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RESEARCH ARTICLE

Comprehensive pollution monitoring of the Egyptian Red Sea coast by using the environmental indicators

Hamdy El Sayed Nour[1] · El Said Nouh[2]

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Abstract

The environmental pollution indicators and multivariate statistical analysis were used to evaluate the potential ecological risk and the contamination of Fe, Mn, Zn, Ni, Pb, Cu, Cd, and Co in surface sediments of the Egyptian Red Sea coast. The results revealed that the studied area suffers from high contamination of certain metals such as the Hurghada area (Pb, Cd, Zn, Ni, and Cu), Quseir City area (Cd, Co, Pb, and Ni), and Safaga and Marsa Alam areas (Cd and Pb). Enrichment factor and principal components analysis reported that the pollution sources of Fe, Mn, and Co are related to natural weathering process while Cu, Zn, Ni, and Pb are related to anthropogenic sources as landfill, plastic rubbish, fishing boats, phosphate operations, and tourist activities. Moreover, Co and Cd metals can come from both of natural and anthropogenic sources. The average concentrations of Cd, Cu, Zn, Pb, Ni, and Co in sediments of the Egyptian Red Sea coast are higher than those in the coasts of the Red Sea (Saudi Arabia), Mediterranean Sea (Egypt and Libya), Bengal bay (India), and the Caspian Sea (Russia). However, the studied metal content is lower than the sediment quality guideline values except for Cd.

Keywords Pollution monitoring · Red Sea · Environmental indicators · Sediments · Egypt

Introduction

All living organisms need a specific amount of trace metals in order to perform their vital functions. However, any increase in these proportions more than the permissible limits will lead to high risk to their health (Chapman 2007; Qing et al. 2015). Sediments can accumulate and store trace metals for a long time, which can cause negative effects on ecosystems and human health (Kaushik et al. 2009; Shang et al. 2012). Recently, the environmental researchers have done collective efforts to save our planet from the risk of contamination. They became interested in environmental monitoring studies of the marine environment, which are based on the detailed study of a specific area, either by evaluating the quality of coastal sediments (Chen et al. 2007; Özseker and Erüz 2011; Wang et al. 2018, Nour 2019a), seashells (Ziko et al. 2001; Ali et al. 2011; El-Sorogy et al. 2012,2013; Abdo et al. 2017), and/or water (Brewer et al. 1969; Wu et al. 2015; Nour 2015; El-Sorogy and Attiah 2015).

However, the present work is a general insight which aims to establish a comprehensive environmental assessment of the potentially toxic metals and their sources in several sites within the four major cities along the Egyptian Red Sea coast through the use of several important environmental indicators. Moreover, the current pollution status of the studied area will be compared along with other worldwide coasts and also compare them to the geochemical background of metal content. The periodic monitoring of the concentration of trace elements in the sediments of the Egyptian beaches is very important because it indicates the environmental status of these beaches, and these results may indicate the necessity of conducting more detailed studies for some sites that may be suffering from the presence of more pollutants. In addition, this data is a basic for continuous monitoring of environment because of its crucial importance to the health of the marine ecosystem and also to human health.

Several environmental monitoring studies have demonstrated the importance of the environmental indicators in assessing the impacts and the sources of pollutants, and it

Responsible editor: Vedula VSS Sarma

✉ Hamdy El Sayed Nour
nour_geo@yahoo.com

[1] Geology Department, Faculty of Science, Zagazig University, Zagazig, Egypt

[2] Egyptian Nuclear Material Authority, Cairo, Egypt

confirmed that these indicators are the ideal way to monitor environmental pollution (Yu et al. 2011; Dung et al. 2013; Nour 2019b). These environmental indicators depend on the geochemical background in their assessment of the degree of pollution, which may be the average concentration of the elements in shale in the Earth's crust (Turekian and Wedepoh 1961) as in the case of measuring the geo-accumulation index, the enrichment factor, contamination factor, and potential contamination index, whereas in the case of soil pollution index, the permissible levels of metals in sediments (USEPA 1983) were used as geochemical background.

The Egyptian Red Sea coast extends for almost 1250 km from Suez to the Sudanese border. Marine environment is very important to humans because it provides them food resources and ecosystem services. However, human activities usually result in negative impacts on the marine ecosystem. Therefore, the periodic monitoring processes have become very important to predict and provide solutions. The sources of pollution along the Red Sea coast vary from natural to anthropogenic sources. Industrial activities, petroleum industries, urban development, tourism activities, fishing, shipping, resorts, and harbor activities are the common pollution sources. In addition, the erosion of rocks for the hinterland mountains, especially during the periods of flooding is considered a remarkable cause of such a problem. The distribution of the potentially toxic metals in sediments of the Red Sea coast can provide us with valuable information about the environmental condition of the ecosystem (Mansour et al. 2011; Attia and Ghrefat 2013; Nour et al. 2018). Certainly, surface sediments in each site contain different proportions of trace metals, which can indicate the degree of pollution and its sources, and also the related effects on the ecosystem (Zhang et al. 2014). Therefore, the study of the distribution of potentially toxic metal concentrations and their related ecological risk in the sediments is pivotal to recognize the degree of trace metal pollution in the environment which is directly related to human activities (Song et al. 2014; Nour et al. 2019).

Materials and methods

Study area

The present study is concerned with four major cities on the Egyptian Red Sea coast, including 22 sampling sites with a total length of 290 km, extending from Hurghada youth hostel to 30 km south Marsa Alam. These sites were specifically selected to cover the most important localities along the western coast of Red Sea (Figs. 1 and 2). Moreover, this area has shown extensive development in the recent decades on the eastern coast of Egypt. Sampling locations were identified with the global positioning system (GPS).

(1) The Hurghada area was a small fishing city. Nowadays, it can be considered the largest Egyptian resort city in the Red Sea. It includes five sampling sites: youth hostel site which has a rocky and sandy beach surrounded by Pleistocene raised reefs; the Marine Museum, which has a sandy beach rich in a different collection of marine shells; the Public beach site that has about 20 m of raised reef and intensive landfill in addition to the common marine fauna; Magawish village site which has a sandy beach with some plastic rubbish; and Makadi bay site having a fine sandy beach. This bay was partially separated from the open sea by a sand bar in addition to few landfills of tourist buildings. (2) Safaga city is located 60 km south Hurghada. It is a tourist and industrial area on the Red Sea coast where it has several tourist resorts, marine port, and phosphate port. The Safaga area includes six sampling sites: Suma bay site has three units of raised reefs on the beach with highly calcareous sand formed from reef debris; North Safaga bay site has a sandy beach poor in marine skeletons; South Safaga bay site has a shoreline delineated by ill-sorted gravels, angular basement fragments, and overlaid by a landfill of older raised reefs in the west; Umm El Huweitat site has a sandy beach rich in *Sorites* tests; Wadi Jasus site has some raised reefs on the beach with sands. Lastly, Kalawy bay site has a reefal beach, characterized by high diversity of recent gastropod shells. (3) Quseir City located 135 km south of Hurghada. It is a tourist city, where scuba diving and snorkeling are popular. This area includes five sampling sites: 25 km north Quseir site has sandy beach; El-Hamrawein port site has raised reefal beach and this site is a phosphate ore shipping port; Quseir City site has sandy beach; 9 km south Quseir site has a muddy reefal beach and large numbers of live *Chama* sp., which can distinguish this shore especially during the low tide. In the end, 24 km south Quseir site has raised reef beach with many tidal channels. (4) Marsa Alam city is located 265 km south Hurghada. It is a tourist area and includes six sampling sites: 30 km north Marsa Alam site has flattened recent raised reefs covered by thin sands and characterized by enormous amounts of living *Modiulus* sp. which arranged around older heads of coral reefs; 19 km north Marsa Alam site has open sea beach with consolidated rocky shore overlaying the young raised reefs; Marsa Alam city site has a sandy beach with some variety of rock fragments; 8 km south Marsa Alam site has a sandy beach; 20 km south Marsa Alam site has a sandy beach; and 32 km south Marsa Alam site has a rocky coralline flattened beach.

Geology of the study area

There are several geological studies on the Egyptian Red Sea coast (El-Akkad and Dardir 1966; Said 1990;

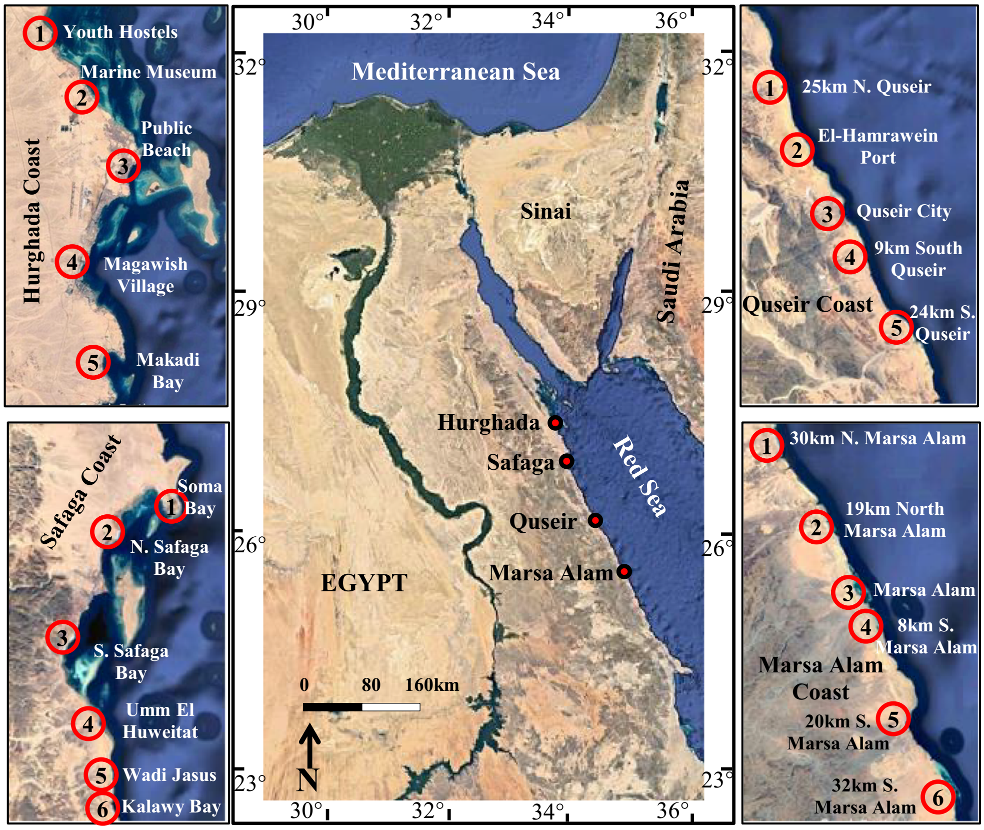

Fig. 1 The location and sampling map of the studied sites

Khalil and McClay 2009). The sedimentary rocks of the Hurghada area consist of Quaternary deposits found as recent gravels and Pleistocene coral reefs (Hume 1916), while the rocks on the coastal plain of the Safaga area range in age from Miocene to Quaternary (El-Asmar and Abel-Fattah 2000). The Quseir area contains

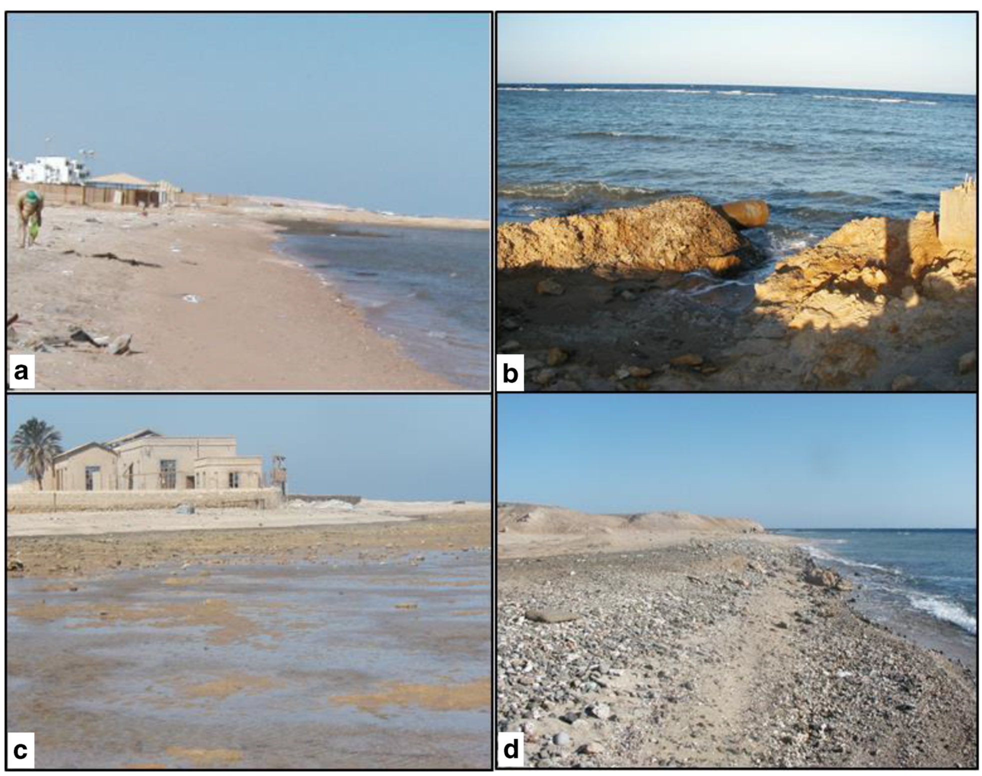

Fig. 2 Different sources of pollutants along the Red Sea coast. **a** Tourist activity (Hurghada area), **b** industrial sewage (Safaga area), **c** urban activities (Quseir area), and **d** rock fragments (Marasa Alam)

sedimentary beds of Miocene evaporite series, Pliocene *Clypeaster-Laganum* series, and oyster and Pleistocene terraces raised beaches (Said 1990). El Bassyony (1982) studied the exposed sedimentary rocks in the area between Quseir and Mersa Alam and subdivided the sequence into recent coral reefs, gravel terraces and Wadi alluvial deposits, Pleistocene Um Gheig and Wizr formations, Pliocene Shagra and Gabir formations, and Middle Miocene Samh, Abu Dabbab, and Gebel El-Rusas formations.

The main sources of sediments to the Egyptian Red Sea coast are the terrigenous rock fragments transported from the hinterland mountains during the occasional run-offs through the numerous wadis and from skeletal carbonates from the sea (El Mamoney and Rifaat 2001). The type and composition of rocks nearby the sea coast, wave movement and coastal currents, and the conditions of sedimentation environment have been controlling the distribution of sediments in the coastal area (EL-Wekeil et al. 2012). The beach sediments in the studied area are poorly sorted and consist of marine shells, coarse sand, rock fragments, sea grass, and mud. These sediments are mineralogically composed of a mixture of carbonates and siliciclastic grains (Mansour et al. 2000). The coastal plain in the studied area varies from place to place in width, sediments, and topography. Coastal plain in the Hurghada area averages about 30 km, then it narrows till reaching less than 5 km in the area from Safaga to the south of Marsa Alam.

According to the type of shore materials, the shoreline in the studied area could be classified into the following types: (i) Reefal beaches, which are composed of hard, massive algal coralline limestone of the youngest Pleistocene coral reef as in Soma bay, 24 km south Quseir, 30 km northern Mersa Alam, 19 km north Mersa Alam, and 32 km south Mersa Alam. (ii) Gravelly beaches have been formed of non-consolidated pebbles to cobbles of different origin (basement and sedimentary rocks). These clasts are transported to the shore from the hinterland mountains as in Safaga area. It is noted that the gravelly beaches of basement origin decrease southwards. (iii) Sandy beaches are mostly present along the entrances of large wadis and formed friable sandy and locally gravelly sediments as well as shell fragments. They are drifted by storms and high tide above these beaches as 25 km north Quseir, Quseir City, and 19 km north Mersa Alam. (iv) Man-made beaches are local landfill beaches formed of moderate to huge concrete masses, rock fragments, mining products, and sands. They are present around the main cities as a wave break to protect buildings from high storms. Also, they are used to make artificial lagoons and pools in tourist villages and resorts and as platforms in harbors. There are also some man-made modifications in many parts of the studied shore, e.g., construction remnants and waste accumulation of different origins, shapes, and sizes (plastic, wood, metals, concrete, tar balls, and sheets). These wastes change locally the nature of the shoreline, as the presence of local hard substrates in a sandy shoreline affects the structure of the natural community. Man-made beaches are represented along the coast by the following localities: Magawish village, Makadi bay and El-Hamrawein.

Analytical procedures

Samples of 44 surface beach sediments were collected by using a plastic box (0–10 cm) depth from the beach of four major cities (10 samples from Hurghada area, 12 samples from Safaga area, 10 samples from Quseir area, and 12 samples from Marsa Alam area) along the Egyptian Red Sea coast from lat. 27° 17′ 09″ N, long. 33° 46′ 07″ E to lat. 24° 4′ 16″ N, long. 35° 04′ 02″ E, whereas two surface sediment samples were collected from each site. Each time the plastic box was washed with distilled water before taking the sample to prevent mixing of the samples. Each sediment sample was placed in a separate plastic bag and the site data were written on it. In the laboratory, sediment samples were washed with distilled water and dried at room temperature. About 5 g of each sample was grounded in an agate mortar. According to Oregioni and Astone (1984), an acidic mixture of 15 ml nitric acid, 10 ml perchloric acid, and 5 ml hydrofluoric acid was used to digest about 0.2 g of each powder sample. This solution was diluted to double with distilled water and then filtered. The mentioned solution was then ready to measure trace metal concentrations (Fe, Mn, Cu, Zn, Pb, Ni, Cd, and Co) by using the atomic absorption spectrophotometer (AAS, GBC 932A Ver. 1.1). To verify the accuracy of these chemical measurements, duplicated samples were measured and revealed the same measured values, which reflects the high accuracy of the equipment and reagent blanks. In addition, the detection limits of measured metals were as follows: Fe 0.05 μg/g, Mn 0.02 μg/g, Cu 0.033 μg/g, Zn 0.01 μg/g, Pb 0.07 μg/g, Ni 0.05 μg/g, Cd 0.013 μg/g, and Co 0.06 μg/g.

Statistical analysis

In order to assess the trace metal content in sediments, two methods were used. The first method was to compare the average measured metal content of each studied area with the sediment quality guidelines (SQGs) such as the effect range low (ERL) (Long et al. 1995) and lowest effect level (LEL) (Persaud et al. 1993). The second method was measuring the values of the environmental

Table 1 The equations of the environmental pollution indicators and their risk categories

<table>
<tr><th colspan="4">Environmental Pollution Indicators</th><th colspan="3">References</th></tr>
<tr><td colspan="4">CF = Concentration $_{metal}$ / Concentration $_{background}$
Contamination factor has four categories in sediments</td><td colspan="3">Hakanson (1980)</td></tr>
<tr><td colspan="2">Cf < 1</td><td>1 - 3</td><td colspan="2">3 - 6</td><td colspan="2">> 6</td></tr>
<tr><td colspan="2">low contamination</td><td>moderate contamination</td><td colspan="2">considerable contamination</td><td colspan="2">very high contamination</td></tr>
<tr><td colspan="4">Cp = Concentration $_{max.\ content}$ / Concentration $_{background}$
potentional contamination index has three categories in sediments</td><td colspan="3">Hakanson (1980)
Davaulter and Rognerud (2001)</td></tr>
<tr><td colspan="2">Cp < 1 indicates</td><td colspan="2">$1 \leq Cp \leq 3$</td><td colspan="3">Cp > 3</td></tr>
<tr><td colspan="2">low contamination</td><td colspan="2">moderate contamination</td><td colspan="3">severe or very severe contamination.</td></tr>
<tr><td colspan="4">I_{geo} = Log2 (Concentration $_{metal}$ / 1.5 x Background $_{metal}$)
Geoaccumulation index has seven categories in sediments</td><td colspan="3">Muller (1979)
Forstner et al. 1993</td></tr>
<tr><td>Igeo < 0</td><td>0 - 1</td><td>1 - 2</td><td>2 - 3</td><td>3 - 4</td><td>4 - 5</td><td>> 5</td></tr>
<tr><td>unpolluted</td><td>uncontaminated to moderately contaminate</td><td>moderately polluted</td><td>moderately to strongly contaminated</td><td>heavily contaminated</td><td>strongly to very strongly contaminated</td><td>extremely contaminated</td></tr>
<tr><td colspan="4">SPI = Concentration $_{metal}$ / Concentration $_{MPL}$
soil pollution index has three categories in sediments</td><td colspan="3">Kabata-Pendias &Pendias (2001)
Chen et al., 2005)</td></tr>
<tr><td colspan="2">(SPI < 1)</td><td colspan="2">$(1 \leq SPI \leq 3)$</td><td colspan="3">(SPI > 3)</td></tr>
<tr><td colspan="2">low contamination</td><td colspan="2">moderate contamination</td><td colspan="3">high contamination</td></tr>
<tr><td colspan="4">PERI = Σ^{n}_{i} (Trf x CF)
Potential ecological risk has five categories in sediments</td><td colspan="3">Hakanson (1980)
Qing et al., 2015</td></tr>
<tr><td>PERI < 40</td><td>$40 \leq$ PERI< 80</td><td colspan="2">$80 \leq$ PERI <160</td><td colspan="2">$160 \leq$ PERI < 320</td><td>≥ 320</td></tr>
<tr><td>low risk</td><td>moderate risk</td><td colspan="2">considerable risk</td><td colspan="2">high risk</td><td>very high risk</td></tr>
<tr><td colspan="4">EF = (metal / Fe)sample / (metal /Fe)background
Enrichment factor has seven categories in sediments</td><td colspan="3">Simex and Helz (1981)
Acevedo-Figueroa et al. (2006)</td></tr>
<tr><td>EF < 1</td><td>1 - 3</td><td>3 - 5</td><td>5 - 10</td><td>10 - 25</td><td>25-50</td><td>> 50</td></tr>
<tr><td>no enrichment</td><td>minor enrichment</td><td>moderate enrichment</td><td>moderately severe enrichment</td><td>severe enrichment</td><td>very severe</td><td>extremely severe</td></tr>
</table>

parameters such as the enrichment factor (EF), which is used according to Sinex and Helz (1981) to assess the anthropogenic impacts on sediments. To estimate the intensity of trace metals pollution in sediments, the geoaccumulation index (I_{geo}) is measured according to Muller (1979) based on matching present situation with the background levels. To assess the extent of trace metals in sediment samples, the contamination factor (CF) is calculated according to Hakanson (1980) and the potential contamination index (Cp) is calculated according to Hakanson (1980). To assess the degree of trace metal pollution in surface sediments, the potential ecological risk index (PERI) is measured according to Hakanson (1980). To identify single-element contamination indices in the sediment sample, soil pollution index (SPI) is calculated according to Kabata-Pendias and Pendias (2001). All equations for calculating these environmental parameters and their categories are presented in Table 1.

Moreover, to illustrate the linkage between trace metals in the surface sediments, hierarchal cluster analysis (HCA) and Pearson's correlation coefficients were measured with the SPSS program. Regarding the estimation of the possible

Table 2 The average concentration of trace metals in beach sediments of 22 sites (2 samples/site) along the Red Sea coast

S.N.	Site name	Lat	Long	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co
Hurghada	Youth hostels	27° 17′ 09″ N	33° 46′ 07″ E	1233	99.263	36.25	83.15	22.51	82.71	0.12	1.18
	Marine Museum	27° 17′ 01″ N	33° 46′ 20″ E	1060	76.651	17.42	41.35	79.81	17.39	0.11	1.35
	Public beach	27° 14′ 54″ N	33° 50′ 24″ E	1698	187.51	56.0	109.5	54.51	73.05	0.23	1.66
	Magawish village	27° 08′ 43″ N	33° 49′ 41″ E	1720	178.25	64.25	106.6	70.0	76.73	0.16	1.84
	Makadi bay	27° 00′ 18″ N	33° 54′ 46″ E	1205	156.65	61.0	92.46	43.22	85.43	0.17	1.45
Average value				1383	139.66	46.98	86.61	54.00	67.06	0.158	1.496
Std. deviation				± 304.7	± 49.2	± 19.8	± 27.5	± 22.5	± 28.2	± 0.04	± 0.26
Safaga	Soma bay	26° 51′ 12″ N	33° 58′ 42″ E	1352	198.74	24.21	28.97	13.74	21.24	1.02	1.28
	North Safaga bay	26° 48′ 58″ N	33° 56′ 50″ E	2761	552.0	46.62	52.47	29.24	77.24	1.34	9.71
	South Safaga bay	26° 44′ 04″ N	33° 56′ 28″ E	2411	424.2	27.57	58.49	17.68	42.45	1.07	6.14
	Umm El Huweitat	26° 38′ 55″ N	33° 58′ 20″ E	3026	914.34	36.47	67.45	31.24	64.57	1.47	5.74
	Wadi Jasus	26° 37′ 38″ N	33° 59′ 39″ E	2100	423.27	11.45	40.25	12.57	33.58	0.31	2.14
	Kalawy bay	26° 30′ 33″ N	34° 03′ 58″ E	1875	142.4	5.10	11.41	18.36	6.24	0.24	4.86
Average value				2254	442.5	25.24	43.17	20.47	40.89	0.908	4.98
Std. deviation				± 609.6	± 277.4	± 15.3	± 20.6	± 7.9	± 26.5	± 0.51	± 3.03
Quseir	25 km north Quseir	26° 20′ 44″ N	34° 09′ 29″ E	1267	157.25	4.253	28.24	28.37	16.25	2.68	5.77
	El-Hamrawein port	26° 09′ 27″ N	34° 14′ 42″ E	2214	559.28	13.25	52.05	39.31	62.81	4.61	13.3
	Quseir City	26° 05′ 58″ N	34° 16′ 58″ E	2247	156.27	18.54	47.25	31.78	43.25	3.09	10.2
	9 km south Quseir	26° 01′ 21″ N	34° 19′ 30″ E	1147	124.17	6.241	26.25	26.24	21.25	3.21	6.24
	24 km south Quseir	25° 56′ 30″ N	34° 23′ 22″ E	1357	77.524	8.255	11.24	18.24	7.24	1.25	7.25
Average value				1646.4	214.9	10.11	33.01	28.79	30.16	2.968	8.556
Std. deviation				± 490.6	± 177.1	± 5.55	± 17.3	± 8.1	± 22.4	± 1.54	± 3.2
Marsa Alam	30 km north Marsa Alam	25° 20′ 29″ N	34° 44′ 17″ E	2357	221.77	5.146	21.50	18.23	14.14	0.74	8.77
	19 km north Marsa Alam	25° 23′ 46″ N	34° 42′ 16″ E	2368	631.41	2.472	23.53	27.27	21.44	2.58	9.24
	Marsa Alam City	25° 04′ 25″ N	34° 53′ 48″ E	3107	889.52	38.57	91.26	36.33	71.25	2.38	15.3
	8 km south Marsa Alam	25° 00′ 23″ N	34° 55′ 58″ E	3589	427.88	20.24	29.92	31.57	42.11	0.17	11.3
	20 km south Marsa Alam	24° 53′ 00″ N	34° 59′ 07″ E	3012	212.84	6.145	25.23	7.412	4.25	3.12	7.24
	32 km south Marsa Alam	24° 45′ 16″ N	35° 04′ 02″ E	1357	317.21	4.871	11.52	11.17	11.24	0.23	4.25
Average value				2631.7	450.11	12.91	33.83	22.00	27.41	1.537	9.35
Std. deviation				± 781.9	± 265.5	± 14.1	± 28.8	± 11.6	± 25.1	± 1.3	± 3.7

sources of trace metals in the studied area, a principal component analysis (PCA) was calculated.

Results and discussions

Trace metal distribution in studied sites

Sediments of the Red Sea coast are composed of varying components such as gravels, sands, and muddy sand, as well as marine skeletons of different fauna (molluscs, echinoderms, scleractinian corals, foraminifers, and ostracods). The obtained data of the mean concentrations of eight trace metals in 22 famous sites along the Egyptian Red Sea coast are shown in Table 2. The comparative data regarding the mean trace metal concentrations in sediments of the Egyptian Red Sea coast with other worldwide ones, geochemichal background, and sediment quality guidelines (SQGs) are presented in Table 3.

Iron concentration in the present work ranged from 3589 μg/g in 8 km south Marsa Alam to 1060 μg/g in the Hurghada Marine Museum. The presence of Fe in the coastal sediments relatively indicates terrigenous contamination sources (Mansour et al. 2000). The average content of Fe in the present study (2021 μg/g) was lower than the background value in shale (Turekian and Wedepoh 1961), continental crust (Taylor 1964), and the lowest effect level (LEL) (Persaud et al. 1993). Moreover, it was lower than the Red Sea coast, Saudi Arabia (Youssef and El-Sorogy 2016); the Mediterranean coast in Egypt and Libya (Okbah et al. 2014; Nour and El-Sorogy 2017); Taranto Gulf, Italy (Buccolieri et al. 2006); Arabian Gulf, Saudi Arabia (El-Sorogy et al.

Table 3 The comparison between the mean concentrations of metals in study area and those in other worldwide, geochemical background, and sediment quality guidelines

Region	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co	Reference
Res Sea coast, Egypt	2021.0	324.0	23.38	48.19	30.40	40.72	1.380	6.432	Present work
Red Sea coast, Saudi Arabia	2249.4	102.7	16.00	39.71	50.87	8.690	0.260	4.770	Youssef and El-Sorogy (2016)
Mediterranean coast, Egypt	19144	551.6	13.23	32.03	30.85	28.17	13.41	0.250	Okbah et al. (2014)
Mediterranean coast, Libya	2047.8	34.07	17.13	26.36	11.12	21.87	0.810	5.803	Nour and El-Sorogy 2017
Mediterranean coast, France	–	–	14.82	269.2	206.5	–	1.770	–	Femex et. al. (2001)
Naples harbor, Italy	–	389.0	131.0	303.0	123.0	–	0.900	5.100	Adamo et al. (2005)
Taranto Gulf, Italy	31205	1689	47.20	107.9	59.35	53.50	–	–	Buccolieri et al. (2006)
Arabian Gulf, Saudi Arabia	8474.2	111.6	297.3	48.26	5.250	77.07	2.130	4.010	El-Sorogy et al. (2018)
Bengal bay, India	–	356.0	20.00	71.00	16.00	30.00	0.210	9.000	Selvaraj et al. (2004)
Caspian Sea, Azerbaijan	37100	832.0	31.90	83.20	19.60	50.10	0.140	14.90	De Mora et al. (2004)
Caspian Sea, Russia	5520.0	200.0	8.300	17.10	4.190	14.00	0.060	3.800	
Background shale	47200	850.0	45.00	95.00	20.00	68.00	0.300	19.00	Turekian and Wedepoh (1961)
Background continental crust	56300	950.0	55.00	70.00	12.50	75.00	0.200	25.00	Taylor (1964)
Sediment quality guidelines (ERL)	–	–	34.00	150.0	46.70	20.90	1.200	–	Long et al. (1995)
Sediment quality guidelines (LEL)	4000	460.0	16.00	120	31.0	16.0	0.600		Persaud et al. (1993)

2018); and Caspian Sea in Azerbaijan and Russia (De Mora et al. 2004).

The Um El Huweitat site (Safaga area) recorded the highest value of manganese (914.3 μg/g), while the Marine Museum site (Hurghada area) recorded the lowest value (76.65 μg/g). The main anthropogenic sources of Mn are landfills, marine paints, and pipeline corrosion. In addition, the higher concentrations of Mn in coastal sediments may relate to its incorporation in the crystal lattice of calcite (Nawar and Shata 1989). In the present study, the average concentration of Mn (324 μg/g) was higher than those in the Red Sea coast (Saudi Arabia), Mediterranean coast (Libya), Arabian Gulf (Saudi Arabia), and the Caspian Sea (Russia). However, the concentration of Mn in the studied area was still lower than the average background in shale, continental crust, and LEL.

Copper concentrations ranged from 64.25 μg/g in Magawish Village site (Hurghada area) to 2.47 μg/g in 19 km north Marsa Alam site with an average of 23.4 μg/g. This average content of Cu was higher than those in the Red Sea coast (Saudi Arabia), Mediterranean coast (Egypt, Libya, and France), Bengal bay (India), and the Caspian Sea (Russia). Moreover, Cu in the Hurghada area was higher than the average background in shale and SQGs (Long et al. 1995; Persaud et al. 1993). While the Safaga area recorded higher content of Cu than the LEL value. Cu can enter the marine environment by ship constructions, removing rust, and painting ships. Although copper is vital for the synthesis of hemoglobin (Underwood 1977), the exposure to a high dose of Cu can cause several health problems (Gorell et al. 1997).

Zn can enter the marine environment via paints, mining wastewater, agriculture, and industrial activities. In addition, Zn in the form of zinc sulfate can be found in house construction, cans, galvanized pipes, garbage, and wear of automobile tires (Cameron 1992; Mulligan et al. 2001). Hurghada public beach recorded the highest value of Zn (109.5 μg/g), while the lowest value (11.24 μg/g) was recorded in 24 km south Quseir. The average content of Zn in the present study (48.19 μg/g) was higher than the ones in Red Sea coast (Saudi Arabia), Mediterranean coast (Egypt and Libya), and the Caspian Sea (Russia). However, this concentration was lower than those in the background shale, continental crust, and SQGs.

The highest value of Pb (79.81 μg/g) was recorded in the Hurghada marine museum, while the lowest value (7.41 μg/g) was recorded in 20 km south Marsa Alam. Pb can enter the marine environment by marine paints, oil wastes, domestic sewage, and traffic exhaust (Cameron 1992). In addition, it can be naturally derived from parent rocks. In the present study, the average content of Pb (30.4 μg/g) was higher than the ones in the Mediterranean Sea (Libya), Arabian Gulf (Saudi Arabia), Bengal bay (India), and the Caspian Sea (Azerbaijan and Russia). Moreover, this average content also was higher than the background value in shale and continental crust, whereas the Hurghada area only recorded higher Pb content than SQGs. Organic matter and clay minerals play an important role to extract Pb from sea water to sediment (Irwin et al. 1997).

Nickel concentrations ranged from 85.43 μg/g in Makadi bay to 4.25 μg/g in 20 km south Marsa Alam, with an average of 40.7 μg/g. This value was higher than the ones in the Red Sea coast (Saudi Arabia), Mediterranean coast (Egypt and Libya), Bengal bay (India), and the Caspian Sea (Russia).

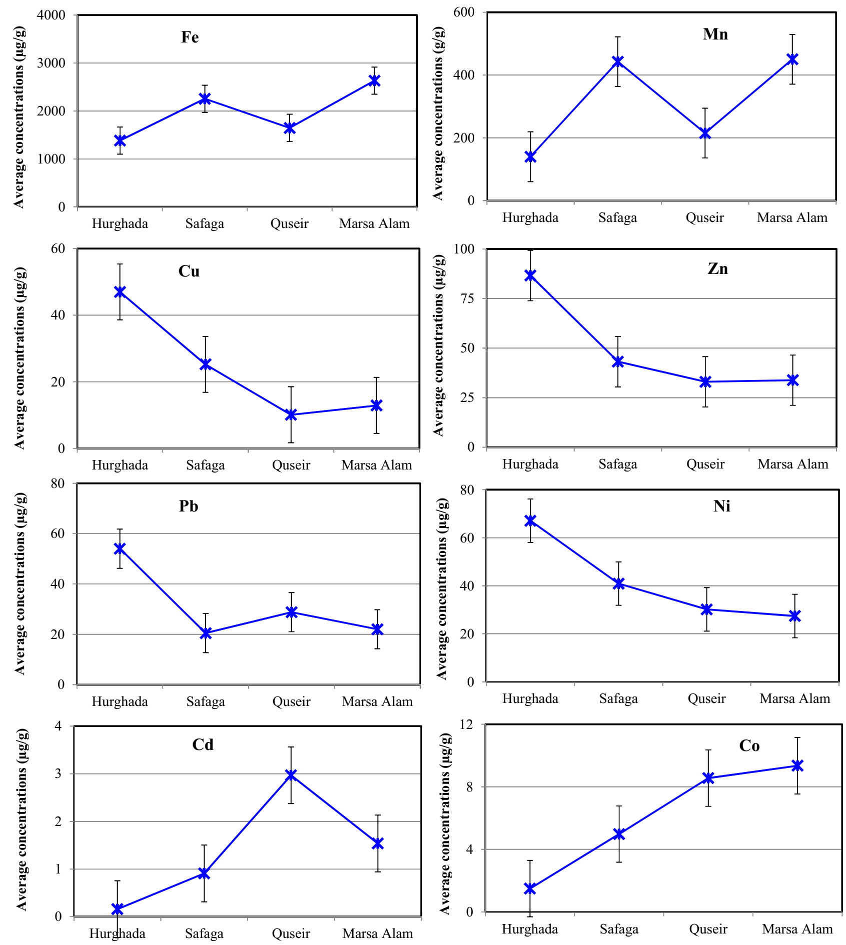

Fig. 3 The average concentration of trace metals (µg/g) in beach sediments of four major cities along the Red Sea coast

Moreover, these average content showed lower values than the background one in shale and continental crust. In contrast to that, all studied areas recorded higher Ni content than the value of SQGs. Ni can enter the marine environment by natural dissolution of rocks and soils or by industrial processes and waste disposal.

Table 4 Contamination factors and the potential contamination indexes for the beach sediment samples of the Egyptian Red Sea coast

Study area	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co
Contamination factor								
Hurghada area	0.029	0.164	1.044	0.912	2.700	0.986	0.527	0.079
Safaga area	0.048	0.521	0.561	0.454	1.024	0.601	3.028	0.262
Quseir area	0.035	0.253	0.225	0.347	1.439	0.444	9.893	0.450
Marsa Alam area	0.056	0.530	0.287	0.356	1.100	0.403	5.122	0.492
Potential contamination index								
Hurghada area	0.036	0.221	1.428	1.153	3.991	1.256	0.767	0.097
Safaga area	0.064	1.076	1.036	0.710	1.562	1.136	4.900	0.511
Quseir area	0.047	0.658	0.412	0.548	1.966	0.924	15.367	0.699
Marsa Alam area	0.076	1.046	0.857	0.961	1.817	1.048	10.400	0.804

The use of colors in all tables is an indication of the degree of pollution, as shown in Figure 1

Table 5 Geo-accumulation factors data for the beach sediment samples of the Egyptian Red Sea coast

S.N.	Site name	I_{geo} Fe	I_{geo} Mn	I_{geo} Cu	I_{geo} Zn	I_{geo} Pb	I_{geo} Ni	I_{geo} Cd	I_{geo} Co
Hurghada	Youth Hostels	0.0052	0.0234	0.1617	0.1757	0.2259	0.2441	0.0803	0.0124
	Marine Museum	0.0045	0.0181	0.0777	0.0874	0.8008	0.0513	0.0736	0.0143
	Public Beach	0.0072	0.0443	0.2495	0.2314	0.5470	0.2156	0.1539	0.0176
	Magawish Village	0.0073	0.0421	0.2865	0.2251	0.7019	0.2265	0.1070	0.0194
	Makadi Bay	0.0051	0.0370	0.2722	0.1953	0.4337	0.2521	0.1137	0.0153
Average value		0.0059	0.0330	0.2095	0.1830	0.5419	0.1979	0.1057	0.0158
Safaga	Soma Bay	0.0057	0.0469	0.1080	0.0612	0.1379	0.0627	0.6823	0.0135
	North Safaga Bay	0.0117	0.1303	0.2079	0.1108	0.2934	0.2280	0.8964	0.1026
	South Safaga Bay	0.0103	0.1002	0.1230	0.1236	0.1774	0.1253	0.7158	0.0649
	Umm El Huweitat	0.0129	0.2159	0.1626	0.1425	0.3135	0.1906	0.9834	0.0606
	Wadi Jasus	0.0089	0.0999	0.0511	0.0850	0.1261	0.0991	0.2074	0.0226
	Kalawy Bay	0.0080	0.0336	0.0227	0.0241	0.1842	0.0184	0.1605	0.0514
Average value		0.0096	0.1045	0.1125	0.0912	0.2054	0.1207	0.6076	0.0526
Quseir	25km north Quseir	0.0054	0.0371	0.0190	0.0597	0.2847	0.0480	1.7928	0.0610
	El-Hamrawein Port	0.0094	0.1320	0.0591	0.1100	0.3944	0.1854	3.0839	0.1403
	Quseir City	0.0096	0.0369	0.0827	0.0998	0.3189	0.1276	2.0671	0.1082
	9km south Quseir	0.0049	0.0293	0.0278	0.0555	0.2633	0.0627	2.1473	0.0659
	24km south Quseir	0.0058	0.0183	0.0368	0.0237	0.1830	0.0214	0.8362	0.0766
Average value		0.0070	0.0507	0.0451	0.0697	0.2889	0.0890	1.9855	0.0904
Marsa Alam	30km north Marsa Alam	0.0100	0.0524	0.0229	0.0454	0.1829	0.0417	0.4950	0.0926
	19km north Marsa Alam	0.0101	0.1491	0.0110	0.0496	0.2736	0.0633	1.7259	0.0976
	Marsa Alam City	0.0132	0.2100	0.1720	0.1928	0.3645	0.2103	1.5921	0.1613
	8km south Marsa Alam	0.0153	0.1010	0.0903	0.0632	0.3168	0.1243	0.1137	0.1197
	20km south Marsa Alam	0.0128	0.0503	0.0274	0.0533	0.0744	0.0125	2.0871	0.0765
	32km south Marsa Alam	0.0058	0.0749	0.0217	0.0243	0.1121	0.0332	0.1539	0.0448
Average value		0.0112	0.1063	0.0576	0.0714	0.2207	0.0809	1.0280	0.0987

The use of colors in all tables is an indication of the degree of pollution, as shown in Figure 1

Cadmium recorded the highest value (4.61 μg/g) in El-Hamrawein port, while the Hurghada Marine Museum site recorded the lowest value (0.11 μg/g). The average content of Cd in the present study (1.38 μg/g) was higher than those in the Red Sea coast (Saudi Arabia), Mediterranean coast (Libya and France), Naples harbor (Italy), Bengal bay (India), and the Caspian Sea (Azerbaijan and Russia). Moreover, these average contents were higher than the background value of shale and continental crust, whereas, Quseir and Marsa Alam areas recorded higher content of Cd than the background value of SQGs. Mostly, cadmium is an output of terrigenous and anthropogenic origin and it has a remarkable ability for mobility in the seawater surface (Bender and Gagner 1976). However, it is classified as a chemical hazard (EC 2001; USFDA 1993). Cd is used in several purposes as in batteries and pigments (Boehme and Panero 2003; Lin et al. 2013).

Cobalt concentrations ranged from 15.27 μg/g in the Marsa Alam City to 1.17 μg/g in youth hostel site (Hurghada area), with an average of 6.19 μg/g. This average was higher than the ones in the Red Sea coast (Saudi Arabia), Mediterranean Sea (Egypt and Libya), Naples harbor (Italy), Arabian Gulf (Saudi Arabia), and the Caspian Sea (Russia). However, this concentration was lower than those in the background shale and continental crust. Cobalt sources vary from natural weathering of basement rocks where it is enriched in mafic relative to felsic igneous rocks (Wedepohl 1978) and anthropogenic sources as steels, fertilizers and lead, iron, and silver

Table 6 The soil pollution index for the beach sediment samples of the Egyptian Red Sea coast

S.N.	Site name	Mn	Cu	Zn	Pb	Ni	Cd	Co
Hurghada	Youth Hostels	0.165	1.208	1.663	2.251	2.068	2.000	0.147
	Marine Museum	0.128	0.581	0.827	7.981	0.435	1.833	0.169
	Public Beach	0.313	1.865	2.191	5.451	1.826	3.833	0.208
	Magawish Village	0.297	2.142	2.131	6.995	1.918	2.667	0.230
	Makadi Bay	0.261	2.034	1.849	4.322	2.136	2.833	0.181
Average value		0.233	1.566	1.732	5.400	1.677	2.633	0.187
Safaga	Soma Bay	0.331	0.807	0.579	1.374	0.531	17.000	0.160
	North Safaga Bay	0.920	1.554	1.049	2.924	1.931	22.333	1.214
	South Safaga Bay	0.707	0.919	1.170	1.768	1.061	17.833	0.768
	Umm El Huweitat	1.524	1.216	1.349	3.124	1.614	24.500	0.718
	Wadi Jasus	0.705	0.382	0.805	1.257	0.840	5.167	0.268
	Kalawy Bay	0.237	0.170	0.228	1.836	0.156	4.000	0.608
Average value		0.737	0.841	0.863	2.047	1.022	15.139	0.622
Quseir	25km north Quseir	0.262	0.142	0.565	2.837	0.406	44.667	0.722
	El-Hamrawein Port	0.932	0.442	1.041	3.931	1.570	76.833	1.660
	Quseir City	0.260	0.618	0.945	3.178	1.081	51.500	1.280
	9km south Quseir	0.207	0.208	0.525	2.624	0.531	53.500	0.780
	24km south Quseir	0.129	0.275	0.225	1.824	0.181	20.833	0.906
Average value		0.358	0.337	0.660	2.879	0.754	49.467	1.070
Marsa Alam	30km north Marsa Alam	0.370	0.171	0.430	1.823	0.354	12.333	1.096
	19km north Marsa Alam	1.052	0.082	0.470	2.727	0.536	43.000	1.155
	Marsa Alam City	1.483	1.286	1.825	3.633	1.781	39.667	1.909
	8km south Marsa Alam	0.713	0.675	0.598	3.157	1.053	2.833	1.416
	20km south Marsa Alam	0.355	0.205	0.505	0.741	0.106	52.000	0.905
	32km south Marsa Alam	0.529	0.162	0.230	1.117	0.281	3.833	0.530
Average value		0.750	0.430	0.676	2.200	0.685	25.611	1.169

The use of colors in all tables is an indication of the degree of pollution, as shown in Figure 1

mining (Reimann and de Caritat 1998). It is worth mentioning that cobalt is more mobile in the surface environment under acidic and reducing conditions (McBride 1994).

Generally, the trace metal distribution along the Red Sea coast (Fig. 3) revealed that the Hurghada area is enriched in Cu, Zn, Pb, and Ni and the Marsa Alam area has high concentrations of Co, Mn, and Fe compared to other sites. On the other hand, the Quseir area is enriched in Cd.

Assessment of sediment contamination

For an overview of the comprehensive evaluation of the potential pollutants in the beach sediments of the Red Sea coast, the environmental indicators were calculated based on the geochemical background. To calculate the ratio between the existence of trace metal concentration in the sediment sample to that in geochemical background given by Turekian and Wedepoh (1961), contamination factor and the potential

Table 7 The potential ecological risk index for the beach sediment samples of the Egyptian Red Sea coast

S.N.	Site name	ecological risk index E^i_r						PERI
		Cu	Zn	Pb	Ni	Cd	Co	
Hurghada	Youth Hostels	4.028	0.875	5.628	7.298	12.00	0.309	30.138
	Marine Museum	1.936	0.435	19.95	1.534	11.00	0.355	35.213
	Public Beach	6.217	1.153	13.63	6.446	23.00	0.437	50.880
	Magawish Village	7.139	1.122	17.49	6.770	16.00	0.484	49.003
	Makadi Bay	6.781	0.973	10.81	7.538	17.00	0.382	43.479
Average value		5.220	0.912	13.50	5.917	15.80	0.394	41.743
Safaga	Soma Bay	2.690	0.305	3.435	1.874	102.0	0.337	110.64
	North Safaga Bay	5.180	0.552	7.310	6.815	134.0	2.556	156.41
	South Safaga Bay	3.063	0.616	4.420	3.746	107.0	1.617	120.46
	Umm El Huweitat	4.052	0.710	7.810	5.697	147.0	1.511	166.78
	Wadi Jasus	1.272	0.424	3.143	2.963	31.00	0.563	39.365
	Kalawy Bay	0.566	0.120	4.590	0.551	24.00	1.280	31.107
Average value		2.804	0.454	5.118	3.608	90.83	1.310	104.13
Quseir	25km north Quseir	0.473	0.297	7.093	1.434	268.0	1.519	278.82
	El-Hamrawein Port	1.472	0.548	9.828	5.542	461.0	3.495	481.88
	Quseir City	2.060	0.497	7.945	3.816	309.0	2.695	326.01
	9km south Quseir	0.693	0.276	6.560	1.875	321.0	1.642	332.05
	24km south Quseir	0.917	0.118	4.560	0.639	125.0	1.908	133.14
Average value		1.123	0.347	7.197	2.661	296.8	2.252	310.38
Marsa Alam	30km north Marsa Alam	0.571	0.226	4.558	1.248	74.00	2.308	82.910
	19km north Marsa Alam	0.274	0.247	6.818	1.892	258.0	2.432	269.66
	Marsa Alam City	4.286	0.961	9.083	6.287	238.0	4.018	262.63
	8km south Marsa Alam	2.249	0.315	7.893	3.716	17.00	2.982	34.154
	20km south Marsa Alam	0.682	0.266	1.853	0.375	312.0	1.905	317.08
	32km south Marsa Alam	0.541	0.121	2.793	0.992	23.0	1.116	28.562
Average value		1.434	0.356	5.499	2.418	153.7	2.460	165.83

The use of colors in all tables is an indication of the degree of pollution, as shown in Figure 1

contamination index were measured (Table 4). These results show that the Hurghada area is moderately contaminated with Pb and Cu (CF = 1–3) and the Quseir area was very highly contaminated with Cd ($C > 6$) and moderately contamination for Pb. Also, Safaga and Marsa Alam areas showed a significant correlation with CF, where they have considerable contamination for Cd (CF = 3–6) and moderate contamination for Pb. These results confirmed by the results of Cp indicate that Quseir and Marsa Alam areas are very severely contaminated with Cd in 9 km south Quseir and 20 km south Marsa Alam sites, respectively. Moreover, Hurghada and Safaga areas are severely contaminated with Pb and Cd respectively. At the same time, the studied beaches are moderately contaminated with Cu, Zn, and Ni in the Hurghada area; Pb, Ni, Mn, and Cu

Table 8 Enrichment factors data for the beach sediment samples of the Egyptian Red Sea coast

S.N.	Site name	EF Mn	EF Cu	EF Zn	EF Pb	EF Ni	EF Cd	EF Co
Hurghada	Youth Hostels	4.47	30.84	33.51	43.08	46.56	15.31	2.37
	Marine Museum	4.02	17.24	19.38	177.7	11.39	16.33	3.16
	Public Beach	6.13	34.56	32.05	75.8	29.86	21.31	2.43
	Magawish Village	5.75	39.18	30.78	96.0	30.96	14.64	2.66
	Makadi Bay	7.22	53.1	38.12	84.6	49.21	22.20	2.99
Average value		5.52	34.99	30.77	95.43	33.60	17.96	2.72
Safaga	Soma Bay	8.16	18.78	10.65	23.98	10.90	118.7	2.35
	North Safaga Bay	11.10	17.71	9.44	24.99	19.42	76.4	8.74
	South Safaga Bay	9.77	11.99	12.05	17.31	12.22	69.8	6.33
	Umm El Huweitat	16.78	12.64	11.07	24.36	14.81	76.4	4.71
	Wadi Jasus	11.19	5.72	9.52	14.13	11.10	23.23	2.53
	Kalawy Bay	4.22	2.85	3.02	23.11	2.31	20.14	6.44
Average value		10.20	11.62	9.29	21.31	11.79	64.11	5.18
Quseir	25km north Quseir	6.89	3.52	11.07	52.8	8.90	332.8	11.32
	El-Hamrawein Port	14.03	6.28	11.68	41.90	19.69	327.6	14.90
	Quseir City	3.86	8.65	10.45	33.38	13.36	216.4	11.32
	9km south Quseir	6.01	5.71	11.37	54.0	12.86	440.3	13.51
	24km south Quseir	3.17	6.38	4.12	31.72	3.70	144.9	13.27
Average value		6.79	6.11	9.74	42.77	11.70	292.4	12.87
Marsa Alam	30km north Marsa Alam	5.22	2.29	4.53	18.25	4.16	49.40	9.24
	19km north Marsa Alam	14.81	1.09	4.93	27.18	6.28	171.4	9.69
	Marsa Alam City	15.90	13.02	14.59	27.60	15.92	120.5	12.21
	8km south Marsa Alam	6.62	5.92	4.14	20.76	8.14	7.45	7.84
	20km south Marsa Alam	3.92	2.14	4.16	5.81	0.98	163.0	5.97
	32km south Marsa Alam	12.98	3.76	4.22	19.43	5.75	26.67	7.76
Average value		9.91	4.70	6.10	19.84	6.87	89.74	8.79

The use of colors in all tables is an indication of the degree of pollution, as shown in Figure 1

in the Safaga area; Pb in the Quseir area; and Pb, Ni, and Mn in the Marsa Alam area, whereas to understand the intensity of the trace metal contamination in the studied area, geo-accumulation index was calculated (Table 5). I_{geo} shows that the Red Sea coast suffers from high concentrations of cadmium, especially in El-Hamrawein site which seems to be heavily contaminated with this metal that may be caused by phosphate extraction and export operations. Moreover, Quseir City, 9 km south Quseir, and 20 km south Marsa Alam sites are moderately to strongly contaminated with Cd. While the sites located 25 km north Quseir City, 19 km north Marsa Alam, and Marsa Alam City are moderately polluted with cadmium.

On the other hand, to identify single-element contamination index in the studied area, soil pollution index (Table 6) showed that the Hurghada area is highly contaminated with Pb (SPI > 3) in most studied sites. In addition, it appears to be moderately contaminated by Cd, Zn, Ni, and Cu. Regarding other studied areas (Safaga, Quseir, and Marsa Alam), they highly contaminated with Cd. Moreover, they are moderately

Table 9 The correlation matrix among the studied trace metals in the beach sediment samples of the Egyptian Red Sea coast

	Fe	Mn	Cu	Zn	Pb	Ni	Cd	Co
Fe	1							
Mn	0526*	1						
Cu	−0.164	0.086	1					
Zn	−0.106	0.157	0.887**	1				
Pb	−0.28	−0.045	0.540**	0.572**	1			
Ni	−0.143	0.262	0.870**	0.875**	0.425*	1		
Cd	0.186	0.151	−0.444	−0.294	−0.208	−0.232	1	
Co	0.424	0.551**	−0.287	−0.288	−0.188	−0.053	0.539**	1

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

contaminated with (Ni and Pb) for Safaga and with (Co and Pb) for Quseir and Marsa Alam areas. These results fully compatible with the potential ecological risk index (Table 7). The Quseir area has a high ecological risk with Cd ($160 \leq PERI < 320$) in most sampling sites, especially in El-Hamrawein port and 9 km south Quseir were very high risk ($PERI \geq 320$). Safaga and Marsa Alam sites show considerable ecological risk with Cd ($80 \leq PERI < 160$).

Pollution source analysis of trace metals

According to the enrichment factors (Table 8), the Hurghada area is extremely severe with Pb in the majority of sample sites and with Cu in youth hostel site. Moreover, it is very severe enriched with (Cu, Ni, and Zn) while being severely to moderately severe enriched with Cd and Mn, respectively, in most sample sites. The Safaga area is extremely severe with Cd and it is severe enriched with Pb, Ni, Cu, and Mn in most sample sites. The Quseir area is extremely severe with Cd and very severely enriched with Pb. To emphasize this point, some sampling sites such as El-Hamrawein port and Quseir City are extremely severe with Cd and Pb. In addition, the Quseir area is severely enriched with Co and Ni. The Marsa Alam area is extremely severe with Cd in most sample sites, while it is severely enriched with Pb especially in 19 km north Marsa Alam and Marsa Alam City sites. The sources of these metals in the studied area are districted according to anthropogenic sources. To emphasize that, Zhang and Liu (2002) stated that when the EF value is more than 1.5, and this would indicate that the possible source of the metals is more likely to be anthropogenic. Field observation point to the fact that the Hurghada area is subjected to different anthropogenic sources such as urbanization, tourism activities, shipyards, plastic rubbish, and landfilling processes. The Safaga area is under the effects of commercial vessels and passenger transport, tourism activities in addition to soil erosion and basement fragments. The Quseir area is related to phosphate shipping movement, fishing boats and tourism industry. The Marsa Alam area has many resorts, diving activities and rock erosion.

The results of the correlation matrix among the studied trace metals (Table 9) revealed that a strongly positive correlation between Cu and each of Zn, Ni, and Pb ($r = 0.887$**, $r = 0.870$**, and $r = 0.540$**) respectively. Zn is well correlated with Ni and Pb ($r = 0.875$** and $r = 0.572$**) respectively. Moreover, Mn is well correlated with Co and Fe ($r =$

Table 10 Principal component loadings for the trace metals in the beach sediment samples of the Egyptian Red Sea coast

Component matrix[a]	Component	
	1	2
Fe	−0.351	0.647
Mn	−0.04	0.871
Cu	0.937	0.189
Zn	0.906	0.287
Pb	0.677	0.005
Ni	0.841	0.395
Cd	−0.537	0.347
Co	−0.447	0.727
% of variance	43.468	26.255
Cumulative%	43.468	69.723

Extraction method: principal component analysis

[a] Two-component extracted

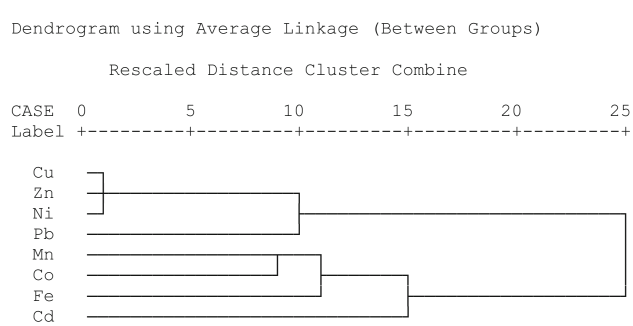

Fig. 4 The dendrogram for hierarchical cluster analysis (HCA) of trace metals in the study area

0.551** and $r = 0.0.526$*) respectively. In addition, there are good correlations noticed between Cd and Co ($r = 0.0.539$**). On the contrary, there are negative correlation between Fe and each of Cu, Zn, Pb, and Ni ($r = -0.164, -0.106, -0.28$, and -0.143 respectively). To distinguish between the potential sources of these metals in the studied area, PCA was used on the examined metals. These results revealed two principal components have been extracted covering 69.72% of the cumulative variance (Table 10). PC1 showed positive loading for Cu (0.937), Zn (0.906), Ni (0.841), and Pb (0.677). PC2 showed positive loading for Mn, Co, and Fe (0.871, 0.727, and 0.647) respectively. This result implied that these metals may have been descended from the same sources. In addition, it shows similarity in migration under the same environmental conditions and show similar behaviors during transportation (Wang et al. 2015). Cu, Zn, Ni, and Pb metals in PC1 are mainly derived from anthropogenic sources (Simeonov et al. 2000; Thuong et al. 2013) such as ship constructions, removing rust from bodies, marine paints, oil wastes, domestic sewage, traffic exhaust, mining wastewater, garbage, galvanized pipes, and wear of automobile tires (Cameron 1992; Mulligan et al. 2001). While Mn, Co, and Fe are mainly from natural rock erosion. On the other hand, Co and Cd are from both natural and anthropogenic sources. Simultaneously, the dendrogram of HCA of trace metals in the study area (Fig. 4), confirmed the results of the correlation matrix and classified the studied trace metals into two clusters: cluster 1 includes Cu, Zn, Ni, and Pb at distance 10 which exactly matches with component one in PCA, while cluster 2 which includes Fe, Mn, Cd, and Co at distance 15 which well correlated with the second component in PCA.

Conclusion

The results of the various environmental pollution indicators in this work confirm that the Red Sea coast in the studied area is a considerable ecological risk with Cd, especially in the Quseir area. The Hurghada area is very severely contaminated with Pb, Zn, Ni, and Cu. Marsa Alam and Safaga areas are severely contaminated with Cd and Pb. When comparing these results to the geochemical background values, the Egyptian Red Sea coast is higher in the concentration of Cd than the background values of shale, continental crust, and SQGs. In addition, Pb concentration in the studied area is higher than in background shale and continental crust; meanwhile, it is lowered than in SQGs. Regarding Ni and Cu concentrations, they are higher than in SQGs. However, the two metal concentrations are lower than the background values of shale and continental crust.

Despite the presence of the weathering effects represented by the presence of basement fragments and phosphate in some sites along the coastal area as in the south Safaga bay and El-Hamrawein port, the anthropogenic sources of trace metals such as landfill, plastic rubbish, phosphate operations, fishing boats, shipyards, population, and tourist activities are the most fundamental factors according to the results of EF, Cp, CF, SPI, and PERI.

In the present study, the average concentrations of Cd, Pb, Cu, Zn, Ni, and Co in sediments of the Egyptian Red Sea coast are higher than the ones in Saudi Red Sea coast, Egyptian and Libyan Mediterranean Sea coast, Indian Bengal bay, and Russian Caspian Sea.

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