Marine Pollution Bulletin 133 (2018) 808–813

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

Assessment of sediment quality using different pollution indicators and statistical analyses, Hurghada area, Red Sea coast, Egypt

Hamdy E. Nour[a], Abdelbaset S. El-Sorogy[a,b,*], Mohamed Abdel-Wahab[c], Sattam Almadani[b], Hussain Alfaifi[b], Mohamed Youssef[b,d]

[a] Geology Department, Faculty of Science, Zagazig University, Egypt
[b] Geology and Geophysics Department, College of Science, King Saud University, Saudi Arabia
[c] National Institute of Oceanography and Fisheries, Red Sea Branch, Hurghada, Egypt
[d] Geology Department, Faculty of Science, South Valley University, Egypt

ARTICLE INFO

Keywords:
Assessment
Sediment quality
Pollution indicators
Hurghada
Red Sea
Egypt

ABSTRACT

Thirty bottom sediment samples were collected from northern Hurghada coast, Red Sea, Egypt to evaluate the level of anthropogenic pollutants, using enrichment factor (EF), potential ecological risk index (PERI), soil pollution index (SPI), potential contamination index (Cp) and multivariate statistical analysis (correlation analysis, principal component analysis, and hierarchical cluster analysis). Fe, Mn, Zn, Pb, Ni, Cu, Co and Cd were analyzed by Atomic Absorption Spectrophotometer. Results indicated that the average values of Pb and Cd were greater than the ones recorded from many other worldwide coastal areas. The studied sediments are extremely severe enrichment with Pb and Cd (EF $>$ 50), severe enrichment with Zn (EF = 10–25), very high risk with Cd (PERI $\geq$ 320), high risk with Pb (160 $\leq$ PERI $<$ 320), highly contaminated with Pb (SPI $>$ 3), a severe contamination with Pb (Cp $>$ 3). The accumulation of pollutants is associated with the muddy and fine sediment; especially the studied area is a semi-closed bay, characterized by long time of water retention. Possible sources of metals pollution in the studied area are shipment operations and anticorrosive and antifouling paints, dredging and land filling, municipal wastewater from tourist centers and fishermen cargo boats.

Heavy metal pollutants find their way into coastal environments through industrial, agricultural and wastewater effluents generated by coastal cities and resorts. As well as, products of rock weathering driven to the water bodies by rainfall and winds (El-Sorogy et al., 2016; Zhaoyong et al., 2018). Many factors affecting the toxicity and availability of metals in coastal sediments, such as pH, dissolved oxygen, the concentration of metal ions, organic and inorganic carbon content, and oxidative–reductive potential (Stauber and Florence, 1987; Attia and Ghrefat, 2013).

The contamination of coastal sediments with heavy metals became a severe problem, particularly in areas of population growth and urban expansion. This is due to environmental persistence of heavy metals and their toxicity, non-biodegradation and their ability to bioaccumulate in the food chain (Wu et al., 2017). In the urban areas, the levels and types of heavy metals entering the bottom sediments depend mainly on the population, industrial activities, and traffic densities (Zhao et al., 2014). Intensive agricultural practices with commercial fertilizers and pesticides, sewage irrigation, and petrochemical activities are the most sources of heavy metals in coastal sediments (Wu et al., 2017).

Hurghada is one of the most famous Egyptian cities on the Red Sea coast. It covers about 40 km stretch along Red Sea coast and is characterized by several tourist resorts, marine sports, fishing operations and ports. These urbanization activities have a negative impact on marine coasts and marine ecosystem. Therefore, the main objectives of the present study are: (1) to evaluate the level of anthropogenic pollutants of the marine bottom sediments of northern Hurghada coast on the front of the National Institute of Oceanography and Fisheries using different pollution indicators and multivariate statistical analysis, (2) to compare between the average levels of metals in the study areas and those in neighboring and worldwide coasts.

The study area is located in front of the Hurghada National Institute of Oceanography and Fisheries (NIOF), which lies on the western Red Sea coast of Egypt (Fig. 1). The coastal plain is bounded by granitic mountains to the west and is covered by raised coral reefs, gravels, and sands. The beach sediments are composed of terrigenous quartz grains, derived from weathering and erosion of the Red Sea Mountains (Moussa et al., 1991). The study area looks like a bay protected by linear barrier

* Corresponding author.
E-mail address: asmohamed@ksu.edu.sa (A.S. El-Sorogy).

https://doi.org/10.1016/j.marpolbul.2018.06.046
Received 23 March 2018; Received in revised form 12 June 2018; Accepted 16 June 2018

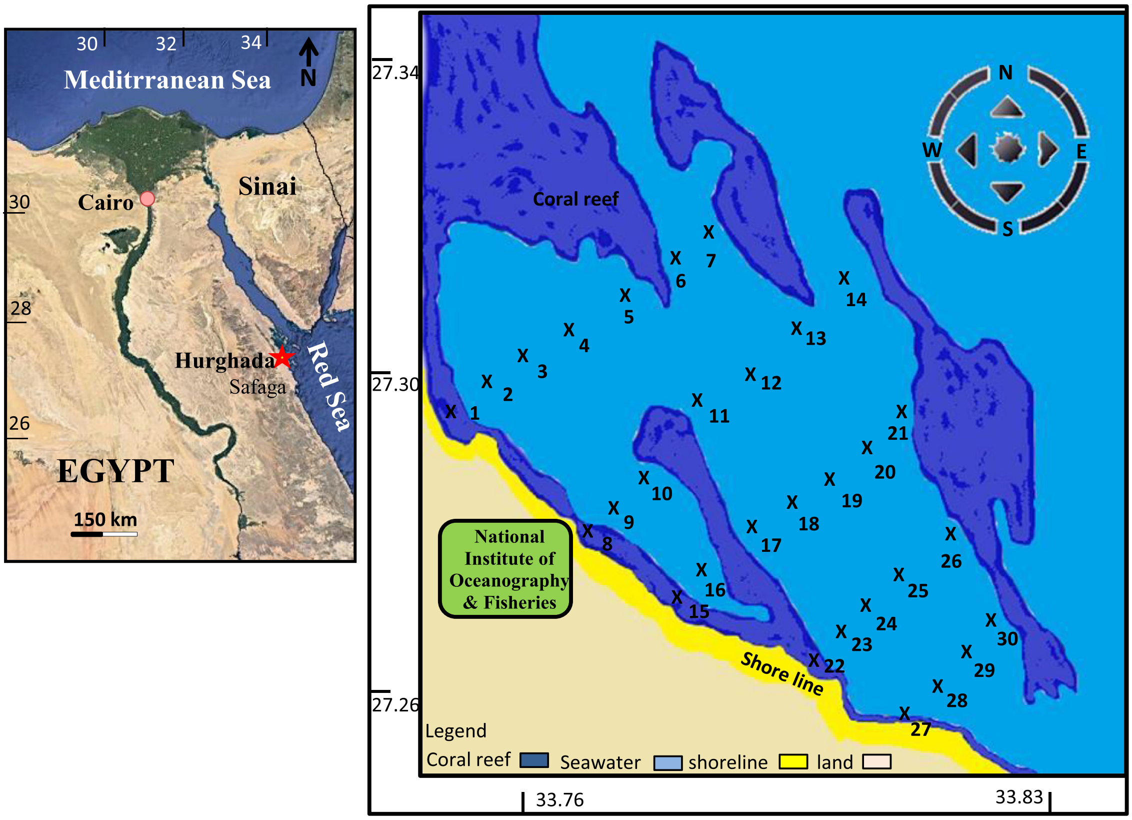

Fig. 1. Location map of study area and location of sediment samples.

reefs, where there are three offshore barrier reefs, aligned parallel to the shoreline with the big channels between them. Two main passages cut the barriers from north to south. The barrier reefs are flat topped and covered by algae. The bottom sediments consist of several components, including sand, mud and biogenic particles in addition to algae and seagrass. The depth of the studied area ranges from 0 to 40 m and inhabited by different marine organisms as coral reefs, molluscs, echinoderms, crustacea, algae, and seagrass (Ebaid-Allah, 1988).

Thirty surface sediment samples covered an area about 40 km^2 were collected from the study area (Fig. 1). Samples were collected by grab sampler from the intertidal sand and the back reef zones. Each sediment sample was gently washed several times with distilled water to remove soluble salts and finally dried at room temperature. Fe, Mn, Zn, Pb, Ni, Cu, Co and Cd have been determined by digesting 0.5 g of each sediment sample in the Teflon cup using 10 ml of a mixture of HF, HNO_3 and HCL_4 acids (Chester et al., 1994), then diluted to 20 ml de-ionized distilled water and finally these trace elements measured by an Atomic Absorption Spectrophotometer (GBC 932, Ver1.1).

To identify the pollution and contamination level in the studied coastal sediments, present study used pollution indicators of enrichment factor (EF), potential ecological risk index (PERI), soil pollution index (SPI), potential contamination index (Cp) (Table 1). In order to establish the relationships between metals of Hurghada coastal sediments, the cluster analysis (Ward's method), correlation analysis (Pearson's correlation coefficients SPSS program) and principal component analysis (PCA) were performed for the studied samples.

Table 2 illustrates the composition, depth and concentrations of 8 metals in 30 coastal sediments along northern Hurghada coast, Red Sea, Egypt. The studied sediments are composed of skeletal, gravelly to muddy sands and sandy mud. The skeletal part includes embryonic stages and fragments of bivalves, gastropods, echinoderms, as well as foraminifers and ostracods. The average metal levels in the 30 surface coastal sediments along northern Hurghada coast were in the following order: Fe > Mn > Pb > Zn > Ni > Co > Cu > Cd.

Results of metal analysis showed that Fe, Mn, Cu, Pb, Ni and Cd exhibit similar trends and their values increase more or less with depth until 20 m, while Zn and Co showed an increasing trend with decreasing depth toward the shoreline of the bay (Table 3). Most high levels of the analyzed metals were recorded in sediments composed of mud, sandy mud, muddy sand, fine sand and biogenic sand (Fig. 2). Table 4 illustrates a comparison between average levels of the studied metals and the same metals in other coastal sediments along the Mediterranean Sea, the Caspian Sea, the Red Sea, the Arabian Gulf, the Gulf of Aqaba, the Indian Ocean, as well as the background shale and background continental crust.

Pb, Cd, Zn, Mn, Ni, Cu and Co gave enrichment factors higher than 2 (424.98, 99.84, 21.80, 9.46, 7.45, 4.41, 4.31, respectively) indicating anthropogenic sources of these metals (Table 5). Some elements are essential and play an important role in cell metabolism and growth of the marine organisms, but high levels of these elements are toxic to corals (Beyersmann, 1994; El-Sorogy et al., 2012). Average EF values indicate that the Hurghada sediments are extremely severe enriched with Pb and Cd ($EF > 50$), severe enriched with Zn ($EF = 10–25$), moderately severe enriched with Mn and Ni ($EF = 5–10$), and moderately enriched with Cu and Co ($EF = 3–5$). Results of potential ecological risk index (PERI) implying that the Hurghada coastal sediments are very high risk with Cd ($PERI \geq 320$), high risk with Pb ($160 \leq PERI < 320$) and low risk with the rest metals ($PERI < 40$). Average values of the soil pollution index (SPI) indicate that the sediments are highly contaminated with Pb ($SPI > 3$), moderately contaminated with Cd ($1 < SPI \leq 3$) and low contaminated with the rest metals ($SPI \leq 1$). Average values of the potential contamination index (Cp) indicate a severe contamination with Pb ($Cp > 3$), a moderate contamination with Cd and Co ($1 < Cp < 3$) and a low contamination with the rest metals ($Cp < 1$).

Table 6 illustrates the results of the principal component analysis

Table 1
Pollution indicators used in the present study and their classifications.

Pollution indicators	Procedures of calculation and classifications						
Enrichment factor (EF)	EF = (M/Fe) sample / (M/Fe) background Where (M/Fe) sample is the ratio of metal and Fe concentrations in the sample, and (M/Fe) background is the ratio of metal and Fe concentrations in the Earth's crust. Birch (2003) determined seven classes of EF in sediments.						
	EF < 1 No enrichment	EF < 3 Minor enrichment	EF = 3–5 Moderate enrichment	EF = 5–10 Moderately severe enrichment	EF = 10–25 Severe enrichment	EF = 25–50 Very severe enrichment	EF > 50 Extremely severe enrichment
Potential contamination index (Cp)	CP = Cmax / Cb where Cmax is the maximum concentration of a metal in sediment, and Cb is the average value of the same metal in a background level. Cp values were classified into three categories.						
	Cp < 1 Low contamination	1 < Cp < 3 Moderate contamination	Cp > 3 Severe or very severe contamination				
Potential ecological risk index (PERI)	PERI = Σni Eir Toxic response factor for metals are in the order; Zn = 1, Cr = 2, Co = Cu = Pb = 5, Ni = 6 and Cd = 30. The degree of ecological risk can be classified into five classes.						
	PERI < 40 Low risk	40 ≤ PERI < 80 Moderate risk	80 ≤ PERI < 160 Considerable risk	160 ≤ PERI < 320 High risk	PERI ≥320 Very high risk		
Soil pollution index (SPI)	SPI = Cs / Cm where, Cs is the concentration of metal in the sample and Cm is the permissible levels of metals in sediments according to USEPA, 1983. The level of each heavy metal was classified into three classes.						
	SPI ≤ 1 Low contamination	1 < SPI ≤ 3 Moderate contamination	SPI > 3 High contamination				

(varimax with Z normalization), which identified three components, explained 72.3% of the total variance for all studied metals. The first principal component (PC1) explains 38.885% and loading heavily on Fe, Mn, Cu, Pb, Ni and Co (0.769, 0.682, 0.790, 0.650, 0.750 and 0.562 respectively), and negative loading of Zn only, indicating stronger relationships. The second principal component (PC2) accounts 18.784% of the total variance and shows positive loading for Mn, Zn and Co (0.537, 0.699 and 0.558 respectively), and negative loading of Fe, Cu,

Table 3
Relationship between samples depth and concentration of heavy metals.

Average depth	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co
1–5 m	269.08	42.89	1.02	10.45	36.38	1.40	0.12	2.18
6–10 m	421.37	57.69	1.18	6.60	43.20	1.58	0.15	0.37
15–20 m	480.83	72.43	2.18	3.14	52.95	2.77	0.15	0.25
> 20 m	174.73	8.99	0.65	5.63	42.02	1.85	0.12	0.51

Table 2
Sediment type, depth (m) and heavy metal concentrations (μg/g) in the studied coastal sediments.

S. N.	Sediment type	Depth/m	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co
1	Biogenic sand	4	919.39	177.61	3.29	9.51	75.78	2.48	0.06	20.27
2	Muddy sand	17	469.04	122.77	1.18	4.5	51.57	2.44	0.05	0.01
3	Sandy mud	18	414.42	75.29	0.54	2.82	52.25	2.42	0.05	0.06
4	Sandy mud	10	303.73	25.47	0.92	2.74	42.02	2.2	0.07	0.3
5	Fine sand	5	187.88	9.75	0.12	12.02	21.79	0.11	0.09	0.4
6	Medium sand	7	399.36	62.87	0.49	12.86	21.97	0.21	0.1	0.6
7	Biogenic sand	7	861.93	76.03	1.25	5.1	32.6	0.52	0.13	0.14
8	Fine sand	6	157.55	109.56	0.33	14.3	21.14	0.75	0.11	0.1
9	Muddy sand	15	317.96	65.21	3.47	3.35	52.62	2.47	0.1	0.3
10	Gravelly sand	5	140.84	24.64	0.32	12.17	21.41	1.03	0.14	1.08
11	Gravelly sand	5	94.26	19.97	0.51	2.37	21.52	0.93	0.15	1.02
12	Sandy mud	32	185.46	15.57	0.58	1.7	62.1	3.3	0.12	0.56
13	Mud	10	616.28	15.08	0.57	2.5	53.24	2.7	0.13	0.81
14	Muddy sand	10	409.56	38.08	0.52	3.07	72.34	1.35	0.05	0.57
15	Gravelly sand	0.5	515.25	73.21	3.11	4.9	22.98	2.04	0.08	0.47
16	Muddy sand	1	356.96	8.01	1.1	2.95	32.34	2.75	0.26	0.87
17	Medium sand	2	150.68	10.3	0.34	12.84	32.96	0.9	0.1	0.43
18	Gravelly sand	5	83.77	4.42	0.23	2.53	22.1	0.58	0.17	0.33
19	Medium sand	38	120.54	4.22	0.36	11.83	30.8	0.34	0.09	0.3
20	Gravelly sand	10	112.4	11.39	0.19	1.46	30.56	0.66	0.04	0.83
21	Biogenic sand	3	297.59	24	0.39	1.99	32.39	1.6	0.08	0.2
22	Medium sand	4	291.25	110.25	0.33	18.96	61.25	2.41	0.07	0.24
23	Muddy sand	6	299.15	89.63	3.12	4.1	71.49	2.33	0.1	0.05
24	Biogenic sand	14	658.59	21.36	3.2	1.5	35.16	2.99	0.17	0.66
25	Biogenic sand	27	218.2	7.19	1.01	3.35	33.15	1.91	0.14	0.67
26	Medium sand	4	88.45	6.89	0.95	23.11	51.01	1.78	0.12	0.55
27	Fine sand	6	154.6	98.56	1.41	17.33	64.11	1.97	0.5	0.24
28	Muddy sand	12	544.14	77.52	2.53	3.51	73.14	3.54	0.4	0.21
29	Biogenic sand	7	899.11	50.21	3.01	2.56	22.56	3.1	0.3	0.09
30	Gravelly sand	2	102.65	45.63	1.5	22.04	40.99	0.21	0.1	0.33
Minimum			83.77	4.22	0.12	1.46	21.14	0.11	0.04	0.01
Maximum			919.39	177.61	3.47	23.11	75.78	3.54	0.5	20.27
Average			355.44	51.95	1.26	7.77	42.38	1.74	0.14	1.66

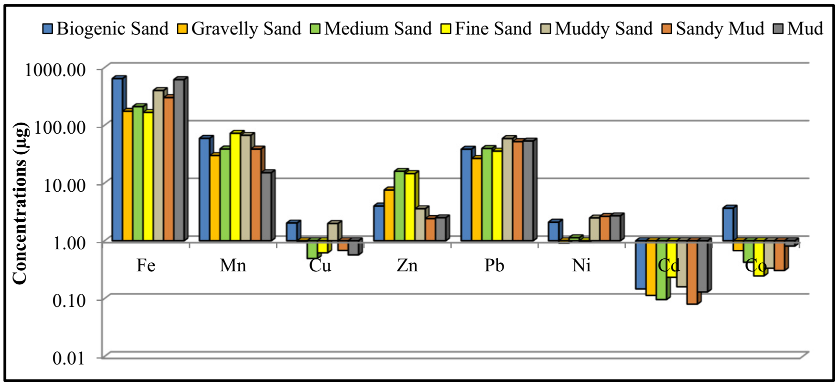

Fig. 2. Relationship between types of sediments and concentration of heavy metals in study area.

Ni and Cd. The third principal component (PC3) accounts 14.667% of the total variance and shows a positive loading for Zn and Cd (0.549 and 0.728), and negative loading of Fe. Results of hierarchical cluster analysis (HCA) are strongly agreed with those of principal component analysis (PCA). Two distinct clusters were observed, possibly implied different sources of pollutants (Fig. 3). Cluster 1 includes Pb, Ni, Fe, Cu, Mn, Cd and Co with three sub-clusters: Pb-Ni; Fe, Cu and Mn; and Cd-Co. Cluster 2 includes Zn.

Correlation analysis using the Pearson's correlation coefficients (Table 7) supported the information obtained from HCA and PCA analyses. Significantly positive correlations were observed between Ni and each of Fe, Cu and Pb ($r = 0.549$, $r = 0.609$ and $r = 0.623$ respectively). Also, significantly positive correlations between Co and each of Mn and Cd ($r = 0.507$ and $r = 0.537$) and between the elemental pairs Cu and Fe ($r = 0.607$). These high correlations could be a potential indicator to the similar sources of pollutants.

Sediment size may play a significant role in distribution of metals in the studied sediment samples, most high levels were recorded in mud, sandy mud, muddy sand, fine sand and biogenic sand (Fig. 2). This is due to fine-grained sediments have large surface areas and mostly associated with high amount of total organic matter and consequently have a great potential to accumulate contaminants from a water column (Alharbi and El-Sorogy, 2017).

Exhibiting Fe, Mn, Cu, Pb, Ni and Cd an increasing trend more or less with depth, pointing to inside origin (within the bay) rather than from the outside origin of these metals. The possible sources of these metals are paints used to protect coastal structures and ships against fouling and corrosive, shipment operations and shipyards. The increasing of Zn and Co levels with decreasing depth toward the shoreline of the bay deducing outside sources of these metals. Possible outside sources include dredging and land filling. As well as, the studied bay

Table 5
Minimum, maximum and average values of the different pollution indicators in the present study.

Metals	EF			Cp	PERI	SPI		
	Min.	Max.	Aver.			Min.	Max.	Aver.
Pb	59.22	1361.04	424.98	3.789	314.835	2.114	7.578	4.198
Cd	10.27	508.84	99.84	1.667	407.000	0.667	8.333	2.261
Zn	1.13	129.81	21.80	0.243	2.358	0.029	0.462	0.149
Ni	0.36	13.97	4.41	0.052	4.634	0.003	0.089	0.043
Mn	1.25	38.62	9.46	0.209		0.007	0.296	0.082
Cu	0.67	15.33	4.31	0.077	4.097	0.004	0.116	0.041
Fe				0.019				
Co	0.05	54.77	7.45	1.067	8.603	0.001	2.534	0.136

Table 6
Principal component loadings and explained variance for the three components with Varimax normalized rotation.

Metals	PC1	PC2	PC3
Fe	**0.769**	−0.100	−0.347
Mn	**0.682**	**0.537**	0.081
Cu	**0.790**	−0.131	0.007
Zn	−0.265	**0.699**	**0.549**
Pb	**0.650**	0.180	0.327
Ni	**0.750**	−0.444	0.163
Cd	0.244	−0.397	**0.728**
Co	**0.562**	**0.558**	−0.286
Variance %	38.885	18.784	14.667
Cumulative %	38.885	57.669	72.337

Bold values = loadings > 0.5.

Table 4
Comparison between metals in the studied sediments and other worldwide localities.

Site	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co	Reference
NIOF	345.70	49.36	1.23	7.47	41.89	1.73	0.14	0.42	Present work
Arabian Gulf, Saudi Arabia	8474.21	111.57	297.29	48.26	5.25	77.07	2.13	4.01	El-Sorogy et al. (2018)
Red Sea, Saudi Arabia	2249.42	102.7	16.00	39.71	50.87	8.69	0.26	4.77	Youssef and El-Sorogy (2016)
Gokcekaya Dam Lake, Turkey	15,495	–	108.99	265.8	74.44	125.7	0.007	85.57	Akin and Kırmızıgu (2017)
Arabian Gulf, Saudi Arabia	7552	113.97	182.97	52.68	5.358	75.10	0.226	4.75	Alharbi and El-Sorogy (2017)
Hurghada harbor, Red Sea	1020	112	4.10	9.1	19.5	8.90	0.30	4.0	Mansour et al. (2011)
Mediterranean Sea, Egypt	19,144	551.6	13.23	32.03	28.17	30.85	13.41	0.25	Okbah et al. (2014)
Gulf of Aqaba, Saudi Arabia	1172–1437	3.9–3.6	7.6–10.8	7.0–7.7	3.7–6.8	–	0.06–0.07	0.51–0.77	Al-Taani et al. (2014)
India, Indian Ocean	2.16–18.35	–	0.10–0.84	0.29–3.64	0.03–0.08	–	0.002–0.09	–	Kesavan et al. (2013)
Bahrain, Arabian Gulf	471–6475	22.6–84.3	2.4–48.3	6.1–52.2	0.7–99	2.46–23.2	0.04–0.2	0.17–2.43	de Mora et al. (2004b)
Azerbaijan, Caspian Sea	37,100	832	31.9	83.2	19.6	50.1	0.14	14.9	
Russia, Caspian Sea	5520	200	8.3	17.1	4.19	14	0.06	3.8	de Mora et al. (2004a)
Background shale	47,200	850	45	95	20	68	0.3	19	Turekian and Wedepohl (1961)
Background continental crust	56,300	950	55	70	12.5	75	0.2	25	Taylor (1964)

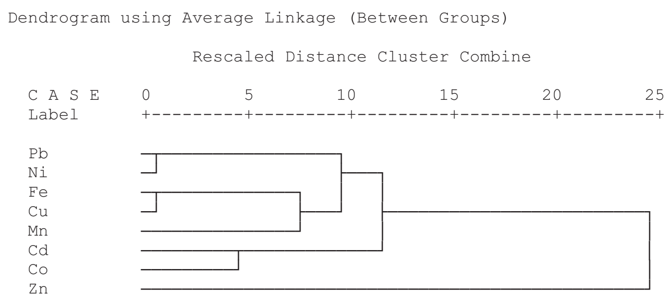

Fig. 3. Dendrogram for hierarchal clusters analyses (HCA) of heavy metals in the study area.

Table 7
Correlation matrix among analyzed metals.

	Fe	Mn	Cu	Zn	Pb	Ni	Cd	
Fe	1							
Mn	0.481**	1						
Cu	0.607**	0.467**	1					
Zn	−0.140	0.376*	−0.022	1				
Pb	0.248	0.495**	0.352*	0.166	1			
Ni	0.549**	0.368*	0.609**	−0.178	0.623**	1		
Cd	0.388*	0.405*	0.464**	0.276	0.349*	0.472**	1	
Co	0.422*	0.507**	0.355*	0.395*	0.331	0.305	0.537**	1

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

receives variable amounts of municipal wastewater from tourist centers and from fishermen and cargo boats (Attia and Ghrefat, 2013). Pouring sewage and wastewater directly on the beach leads to growing of fresh-water plants (Fig. 4).

In comparison with other coastal areas worldwide (Table 4), present sediment recorded Pb values greater than those recorded from the Arabian Gulf, the Red Sea, the Mediterranean Sea, the Indian Ocean and the Caspian Sea (El-Sorogy et al., 2018; Alharbi and El-Sorogy, 2017; Mansour et al., 2011; Okbah et al., 2014; Kesavan et al., 2013; de Mora et al., 2004a). Average value of Cd is greater than the ones recorded from Gokcekaya Dam Lake (Turkey), the Gulf of Aqaba, the Indian Ocean, the Arabian Gulf and the Caspian Sea. The recorded averages of Fe, Mn, Cu, Zn, Ni and Co were less than most of the coastal areas mentioned in Table 4.

The different pollution indicators used in the present study revealed that the studied coastal sediments are highly enriched with metals, like Pb, Cd and Zn. This is because the studied area is a semi-closed bay, characterized by long time of water retention and consequently high levels of heavy metals were accumulated in its bottom sediment. As well as, limited exchange between water in the bay and the open sea, in addition to the restricted effect of flushing suggest receiving bottom sediments to heavy metals of anthropogenic sources.

The average metal levels in 30 surface sediments along northern Hurghada coast were in the following order: Fe > Mn > Pb > Zn > Ni > Co > Cu > Cd. Most of the high levels of these metals were associated with sediments composed of mud, sandy mud, muddy sand, fine sand and biogenic sand. Average values of Pb and Cd were greater than those recorded from many worldwide coastal types of sediment.

Pb, Cd, Zn, Mn, Ni, Cu and Co gave enrichment factors higher than 2 indicating anthropogenic sources of these metals, while potential ecological risk index implies a very high risk with Cd and high risk with Pb. Soil pollution index indicated that the studied sediments are highly contaminated with Pb, while the potential contamination index indicated a severe contamination with Pb.

The different pollution indicators used in the present study indicated that the studied coastal sediments are highly enriched with

Fig. 4. Some sources of pollutants in the study area. A) Landfilling due to new constructions and solid wastes of fishing boats. B) Growing of fresh-water plants along the coast due to housing-sewage. C) Pouring of housing wastewater directly on the beach.

metals, like Pb, Cd and Zn. The studied area is a semi-closed bay, which is characterized by long time of water retention. As a result high levels of metals were accumulated in its bottom sediment. The limited exchange between water in the bay and open sea, as well as the restricted effect of flushing suggest receiving bottom sediments in the bay to heavy metals of anthropogenic sources.

The possible sources of these metals are shipment operations inside the harbor, shipyards and the paints used to protect coastal structures and ships against fouling and corrosive. Outside sources include dredging and land filling, as well as receiving intermittent amounts of municipal wastewater from tourist centers and fishermen cargo boats.

Acknowledgments

The authors would like to extend their sincere appreciation to the Deanship of Scientific Research at King Saud University for its funding this research group No. (RG-1435-033).

References

Akin, B.S., Kırmızıgu, O., 2017. Heavy metal contamination in surface sediments of Gokcekaya Dam Lake, Eskis, ehir, Turkey. Environ. Earth Sci. 76, 402.
Alharbi, T., El-Sorogy, A., 2017. Assessment of metal contamination in coastal sediments of Al-Khobar area, Arabian Gulf, Saudi Arabia. J. Afr. Earth Sci. 129, 458–468.
Al-Taani, A.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. Poll. Bull. 86, 582–590.
Attia, O.E., Ghrefat, H., 2013. Assessing heavy metal pollution in the recent bottom sediments of Mabahiss Bay, North Hurghada, Red Sea, Egypt. Environ. Monit. Assess. 185 (12), 9925–9934.
Beyersmann, D., 1994. Interactions in metal carcinogenicity. Toxicol. Lett. 72, 333–338.
Birch, G., 2003. A scheme for assessing human impacts on coastal aquatic environments using sediments. In: Woodcoffe, C.D., Furness, R.A. (Eds.), Coastal GIS. Wollongong University Papers in Center for Maritime Policy, 14, Australia.
Chester, R., Lin, F.G., Basaham, A.S., 1994. Trace metals solid state speciation changes associated with the down-column fluxes of oceanic particulates. J. Geol. Soc. Lond. 151, 351–360.
Ebaid-Allah, N., 1988. Recent Invertebrates along the Red Sea Coastal Plain between Marsa Alam and Ras Banas. Thesis, Assiut University, M. Sc (239 p).
El-Sorogy, A.S., Abdelwahab, M., Nour, H., 2012. Heavy metals contamination of the Quaternary coral reefs, Red Sea coast. Egypt. Environ Earth Sci. 67, 777–785.
EL-Sorogy, A.S., Tawfik, M., Almadani, S.A., Attiah, A., 2016. Assessment of toxic metals in coastal sediments of the Rosetta area, Mediterranean Sea, Egypt. Environ. Earth Sci. 75, 398.
El-Sorogy, A., Al-Kahtany, K., Youssef, M., Al-Kahtany, F., Al-Malky, M., 2018. Distribution and metal contamination in the coastal sediments of Dammam Al-Jubail area, Arabian Gulf, Saudi Arabia. Mar. Poll. Bull. 128, 8–16.
Kesavan, K., Murugan, A., Venkatesan, V., et al., 2013. Heavy metal accumulation in molluscs and sediment from Uppanar Estuary. southeast coast of India. Thalassas 29 (2), 15–21.
Mansour, A.M., Nawar, A.H., Madkour, H.A., 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.
de Mora, S., Sheikholeslami, M.R., Wyse, E., Azemard, S., Cassi, R., 2004a. An assessment of metal contamination in coastal sediments of the Caspian Sea. Mar. Poll. Bull. 48, 61–77.
de Mora, S., Fowler, S.W., Wyse, E., Azemard, S., 2004b. Distribution of heavy metals in marine bivalves, fish and coastal sediments in the Gulf and gulf of Oman. Mar. Poll. Bull. 49, 410–424.
Moussa, A.A., El Askary, M.A., Nasr, S.M., Elmamoney, M.H., 1991. Unconsolidated reefal sediments in the Jubal Strait region. Red Sea, Egypt. Mar. Geol. 97, 379–390.
Okbah, M.A., Nasr, S.M., Soliman, N.F., Khairy, M.A., 2014. Distribution and concentration status of trace metals in the Mediterranean coastal sediments, Egypt. Soil and sediment contamination, Internat. J. 23 (6), 656–676.
Stauber, J.L., Florence, T.M., 1987. Mechanism of toxicity of ionic copper and copper complexes to algae. Mar. Biol. 94, 511–519.
Taylor, S.R., 1964. Abundance of chemical elements in the continental crust: a new table. Geochim. Cosmochim. Acta 28, 1273–1285.
Turekian, K.K., Wedepohl, K.H., 1961. Distribution of the elements in some major units of the earth's crust. Geol. Soc. Am. 72, 175–192.
Wu, P., Yin, A., Yang, X., Zhang, H., Fan, M., Gao, Ch., 2017. Distribution and source identification of heavy metals in the sediments of a river flowing an urbanization gradient, Eastern China. Environ. Earth Sci. 76, 745.
Youssef, M., El-Sorogy, A., 2016. Environmental assessment of heavy metal contamination in bottom sediments of Al-Kharrar lagoon, Rabigh, Red Sea, Saudi Arabia. Arab. J. Geosci. 9, 474.
Zhao, L., Xu, Y., Hou, H., Shangguan, Y., Li, F., 2014. Source identification and health risk assessment of metals in urban soils around the Tanggu chemical industrial district, Tianjin, China. Sci. Total Environ. 468–469, 654–662.
Zhaoyong, Z., Xiaodong, Y., Shengtian, Y., 2018. Heavy metal pollution assessment, source identification, and health risk evaluation in Aibi Lake of northwest China. Environ. Monit. Assess. 190, 69.