640	1180	460	180	430	204.83	0.121	306.1	93.57	0.134	58.86	7.61	54.29	25.98	252.37	326.02	0.28	10.24
27	58,600	420	540	1170	450	190	340	213.61	0.118	190.82	89.92	0.104	63.91	14.99	50.15	28.27	227.8	400.57	0.241	13.73
28	44,900	430	510	1550	470	190	330	125.997	0.104	263.49	98.02	0.108	69.34	14.02	59.47	23.1	272.85	286.14	0.233	11.08
29	49,900	390	490	1390	470	180	430	183.78	0.114	308.72	94.8	0.109	53.27	10.91	59.25	22.65	273.29	253.45	0.28	10.54
30	53,200	460	570	1620	470	180	370	247.05	0.117	213.54	98.92	0.164	63.96	8.97	53.13	23.53	264.38	214.29	0.251	9.17
Min.	44,900	390	320	1030	450	160	320	115.15	0.104	113.94	82.75	0.104	53.27	7.61	50.15	21.09	215.37	214.29	0.22	8.96
Max.	198,100	590	640	2370	640	2140	1750	652.32	0.29	894.17	175.01	0.349	387.91	42.66	89.4	36.97	399.16	476.45	2.026	47.49
Aver.	109,560	510	460.67	1539	553	860	877.33	374.78	0.18	480.86	114.06	0.20	183.23	24.57	69.78	28.88	298.22	384.68	0.85	24.74

$$\text{Igeo} = \text{Log}_2(\text{Cn}/(1.5 \times \text{Bn}))$$

where Cn is the measured concentration of metal (n) in the sediments, Bn is the geochemical background concentration of the metal (n) in shale (Turekian and Wedepohl 1961), and 1.5 is introduced to minimize the effects of possible variations in the background values which may be attributed to lithologic variations in the sediments (Stoffers et al. 1986; Abrahim and Parker 2008).

Contamination factor (CF)

The contamination factor was also used to assess the level of contamination and the possible anthropogenic impact of contaminants in sediments (Singh et al. 2002; Gonzales-Macias et al. 2006; Farkas et al. 2007; Cevik et al. 2009). To describe the contamination of a given toxic substance in a basin, Hökanson (1980) proposed the CF, which is expressed as;

$$C_f = C_o/C_b$$

where C_o is the sediment metal content in the sample and C_b is the normal background value of the metal. The C_f was classified into four groups (Hökanson 1980; Savvides et al. 1995). $C_f < 1$: low CF; $1 \leq C_f < 3$: moderate CF; $3 \leq C_f < 6$: considerable CF; $C_f \geq 6$: very high CF.

Results and discussion

Table 1 illustrates the concentrations of 20 heavy metals in 30 surface coastal sediments in Abu Khashaba beach. The average metal levels are in the following order: Fe > P > Ba > Ce > Mn > Mg > Ti > Ni > Pb > V > As > Zn > Sr > Co > Cd > U > Cu > Hf > Zr > Cr. The following is a brief description of the concentration, spatial distribution and assessment of metals in the studied beach:

Metal concentrations

Sediment of Abu Khashaba beach is composed of a mixture of coarse sand to sandy mud terrigenous and biogenic materials. The coastal sediment in the area is mainly composed of sand (80.12 %), mud constitutes (10.14 %) and gravel (9.14 %). Terrigenous matters include angular, subrounded to well-rounded quartz grains. Biogenic

Fig. 3 Spatial distribution of Zn (**a**), Ti (**b**) and Mn (**c**) as examples of heavy metals at the study area
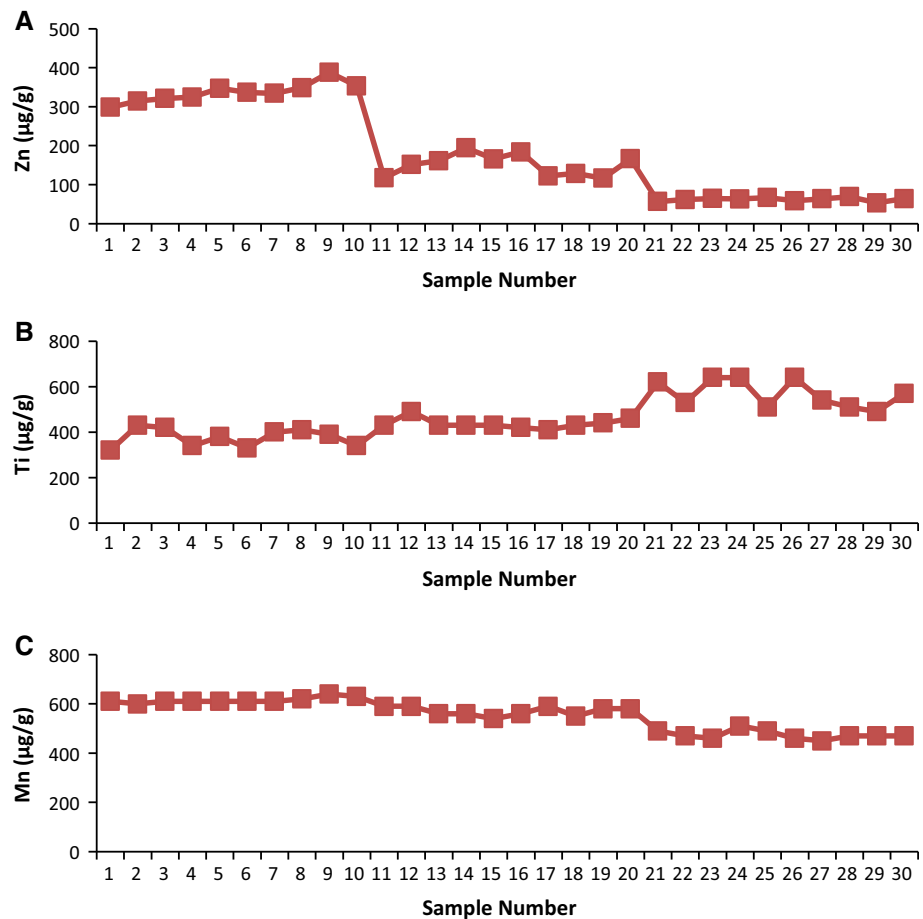
materials include molluscs, foraminifers, ostracods and sea grass.

As shown in Table 1, iron was the most abundant major element in the sediment (44,900–198,100 µg/g), followed by, phosphorus (1030–2370 µg/g), barium (160–2140 µg/g), cerium (320–1750 µg/g), manganese (450-640 µg/g), magnesium (390–590 µg/g), titanium (320–640 µg/g), nickel (113.94–894.17 µg/g), lead (214.29–476.45 µg/g), vanadium (115.15–652.32 µg/g), Arsenic (215.37–399.16 µg/g), zink (53.27–387.91 µg/g), strontium (82.75-175.01 µg/g), cobalt (50.15–89.40 µg/g), cadmium (21.09–36.97 µg/g), uranium (8.96–47.49 µg/g), cupper (7.61–42.66 µg/g), hafnium (0.22–2.03 µg/g), zirconium (0.104–0.349 µg/g) and chromium (0.104–0.290 µg/g).

Concerning spatial distribution, all of Fe, Ba, Ce, Ni, Pb, V, Zn, Sr, Co, Cd, U, Cu, Hf, Cr and Zr showed a significant decrease in concentrations with increasing distance from the coast. Table 1 shows that, Fe, for example, recorded four-times value in sample 4 (close to the coast) higher than that recorded in sample 28 (away from the coast). This behavior may suggest a seawater role in metal concentrations after drifting of beach sediment away. Ti presents a different behavior showing high concentrations away from the coast. P, Mn, Mg and As fluctuated without an obvious general trend (Fig. 3 illustrates examples).

The values of Fe, Mn, Pb, Co, Cd, Cu and Cr in the present coastal sediments (Table 2) were significantly higher than those recorded in coastal sediments of the Gulf of Aqaba (Al-Taani et al. 2014), the Arabian Gulf (Youssef et al. 2015) and in the estuarine and coastal sediments of the Daliao River System, China (Lin et al. 2012). Mg, Ti, and P values were much less than those recorded in Daliao River System, China.

In general, the average values of Fe, Co, Cd, As and Pb are much higher than background shale (Turekian and Wedepohl 1961), continental crust (Taylor 1964) and from other coastal areas, such as Red Sea, Gulf of Aqaba, Arabia Gulf, east China coast, Gulf of Finland (Table 2). Cu values are higher than those reported in coasts of Qatar, UAE, Oman (de Mora et al. 2004a), the Gulf of Aqaba (Al-Taani et al. 2014) and Salaam coast, Tanzania (Rumisha et al. 2012). Our Cu values are much less than values reported in Azerbaijan (de Mora et al. 2004b), the Gulf of Finland (Vallius et al. 2007) and both of shale and continental crust backgrounds (Turekian and Wedepohl 1961; Taylor 1964).

The average values of Ti are much less than those reported in shale and continental crust backgrounds (Turekian and Wedepohl 1961; Taylor 1964), Daliao River System, China (Lin et al. 2012) and are much less than those of the Salaam coast, Tanzania (Rumisha et al. 2012). Mn values (Table 2) are higher than those reported on the coasts of Qatar, the UAE, Bahrain, Oman (de Mora et al. 2004a), the Gulf of

Aqaba (Al-Taani et al. 2014), Salaam coast of Tanzania (Rumisha et al. 2012) and are less than those reported in Daliao River System, China (Lin et al. 2012).

Comparison of the results obtained in this study with those observed in other Mediterranean countries (Table 2) indicated that our results were in the range or even lower in some cases, except for Ni and Cd, which showed higher concentrations than those in recorded from Tetouan coast, North of Morocco (Omar et al. 2015), Algeciras Bay, South of Spain (Diaz-de Alba et al. 2011) and coast of Aliaga, Turkey (Neser et al. 2012). Omar et al. (2015) attributed the high concentrations of cadmium and lead in Egyptian, Turkian and Ionian Mediterranean Sea to the high industrialization of these countries.

Pollutant indicators

Enrichment factor

The Minimum, maximum and average EF values for the trace metals are presented in Table 3. 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 EF values estimated in this work were interpreted as suggested by Birch (2003). EF <1 indicates no enrichment, EF <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.

As shown in Table 3, Cd was the most enriched element in the studied coastal sediment (24.04–85.33) followed by As (4.41–22.07), Pb (4.14–18.83), Ce (4.29–7.26), Ni (1.63–4.44 µg/g) and U (2.03–4.39). The rest elements have EF <2. Accordingly, the sediment is extremely severe enrichment with Cd (average EF = 51.57), severe enrichment with As and Pb (12.64 and 10.60, respectively), moderately severe enrichment with Ce (6.06), moderate enrichment with Ni (3.16) and minor enrichment with U (2.84).

The natural sources Fe, P, Ba, Mn, Mg, Ti, V, Zn, Co, Cu, Hf, Zr and Cr, which have an EF <2, are believed to be the weathering and decomposition of mountain ranges of the Sudan and Ethiopia. Egypt's heavy-mineral sands are derived from times of flooding at the upper reaches of the Nile, transported down the river and its tributaries to the Mediterranean, and concentrated by the sea (Wendorf and Schild 1976). Eroded alluvial material from the upper reaches of the river has undergone natural separation and sorting by rain and wind and dissolution of the soluble minerals.

Table 2 Comparison between heavy metals in the studied sediments and other worldwide localities

Location	Reference	Fe	Ti	Mn	P	Ba	V	Cr	Ni	Zn	Cu	Co	Cd	As	Pb
Rosetta coast, Egypt	Present study	44,900–198,100	320–640	450–640	1030–2370	160–2140	115–652	0.10–0.29	114–894	53–388	7.6–42.7	50–89	21–37	215–399	214–476
North Morocco	Omar et al. (2015)	33,000–51,100	3800–11,600	256.6–6511.7				88.4–161	34.2–79.9	65.7–115.3	2.8–29.1	18.1–31.7	0.1–0.3		35.1–447.8
Arabian Gulf, Saudi Arabia	Youssef et al. (2015)	3447	–	75.2	–	–		27.1	–	17.6	5.8	6.3	0.7	148	58.7
Qatar	de Mora et al. (2004a)	305–5680	–	13.2–127	–	–	2.7–32.1	11.5–40.8	0.7–20.8	–	1.2–8.2	0.10–2.2	0.03–0.09	1.0–6.3	0.4–3.9
UAE		874–29,600	–	32.9–360	–	–	4.5–35.5	17.6–303	2–1010	–	0.6–3.6	0.34–45.2	0.02–11	0.7–9.6	0.7–5.9
Bahrain		471–6475	–	22.6–84.3	–	–	3.5–28.4	3.4–41.8	2.46–23.2	6.1–52.2	2.4–48.3	0.17–2.43	0.04–0.2	3.16–6.88	0.7–99
Oman		334–11,600	–	27.8–265	–	–	4.7–44.1	6.5–133	1.8–77.8	1.6–11.4	0.6–6.7	0.13–6.92	0.1–0.2	0.74–5.01	0.3–1.8
Gulf of Aqaba	Al-Taani et al. (2014)	1172–1437	–	3.9–3.6	–	–	–	3.7–8.0	–	7.0–7.7	7.6–10.8	0.51–0.77	0.06–0.07	12.2–15.1	3.7–6.8
Azerbaijan	de Mora et al. (2004b)	29,300–43,500	–	543–971	–	314—1080	–	56.4–100	34.5–68.0	51.1–110	14.5–57.6	11.5–18.1	0.08–0.2	8.87–22.6	12.2–28.6
Iran		22,200–44,000	–	470–1110	–	200–679	–	59.6–128	29.4–67.8	55.9–146	13.2–50.9	6.9–24.2	0.1–0.2	6.97–20.1	11.3–24.6
Kazakhstan		1940–28,000	–	45–630	–	75–1250	–	1.9–103	1.8–54.8	1.0–59.9	1.2–49.5	0.7–12.1	0.01–0.3	2.13–20.2	1.4–14.6
Russia		1600–9680	–	90–455	–	70–669	–	2.1–69.3	5.4–34.2	2.8–52.9	2.5–21.9	1.3–7.6	0.02–0.1	0.42–6.71	0.7–8.0
Gulf of Finland	Vallius et al. (2007)	–	–	–	–	–	–	45.8–82.7	–	152–260	42.1–76.3	10.1–16.1	0.87–2.7	7.25–19.1	37.3–58.9
East China Sea	Fang et al. (2009)	6200–39,700	–	152–1152	–	–	–	–	–	18.2–114.2	4.3–41.5	–		–	10–49
Spain	Diaz-de Alba et al. (2011)			227.6–896.7				31.8–394.7	0.1–11.6	22.3–103.2	4.4–29.2	3.6–30.1	0.003–0.28		7.7–30.4
Salaam coast, Tanzania	Rumisha et al. (2012)	461–5352	0.002–0.041	17–219	–	–	1.1–13.7	1–9.6	0.4–2.9	2.6–9.3	0.3–2.1	0.21–2.75	0.01–0.4	0.2–1.3	0.8–2.2
Turkey	Neser et al. (2012)			283–1192				65–264	28–240	86–970	20–703		0.06–3.94		91.3–751
Background shale	Turekian and Wedepohl (1961)	47,200	4600	850	700	580	130	90	68	95	45	19	0.3	13	20
Background continental crust	Taylor (1964)	56,300	5700	950	1050	425	135	100	75	70	55	25	0.2	1.8	12.5
Daliao River System, China	Lin et al. (2012)	–	2674–4708	509–1819	442–787	–	62–83	43–45	18.7–19.0	43–657	15–20	8.1–13.2	0.1–4.2	14–34	20–100

Table 3 Minimum, maximum and average values of enrichment factor, geoaccumulation index and contamination factor of the heavy metals

		Pb	Cd	Zn	Cr	Ni	Mn	Cu	Fe	Co	Sr	As	Zr	Ce	V	Hf	Ba	P	Ti	Mg	U
Enrichment factor	Min.	4.14	24.04	0.52	0.001	1.63	0.17	0.14		1.04	0.10	4.41	0.000	4.29	0.77	0.07	0.23	0.45	0.02	0.01	2.03
	Max.	18.83	85.33	1.25	0.002	4.44	0.58	0.45		3.29	0.34	22.07	0.001	7.26	2.13	0.17	0.92	2.33	0.14	0.03	4.39
	Aver.	10.60	51.57	0.79	0.001	3.16	0.36	0.26		1.93	0.20	12.64	0.001	6.07	1.302	0.11	0.51	1.20	0.06	0.02	2.84
Geoaccumulation index	Min.	2.66	4.54	−0.29	−6.475	0.80	−1.50	−3.15	−0.66	0.82	0.58	3.47	−11.17	1.86	−0.76	−4.26	−2.44	−0.03	−4.43	−5.85	−2.63
	Max.	3.46	5.10	1.70	−5.450	2.86	−0.99	−0.66	1.48	1.65	1.66	4.36	−9.43	4.31	1.74	−1.05	1.30	1.17	−3.43	−5.25	−0.23
	Aver.	3.23	4.84	0.72	−5.961	2.11	−1.21	−1.61	0.41	1.27	1.01	3.91	−10.32	2.99	0.76	−2.85	−0.70	0.52	−3.93	−5.47	−1.42
Contamination factor	Min.	10.72	70.30	0.56	0.001	1.68	0.53	0.17	0.95	2.64	0.28	16.57	0.001	5.42	0.89	0.10	0.28	1.47	0.07	0.03	0.24
	Max.	23.57	123.23	4.08	0.003	12.91	0.75	0.83	4.12	4.71	0.59	30.70	0.002	29.66	5.02	0.72	3.69	3.39	0.14	0.04	1.28
	Aver.	18.80	96.27	1.84	0.002	6.69	0.64	0.52	2.22	3.62	0.38	22.59	0.001	14.10	2.75	0.29	1.39	2.18	0.10	0.03	0.67

The anthropogenic sources of Cd, As, Pb, Ce, Ni which have an EF >2 are believed to a wide range of potential effects of the coastal ecosystems, particularly from point and non-point sources of pollution. Storm water runoff from the hinterland and the sewage input released into the Nile Delta ecosystem are the main sources of heavy metals in the studied sediments. The heavy metals produced from industrial, sewage, irrigation, and urban runoff have accumulated over a long period of time in the surface sediment of the area.

Generally the difference in EF values for the different metals in the studied sediments may be due to the difference in the magnitude of input for each metal into the sediment and/or the difference in the removal rate of each metal from the sediment. Calmano et al. (1990) and Almasoud et al. (2014) stated that metals can be released into the water phase when changes occur to its physochemical conditions like pH, redox potential, ionic strength, and the concentration of organic complexing agents.

Geoaccumulation index

Muller (1981) determined seven classes of Igeo in sediments: (1) Igeo < 0 for unpolluted, (2) 0 < Igeo < 1 for unpolluted to moderately polluted, (3) 1 < Igeo < 2 for moderately polluted, (4) 2 < Igeo < 3 for moderately to strongly polluted, (5) 3 < Igeo > 4 for strongly polluted, (6) 4 < Igeo < 5 for strongly to very strongly polluted, and (7) Igeo > 5 for very strongly polluted conditions.

As shown in Table 3, the sediment is strongly to very strongly polluted with Cd (4.54–5.10 averaging 4.84), strongly polluted with As (3.47–4.36 averaging 3.91) and Pb (2.66–3.46 averaging 3.23), moderately to strongly polluted with Ce (1.86–4.31 averaging 2.99) and Ni (0.80–2.86 averaging 2.11), moderately polluted with Co (0.82–1.65 averaging 1.27) and Sr (0.58–1.66 averaging 1.01), unpolluted to moderately polluted with V (−0.76 to 1.74 averaging 0.76) and Zn (−0.29 to 1.70 averaging 0.72). According to Muller (1981), the studied coastal sediment is unpolluted with the other elements.

Contamination factor (CF)

The CF values for the trace metals are shown in Table 3. According to Hökanson (1980), the sediments are very highly contaminated with Cd (70.30–123.23 averaging 96.27), As (16.57–30.70 averaging 22.59), Pb (10.72–23.57 averaging 18.80), Ni (1.68–12.91 averaging 6.69), Ce (5.42–29.66 averaging 14.10); considerably contaminated with Co (2.64–4.71 averaging 3.62); moderately contaminated with Fe (0.95–4.12 averaging 2.22), P (1.47–3.39 averaging 2.18), Ba (0.28–3.69 averaging 1.39),

Table 4 Correlation matrix of trace metals along the study coasts

	Fe	Mg	Ti	P	Mn	Ba	Ce	V	Cr	Ni	Sr	Zr	Zn	Cu	Co	Cd	As	Pb	Hf	U
Fe	1																			
Mg	0.774[b]	1																		
Ti	-0.748[b]	-0.824[b]	1																	
P	0.544[b]	0.468[b]	-0.565[b]	1																
Mn	0.827[b]	0.855[b]	-0.843[b]	0.555[b]	1															
Ba	0.989[b]	0.741[b]	-0.736[b]	0.585[b]	0.798[b]	1														
Ce	0.992[b]	0.732[b]	-0.714[b]	0.538[b]	0.787[b]	0.990[b]	1													
V	0.928[b]	0.825[b]	-0.789[b]	0.476[b]	0.862[b]	0.904[b]	0.913[b]	1												
Cr	0.950[b]	0.807[b]	-0.759[b]	0.471[b]	0.855[b]	0.920[b]	0.932[b]	0.894[b]	1											
Ni	0.962[b]	0.767[b]	-0.728[b]	0.546[b]	0.816[b]	0.947[b]	0.950[b]	0.934[b]	0.906[b]	1										
Sr	0.815[b]	0.793[b]	-0.759[b]	0.348	0.771[b]	0.797[b]	0.806[b]	0.858[b]	0.795[b]	0.809[b]	1									
Zr	0.841[b]	0.799[b]	-0.767[b]	0.602[b]	0.819[b]	0.836[b]	0.815[b]	0.883[b]	0.778[b]	0.851[b]	0.770[b]	1								
Zn	0.974[b]	0.809[b]	-0.796[b]	0.612[b]	0.874[b]	0.969[b]	0.957[b]	0.933[b]	0.930[b]	0.952[b]	0.792[b]	0.886[b]	1							
Cu	0.799[b]	0.807[b]	-0.767[b]	0.403[a]	0.872[b]	0.755[b]	0.749[b]	0.771[b]	0.871[b]	0.788[b]	0.792[b]	0.688[b]	0.798[b]	1						
Co	0.955[b]	0.828[b]	-0.800[b]	0.570[b]	0.897[b]	0.947[b]	0.943[b]	0.912[b]	0.942[b]	0.933[b]	0.822[b]	0.852[b]	0.962[b]	0.845[b]	1					
Cd	0.780[b]	0.696[b]	-0.680[b]	0.457[a]	0.825[b]	0.769[b]	0.756[b]	0.770[b]	0.762[b]	0.762[b]	0.710[b]	0.644[b]	0.767[b]	0.757[b]	0.774[b]	1				
As	0.414[a]	0.446[a]	-0.413[a]	0.382[a]	0.593[b]	0.404[a]	0.394[a]	0.381[a]	0.423[a]	0.426[a]	0.386[a]	0.280	0.407[a]	0.529[b]	0.444[a]	0.719[b]	1			
Pb	0.387[a]	0.475[a]	-0.269	-0.027	0.380[a]	0.345	0.353	0.346	0.491[b]	0.367[a]	0.442[a]	0.265	0.355	0.665[b]	0.416[a]	0.367[a]	0.197	1		
Hf	0.991[b]	0.722[b]	-0.709[b]	0.547[b]	0.778[b]	0.994[b]	0.996[b]	0.903[b]	0.925[b]	0.948[b]	0.776[b]	0.813[b]	0.962[b]	0.739[b]	0.937[b]	0.749[b]	0.393[a]	0.335	1	
U	0.980[b]	0.780[b]	-0.787[b]	0.567[b]	0.847[b]	0.980[b]	0.971[b]	0.934[b]	0.911[b]	0.948[b]	0.812[b]	0.878[b]	0.976[b]	0.771[b]	0.951[b]	0.807[b]	0.422[a]	0.361	0.973[b]	1

[a] Correlation is significant at the 0.05 level (2-tailed)

[b] Correlation is significant at the 0.01 level (2-tailed)

V (0.89–5.02 averaging 2.75), Zn (0.56–4.08 averaging 1.84). The sediment has low contamination with Mg, Ti, Mn, Cr, Sr, Zr, Cu, Hf and U (Table 3).

Correlation analysis

In order to establish the relations between elements in Abu Khashaba coastal sediments Pearson correlation coefficients were calculated with the normalized data. As shown in Table 4, most of the analyzed metals were correlated positively with each other. However, As and Pb do not show correlation with any other element (except Mn, Cu and Cd for the former and Cu for the later) while Ti shows a negative correlation with all elements.

The gathering metals agents Fe and Mn are well associated will each other ($r = 0.827$) and each shows positive association with Al ($r = 0.492$ and 0.337, respectively), referring to be all originated from same source. Both Cu and Zn are well associated with each other ($r = 0.798$). Each shows good association with the essential components of the sediments Fe and Mn rather than Al. Zinc is associated with Al while Cu shows no significant relationship with Al. Each of Cd and U are well associated will each other ($r = 0.807$) and each shows positive association with Fe, Mg, Mn, Ba, Ce, V, Cr, Ni, Sr, Zr, Zn, Cu, Co. Pb shows to be well associated with Cu ($r = 0.665$) and no significant relationship and negative relation with the other elements (Table 4).

Conclusions

The coastal sediments collected from the Rosetta area have shown average metal levels in the following order: Fe > P > Ba > Ce > Mn > Mg > Ti > Ni > Pb > V > As > Zn > Sr > Co > Cd > U > Cu > Hf > Zr > Cr. The EF indicated an extremely severe enrichment of Cd, severe enrichment of As and Pb, moderately severe enrichment of Ce, moderate enrichment of Ni and minor enrichment of U and consequently these toxic metals could be attributed to anthropogenic inputs. The pollutant indicators of the other metals suggested a natural source.

The GI indicated that the studied sediments are strongly to very strongly polluted with Cd, strongly polluted with Pb and As, moderately to strongly polluted with Ni and Ce, moderately polluted with Co and Sr and unpolluted to moderately polluted with Zn and V. The CF indicated that the sediments are very highly contaminated with Cd, As, Pb, Ni and Ce, considerably contaminated with Co, moderately contaminated with Fe, P, Ba, V and Zn and have low contamination with Mg, Ti, Mn, Cr, Sr, Zr, Cu, Hf and U.

References

Abrahim G, Parker R (2002) Heavy metal contaminants in Tamaki Estuary: impact of city development and growth, Auckland, New Zealand. Environ Geol 42:883–889

Abrahim G, Parker R (2008) Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environ Monit Assess 136:227–238

Adamo P, Arienzo M, Imperato M, Naimo D, Nardi G, Stanzione D (2005) Distribution and partition of heavy metals in surface and sub-surface sediments of Naples city port. Chemosphere 61(6):800–809

Almasoud FI, Usman AI, Al-Farraj AS (2014) Heavy metals in the soils of the Arabian Gulf coast affected by industrial activities: analysis and assessment using enrichment factor and multivariate analysis. Arab J Geosci. doi:10.1007/s12517-014-1298-x

Al-Taani AA, 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 Poll Bull 86:582–590

Birch G (2003) A scheme for assessing human impacts on coastal aquatic environments using sediments. In: Woodcoffe CD, Furness RA (eds) Coastal GIS. Wollongong University Papers in Center for Maritime Policy, 14, Australia

Calmano W, Ahlf W, Forstner U (1990) Exchange of heavy metals between sediments components and water. In: Brockaert JAC, Gvear S, Adams F (eds) Metal speciation in the environment, NATOASI series, vol G23. Springer-Verlag, Berlin, Heidelberg, pp 503–522

Carman CM, Li XD, Zhang G, Wai OWH, Li YS (2007) Trace metal distribution in sediments of the Pearl River Estuary and the surrounding coastal area, South China. Environ Pollut 147:311–323

Cevik F, Göksu MZL, Derici OB, Fındık Ö (2009) An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. Environ Monit Assess 152:309–317

Cheremisinoff NP (2002) Handbook of water and wastewater treatment technologies. Butterworth-Heinemann, Elsevier, Oxford, United States of America, p 636

Christophoridis C, Dedepsidis D, Fytianos K (2009) Occurrence and distribution of selected heavy metals in the surface sediments of Thermaikos Gulf. N. Greece. Assessment using pollution indicators. J Hazard Mater 168:1082–1091

Dabbour GA (1980) Geological and mineralogical studies on rutile in the black sand deposits from the Egyptian Mediterranean coast. Ph.D. Thesis, Cairo University, Giza

Dabbour GA (1995) Estimation of the economic minerals reserves in Rosetta beach sands. Egypt Miner 7:1–6

Dawod YH, Abdelnaby MH (2007) Mineral chemistry of monazite from the black sand deposits, northern sinai, Egypt: a provenance perspective. Min Mag 71(4):389–406

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

de Mora S, Sheikholeslami MR, Wyse E, Azemard S, Cassi R (2004b) An assessment of metal contamination in coastal sediments of the Caspian Sea. Mar Pollut Bull 48:61–77

Diagomanolin V, Farhang M, Ghazi-Khansari M, Jafarzadeh N (2004) Heavy metals (Ni, Cr, Cu) in the Karoon waterway river. Iran Toxicol Lett 151:63–68

Diaz-de Alba M, Galindo-Riano MD, Casanueva-Marenco MJ, Garcia-Vargas M, Kosore CM (2011) Assessment of the metal pollution, potential toxicity and speciation of sediment from Algeciras Bay (South of Spain) using chemometric tools. J Hazard Mater 190:177–187

El-Miligy MN, El-Azab AA (1994) Black sand project. EGSA Ann 67:1–24

El-Sorogy AS, Abdelwahab M, Nour H (2012) Heavy metals contamination of the Quaternary coral reefs, Red Sea coast, Egypt. Environ Earth Sci 67:777–785

Fang TH, Chen RY (2010) Mercury contamination and accumulation in sediments of the East China Sea. J Environ Sci 22(8):1164–1170

Fang TH, Li JY, Feng HM, Chen HY (2009) Distribution and contamination of trace metals in surface sediments of the East China Sea. Mar Environ Res 68:178–187

Farkas A, Erratico C, Vigano L (2007) Assessment of the environmental significance of heavy metal pollution in surficial sediments of the River Po. Chemosphere 68:761–768

Frihy OE, Lotfy MF (1994) Mineralogy and textures of beach sands in relation to erosion and accretion along the Rosetta promontory of the Nile Delta, Egypt. J Coast Res 10(3):588–599

Frihy OE, Shereet SM, El Banna MM (2008) Pattern of beach erosion and scour depth along the Rosetta Promontory and their effect on the existing protection works, Nile Delta, Egypt. J Coast Res 24:857–866

Gonzales-Macias C, Schifter I, Lluch-Cota DB, Mendez-Rodriguez L, Hernandez-Vazquez S (2006) Distribution, enrichment and accumulation of heavy metals in coastal sediments of Salina Cruz Bay, Mexico. Environ Monit Assess 118:211–230

Hahladakis J, Smaragdaki E, Vasilaki G, Gidarakos E (2013) Use of Sediment Quality Guidelines and pollution indicators for the assessment of heavy metal and PAH contamination in Greek surficial sea and lake sediments. Environ Monit Assess 185(3):2843–2853

Hökanson L (1980) An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res 14:975–1001

Hung JJ, Lu CC, Huh CA, Liu JT (2009) Geochemical controls on distributions and speciation of As and Hg in sediments along the Gaoping (Kaoping) Estuary Canyon system off southwestern Taiwan. J Mar Syst 76(4):479–495

Kaiser MF, Aboulela HA, El-Serehy HA, Ezz El-Din H (2012) Heavy metals contamination of a Mediterranean coastal ecosystem, Eastern Nile Delta, Egypt. In: Young SS, Silvern SE (eds) International perspectives on global environmental change. InTech, Croatia, pp 297–310

Karageorgis AP, Nikolaidis NP, Karamanos H, Skoulikidis N (2003) Water and sediment quality assessment of the Axios River and its coastal environment. Cont Shelf Res 23:1929–1944

Leivouri M (1998) Heavy metal contamination in surface sediments in the Gulf of Finland and comparison with the Gulf of Bothnia. Chemosphere 36:43–59

Leopold EN, Jung MC, Auguste O, Ngatcha N, Georges E, Lape M (2008) Metals pollution in freshly deposited sediments from River Mingoa, main tributary to the municipal lake of Yaounde, Cameroon. Geosci J 12(4):337–347

Lin C, He M, Liu S, Li Y (2012) Contents, enrichment, toxicity and baselines of trace elements in the estuarine and coastal sediments of the Daliao river system, China. Geochem J 46:371–380

Mahmoud HH, Abdel-Lateef AM, Attiah AM (2013) Distribution of some elements in the Egyptian black sands from Abu Khashaba beach area. J Analyt Sci Methods Instrum 3:62–66

Mange MA, Wright DT (eds) (2007) Heavy minerals in use. Developments in sedimentology, vol 58. Elsevier, Italy, p 1283

Morton B, Blackmore G (2001) South China Sea. Mar Poll Bull 42:1236–1263

Muller G (1979) Heavy metals in the sediment of the Rhine-Changes seity, 1971. Umsch Wiss Tech 79:778–783

Muller G (1981) Die Schwermetallbelastung der Sedimenten des Neckars und Seiner Nebenflusse. Chem Ztg 6:157–164

Neser G, Kontas A, Unsalan D, Uluturhan E, Altay O, Darılmaz E, Kucuksezgin F, Tekogul N, Yercan F (2012) Heavy metals contamination levels at the Coast of Aliaga (Turkey) ship recycling zone. Mar Pollut Bull 64:882–887

Omar MB, Mendiguchia C, Er-Raioui H, Marhraoui M, Lafraoui Gh, Mk Oulad-bdellah, Garcia-Vargas M, Moreno C (2015) Distribution of heavy metals in marine sediments of Tetouan coast (North of Morocco): natural and anthropogenic sources. Environ Earth Sci 74:4171–4185

Rumisha C, Elskens M, Leermakers M, Kochzius M (2012) Trace metal pollution and its influence on the community structure of soft bottom molluscs in intertidal areas of the Dar es Salaam coast, Tanzania. Mar Poll Bull 64:521–531

Savvides C, Papadopoulos A, Haralambous KJ, Loizidou M (1995) Sea sediments contaminated with heavy metals: metal speciation and removal. Water Sci Tech 32(9–10):65–73

Selvaraj K, Ram Mohan V, Szefer P (2004) Evaluation of metal contamination in coastal sediments of the Bay of Bengal, India: geochemical and statistical approaches. Mar Poll Bull 49:174–185

Sinex SA, Helz GR (1981) Regional geochemistry of trace elements in Checapeake Bay sediments. Environ Geol 3:315–323

Singh M, Muller G, Singh IB (2002) Heavy metals in freshly deposited stream sediments of rivers associated with urbanisation of the Ganga Plain, India. Water Air Soil Poll 141:35–54

Stoffers P, Glasby GP, Wilson CJ, Davis KR, Watter P (1986) Heavy metal pollution in Wellington Harbour. NZ J Mar Freshwat Res 20:495–512

Taylor SR (1964) Abundance of chemical elements in the continental crust: a new table. Geochim Cosmochim Acta 28:1273–1285

Turekian KK, Wedepohl KH (1961) Distribution of the elements in some major units of the earth's crust. Geol Soc Am 72:175–192

Vallius H, Ryabchuk D, Kotilainen A (2007) Distribution of heavy metals and arsenic in soft surface sediments of the coastal area off Kotka, northeastern Gulf of Finland, Baltic Sea. In: Vallius H (ed) Holocene sedimentary environment and sediment geochemistry of the eastern Gulf of Finland, Baltic Sea. Geological Survey of Finland, Special Paper 45:33–48

Wendorf V, Schild R (1976) Prehistory of the Nile valley. Academic Press, New York, p 401

Youssef M, El-Sorogy AS, Al-Kahtany KH, Al-Otaibi N (2015) Environmental assessment of coastal surface sediments Tarut Island, Arabian Gulf (Saudi Arabia). Mar Poll Bull. doi:10.1016/j.marpolbul.2015.05.010

Zhang J, Liu C (2002) Riverine composition and estuarine geochemistry of particulate metals in China—weathering features, anthropogenic impact and chemical fluxes. Estuar Coast Shelf Sci 54:1051–1070