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Environmental Assessment of Heavy Metals in Coastal Water of Suez Bay, Northern Red Sea Coast

Mohannad M. Garoub[1] and Hamdy E. Nour*[2]

[1]***Environmental and Occupational Health Department, Faculty of Public Health and Health Informatics, Umm Al-Qura University, Makka, Saudi Arabia***
[2]***Geology Department, Faculty of Science, Zagazig University, Egypt***

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ABSTRACT

A variety of environmental indicators and multivariate statistical analyses were utilized to assess levels of heavy metal (HM) concentrations and to identify potential sources of pollution in coastal seawater samples collected from Suze Bay, Red Sea, Egypt. To accomplish this goal, the levels of HMs were assessed at 18 sites spanning across the majority of the Bay. The results revealed that the average concentration of various HMs (μg/l) was 3.404 for Ni, 2.73 for Cr, 2.72 for Fe, 1.74 for Zn, 1.05 for Cu, 0.85 for Mn, 0.224 for Pb, 0.193 for Cd, 0.054 for Hg and 0,038 for Co. Based on the values of HM evolution index (HEI), 83.3 % of the surface water samples were categorized as having low pollution (HEI < 5), while 16.7 % showed moderate pollution levels. Furthermore, the heavy metal pollution index (HPI) and the degree of water contamination (Cd) indicated low contamination levels, which reported that the water of Suez Bay is no threat to human health. The multivariate analysis suggested that the sources of the investigated metals were in some samples a combination of both human-related and natural factors. Natural sources are the weathering of rocks surrounding the area, while anthropogenic sources are associated with industrial and urbanization activities in the vicinity of the investigated bay. Importantly, these average HM concentrations were found to be within the maximum allowable limits set by the World Health Organization.

Key words: *Assessment, Environment, Coastal water, Red Sea, Suze Bay*

Introduction

Despite the importance of heavy metals (HMs) in the lives of living organisms, the increasing levels of their emissions into the environment through ongoing human industrial and local activities have a significant impact on ecological systems (Chen *et al*., 2007; Nour, 2015 and Al-Kahtany *et al*., 2023a). Even low levels of Pb, Hg, Cd, and Ni are classified as mutagenic and carcinogenic agents to humans, causing severe harm to living organisms and their diversity (Al-Kahtany *et al*., 2023b and Alharbi *et al*., 2023). The presence of HMs from natural sources in the environment as rock weathering and volcanic dust at low concentrations often does not have negative and harmful effects on the environment, while HMs from human sources are characterized by higher concentrations with severe negative environmental effects (Bazzi, 2014; Swarnalatha *et al*., 2015 and Nour *et al*., 2021). For example, coastal environments are known for their high biodiversity, but the presence of HM pollution due to chemical and oil spills, sewage, agricultural and industrial waste, and ship maintenance operations can lead to a severe and dangerous deterioration of the marine ecosystem in these vital regions (Gu *et al*., 2016 and

Aghadadashi *et al.*, 2019), which represent an important source of global food security.

Most countries continuously develop their coastal regions in search of economic prosperity and increased national income, but these activities often result in many negative impacts on the coastal environment. Since these pollutants, such as HMs, do not evenly disperse in the marine environment but are primarily concentrated in coastal waters and, subsequently, in beach sediments, coastal environments are considered crucial for ongoing environmental assessment and monitoring studies (Karadede and Unlu, 2000; and Nour and Nouh, 2020a). Especially since its survival time is very long in these environments.

Numerous environmental assessment studies have been conducted on coastal sediments along the Red Sea coasts and their associated environments (Shriadah *et al.*, 2004; Nour and Nouh 2020a,b and Al-Kahtany *et al*. 2023a,b). Some studies focused on assessing the environmental impact of HMs contamination in coastal sediment samples from the Suez Bay region (Nour and El-Sorogy, 2020 and Nour *et al.*, 2022). The researchers found that in certain locations, coastal sediments exhibited high concentrations of Cd and Hg, possibly due to the presence of ports, industrial activities, sanitation, shipbuilding workshops, and the heavy traffic of commercial ships. However, this study was not comprehensive as it did not examine the quality of coastal water or the distribution of HM concentrations within it. Environmental assessment studies of HMs in coastal water are relatively scarce. Therefore, the current study aims to investigate the distribution and evaluation of HM concentrations in coastal seawater along the Suez Bay using pollution indicators. Additionally, the study seeks to identify potential sources of HMs using various statistical criteria.

Materials and Methods

Study area and Sampling

Suez Baylocated in the northern Red Sea region of Egypt, constitutes the upper part of the Gulf of Suez and is of significant importance due to its industrial and economic activities. This area encompasses tourist resorts, oil and commercial ports, power generation stations, oil factories, and ship repair and maintenance workshops. Given the presence of these diverse facilities, environmental monitoring of this region is both crucial and necessary.

To facilitate this study, a total of 18 surface seawater samples were collected along the coast of Suez Bay (Fig. 1) by a polyethylene water sampler to an acidified polyethylene bottle. These samples were gathered randomly at various distances, reflecting the challenges of obtaining samples from certain restricted areas associated with companies, factories, ports, or government sites. The precise coordinates of each collection site were determined using the Global Positioning System (GPS). The collected samples were drawn from a range of locations, including a tourist resort beach (S1,2 and S5,6), a public beach (S3,4 and S17,18), a beach near El-Naser petroleum company (S7,8), a beach adjacent to Suez thermal power station (S9,10), a beach near El-Temsah shipyard (S11, 12), beach of Suez national institute of marine sciences and fisheries (S3,14), Arab oil and chemicals association drain (S15), and a beach near Arab oil and chemicals association factory (S16).

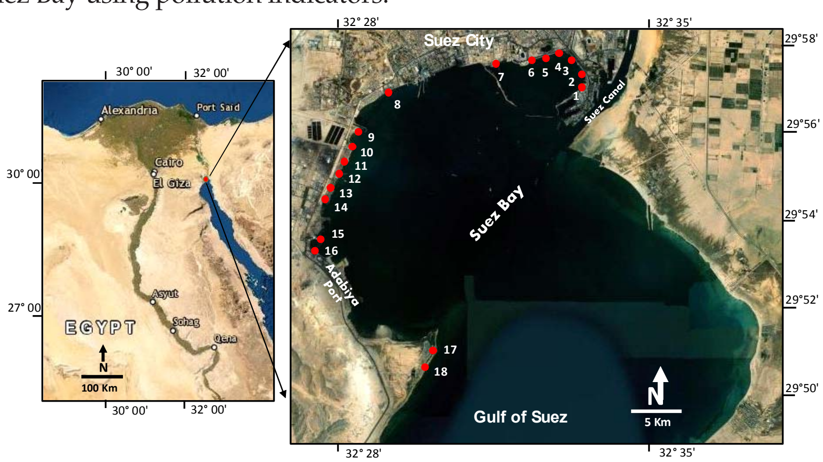

Fig. 1. Sampling and study area

Laboratory work and quality assurance

Eighteen water samples were collected in an acidified polyethylene bottle (approximately 1 liter each). Each sample filtered with o.45 µm and nitric acid (HNO_3, 70% concentration) was added to them (Vicente-Martorell *et al*., 2009). They were then transported in a cooler to the laboratory for analysis. Physicochemical parameters of seawater such as pH, salinity, temperature and dissolved oxygen were measured in situ. Subsequently, approximately 50 ml of each sample was digested using a mixture of concentrated nitric acid (HNO_3, 5 ml) and perchloric acid ($CHlO_4$, 2 ml), and the solution was left for 24 h to achieve complete digestion. Then, the samples were gradually heated from 100 to 225 C for 6 h. Afterward, each sample was diluted by adding up to 50 ml of distilled water before filtration, following water quality standards (APHA, 2005).A unified atomic absorption spectrophotometer (AAS) with a hydride generation system was used to determine the concentration of mercury in the Central Laboratory of the Faculty of Development and Technology at Zagazig University. This instrument was also used to measure the concentrations of Hg, Mn, Cu, Cd, Pb, Zn, Ni, Co, Cr and Fe in the studied samples.

To ensure the quality of the analyses, the device was calibrated and programmed to extract the required element concentrations. The relative standard deviation (RSD) values were less than 5%, indicating the precision of the measurements. Analytical data integrity was ensured by employing rigorous laboratory quality assurance and methods. This involved adhering to standard operating procedures, calibrating with standards, and examining reagent blanks and replicates. Every sample underwent triplicate analysis, with two standards analyzed after every three samples. Calibration curves were fine-tuned by consistently applying quality control standards throughout the sample measurement process.

Statistics of quality water assessment

Three water pollution indices were utilized to evaluate the quality of Suez Bay coastal water:(1) Contamination degree (Cd) provides a consolidated assessment of the cumulative impacts of multiple quality parameters that are deemed detrimental to water quality (Backman *et al*., 1997 and Ramadan *et al*., 2021). It is calculated using the following formula:
$Cd = \Sigma^{n}_{i=1}(Cfi)$, where Cfi is the contamination factor of ith component. (2) Heavy metal evaluation index (HEI) evaluates the collective impact of each parameter on water quality (Ghaderpoori *et al*., 2018 and Saleem *et al*., 2019). It is calculated using the following equation:$HEI = \sum_{i=1}^{n} \frac{Mi}{MACi}$, where M_i represents the monitored value of each parameter, and MAC_i corresponds to the maximum allowable concentration for that specific parameter. (3) Heavy metal pollution index (HPI) is a measure used to assess the influence of each heavy metal on the overall water quality (Vicente-Martorell *et al*., 2009 and Ghaderpoori *et al*., 2018). It is calculated using the following formula: $HPI = \Sigma^{n}_{i=1}(Wi \times Qi)/\Sigma^{n}_{i=1}(Wi)$, where W_i is the relative weight of each parameter and Q_i is the water quality rating.

The potential sources of HMs in the study area were identified through statistical analyses, such as Cluster analysis, Pearson correlation coefficientand Principal components. IBM SPSS program (version 20) and Microsoft Excel 365 statistical software were employed for this purpose.

Results and Discussion

Seawater physicochemical parameters

The temperature of Suez Bay surface water fluctuated between 29.1 and 29.9 °C, aligning with typical summer season patterns. Salinity levels varied from 41.2 ‰ to 42.50 ‰, with the lowest value observed at stations 15 and 16, potentially attributed to a mix of fresh and marine water through the Arab Oil and Chemicals Association company drain into the sea. Seawater pH values fell within the range of 7.88 to 8.34, indicating a slightly alkaline nature (Hamed 1992 and Saleem *et al*., 2019). Additionally, dissolved oxygen (DO) values ranged from 5.03 to 8.76 mg/l. Notably, surface water exhibited the highest DO values over time, likely influenced by oxygen entry from the atmosphere and subsequent algal photosynthesis. Conversely, lower DO values may be attributed to organic matter decomposition, marine organism respiration, and biochemical reactions (Hamed, 1992 and Saleem *et al*., 2019).

Attendance and distribution of HMs

The concentrations of HMs differ across sampling sites due to the unique environmental conditions and the presence of various sources of these elements. Fig. 2 provides a visual representation of the concentration distribution of the HMs in Suze Bay. Among the locations studied, the Arab Oil and Chemicals Association drain site had the highest concentrations of Cu, Cd and Fe levels (1.96, 0.219 and 3.496 µg/l respectively), while El-Temsah shipyard beach recorded the highest levels of Pb, Ni and Co (0.392, 4.155 and 0.043 µg/l respectively). In addition, El-Naser Petroleum company beach recorded the highest levels of Mn, Zn and Cr concentrations (0.99, 2.97 and 3.35 µg/l respectively).

The sequence of average HM concentrations was as follows: Ni (with an average of 3.404 µg/l) >Cr

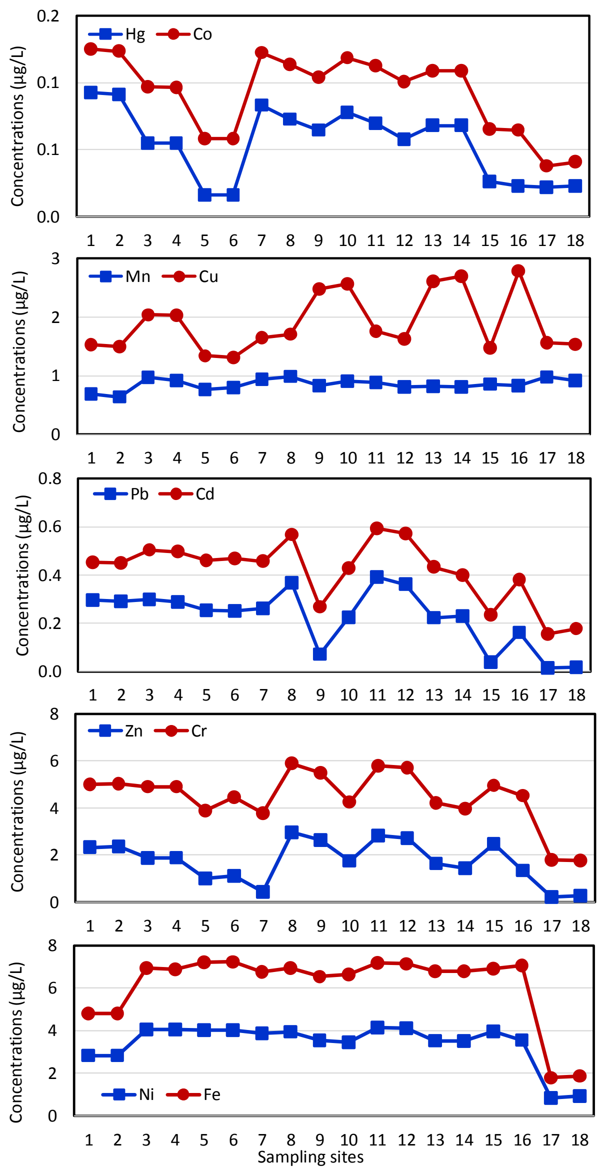

Fig. 2. Distribution of heavy metals in seawater samples.

(2.73) >Fe (2.72)>Zn (1.74) >Cu (1.05) >Mn (0.85) >Pb (0.224) >Cd (0.193) >Hg (0.054) >Co (0.038). The analysis of HM concentrations in the coastal water of Suez Bay reveals that they are below the permissible limits established by both the World Health Organization and the United States Environmental Protection Agency (Table 1). In contrast, the findings presented in Table 2 indicate elevated levels of the studied HMs in Suez Bay beach compared to corresponding levels in neighboring regions. The average concentrations of Cu, Cd, Ni and Cr were higher than those recorded on the Red Sea coast, Egypt (Shriadah *et al*., 2004; El-Moselhy and Gabal, 2004 and Nour and Nouh, 2020b). Additionally, the levels of Zn and Ni in the Suez Bay exceed the average concentrations found in the North Atlantic and Pacific Oceans (Donat and Bruland, 1995).

Pollution Indices and Multivariate Analyses

HM contamination in marine ecosystems is increasingly a significant worldwide environmental issue. It highlights significant alterations in environmental conditions and establishes a basis for acknowledging human-induced impacts on marine environments. HM concentrations in the water can be employed to evaluate water quality as an indicator of pollution levels. Three environmental indices are computed to gauge the extent of metal pollution in Suez Bay, regarding the maximum permissible concentration (MAC), the guidelines provided by the US EPA, and the allowable thresholds for HMs established by the Canadian Council of Ministers of the Environment (Siegel, 2002; CCME, 2007; WHO, 2011 and USEPA, 2020), aimed at safeguarding aquatic life.

The spatial variation of pollution indicators (HEI, HPI, and Cd) aligns closely with the spatial distribution of HMs in the Suze Bay region (Fig. 3). The HM evaluation index results revealed that all water samples within the Suez Bay region fell under 10, indicating low polluted impact. The HEI findings indicated that there were no significant variations among the different locations along the Suez Bay. Nonetheless, the Tourist Village in Suez City (S8) and the Suez Thermal Power Company (S11 and 12) exhibited the highest HEI levels compared to the other sampling sites. HM pollution index quantifies the overall impact of individual HMs on the quality of surface water. Each HM is assigned a rating in this index, which is determined concerning its importance and is inversely related to the recom-

Table 1. Statistics of HMs measured in Suez Bay surface seawater as compared to the maximal admissible concentration of WHO and US EPA

	Aver.	*Max.*	*Min.*	WHO (2011)	US EPA (2020)
pH	8.23	8.34	7.88	6.5-8.5	6.5-8.5
temp. (C°)	29.44	29.90	29.10	25-30	
Salinity (‰)	41.70	42.50	41.20		
DO (mg/L)	6.154	8.762	5.032		
Hg	0.054	0.093	0.016	6	2
Mn	0.854	0.990	0.640	50	50
Cu	1.047	1.960	0.510	1000	1300
Cd	0.193	0.219	0.141	3	5
Pb	0.224	0.392	0.014	10	15
Zn	1.738	2.970	0.210	40	50
Ni	3.404	4.155	0.845	10	10
Co	0.038	0.043	0.016	10	NA
Cr	2.725	3.349	1.510	50	100
Fe	2.721	3.496	0.933	200	300

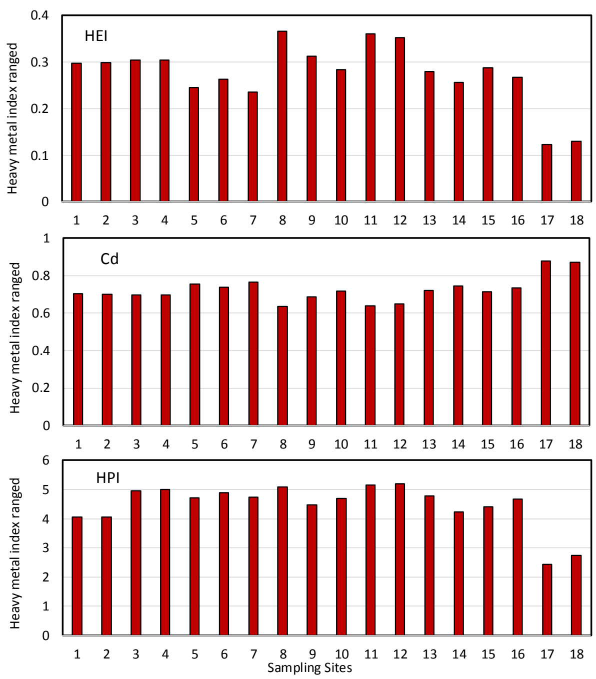

Fig. 3. Distribution of water quality indices in seawater samples

mended standard value for that specific HM. The results of HPI showed a significant agreement with the results of HEI, as 83.3 % of samples confirms that the levels of HMs in the waters of the Suez Bay are considered low pollution (HEI < 5). Simultaneously, 16.3 % of water samples fill in medium pollution levels (HEI = 5-10). Not only this, but also the results of the contamination degree index indicate that all samples of the bay record low levels of pollution, especially in Public Suez beach samples (S17 and 18), which posed no threat to human health. This may be due to the fact that the public beach area is located on the outskirts of the bay, towards the Gulf of Suez, where there are open waves, and far from various sources of pollution, such as ship manufacturing and maintenance workshops, oil companies, and ports.

The environmental assessment of surface waters in Suez Bay revealed a low level of pollution. Nevertheless, the study area is likely attributed to the semi-enclosed nature of the bay and the diverse range of human activities taking place there, such as commercial and oil ship traffic, power generation facilities, oil refineries company, commercial ports, and tourism. Conversely, water samples taken from the broader bay area, outside the Suez Bay and at the Gulf of Suez entrance, exhibited low pollution levels. Moreover, the concentrations of all HMs examined remained well below the permissible limits set by the World Health Organization and the United States Environmental Protection Agency.

Pearson's correlation analysis is a statistical technique employed to discern the degree of similarity between various sources of HMs based on their close associations (Vrhovnik *et al.*, 2013 and Al-Kahtany *et al.*, 2023a). The findings reveal robust positive correlations among several pairs (Table 3), such as the strong positive associations of Cd with Ni, Co, Cr, and Fe (with correlation coefficients of r = 0.816**, 0.839**, 0.738**, and 0.850**, respectively), Ni with Co, Cr, and Fe (r = 0.978**, 0.880**, and 0.907**, respectively), Cr with Fe (0.782**), and pH

Table 2. Comparison between HM levels in the investigated seawaters and those in other worldwide sites.

	Hg	Mn	Cu	Cd	Pb	Zn	Ni	Co	Cr	Fe	Reference
Suze Bay	0.054	0.854	1.047	0.193	0.224	1.738	3.404	0.038	2.725	2.721	Present Study
Gulf of Suez			0.43	0.09	0.51	0.23	0.01			1.97	Nour & El-Sorogy (2020)
Red Sea, Egypt		0.3-0.6	0.8-2.6	0.10-0.30	1.2-4.5	2.1-14.4				8.4-33.7	El Metwally *et al.* (2019)
Red Sea, Egypt			0.97	0.06	0.3	5.5	0.76		0.18		Ali (2012)
Red Sea, KSA		0.81-4.63	0.92-5.38	0.11-0.84	0.84-2.34	11.2-35.7	1.15-2.14			12.5-68.6	Al-Mur (2017)
Gulf of Aqaba, Egypt			0.14	0.57	0.32	0.24	0.22				Shriadah *et al.* (2004)
Gulf of Aqaba, KSA	0.06		6.18	0.03	0.2	3.32			0.96		Al-Taani *et al.* (2014)
Caspian beach			5.02	0.27	1.67	16.94	9.93		-		Abadi *et al.* (2018)
Jinzhou Bay			3.06	0.92	0.61	11.87					Wang *et al.* (2012)
Luoyuan Bay			5.58	2.5	0.16	4.99					Qu *et al.* (2009)
North Atlantic	1–7		1.15	5.5	125	0.15	2		3.5		Donat and Bruland (1995)
North Pacific	0.5–10		0.9	5.5	32	0.15	2		3		

with Mn (r = 0.790**). Additionally, there exists a strong to moderately positive correlation between Pb with Zn, Ni, Co, and Cr (with correlation coefficients of r = 0.499*, 0.637**, 0.619**, and 0.659**, respectively), Zn with Ni, and Co (r = 0.550*, and 0.527*, respectively), Hg with Pb and Zn (r = 0.540*, and 0.488*) and Cu with Fe (r = 0.476*). Furthermore, apositive correlation is evident between pH with temp., and DO (with correlation coefficients of r = 0.557*, and 0.478*), temp. with Mn (r = 0.525*), and salinity with Hg, Pb, and Cr (r = 0.542*, 0.496*, and 0.490*). The existence of robust positive correlations among various pairs of HMs suggests that these elements are likely sourced from human-made contamination sources (Vrhovnik *et al*. 2013 and Al-Kahtany *et al*. 2023b). Furthermore, the presence of correlations among Cu, Cd, Ni, Co, and Cr with Fe indicates that these metals may have arisen from a combination of natural geological processes and human activities. These metals appear to be associated with the oxides and hydroxides of iron, particularly during the weathering of rocks (Chen and Lu, 2018, and Hao *et al*., 2021). In a related context, it's noteworthy that pH demonstrates a strong positive relationship with Mn (r = 0.790**).

The findings from Pearson's correlation analysis and hierarchical cluster analysis (HCA) show a consistent agreement. The HCA results classify the studied HMs into three distinct clusters (Fig. 4). The first cluster comprises only samples 17 and 18, which exhibit the lowest concentrations of Cd, Pb, Zn, Ni, Co, Cr, and Fe. Meanwhile, the second cluster consists of three samples 14, 15, and 16. In contrast, the third cluster consists of the remaining 13 samples, which can subcluster into (S5-7) and (S1-4, S8-13). Notably, the presence of Fe with Co and Ni in the same cluster (Fig. 5) suggests that these elements likely originate from geogenic sources.

Simultaneously, the principal component analysis (PCA) has further partitioned the examined HMs into four principal components (Table 4). The variance ratios for these components are PC1 = 42.478, PC2 = 20.766, PC3 = 11.741, and PC4 = 8.997 with a cumulative ratio of 42.478, 63.244, 74.985 and 83.982, respectively. The first component exhibits strong positive loadings for Co, Ni, Cr, Fe, Pb, Cd, and Zn, with respective loadings of 0.957, 0.950, 0.904, 0.869, 0.778, 0.754, and 0.607. In contrast, the second component PC2 demonstrates high positive loadings for Mn and pH, with loadings of 0.892 and 0.785. On the other hand, PC3 and PC4 include a positive loading

Table 3. Correlation matrix of the investigated HMs.

	Correlations													
	pH	Temp.	Salinity	DO	Hg	Mn	Cu	Cd	Pb	Zn	Ni	Co	Cr	Fe
pH	1													
Temp.	0.557*	1												
Salinity	0.205	0.381	1											
DO	0.478*	0.242	-0.361	1										
Hg	-0.176	-0.029	0.542*	-0.468	1									
Mn	0.790**	0.525*	0.283	0.329	-0.206	1								
Cu	0.271	0.106	-0.013	0.061	0.258	-0.090	1							
Cd	0.243	0.195	0.332	-0.403	-0.163	0.143	0.241	1						
Pb	-0.175	-0.309	0.496*	-0.665	0.540*	-0.158	-0.049	0.372	1					
Zn	-0.186	-0.104	0.247	-0.449	0.488*	-0.236	0.129	0.269	0.499*	1				
Ni	0.015	0.102	0.445	-.510-*	0.209	-0.083	0.172	0.816**	0.637**	0.550*	1			
Co	0.044	0.092	0.402	-0.490	0.224	-0.119	0.348	0.839**	0.619**	0.527*	0.978**	1		
Cr	-0.172	0.016	0.490*	-0.607	0.228	-0.157	0.120	0.738**	0.659**	0.374	0.880**	0.860**	1	
Fe	0.145	0.207	0.334	-0.312	0.101	-0.070	0.476*	0.850**	0.452	0.391	0.907**	0.962**	0.782**	1

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

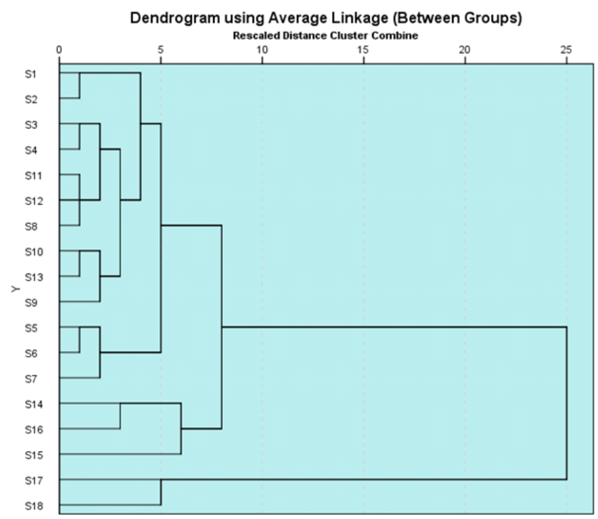

Fig. 4. R-mode HCA of heavy metals in surface water samples

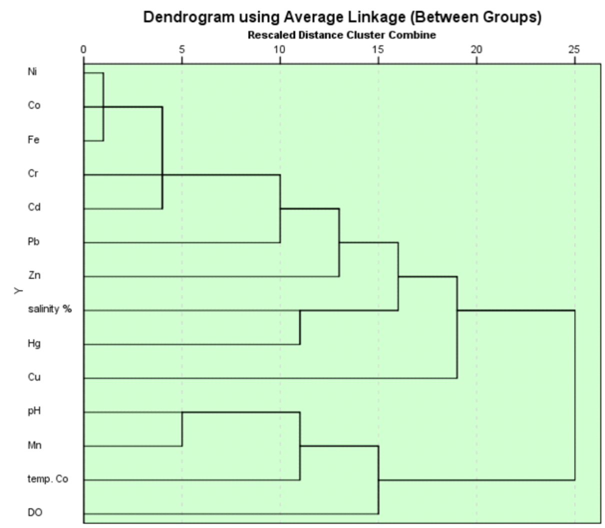

Fig. 5. Q-mode HCA of heavy metals in surface water samples

for only Hg and Cu respectively. The presence of substantial loadings in the PCA suggests the influence of anthropogenic sources (Vrhovnik *et al*., 2013 and Hao *et al*., 2021). Moreover, the notable loading of Fe in PC1 may be attributed to a combination of geogenic and anthropogenic sources for these HMs. These sources likely stem from processes like rock weathering and various industrial activities, including the operation of a thermal power company, petroleum company, shipyard station, tourist villages, steel manufacturing, and an oil company in the study area.

Conclusion

The study highlights the increasing concern of HM contamination in marine ecosystems, with a focus on Suez Bay. The assessment of environmental conditions and the impact of human activities on marine environments is evident. The use of HM concentrations as water quality indicators has shown that the Suez Bay region exhibits moderately polluted water, except for the public Suez beach, which has low pollution levels. The semi-enclosed nature of Suez Bay and various human activities, including

Table 4. Principal component loadings with three variances for the components

Component Matrix[a]				
	Component			
	PC1	PC2	PC3	PC4
pH	-0.068	0.892	0.162	0.115
Temp.Co	0.037	0.756	0.273	0.041
Salinity	0.553	0.235	0.680	-0.124
DO	-0.669	0.477	-0.171	0.195
Hg	0.405	-0.343	0.689	0.453
Mn	-0.152	0.785	0.352	-0.253
Cu	0.263	0.251	-0.215	0.850
Cd	0.778	0.397	-0.341	-0.206
Pb	0.754	-0.316	0.288	-0.156
Zn	0.607	-0.270	0.168	0.243
Ni	0.950	0.124	-0.146	-0.099
Co	0.957	0.147	-0.209	0.048
Cr	0.904	-0.016	-0.106	-0.205
Fe	0.869	0.302	-0.321	0.141
% of Variance	42.478	20.766	11.741	8.997
Cumulative %	42.478	63.244	74.985	83.982

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

commercial shipping, power generation, oil refineries, commercial ports, and tourism, contribute to moderate pollution levels. However, water samples taken from areas outside Suez Bay and at the Gulf of Suez entrance show low pollution levels. Importantly, the concentrations of HMs in all samples remain below the permissible limits set by the World Health Organization and the United States Environmental Protection Agency. This research provides valuable insights into the environmental challenges and pollution levels in Suez Bay, aiding in the understanding and management of HM contamination in this marine ecosystem.

Conflict of interest

The authors declare no conflict of interest.

References

Abadi, M., Zamani, A., Parizanganeh, A., Khosravi, Y. and Badiee, H. 2018. Heavy metals and arsenic content in water along the southern Caspian coasts in Iran. *Environ. Sci. Pollut. Res.* 25: 23725–23735.

Aghadadashi, V., Neyestani, M. and Mehdinia, A. 2019. Spatial distribution and vertical profile of heavy metals in marine sediments around Iran's special economic energy zone; arsenic as an enriched contaminant. *Mar. Pollut. Bull.* 138 : 437–450. https://doi.org/10.1016/j.marpolbul.2018.11.033

Alharbi, T., Nour, H.E., Al-Kahtany, K., Giacobbe, S. and El-Sorogy, A. 2023. Sediment's quality and health risk assessment of heavy metals in the Al-Khafji area of the Arabian Gulf, Saudi Arabia. *Environmental Earth Sciences*. 82(20): 471. https://doi.org/10.1007/s12665-023-11171-z

Ali, A. 2012. *Sudanese Coastal Water—Composition and Some Environmental Aspects*. Master's Thesis, Universitas Bergensis, Bergen, Norway.

Al-Kahtany, K., Nour, H.E., El-Sorogy, A. and Alharbi, T. 2023a. Ecological and health risk assessment of heavy metals contamination in mangrove sediments, Red Sea coast. *Marine Pollution Bulletin*. 192: 115000. https://doi.org/10.1016/j.marpolbul.2023.115000

Al-Kahtany, K., El-Sorogy, A., Alharbi, T., Giacobbe, S. and Nour, H.E. 2023b. Health risk assessment and contamination of potentially toxic elements in southwest of the Red Sea coastal sediment. *Regional Studies in Marine Science*. 65: 103103.https://doi.org/10.1016/j.rsma.2023.103103

Al-Mur, B., Quicksall, A. and Al-Ansari, A. 2017. Spatial and temporal distribution of heavy metals in coastal core sediments from the Red Sea, Saudi Arabia. *Oceanologia.* 59: 262-270.

Al-Taani, A., Batayneh, A., Nazzal, Y., Ghrefat, H., Elawadi, E. and Zaman, H. 2014. Status of trace metals in surface seawater of the Gulfof Aqaba, Saudi Arabia. *Mar. Pollut. Bull*. 86: 582-590.

APHA 2005. *Standard Methods for the Examination of Water and Wastewater,* 21st ed. American Public Health Association/American Water Works Association/ Water Environment Federation: Washington, DC, USA.

Backman, B., Bodis, D.,Lahermo, P., Rapant, S. and Tarvainen, T. 1997. Application of a groundwater contamination index in Finland and Slovakia. *Environ. Geol*. 36: 55-64.

Bazzi, A. 2014. Heavy metals in seawaters, sediments, and marine organisms in the Gulf of Chbahar, Oman Sea. *Journal of Oceanography and Marine Science.* 5(3): 20–29.

CCME (Canadian Council of Ministers of the Environment), 2007. For the protection of aquatic life 2007. In: *Canadian environmental quality guidelines*, *1999*, Canadian Council of Ministers of the Environment, 1999, Winnipeg

Chen, X. and Lu, X. 2018. Contamination characteristics and source apportionment of heavy metals in topsoil from an area in Xi'an city, China. *Ecotoxicol. Environ. Saf*. 151: 153–160.

Chen, C., Kao, C., Chen, C. and Dong, C. 2007. Distribution and accumulation of heavy metals in the sediments of Kaohsiung Harbor, Taiwan. *Chemosphere.*

66(8): 1431–1440.
Donat, J. and Bruland, K. 1995. Trace Elements in the Oceans. In: *Trace Elements in Natural Waters*; Salbu, B., Steinnes, E., Eds.; CRC Press: Boca Raton, FL, USA, pp. 247-292.
El-Moselhy, K. and Gabal, M. 2004. Trace metals in water, sediments, and marine organisms from the northern part of the Gulf of Suez, Red Sea. *Journal of Marine Systems.* 46: 39-46.
Ghaderpoori, M., kamarehie, B., Jafari, A., Ghaderpoury, A. and Karami, M. 2018. Heavy metals analysis and quality assessment in drinking water–Khorramabad City, Iran. *Data in Brief.* 16: 685-692. https://doi.org/10.1016/j.dib.2017.11.078.
Gu, C.M., Liu, Y. and Liu, D. 2016.Distribution and ecological assessment of heavy metals in irrigation channel sediments in a typical rural area of south China. *Ecol. Eng.* 90: 466-472. https://doi.org/10.1016/j.ecoleng.2016.01.054
Hamed, M.A. 1992. *Seawater quality at the northern part of the gulf of Suez and the nearby area of the Suez canal,* M.Sc. Thesis, Faculty of Science, Mansoura University, Egypt.
Hao, J., Ren, J., Tao, L., Fang, H., Gao, S. and Chen, Y. 2021. Pollution evaluation and sources identification of heavy metals in surface sediments from upstream of Yellow River. *Pol. J. Environ. Stud*. 30: 1161-1169.
Karadede, H. and Unlu E. 2000. Concentrations of some heavy metals in water, sediment, fish and some benthic organisms from Tigris River, Turkey. *Envi. Monit. Assess.* 131: 323-333.
Nour, H.E. 2015. Distribution of hydrocarbons and heavy metals pollutants in groundwater and sediments from northwestern Libya. *Indian Journal of Geo-Marine Sciences.* 44(7): 993–999.
Nour, H.E. and El-Sorogy, A. 2020. Heavy metals contamination in seawater, sediments and seashells of the Gulf of Suez, Egypt. *Environmental Earth Sciences*. 79(11): 274. https://doi.org/10.1007/s12665-020-08999-0
Nour, H.E. and Nouh, E.S. 2020a. Using coral skeletons for monitoring of heavy metals pollution in the Red Sea Coast, Egypt. *Arabian Journal of Geosciences.* 13(10): 341. https://doi.org/10.1007/s12517-020-05308-8
Nour, H.E. and Nouh, E.S. 2020b. Comprehensive pollution monitoring of the Egyptian Red Sea coast by using the environmental indicators. *Environmental Science and Pollution Research*. 27(23): 28813–28828. https://doi.org/10.1007/s11356-020-09079-3
Nour, H.E., Ramadan, F., Aita, S. and Zahran, H. 2021. Assessment of sediment quality of the Qalubiya drain and adjoining soils, Eastern Nile Delta, Egypt. *Arabian Journal of Geosciences.* 14(7): 535. https://doi.org/10.1007/s12517-021-06891-0
Nour, H.E., Helal, S. and Abdel Wahab, M. 2022. Contamination and health risk assessment of heavy metals in beach sediments of Red Sea and Gulf of Aqaba, Egypt. *Marine Pollution Bulletin.* 17: 113517. https://doi.org/10.1016/j.marpolbul.2022.113517
Ramadan, F., Nour, H.E., Aita, S., Zahran, H. 2021. Evaluation of heavy metals accumulation risks in water of the Qalubiya drain in East Delta, Egypt. *Arabian Journal of Geosciences.* 14: 1750. https://doi.org/10.1007/s12517-021-08198-6
Qu, H., Dong, S., Tang, Z. and Wu, Y. 2009. Distribution and ecological evaluation of heavy metals in multi-medium of Luoyuan Bay. *Mar Environ Sci.* 28: 293–308.
Saleem, M., Iqbal, J. and Shah, M. 2019. Seasonal variations, risk assessment and multivariate analysis of trace metals in the freshwater reservoirs of Pakistan. *Chemosphere.* 216: 715-724.þ
Shriadah, M.,Okbah, M. and El-Deek, M. 2004. Trace metals in the water columns of the Red Sea and the Gulf of Aqaba, Egypt. *Water Air Soil Pollut*. 153: 115–124.
Siegel, F.R. 2002. *Environmental Geochemistry of Potentially Toxic Metals,* 1st ed.; Springer: Berlin/Heidelberg, Germany; New York, NY, USA.
Swarnalatha, K., Letha, J., Ayoob, S. and Nair, A. 2015. Risk assessment of heavy metal contamination in sediments of a tropical lake. *Environmental Monitoring and Assessment.* 187: 322.
USEPA 2020. National Recommended Water Quality Criteria -Aquatic Life Criteria Table. https://www.epa.gov/wqc/nationalrecommended-water-quality-criteria aquaticlifecriteria-table#table.
Vicente-Martorell, J., Galindo-Riaño, M., García-Vargas, M. and Granado-Castro, M. 2009. Bioavailability of heavy metals monitoring water, sediments and fish species from a polluted estuary.*Journal of Hazardous Materials.* 162: 823-836.
Vrhovnik, P.,Šmuc, N., Dolenec, T.,Serafimovski, T. and Dolenec, M. 2013. An evaluation of trace metal distribution and environmental risk in sediments from the Lake Kalimanci (FYR Macedonia). *Environ. Earth Sci.* 70: 761–775.
Wang, C., Liu, S., Zhao, Q., Deng, L., Dong, S. 2012. Spatial variation and contamination assessment of heavy metals in sediments in the Manwan Reservoir, Lancang River. *Ecotoxicol Environ.* 82: 32-39
World Health Organization (WHO) 2011. Guidelines for Drinking Water Quality, 4th edn. World Health Organization, Geneva, 564.