Eco. Env. & Cons. 30 (1) : 2024; pp. (389-397)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2024.v30i01.070

Pollution status and ecological risks of metals in coastal seawater of Red Sea and Gulf of Aqaba

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

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

(Received 2 December, 2023; Accepted 18 January, 2024)

ABSTRACT

Recognizing the crucial significance of marine environments, and evaluating and monitoring pollutants emerges as a substantial challenge. To address this, twenty coastal water samples were systematically collected from key beach sites along the Gulf of Aqaba and the Red Sea coasts. Iron, zinc, copper, lead, cobalt, and mercury levels were scrutinized using an atomic spectrometer. The findings reveal the average concentration of various heavy metals (HMs) in descending order (µg/l): Fe (3.98) > Zn (1.60) > Cu (0.67) > Pb (0.35) > Cd (0.17) > Hg (0.016). Furthermore, the results of the heavy metal evolution index (HEI) underscore the absence of significant contamination across all examined samples (HEI < 5). Simultaneously, the results derived from the heavy metal pollution index (HPI) reveal that 45% of the studied areas exhibit low levels of heavy metals (HPI < 100), with the remaining sites registering moderate contamination levels. However, the general status of pollutant assessment in the study areas indicates the absence of significant pollution and the current water quality situation in these areas does not threaten human health. It underscores the resilience of these environments against the backdrop of continuous human development activities. Nevertheless, it is prudent to recommend ongoing environmental monitoring of these beaches to assess and promptly address any potential decline in water quality.

Key words: *Pollution status, Ecological risk, Surface water, Red Sea, Gulf of Aqaba*

Introduction

Heavy metals have the potential to amass in diverse environmental components, encompassing water, sediments, and living organisms, posing a significant environmental hazard due to their limited solubility in water. Since approximately three-quarters of the Earth's surface is covered by different water bodies, such as oceans, seas, rivers, and lakes, these areas are recognized as substantial metal reservoirs. Human activities, notably industrial, agricultural, and sanitary drainage, are primary contributors to releasing these metals (Nour, 2015; Nour 2019a; Ramadan *et al*., 2021 and Al-Kahtany *et al*., 2023a). Water bodies serve as a crucial food source, underscoring the importance of closely monitoring their water quality. This scrutiny is paramount due to its direct repercussions on the ecosystem and human health (Nour *et al*. 2021 and Alharbi *et al*., 2023).

Elevated levels of metal accumulation in the human body can lead to various health issues, such as neurological and skin diseases, disorders in the digestive system, and an increased risk of certain types of cancers (Sun *et al*., 2021; and Lin *et al*., 2023). Coastal environments stand out as crucial marine ecosystems owing to their rich biodiversity and vitality. Spanning extensive areas globally, these environments face a range of human activities, including the expansion of tourist resorts and the establishment of commercial and oil ports. Such activities expose coastal areas to heightened environmental risks and elevated metal contamination levels (Nour 2019b; Al-Kahtany *et al*., 2023b and Diganta *et al*., 2023). Furthermore, the escalation of tourist activity, rising urbanization in proximity to transitional zones, ineffective planning, inadequate management practices, and the discharge of untreated sewage all contribute to accelerating the pollution process in coastal environments (Nour and Nouh, 2020a and Diganta *et al*., 2023).

Research endeavors assessing environmental pollution in the marine ecosystem through seawater analysis have demonstrated substantial importance and effectiveness (Bazzi 2014; Abadi, 2018; Nour *et al.* 2022 and Cüce *et al*., 2022). Some efforts have been made to evaluate environmental pollution in specific coastal locations along the Red Sea in Egypt (Al-Taani *et al*., 2014; Nour and Nouh, 2020b and Garoub and Nour, 2024). Nevertheless, these studies remain relatively limited, and there is a recognized need for ongoing, practical, and consecutive monitoring. Hence, the present study holds exceptional significance as it comprehensively addresses key areas in the Gulf of Aqaba and along the Red Sea coasts. The primary objective of the ongoing study is to assess the distribution of heavy metal levels in the coastal waters of the Red Sea and the Gulf of Aqaba. The study aims to identify potential contamination with these metals, pinpoint their sources, and draw comparisons with findings from similar studies worldwide. An additional goal is to amass fundamental data for the ongoing environmental monitoring of Egyptian coastal environments, shedding light on the impact of sustained and intense urban development along the Egyptian coasts.

Materials and Methods

Study area and sampling

The coastal regions of the Red Sea and the Gulf of Aqaba hold significant prominence as key tourist destinations in Egypt, playing a crucial role in the country's economic landscape. Twelve pivotal sites along the Gulf of Aqaba and eight sites along the Red Sea coasts have been carefully chosen for special consideration. The chosen sites exhibit diverse human activities, ranging from tourism and industrial operations to commercial and oil ports, as well as mining activities. Additionally, some sites are designated as natural reserves. These sites are strategically distributed among key coastal cities in eastern Egypt (Fig. 1), including Taba (GA_1), Nuweiba (GA_3), Dahab (GA_7), Sharm El Sheikh (GA_10 and GA_11), Ras Mohammed (GA_12) on the Gulf of Aqaba coast, while Hurghada (RS_1), Safaga (RS_3 and RS_4), El Quseir (RS_6 and RS_7), and Marsa Alam (RS_8) on the Red Sea coast. Surface water samples were gathered from 20 designated locations within the study area to evaluate metal contamination levels and assess associated environmental risks. To ensure the integrity of the samples, polyethylene containers were meticulously cleaned and rinsed three times with water before collection, following the protocol outlined by Rahman *et al*. (2021). The containers were submerged beneath the water surface, allowing them to be filled without the introduction of air bubbles. To prevent metal oxidation, pure HNO_3 was promptly introduced to each bottle, lowering the pH of the samples to below 2.

Fig. 1. Sampling and study area

Subsequently, the bottles were securely sealed, placed in a cool box, and transported to the laboratory.

Laboratory work and quality assurance

In the lab, collecting water samples was filtrated using filter paper < 45 µm, following digestion with a mixture of nitric and Perchloric acids for 24 hours. Subsequently, the digested samples underwent heating at 100 °C for 6 hours and were then diluted with 50 ml of distilled water (APHA 2005). The concentration levels of Fe, Cu, Zn, Pb, Cd and Hg were determined by using an atomic absorption spectrophotometer (AAS) equipped with a hydride generation system. Additionally, physico-chemical parameters such as temperature, pH and total dissolved oxygen levels were recorded at the respective sample collection sites. The analytical process adhered to international standards, involving rigorous checks on reagents, triplicate analysis for selected samples, and periodic analysis of standard samples after every fourth sample. The results demonstrated a relative standard deviation (RSD) of less than 5%, affirming the precision and accuracy of the measurements.

Statistics of quality water assessment

To assess the pollution levels at various sampling sites within the study area, the environmental indices were employed: the heavy metal pollution index (HPI), and heavy metal evaluation index (HEI).

Heavy metal pollution index (HPI) is calculated by Eq (1): HPI $=\sum_{i=1}^{n}(Wi \times Qi)/\sum_{i=1}^{n}(Wi)$, (Vicente-Martorell *et al*., 2009 and Ghaderpoori *et al*., 2018), and the heavy metal evaluation index (HEI) is calculated by Eq (2): HEI = $\sum_{i=1}^{n}\frac{Mi}{MACi}$, (Ghaderpoori *et al*., 2018), where M_i represents the monitored value of each parameter, and MAC_i corresponds to the maximum allowable concentration for that specific parameter, Wi is the relative weight of each parameter and Qi is the water quality rating.

Within the same context, statistical analyses were conducted to identify potential sources of heavy metals and the relationships among them in the study area. These analyses included the computation of the Pearson correlation coefficient, hierarchical cluster analysis (HCA), and principal components analysis (PCA). The software tools utilized for these analyses were SPSS 20 and Microsoft Excel 365 statistical program.

Results and Discussion

Physico -chemical parameters

The average degrees of surface water temperature in the Gulf of Aqaba and the Red Sea were recorded (29.49 and 29.78 ˆC), respectively, while the salinity degrees were between 41.9 and 38.87 ‰, respectively, and the pH recorded 8.27 and 8.11, respectively. In addition to the percentage of dissolved oxygen in the waters of the Gulf of Aqaba (6.15 mg/l) and the Red Sea (6.66 mg/l). All of these values fall within the global averages, as defined by WHO and US EPA (Table 1). These results indicate that the Gulf of Aqaba was higher in salinity and pH compared to the Red Sea while recording lower levels of both temperature and dissolved oxygen. This may be due to the narrow and deep nature of the Gulf, while the sea is wider and more active with sea currents. The pH results for the study areas suggest a slightly alkaline nature. Furthermore, the observed dissolved oxygen (DO) values are within average

Table 1. Descriptive statistics data and background values

	Aver.	*Max.* *Gulf of Aqaba*	*Min.*	*Aver.*	*Max.* *Red Sea*	*Min.*	WHO (2011)	US EPA (2020)
pH	8.271	8.36	7.76	8.11	8.21	7.84	6.5-8.5	6.5-8.5
temp. (C°)	29.491	30.19	29.19	29.78	30.21	28.67	25-30	
Salinity (‰)	41.908	42.8	40.11	38.87	41.45	36.78		
DO (mg/L)	6.149	8.72	5.034	6.656	8.992	5.545		
Fe	3.346	8.933	1.071	4.929	8.933	1.291	200	300
Cu	0.790	1.881	0.215	0.492	0.822	0.196	1000	1300
Zn	1.010	1.93	0.222	2.493	6.66	0.237	40	50
Pb	0.346	0.93	0.110	0.343	0.79	0.14	10	15
Cd	0.166	0.34	0.040	0.183	0.29	0.03	3	5
Hg	0.019	0.081	0.007	0.012	0.021	0.001	6	2

ranges. The decline in dissolved oxygen levels could potentially be attributed to processes such as the decomposition of organic materials, respiration of marine organisms, and biochemical reactions, as discussed by Hamed (1992).

Spatial distributions of toxic metals

The average concentrations of dissolved toxic metals measured in surface seawater samples from the two selected study regions were presented in Table 1. The recorded values are arranged in descending order as follows (µg/l): Fe (3.35-4.93), Zn (1.01-2.49), Cu (0.79-0.49), Pb (0.35-0.34), Cd (0.166-0.183), and Hg (0.019-0.012), in the Gulf Aqaba and Red Sea coasts respectively.

Numerous studies have provided evidence that certain metals exhibit a propensity to dissolve in water, leading to higher concentrations in sediments compared to water samples. This phenomenon arises from the deposition and accumulation of metals within sediments. Conversely, there is the potential for the reverse process, involving the transfer of metals from sediments to water (Jafarabadi *et al.*, 2017; Nour 2020 and Varol and Tokatl, 2023). In the context of this study, the variation in the characteristics of sample collection sites and the diverse human activities associated with them has led to a heterogeneous distribution of metal levels, as depicted in Fig. 2. Specifically, the sites of GA_7, GA_10, and GA_11 along the Gulf of Aqaba exhibited the highest concentrations of Cd (0.34 µg/L), Cu (1.88 µg/L), Pb (0.93 µg/L), and Hg (0.081 µg/l) respectively. Meanwhile, the sites situated along the Red Sea coast, namely RS_1 and RS_5, registered elevated levels of Fe (8.93 µg/l) and Zn (6.66 µg/l). The field investigation reveals widespread tourist and recreational activities in these locations, along with the presence of ports and mining. Consequently, the elevated metal levels in these sites could be attributed to either the leaching of metals from sediments into the water or the direct discharge of metals into the water due to human activities.

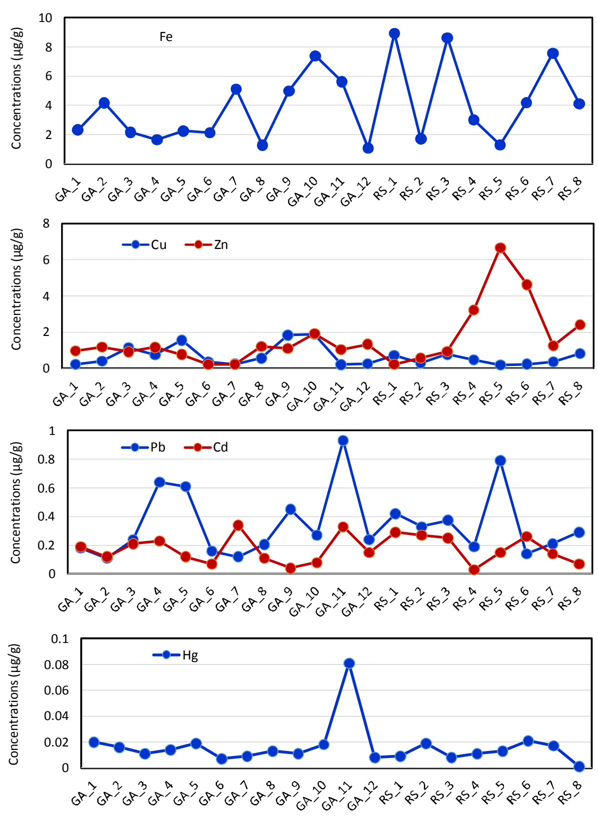

Fig. 2 Distribution of HMs in seawater samples.

Figure 3 illustrates the results of comparing metal concentration levels between the Gulf of Aqaba and Red Sea sites. The findings indicate that the coasts of the Gulf of Aqaba exhibit higher average concentrations of Cu (0.79 µg/l), Pb (0.35 µg/l), and Hg (0.019 µg/l) compared to their counterparts along the Red Sea coasts. This discrepancy may be attributed to the geographical characteristics of the Gulf of Aqaba, characterized by its narrow space and closed end in the northeastern direction, resulting in less mobile water currents that allow for the retention of metals. Conversely, the Red Sea coast shows higher levels of Fe (4.93 µg/l), Zn (2.49 µg/l), and Cd (0.183 µg/l) concentrations than the Gulf of Aqaba, possibly influenced by natural weathering processes and various human activities along the Red Sea coastline.

Using the data from Table 2, a comparison was made between the metal distribution results in the two study regions and some neighboring places as well as other locations worldwide. The findings re-

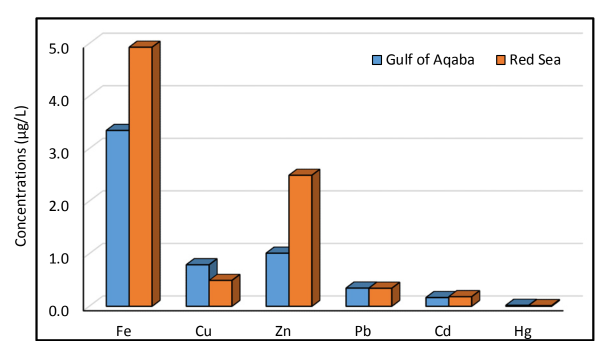

Fig. 3. Comparison between average HM levels in the Gulf of Aqaba and Red Sea Coasts.

veal that certain metals exhibit higher levels than those in the Suez Bay (Garoub and Nour, 2024), the Gulf of Suez (Nour and El-Sorogy, 2020), the Red Sea (Ali 2012), the coast of China (Wu *et al*., 2020), and the North Atlantic and the Pacific Oceans (Donat and Bruland, 1995). Conversely, some metals recorded the lowest levels when compared to their counterparts in the Red Sea (El Metwally *et al.*, 2019 and Al-Mur, 2020), the Mediterranean Sea (Darwish *et al*., 2022), the Caspian Sea (Abadi *et al*., 2018), the Indian Coast (Lakshmanna *et al*., 2022), and the North Atlantic and Pacific Oceans (Donat and Bruland, 1995). All the metals investigated in the study exhibited values lower than the reference background, as defined by the World Health Organization (WHO), and US EPA as indicated in Table 1.

Pollution and ecological risk assessment

The issue of marine environment pollution has emerged as a significant global challenge. Consequently, conducting studies to assess environmental impacts and maintaining continuous monitoring of these environments has become crucial. In pursuit of this objective, the HPI and HEI indices were assessed using reference values the maximum allowable concentrations (MAC), and guidelines from the US Environmental Protection Agency (US EPA), (WHO, 2011 and USEPA, 2020).

The results of HPI revealed a range of values, with the lowest recorded at 0.879 in site GA_11 (Sharm El-Sheikh) and the highest at 8.202 in site RS_4 (South Safaga) (Fig. 4). According to the HPI classification, 45% of the surveyed sites exhibit low pollution levels for heavy metals (HPI < 5), while the remaining sites show moderate pollution (HPI = 5-10). Concurrently, the HEI results demonstrate a significant consistency in the distribution of studied elements across all sites, indicating a notable similarity in metal conditions between the Gulf of Aqaba and the Red Sea coasts. HEI values for all samples are below 1, signifying no threat to human health. This outcome could be attributed to the study sites being open beaches exposed to the sea or the Gulf, where active waves facilitate constant water renewal.

Despite field observations suggesting the potential presence of pollutants in the coastal waters at the study sites, the results contradicted these indications. Most of the study sites did not face substantial threats or acute pollutants, suggesting a lack of significant pollutants in these areas. The measured values of metals in the study sites were consistently below their respective reference values as stipulated by the World Health Organization and the United States Environmental Protection Agency.

Source analysis of metals

In this investigation, the coefficient of variation (CV) values for the metal content across various study sites were gauged, and assessed the extent of their susceptibility to human activities (Table 2 and Fig.

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

Location	Fe	Cu	Zn	Pb	Cd	Hg	Reference
Gulf of Aqaba	3.346	0.790	1.010	0.346	0.166	0.019	Present work
Red Sea, Egypt	4.929	0.492	2.493	0.343	0.183	0.012	
Coefficient of variation	0.639	0.801	0.992	0.671	0.554	0.977	
Skewness	0.724	1.338	2.197	1.316	0.253	3.692	
Suze Bay	2.721	1.047	1.738	0.224	0.193	0.054	Garoub and Nour (2024)
Gulf of Suez	1.97	0.43	0.23	0.51	0.09		Nour and El-Sorogy (2020)
Red Sea, Egypt	8.4-33.7	0.8-2.6	2.1-14.4	1.2-4.5	0.10-0.30		El Metwally *et al* (2019)
Red Sea, Egypt		0.97	5.5	0.3	0.06		Ali (2012)
Red Sea, KSA	12.5-68.6	0.92-5.38	11.2-35.7	0.84-2.34	0.11-0.84		Al-Mur (2020)
Gulf of Aqaba, Egypt		0.14	0.24	0.32	0.57		Shriadah *et al* (2004)
Gulf of Aqaba, KSA		6.18	3.32	0.2	0.03	0.06	Al-Taani *et al* (2014)
Mediterranean Sea, Egypt	56.5	4.28	24.77	18.37	1.45		Darwish *et al*. (2022)
Caspian beach		5.02	16.94	1.67	0.27		Abadi *et al*. (2018)
Coastal waters, China		136.26	32.42	2.08	0.14		Wu *et al*. (2020)
East coast of India	11.96	19.78	25.82	10.05	14.83		Lakshmanna *et al*. (2022)
North Atlantic		1.15	0.15	125	5.5	1–7	Donat and Bruland (1995)
North Pacific		0.9	0.15	32	5.5	0.5–10	

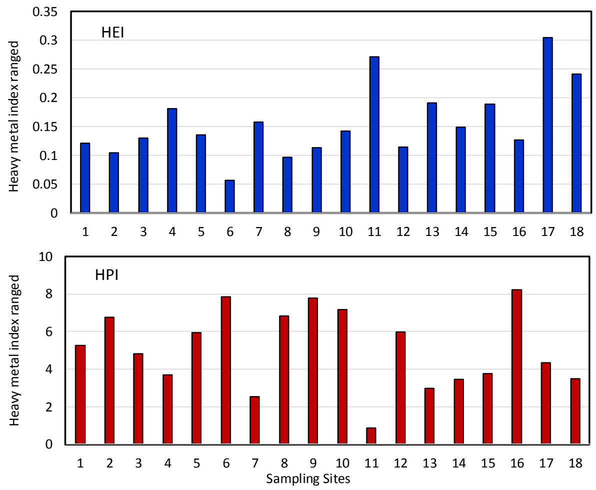

Fig. 4. Distribution of water quality indices in seawater samples

5). The CV outcomes suggest that the spatial distribution of metal content is likely to be heterogeneous, with a pronounced influence from human activities, particularly in the case of Hg, Zn, and Cu, where the CV percentage exceeds 80% (Chen *et al.*, 2023). This observation is further supported by the results of skewness values for the studied metals, which consistently registered positive values for all metals, affirming the potential impact of human activities on water (Li *et al.*, 2022). However, the relatively low cadmium values, approaching zero, may suggest moderate effects.

Pearson's correlation coefficient, as elucidated by Al-Kahtany *et al*. (2023b) is instrumental in discerning the degree of association between metals in the environment, providing insights into potential sources. The study results reveal a positive correla-

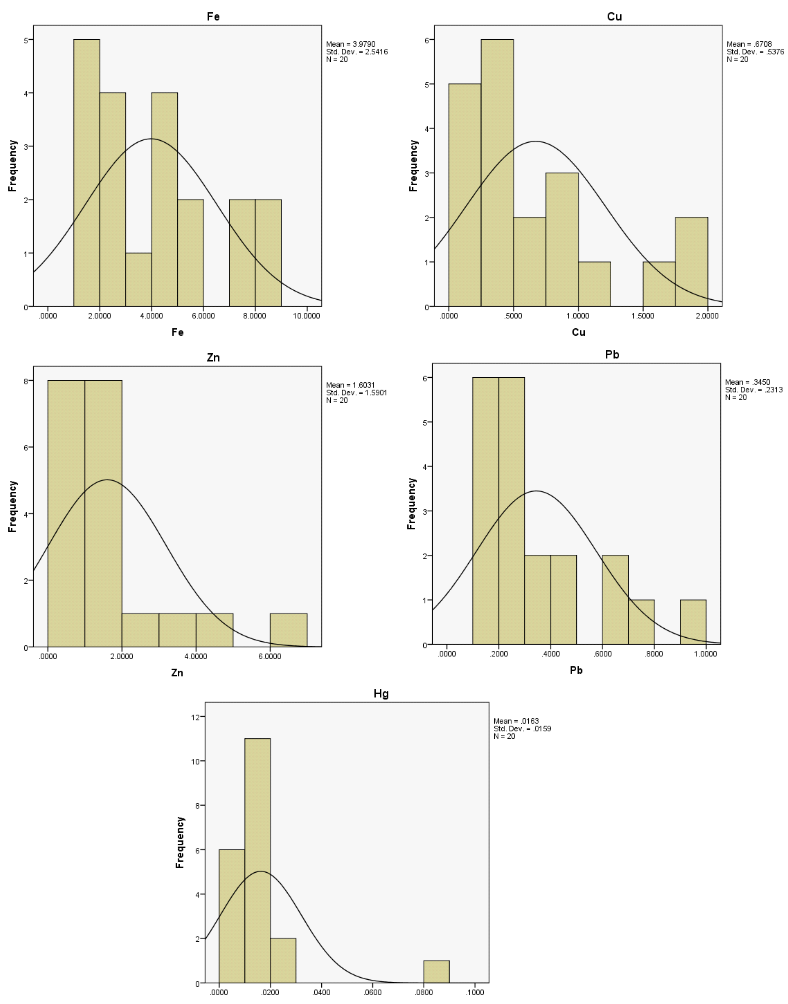

Fig. 5. The coefficient of variation of HMs in studied samples

tion between Hg with Pb and Cd (r = 0.569**, 0.411 respectively), suggesting a likelihood of their origin from a common source, in line with findings by Hao *et al*. (2021) and Varol and Tokatlý (2023). Additionally, a positive relationship is observed between salinity and pH. Conversely, there are weak and negative correlations among the other metals, underscoring the diversity of their respective sources as natural geological processes and human activities (Table 3).

The outcomes of the principal component analysis (PCA) reveal a categorization of the examined metals into four primary components (Table 4). These findings suggest a weak correlation among most metals, as indicated by the variance ratios for these components: PC1 = 22.50, PC2 = 20.70, PC3 = 16.29, and PC4 = 13.18, contributing to cumulative percentages of 22.50, 43.20, 59.49, and 72.67, respectively. Within the first and third components, no robust positive values were observed for the loadings between the heavy metals. However, the second component (PC2) exhibited notable positive loadings for Hg (0.732), Cd (0.728), and Pb (0.6888), strongly suggesting a potential association with human sources (Hao *et al*., 2021). Conversely, the fourth component displayed elevated positive loadings for Fe (0.744) and Cu (0.613), hinting at the influence of both natural weathering and anthropogenic activities. Simultaneously, the results from the hierarchical cluster analysis (HCA) on the correlation between sampling sites and metals (Fig. 6) indicate that the selected sites can be segregated into four distinct groups. The first group comprises GA_4, GA_8, GA_3, GA_1, GA_12, RS_2, GA_5, and GA_6. The second group encompasses GA_7, GA_11, GA_2, GA_9, and GA_10. The third group includes RS_4, RS_8, and RS_6, while the fourth group consists of RS_1, RS_3, RS_7, and RS_5. These results indicate the diversity of sources of these metals.

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

	Component Matrix[a]			
	Component			
	1	2	3	4
pH	0.630	0.044	0.482	0.116
temp. Co	-0.289	0.539	0.155	-0.109
Salinity %	0.724	-0.044	0.373	-0.449
DO	-0.528	0.092	0.620	0.081
Fe	0.164	0.086	-0.532	0.744
Cu	0.329	-0.418	0.395	0.613
Zn	-0.794	0.215	0.187	0.088
Pb	0.065	0.688	0.480	0.346
Cd	0.301	0.728	-0.378	-0.142
Hg	0.327	0.732	-0.042	0.090
% of Variance	22.50	20.70	16.29	13.18
Cumulative %	22.50	43.20	59.49	72.67

Extraction Method: Principal Component Analysis.

Conclusion

Given the vital role of marine environments as a significant food source and the backdrop for various human activities, the monitoring and assessment of pollutants within these ecosystems are of paramount importance. Extensive studies were conducted along the coasts of the Gulf of Aqaba and the Red Sea, encompassing key sites associated with diverse human endeavors such as industry, tourism, trade, and mining. The geological characteristics of the Gulf of Aqaba impart a distinct nature to its

Table 3. Correlation matrix of the investigated HMs.

	pH	temp. Co	Salinity %	DO	Fe	Cu	Zn	Pb	Cd	Hg
pH	1	-0.159	0.458*	0.047	-0.018	0.314	-0.302	0.233	0.150	0.105
temp. Co		1	0.039	0.293	-0.002	-0.130	0.288	0.218	0.338	0.062
Salinity %			1	-0.232	-0.357	0.208	-.537-*	0.019	0.059	0.152
DO				1	-0.234	-0.032	0.335	0.273	-0.249	-0.196
Fe					1	0.236	-0.209	-0.016	0.235	0.113
Cu						1	-0.188	0.114	-0.417	-0.183
Zn							1	0.207	-0.197	-0.035
Pb								1	0.237	0.569**
Cd									1	0.411
Hg										1

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

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

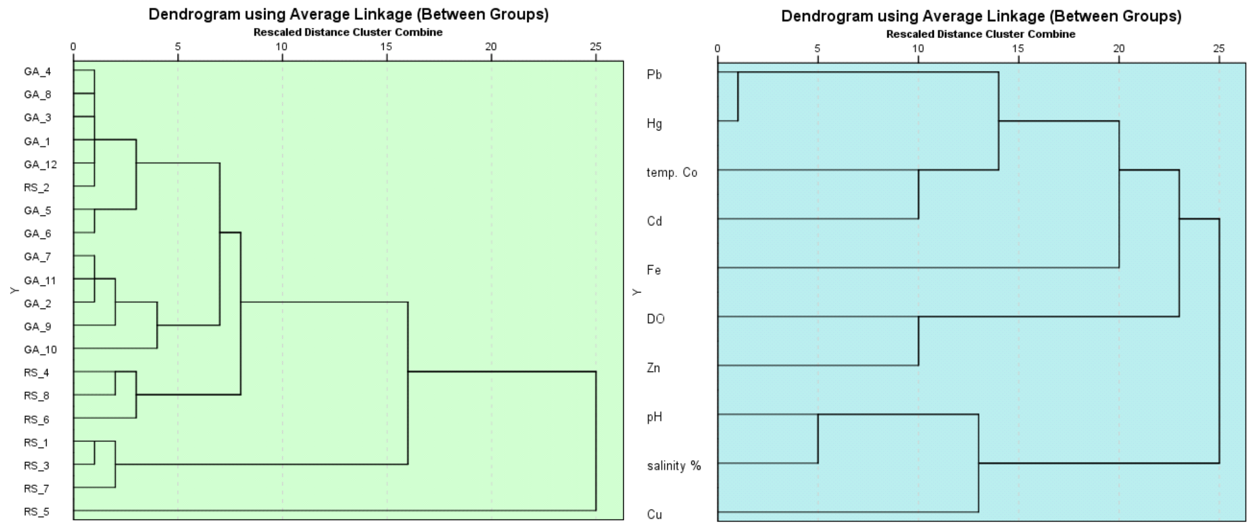

Fig. 6. R and Q-modes HCA of HMS in surface water samples

coastal areas, influencing water current patterns. Despite these differences, the results obtained from the assessment of water quality parameters as heavy metal pollution index and heavy metal evaluation index unequivocally indicate the absence of detrimental pollution across all study sites. Remarkably, these areas, despite hosting a variety of human activities, maintain a state of good to moderate water quality. This underscores the resilience of these marine environments in the face of anthropogenic pressures, highlighting the importance of continued monitoring and conservation efforts to sustain their health and functionality.

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.

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

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

Al-Mur, B., Quicksall, A. andAl-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 Gulf of 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.

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.

Chen, Z., Zhao, Y., Chen, D., Huang, H., Zhao, Y. and Wu, Y. 2023. Ecological risk assessment and early warning of heavy metal cumulation in the soils near the Luanchuan molybdenum polymetallic mine concentration area, Henan Province, central China. *China Geol.* 6: 15–26.

Cüce, H., Kalýpcý, E., Ustao¢glu, F., Kaynar, ÿI., Baser, V. and Türkmen, M. 2022. Multivariate statistical methods and GIS based evaluation of the health risk potential and water quality due to arsenic pollution in the Kýzýlýrmak River. *Int. J. Sediment Res.* 37: 754–765.

Darwish, D., Basiony, A. and El-Alfy, M. 2022. Mapping heavy metals contamination and eco-risk along Mediterranean Sea coast, Egypt. *Geocarto Int.* 37: 8645–8671.

Diganta, M., Saifullah, A., Siddique, M., Mostafa, M., Sheikh, M. and Uddin, M. 2023. Macroalgae for biomonitoring of trace elements in relation to environmental parameters and seasonality in a subtropical mangrove estuary. *J. Contam. Hydrol*. 256: 104190.

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 Metwally, M., Othman, A. and El-Moselhy, K. 2019. Distribution and assessment of heavy metals in the coastal area of the Red Sea, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*. 23(2): 1-13

Varol, M. and Tokatlý, C. 2023. Evaluation of the water quality of a highly polluted stream with water quality indices and health risk assessment methods. *Chemosphere.* 311: 137096.

Garoub, M. and Nour, H.E. 2024. Distribution and Assessment of Heavy Metals in Coastal Water of Suez Bay, Northern Red Sea Coast. *Ecology, Environment and Conservation*. 30(1): 1-9.

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.

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, *Fac. Sc., Mansoura Uni.,* 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.

Ramadan, F., Nour, H.E., Aita, S. and 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

Jafarabadi, A., Bakhtiyari, A., Toosi, A. and Jadot, C. 2017. Spatial distribution, ecological and health risk assessment of heavy metals in marine surface sediments and coastal seawaters of fringing coral reefs of the Persian Gulf, Iran. *Chemosphere.* 185: 1090–1111.

Lakshmanna, B., Jayaraju, N., Sreenivasulu, G., Prasad, T., Nagalakshmi, K., Kumar, M., Madakka, M. and Vijayanand, P. 2022. Evaluation of heavy metal pollution from coastal water of Nizampatnam bay and Lankevanidibba, East coast of India. *J. Sea Res.* 186: 102232.

Li, D., Yu, R., Chen, J., Leng, X., Zhao, D., Jia, H. and An, S. 2022. Ecological risk of heavy metals in lake sediments of China: a national-scale integrated analysis. *J. Clean. Prod*. 334: 130206.

Lin, B., Pan, P., Wei, C., Chen, X., Zhang, Z., Fan, Q., Liu, F., Liu, B., Wu, L. 2023. Health risk assessment of trace metal (loid) s in agricultural soil using an integrated model combining soil-related and plants-accumulation exposures: a case study on Hainan Island, South China. *Sci. Total Environ.* 165242

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. 2019a. Distribution, ecological risk, and source analysis of heavy metals in recent beach sediments of Sharm El-Sheikh, Egypt. *Environ. Monit. Assess*. 191:546:https://doi.org/10.1007/s10661-019-7728-1

Nour, H.E. 2019b. Assessment of heavy metals contamination in surface sediments of Sabratha, Northwest Libya. *Arabian Journal of Geosciences*. 12:177-186.

Nour, H.E. 2020. Distribution and accumulation ability of heavy metals in bivalve shells and associated sediment from Red Sea coast, Egypt. *Environmental Monitoring and Assessment*. 192(6): 353. https://doi.org/10.1007/s10661-020-08285-3

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. 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. and Nouh, E. 2020b. 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., 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