Frontiers in Scientific Research and Technology

Online ISSN: 2682-2970
Print ISSN: 2682-2962
http://fsrt.journals.ekb.eg

FSRT J 7 (2023) 97 - 107 10.21608/FSRT.2023.238650.1108

Distribution and assessment of heavy metals in sediments from the Red Sea, Egypt during 2019

Safaa A. Mahmoud[1], Lamiaa I. Mohamedein[2], Adel S. Orabi[3], Khalid M. El-Moselhy[2] and Eman M. Saad[1,*]

[1] Department of Chemistry, Faculty of Science, Suez University, Suez, Egypt
[2] National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt
[3] Department of Chemistry, Faculty of Science, Suez Canal University, Ismailia, Egypt

ARTICLE INFO

Article history:
Received 24 September 2023
Received in revised form 4 October 2023
Accepted 7 October 2023
Available online 11 October 2023

Keywords
Heavy metals,
sediments,
Gulf of Suez,
Aqaba Gulf,
Red Sea,
pollution indices.

ABSTRACT

The present investigation is aimed to determine the concentration of some heavy metals (Pb, Cd, Cu, Zn, Co, Ni, Mn and Fe) in sediments from Egyptian Red Sea, and assess its contamination state using different pollution indices. Sediments were sampled biannually in winter and summer of 2019 at nineteen sites covering Gulf of Suez, Aqaba Gulf and Red Sea proper. Levels of the investigated metals were measured by Flame Atomic Absorption Spectrophotometer method. Results showed that the examined metals revealed annual average of 22.96, 2.68, 3.70, 24.25, 11.77, 17.26, 67.61 and 3840.58 µg/g (Gulf of Suez), 18.44, 1.52, 4.27, 49.58, 10.81, 12.24, 169.96 and 22185.8 µg/g (Aqaba Gulf) and 19.24, 2.05, 6.41, 65.41, 11.47, 24.92, 149.20 and 11533.8 µg/g (Red Sea proper) for Pb, Cd, Cu, Zn, Co, Ni, Mn and Fe, respectively. The highest means of Pb, Cd and Co were recorded in the Gulf of Suez sediments, Mn and Fe were in the Aqaba Gulf, while Cu, Zn and Ni were found in the Red Sea proper. According to ANOVA analysis, only Cd, through all the investigated regions, showed significant variation between the examined seasons ($p < 0.05$). Regionally, average values of Cd, Mn and Fe displayed significant differences ($p < 0.05$) between the different investigated regions. The indices of pollution (as CF, PLI, MPI, I_{geo} and EF) were estimated to evaluate contamination state by metals in the different studied regions. The calculated indices indicated that the present examined regions reflected slight to moderate pollution states.

Introduction

Heavy metals entered water ecosystems by natural routes and human actions. Natural routes include rock weathering, river discharge, wind-produced dust from arid and semi-arid areas, and volcanic actions. Anthropogenic sources of metals comprise oil activities, agriculture releases, industrial wastes, chemical productions, refining and burning, and accidental & intentional releases (Rainbow, 1990; Lias etal., 2013; Krishnakumar etal., 2018 and Boxberg etal., 2020).

Trace values of metals naturally found in the aquatic ecosystem, some of them at small concentrations, are essential for aquatic organisms. On the contrary, if their levels exceed the probable concentrations, it will be dangers to organisms. Recently, global metal contamination is becoming more danger.

Cadmium, lead, copper, zinc, chromium, mercury, arsenic, and other metals have reached the marine ecosystem, producing severe marine environmental contamination (Zhang etal., 2016 and Manzoor etal., 2018). Subsequently, metals commonly adsorb on suspended matters and steadily precipitous into the sediments. When water environ is altered, metals will be released once more into the water column, resulting direct or indirect toxic effects on marine organisms. As sediments repeatedly become the main end point of contaminants in the aquatic bodies, metals measurement in aquatic sediments may describe the status of metal contamination in water that are regularly named indicators (Gao etal., 2015 and Xu etal., 2016). So, sediments data will provide important facts on assessing condition of environmental quality and evaluating ecological risk.

The Egyptian Red Sea has unique ecosystems including algae, seagrass, coral reefs and mangrove. Its coast is about 1250 km from Suez to the Sudanese border. At the northern end, it splits into Gulf of Suez and Aqaba Gulf. Gulf of Suez is about 300 km long, and 50 km wide, and average depth of 40 m; Aqaba Gulf is about 180 km

* Corresponding author at Suez University
E-mail addresses: emmsaad@yahoo.com (E.M. Saad)

long, and 25 km wide, and depths over 1800 m (Morcos, 1960; Meshal, 1970; El-Moselhy and Gabal, 2004, El Mamoney and Khater, 2004; Abdel Zaher etal., 2011; El-Metwally, 2014).

In the previous years, several researches have documented metal pollutants in sediments of the Red Sea, Egypt (Hamed & El-Moselhy, 2000; Abouhend & El-Moselhy, 2015; El-Moselhy etal., 2016; El-Metwally etal., 2017 & 2019 and Farhat etal., 2022). These studies were usually carried out only restricted coasts of the Red Sea, and the results could not describe and compare the metal contents in the sediments from whole coasts of the Egyptian Red Sea. Therefore, the goal of the current investigation is to display and evaluate the existence of some metals (Pb, Cd, Cu, Zn, Co, Ni, Mn and Fe) in sediment samples collected along the Egyptian Red Sea coasts. The present investigation includes studying of regional and temporal influences on metals in sediments. As well as, pollution indices (CF, PLI, MPI, I_{geo} and EF) were used to compare and assess metals pollution in the different investigated sites of the Egyptian Red Sea.

Materials and Methods

Study area

To well describe different sources of metals pollution and evaluate its influence, the investigated sites were extent alongside wide region of the Red Sea coasts of Egypt, and representing different ecological conditions and land-based activities, such as urban, industrial & petroleum activities, fishing & shipping activities, touristic activities, and complicated habitats like a coral reef, seagrass and mangrove. The selected sites were distributed alongside: seven sites designated on the Red Sea proper, nine sampling sites at the Gulf of Suez and three at the Aqaba Gulf.

Sampling sites

Nineteen sites were scheduled along the Egyptian Red Sea coasts for samples collection concerning pollution sources and ecological habitats. Nine stations were in the Gulf of Suez (SG1 – SG9) from Port Tawfic to El-Tur City. Three stations were in the Aqaba Gulf (AG1 – AG3) from Nuweibaa City to Sharm El-Sheikh City. Seven stations were in the Red Sea proper (RS1 – RS7) from north of Hurghada City to Shalateen City (Fig. 1).

Sampling

Sediments were sampled biannual through winter and summer of 2019 at the intertidal zone of the investigated sites (Fig. 1), Sediments were sampled using plastic spatula, stored in plastic bags, then transported to the lab, dried at ambient temperature, and kept until investigation.

Heavy metals measurement

Dry sediments were retained by a sieve, and 0.5 g of the portion of < 0.063 mm was extracted using conc. HNO_3, $HClO_4$ and HF acids (with a ratio of 3:2:1), in Teflon containers and leftward overnight (Oregioni and Aston, 1984). Samples were heated at about 100 ºC for 2 hrs., cool and dilute to 15 ml by de-ionized waters. Metals were analyzed using FAAS-Flame Atomic Absorption Spectrophotometer (Perkin Elmer model AAnalyst 100). The obtained results were definite as µg/g.

Solutions, standard, and blanks were prepared freshly using de-ionized distilled water. The vessels and glassware were soaked in 10% HNO_3 overnight and rinsed by distilled water. Accuracy of the method was confirmed by investigating replicate measurements of the investigated metals in sediment sample. The attained results displayed a precision of 7.3 – 14.8 % for the studied metals.

Statistical analysis

Data of the heavy metals were handled by analysis of variance “ANOVA” to detect the variations amongst seasons and regions mean concentrations (at $p \leq 0.05$). In addition, Tukey, Fisher, Bonferroni and Duncan tests were used further to describe the variance position in the significant data. XLSTAT 2014.5.03 software, Origin Pro 9 and Excel were used for the data processing.

Results and Discussion

Heavy metals concentration in sediments

The examined metals (Pb, Cd, Cu, Zn, Co, Ni, Mn and Fe) in sediments collected in winter and summer from the different studied sites alongside the Egyptian part of the Red Sea is presented in Tables (1-3). The annual mean in each part “Gulf of Suez, Aqaba Gulf & Red Sea proper” is existing in Figure (2). In general, it can be observed that the mean value, through all the investigated sites, of Fe indicated the maximum value (12520.07 µg/g) followed by Mn (128.93 µg/g) then Zn (46.41 µg/g), Pb (20.21 µg/g), Ni (18.14 µg/g), Co (11.35 µg/g), Cu (4.79 µg/g), and Cd was the lowest metal (2.08 µg/g).

Concerning the seasonal difference, in the sediment samples all the studied metals showed the highest mean during winter season except Cu and Fe were in the summer season. In agree with the current examination, Abouhend and El-Moselhy (2015) stated a slight temporal variation of metal levels in sediment samples from northern region of the Red Sea with rise levels in winter and autumn times. Contrary, Bazzi (2014) and El-Moselhy etal. (2016) reported that the highest studied metals were presented in summer. Owing to unstable weather, strong waves and water actions during late autumn and early winter, the suspended matter's loaded soluble metals are precipitated in the sediments in addition to the decay of the suspended microorganisms. In this situation, Duman and Kar (2012) indicated that the common suspended matters in water is strongly attracted to bind metals, and form a complex with suspended particles, which subsequently precipitate in the bottom sediments. In addition, sediments are considering the most significant main sink of metals in coastal waters owing to their strong metal-adsorbing ability (Pan and Wang, 2011). Significant different between average values of metals in the two investigated seasons was treated using ANOVA analysis; the results showed that only Cd exposed significant variance amongst the two seasons ($p < 0.05$), whereas the other metals displayed non-significant variances ($p > 0.05$).

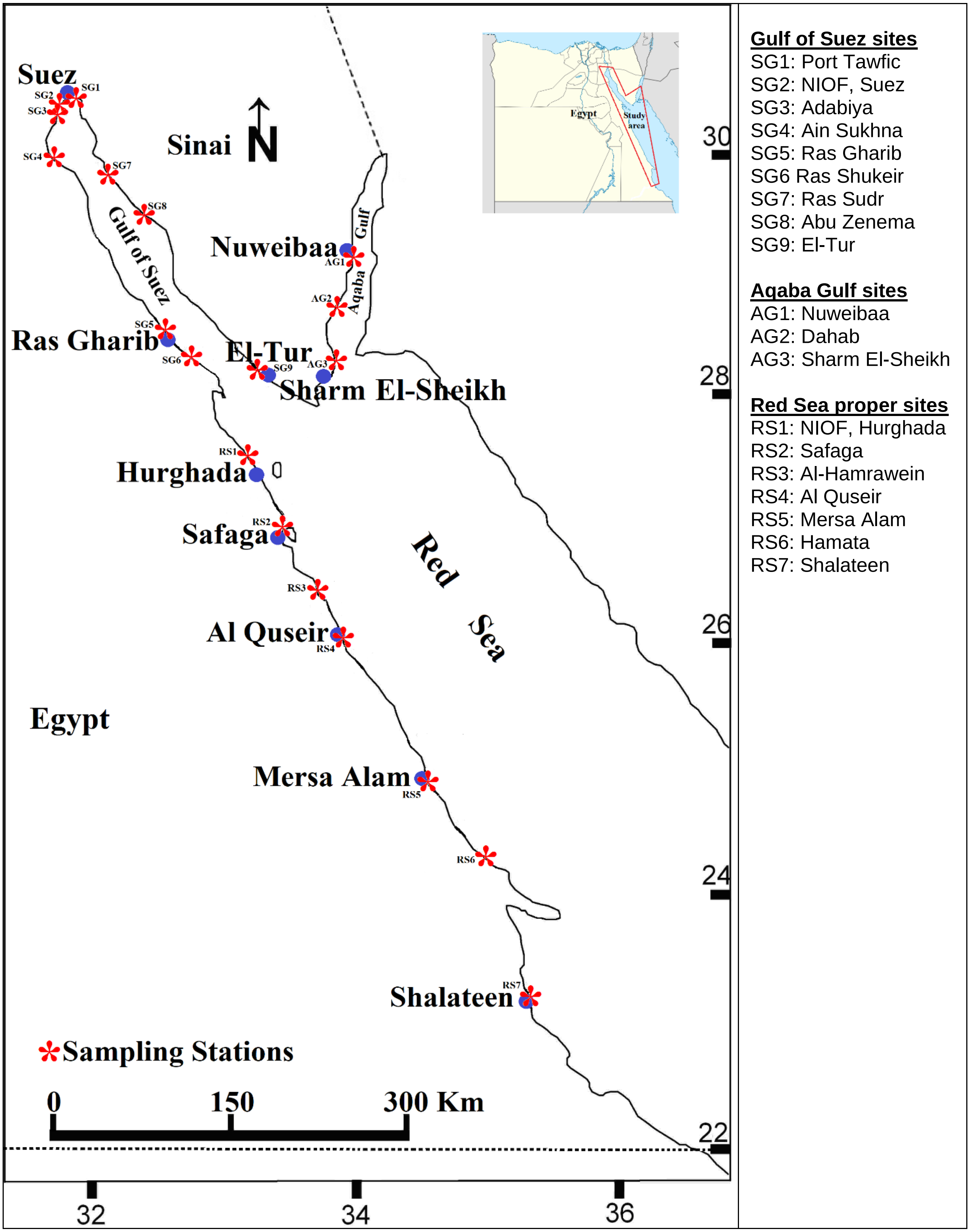

Figure (1): Map of the Egyptian Red Sea showing the sampling sites

Table (1): Values of heavy metals (µg/g) in sediment samples from the Gulf of Suez during winter and summer 2019.

Metal	Season	Gulf of Suez								
		SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9
Pb	Winter	29.33	28.92	24.76	24.17	25.90	21.29	21.82	10.49	20.22
	Summer	17.80	26.82	37.30	22.68	23.21	21.88	20.14	16.37	20.09
	Mean	**23.57**	**27.87**	**31.03**	**23.43**	**24.56**	**21.59**	**20.98**	**13.43**	**20.16**
Cd	Winter	2.92	3.56	3.17	3.34	2.89	2.72	3.12	1.55	2.26
	Summer	1.34	2.83	3.52	3.21	2.13	2.59	2.93	1.83	2.25
	Mean	**2.13**	**3.20**	**3.35**	**3.28**	**2.51**	**2.66**	**3.03**	**1.69**	**2.26**
Cu	Winter	6.17	2.52	3.55	1.97	5.14	1.33	1.76	1.78	2.28
	Summer	3.85	7.51	10.14	4.83	2.84	1.95	2.27	3.94	2.69
	Mean	**5.01**	**5.02**	**6.85**	**3.40**	**3.99**	**1.64**	**2.02**	**2.86**	**2.49**
Zn	Winter	31.75	29.29	32.48	17.99	27.61	17.54	17.92	28.30	25.19
	Summer	20.39	45.93	55.25	13.37	12.68	8.74	10.15	27.84	14.09
	Mean	**26.07**	**37.61**	**43.87**	**15.68**	**20.15**	**13.14**	**14.04**	**28.07**	**19.64**
Co	Winter	13.44	15.14	13.31	14.90	13.61	11.93	13.03	6.18	10.20
	Summer	6.91	12.24	14.86	12.83	10.32	10.77	12.69	9.39	10.09
	Mean	**10.18**	**13.69**	**14.08**	**13.87**	**11.97**	**11.35**	**12.86**	**7.79**	**10.15**
Ni	Winter	18.74	32.75	19.26	19.57	17.94	15.10	17.99	10.08	13.79
	Summer	8.93	32.98	21.23	16.06	11.70	12.78	14.96	14.21	12.65
	Mean	**13.84**	**32.87**	**20.24**	**17.82**	**14.82**	**13.94**	**16.48**	**12.15**	**13.22**
Mn	Winter	85.54	77.35	40.74	60.67	99.71	22.92	50.60	36.99	95.39
	Summer	58.40	105.60	83.88	80.10	34.55	34.10	42.40	113.90	94.20
	Mean	**71.97**	**91.48**	**62.31**	**70.39**	**67.13**	**28.51**	**46.50**	**75.45**	**94.80**
Fe	Winter	5176	2125	2621	3490	5342	821.0	3391	3035	2232
	Summer	3916	5093	5988	3661	2017	866.4	1620	15711	2025
	Mean	**4546.0**	**3609.0**	**4304.5**	**3575.5**	**3679.5**	**843.7**	**2505.5**	**9373.0**	**2128.5**

Table (2): Values of heavy metals (µg/g) in sediment samples from the Aqaba Gulf during winter and summer 2019.

Metal	Season	Aqaba Gulf		
		AG1	AG2	AG3
Pb	Winter	15.14	20.70	22.75
	Summer	15.03	25.78	11.24
	Mean	**15.09**	**23.24**	**17.00**
Cd	Winter	1.66	1.88	2.13
	Summer	0.93	1.61	0.91
	Mean	**1.30**	**1.75**	**1.52**
Cu	Winter	2.23	5.32	3.35
	Summer	2.53	10.15	2.01
	Mean	**2.38**	**7.74**	**2.68**
Zn	Winter	19.72	53.25	95.96
	Summer	39.66	80.21	8.67
	Mean	**29.69**	**66.73**	**52.32**
Co	Winter	7.68	14.27	12.73
	Summer	5.85	19.45	4.89
	Mean	**6.77**	**16.86**	**8.81**
Ni	Winter	10.61	17.02	13.91
	Summer	6.17	19.83	5.88
	Mean	**8.39**	**18.42**	**9.90**
Mn	Winter	66.55	30.84	419.60
	Summer	70.40	399.00	33.50
	Mean	**68.48**	**214.92**	**226.55**
Fe	Winter	3455	36040	23230
	Summer	2964	64750	2676
	Mean	**3209.5**	**50395.0**	**12953.0**

Table (3): Values of heavy metals (µg/g) in sediment samples from the Red Sea proper during winter and summer 2019.

Metal	Season	Red Sea proper						
		RS1	RS2	RS3	RS4	RS5	RS6	RS7
Pb	Winter	24.85	16.51	22.42	21.07	23.83	12.96	23.89
	Summer	13.80	9.71	25.00	25.41	20.18	8.15	21.52
	Mean	**19.33**	**13.11**	**23.71**	**23.24**	**22.01**	**10.56**	**22.71**
Cd	Winter	2.63	1.74	2.68	2.05	2.46	1.46	4.05
	Summer	1.27	0.72	2.34	1.87	1.52	0.70	3.26
	Mean	**1.95**	**1.23**	**2.51**	**1.96**	**1.99**	**1.08**	**3.66**
Cu	Winter	3.01	2.58	6.35	7.36	18.68	3.27	2.21
	Summer	2.19	3.02	7.65	12.30	12.65	2.54	5.99
	Mean	**2.60**	**2.80**	**7.00**	**9.83**	**15.67**	**2.91**	**4.10**
Zn	Winter	22.15	24.50	28.77	43.57	550.00	33.77	19.00
	Summer	9.31	12.78	51.54	59.84	40.30	14.06	6.15
	Mean	**15.73**	**18.64**	**40.16**	**51.71**	**295.15**	**23.92**	**12.58**
Co	Winter	12.61	9.61	13.83	9.72	18.03	9.98	16.84
	Summer	6.41	5.47	13.05	12.21	13.55	5.86	13.35
	Mean	**9.51**	**7.54**	**13.44**	**10.97**	**15.79**	**7.92**	**15.10**
Ni	Winter	15.81	12.12	28.89	28.52	84.85	13.15	25.08
	Summer	7.83	6.47	23.53	32.34	46.93	6.02	17.27
	Mean	**11.82**	**9.30**	**26.21**	**30.43**	**65.89**	**9.59**	**21.18**
Mn	Winter	161.50	92.85	201.80	121.60	284.20	192.70	40.61
	Summer	67.90	86.30	258.70	187.40	261.10	90.40	41.80
	Mean	**114.70**	**89.58**	**230.25**	**154.50**	**272.65**	**141.55**	**41.21**
Fe	Winter	7323	9660	10280	8954	35120	13390	5480
	Summer	2025	4686	17422	18422	20100	7093	1518
	Mean	**4674.0**	**7173.0**	**13851.0**	**13688.0**	**27610.0**	**10241.5**	**3499.0**

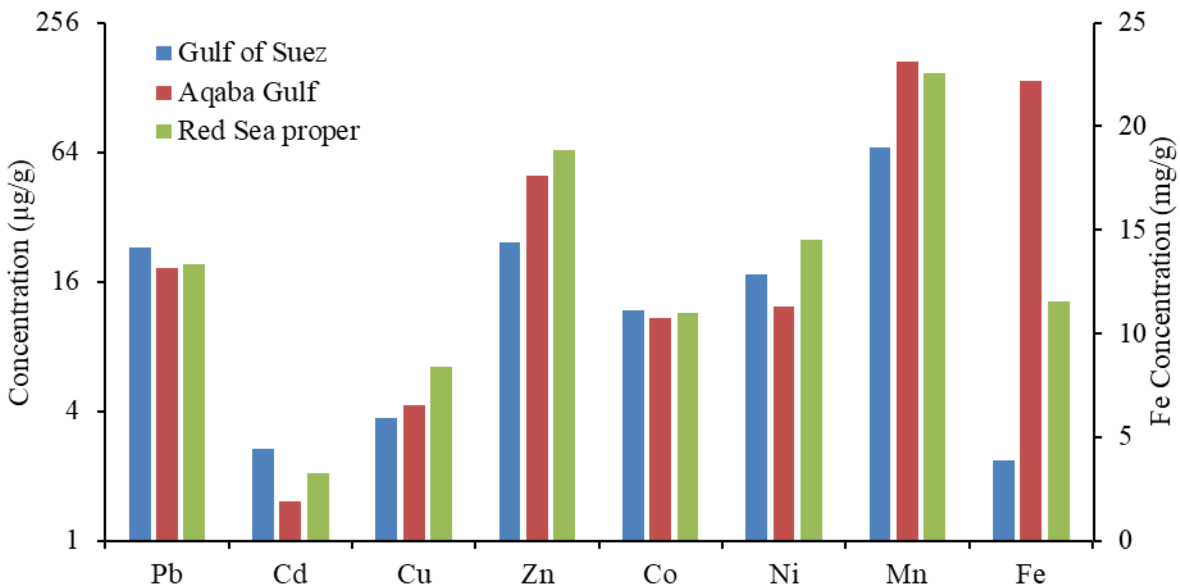

Figure (2): Annual mean concentrations of heavy metals in sediments (µg/g) from different regions of the Red Sea.

According to the local differences of the examined metals along the studied regions. It could be noticed that Pb, Cd and Co revealed the highest annual average (22.96, 2.68 and 11.77 µg/g, respectively) in the Gulf of Suez sediments. Copper, zinc and nickel (6.41, 65.41 and 24.92 µg/g, respectively) were presented in the Red Sea proper. Whereas, Mn and Fe (169.98 and 11533.8 µg/g, respectively) showed the highest annual mean in the Aqaba Gulf (Fig. 2). Existence of the studied metals over all the investigated regions pointed out that there is a specific-metal-area depends on contamination sources. Industrial and oil activities in addition to shipping and harbor activities characterized the Gulf of Suez sites, and showing high non-essential metals (Cd and Pb). On the other hand, essential metals (Zn, Cu, Fe and Mn) were found in Aqaba Gulf and Red Sea proper that characterized by natural sources as wind-loading fine sand from the nearby mountains and valleys flood. Land-based activities, ships & harbors activities, and industrial & sewage drains are the main metals contamination sources in Gulf of Suez (El-Moselhy etal., 1999 & 2016 and El-Moselhy & Gabal, 2004). Instead, the minimum annual average of Cd, Pb Co and Ni were found in the Aqaba Gulf, which is far from contamination sources. While Cu, Zn, Mn and Fe revealed their minimum annual mean in the Gulf of Suez region. Regarding the statistical analysis, mean values of Cd, Mn and Fe displayed significant variances ($p < 0.05$) between the different investigated regions, while the other metals showed insignificant variations ($p > 0.05$). Furthermore, the high mean of Cd and the opposing, low mean of Mn in sediments from the Gulf of Suez were the values responsible on the significant variations within different regions. Relating to Fe levels, the remarkably high mean in the Aqaba Gulf and very low mean in the Gulf of Suez were accompanying to display the significance different.

Heavy metals in the sediments of current studied regions were found within range of the other studies in the Egyptian coastal regions and elsewhere (Hamed & El-Moselhy, 2000; El-Moselhy & Gabal, 2004; El-Moselhy & Hamed, 2006; Abouhend & El-Moselhy, 2015; Zaghloul, 2015; Saad etal., 2016; El-Moselhy etal., 2016; El-Metwally etal., 2017 & 2019; El-Amier etal., 2021; Tepe etal., 2022; Feki etal., 2022; Tian etal., 2022 and Radomirović etal., 2023). By comparing the present results with background levels and typical concentrations of metals in sediment samples, which were 20 (Pb), 0.3 (Cd), 45 (Cu), 95 (Zn), 19 (Co), 68 (Ni), 850 (Mn) and 47200 µg/g (Fe) (Turekian & Wedepohl, 1961 and Armiento etal., 2022). We can be noticed that the annual means of metals in the current investigation displayed lower levels, with the exception of Cd from all studied sites, Pb in the most investigated sites and Fe in site AG2, which found higher than the background values.

Assessment of heavy metals contamination

In the current valuation, delineate of the background values of studied metals is an essential influence. In the sediments, many researches used the mean values of shale as reference backgrounds to definite the distribution of the metals in the Earth's crust (Turekian & Wedepohl, 1961; Wedepohl, 1995; Loska & Danuta, 2003; Goher etal., 2014; El-Moselhy etal., 2016 and Armiento etal., 2022). The background values were 20, 0.3, 45, 95, 19, 68, 850 and 47200 µg/g for Pb, Cd, Cu, Zn, Co, Ni, Mn and Fe, respectively. To evaluate the pollution degree in the sediments collected from the current investigated regions, the most regularly used indices were calculated, such as contamination factor (CF), metal pollution index (MPI), pollution load index (PLI), geo-accumulation index (I_{geo}) and enrichment factor (EF) (Muller, 1969 & 1981; Hakanson, 1980; Tomlinson etal., 1980; Sinex & Helz, 1981; Usero etal., 2005 and Mmolawa etal., 2011). The indices were estimated according to the following formulae:

$$\textit{Contamination Factor}\ (CF) = C_{sample} / C_{backgroung} \quad \textbf{(1)}$$

Where C_{sample} is a given sample's metal concentration and $C_{background}$ is baseline metal concentration. Hence, the values of CF can show the enrichment of a metal in samples above a limited time. Hakanson (1980) divided the level of pollution according to the following categorizations: CF<1 means low contamination, 1≤CF<3 shows moderate contamination, 3≤CF< 6 refers to considerable contamination, and CF>6 shows very high contamination. In the present study, the level of CF in sediments displayed the ranges of 0.02 - 12.18 (Tables 4), with a high value of Cd (3.60 - 12.18). Permitting to Hakanson classifications, the current studied regions were differed among low and moderate contamination except for Cd that reflected very high contaminated sediments particularly in Gulf of Suez and Red Sea proper sites.

$$\textit{Pollution load index}\ (PLI) = (CF_1 \times CF_2 \times CF_3 \ldots CF_n)^{1/n} \quad \textbf{(2)}$$

Where n is metal number, and CF is contamination factor. Multi-metal index PLI could be used to evaluate the overall sample pollution, if the values of PLI are <1, it recommends a low level of contamination, a value of one shows the presence of only a baseline level of contaminants and values above one indicate progressive deterioration of the site quality. In the aquatic environments, the contamination level was commonly assessed by using the pollution load index - PLI (Tomlinson etal., 1980; Shams El-Din etal., 2014; El-Moselhy etal., 2016 and Armiento etal., 2022). Mean values of the estimated PLI in the present study fluctuated between 0.35 - 0.53 showing a low pollution level (Table 4).

$$\textit{Metal pollution index}\ (MPI) = (M_1 \times M_2 \times M_3 \ldots M_n)^{1/n} \quad \textbf{(3)}$$

Where n is metal number and M is metal concentration. The calculation of the MPI used to evaluate quality of the study regions.

Table (4): Values of contamination factors (CF), pollution load index (PLI) and metal pollution index (MPI) in the sediments collected from the Egyptian Red Sea regions during 2019

Region		CF								PLI	MPI
		Pb	Cd	Cu	Zn	Co	Ni	Mn	Fe		
Gulf of Suez	SG1	1.18	7.10	0.11	0.27	0.54	0.20	0.08	0.10	0.35	27.23
	SG2	1.39	10.65	0.11	0.40	0.72	0.48	0.11	0.08	0.46	35.45
	SG3	1.55	11.15	0.15	0.46	0.74	0.30	0.07	0.09	0.45	35.25
	SG4	1.17	10.92	0.08	0.17	0.73	0.26	0.08	0.08	0.34	26.65
	SG5	1.23	8.37	0.09	0.21	0.63	0.22	0.08	0.08	0.34	26.12
	SG6	1.08	8.85	0.04	0.14	0.60	0.21	0.03	0.02	0.21	16.18
	SG7	1.05	10.08	0.04	0.15	0.68	0.24	0.05	0.05	0.28	21.42
	SG8	0.67	5.63	0.06	0.30	0.41	0.18	0.09	0.20	0.31	24.31
	SG9	1.01	7.52	0.06	0.21	0.53	0.19	0.11	0.05	0.29	22.25
	Mean	**1.15**	**8.92**	**0.08**	**0.26**	**0.62**	**0.25**	**0.08**	**0.08**	**0.35**	**27.09**
Aqaba Gulf	AG1	0.75	4.32	0.05	0.31	0.36	0.12	0.08	0.07	0.24	19.03
	AG2	1.16	5.82	0.17	0.70	0.89	0.27	0.25	1.07	0.69	53.82
	AG3	0.85	5.07	0.06	0.55	0.46	0.15	0.27	0.27	0.40	31.32
	Mean	**0.92**	**5.07**	**0.09**	**0.52**	**0.57**	**0.18**	**0.20**	**0.47**	**0.47**	**36.21**
Red Sea proper	RS1	0.97	6.50	0.06	0.17	0.50	0.17	0.13	0.10	0.30	23.50
	RS2	0.66	4.10	0.06	0.20	0.40	0.14	0.11	0.15	0.27	21.01
	RS3	1.19	8.37	0.16	0.42	0.71	0.39	0.27	0.29	0.59	45.63
	RS4	1.16	6.53	0.22	0.54	0.58	0.45	0.18	0.29	0.58	44.84
	RS5	1.10	6.63	0.35	3.11	0.83	0.97	0.32	0.58	1.02	79.44
	RS6	0.53	3.60	0.06	0.25	0.42	0.14	0.17	0.22	0.30	23.31
	RS7	1.14	12.18	0.09	0.13	0.79	0.31	0.05	0.07	0.33	25.81
	Mean	**0.96**	**6.85**	**0.14**	**0.69**	**0.60**	**0.37**	**0.18**	**0.24**	**0.53**	**41.10**

In the current study, MPI mean values ranged between 27.09 - 41.10 (Table 4). As recorded in PLI, MPI showed its maximum values in the Red Sea proper. MPI was used before to assess the metal pollution in sediments, and compare the contamination grade among localities (El-Sikaily, 2008 and El-Moselhy etal., 2016).

$$Geo - accumulation\ index\ (I_{geo}) = Log_2\ (C_m/1.5B_m) \quad (4)$$

Where, C_m is the determined level of a metal in sediments, B_m is the geochemical background level in average shale of metal m, and factor 1.5 is the background matrix correction due to terrigenous effects. The geo-accumulation index (I_{geo}) was recognized into seven classes as follows (Muller, 1981) (Table 5):

Table (5): The geo-accumulation index classifications

Value of I_{geo}	Class of I_{geo}	Sediments Quality
≤0	0	Unpolluted
0–1	1	unpolluted - moderately polluted
1–2	2	Moderately polluted
2–3	3	moderately - strongly polluted
3–4	4	Strongly polluted
4–5	5	strongly - extremely polluted
>5	6	Extremely polluted

Geo-accumulation index (I_{geo}) describes contamination degree of sediment samples. In the present investigation region, values of I_{geo} are presented in Table (6). I_{geo} exhibited mean values less than 0 for all studied metal except Cd with mean values of 2.57, 1.76 and 2.19 for sediments from Gulf of Suez, Aqaba Gulf, and Red Sea proper, respectively. Concerning the Muller classifications, all studied metal (except Cd) reflected unpolluted sediments in all the investigated regions. For Cd, Aqaba Gulf showed moderately polluted sediments, while Gulf of Suez and Red Sea proper revealed moderately to strongly contaminated sediments.

Table (6): Geo-accumulation index (I_{geo}) of heavy metals in the sediments collected from the Egyptian Red Sea regions during 2019

Site		Pb	Cd	Cu	Zn	Co	Ni	Mn	Fe
Gulf of Suez	**SG1**	-0.35	2.24	-3.75	-2.45	-1.49	-2.88	-4.15	-3.96
	SG2	-0.11	2.83	-3.75	-1.92	-1.06	-1.63	-3.80	-4.29
	SG3	0.05	2.89	-3.30	-1.70	-1.02	-2.33	-4.35	-4.04
	SG4	-0.36	2.86	-4.31	-3.18	-1.04	-2.52	-4.18	-4.31
	SG5	-0.29	2.48	-4.08	-2.82	-1.25	-2.78	-4.25	-4.27
	SG6	-0.47	2.56	-5.36	-3.44	-1.33	-2.87	-5.48	-6.39
	SG7	-0.52	2.75	-5.07	-3.34	-1.15	-2.63	-4.78	-4.82
	SG8	-1.16	1.91	-4.56	-2.34	-1.87	-3.07	-4.08	-2.92
	SG9	-0.57	2.33	-4.76	-2.86	-1.49	-2.95	-3.75	-5.06
	Mean	**-0.39**	**2.57**	**-4.19**	**-2.55**	**-1.28**	**-2.56**	**-4.24**	**-4.20**
Aqaba Gulf	**AG1**	-0.99	1.52	-4.83	-2.26	-2.07	-3.60	-4.22	-4.46
	AG2	-0.37	1.96	-3.13	-1.09	-0.76	-2.47	-2.57	-0.49
	AG3	-0.82	1.76	-4.65	-1.45	-1.69	-3.37	-2.49	-2.45
	Mean	**-0.70**	**1.76**	**-3.98**	**-1.52**	**-1.40**	**-3.06**	**-2.91**	**-1.67**
Red Sea proper	**RS1**	-0.63	2.12	-4.70	-3.18	-1.58	-3.11	-3.47	-3.92
	RS2	-1.19	1.45	-4.59	-2.93	-1.92	-3.46	-3.83	-3.30
	RS3	-0.34	2.48	-3.27	-1.83	-1.08	-1.96	-2.47	-2.35
	RS4	-0.37	2.12	-2.78	-1.46	-1.38	-1.75	-3.04	-2.37
	RS5	-0.45	2.14	-2.11	1.05	-0.85	-0.63	-2.23	-1.36
	RS6	-1.51	1.26	-4.54	-2.57	-1.85	-3.41	-3.17	-2.79
	RS7	-0.40	3.02	-4.04	-3.50	-0.92	-2.27	-4.95	-4.34
	Mean	**-0.64**	**2.19**	**-3.40**	**-1.12**	**-1.31**	**-2.03**	**-3.10**	**-2.62**

$$EF = (Me/Fe)_{sample} / (Me/Fe)_{backgroud} \quad (5)$$

Where $(Me/Fe)_{sample}$ is metal to Fe ratio in the sediments sample, $(Me/Fe)_{background}$ is background value of metal to Fe ratio. According to Mmolawa etal. (2011), EF was recognized into the following categories (Table 7):

Table (7): Categories of Enrichment factor

Enrichment Factor (EF)	Categories of EF
EF<2	Deficiency - minimal enrichment
2≤EF<5	Moderate enrichment
5≤EF<20	Significant enrichment
20≤EF<40	Very high enrichment
EF≥40	Extremely high enrichment

Values of enrichment factor for the present studied metal are found in Table (8). Only Cd in the sediments from the Gulf of Suez was extremely high enrichment (EF > 40), while in the Red Sea proper was very high enrichment (EF < 40). Other EF values for all metals varied between minimal (EF < 2) and significant (EF < 20) enrichment. EF of heavy metals in the different investigated region displayed the following order: Gulf of Suez > Red Sea proper > Aqaba Gulf.

Table (8): Enrichment factor (EF) of heavy metals in the sediments collected from the Egyptian Red Sea regions during 2019

Site		Pb	Cd	Cu	Zn	Co	Ni	Mn
Gulf of Suez	**SG1**	12.23	73.72	1.16	2.85	5.56	2.11	0.88
	SG2	18.22	139.29	1.46	5.18	9.42	6.32	1.41
	SG3	17.01	122.26	1.67	5.06	8.13	3.26	0.80
	SG4	15.46	144.11	1.00	2.18	9.63	3.46	1.09
	SG5	15.75	107.33	1.14	2.72	8.08	2.80	1.01
	SG6	60.38	495.10	2.04	7.74	33.42	11.47	1.88
	SG7	19.76	189.96	0.84	2.78	12.75	4.56	1.03
	SG8	3.38	28.37	0.32	1.49	2.06	0.90	0.45
	SG9	22.35	166.68	1.22	4.58	11.84	4.31	2.47
	Mean	**14.11**	**109.61**	**1.01**	**3.14**	**7.61**	**3.12**	**0.98**
Aqaba Gulf	**AG1**	11.09	63.48	0.78	4.60	5.24	1.81	1.18
	AG2	1.09	5.45	0.16	0.66	0.83	0.25	0.24
	AG3	3.10	18.46	0.22	2.01	1.69	0.53	0.97
	Mean	**1.96**	**10.78**	**0.20**	**1.11**	**1.21**	**0.38**	**0.43**
Red Sea proper	**RS1**	9.76	65.64	0.58	1.67	5.05	1.76	1.36
	RS2	4.31	26.98	0.41	1.29	2.61	0.90	0.69
	RS3	4.04	28.51	0.53	1.44	2.41	1.31	0.92
	RS4	4.01	22.53	0.75	1.88	1.99	1.54	0.63
	RS5	1.88	11.34	0.60	5.31	1.42	1.66	0.55
	RS6	2.43	16.59	0.30	1.16	1.92	0.65	0.77
	RS7	15.31	164.35	1.23	1.79	10.72	4.20	0.65
	Mean	**3.94**	**28.01**	**0.58**	**2.82**	**2.47**	**1.50**	**0.72**

Conclusion

Red Sea is an essential water body joining the south countries with the north world. However, Egyptian Red Sea coast suffered from various pollution sources as the industrial activities, several land-based activities, oil production, shipping, mining, and tourism. All these activates are considering as significant metals pollution sources in the Red Sea. Concentrations of the current investigated metals (Pb, Cd, Cu, Zn, Co, Ni, Mn and Fe) in sediments collected from Red Sea proper, Gulf of Suez and Aqaba Gulf were varied amongst regions and seasons. As well as, contamination indices (CF, PLI, MPI, I_{geo} and EF) in sediments were used to define the pollution degree of heavy metals in the investigated regions, they showed that the present regions had low and moderate contamination with considerable pollution of Cd. Gulf of Suez, which characterized by several activities as petroleum, industrial, harbor and shipping, revealed high values of non-essential toxic metals (Pb and Cd). In which, essential metals (Cu, Zn, Mn and Fe) were recorded in the Aqaba Gulf and Red Sea proper, that characterized by natural sources of pollution.

References

Abdel Zaher, M.; Saibi, H.; El Nouby, M.; Ghamry, E. and Ehara, S. (2011). A preliminary regional geothermal assessment of the Gulf of Suez, Egypt. *J. Afr. Earth Sci*., 60: 117–132.

Abouhend, A.S. and El-Moselhy, Kh,M. (2015). Spatial and seasonal variations of heavy metals in water and sediments at the northern Red Sea coast. *Amer. J. Water Resour*., 3(3): 73-85.

Armiento, G.; Barsanti, M.; Caprioli, R.; Chiavarini, S.; Conte, F.; Crovato, C.; De Cassan, M.; Delbono, I.; Montereali, M.R.; Nardi, E.; Parrella, L.; Pezza, M.; Proposito, M.; Rimauro, J.; Schirone, A. and Spaziani, F. (2022). Heavy metal background levels and pollution temporal trend assessment within the marine sediments facing a brownfield area (Gulf of Pozzuoli, Southern Italy). *Environ. Monit. Assess*., 194: 814. https://doi.org/10.1007/s10661-022-10480-3

Bazzi, A.O. (2014). Heavy metals in seawater, sediments and marine organisms in the Gulf of Chabahar, Oman Sea. *J. Oneanogr. & Mar. Sci*., 5(3): 20–29.

Boxberg, F.; Asendorf, S.; Bartholomä, A.; Schnetger, B.; de Lange, W. P. and Hebbeln, D. (2020). Historical anthropogenic heavy metal input to the south-eastern North Sea. *Geo-Marine Letters*, 40: 135–148.

Duman, F. and Kar, M. (2012). Temporal variation of metals in water, sediment and tissues of the European Chup (*Squalius cephalus*). *Bull. Envi. Contam. Toxi*., 89: 428-433.

El-Amier, Y.A.; El-Alfy, M.A.; Darwish, D.H.; Basiony, A.I.; Mohamedien, L.I. and El-Moselhy, Kh.M. (2021). Distribution and ecological risk assessment of heavy metals in core sediments of Burullus Lake, Egypt. *Egypt. J. Aquat. Biol. Fisher*., 25(1): 1041-1059.

El Mamoney, M.H. and Khater, A.E.M. (2004). Environmental characterization and radio-ecological impacts of non-nuclear industries on the Red Sea coast. *J. Environ. Radioact*., 73: 151–168.

El-Metwally, M.E.A. (2014). Monitoring of heavy metals pollution in the Egyptian Red Sea coast and response of marine organisms. Ph. D. Thesis, Fac. Sci., Mansoura Univ., pp. 275.

El-Metwally, M.E.A.; Abouhend, A.S.; Dar, M.A. and El-Moselhy, Kh.M. (2017). Effects of urbanization on the heavy metal concentrations in the Red Sea coastal sediments, Egypt. *Internat*. *J. Mar. Sci*., 7(13): 114-124.

El-Metwally, M.E.A.; Othman, A.I. and El-Moselhy, Kh.M. (2019). Distribution and assessment of heavy metals in the coastal area of the Red Sea, Egypt. *Egypt. J. Aquat. Biol. & Fisher*., 23(2): 1-13.

El-Moselhy, Kh.M. and Gabal, M.N. (2004). Trace metals in water, sediments and marine organisms from the northern part of the Gulf of Suez, Red Sea. *J. Mar. Sys*., 46: 39–46.

El-Moselhy, Kh.M. and Hamed, M.A. (2006). Impact of land-based activities on hydrographic condition and level of heavy metals in water and sediments along the Mediterranean coast of Egypt. *Egypt. J. Aquat. Res*., 32(2): 63-82.

El-Moselhy, Kh.M.; Diab, A.A.; Tolba, M.R. and Mohamadein, L.I. (1999). Levels of some heavy metals in coastal water, sediment and the limpet Patella sp. from the northern part of the Gulf of Suez (Suez Bay). *Egypt. J. Aquat. Biol. & Fish*., 3(2): 69-84.

El-Moselhy, Kh. M.; Saad, E. M.; El-Shaarway, R. F.; Mohamadein, L. I. and Mahmoud, S. A. (2016). Assessment of heavy metals pollution using sediments and bivalve *Brachidontes variabilis* as bioindicator in the Gulf of Suez, Egypt. *Inter. J. Mar. Sci*., 6(26): 1 – 13. https://doi: 10.5376/ijms.2016.06.0025

El-Sikaily, A. (2008). Assessment of some heavy metals pollution in the sediments along the Egyptian Mediterranean coast. *Egypt. J. Aquat. Res*., 34(3): 58-71.

Farhat, H.I.; Gad, A.; Saleh, A. and Abd El Bakey, S.M. (2022). Risks assessment of potentially toxic elements' contamination in the Egyptian Red Sea surficial sediments. *Land*, 11(9): 1560. https://doi.org/10.3390/land1109156

Feki, N.; Khannous, L.; Keskes, F.A.; Ben Slama, A. and Levacher, D. (2022). Mobility of trace metals and microbiological pollution from dredged sediments to the Gulf of Gabes, Tunisia. *Environ. Monit. Assess*., 194: 815. https://doi.org/10.1007/s10661-022-10451-8

Gao, X. L.; Zhuang, W.; Chen, C. T. A. and Zhang, Y. (2015). Sediment quality of the SW coastal Laizhou Bay, Bohai Sea, China: A comprehensive assessment based on the analysis of heavy metals. *PLoS One*, 10: e0122190.

Goher, M.E.; Farhat, H.I.; Abdo, M.H. and Salem, S.G. (2014). Metal pollution assessment in the surface sediment of Lake Nasser, Egypt. *Egypt. J. Aquat. Res*., 40: 213–224. http://dx.doi.org/10.1016/j.ejar.2014.09.004

Hakanson, L. (1980). An ecological risk index for aquatic pollution control a sedimentological approaches. *Water Research*, 14(8): 975-1001. https://doi:10.1016/0043-1354(80)90143-8

Hamed, M.A. and El-Moselhy, Kh.M. (2000). Levels of some metals in the coastal water and sediments of the Red Sea, Egypt. *A.M.S.E*., 61(1,2): 43 – 57.

Krishnakumar, P. K.; Qurban, M. A. and Sasikumar, G. (2018). Biomonitoring of trace metals in the coastal waters using bivalve molluscs. In: Saleh H.M. and El-Adham E., editors. Trace Elements - Human Health and Environment, intechopen press, pp. 153 - 176. http://dx.doi.org/10.5772/intechopen.76938

Lias, L.; Jamil, T. and Aliaa, S.N. (2013). A preliminary study on heavy metal concentration in the marine bivalves *Marcia marmorata* species and sediments collected from the coastal area of Kuala Perlis, North of Malaysia. *IOSR J. Appl. Chem*., 4(1): 48-54.

Loska, K. and Danuta, W. (2003). Application of principal component analysis for the estimation of source of heavy metal contamination in surface sediments from the Rybnik Reservoir. *Chemosphere*, 51: 723–733.

Manzoor, R.; Zhang, T. W.; Zhang, X. J.; Wang, M.; Pan, J. F.; Wang, Z. M. and Zhang, B. (2018). Single and combined metal contamination in coastal environments in China: Current status and potential ecological risk evaluation. *Environmental Science and Pollution Research*, 25: 1044–1054.

Meshal, A. H. (1970). Water pollution in Suez Bay. *Bull. Inst. Oceanogr. & Fish., ARE*., 1: 463-473.

Mmolawa, K.; Likuku, A. and Gaboutloeloe, G. (2011). Assessment of heavy metal pollution in soils along roadside areas in Botswana. *African Journal of Environmental Science and Technology*, 5(3): 186- 196.

Morcos, S.A. (1960). The tidal currents in the southern part of the Suez Canal. *Gen. Ass. Helsinki, Finland.*, 51: 307-316.

Muller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *GeoJournal*, 2(3): 108-118.

Muller, G. (1981). The heavy metal pollution of the sediments of Neckars and its tributary. *A Stocktaking Chemische Zeit*, 150: 157-164.

Oregioni, B. and Aston, S.R. (1984). The determination of selected trace metals in marine sediments by Flamless/Flam-atomic absorption spectrophotometery, JAEA Monaco Lab., International Report.

Pan, K. and Wang, W. X. (2011). Trace metal contamination in estuarine and coastal environments in China. *Sci. Total Envi*., 421(422): 3-16.

Radomirović, M.; Miletić, A. and Onjia, A. (2023). Accumulation of heavy metal(loid)s and polycyclic aromatic hydrocarbons in the sediment of the Prahovo Port (Danube) and associated risks. *Environ. Monit. Assess*., 195: 323. https://doi.org/10.1007/s10661-023-10926-2

Rainbow, P. S. (1990). Heavy metal levels in marine invertebrates. In: Furness R.W., Rainbow P.S., editors. Heavy metals in marine environment. Boca Raton, Florida: CRC Press, pp. 67 - 79.

Saad, A-E.A.; Emam, W.M.; El-Moselhy, Kh.M.; Abou El-Naga, E.H. and Baleg, A.O. (2016). Comparative study on some heavy metals in water, sediments and fish along the Suez Canal, Egypt. *Inter. J. Environ, Sci. & Engineer*. (*IJESE*), 7: 19–29.

Shams El-Din, N.G.; Mohamedein, L.I. and El-Moselhy, Kh.M. (2014). Seaweeds as bioindicators of heavy metals off a hot spot area on the Egyptian Mediterranean Coast during 2008–2010. *Environ. Monit. Assess*., 186(9): 5865–5881.

Sinex, S. and Helz, G. (1981). Regional geochemistry of trace elements in Chesapeak Bay sediments. *Environmental Geology*, 3(6): 315-323. https://doi:10.1007/BF02473521

Tepe, Y.; Şimşek, A.; Ustaoğlu, F. and Taş, B. (2022). Spatial–temporal distribution and pollution indices of heavy metals in the Turnasuyu Stream sediment, Turkey. *Environ. Monit. Assess*., 194: 818. https://doi.org/10.1007/s10661-022-10490-1

Tian, ZX.; Zhang, Y.; Mei, X.; Xiong, W.; Mi, B-B. and Wang Z-L. (2022). Spatial distribution and ecological risk assessment of heavy metals in surface sediments from the northern Bohai Strait, China. *Environ. Monit. Assess*., 194: 802. https://doi.org/10.1007/s10661-022-10470-5

Tomlinson, D.L.; Wilson, J.G.; Harris, C.R. and Jeffrey, D.W. (1980). Problems in the assessments of heavy metal levels in estuaries and formation of a pollution index. *Helgol Meeresunters*, 33: 566–575.

Turekian, K.K. and Wedepohl, K.H. (1961). Distribution of the elements in some major units of the earth's crust. *Geological Society of America Bulletin*, 72: 175-192. https:// doi.org/ 10. 1130/ 0016- 7606(1961) 72[175: DOTEIS] 2.0. CO;2

Usero, J.; Morillo, J. and Gracia, I. (2005). Heavy metal contamination in mollusks from the Atlantic coast of southern Spain. *Chemosphere*, 59: 1175-1181.

Wedepohl, K.H. (1995). The composition of the continental crust. *Geochim. Cosmochim. Acta*., 59: 1217–1232.

Xu, F. J.; Tian, X.; Yin, F.; Zhao, Y. F. and Yin, X. B. (2016). Heavy metals in the surface sediments of the northern portion of the South China Sea shelf: Distribution, contamination, and sources. *Environmental Science and Pollution Research International*, 23: 8940–8950.

Zaghloul, Gh.Y.H. (2015). Organic and Inorganic pollutants in Suez Canal. Ph. D. Thesis, Fac. Sci. (Girls Br.), Al Azhar Univ., pp. 269.

Zhang, Y.; Lu, X. Q.; Wang, N. L.; Xin, M. N.; Geng, S. W.; Jia, J. and Meng, Q. H. (2016). Heavy metals in aquatic organisms of different trophic levels and their potential human health risk in Bohai Bay, China. *Environmental Science and Pollution Research International*, 23: 17801–17810.