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Effects of Urbanization on the Heavy Metal Concentrations in the Red Sea Coastal Sediments, Egypt

Mohamed E.A. El-Metwally, Ahmed S. Abouhend, Mahmoud A. Dar, Khalid M. El-Moselhy
Division of Marine Environment, National Institute of Oceanography and Fisheries, Egypt
Corresponding email: khalidelmoselhy@yahoo.com
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Abstract The total concentrations of heavy metals (Cu, Zn, Pb, Cd, Fe, Mn, Ni and Co) were determined in surface sediments from the coastal area of the Red Sea in four cities (Ras-Gharib, Hurghada, Safaga, and Qusier). In all sediment samples, the mean concentration ranges in (μg/g) of the studied metals were 11.2-145.3, 14.2-225.5, 18.5-90.8, 1.4-5.6, 1373-31,089, 72.5-758.5, 15.3-65.7 and 10.2-26.3, respectively. The effects of population pressure and different activities on metal contamination were evaluated, and metals were grouped according to sources of contamination using Principal Component Analysis (PCA). Maritime activities in Hurghada showed highest risk of contamination with Cu, Zn and Pb, while the sediments of Safaga City showed highest contaminated with Fe and Mn. The sediments quality and ecological risk of heavy metals were assessed relating to the sediments background levels of metals and calculating contamination factor (CF), metal pollution load index (MPI), enrichment factor (EF) and geo-accumulation index (I_{geo}). Average values of EF showed that Pb and Cd were highly enriched from anthropogenic contamination. The recorded (I_{geo}) values of Co and Cd were categorized as moderately polluted, while Pb was strongly effective pollutant in the studied sediments.
Keywords Heavy metals; Pollution; Red Sea; Sediments; Ecological risk

Introduction

Marine coastal areas experience active land-ocean interactions. One of the important problems of this interaction is the ecotoxicological effect of heavy metals contamination in the coastal sediments (Amin et al., 2009). Most of the heavy metals discharged into coastal environment are deposited due to strong affinities for sediments particles (Abu-Hilal and Badran, 1990). Therefore, marine sediments are recognized as the ultimate reservoir for heavy metals in aquatic system (Gargouri et al., 2011). Enriched sediments with heavy metals pose a complex environmental problem; they can directly endanger marine organisms and human health through accumulation in food chain. Furthermore, when the environmental condition changes, metals could be released into water column again to cause secondary pollution (Hu et al., 2011).

Most tropical near-shore marine habitats have become under increasing pressure due to urban and industrial wastes, coastal constructions and recreational activities (McClanahan et al., 2000). The Red Sea is not exception; its environment has been considered for long time unpolluted, however due to rapid recreational and tourism activities in the last three decades, there is evidence of increased pollution in various locations (Hanna and Muir, 1990; El-Moselhy et al., 2014). Coastal regions, particularly, lagoons and tidal flat play major biological and environmental role for marine life and fisheries. However this zone is typically frail and sensitive to contamination. Increasing population, urban and industrial expands adjacent to these areas usually associated with higher threat from chemical contaminants on tropical marine ecosystem (Peters et al., 1997).

Although large parts of the Red Sea coastline are still undeveloped, other areas are facing increasing hazard from industrial and urban development. Principal anthropogenic pressure in coastal cities originated from oil production, desalination plants, untreated sewage, land reclamation and dredging and ship traffic (McClanahan et al., 2000; Bruckner et al., 2011). Evaluating the effects of anthropogenic influence is crucial for protection and sustainable management of the fragile aquatic system in the Red Sea. The concentrations of heavy metals in surface sediments of the Red Sea region have been determined in some previous studies (e.g., Hamed and El-Moselhy, 2000; Madkour and Dar, 2007; Mansour et al., 2013; El-Metwally, 2015; Dar et al., 2016). But the ecological risk of population expansion and anthropogenic activities of the coastal cities have not been evaluated.

The main objectives of this study are: 1) to provide preliminary data on the environmental conditions and to evaluate the risks of coastal cities expansion. 2) to perform a sediments quality assessment using geo-accumulation index (Igeo), enrichment factor (EF) and metal pollution index (PMI). 3) to identify major factors and characterize contamination in the coastal sediments using principal component analysis (PCA). In the study, we will determine heavy metal concentrations in densely populated, sparsely populated and undisturbed natural areas of Ras-Gharib, Hurghada, Safaga and Quseir Cities.

1 Materials and Methods

1.1 Area of study and sampling locations

A total of 12 sampling locations were selected along the Egyptian coastal area of the northern Red Sea "three locations in each city of Ras Gharib, Hurghada, Safaga and Quseir" (Figure 1). Ras Gharib is a small city on the Gulf of Suez. Its coastal area is affected by petroleum production and poorly treated sewage effluents. The 1st studied location (G1) is affected by the direct discharge of sewage, the 2nd location (G2) corresponded to a tidal flat in the center of the city. The 3rd location (G3) situated in front of an oil company and affected by limited public activities. Hurghada is the second largest city on the Egyptian Red Sea coast after Suez. The coastal area of Hurghada is under the stress from the large population, tourism industry including hotels, marinas, shipyards, and sedimentation from landfilling locations. The location (H1) is surrounded by a small population area and influenced by the sedimentation from landfilling operations in the north of the city. (H2) is located in the center of the tourist area; the site is between the shipyard area, marina and fishing boats, in addition, it was previously received domestic wastewater from the center of the city. The location (H3) is restricted to touristic activity including several ships and hotels. The anthropogenic activities in Safaga City are related to transportation and shipping activities in addition to tourism. The location (S1) is covering the main marina of touristic boats and small ships, (S2) adjacent to site used for shipping of phosphate, (S3) is undisturbed mangrove swamp area. Quseir is an old city, previously was relying on fishing and shipping of ores especially phosphate ore, and recently limited tourism industry is introduced. The studied location (Q1) is affected by a small touristic village. The location (Q2) is at the old port that was previously used for shipping of phosphate. (Q3) is a reference undisturbed site at the southern part of the city.

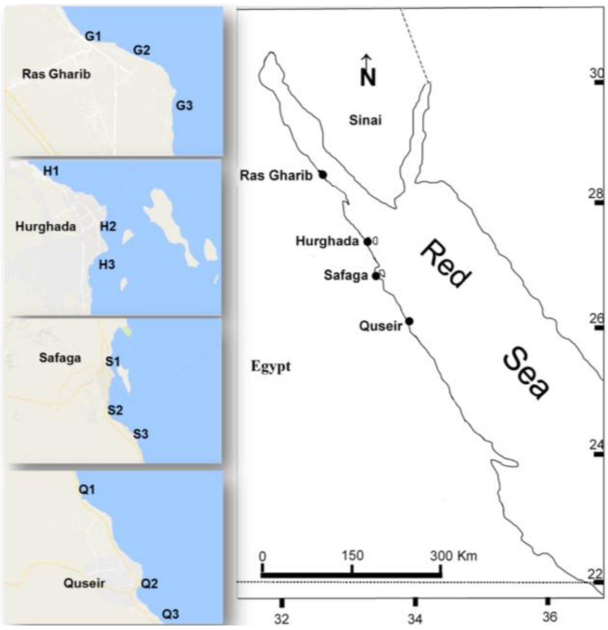

Figure 1 Sampling locations at different cities, Red Sea, Egypt

1.2 Sampling and analysis

A total of 36 recent surface sediment samples (0-10 cm depth) were collected during summer 2015 from the near-shore zone using plastic spatula. Sediments were transported cooled in polyethylene bags. In the laboratory, sediments were dried to constant weight, disaggregated and fractionated through stainless sieves. Because most bioavailable metals were principally associated with fine grains (Salomons and Forstner, 1984), the < 63µm fraction was used for this study.

A mixture of concentrated nitric, percholoric and hydrofluoric acid (3:2:1 in volume) were added to about 0.5 g of each sediment samples in Teflon cups, and left for 12 hours before complete digestion at 100 ℃ (Oregioni and Aston, 1984). The residue was diluted to 25 ml with deionized water, and filtered using Whatman filter paper. The resulted solution was analyzed for metals using atomic absorption spectrophotometer (AAS, GBC 932A). The results were obtained in µg/g. For quality control, all reagents and chemicals were of high analytical grads. Glassware was soaked in 10% nitric acid and rinsed with distilled water prior to use. Samples were measured against acid blank. For accuracy, the method was verified by analysis of replicate measurements for the studied metals in a sample of sediments. A satisfactory performance was obtained within the precision range of 6.2-14.8% for all studied metals.

1.3 Statistical analysis

The results were subjected to one-way analysis of variance (ANOVA) to test significant differences between sites. Assumption of homogeneity (Batlett's test) and normality (Shapiro-Wilk test) of data were assessed prior to ANOVA, then Duncan's multiple range test was used to further determine the position of the variance. For multivariate analysis, Pearson's correlation and principal component analysis (PCA) were conducted. Statistical analysis was carried out using software packages SPSS 18.0 for windows.

1.4 Assessment of sediments quality

To interpret and assess the status of metal contamination in sediments, metal levels were compared to the background levels of heavy metals recorded by Hanna (1992) in sediments of the Red Sea (collected during 1943), and with the global standard shale values (Forstner and Wittmann, 1979). The contamination condition was also evaluated by metal assessment indices: contamination factor (CF), metal pollution load index (MPI), Enrichment factor (EF) and geo-accumulation index (I_{geo}). These indices were widely used to describe the contamination condition of surface sediments in aquatic environment (Chen et al., 2007).

The contamination factor (CF) is the ratio obtained by dividing the concentration of each heavy metal in the sediments ($C_{heavy\ metal}$) by the concentration in the background ($C_{background}$). In our study, the mean results of Hanna (1992) for sediments collected from the Red Sea during 1943 were used for calculating the background values:

$$CF = C_{heavy\ metal}/C_{background}$$

The overall effect of heavy metals in sediments was estimated by metal pollution load index (MPI) that proposed by Tomlinson et al. (1980). The MPI is a simple comparative way obtained from the mutual effects of all studied metals with respect to the background values and calculated from the formula:

$$MPI = (CF_1 x CF_2 x CF_3 \ \dots\dots \ x CF_n)^{1/n}$$

EF was efficiently used to differentiate between naturally and anthropogenic source of metals. Where metals (M) were normalized to the textural characteristics of the sediments according to the formula:

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

According to Zhang and Liu (2002), the heavy metals are largely from natural sources (crustal materials) when the EF below 1.5 (i.e. $0.5 \le EF \le 1.5$), but when EF value is greater than 1.5 ($EF > 1.5$), the significant portion of heavy metals originated from anthropogenic sources.

The geo-accumulation index (I_{geo}) used to estimate the pollution condition of metals in sediments based on comparing current state with the preindustrial levels. This index was defined by Muller (1979) as the following equation:

$$I_{geo} = Log_2[C_n/(1.5 \, x \, B_n)]$$

Where C_n is the measured metal concentration, and B_n is the background level. The pollution extent could be classified according to the scale proposed by Muller (1981) who distinguished seven classes of contamination (Table 1).

Table 1 Classification of geo-accumulation index (I_{geo}) (Muller, 1981)

I_{geo} value	Class	Sediments quality
<0	0	Unpolluted
0–1	1	Unpolluted to moderately polluted
1–2	2	Moderately polluted
2–3	3	Moderately to strongly polluted
3–4	4	Strongly polluted
4–5	5	Strongly to very strongly polluted
>5	6	Very strongly polluted

2 Results and Discussions

2.1 Total concentrations of heavy metals

Mean concentrations of heavy metals in the surface sediments are shown in Table 2. Overall collected samples, the mean of metal concentrations ranged from 11.2 to 145.3, 14.2-225.5, 18.5-90.8, 1.4-5.6, 1373-31089, 72.5-758.5, 15.3-65.7 and 10.2-26.3 µg/g for Cu, Zn, Pb, Cd, Fe, Mn, Ni and Co, respectively. Regarding the order of metal abundance, average concentrations of metals were found in following order: Cd (3.5) < Co (15.6) < Ni (32.0) < Cu (41.3) < Pb (46.7) < Zn (58.4) << Mn (277.4) <<< Fe (10,603 µg/g).

Table 2 Mean of heavy metals concentrations (µg/g) in surface sediments from different locations

Location	Cu	Zn	Pb	Cd	Fe	Mn	Ni	Co
G1	25.0±7.2	34.3±17.7	32.7±5.4	3.2±0.6	5289±820	148.3±81.3	24.0±4.4	13.7±1.2
G2	22.1±2.7	31.1±11.0	39.4±8.8	3.4±0.8	4128±868	129.8±92.8	22.1±2.6	13.6±1.4
G3	25.1±10.4	24.9±11.2	46.0±4.7	4.0±0.6	3324±1309	135.3±64.2	18.3±2.1	13.8±1.7
H1	38.6±19.3	47.5±15.4	45.5±8.7	3.6±0.5	8258±2716	250.3±88.1	28.4±6.1	14.8±1.4
H2	106.8±30.5	174.2±36.1	76.1±11.4	4.4±0.9	10984±2112	214.3±20.8	38.4±14.5	14.3±3.0
H3	45.4±27.7	39.9±17.0	49.5±11.2	3.1±0.5	6861±317	161.9±61.0	22.2±3.9	14.3±3.2
S1	74.5±34.4	73.3±23.6	56.4±13.8	3.5±0.4	17998±5490	378.5±187.8	38.4±17.8	19.1±5.4
S2	34.3±9.8	70.2±20.8	46.7±11.8	4.3±0.5	16436±2120	470.0±89.3	34.6±7.1	14.0±2.0
S3	28.8±14.5	46.6±19.5	30.9±13.0	2.7±0.3	19296±8007	536.7±203.0	35.1±6.0	19.2±4.7
Q1	24.9±13.8	32.4±23.1	49.1±10.5	1.9±0.5	5258±1885	185.2±48.2	27.9±9.8	14.5±3.5
Q2	43.5±9.9	88.2±19.4	54.8±16.0	5.1±0.5	17676±1052	431.0±123.1	58.9±7.4	20.4±2.5
Q3	26.1±8.3	37.9±6.8	33.7±12.1	2.9±1.1	11731±1960	288.1±44.0	35.7±7.3	15.2±5.7
Average	41.3	58.4	46.7	3.5	10603	277.4	32.0	15.6
Max.	106.8	174.2	76.1	5.1	19296	536.7	58.9	20.4
Min.	22.1	24.9	30.9	1.9	3324	129.8	18.3	13.6

Variations in metal concentrations along studied locations were considerable. Table 3 shows ANOVA results for significant differences between locations. As shown in Figure 2, Cu recoded highest concentrations in H2 (106.8±30.5 µg/g) followed by S1 (74.5±34.4 µg /g) which corresponded to the stations of Hurghada Port area and Safaga Marina, respectively. Other stations were significantly lower than those values. Similarly, significant high levels of Zn were recorded in Hurghada port (H2), (174.2±36.1 µg/g), which is high with about two times the concentrations in other locations. Apparently, this high sedimentary Zn and Cu in the port (and partially in marina) is attributed to the antifouling paints from the boats and the nearby shipyard. Copper and zinc-based antifouling paints have been widely identified as major source of these metals in estuaries and harbours (Chouba and Mazoughi, 2013). A significant high Zn concentration was also observed in Qusier harbour (Q2) (88.2±19.4 μg/g), which was due to the past sedimentation of raw materials during the shipping operations. Phosphate rock, particularly, contains considerable amounts of Zn and Cd as impurities (McMurtry et al., 1995).

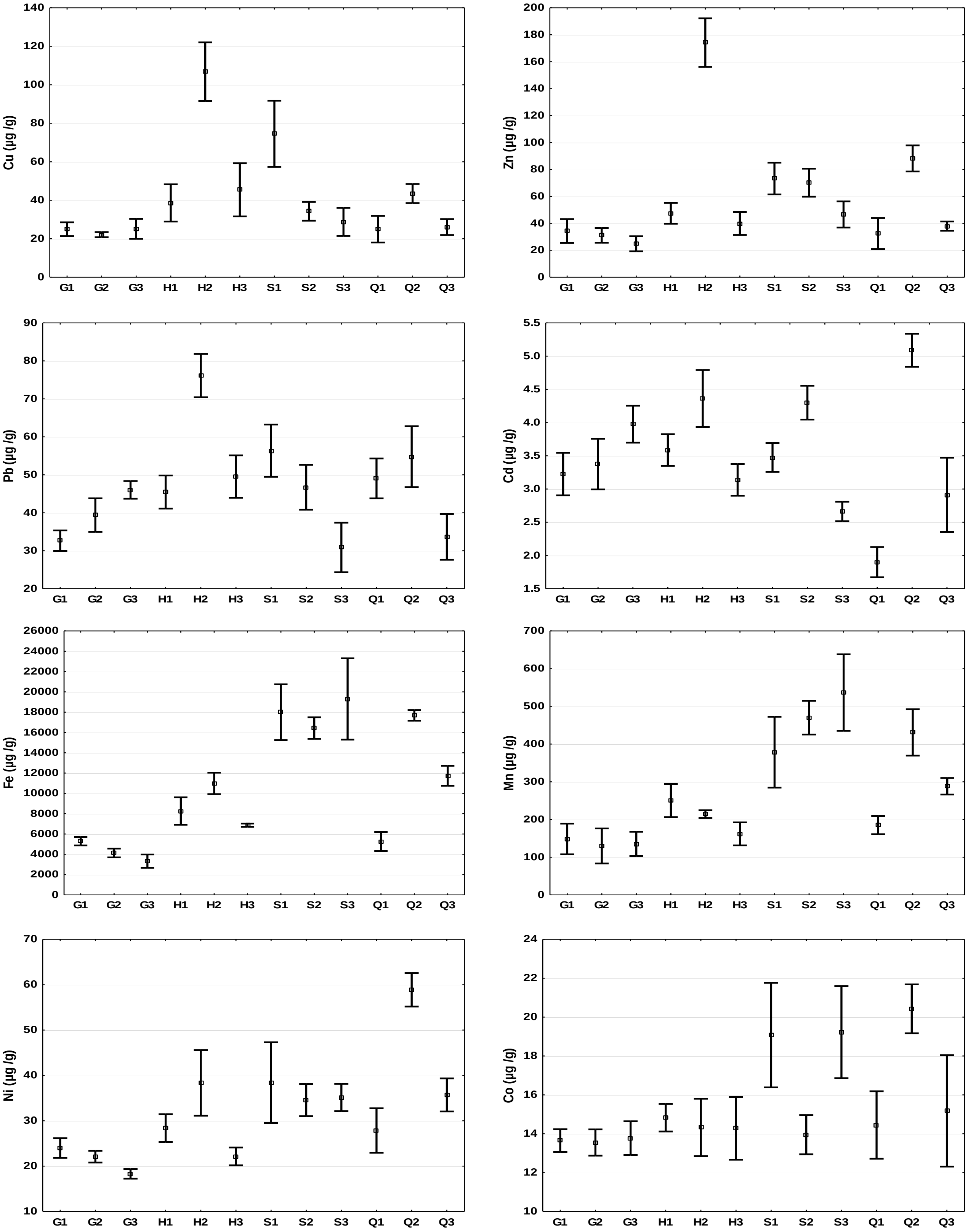

Figure 2 Mean ±SE of heavy metals (μg/g) in sediments from different study sites

Table 3 One way ANOVA showing variations in metals between locations

	df	F	P
Cu	11	7.5	<0.001
Zn	11	17.4	<0.001
Pb	11	5	<0.001
Cd	11	7.4	<0.001
Fe	11	13.8	<0.001
Mn	11	7.2	<0.001
Co	11	2.2	0.07

The levels of Pb, Cd and Ni showed narrow but significant variations between locations. Pb ranged between 30.9±13.0 µg/g in Mangrove sediments (S3) and 76.1±11.4 µg/g in Hurghada port (H2). Concentrations of Cd ranged from 1.9±0.5 µg/g in (Q1) to 5.1±0.5 µg/g in the old port (Q2). Nickel values were ranged between 18.3±2.1 in (G3) and 58.9±7.4 µg/g in (Q2). Although, variations of Co between locations were not significant, there was a higher trend of Co in (S1), (S3) and (Q2). The range of Co values in different locations was 13.6-20.4 µg/g.

As shown in Figure 2, the spatial distribution of Fe and Mn was quite similar. Different stations of Ras Gharib (G1, G2 and G3) significantly recorded low levels of Fe and Mn. In contrast, Safaga locations recorded highest levels of them. The sediments content of Mn varied between 129.8 and 536.7 µg/g while the for Fe was 3324-19296 µg/g. Association of Fe and Mn in rocks is well known; Mn is present in divalent state associated with ferromagnesium and accessory iron minerals (Madkour, 2005). Therefore, they are terrigenous origin and move to marine environments through various ways.

Comparing our data with the background levels of metals (average shale and background levels in the Red Sea) (Table 4) indicated that, all studied metals were above the background levels of Red Sea sediments (Hanna, 1992), whereas, the concentrations of Cu, Zn, Cd, Pb and Fe were generally above the levels of average shale (Forstner and Wittmann, 1979). The present data were also compared to levels for marine sediments from other locations worldwide. The concentrations of Cu, Zn, and Pb in the sediments collected from the tidal flats of coastal cities of Red Sea were lower than those recorded in sediments from other tropical regions like Singapore coast, Shanghai tidal flat, Korean coast (Table 4). However the concentration of Cd as well as Zn, Cu, Pb (in sites H2 and Q2) were higher than those reported in unpolluted marine sediments around the world.

Table 4 Levels of heavy metals in Red Sea sediments and other tropical locations worldwide comparing to background concentrations

Location	Cu	Zn	Pb	Cd	Fe	Mn	Ni	Co	References
Coastal sediment, Singapore	12.8-118.3	43.1-370.5	1.1-6.1	0.16-0.73			7.2-60.7		Cuong et al., 2008
Shanghai tidal flat	91-351	189-828	47-149	0.03-0.1					Chen et al., 2001
Tidal flat, coastal area, Korea	8.3-164.4	45.5-225.9	25-360	0.07-0.43			5.2-33.4		Na and Park, 2012
Korean coast	5.1- 91.2	26.5-233	21.1- 56	0.07-1.02			10-38.4	4.8-13.9	Ra et al., 2013
Shantou Bay, China	24.4-79.3	84.9-246.5	35.6-64.8	0.3-1.74	29300 - 39300	428-809	16.9-31.5		Qiao et al., 2013
Safax coast, Tunisia	13-29	39-117	18- 88	5.5-7	41011 - 50163				Gargouri et al., 2011
North Gulf of Suez	1.84-10.25	4.26-23.68	13.9-28.3	2.3-4.4					El-Moselhy and Gabal, 2004
Aqaba Gulf, Jordan	7.14-24	24-195	96.3-182	3.9-13.7	3400 - 14600	68.2-263	24-195		Abu-Hilal et al., 1988

Continued Table 4

Location	Cu	Zn	Pb	Cd	Fe	Mn	Ni	Co	References
Red Sea coastal area	22.1-106.8	24.9-174.2	30.9-76.1	1.9- 5.1	3324 - 19296	129.8-536.7	18.3-58.9	13.6-20.4	present study
Red Sea background	17.6	24	3	0.4	3000	116	16	3	Hanna, 1992
Average Shale	45	95	20	0.3		850	68	19	Forstner and Wittmann, 1979

2.2 Correlations between metals and PCA

The correlation matrix (Table 5) showed that a strong significant positive correlation (0.76 < r < 0.84) was obtained between metal pairs Zn, Cu and Pb, as well as between Fe and Mn. The levels of Ni also correlated significantly with Zn (r=0.59), Fe (r=0.55) and Mn (r=0.63). The correlation between metals in surface sediments usually related to discharging of contaminants and their effect on partitioning of metals in aquatic system and may be influenced by differences in physical, chemical and biological processes in aquatic environment (Usman et al., 2013).

Table 5 The correlation coefficient among heavy metals in sediments

	Cu	Zn	Pb	Cd	Fe	Mn	Ni	Co
Cu	1.00							
Zn	0.84**	1.00						
Pb	0.77**	0.78**	1.00					
Cd	0.32	0.45	0.34	1.00				
Fe	0.26	0.33	0.04	0.20	1.00			
Mn	0.18	0.32	0.18	0.11	0.76**	1.00		
Ni	0.37	0.59**	0.44	0.42	0.55**	0.63**	1.00	
Co	-0.10	0.03	-0.09	0.12	0.48	0.29	0.26	1.00

Note: ** Two-tailed correlation significant at $p \leq 0.01$

Principal component analysis (PCA) was performed to elucidate potential sources of metals in the present study. The results showed two principal components with eigenvalues > 1; they accounted for 67.27% of the total variance. Factor one (accounting for 42.05%) grouped Cu, Zn, Pb and Ni. As shown in PCA bi-plot (Figure 3), the sites associated with this factor were mainly those which experienced sever maritime activities (H2, S2) which suggest the anthropogenic sources of these metals. The second factor (accounting for 25.22% of total variance) grouped Fe, Mn and partially Co. The spatial distribution of these metals was related to locations of Qusier and Safaga Cities. On the other hand, the reference location and Ras Gharib locations were in the fourth quarter of the bi-plot which indicates relatively low contribution of heavy metals (Figure 3).

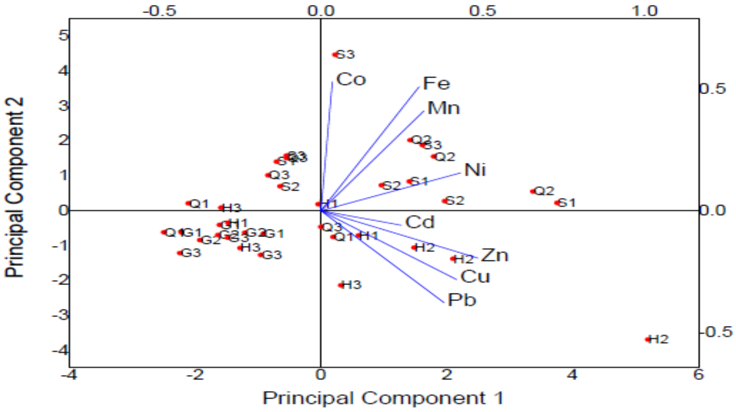

Figure 3 Principal component bi-plot showing variables and sampling locations

2.3 Metal pollution index (MPI), Contamination Factor (CF), Enrichment factor (EF) and geo-accumulation index (I_{geo})

Table 6 presents the results of CF and MPI values. The highest contamination (i.e., CF value) for Cu, Zn and Pb was found in the locations (H2). Highest CF for Cd, Ni and Co was found in site (Q2). While the CF values of Fe and Mn indicated high contamination in all sites of Safaga. Regarding the integrated effect of metals, values of MPI in the present study ranged from 2.5 to 2.7 in Ras Gharib, 3.2-5.6 in Hurghada, 4.2-5.3 in Safaga, and 2.8-5.7 in Qusier. These results indicated lowest contamination effects of heavy metals in Ras Gharib City.

Table 6 Contamination Factor and MPI in different sites

Locations	CF								*MPI*
	Cu	Zn	Pb	Cd	Fe	Mn	Ni	Co	
G1	1.42	1.43	10.88	8.06	1.76	1.28	1.50	4.55	2.69
G2	1.26	1.30	13.13	8.44	1.38	1.12	1.38	4.52	2.54
G3	1.43	1.04	15.34	9.94	1.11	1.17	1.14	4.59	2.50
H1	2.19	1.98	15.15	8.97	2.75	2.16	1.77	4.94	3.64
H2	6.07	7.26	25.38	10.91	3.66	1.85	2.40	4.78	5.58
H3	2.58	1.66	16.51	7.84	2.29	1.40	1.38	4.76	3.22
S1	4.23	3.05	18.78	8.69	6.00	3.26	2.40	6.36	5.31
S2	1.95	2.93	15.57	10.75	5.48	4.05	2.16	4.65	4.63
S3	1.63	1.94	10.29	6.66	6.43	4.63	2.20	6.41	4.17
Q1	1.42	1.35	16.35	4.75	1.75	1.60	1.74	4.82	2.77
Q2	2.47	3.67	18.26	12.72	5.89	3.72	3.68	6.81	5.73
Q3	1.48	1.58	11.22	7.28	3.91	2.48	2.23	5.06	3.47

The enrichment factor (EF) values for heavy metals in sediments are presented in Table 7. The average values of Cu, Zn, Mn and Ni were < 1, indicating weak enrichment; while Pb and Cd (6.01 and 3.38, respectively) showed the highest enrichment in Red Sea sediments. EF index was generally applied to predict the source of heavy metals (naturally or anthropogenic). Therefore, Pb and Cd in the present study were generally enriched from anthropogenic sources. Also, a significant portion of Cu, Zn, Pb and Cd in the location (H2) in Hurghada are due to anthropogenic contamination. Although the total levels of heavy metals in Ras Gharib were generally low, the EF showed that the highest portion of Pb, Cd and Co in Ras-Gharib sediments originates from anthropogenic (non-terrestrial) sources.

Table 7 Enrichment Factor (EF) of heavy metals from different sites on the Red Sea

Locations	Cu	Zn	Pb	Cd	Mn	Ni	Co
G1	0.80	0.81	6.17	4.57	0.72	0.85	2.58
G2	0.91	0.94	9.54	6.13	0.81	1.00	3.28
G3	1.29	0.93	13.84	8.97	1.05	1.03	4.14
H1	0.80	0.72	5.50	3.26	0.78	0.64	1.80
H2	1.66	1.98	6.93	2.98	0.50	0.65	1.30
H3	1.13	0.73	7.22	3.43	0.61	0.61	2.08
S1	0.71	0.51	3.13	1.45	0.54	0.40	1.06
S2	0.36	0.53	2.84	1.96	0.74	0.39	0.85
S3	0.25	0.30	1.60	1.03	0.72	0.34	1.00
Q1	0.81	0.77	9.33	2.71	0.91	0.99	2.75
Q2	0.42	0.62	3.10	2.16	0.63	0.62	1.16
Q3	0.38	0.40	2.87	1.86	0.64	0.57	1.29
Average	0.79	0.77	6.01	3.38	0.72	0.68	1.94

Table 8 presents the values of I_{geo} in different locations. According to the Muller's (1981) scale, the average values indicated non contaminated sediments with Cu, Zn, Fe, Mn and Ni, but was moderately polluted with Co, Cd and moderately to strongly polluted with Pb. Regarding regional distribution, the port area of Hurghada (H2) showed moderately pollution with Cu, Zn, Cd, Co, Fe and strongly polluted with Pb.

Table 8 Geo-accumulation index of heavy metals from different locations on the Red Sea

Locations	Cu	Zn	Pb	Cd	Fe	Mn	Ni	Co
G1	-0.08	-0.07	2.86	2.43	0.23	-0.23	0.00	1.60
G2	-0.25	-0.21	3.13	2.49	-0.12	-0.42	-0.12	1.59
G3	-0.07	-0.53	3.35	2.73	-0.44	-0.36	-0.39	1.61
H1	0.55	0.40	3.34	2.58	0.88	0.52	0.24	1.72
H2	2.02	2.27	4.08	2.86	1.29	0.30	0.68	1.67
H3	0.78	0.15	3.46	2.39	0.61	-0.10	-0.12	1.67
S1	1.50	1.03	3.65	2.53	2.00	1.12	0.68	2.08
S2	0.38	0.96	3.38	2.84	1.87	1.43	0.53	1.63
S3	0.12	0.37	2.78	2.15	2.10	1.62	0.55	2.09
Q1	-0.08	-0.15	3.45	1.66	0.22	0.09	0.21	1.68
Q2	0.72	1.29	3.61	3.08	1.97	1.31	1.29	2.18
Q3	-0.02	0.08	2.90	2.28	1.38	0.73	0.57	1.75
Average	0.46	0.47	3.33	2.50	1.00	0.50	0.34	1.77

3 Conclusions

Studying the concentrations of heavy metals in coastal sediments of the Red Sea showed that, intensive maritime activities in the inter-harbour zone and marinas had significant effects on the levels of Cu, Zn and Pb in sediments. The concentrations of Fe and Mn recorded highest values in Safaga City which was originated from terrigenous sediments. Lower levels of heavy metals were observed in Ras Gharib City indicating inferior effect of oil industry on metal contamination. The recorded levels of heavy metals in present study were higher than the background values in sediments. However average metal values of current study were lower than those recorded in other tropical regions around the world. According to enrichment Factor (EF), considerable portion of Pb and Cd are likely from anthropogenic contamination. Regarding the (I_{geo}), levels of Co and Cd considered moderately polluted sediments, while Pb revealed strong polluted sediments.

Authors' contributions

Mohamed E.A. El-Metwally contributed to the paper by collecting samples, analyses, processing the data, and writing the manuscript. Ahmed S. Abouhend contributed to the paper by collecting samples and analyses. Mahmoud A. Dar contributed by analyses and lab management. Khalid M. El-Moselhy contributed by processing the data and revising the manuscript.

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